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UNIVERSITY OF CALIFORNIA, SAN DIEGO

Technology and Social Process: Oscillations in Iron Age Copper Production and Power in Southern Jordan

A dissertation submitted in partial satisfaction of the requirements for the degree Doctor of Philosophy

in

Anthropology

by

Erez Ben-Yosef

Committee in charge:

Professor Thomas E. Levy, Chair
Professor Geoffrey E. Braswell
Professor William H.C. Propp
Professor Joel Robbins
Professor Lisa Tauxe

2010

The Dissertation of Erez Ben-Yosef is approved, and it is acceptable in quality and form for publication of microfilm and electronically:

Chair

University of California, San Diego 2010

DEDICATION

To the love I sacrificed, the deepest love I have ever known, and to the love I attempted to create, the one inherent to all of us humans;

And to my parents, Miri and Moshe, who nurtured me with love of my homeland's landscapes, both physical and human, through countless intimate encounters

EPIGRAPH

A land of wheat, and barley, and vines, and fig trees, and pomegranates; a land of oil olive, and honey;

A land wherein thou shalt eat bread without scarceness, thou shalt not lack any thing in it; a land whose stones are iron, and out of whose hills thou mayest dig brass. (Deuteronomy 8:8-9)

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of Katerina Semedeferi, for whom I was a Teaching Assistant in my first quarter as a graduate student on campus.

All of the figures in this dissertation should be credited to the UCSD Levantine Archaeology Laboratory, unless noted otherwise in the caption. A major portion of the archaeomagnetic data presented here is the result of laboratory experiments conducted by Jason Steindorf at the paleomagnetic laboratory of SIO (directed by Lisa Tauxe) and Ron Shaar at the paleomagnetic laboratory of HUJI (directed by Hagai Ron). I am thankful to the staff of these laboratories for their kind permission to use these data. The OSL measurements (Chapter 6) were done in the Luminescence Laboratory of the Geological Survey of Israel (GSI) by Naomi Porat (with limited help from the present author). I am thankful to Naomi for her work, and moreover for her excellent tutoring (in a limited timeframe), advice, encouragement and patience; I am glad for the opportunity to work with her, even if for too short of a time. The XRD measurements and petrography of slag analyses (Chapter 8) were done in the research facilities of the Deutsches Bergbau-Museum (German Mining Museum, GMM) in Bochum. I am thankful to Dirk Kirchner, Andreas Ludwig and Michael Prange for their work in the laboratory and kind advice. Special thanks are due to Andreas Hauptmann of the GMM and the Ruhr-Universität, Bochum, for his devoted collegiality and advice while I was visiting Bochum in the summer of 2010. Andreas's company, together with the hospitality of Stefan Brüggerhoff, made my stay in the museum research facilities a pleasant and fruitful experience. I only wish I had had more time to spend

there, as the horizons of future research only widened with each of my short visits. The support I have gotten from and the enriching conversations with many of the students and faculty of the GMM have also made my visit productive and memorable, and I thank them for that.

I wish to thank Thilo Rehrn for the invitation to participate in the archaeometallurgical summer school at the Institute for Archaeo-Metallurgical Studies at the University College, London (IAMS – UCL) in 2008. The (too short) experience in the research center in London exposed me to many new research avenues, some of which I have pursued in my study of Iron Age copper smelting technologies presented here. I am grateful for the opportunity to study in the research center that was founded as part of the pioneering study of the archaeometallurgical record of the Arabah, the same research field of the current work. Thilo, Tim Shaw and all of the other lecturers were enthusiastic about their research, and were able to pass it on to us, the students. Even though we were a very small group, the great hospitality and attention we experienced made our stay in London pleasant and fruitful.

A significant portion of this dissertation is based on field work conducted in Timna in 2009. This work could not have been executed without the generous help I was fortunate to get from various people. Above all I wish to thank Ron Shaar, my friend and colleague, for his unreserved support, advice, and help in the field. Ron also directed the archaeomagnetic part of this new project, and kindly allowed me to use

the laboratory data and his interpretations. I truly believe that the archaeological study of Timna has benefited considerably from Ron's devotion and precision in work. I would like to thank in particular to Beno Rothenberg, for his supportive approach, encouragement, collegiality, and abundant help in many aspects of the current research in Timna. I always felt welcome in the home of Yehudit and Beno in Ramat Gan, and even when new field and laboratory evidence challenged some of the conclusions of Beno's own life-long work, the conversation has always been pleasant and followed reason. It requires a great scale of magnanimity and broad-mindedness to accept changes that inevitably accompany a new generation of research and new technologies. Unfortunately, this is not common in the archaeology scene of the southern Levant, and I can only be awed by Beno's approach. Perhaps it was Beno's own experience with fierce 'scholarly' debates regarding his work, often encroaching the personal sphere, that inspired him to give more weight to hard data than to personal agendas. In any case, it was and still is an enriching experience to work with him. Regarding the new Timna project, thanks are also due to Miki Golan, for helping with supply and organization, to Hagit Gal, the Director of Park Timna, for her support of the project, to Michael Lavie (Levko) for his support in the first step of the archaeomagnetic project in the Arabah, to the staff of the Timna Park for their hospitality and logistical help, to Assaf Holzer, for his advice, to Uri Davidovich and Hai Ashkenazi for volunteering at the excavations, their productive advice and for their help in logistic issues, to Tamir Grodek for the help with the total station, to Yehuda Enzel for his support of the project, and to Yuval Yekutieli for his support,

advice, and collaboration with various parts of the archaeomagnetic research. Finally, I wish to thank the Israeli Antiquities Authority and Gideon Avni for their support of the new project at Timna.

I would like to express special thanks to Cindy Beck and Breanne Kebely for their invaluable help in the archaeometallurgical collection at UCSD. Working with them was a great pleasure, and the discussions about artifacts, furnaces, ceramics and slag were very fruitful. Other volunteers helped in the archaeometallurgical collection, in the tedious work of crushing slag at the rock-crushing laboratory at SIO, and in measuring samples with the XRF instrument. I am grateful for all of them, and the list is too long to name them all here; I should, however, mention Castillo Paterno for his kind permission to use his laboratory for crushing rocks at SIO, and Cathy Tully for her devotion and many hours of XRF measurements. Karen Brehm, Janell Bryant, Eric Olson and Joshua Van Ee are a few of the many volunteers that contributed to this research in the field and in the laboratory. Finally I would like to thank the Bedouins of Qurayqira, whose work in the field has also found its way into the following chapters. In particular I thank Suleiman ‘Aid Mana’aja, Awa’ied Saydin and Juma’a Ali al-Azazmeh for their company on the desert trails and their insights on ancient piles of slag and rocks.

I would like to thank Tracey Hughes of the UCSD GIS laboratory for her help with GIS and Google Earth matters related to this work, Dalit Weinblatt Krauz for the

illustrations and photographs of artifacts from Timna Site 30, Mimi Lavi from the Conservation Laboratory of the Hebrew University of Jerusalem for taking great care of the artifacts from Timna Site 30, Bruce Kaiser for his painstaking tutoring, advice, and review of the XRF part of this work, Nils Anfinset for his kind permission to include some of his photographs of traditional copper production in Nepal, and Erica Hanning for her kind permission to include some of her photographs of experimental archaeology of copper smelting.

I would also like to express special thanks to Amihai Mazar for his advice regarding ceramics, interesting conversations, support and encouragement along the long way, from my undergraduate studies at the Department of Archaeology in Mount Scopus, through my Masters program at the Hebrew University to various aspects of my PhD research. My most interesting and in-depth encounters with the Iron Age so far were through his lectures and research at Tel Rehov, in which I had the opportunity to partake during the summer of 2003.

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2006-2007; the F.G. Bailey Fellowship, UCSD Department of Anthropology (dissertation improvement award); and the Judaic Studies Program at UCSD, Judaic Studies Graduate Fellowship 2007 – 2008.

Finally, I truly believe that there are permanent aspects of being a student that surpass the transitory implication of this title. I am indeed fortunate to be a student of Hagai, Amotz, Lisa and Tom, to whom I am indebted for enriching tutoring and supportive company during my years of studies. I am sure that also in the future they will always be a resource and an inspiration for me.

VITA

Academic Experience / Education

Research and Teaching Interests

Archaeology of the Levant and the Ancient Near East
Archaeometallurgy: copper production and metal trade in the Ancient Near East
Geoarchaeology: application of geological techniques and methodologies in archaeology
Iron Age archaeology of the southern Levant
Ancient technology and social change
Archaeology and history of Jordan
Landscape archaeology
Anthropological approaches in archaeology

Academic Degrees

2006-2010 **Ph.D.** in Anthropology, University of California, San Diego

2006-2008 **M.A.** in Anthropology (Archaeology), University of California, San Diego (6/2008)
Advisor: Professor Thomas E. Levy
Committee members: Professor Geoffrey E. Braswell and Professor Guillermo Algaze
Thesis title: *Technology and Society: Some Insights on the Development of Metallurgy in the Southern Levant in the Light of New Dates of Slag Deposits*

2003-2006 **M.Sc.** in Geology, The Hebrew University of Jerusalem (6/2006) (***summa cum laude***)
Advisors: Professor Hagai Ron and Professor Amotz Agnon
Committee members: Professor Yehoshua Kolodny, Professor Yehouda Enzel (partially) and Professor Amihai Mazar
Thesis title: *Geomagnetic Paleointensity Secular Variation of the Last 6 Millennia Recorded in Slag Deposits from Archaeological Sites in Southern Levant* (in Hebrew with English abstract)

1999-2004 **B.A.** in Archaeology (major) and General Studies (minor), The Hebrew University of Jerusalem (9/2004) (***magna cum laude***); course divisions in Biblical Archaeology, Classical Archaeology, Islamic Art and Architecture, History of the People of Israel, and Historical Geography

1999-2003 **B.Sc.** in Geology, The Hebrew University of Jerusalem (9/2003)

Complementary Academic Studies / Experiences

6-7/2010	Guest researcher at the archaeometallurgical laboratories of the German Mining Museum, Bochum (invited by Professor Andreas Hauptmann)
7/2008	University College London (IAMS: Institute of Archaeometallurgical Studies): Summer school in archaeometallugy (Professor Thilo Rehern, Professor Tim Shaw and others)
3-4/2007	US Department of State / Institute of International Education: Chicago Fulbright Enrichment Seminar: Leadership and Public Service
7-8/2006	Centre de Linguistique Appliquée de Besançon: Course Intensif de Français (Niveau B2 du cadre européen commun de référence pour les langues)

Technical Skills

Graduate Certificate in Geographical Information Systems (GIS)
Laboratory experience: paleomagnetism / rock magnetism (The Hebrew University of Jerusalem & Scripps Institution of Oceanography), XRF and XRD analyses, Petrography, SEM, OSL
Survey Accessories: GPS, Total Station – (EDM)
Computer applications: ArcGIS suit (ESRI), Adobe suite, Microsoft Office, HTML, Java

Awards, Distinctions and Scholarships

2010	**F.G. Bailey Fellowship**, UCSD Department of Anthropology (dissertation improvement award)
2010	**Ruhr-Universitat and the German Mining Museum, Bochum**- scholarship for summer research at the museum's laboratories
2009	**Yad Ben Zvi** Research Institute (Jerusalem) - scholarship for doctoral students studying the settlement history of the Land of Israel
2009	University of California, San Diego – **Judaic Studies Program** Travel Award for participating at TAG, Stanford
2009	University of California, San Diego – **Department of Anthropology** Travel Award for participating at the Archaeological Congress in Israel 2009
2009	University of California, San Diego – **Dean of Social Sciences** Award for Research Travel
7/2008	**Institute for Archaeo-Metallurgical Studies** (IAMS) at the University College London (UCL) - scholarship for participating in the Archaeometllurgicy Summer School
7/2008	University of California, San Diego – **Judaic Studies Program** Research Travel Award
2008	University of California, San Diego – **Department of Anthropology** Travel Award for participating at the ASOR and SBL Annual Meetings

	2008, Boston
2008	**American Schools of Oriental Research**, Travel Award for non-American students attending the 2008 Annual Meeting, Boston
7/2007	University of California, San Diego – **Department of Anthropology** Travel Award for participating at ICHAJ X conference, Washington
2006-2008	University of California, San Diego - **Judaic Studies Program** Graduate Fellowship
2006-2008	**Fulbright** grant for excellent foreign doctoral students in the USA (Grantee No. 15064706)
2006-2007	University of California, San Diego – **Department of Anthropology** Tuition Fellowship and Research Fellowship
2006	The **French Embassy in Israel** Award for Cultural Exchange (for participating in the French summer school at France)
6/2006	The Hebrew University of Jerusalem, MSc in Geology - *summa cum laude*
2003-2005	The Hebrew University of Jerusalem - **Faculty of Science** scholarship for excellent graduate students (top students at each department)
9/2004	The Hebrew University of Jerusalem, BA in Archaeology - *magna cum laude*
2002-2003	The Hebrew University of Jerusalem, **Faculty of Humanities Dean Award** for Excellency
2002-2003	The Hebrew University of Jerusalem, **Faculty of Science Dean Award** for Excellency
2001-2002	The Hebrew University of Jerusalem, **Faculty of Humanities Dean Award** for Excellency
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2003-present	<u>Research grants (participating as a Graduate Research Student)</u> NSF Grant #: 0636051, PI: Tauxe, Lisa and Levy, Thomas E. NSF Grant #: 0944137, PI: Tauxe, Lisa and Levy, Thomas E. BSF Grant #: 2004/98, PI: Ron, Hagai and Tauxe, Lisa ISF Grant #: 1334/05 PI: Ron, Hagai and Agnon, Amotz

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Conference Presentations and Published Abstracts

American Geophysical Union (AGU) Fall Meeting 2010, San Francisco (December 2010)

Mitra, R., Tauxe, L., Tripathy, V., and Ben-Yosef, E. 2010. Indian archaeointensity from
1000 BC to 1200 AD. In: *EOS Trans. AGU, Fall Meeting Suppl.* XX(xx)

American Geophysical Union (AGU) Fall Meeting 2010, San Francisco (December 2010)

Shaar, R., Ben-Yosef, E., Ron, H., Tauxe, L., Agnon, A., and Kessel, R. 2010. Geomagnetic field intensity: How high can it get? How fast can it change? Constraints from Iron Age copper-slag. in: *EOS Trans. AGU, Fall Meeting Suppl.* XX(xx)

American Geophysical Union (AGU) Fall Meeting 2010, San Francisco (Invited paper, December 2010)

Shaar, R., Ron, H., Tauxe, L., Ben-Yosef, E., Agnon, A., Kessel, R., and Feinberg, J.M., 2010. Paleointensity Using Copper Slag Material: Extending Accuracy and Time Resolution of Geomagnetic Field Intensity Records. in: *EOS Trans. AGU, Fall Meeting Suppl.* XX(xx)

American Schools of Oriental Research (ASOR) Annual Meeting 2010, Atlanta (November 2010)

Ben-Yosef, E., Shaar, R., Tauxe, L., Ron, H., Agnon, A., and Levy, T.E., 2010. Timna 30 revisited: high resolution dating indicates intense Iron Age (11th to 9th c. BCE) copper production in the southern Negev

American Schools of Oriental Research (ASOR) Annual Meeting 2010, Atlanta (November 2010)

Levy, T. E., Petrovic, V., Wypch, T., Gidding, A., Knabb, K., Hernandez, D., Smith, N. G., Schulz, J. P., Savage, S. H., Kuester, F., Ben-Yosef, E., Buitenhuys, C., Barrett, C. J., DeFanti, T., 2010. On-Site Digital Archaeology 3.0 and Cyber-Archaeology: Into the Future of the Past - New Developments, Delivery and the Creation of a Data Avalanche

The 11th International Conference on the History and Archaeology of Jordan (ICHAJ XI) 2010, Paris

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Israel Geological Society (IGS) Annual Meeting 2010, Kibbutz Eilot, Israel

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The 14th Israel Materials Engineering Conference (IMEC) 2009, Tel-Aviv

Shaar, R., Ben-Yosef, E., Ron, H., Tauxe, L., Kessel, R., and Agnon, A., 2009. Archaeomagnetic study of Iron Age copper slag

Seventh International Conference on The BEGINNINGS OF THE USE OF METALS AND ALLOYS (BUMA-VII) 2009, Bangalore

Ben-Yosef, E., Levy, T.E., and Najjar, M., 2009. New avenues for studying the Iron Age copper industry in the southern Levant

Seventh International Conference on The BEGINNINGS OF THE USE OF METALS AND ALLOYS (BUMA-VII) 2009, Bangalore

Ben-Yosef, E., Tauxe, L., Levy, T.E., Ron, H., and Agnon, A., 2009. Geomagnetic archaeointensity of slag samples as a tool for dating slag deposits: examples from the southern Levant

Theoretical Archaeology Group (TAG) Annual Meeting 2009, Stanford

Ben-Yosef, E., 2009. Questioning the deterministic paradigm: Reflection of Bedouin folklore in the archaeological evidence in Faynan, Jordan

The 35th Archaeological Congress in Israel 2009, Jerusalem, Israel

Ben-Yosef, E., Levy, T.E., and Najjar, M., 2009. The Levantine Copper Industry in the Beginning of the Iron Age: New Discoveries in the Faynan Region (Jordan) and Results of First Excavation Season at Khirbat al-Jariya (in Hebrew)

Society of Biblical Literature (SBL) Annual Meeting 2008, Boston

Ben-Yosef, E., and Levy, T.E., 2008. Metal Production and Social Complexity in Iron Age Edom: Preliminary Results from Excavations in Faynan, Jordan

American Schools of Oriental Research (ASOR) Annual Meeting 2008, Boston

Ben-Yosef, E., 2008. The Iron Age Roads to Busayra: A New Regional Survey in Edom, Jordan

MedArchNet 2008: First International Workshop on Cyberinfrastructure for the Mediterranean Archaeology Network, Calit2, San Diego

Ben-Yosef, E., Knabb, K., Levy, T.E., and Najjar, M., 2008. Regional Iron Age Settlement Patterns and GIS for Edom, Jordan

American Schools of Oriental Research (ASOR) Annual Meeting 2007, San Diego

Ben-Yosef, E., Ron, H., Tauxe, L., Agnon, A., Levy, T.E., Avner, U., and Najjar, M., 2007. Archaeological applications of new approach to archaeomagnetic paleointensity investigation

The 10th International Conference on the History and Archaeology of Jordan (ICHAJ) 2007, Washington

Ben-Yosef, E., Levy, T.E., and Najjar, M., 2009. Ras al-Miyah Fortresses: New Discoveries at One of the Gateways to the Iron Age Copper Production District of Faynan, Jordan, In: *Studies in the History and Archaeology of Jordan X*

The 32nd Archaeological Congress in Israel 2006, Jerusalem, Israel

Ben-Yosef, E., 2006. Is the installation in site 39B in Timna really the oldest smelting furnace in the world? New evidence from a study on the quality of slag as geomagnetic paleointensity recorder. (in Hebrew)

Israel Geological Society (IGS) Annual Meeting 2006, Beit-Shean, Israel

Ben-Yosef, E., Ron, H., Agnon, A., Tauxe, L., Levy, T.E., Avner, U., and Najjar, M., 2006. New Geomagnetic Paleointensity Data from Slag Deposits and an Archaeological Aspect, in: *Israel Geological Society Annual Meeting 2006 -Beit-Shean*

American Geophysical Union (AGU) Fall Meeting 2005, San Francisco

Ben-Yosef, E., Tauxe, L., Ron, H., Agnon, A., Levy, T.E., Avner, U., Kessel, R., Najjar, M., Holtzer, A., and Steindorf, J., 2005. The Intensity of the Geomagnetic Field During the Last 6 Millennia as Recorded by Slag Deposits From Archaeological Sites in the Southern Levant, in: EOS Trans. AGU, Fall Meeting Suppl. 86(52)

Israel Geological Society (IGS) Annual Meeting 2005, Mashabim, Israel

Ben-Yosef, E., Ron, H., Agnon, A., Tauxe, L., Levy, T.E., Avner, U., and Najjar, M., 2005. The Intensity of the Geomagnetic Field During the Last 6 Millennia - Recorded in Slag Deposits from Archaeological Sites in the Southern Levant, in: *Israel Geological Society Annual Meeting 2005 - Mashabim.* ed. Gardosh, M.

Professional Memberships

Society of American Archaeology (SAA) (2010-)
Society of Biblical Literature (SBL) (2007-)
American Schools of Oriental Research (ASOR) (2007-)
Israel Exploration Society (IES) (2005-)
Israel Geological Society (IGS) (2005-)
American Geophysical Union (AGU) (2005-)

Teaching Experience

2008 Teaching Assistant at Scripps Institute of Oceanography, Department of Geology, University of California, San Diego
Course taught:
- *Intro to Field Geology*, with Professor Lisa Tauxe

2007-2008 Teaching Assistant at Eleanor Roosevelt College, Making of the Modern World Program, University of California, San Diego
Courses taught:
- *Prehistory and the Birth of Civilization* (MMW1), with Professor David K. Jordan
- *The Great Classical Traditions* (MMW2), with Dr. David Miano
- *The Medieval Heritage* (MMW3), with Professor Charles Chamberlain

2006-2007 Teaching Assistant at the Department of Anthropology, University of California, San Diego
Courses taught:
- *Field Archaeology and Desert Ecology*, with Professor Thomas E. Levy

- *Human Origins*, with Professor Katerina Semendeferi
- *Foundation of Archaeology* (previously: *Anthropological Archaeology: Method and Theory*), with Professor Thomas E. Levy

2003-2005 Teaching Assistant at the Institute of Earth Sciences, the Hebrew University of Jerusalem
Courses taught:
- *Dynamic Earth* (Introduction to Geology for Geologists), with Professor Zvi Garfunkel
- *Introduction to Geomorphology*, with Professor Yehouda Enzel
- *The Physics of Earthquakes*, with Professor Amotz Agnon
- *Sedimentary Petrology*, with Professor Harvey Blatt
- *Northern Negev Geological Field Trip*, with Professor Amotz Agnon
- *Advanced Field Geology and Geological Mapping*, with Professor Amotz Agnon
- *Underwater and Bathymetric Mapping*, with Professor Amotz Agnon

Excavations and Field Experience

Excavations and surveys as part of Edom Lowland Regional Archaeology Project (ELRAP), Faynan, Jordan - Directed by Prof. Tom Levy and Dr. Mohammad Najjar:

10-11/2009	Supervising excavations at Khirbat al-Ghuwayba and JAJ1 pit mines; topical surveys
3/2009	Survey of Jabal al-Jariya Copper mines (JAJ pit mines)
6-8/2007	Supervising a regional archaeology survey
9-12/2006	Supervising the excavations in area M at Khirbat en-Nahas, Faynan (together with Marc Beherec) Supervising the excavations in area A at Khirbat al-Jariya, Faynan Supervising the excavations in the fortress of Ras al-Miyah East Supervising the archaeometallurgical recording process at Khirbat en-Nahas
7/2004	Survey of slag deposits in Faynan, as part of the geomagnetic archaeointensity project Excavating at the Iron Age cemetery of Wadi Fidan 40

Archaeological Field Experience in Israel

4/2009 (9-17/4/09)	Directing excavation at Timna, Site 30 (collaborative project of UCSD-HUJI aimed at exploring the Iron Age II copper industry in this region, and the archaeomagnetic record at this period) – License to Erez Ben-Yosef, # G-38/2009)
2002-2006	Participating in small salvage excavations of the Israel Antiquity Authority
2004-2005	Survey of archaeometallurgical sites as part of the geomagnetic archaeointensity project

6/2005	Directing an underwater survey of prehistoric settlement at the Gulf of Eilat
7/2003	Excavating at Tel-Rehov, area C (Directed by Professor Amihai Mazar)
2001	Survey of quarries and geological investigation of Byzantine Shivta. Supervised by Prof. Yizhar Hirschfeld

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Work Experience and Extra Curricular Activities

2000-2006	Yad Ben-Zvi organization, Jerusalem (guiding youth, soldiers and adults groups in Jerusalem and its vicinity; leading seminars for tour guides on the connection between geology and human history in Jerusalem; guiding Jewish youth groups from abroad, mainly from the U.S.A)
1999-2006	Tourist Guide in Israel and neighboring countries (guiding hikes and tours of adult groups in Israel, some on a regular basis; guiding tours in the Sinai Peninsula, Jordan and the Egyptian Sahara Desert with the tourist companies "Eko Tours" (Eilat), "Ayala Tours", The Society for Protection of the Nature in Israel [SPNI], and independently)
1999-2004	Hugei-Sayarut ("hiking groups", a youth movement focusing on backpacking, hiking, navigating, nature, environment etc.) of the Uri-Maimon Association (youth guide [1999-2000]; leading various regional seminars for guides in the youth movement; organizing and directing the Adult Guides Course [October 2003])

Professional Courses

1999-2001	Israel Ministry of Tourism Certified Tourist Guide Course; certified with honor (license number: 6954)
8-9/2000	Professional Jerusalem Tourist Guide Course, Yad Ben-Zvi Organization
11/1999	The Wingate Institute Certified Rappelling and Adventurous Sports Guide Course
1995	Professional Scuba Diver (2 stars)

Languages

Hebrew (mother tongue)
English (highly proficient in reading, writing and communication)
French (medium reading, writing and communication skills, Niveau B2 du cadre européen commun de référence pour les langues)
Arabic (colloquial Palestinian; medium communication skills)

ABSTRACT OF THE DISSERTATION

Technology and Social Process: Oscillations in Iron Age Copper Production and Power in Southern Jordan

by

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Doctor of Philosophy in Anthropology

University of California, San Diego, 2010

Professor Thomas E. Levy, Chair

Records of technological practice provide an important lens for studying societies and cultures across time and space. This dissertation takes a diachronic view of the role of ancient copper production in the formation and oscillations of power when historical 'state' level societies emerged during the late 2^{nd} – 1^{st} millennium BCE in the southern Levant. The primary study area is Jordan's Faynan district that contains the richest copper ore deposits in the southern Levant and constitutes one of the best preserved records of ancient copper extraction in the world. As demonstrated

here, ancient metallurgy played a major role in socio-political processes for south Levantine complex societies during the Iron Age (12^{th} – 6^{th} centuries BCE). The core of this study is the identification of detailed *chaînes opératoires* of changing Iron Age copper production systems. Based on newly excavated archaeometallurgy material culture, surveys, analyses of large technology-related assemblages, and previously published data, the basic components of the changing production systems are defined, and social meanings are extracted.

Introduction: research questions and general context

Statement of purpose

The point of departure of this research is the recognition that technology embodies both functional and social dimensions. Thus the study of ancient technology is a tool to extract social and cultural meanings and to obtain better understandings of social and political processes of the past. The case study presented here is concerned with specialized technologies related to copper exploitation in southern Jordan and adjacent areas during the Iron Age (12^{th} – 6^{th} centuries BCE). The research was aimed at examining the interrelations between human societies and a natural resource, and between technological practices and social processes in a period in which ancient Near Eastern textual, Biblical and archaeological records do not always agree. Applying analytical and conceptual tools gleaned from the anthropology of technology and production provides a fresh perspective for the interpretation of archaeological datasets from a period that is relatively well studied through other avenues (culture-history, textual and biblical approaches). Although Iron Age Levantine archaeology has been the focus of intensive research since the early 20^{th} century, the social dimension of material culture, and in particular of technology-related assemblages have often been secondary to other research goals. This study is intended to help remedy this situation in the archaeological research of southern Jordan.

The case study presented here is also a means for assessing *general* mechanisms of interactions between human societies and natural resource. These interactions occur through the medium of technology, and are reflected in the archaeological record of technological systems. By providing a robust model of one case study synchronized in time and space, this research aims at providing tools for elucidating social components in similar cases of technology-related social processes, especially those concerning craft specialization and exploitation of relatively rare natural resources.

In addition, the detailed descriptions of the substantial new datasets obtained as part of the current research, and a comprehensive survey of relevant published materials are intended to provide a thumbnail sketch of the Iron Age copper production archaeometallurgical record of the southern Levant. This is one of the most important and results of this study that, we hope will serve as a robust basis for future research. Although culture history *per se* was not embraced here as a research approach, chronological concerns and descriptions of material culture are the first steps of *any* archaeological investigation, especially if they include a substantial diachronic component. Therefore, establishing a firm material culture database grounded in an objective chronological framework was considered as a crucial part of the methodology adopted in the present study.

The basic anthropological tool we applied in this study is the *chaîne opératoire* (section 1.1.2). This way of organizing technological and technology-related components helps outline the fundamental skeleton of technological and production systems. In turn, the comparative study of this framework facilitates the extraction of social meanings. Although the dataset includes various aspects of material culture from production sites, the main focus is on copper extraction technology systems, i.e., the core of the dataset used in the current research is composed of archaeometallurgy material culture in its contexts at archaeometallurgical sites, and the inventory of copper production sites itself (typology, distribution). Accordingly, some of the fundamental components of social and anthropological studies in archaeology, in particular ceramics, are not discussed in detail in this work. Nevertheless, new data retrieved in field work carried out for this dissertation are presented here, even if they are not directly related to the copper production system. These include ceramic assemblages from the newly excavated sites and other material culture finds that, published here for the first time. Insights from other relevant material culture studies, such as ground stones, paleobotany and ceramics, are incorporated in this work when relevant.

The research area

The research area is located primarily in the Faynan copper ore district, Jordan (Fig.I.1), which is in the northern part of the Arabah Valley separating modern Jordan

and Israel (Fig.I.2). This area constitutes one of the best field laboratories in the world for studies related to the archaeometallurgy of copper, because of the relatively well preserved record and the accessibility of the sites (Chapters 2 and 3). To complement the dataset of the current research, we conducted a limited investigation in Timna, another important copper ore district, located in the southern Arabah Valley, ca. 100 km south of Faynan (Fig.I.2) in Israel. Together with discussion regarding a few relevant copper production sites in southern Sinai, this work covers the entire currently available field evidence of Iron Age primary copper exploitation in the southern Levant.

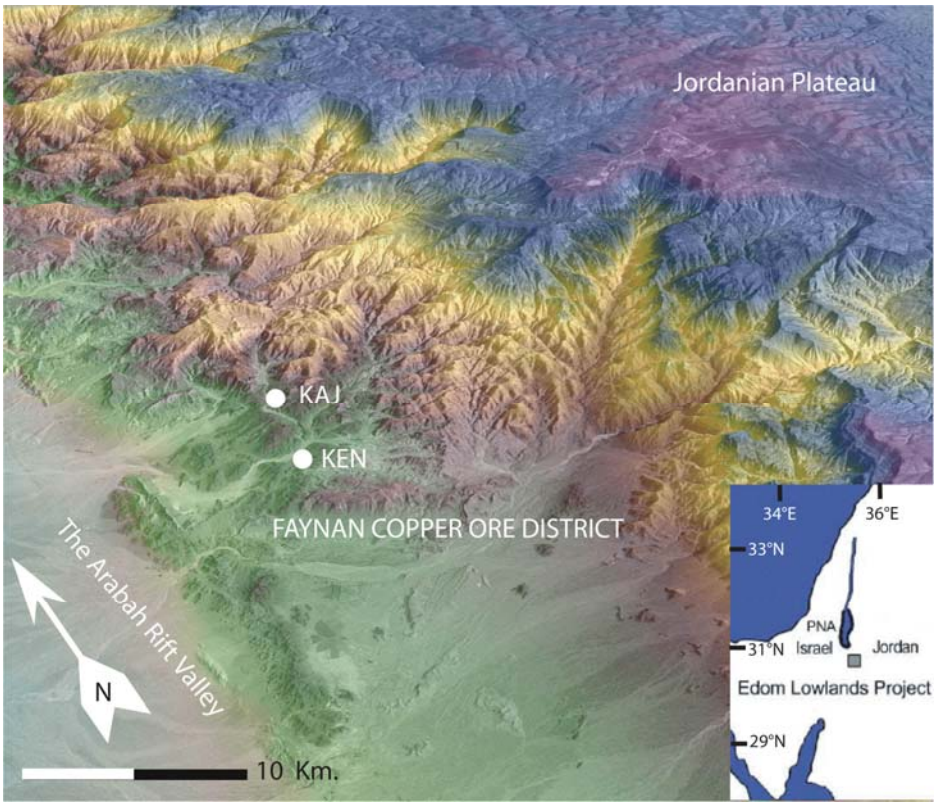


Fig.I.1: Faynan copper ore district in the northern Arabah Valley and the location of two primary Iron Age copper smelting sites that are a major part of the current research (Khirbat en-Nahas, KEN, and Khirbat al-Jariya, KAJ). False color satellite image courtesy of ROHR, Nicosia, Cyprus.



Fig.I.2: The location of the main research area (Faynan, Jordan) and additional research areas (Timna, Israel, southwestern Sinai, Egypt) of the current study. These locations cover the entire known remains of Iron Age copper smelting sites in the southern Levant and correspond to the distribution of copper ore outcrops (point size proportional to the scale of copper exploitation activities in each location).

Research structure and affiliations (see next section for abbreviations)

The research presented here had three parts, conducted intermittently because of organizational constraints. These include field work, study of artifact collections and laboratory analyses. The bulk of the work was done by the author as part of the projects of the Levantine Archaeology Laboratory, Department of Anthropology, UCSD (for abbreviations see last section of this chapter) under the direction of Professor Thomas E. Levy.

(1) Field work: ELRAP 2006 (co-supervisor of the excavations at KEN-Area M, supervisor of the excavations at KAJ-A, supervisor of the archaeometallurgical

collection), 2007 (supervisor of FBRS, supervisor of the archaeometallurgical collection), 2009 (supervisor of the excavations at JAJ-1 and KAG-E); excursion (field survey) of the JAJ mines during March 2009; director of the new excavations at Timna 30 (April 2009)

(2) Study of artifacts: UCSD Iron Age archaeometallurgical collection, Spring 2010

(3) Laboratory analyses: GIS and XRF (UCSD Levantine Archaeology Laboratory and SIO, 2009 – 2010); XRD and petrography (DBM-Bochum, Summer 2010, with Professor Andreas Hauptmann), OSL (GSI, 2010, with Dr. Naomi Porat), archaeomagnetism (SIO, 2004 – 2010, with Professor Lisa Tauxe)

The new excavations at Timna Site 30 were part of a collaborative project of UCSD – Department of Anthropology, UCSD – SIO and HUJI – Institute of Earth Sciences. The geomagnetic investigations of the site are part of the Ph.D. dissertation of Ron Shaar from the Institute of Earth Sciences at HUJI supervised by H. Ron and A. Agnon. Some of the archaeomagnetic experiments were done in the SIO Paleomagnetic Laboratory, directed by L. Tauxe.

Some materials used in this work were produced by the author already as part of the slag archaeomagnetic project of the Institute of Earth Sciences at HUJI and SIO at UCSD, including a field survey of archaeometallurgical sites, collection of sample and archaeomagnetic laboratory work.

Organization

As noted above, the basic analytic tool used in this research is the *chaîne opératoire*. Accordingly, the chapters of the dissertation are structured to provide detailed evidence (Chapters 2, 5 – 8) for the changing Iron Age *chaînes* of copper production presented in Chapter 9 and further discussed in Chapter 10. These chapters, together with several methodological background chapters, are organized in three parts: (I) anthropological theory, physical environment, history of research and challenges in establishing a reliable chronological framework for the sites under investigation (Chapters 1 – 4), (II) field (Chapters 5 – 6) and laboratory (Chapters 7 – 8) archaeometallurgical evidence, and (III) synthesis (Chapters 9 – 10 and conclusions). The following is a brief summary of the different chapters.

Chapter 1 ('Theoretical framework') provides a background concerning the anthropology of technology and the analyses of ancient production systems. It includes a brief survey of various approaches and emphasizes the interpretive path taken in the current research. Chapter 1 also provides definitions of concepts used in this work, and an outline of the analytic method *chaîne opératoire* (section 1.1.2). Chapter 2 ('Geographic and environmental setting') provides a detailed discussion of the environmental background to the research area (Faynan and the Arabah Valley), including the geology of the copper ore deposits - the raw material used for copper

production during the Iron Age. This chapter also reviews geographical issues including the physical landscape, trade routes and the historical geography of Edom - the Iron Age polity associated with southern Jordan during this period. A survey of currently available data for Iron Age paleoclimate in the region of the research is also provided. Chapter 3 ('History of the research') details the history of Iron Age research in the copper mines and smelting sites of the Arabah Valley, including fundamental issues regarding culture history interpretations and contentious scholarly debates to which the current study attempts to contribute. Finally, the last chapter in Part I, Chapter 4 ('Challenges in dating archaeometallurgical sites in the southern Levant'), discusses particular challenges in dating the archaeometallurgical sites of the Arabah and provides a background to the new approach and dating methods used in the current study.

Chapter 5 ('Iron Age copper production sites in Faynan, Jordan'), the first chapter of Part II, presents the primary archaeological excavations and surveys relied on for the current research and is the main reference for the following analyses and interpretation. This chapter details the Iron Age archaeological evidence from Faynan, including substantial amounts of new data and a comprehensive overview of published literature. The focus of this chapter is on the spatial distribution of archaeometallurgical *and* related sites, as well as the basic stratigraphy, intra-site organization, and chronological framework of Iron Age Faynan. Chapter 6 ('Contemporary copper production sites from the southern Arabah and Sinai')

provides complementary data from Timna, the southern counterpart of the Faynan ore deposits, and surveys the available information regarding Iron Age copper production in the Sinai Peninsula. It includes surprising new evidence of temporal and technological correlation to Faynan, and suggests a revision of the commonly accepted chronological framework of the southern Arabah. Chapter 7 ('The material culture of Iron Age copper production in the southern Levant') introduces the archaeometallurgical material culture inventory based on substantial amounts of new data from recent excavations. The context of the technological remains is the anchor for tracking technological changes through time and space. This chapter concerns the study of artifacts in archaeometallurgical collections, and is complemented by laboratory analyses introduced in Chapter 8 ('New analytical data and technological insights on Iron Age copper production'). The latter chapter presents results from a large array of laboratory techniques applied to archaeometallurgical artifacts, and in particular slag. The laboratory data help extract additional new technological insights, such as a gradual improvement in efficiency and other elements that are difficult to or impossible to detect by visual examination of the artifact.

Part III of the dissertation relies on the insights from all of the previous chapters to summarize the archaeological evidence and present social (and limited historical) interpretations. Chapter 9 ('Chaînes opératoires') introduces five distinct *production systems* identified in the current research for the Iron Age copper exploitation enterprise in the southern Levant. The different *chaînes opératoires*, each

of which is associated with particular production system, are also detailed in Chapter 9. Chapter 10 ('Modeling society through technology') summarizes the *main* social meanings gleaned in this work for the Iron Age societies engaged in copper production. It also presents basic culture history interpretation of the technological record. The Conclusions section of Chapter 10 emphasizes the main contribution of the work and a number of research questions that await further study.

The Iron Age in the southern Levant

The Iron Age period in the southern Levant (ca. 1200 – 500 BCE) starts with the collapse of Late Bronze Age civilizations in the eastern Mediterranean and a total change of the political, social and economic systems (Mazar, 1990:287-291). The resulting power vacuum allowed the emergence of local complex polities, some of which are described in historical sources (ibid.295-367). The end of the Late Bronze Age also marked the end of Cypriot dominance in the copper market, a 'monopoly' that lasted throughout most of the 2nd millennium BCE (Muhly, 1999). This change in market forces, coupled with the collapse of the political power-balance is the background against which this work examines the culture history framework and social processes associated with Iron Age copper production in the southern Levant.

The term Iron Age refers to the first *appearance* of iron in the archaeological record of the southern Levant[1]. However, during the first few centuries of the period iron was not a significant metal for utilitarian or other uses. Copper, mostly as bronze (alloy of copper with 5 – 10 wt.-%), was still the dominant metal for production of weapons, working tools and other metal objects during the Iron Age I (1200 – 1000 BCE) and perhaps even later (e.g., Veldhuijzen, 2005). Iron became more dominant gradually during the 10th century BCE. Nevertheless, scholars cannot identify a *sharp* shift in metal type in the archaeological record at this time. Copper was an important resource in the following centuries, and probably throughout the Iron Age, although sometime during the early part of the 1st millennium BCE it lost its primacy.

Although this thesis focuses on copper production during the Iron Age, it is important to briefly discuss the origins of iron smelting to help set the socio-economic stage in which copper production operated at this time. The origin of iron smelting technologies is far from being clear (see e.g., Wertime and Muhly, 1980). The first appearance of iron in the Iron Age southern Levant has been attributed to local technological development in the southern Levant (Muhly, 1980:51) and considered to represent the source of technological knowledge that spread from there through Cyprus to the Aegean (ibid., Gale et al., 1990). Others argue that the iron smelting

[1] In Anatolia and other parts of the Old World iron objects are found already in the Late Bronze Age or even earlier (e.g., Wertime and Muhly, 1980; Pleiner, 2000), including utilitarian tools (although most of the finds are considered prestigious objects and come from funerary contexts). Limited evidence of iron objects in a Late Bronze Age contexts does exist also in the southern Levant, for example in the copper smelting sites of Timna (Gale et al., 1990) (although, as shown in the current work, the date of these sites is insecure), and blade from Pella, Jordan (Smith et al., 1984).

technology should be associated with the Sea Peoples, and in particular the Philistine (Wright, 1939; Snodgrass, 1980, 1982)[2], i.e., the technological knowledge regarding iron metallurgy came from the Aegean[3]. The increase in the use of iron during the late 10th century BCE and maybe its succeeding of copper as the dominant metal at this time is evident, in addition to metal finds in sites from this period, in a recent discovery of iron smelter at Tell Hammeh in the Jordan Valley and probably a corresponding smithy in Tel Beth-Shemesh in the Judean Hills west of Jerusalem (Veldhuijzen and Rehren, 2007)[4]. Further support comes from the iron metal artifacts from Taanach, dated to ca. 900 BCE (Stech-Wheeler et al., 1981) demonstrating an advanced technology of steel production. The Neo-Assyrian empire played an important role in the promotion of iron technology and trade, as demonstrated, among other things, by the impressive discovery of ca. 160 tons of iron in a store house of Sargon II (722 – 705 BCE) in Dur Sharrukin at Khorsabad (Loud, 1936), including a wide variety of weapons and tools. Assyria became an important player in the southern Levant during the 8th century BCE, and it surely had influence also on trends of metal trade.

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[2] The Biblical accounts were the 'inspiration' for this direction in early research, cf. e.g., Samuel 13:19-22: "There was no smith to be found in all the land of Israel, for the Philistines had said to themselves, 'The Hebrews might make swords or spears!' So all Israel would go down to the Philistines to repair any of their plow shares, mattocks, axes or sickles. The price was a palm for plowshares and mattocks and a third of a shekel for picks and axes or setting an ox-goad. So at the time of the battle of Michmash neither sword nor spear was available to any of the soldiers who were with Saul and Jonathan—only Saul and Jonathan had them." (*Anchor Bible* translation)

[3] It is interesting to note here Rothenberg's (1998) suggestion that the copper smiths of the Arabah were also connected to the Sea Peoples. However, his arguments are weak (see also Ben-Yosef, in press).

[4] The iron production in the Jordan Valley (Tell Hammeh) and iron mining at Mugharat al-Wardah in the Gila'ad Mountains (Al-Amri, 2008), were linked directly to Iron Age social processes and early state formation. We suggest here a similar mechanism for the development of Edom around the copper production in Faynan.

The Iron Age period in the southern Levant is, to some degree, historical. It has associated contemporary textual evidence (inscriptions), mostly from neighboring areas, and is reflected in the accounts of the Hebrew Bible (Old Testament). However, the historicity of the Hebrew Bible accounts, especially those concerning the early part of the Iron Age (ca. 1200 – 900 BCE), is a matter of an ongoing debate among biblical scholars and archaeologists (e.g., Handy, 1997; Levy and Higham, 2005b; Kratz and Spieckermann, 2010). The research area of the present work is commonly regarded as the western margins of the Biblical Kingdom of Edom (Glueck, 1936a:144; but cf. Finkelstein, 2005b; Zucconi, 2007 and section 2.1.1 below), of which the primary historical source is the Hebrew Bible (Bartlett, 1989a). Edom is mentioned in contemporary textual evidence from Egypt (Kitchen, 1992), Assyria (Millard, 1992), and local, late Iron Age inscriptions mostly from Cisjordan (DiVito, 1993; Beit-Arieh, 1995b).

The history of research of Iron Age Edom is detailed in Chapter 3. Similar to the history of research in the entire southern Levant, in southern Jordan and the Arabah Valley early research was based on literal reading of the Hebrew Bible (e.g., Glueck, 1940c), notwithstanding the difficulty of extracting historical realities from the text regarding this particular region (Bartlett, 1992). This has changed in the second half of the 20th century (cf., Bennett, 1966; LaBianca and Younker, 1995;

Bienkowski and van der Steen, 2001; Porter, 2004; Levy et al., 2008a), although also in later research Biblical influence is present (cf. Whiting, 2007).

Dates and terminology

In this dissertation we follow the terminology as summarized in Table I, and the traditional chronology.

Table I: Chronological terminology used in the current research and corresponding historical and biblical events (after Mazar, 1990; Herr and Najjar, 2001; and Finkelstein, 2005a; Mattingly et al., 2007b)

Archaeological period	Dates traditional / Low Chronology (BCE)	Historical context	Biblical context (Palestine)
Late Bronze Age	1550 – 1200	Canaanite city states under Egyptian New Kingdom control	Canaanite city states
Iron Age I	1200 – 1000 / 1150 – 930	1174: 'Sea Peoples' arrive to the region; no external control	Judges
Iron Age IIA	1000 – 925 / 930 – 800	Local, peer-polity states (kingdoms)	United monarchy (David and Solomon); rival Edomite Kingdom in southern Jordan
Iron Age IIB	925 – 700 / 800 – 700		Divided monarchies (Israel and Judah)
Iron Age IIC	700 – 586	Assyrian control / influence	Judahite kingdom
Iron Age III (Babylonian and Persian periods)	587 – 332	Babylonian and Persian control	Babylonian exile, The Return to Zion in the days of Ezra and Nehemiah
Hellenistic	332 – 67	Conquests of Alexander the Great, Seleucid and Ptolemaic Dynasties, Hasmoneans and Nabataean local Dynasties.	

The recent research in Faynan, including the current dissertation, has implications on the ongoing debate regarding the Iron Age chronology of the southern Levant (see overview in Mazar, 2005). The basic chronological framework for the

Iron Age was established in the early 20th century, based primarily on the accounts of the Hebrew Bible. In the 1990s a revision of the conventional chronology was suggested by I. Finkelstein (Finkelstein, 1995, 1996). Essentially, based on field observation and stratigraphic considerations, in the revised chronology the Iron Age IA begins only in the end of the 10th century BCE instead of the conventional date of ca. 1000 BCE (Table I). Accordingly, this chronological framework was termed the "Low Chronology" (and the conventional date "High Chronology"). Although the Low Chronology revision concerns less than a century, it entails new correlation between the biblical accounts and the archaeological record. This new correlation has dramatic ramifications to the historical credibility of many biblical accounts and their interpretation.

The 10th century BCE is associated with the period of the United Monarchy and the days of Kings David and Solomon. By extending the Iron Age I period to include this century, the glorious days of the United Monarchy do not have an adequate corresponding archaeological record. The archaeology of southern Jordan is an important component in the chronology debate because the United Monarchy interacts with the kingdom of Edom (cf. 2 Samuel 8:14, 1 Chronicles 18:13), including wars and establishment of garrison in the Edomite land. Thus, the 10th century BCE socio-political reality of southern Jordan is fundamental to those who wish to corroborate or contradict the biblical narrative. The 10th century copper production systems and the associated societies in southern Jordan are a major part of the current

study. However, we think that the debate itself has basic flaws (Chapter 10), and in any case the evaluation of the biblical narratives for their (degree of) historicity and/or their reflection in the archaeological record was *not* a goal of this work. Further (limited) discussion regarding the Low Chronology, the biblical accounts and the copper mines of Edom ("King Solomon's Mines) is provided in the conclusions of this work (Chapter 10).

Iron Age State Formation Processes in the southern Levant

During the early Iron Age several polities emerged in the southern Levant, including ancient Israel, Judah, Ammon, Moab and Edom. These socio-political processes were subjected to intensive research, especially regarding ancient Israel (e.g., Noth, 1960; Gottwald, 1983; Frick, 1985; Dever, 1995; Finkelstein and Silberman, 2001; Master, 2001; Joffe, 2002; Faust, 2003, 2006). The emergence of the Transjordanian Iron Age polities was the subject of several important recent studies (LaBianca and Younker, 1995; Routledge, 2003, 2004), including a few that focused particularly on Edom (Knauf, 1992; Levy et al., 2005c; Mattingly et al., 2007b; Levy, 2009b; Smith, 2009). The more recent studies concerning the emergence of Edom take into account the copper production enterprise in the early Iron Age[5]. For example, Mattingly et al. (2007b:273) concluded that it is "plausible to consider the level of social organization needed for large-scale mobilization of labor and the use of

[5] It is surprising how little attention was paid to the potential significance of copper production in the formation of the Edomite Kingdom in previous research (e.g., Bartlett, 1989a; LaBianca and Younker, 1995).

specialized technologies of mining and smelting, as more commonly to have been features associated with states than nomadic societies." In addition, the new and early dates for the Iron Age activities in the lowlands of Edom (Faynan), entailed a reconsideration of the core-periphery model of state formation that until recently had been commonly applied to Edom (Bienkowski, 2001; Crowell, 2004; Whiting, 2007). According to this model the 'core' and trigger for development of a state level society in Edom was the Assyrian Empire, whose influence in the region became significant only in the late 8th century BCE. Since the current evidence from Faynan indicates much earlier activities of complex, probably state-level society in Edom[6], other models should be considered, such as peer-polity interactions (Levy et al., 2004c; Levy and Najjar, 2006a; Levy et al., 2007).

The current models for the development of social complexity and the early state in Edom are based on the underlying assumption that societies in southern Jordan had substantial components of semi-nomadic pastoralist and tribal groups, even when they had consolidated into early state and gained significant regional power. For example, the model of La Bianca and Younker (1995) suggests that the Transjordanian Iron Age polities should be seen as a tribal kingdoms, a social institution that differ from the common notion of 'state' in anthropology (e.g., Kamp and Yoffee, 1980:87; Renfrew and Bahn, 2004:178-181) by the domination of tribal social mechanisms

[6] Finkelstein's (2010:15) succinct and not supported statement that "Khirbat en-Nahas is not located in Edom" represents a fundamental issue in the current debate regarding the new evidence from the Iron age copper production sites of southern Jordan. As we show in section 2.1.1 below, the boundaries of early Edom could have definitely included the area of Faynan.

(*tribalism*) in the accumulation of political power. The main stimulation for the supra-tribal reorganization of Transjordan, according to LaBianca and Younker (1995:405), was external threat and the need to protect the homeland based on more credible alliances[7]. The notion of tribalism as the main mechanism behind the development of the Edomite polity was pursued by others (e.g., Bienkowski and van der Steen, 2001; Levy, 2008b; Levy, 2008a). The study presented here concerning the Iron Age copper production technological record and associated production systems in southern Jordan contributes to our understanding of early state formation processes in this region. In essence, this study supports the tribalism concept and helps refine models derived from this view of the Edomite society (Chapters 9 and 10).

Traditional copper production today and the archaeometallurgy of copper

Several of the main challenges in the study of ancient copper production stem from the scarcity of contemporary ethnographic evidence of mining and smelting in traditional societies. These challenges concern the reconstruction of the technologies themselves, as the archaeological record of ancient copper mining and smelting activities is extremely fragmentary. Even more than the technological reconstruction, the lack of ethnographic parallels presents a serious challenge to the interpretation of

[7] According to these scholars (1995:406-407), the Transjordanian tribal kingdoms were developed successively from north to south, with Ammon as the first to emerge in the 10th century BCE, Moab around the 9-8th centuries BCE and Edom the last, in the 7th century BCE. The reason for this pattern is the availability of cultivable land which gets limited towards the south. As these polities are based on the interaction between nomadic and sedentary population and changes in their proportions, as less cultivable land available, the tribes of the region are less likely to form a coalition based on some sedentary core.

the social context, cultural meaning and associated social practices (rituals, cult, training processes, etc.) of copper production in ancient societies.

The archaeological record of copper production is often fragmentary because many of the installations, including furnaces, crucibles, molds and tuyères, were broken as part of the metal extraction process. To date, from a 'world archeology' perspective, there are only a few examples of *in situ* and/or intact installations in the entire archaeometallurgical record. Thus, any additional evidence of archaeometallurgical material culture, especially from well defined contexts, is fundamental for the reconstruction of ancient smelting technologies.

Traditional copper production is practiced today, as far as we know from ethnographic studies, only in Nepal (Anfinset, 2000) (Fig.I.3). However, some information is available from relatively recent historical and ethnographic accounts concerning traditional copper production in Africa (e.g., Bisson, 2000), south and north America (e.g., Barba, 1992 [1639]; Shimada, 1994; Buren and Mills, 2005 and note especially the reference there to the 1639 account of Barba) and other locations (e.g., Percy, 1861). Some information can be gleaned out of the famous Medieval book of Agricola (1556), but this cannot replace modern ethnographic studies.

The ethnographic evidence for copper smelting technology primarily concerns sulphidic copper ores, the most common resource for copper production found in the

Earth's crust. In the Arabah Valley, the focus of the current research, the main ore is oxidic, thus the smelting processes (throughout the history of metallurgy in the region) was different to some degree from those described in most of the ethnographic accounts (Chapter 2).

Additional relevant ethnographic sources concern contemporary iron production, mainly from Africa (e.g., Bisson et al., 2000; David and Kramer, 2001:328-346; Killick, 2004b). Although the technologies of iron smelting are significantly different from copper extraction, the role of these technologies in traditional societies and the symbolic, cultural and social meanings it embodies probably have substantial overlapping components related to the practice of metallurgical activities in general (Rowlands, 1971). Above all, the studies on iron metallurgy in traditional societies demonstrate the complexity of technology and its place in society that usually *has no parallels* in other technological practices. Different studies examined various aspects of iron production, including power and control (Wade, 1989), the role of metallurgy in political institutions (de Barros, 1986; Childs and Killick, 1993; Kusimba, 1996; Killick, 2004b), the social meaning of products and artifacts (Childs, 1991), and issues of gender and rituals an cult (Herbert, 1988; Childs and Killick, 1993; Goucher and Herbert, 1996).



Fig.I.3: Contemporary copper smelting in Nepal (photograph courtesy of Nils Anfinset). The furnace has archaeological parallels for smelting sites of sulphidic ore (a different type of copper mineral than those of the Arabah Valley). Note the two hand bellows made of goat skin and the bended tuyères.

The comparison between recent ethnographic evidence and the archaeological record should be done with great caution and the parallels are not always adequate. However, the studies of traditional metallurgy practice illustrate several guiding principles in the interpretation of the 'silent' archaeometallurgical record, including the enormous array of choices available in the *chaîne opératoire* (section 1.1.2 below), the interconnections ('seamless web') between technology and society (Chapter 1) and the practice of fundamental and *always present* associated social activities that are beyond techniques and usually leave nothing in the archaeological record (e.g., social,

ritual, and other behaviors). This is well demonstrated, for example, in the ethnographic evidence of copper mining and smelting in Nepal (Anfinset, 1996, 1999, 2000). In his study, Anfinset documented a wide range of rituals, symbols and social meanings that would not have any recognizable reflection in archaeology. This sphere of activities is often intricately related to social structure, caste affiliation and manifestation of power in the miners and smelters society. Regarding the mining of copper, Anfinset (1996:45) describes a rich array of spiritual activities:

> The mining and its related activities were controlled and administrated by the state on a macro level. On a local level, offering and sacrifices played an important part to make the mining and smelting successful… Offerings and sacrifice were performed by the miners twice a month… [or] on an exceptional day, for example if there was not much copper in the mine… during these offerings, sacred threads were [introduced to commemorate] all persons that had lost their lives in the mine… the sacred threads would be left in bushes next to the entrance while saying a mantra. […] In addition, a cock would be sacrificed and incense burned outside the mine entrance. […] When all the preparations were finished, the head of the cock was cut off, while saying a mantra. Blood was squirted in the bowl of cowdung, while the rest was pumped into a cup of aluminum to be used later at home together with the rest of the chicken. A piece of every part of the cock was cut off and left in the bowl of cowdung. These included parts of the claw, the comb, the bill, the wattle and some feathers… blood from the animal's slit throat is squirted onto the stone [of the mines]

This excerpt is part of a lengthy description of rituals and social conventions that have very little related material culture and thus leave no physical trace. The use of animal blood (Fig.I.4) to secure good luck of newly established facilities is common in many societies, including those described in the Hebrew Bible (e.g., Milgrom, 1991). There are additional and different rituals and cosmologic meanings related to the smelting practices of the Nepali society. However, the first step for establishing a basis for correlation between ethnographic and archaeological evidence is the characterization of the society reflected in the archaeological record. For example, if the Iron Age copper mining in Faynan was part of an attached production system, controlled by

elite and powered by corvée as the source of labor, the comparison with current evidence from semi-independent production system as the one of Nepal is irrelevant as the social mechanisms and accompanying suite of symbols and rituals would necessarily be different, or have different social functions.

In the current research the focus is on characterizing the socio-cultural nature of the Iron Age societies that engaged in copper production in the southern Levant. In turn, this characterization enables better comparison with ethnographic evidence regarding the socio-cultural context of this technology. Where relevant, references to ethnographic examples regarding technological practice are incorporated in this work (e.g., the use of slag material as flux, Chapter 9).



Fig.I.4: Sacrificing a cock to ensure the safety and success of contemporary copper mining in Nepal (photograph courtesy of Nils Anfinset). The blood is squirted on the rocks of the mine, representative parts of the cock are left in a cowdung bowl in the mine entrance, and the ritual involves saying a mantra and other elements – all of which leave very little physical evidence.

Additional challenges in the archaeometallurgy of copper are addressed, to some degree, in the current research. These include (1) the difficulty of assessing ore quality in antiquity (e.g., Hauptmann, 2007:9-13), as in most cases the archaeological record contains the *discarded* ore (thus represents the minimum quality), (2) reconstruction of installations and apparatuses related to smelting technologies: notwithstanding intensive previous research that included experimental archaeology (e.g., Merkel, 1983; Tylecote and Merkel, 1985; Merkel, 1990; Timberlake, 2007) the

current suggestions are far from being satisfactory, especially regarding the Iron Age (e.g., Hauptmann, 2007:15), (3) the question of deliberate fluxing (when and to what degree), especially regarding the history of development of copper metallurgy in the southern Levant, (4) smelting conditions (maximum temperature of the furnace, the redox conditions achieved, etc.) and level of control over the smelting processes (Bachmann, 1982b; Hauptmann, 2007:18-27), (5) calculation of the amount of metal produced in a specific context of time and space, and estimation of the industrial intensity (e.g., Hauptmann and Weisgerber, 1987; Hauptmann et al., 1992; Hauptmann and Weisgerber, 1992), (6) characteristics of metal production debris, composition, typology and stratigraphic structure of 'slag mounds' - notwithstanding various publications, as will be shown here, 'slag mounds' are composed of mostly non-slag sediments and various components of the archaeometallurgical material culture (cf. new results from "Exmoor Iron Project", http://www.ndas.org.uk/exiron.htm); (7) characteristics of depositional processes of metallurgical debris and correlation with time - field observations provide little information regarding time span represented by metallurgical deposits, as, for example, a 6 m 'slag mound' could be the result of intensive smelting in a short period or low scale production during a long period of time (high precision radiometric dating helps us address this problem), (8) issues concerning the final production steps: characterizing the raw smelting product and refining technologies; melting processes and types of mold used for casting ingots and/or final products, etc. These issues are still open and some are debated in the

archaeometallurgical research of copper production. Thus, the present work attempts to also contribute to some aspects of the archaeometallurgy of copper.

List of frequently used abbreviations in this volume

Note: Excavation Areas within a site are attached to the site abbreviation, e.g., KEN-A

(=Khirbat en-Nahas, Excavation Area A)

DBM – Deutsches Bergbau Museum, Bochum
ELRAP – Edom Lowlands Regional Archaeology Project (UCSD)
FBRS – Faynan Busayra Regional Archaeology Survey
GMM – German Mining Museum
GSI – Geological Survey of Israel
HUJI – the Hebrew University of Jerusalem, Israel
IA – Iron Age
JAJ – Jabal al Jariya mines
JHF – Jabal Hamrat Fidan Project (UCSD & Department of Antiquities of Jordan)
KAG – Khirbat al-Ghuweiba
KAJ – Khirbat al-Jariya
KEN – Khirbat en Nahas
KHI – Khirbat Hamra Ifdan
RHF – Rujm Hamra Ifdan
SIO – Scripps Institution of Oceanography
UCSD – University of California, San Diego
UCSD-LAL – University of California, San Diego, Levantine Archaeology Laboratory
WFLS – Wadi Faynan Landscape Survey

PART I

BACKGROUND TO IRON AGE COPPER PRODUCTION IN SOUTHERN JORDAN: ANTHROPOLOGICAL APPROACHES AND THE PHYSICAL ENVIRONMENT

1. Theoretical framework: the anthropology of technology

1.1 Anthropology, technology and social dynamics

> It is the signal task of the history of technology to decode and explain this culture embedded in material. (Pursell, 1985:122)

Because this thesis focuses on the relationship between technology and society, it is important to consider how the concept of *technology* and its meaning have changed in the course of history. Technology is not a construction of anthropologists and archaeologists created to assist in their investigations, but rather a widely used concept that came into general use as part of the development of Western thought in the last couple of centuries (Ingold, 1999). The concept of technology is to some degree, equivalent to the concepts of society and culture; all are widely used in daily language and have a load of meanings, and thus should be defined by their application in each case. Claims made using the term 'technology' should be a reference for discussion rather than implying absolute derivatives. The word 'technology' is derived

from the Greek root *tekhnē*; which essentially means the same as the Old French *ars* (the base of the English *art*), namely *skill* of the sort associated with craftsmanship. This sense has been preserved in the English *technique* (borrowed from the French), and in the words related to technological practice such as 'artful', 'artifice', 'artisan', and 'artifact.' However, *technology* itself has evolved to denote an opposition between art and craft, which is "but one instance of the more general dichotomy in Western thought between freedom and necessity." (Ingold, 1999:viii). Ingold's comment emphasizes the semantic and conceptual difference between our modern perception of the term and the holistic embeddedness of its signified meanings in traditional or pre-modern societies, in which there is no direct equivalent to 'freedom' as defined in modern societies. Thus, there is less, or no difference between technology and what is termed as artistic activities or other types of outcomes of technical skills associated with 'freedom' in modern societies. The technician, artisans, sculptors and artists were all part of the same category of people that utilize technological skills to achieve necessary objectives in a given society. Accordingly, in the study of ancient technologies the sense of the Greek root is more appropriate. In any case the concept used by the society under investigation to describe what we term as *technology* necessarily bore different meanings and had specifics that we cannot decipher today. That said, in the study presented here the concept of *technology,* as defined by several recent anthropological and archaeological studies, is applied to test a case study in Jordan to parse out the role of technological practices in social processes.

Technology encompasses every aspect of human experiences, and thus, as Mauss argued (1935) is a "total social fact," constituting more than the material and gestural actions transforming natural resources into cultural products. It is here where the objective of studying technology as part of an archaeological investigation resides. This is because technological choices and practices are embedded within social meanings and the study of technology is a means to gain insights into the society responsible for it.

Various approaches to the study of technology and social context have been applied in archaeological research, and some have been adopted directly from the social sciences (see overviews in: Nelson, 1991; Hamilton, 1996; Schiffer, 2001b; Killick, 2004a; Dobres, 2010). In some recent reviews of this topic (e.g., Hamilton, 1996), the methodological approaches to the study of technology in archaeology have been classified as "French" (e.g., Mauss, 1923, 1935; Leroi-Gourhan, 1943, 1957; Lemonnier, 1986, 1989b, 1990, 1992, 2002) or "Anglo-American" (e.g., Childe, 1929; Childe, 1936, 1944; and the recent works of Pfaffenberger, 1992; Pfaffenberger, 1999, 2001) schools of thought. Recently the concept of *agency* has been introduced as part of technological studies in archaeology (Dobres, 1999; Hoffman, 1999; Dobres, 2000; Dobres and Robb, 2000). *Agency theory* together with T. Hughes' (1986) concept of the 'seamless web', is used to emphasize the role of political relations between various individual agents or agent groups in society and to explore issues of control over knowledge, resources and production itself. Although intriguing, especially when

applied to investigation of the relations between emergence of local Iron Age polities and copper production in the southern Levant, this approach is highly debated and we found it to have only limited practical use in the current research. This is because agents are difficult to identify in the archaeological record, in particular when there is no historical context (or when the historical context is much debated as in the case under investigation), and because of the abstractness of concepts and the deficiency in practical tools this approach provides.

The term *technology* was used during the first half of the 20th century without direct reference to its socio-cultural context. Investigations of technology were concerned with simply examining the physical treatment of materials and the technological knowledge, mental rules, and skills necessary for that manipulation (Schiffer and Skibo, 1987:595). Such approaches have been adequately termed by Bryan Pfaffenberger (1992) as the *'Standard View'* of technology; and usually comprises three principal premises: 'necessity is the mother of invention', 'form follows function and style, and meaning is a surface matter', and 'development (evolution) is unilinear, from simple to complex'. During the 1960s and 1970s 'culture' entered the definition of technology; it became clear that the 'Standard View' was too simplistic and does not reflect the complexity of technological assemblages with their intricate cultural meanings. Notwithstanding this development and other major contributions to archaeological theory, the 'Standard View' still prevails in some current archaeological research, and has been a fundamental interpretive

framework of the metallurgical remains in the research area of the present study. For example, such approach characterizes the work of Rothenberg (e.g., Rothenberg, 1999b; Rothenberg, 1999a) and in particular his interpretations of technological evolution. This problem is discussed in more detail in sections 4.1 and 6.2.3 below.

Another significant development regarding the concept of *technology* took place during the 1990s when Lemonnier and Pfaffenberger introduced their *system view* under the wider school of anthropology of technology. This more recent view of technology elaborates on the culture-based definition by adding the social context and meaning of technological activities (e.g., Lemonnier, 1992; Pfaffenberger, 1992). The *system view* of technology includes the 'social coordination of labor' in addition to the previously studied aspects of techniques and material culture. These components of technology comprise a *sociotechnical system*, which encompasses the social nature of human technological activity, and consists of the physical world, knowledge, know-how, social organization, as well as meaning and values (Pfaffenberger, 1992). As technology constitutes part of almost any daily activity, the *sociotechnical system* can ultimately be defined as the entire culture (see overview in Hamilton, 1996:3).

In the current research the concept of *technology* is used to refer to the practical application of knowledge and know-how to the production process of specific goods. Furthermore, the production process analyzed here is highly specialized and limited to particular social, environmental and temporal contexts. In

many theoretical treatments of technology, the concept of *technology* designates everyday practices with emphasis on subsistence, and generalizations often refer to this broad aspect of the term. For example, Lechtman and Steinberg (1979:136) conclude that:

> Technologies are the cultural traditions developed in human communities for dealing with the physical and biological environment… They are important not only because they affect social life, but also because they constitute a major body of cultural phenomena in their own right.

And even more broadly is the statement of Levi-Strauss (1976:11):

> … even the simplest techniques of any primitive society take on the character of a system that can be analyzed, in terms of a more general system. The techniques can be seen as a group of significant choices which each society – or each period within a society's development – has been forced to make, whether they are compatible or incompatible with other choices.

Although it may be correct to regard ancient copper exploitation as 'dealing with the physical environment', and that choices are, to some level, reflected in the archaeometallurgical record, it is clear that this technology and its relation to society cannot be treated in exactly the same way as technologies of necessity or common practices like plowing, flint napping, ceramic production, etc. The relative rareness of the former in the world-wide archaeological record makes it harder to conduct a comparative research and construct well-based models of social mechanism. In addition, it is usually the case that such specialized craft has unique components in the social fabric than more common technologies. For example, substantial practice of magic and cult are often associated with metallurgical crafts (see Introduction and Chapter 10).

The research presented here is concerned with the social and technological context of Iron Age primary copper production in the southern Levant. We approach this topic using several different concepts borrowed from technological studies and the directly related higher-tier field of ancient economies studies. For analyzing the archaeometallurgical material culture of copper exploitation we found most useful the concept of *'chaîne opératoire'*, a fundamental analytic method in the study of technology, as well as the concept of *sociotechnical system* mentioned above. For the broader discussions on the social context of this technology we found the concepts of *mode of production, organization of production* and *production* itself to be useful. These are mostly related to the study of ancient economics and usually complemented by study of *exchange* and *markets*. In the current research we deal with the latter only marginally and speculatively; contribution of new data regarding the questions of end destination of products, market demands, and to a certain degree also exchange, was beyond the scope of this work. These topics are discussed only in light of other researches and what we assume to be the geopolitical situation of the time based on general archaeological and historical contexts in the study area. *Exchange* of goods produced is also discussed in light of the archaeological finds in the production sites.

1.1.1 *Sociotechnical systems*

Technology, according to most contemporary theories (including the debated *agency theory*) is not an isolated phenomenon. It is an integral part of a system and

entirely interactive in society and culture. Technology forms a "seamless web" (Hughes, 1986) with society, and is shaped by human choices with the basic assumption that variety of ways to perform a given task are available. Technological choices evolve from social structure, beliefs and earlier choices (learned knowledge), and technological change may be ascribe to various factors and take different paths (cf. Killick, 2004a). This approach is opposed to *technological determinism* that does not recognize the socio-cultural and idiosyncratic component of the "frozen" technological record, and is embedded in the concept of *sociotechnical system*. The latter concept was first developed as part of social and historical studies of industrial societies (Hughes, 1990), and was shown to be fruitful for integrating anthropological insights into studies of preindustrial technologies by Pfaffenberger (1992). In short, the *sociotechnical system* concept

> …put forward a universal conception of human technological activity, in which complex social structures, nonverbal activity systems, advanced linguistics communication, the ritual coordination of labor, advanced artifact manufacture, the linkage of phenomenally diverse social and non-social actors, and the social use of diverse artifacts are all recognized as part of a single complex that is simultaneously adaptive and expressive. (Pfaffenberger, 1992:513)

The difference between *sociotechnical system* and what Dobres (2010) describes as *cultural reason ontologies* is mostly terminological. According to Dobres (ibid. 104), in contemporary archaeological theory, there are two main ways to interpret the socio-cultural components of ancient technologies. One is through *practical reason* ontologies, and the other is through *cultural reason* ontologies. Practical reason comprises much of mainstream research. It favors a positivist epistemology and regards technology as the practical, physical and rational buffer

between culture and the external environment (cf. Benford's [1965:209] definition of culture as 'man's extrasomatic means of adaptation'). In practical reason approach, technology underlies and shapes economics and social organization, politics and identity formation, symbolic construct and social values. Technology is modeled using cost/benefit economic theories (e.g., Bleed, 2001) with emphasis on the universality of 'artifact physics', assuming inherent performance characteristics in raw materials (e.g., Schiffer, 2001a). On the other hand, cultural reason interpretations are explicitly humanistic and put people as the ontological starting point of research of ancient technologies. That is, they place humans in the center of any attempt to apply interpretative models to social phenomena. Such interpretations emphasize the inseparability of art, skill, craft, methods, knowledge, understanding and awareness, and –

> …because knowledgeable practice and practical knowledge are inseparable dimensions of technological endeavors – understandings forged in everyday practice – cultural reason orientations purposefully blur the heuristic line typically drawn between practical material matters and cultural value systems and beliefs. The operative premise here is that in the technological transformation of nature into culture, prehistoric knowledge about the properties of natural materials and how best to work them was necessarily meditated by culture (rather than the 'practical reason' ontology that prehistoric technology mediated between nature and culture). (Dobres, 2010:106)

Both Pfaffenberger's *sociotechnical system* concept and Dobres' *cultural reason* ontologies possess strong post-processual attributes and belong to a high tier of abstractness in archaeological research. In the field of archaeometallurgy, such approach has been introduced quite recently and is practiced only to a very limited degree (e.g., Budd and Taylor, 1995). The reason for this situation in archaeometallurgical research guided us to choose additional avenues in the

explorations of the Iron Age copper technologies of the southern Levant. Although we recognize the relevance and merit of humanistic approaches, and strongly believe that not only in rare cases primarily social and cultural mechanisms were behind many aspects of ancient technologies, the expression of such mechanisms is simply invisible in most archaeological records, rendering such approaches impractical. Nonetheless, recognizing that technology is related to society and culture in a web-like structure of interactions, that society affects and is affected by technology and that *people matter* in such processes, is an important complement to any reconstruction or insight about ancient technologies.

1.1.2 C*haîne opératoire and technical systems*

C*haîne opératoire* (Cresswell, 1983; Pelegrin et al., 1988; Edmonds, 1990; Balfet, 1991) is an analytical method growing in popularity across the 'practical :: cultural reason' divide (Dobres, 2010, and section 1.1.1 above), providing a neutral and fertile ground for radically different orientations. It is also called 'behavioral chain analysis', and more generally 'life history' research (Schiffer, 1975, 2004), and essentially is a tool for documenting in extraordinary detail the sequence of physical actions and bodily gestures ancient technicians employed to make, use, and repair objects. In turn, this sequence is embedded with social relations and reasons that are easier to extract out of the structured observations.

In the current research we utilize the concept of *chaîne opératoire* as formulated by the work of Lemonnier (e.g., 1986; 1989b). The 'French school' was the first to apply this analytical technique to archaeological inquiry, with the pioneering work of André Leroi-Gourhan (1943; 1957). Building on the work of Leroi-Gourhan and under the broad 'system view' approach, Lemonnier developed the concept of *technical system* in which technique and technology consist of five elements: (1) matter – the material acted upon; (2) energy – forces of movement and transformation of that matter; (3) objects – tools or means of work (e.g., a hammer or factory); (4) gestures – which 'move' the object, these are organized into linear operational sequences called the *chaîne opératoire*; and (5) specific knowledge – know-how (*savoir-faire*), the end result of all perceived possibilities and choices concern with the technological action. The fundamental quality of these elements is demonstrated by Lemonnier's (1989a:156) own words: "without gestures that move it, without matter on which it acts, without the knowledge involved in its use, an artifact is as strange as a fish without water"; however, these five elements are only the base of a much wider approach to the anthropology of technology, in which the reciprocal effects of a technological system and social system have to be considered as well as the physical aspects themselves (matter and energy) combined with stylistic traits. In other words, the basic elements of *technical system* are only the bricks in a wider discussion, used to (re)construct social meanings relevant to the seam between acts and social identities and structure.

In the core of a technical system and associated interpretive analyses lies the basic and detailed investigation of *chaînes opératoires*. This 'skeleton' of technological practice allows isolation of what Lemonnier (ibid. 156) calls *strategic moments*: technological operations that are essential and unalterable if the given result is to be achieved. Identifying *strategic moments* is a key to parse the technical system into its different social components and to reveal technological variants (i.e., different actions or ways leading to the same result). Those variants "often designate different social realities" (Lemonnier, 1986:155) and can represent social choices.

The advantage of having *chaîne opératoire* at the core of the current study is the introduction of an empirically valid new dataset of one of the major and most influential technologies in the southern Levant during the Iron Age (ca. 1200 – 500 BCE). Structuring, contextualizing and detailing this technology, from the level of site and raw materials distributions to the instrumental, artifactual and environmental reconstructions is a key to understanding the social context, and a solid reference for further studies. Further more, recognizing diachronic changes in *chaînes* of the same technology is one of the strongest and more empirical arguments for social and political changes. As social insights are subjected to theoretical orientation of the researcher (see above), we consider the *chaîne opératoire* as a more 'solid' contribution of the current research. The entire work presented here is oriented towards establishing and detailing the changing *chaînes* of Iron Age copper production in southern Jordan; the environmental background is detailed in Chapter 2, the sites

typology, distribution, chronology and internal organization are presented in chapters 5 and 6, the material culture of Iron Age archaeometallurgy is presented in Chapter 7, analytic analyses of technological components are presented in Chapter 8, and a synthesis of the entire dataset is presented in Chapter 9, which is based on all of the previous chapters and organized according to the flow of the basic *chaîne opératoire,* with references to diachronic and synchronic spatial differences and interpretative models. A model of Iron Age societies and social processes based on the changing *chaînes opératoires* is presented in Chapter 10.

1.1.3 *The concept of 'technological style'*

Technological style is important for the research presented here because it helps to establish correlations between 'technology and peoples' or 'technology and ethnicity', a very fragile (and often controversial) task when the evidence comes only from archaeology. The concept of *technological style* is clearly related to Lemonnier's (above) notion of social choice, however, here that 'choice' extends beyond a single material or technological context of that material into the entire technological universe of a particular society. The concept is dominant in the work of Heather Lechtman (e.g., Lechtman and Steinberg, 1979) who developed a system of investigations in order to reconstruct the *technological style* out of the archaeological record. This system includes tracking the *chaîne opératoire* through extensive laboratory analysis of both artifacts and processes of manufacture in conjunction with comparative studies

from a greater cultural context of processes of innovation and retention of technologies, to trace idiosyncratic approaches to materials (ibid.).

The *technological style* of a society can be expressed by a common attitude toward different materials; it contains information about the symbolic message of the technology itself, as well as about cultural codes, values, standards, and rules that underlay the technological performance (Lechtman, 1977:17). For example, the shared features of the Inca's gold and textile industries demonstrate a preoccupation with integrity or 'essence', and reveal some elements of the Inca value system (Lechtman, 1977). Interpretation of the archaeological record in the light of this concept may be a key for identifying cultural boundaries, although essentially the *technological style* itself is constructed within predefined cultural context. When approaching the study of ancient metallurgy, it seems useful to bear in mind the broader technological universe in which the specific *chaîne opératoire* exists. This is because identifying similar and characteristic patterns in other technologies that are practiced by the same social group (e.g., pottery production) may be used to strengthen arguments about social boundaries that may be based on other aspects, besides technology.

1.1.4 *Technological innovation*

Another important aspect of technology is *innovation*, and much has been written on the economic and political contexts in which technological innovation

occurs (e.g., Van der Leeuw and Torrence, 1989; Barber, 1991; Barnett and Hoopes, 1995; Wailes, 1996:9). *Innovation* should first be recognized and characterized in the archaeological record. Any improvement in technology is considered innovation, and a key factors to analyze should include: (1) Degree of change (how much efficiency was increased? etc.); (2) what is the geographic extent of the new feature?); (3) pace of change (is evidence for "trial and error" present?); (4) How rapid and conclusive was the change?); and (5) context of change (correlation to other archaeological / historical / social patterns etc.) (e.g., Van der Leeuw and Torrence, 1989). A major challenge in such studies is to define if the 'innovation' is internal to the society studied, or did the new technology originate elsewhere, and if it did, what was the mechanism of transition of technological knowledge and know-how (diffusion?). Substantial and sharp technological change may indicate change in population ('technology equals people' has the same problems as the long-discussed and debated subject of "pots equals peoples"), change in political structure and power status on a regional scale, or simply infiltration of new technology quickly adopted by the local society. By taking a diachronic approach, the current research aims at identifying *innovations* and *technological changes* throughout the Iron Age (a time interval of about seven centuries).

1.2 Ancient economy and social organization

Another dimension of the research presented here concerns ancient economies, of which the study of technology outlined above is a lower tier. Similar to the study of technology, two general approaches exist when analyzing ancient economies, namely - *rational* vs. *integral* (Morrison, 1994:113) or formalists vs. substantivists (Plattner, 1989), which are essentially rooted in the same epistemological contexts (respectively) as *practical reason* vs. *cultural reason* ontologies (Dobres, 2010) presented above in regard to ancient technologies (section 1.1.1). While rational approaches emphasize the principle of maximization of return and minimization of effort (e.g., Earle, 1989), integral approaches recognize that production is integrated with other social activities and derived also from other aspects of society and culture (e.g., Bohannon and Dalton, 1962), as is well expressed by Polanyi's words (1957:248, 250): "[economy] is embedded and enmeshed in institutions, economic and non-economic." While we recognize the 'embeddedness' of ancient economy in social institutions, here (as with technology related concepts above) we prefer a more pragmatic approach and, following Braswell (1996:22), adopt a definition of economy that does not exclude formalist principles:

> Economies are open systems that extract matter, energy, and information from their environments for use by human populations. Such systems consist of "a set of objects together with the relationships between the objects and their attributes" [(Hall and Fagan, 1956:18)]. The objects in an economic system are those activities and organizations which perform a role in the operation of an economy, whereas the relationships between the objects are the connections that hold the system together. [(Lloyd and Dicken, 1972)] (Santley, 1994:243)

Although the definition of economy definitely encompasses the physical movement and distribution of products, their consumption and consequently the market systems as a whole, the current research focuses, consciously, on the node of *production*. The reason is practical: the study of *exchange* in metal goods is complex, and contribution of novel insights on the topic in the context of the ancient Levant can hardly be achieved in a single *archaeological* project. If "hard" data are concerned, it requires accumulation of data from many field projects and related laboratory work to map possible destinations of products. The most commonly used analytical technique is problematic in itself (Lead Isotope Analysis, Scaife et al., 1999; Knapp, 2000; Ben-Yosef, 2010, and see section 2.2.3 below), and neither development of new analytical method nor gathering of (scarcely existent) data were in the scope of the current research. Similarly, historical data are not a central object of study in this archaeologically oriented project (cf. Muhly, 1973a, 1976b). Both the historical sources and some of the available analytical data are discussed to a limited degree in Chapter 10, with focus on possible destination of products, market demands and structure, trade and the interrelation of production in the changing geopolitical system of the Iron Age Levant.

1.2.1 *Production*

Production is the making, constructing, or creating actions of human beings (Morrison, 1994:114), it has been defined as

> …the totality of operations aimed at procuring for a society the material means of existence… In the end we see that all production is a twofold act subject to the technical norm of a certain relationship between men and nature and to the social norms governing these relations between men and their use of the factors of production. (Godelier, 1978:71)

Extraction of natural resources is clearly part of such definition; extraction of rare resources such as copper is part of 'procuring material means of existence' for a society through *exchange*, and technical and social norms comprise any production activities. Copper production in the study case of Iron Age southern Jordan goes beyond 'means of existence' and surplus (see below) probably was used as a socio-political leverage. It is interesting to look at marginal cases such as servile labor or production(s) in which the labor itself is a commodity in an exchange system, and done by one social group in the context of another. Such scenarios have been suggested in the context of Iron Age highly specialized copper production (cf. Glueck, 1940c, in several places) and should be examine with the conceptual anthropological tools against the field evidence.

Production is a social activity because participation in it as a craftsperson shapes one's role in society, access to goods and services, generation of interpersonal ties and obligations, and represents differences in status and power (Clark, 1991; Costin, 1998). Production can be studied from many different theoretical perspectives such as Marxian (e.g., Gilman, 1991; Bernbeck, 1995), cultural ecology (e.g., Kolb and Lackey, 1988; Arnold, 1993) and political economy (Earle, 1987; Cobb, 1993;

Clark, 1996). The study of craft production in archaeology has been linked to sociopolitical organization thorough emphasis on specialization and its connection to the rise of complex society (Childe, 1936; Service, 1962), through the study of organization of production and its connection to social structure and social process (e.g., Cobb, 1993; Pope and Pollock, 1993), and through the investigation of the utility and social meaning of craft objects (e.g., Hodder, 1982; Weiner, 1994; Schiffer and Miller, 1999). A comprehensive and detailed survey of different aspects of the study of production in archaeological contexts is provided by Costin (2001). Here we present only those concepts that are relevant to the current research. Those are a) *stratification, b) intensification of production, c) surplus, d) modes of production, e) attached and independent productions, f) specialists and specialization, and g) efficiency*.

a) Stratification

The link between social stratification and production is in the center of Marxian anthropological thought. The definition of stratification commonly entails differential access to or control over the means of production (Fried, 1976); stratification *is* a materialist economic concept (Braswell, 1996:24). Following Braswell (ibid.), we find the broader definition of stratification provided by C. Smith (1976:310) to be useful. Based on her observations on agrarian societies, where

control over means of production does not entail division into social classes, she suggested that stratification results from differential access to the means of exchange:

> [t]he basis for stratification… is, without exception, control over some critical resource by select members of [a] society. The critical resource may be a means of production, such as land, or a means of destruction, such as fire power. But it may also be a simple means of subsistence, such as salt, that cannot be locally procured or produced. In any case, if a stable system of inequality is to be sustained, the stratification system is institutionalized by a system of exchanges in which the [*economic*] elite control the critical nodes or means of exchange. (Smith, 1976:311)

Control over *exchange* is possibly one of the main factors in the development of the stratified society that became the polity of Edom in southern Jordan. The geographic conditions provide relatively easy mechanisms for control over import, export and transition of goods (e.g., on their way from Arabia / Red Sea to the Levant), and economic elite groups could have been established based on power gained by differential access to the means of exchange (routes, draft animals [especially with the introduction of the camel], transporters, markets, etc.).

b) Intensification of production

Intensification of production is defined as augmentation of inputs of human resources in regard to exploitation of natural resource complexes (land, ore, etc.); it should be measured by inputs only of capital, labor, and skills against a constant resource (Brookfield, 1972:31; Braswell, 1996:26). Intensification can occur in a few different ways (Morrison, 1994): intensification proper (corresponding to Brookfield's definition), specialization (reducing of diversity at the level of the individual

producer), and diversification, namely the addition of extensive of production strategies that on the long run hedge against systemic failures.

c) Surplus

Surplus, in its strict sense, is described as production above the level needed for survival (Braswell, 1996:27). The concept is widely applied in studies of agricultural societies in which the products are also part of subsistence (cf. Childe, 1936); the definition has to be modified when nonagricultural commodities are considered to include "that which producers need to continue to produce at the same level" (Braswell, 1996:27). Rather then originate or be related to intensification of production, surplus can be related to imbalance *exchange* when the elite have control over some of its components (Smith, 1976:312). Surplus is considered to be a major factor in social change. Following the line of surplus in social context, another definition of the concept is that it represents "that portion of production which extends beyond the sphere of individual households" (Kirch, 1984) and that it is created in order to "'finance' political and social elaboration, trade and other public or elite ventures" (Morrison, 1994:126). Intensification of production, economic stratification and rise of civilization have all been linked to surplus and/or scarcity (e.g., Childe, 1936).

d) Modes of production

In archaeological research, several typologies of production are regularly cited (in particular those of van der Leeuw, 1977; Peacock, 1982; Rice, 1987; Costin, 1991). Types (or modes) of production are heuristic models of the organization of production; for example, household-based vs. extrahousehold, or 'workshop' production are two models used by all of the common typologies. The typology of Costin (1991; 2001) introduces a distinct separation between production for general consumption (*independent production*) and production by/for elites for use within the political economy (*attached production*). The latter typology is most suitable for approaching the archaeological evidence from the copper ore district of the Arabah, as we consider it to represent, at least in parts of the Iron Age, an *attached production*, strongly connected to the local and regional political economy. Thus, in the current research, we follow Costin's (e.g., 2001) definitions (and see specialization below).

Accordingly, organization of production can be divided into four basic types: household production, workshop production, independent specialization and attached specialization. However, it is unlikely that these rigid categories adequately describe the range of organizational modes and production contexts with which archaeologists work. Thus, a useful approach is breaking the production system into various components and describing each of those separately as part of the analysis of the entire organization of production in a given case. Such components, according to Costin

(2001), are: the *artisans* (producers), *means of production* (technology is included here, and see section 1.1 above), *organization and social relationships of production*, *objects*, *relationships of distribution*, and *consumers*. These are all related to the four basic modes, but help to establish a more flexible view of the production system under investigation. For comprehensive analysis of a production system one should consider the consumer end of the processes (*consumers, relationship of distribution,* and *objects* in the context of the consumer). This is discussed in here only in the broad context of the Iron Age southern Levant; contribution of new data from this end of the system was beyond the scope of the current research.

e) Attached vs. independent production

The notion that the context of production within social space can be defined as one of two types, 'independent' or 'attached', was first raised by Earle (1981), and later modified by Clark and Parry (1990) and others (Costin, 2001:297). These terms are directly related to the sociopolitical contexts of production, and are extremely useful in particular when discussing organizational types that are beyond household-based production. The distinction between attached and independent is based on two aspects of the production system, control over manufacturing processes and the nature of the goods themselves. Often in the extensive literature on this topic, independent production is defined from the perspective of the producer whereas attached production is defined from the perspective of the sponsor or consumer. The latter

usually entails the development of institutions and practices, such as slavery, tribute/taxation and other bureaucratic mechanisms.

Attached production defines production systems in which control over components of the production system is in the hands of individuals, groups or institutions that are external to the production unit. These external entities are empowered to make decisions about one or more of the following (thus 'degree' of attachment can be attributed to a system) (Costin, 2001:298): (1) means of production (including access to materials and knowledge as well as choices about types of raw materials, tools, and/or techniques used); (2) the organization of labor (including artisan recruitment, labor intensity, the organization of workshops, and task allocation within workgroups); (3) the visual appearance of objects; (4) the principles and mechanisms of distribution. In contrast, only when producers are free from external interference, including having unfettered access to the means of production, freedom of technological choices *and* unrestricted access to consumer, the production is independent.

Attached and independent productions are also defined by the class of goods each system produces. Usually the separation is along the line of utilitarian/luxury goods, in which attached is most often correlated with hypertrophic, sumptuary items (e.g., Clark and Parry, 1990); however, this is not always the case and, as Costin

(1996) and Stein (1996) demonstrate, attached production can be related to inexpensive, utilitarian items as well. The key is

> that attached artisans produce goods with extrinsic, extra-utilitarian functions that can be exploited only by a subset of the population. Fundamentally, attached forms of production function to uphold or enhance one social groups' unequal access to resources, labor, and/or wealth. They do so by facilitating control of the distribution and consumption of objects used to secure that inequality through exercise of economic, political, military, or ideological power. These objects produced by attached specialists can be military gear, items used in elite sponsored exchange, goods used for the support of other workers, prestige objects, or symbols of legitimization. (Costin, 2001:298-299)

The interpretation of the archaeological record in light of independent vs. attached productions is difficult, as the terms relate to social contexts that may not directly be reflected in the physical remains. It is often difficult to recognize attached production system as such, when no architectural or artifactual remains (e.g., administrative artifacts, seals, texts, etc.) exist to attest for external control, although external control based only on 'invisible' social context may be present. This situation is sometime recognized when historical evidence is available. If archaeological evidence does support attached production, it is often difficult to reconstruct the social context as a whole. Attached and independent are useful heuristic devices, but it is important to consider the gradual transition between both ends (Fig.1.2).

When considering *intensity of production* and *scale of production,* together with the degree of government or elite participation in production systems, there are eight commonly used categories of specialized production, according to scale and intensity. They are presented in Fig.1.1.

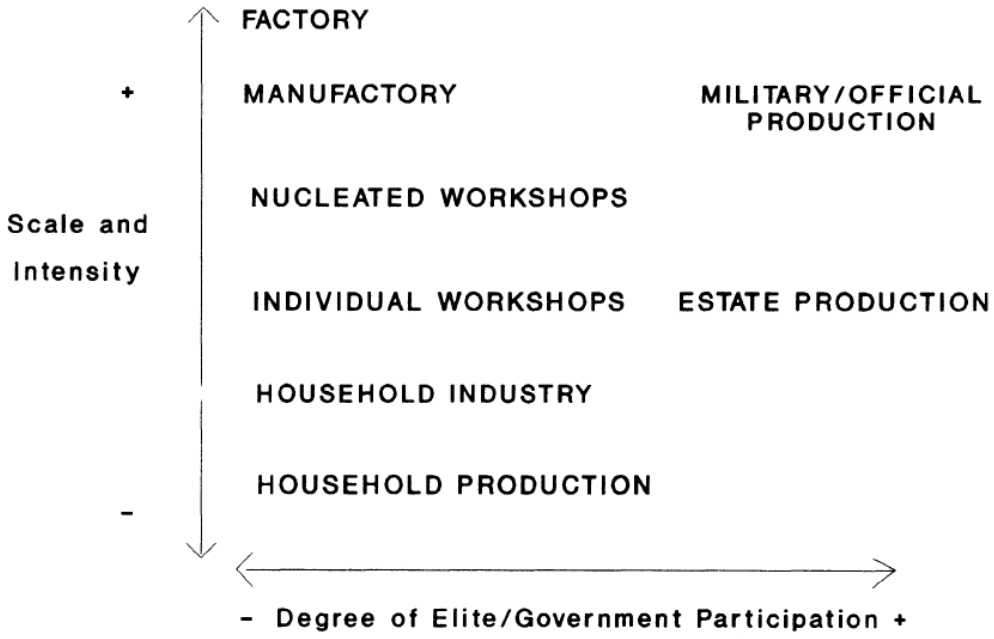


Fig.1.1: Types of specialized production based on intensity, scale and degree of elite/government participation. From Costin (1991:7) based on Peacock (1982).

f) Specialists and specialization

Specialization has been the focus of many works regarding the organization of production .(e.g., Brumfiel and Earle, 1987; Clark and Parry, 1990; Peregrine, 1991) The use of this concept commonly involves four premises (Costin, 2001:275): (1) specialization is a suprahousehold phenomenon; (2) the specialist is 'freed' in part from 'other' subsistence pursuits; (3) a specialist does not produce all the other goods/services she or he needs; (4) a specialist is materially compensated for goods or services he or she provides and uses that compensation to participate in some form of 'exchange' to procure all other desired goods and services. These premises were criticized on various grounds, and here we focus on the parsimonious definition of

Costin (2001:276), following others (e.g., Byrne, 1994:246; Clark, 1995:290-291), that specialization is when "fewer people make a class of objects than use it." This definition, of course, renders all remains of copper exploitation activities in the research area evidence of specialization; ascribing 'degrees' of specialization is rather subjective in archaeological research (Clark, 1995). Relative investigations through changes in time or space can help with assessing complexity of specialization (or 'degrees').

Costin (1991:8-9) suggested eight-part typology for the organization of specialist production (Table 1.1): (1) individual specialization: individuals or households produce for unrestricted local consumption; (2) dispersed workshop: production beyond households, larger production for unrestricted local consumption; (3) community specialization: autonomous individuals or household-based production units, aggregated within a single community, producing for unrestricted regional consumption; (4) nucleated workshops: larger workshops aggregated within a single community producing for unrestricted regional consumption; (5) dispersed corvée: part-time labor producing for elite or government institutions within a household or local community setting; (6) individual retainers: individual artisans, usually working full time, production for elite patrons or government institutions within elite (e.g. a palace) or administered setting; (7) nucleated corvée: part time labor recruited by government institution, working in a special-purpose, elite , or administered setting or facility; retainer workshop: large-scale operation with full time artisans working for an

elite patron or government institution within a segregated, highly specialized setting or facility. These eight categories are based on four basic factors of specialized production (Fig.1.2): socio-political context (attached vs. independent), concentration (geographic distribution of artisans), scale (based on size of production unit [number of individual participating] and principles of labor recruitment) and intensity of specialization (the amount of time producers spend on their craft) (Costin, 1991). In the current research, this model helps to evaluate changes through time in the organization of production and social context of the Iron Age copper production system; as noted above, specialization studies benefit the most from a comparative approach, as assigning absolute values is rather subjective. In addition to changes within the Iron Age, this model helps to characterize the Iron Age production systems in relations to other similar technological practices across time (different periods, same region) and space (same period, different production systems [exploiting the same ore deposits, or entirely different ones]).

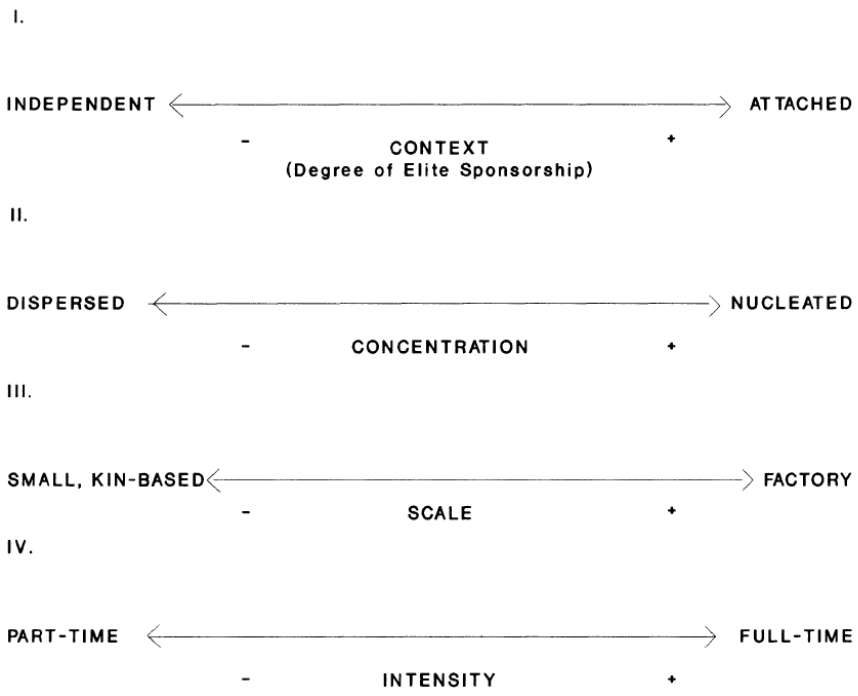


Fig.1.2: Organization of production according to four fundamental parameters (Costin, 1991:9).

Table 1.1: Multidimensional typology of specialized production (from Costin, 1991:10), based on four parameters (Fig.1.2) that characterize the organization of production

	Context		Concentration		Scale (Composition)		Intensity	
	Attached	Independent	Nucleated	Dispersed	Labor	Kin-based	Part-time	Full-time
Individual		X		X		X	(X)	(X)
Dispersed workshop		X		X	X			X
Community		X	X			X	(X)	(X)
Nucleated workshop		X	X		X			X
Dispersed corvee	X			X	(X)	(X)	X	
Individual retainer	X		(X)			(X)		X
Nucleated corvee	X		X		X		X	
Retainer workshop	X		X		X			X

g) Efficiency

Another variable that is important for relative investigations of production systems is *efficiency.* This concept is defined as "the amount of energy (time) and raw material input per unit of output" (Costin, 2001:289). Efficiency is determined by three factors: the technology, the work skills and habits of individuals, and/or the way production is organized. It is a relative concept, measured against other production systems, and in its core is based on the least-cost and optimizing models of productions. Costin (2001:289-290) argues that "the use of the concept of efficiency in craft production systems is problematic and misleading… The assumption that efficiency is a primary goal of producers is deeply rooted in Western, capitalist economic concepts and value." She suggests to measure instead *labor investment,* a less market-oriented measure (vs. economic efficiency) that focuses on more objective investigation of production systems, based on more empirical data. Labor investment is a concrete, stand alone measure of the time takes to produce an object, and thus eliminates a biased assumption that the system as a whole is oriented towards economic efficiency, and that any production system will tend to evolve into a 'more efficient system'. Although basically justified, Costin's attempts to avoid 'imposing' Western concepts on ancient production systems appear in this case to give over-weight to only possible other factors (e.g. rituals, symbolic features that 'reduce' efficiency, etc.), usually negligible when analyzing the system as a whole because

production, in its essence, relates to (market) demands. In any case, efficiency is relative, and is based on labor investment. The latter should be measured for any part of the production sequence (e.g., mining, ore dressing, transportation, and so on), and is usually based on ethnographic records. Labor investment depends (in addition to the underlying technology) on the skill level of the artisans, a quite difficult quality to assess.

A common underlying premise in studies of efficiency is probably not always correct. It assumes that independent artisans are efficient and attached specialists are not, because of the difference in the mechanism of distribution. As independent artisans are directly related to the market, they are subjected to the competitiveness of commerce and thus produce their products heeding to efficiency. Attached artisans have an 'assured' market, through patronage (e.g., Clark and Parry, 1990; Earle, 1990; Peregrine, 1991; White and Pigott, 1996:169). However, in certain cases even elite and institutional patrons will pay heed to the unit 'costs' of the goods they commission (Costin, 1996:212), and see case studies in Wright (1998) and Rothman (1994). Recognized technological developments are used in the current research to assess variables that relate to efficiency.

1.2.2 *Exchange*

Although exchange is not directly part of the current research, analysis of production systems is not complete without synthesizing factors related to consumers, markets, and distribution, in particular when the subject matter is an attached production that played significant role in a regional geopolitical system. Extraction is "the transference of goods, services or information between individuals and groups" (Braswell, 1996:37). Following Smith (1976), exchange can be divided into five different categories: *dyadic exchange* entails direct exchange between two individuals of equal status; *polyadic exchange* entails direct exchange between elite and several subordinates; *administered market exchange* implies that exchange is part of commerce system which is controlled by political concerns; *monopolistic market exchange* entails that exchange is part of commerce system which support the domination of political concerns; and *competitive market exchange* implies that only market forces of supply and demand determine the value of goods. The difference between *administered market exchange* and *monopolistic market exchange* is the role of the elite in regulating the economy and extract surplus, and the role of market forces in governing exchange. While in the former elite regulates the economy through control over middlemen and trade, in the latter it does so by regulating the exchange between the producer and the middlemen and retailing follows market principles.

Different levels of commercialization are defined for each category of exchange. While *dyadic* and *polyadic* are uncommercialized, *administered* and *monopolistic market exchange* are partially commercialized (it has a noncompetitive or controlled market aspect), and only *competitive market exchange* is fully commercialized. Usually multiple categories co-exist in the broader economic system and the exchange practice may be product-dependant as well as socio-political structure dependent. It is noticed that factors emphasized by *integral* approaches to ancient economy have more weight in the uncommercialized exchange systems.

1.3 Summary

Investigating technology and organization of production with anthropological approach is a fresh contribution to the study of the ancient copper production activities in the southern Levant in general, and to the study of Iron Age societies in southern Jordan in particular. The intensive research conducted in the study area so far has scarcely been focused on anthropological avenues for investigating the archaeological remains (Chapter 3) and here we aim to present a new perspective on the previously recorded data coupled with a substantial new dataset. The new data were collected as part of the current research specifically to answer anthropological oriented questions. By applying models and concepts from the social sciences we hope to present new insights regarding the society behind the technological record, both in synchronic and diachronic perspectives. The basic hypothesis is that social changes within the Iron

Age are reflected in the archaeological record of technology, and that synchronic differences are a key to understand social structure and probably also interactions between *different* social groups. The history of human – technologies – environment interactions is much more dynamic than the monolithic picture rising from previous research. By using the concept of *chaîne opératoire,* the basic methodological concept applied in the current research, we hope to refine our understanding of this social history.

Many approaches exist to the study of technology and ancient economies. Although we embrace post-processual epistemologies embedded in concepts such as *sociotechnical systems* and *system view*, we adopt here a more pragmatic approach that includes components that take into account the human factor. This approach regards *technology* as part of *production system* which is a part of *ancient economic structure*. The models and concepts we use are derived from several theoretical spheres, and when put together they constitute a useful 'toolkit' to approach the specific study case (of specific technology and research questions) and yet to deduce insights that applicable to understanding the general role of technological practices in societies, and how societies are reflected in the technological record.

Ancient metallurgy, like other technologies such as wheel-made pottery, is often viewed as inherently a specialized, full-time practice, because of its inferred technical complexity (Childe, 1934, 1936; White and Pigott, 1996:151). Thus, Iron

Age copper production in the southern Levant is a case study of specialized craft production, dynamically related to social structure and social development. Investigation of the organization of production is a substantial key to understanding socio-political conditions and inter- and intra- social power relations; by the study of organization of production *and* the associated technologies we aim to shed light on these issues, as well as on a basic hypothesis that regards the Iron Age copper production as an *attached* production system. As Costin (2001:288) notes, there is a great advantage in an integral research:

> Studies of manufacturing techniques are no longer an end into themselves, but are usually geared toward complementing other analyses. Studies of technology done in conjunction with studies of the organization of production improve results by contributing a better understanding of raw materials processing, manufacturing sequences/techniques, and production stages… There is a real need to understand the full technological process in order to interpret other characteristics of production, such as potential task division, labor investment, requisite training and skill, and the like.

The correlation between technology and organization of production is more complex than usually presented in the archaeological literature. Frequently researches regard technological complexity as representing organizational complexity, but as Costin (2001:289) rightfully points out, there is little theoretical or empirical evidence to support this assumption. Technological complexity is evaluated in the current research in a relative manner; it is the comprehensive diachronic overview that enables us to attribute degrees of technological advancement to the archaeological records within the entire Iron Age (ca. 700 years), with references to earlier and younger periods. Inferences about the complexity of organization of production are based on factors like *efficiency*, *intensification* (and scale), *surplus*, and *standardization*, and

also on analysis of the spatial distribution of labor. The latter is related to *scale* of production and extent of production system and can be used, cautiously, to infer on the complexity of the organization and the society responsible for it.

In addition to compilation of relevant data regarding the entire suite of known copper exploitation related *sites* (typology, location, etc.), the current research is concerned with technological artifacts. The approach promoted by Costin (e.g., 1991; Costin and Wright, 1998; Costin, 2001) comprises a practical framework to the investigation of records of ancient production in a site level by focusing more on the 'visible' aspects of production activities. Equivalent to Lemonnier's *technical system* and Pfaffenberger's *sociotechnical system* Costin uses the term *craft production systems* to denote the seamless web that exits between production practices and people, social institutions and social processes, including those directly related to symbolic and cultural ones. Costin's concepts, many of which are applied in the current research, parse out the complexity of technological systems and provide a pragmatic tool for describing and analyzing technological systems.

The basis for analyzing production systems is the concept of *chaîne opératoire*. This analytic approach is extremely productive, as it facilitates the accumulation and organization of data regarding all physical aspects of a production system, as well as links to the interpretive / inferred level of analysis. The concept of *chaîne opératoire* cross-cuts different theoretical and epistemological approaches to

technology, production and ancient economies. It provides a neutral foundation to any model or insights about the artisans and their society, and is also a useful and objective tool to track diachronic and synchronic changes of craft production systems and all the associated layers of inferred meanings. In turn, after evidence-based construction of the *chaînes opératoires,* they can be interpreted in light of specific concepts which have theoretical bearings and thus used to gain insights regarding the societies behind them.

There is an intrinsic and well recognized gap between models, concepts and theories and the physical archaeological record. Applying concepts from the social sciences and anthropology, or even those derived directly from archaeological theory to the fragmented field evidence of ancient human activities, presents major difficulties and almost inevitably multiple ways of interpretation (Costin, 2001:278; Killick, 2004a). When trying to establish social reconstructions and insights that can be *reproduced* by other scholars based on the same field and laboratory evidence there should at least be a common terminology. Unfortunately, this is currently not the case, and more standardization of the discourse is needed (Killick, 2004a). We hope that future studies of ancient copper (and metal) technologies will find the approach presented here useful; in any event, clarification of the terminology and concepts is an important part of any anthropological oriented studies of ancient technologies.

For a sound reconstruction of the *craft production system*, more than one line of evidence is needed. The current research is deeply integrated in a long-term study of other aspects of the Iron Age societies in southern Jordan (see section 3.2.5 below), and insights from other anthropological avenues of research are part of the wider synthesis presented here (Chapters 9 and 10). Furthermore, production sites cannot be stripped off of other, non-technological or non-production related features. Thus, sites investigated as part of this work are presented fully, including ostensibly not production-related finds. As the concept of *sociotechnical system* well demonstrates, production is rather only one dependent aspect of a multifaceted society.

2. Geographic and environmental setting

During the Iron Age primary copper production (smelting of copper minerals to produce copper metal) in the southern Levant took place in the vicinity of the ore bodies and were a direct continuation of the mining activities. The extracted copper was most probably exported from the mining areas as a final product consisting of pure copper ingots. The entire *chaîne opératoire* of copper manufacture with its associated infrastructure took place in a rather limited area determined by the location of the mines. The physical characteristics of the mining environment as well as those of the ore bodies themselves are fundamental for understanding the nature of the local Iron Age societies who interacted with these resources. In the Saharo-Arabian desert environment of the Arabah Valley, the exploitation of copper ore was the *raison d'être* of Iron Age settlement in Faynan and Timna. As will be shown in this dissertation, the interaction between societies and natural resources were at the core of their existence. These interactions directly influenced both social processes and the social structure of those societies associated with the organization of metal production. Factors such as the ore quality, fuel and water resources, accessibility to mines, trade routes, food and building material supplies, were fundamental in shaping social features as well as technological choices, installations and products.

In addition to the interactions between society and natural resources, the geographic setting of the mining areas in the southern Levant, and in particular

Faynan, is also a key for interpreting social boundaries and ethnicity, an elusive definition in archaeological research (e.g., Emberling, 1997, and references therein). In the case of southern Jordan in the Iron Age, the archaeological evidence (including inscriptions) coupled with historical sources suggests the dominance of the Edomites, although the exact extant of their territory throughout the Iron Age is not clear and seems to have oscillated (see section 2.1.1 below). Moreover, the dramatic landscape of the Arabah Valley and the western slopes of the Jordanian plateau took part in shaping the local society and its perception by other social groups and polities in the southern Levant. It is therefore important to consider the physical background in the interpretation of the archaeological evidence of this region. Detailed surveys of the nature and geography of Faynan are available in Hauptmann (2007, Chapter 3) and Palmer et al. (2007), and more generally for the Arabah Valley in Bruins (2006) and MacDonald (1992a).

2.1 Geography

The copper ore district of Faynan is located ca. 40 km south of the Dead Sea and ca. 130 km north of the Gulf of Aqaba, along the eastern margin of the Arabah Valley and in the foothills of the Jordanian plateau (Figs.I.1 and I.2 above). Approximately 100 km south of Faynan and along the western margin of the Arabah Valley is the smaller copper ore district of Timna that also contains important Iron Age remains of copper production (see below). The Faynan district is named after the

major archaeological site of Khirbat Faynan (not to be confused with the small, mainly Pottery Neolithic site of Tell Wadi Faynan found in the 1980s), located on the confluence of Wadi Dana and Wadi Ghuweir and identified as biblical Punon (Num.33:42f., 1 Chron. 1:52 and see also 'Pinon' in Genesis 36:40-43) (first by Zeetzen in 1854, see Edelman, 1995)(Edelman 1995)[8].

The Faynan region is located on the eastern margins of the Dead Sea – Wadi Arabah rift system, a major geological feature that is responsible for the dramatic morphology of the landscape and the distribution of different rock formations and ore outcrops. The rifting process resulted in the creation of the deep Gulf of Aqaba, the elongated Arabah Valley, the depression of the Dead Sea (as is well known, the lowest place on earth) and an uneven lifting of both sides of the rift valley. While the Negev hills to the west rise gradually above the Arabah up to an elevation of a few hundred meters above sea level, the Edomite Mountains to the east rise abruptly up to an elevation of almost 2,000 meters above sea level, and create a substantial topographic obstacle (Fig.2.1). Approximately 1,000 meters in elevation separate Faynan and the late Iron Age administrative center of Busyra. This elevation difference, over a distance of less than 15 km as the crow flies, was overcome by well built routes (Ben-Yosef et al., in press).

[8] The Greek (φινω, φαινων) and Latin (Phunon) names of the area also followed the Hebrew Punon and helped preserve this origin in the Arabic name (see Freeman-Grenville et al., 2003).

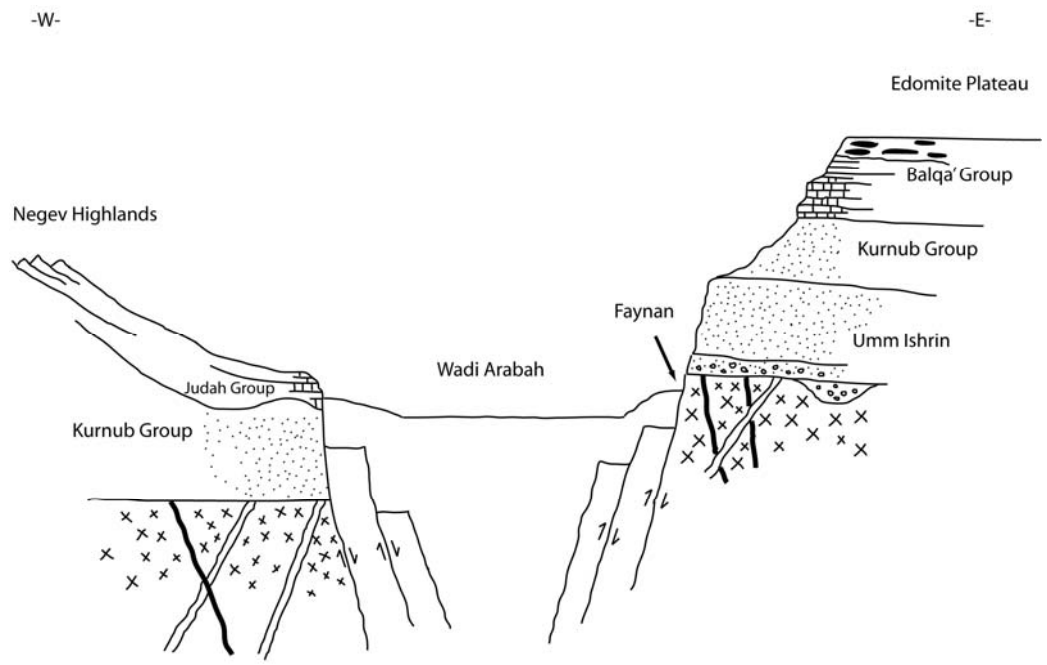


Fig.2.1: Schematic cross section of the Dead Sea – Arabah Rift System around the location of Faynan, showing the main geological units. The topographic terrain is much more difficult and dramatic on the eastern side of the rift and the slopes of the Edomite plateau are a natural barrier (revised after Ravek and Shemida, 2000).

The considerably greater uplifting of the eastern side of the Arabah Valley resulted in the exposure of deep rock formations that represent the slopes of the Edomite Mountains and generally are not exposed in the western side (the Negev). Among these formations is the Umm Ishrin whose red sandstone characterizes the Edomite landscape and constitutes the physical background of important sites such as Umm al-Byara and Sel'a, and the Burj formation, the principal ore bearing horizon (see below).

The Faynan area covers approximately 300 km^2 and includes two major wadi basins (separate water catchments zones) that are part of the Wadi Arabah and the

Dead Sea drainage system (Fig.2.2). The wadi basins from north to south are Wadi al-Ghuweiba (Arabic for a little grove, probably after the one at the oasis of ‘Ain al-Ghuweiba) and its tributaries and Wadi Fidan and its pronounced tributaries of Wadi Dana and Wadi Ghuweir, along which many of Faynan’s important sites are located, including Khirbat Faynan and Khirbat Hamra Ifdan. The wadis are dry valleys or canyons, carrying water in rare occasions of strong local rains during the winter or the transformation seasons, usually in the form of flesh floods. However, in each of the major wadi basins there are permanent springs that support small oases and are reliable water sources in the desert region of southern Jordan and the Arabah (‘Ain al-Ghuweiba and ‘Ain Fidan respectively; ‘Ain is Arabic for a spring, Fig.2.2). In addition to the well known oases, the Faynan-Busayra Regional Survey (Ben-Yosef et al., in press, and section 3.2.5 below) recorded other water sources in the area that mostly include *thmilat*, dug depressions into high water tables in wadi beds, representing additional water sources possibly available in antiquity as well. A traveler or a caravan passing through the landscape of southern Jordan and in particular its lowlands is entirely dependent on such water sources (see section 2.3 below).

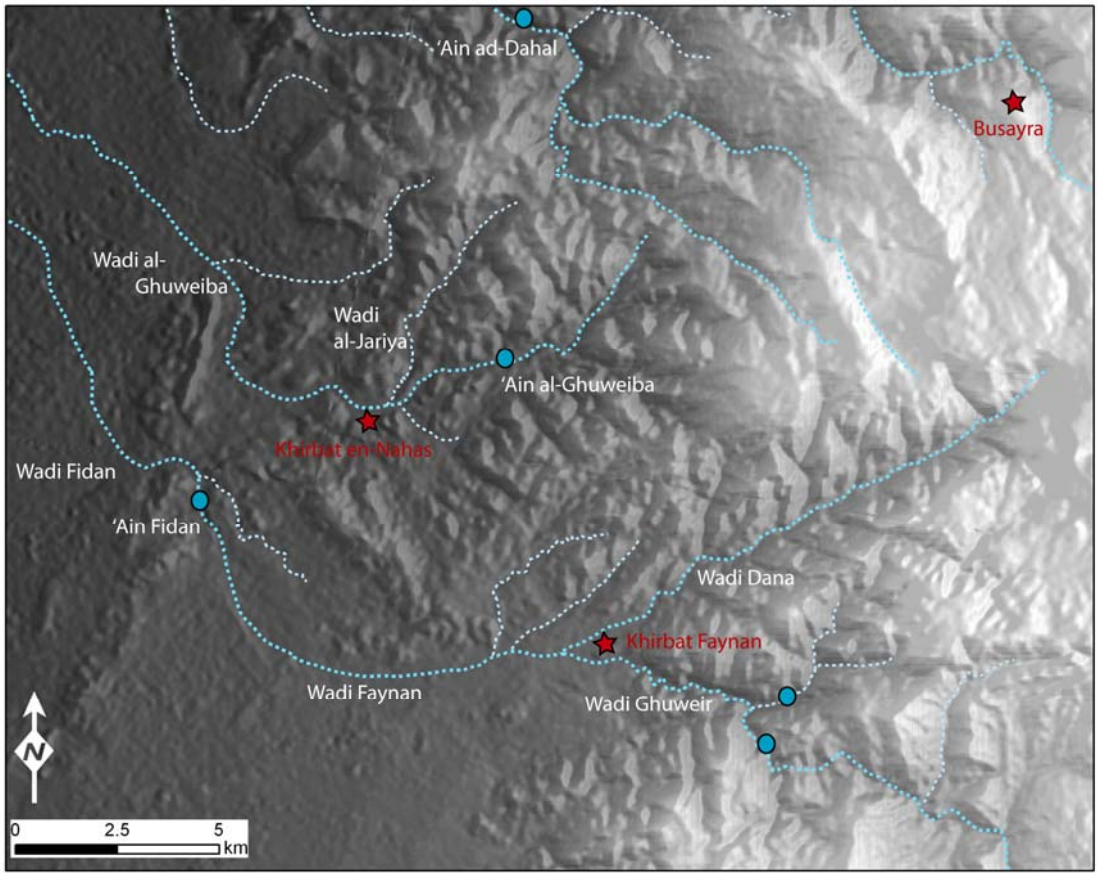


Fig.2.2: Major wadi basins and springs in the area of Faynan, Jordan. The wadis are part of the Dead Sea catchment and drain through the Wadi Arabah to the northwest. Wadi Ghuweir is a perennial stream that fed agricultural fields in the vicinity of Khirbat Faynan in different periods.

2.1.1 *Geographical boundaries of Edom*

One of the most difficult challenges regarding Iron Age copper production in the region of Faynan (and also in Timna) is identifying the ethnicity of the workers and the social group that had control over this enterprise. Lacking written evidence found in the local archaeological record (i.e., in the mining and smelting sites themselves), the primary source for identifying ethnicity is the material culture, and in particular ceramic studies, with all the serious problems these studies imply (e.g.,

Jones, 1997, and references therein). In Faynan, a major ceramic study with a detailed discussion on social boundaries and ethnicity was published recently (Smith and Levy, 2008; Smith, 2009; Smith and Levy, in prep.; Smith et al., in press-b). The results of this study are presented and discussed in Chapter 10 below, together with insights concerning ethnicity derived from the archaeometallurgical remains discussed in this dissertation (including a well established connection between Faynan and Timna reflected in the metallurgical material culture of the early Iron Age identified here).

In addition to the archaeological record and the material culture, another source for reconstructing social boundaries are historical accounts regarding the geographic region of Faynan in the Iron Age. The most important, albeit difficult, source is the Old Testament or Hebrew Bible (e.g., Bartlett, 1989a; 1992, and references therein), referring to the Kingdom of Edom in the mountainous region of southern Jordan and the Negev highlands (Avishur, 2007). Edom appears also in earlier Egyptian (Kitchen, 1992) and Assyrian (Millard, 1992) texts, as well as in late Iron Age ostraca found in some of the Negev sites (Beit-Arieh, 1995b).

The extent of the biblical / Iron Age kingdom of Edom fluctuated throughout the 12th to 6th centuries BCE and is poorly delineated in biblical and other historical accounts. It is generally accepted that the mountain region of southern Jordan was the heart of this polity (Bartlett, 1989a; Edelman, 1995), with Bozrah (Gen. 36:22; Isa. 34:6; 63:1; Jer. 49:13,22; Amos 1:12), one of its few securely identifiable settlements

(modern Busayra), as its administrative center at least during the late Iron Age (Bienkowski, 1995, 2002a). It is also widely accepted that the term 'Edom' referred initially to a distinct geographic region (e.g., 2 Sam. 8:14) and only later became to designate a polity or people. This is exemplified by the earliest known reference to Edom in the Egyptian source of Papyrus Anastasi VI[9] (referring to an event in the late thirteenth century BCE) (Bartlett, 1989a:37-38), and maybe by the descriptive nature of the term Edom, meaning "red" in Hebrew and probably referring to the prominent red sandstone cliffs of the mountain slopes of southern Jordan (Edelman, 1995). A few other geographic terms in the Bible are associated with Edom, including Se'ir, Gebal and Teman. Se'ir was suggested to represent the wooded land of southern Jordan following the Hebrew meaning 'hairy', the area south of Shawbak following the modern Arabic district name of 'es-Shera', or areas in the Negev following the reading of Egyptian texts[10] (see in particular Bartlett, 1989a; Edelman, 1995; Zucconi, 2007); Gebal is perhaps the area north of Shawbak following the modern Arabic district name el-Jibal, Eusebius reference to Gebalene and Josephus reference to Gobolitis (Bartlett, 1989a:39; Freeman-Grenville et al., 2003); and Teman is probably a territory in southern Edom and not a specific settlement as was suggested before (de Vaux, 1969; Bartlett, 1989a).

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[9] Papyrus Anastasi VI dates to the end of the 13th century BCE and states "we have just finished letting the Shasu people of Edom pass the fortress of Merneptah-hotphima-'e (life, prosperity, health), which is in Tjeku, to the pools of Pi-tum" (ANET, 259).

[10] Seir is mentioned in Amarna letter no. 88 and in descriptions from the days of Rameses II and III, without mentioning Edom, while in Papyrus Anastasi VI (note 2 above) the Shasu of Edom are mentioned without S'eir. There is no connection between the two terms in any other Egyptian text except that both regions are peopled by Shasu. S'eir is more frequently mentioned perhaps because it is closer to Egypt (see Kitchen, 1992).

Glueck (1936a) concludes that "the western boundary of Edom during the period of its independent political existence was formed by the 'Arabah valley, and never extended west of the 'Arabah. However as a result of Nabataean pressure, many Edomites infiltrated into southern Palestine, the territory occupied by them becoming known as Idumaea". According to Glueck (ibid.), the idea that an independent Edom ever occupied both sides of the Arabah Valley is derived from biblical texts that are all post-exilic (6th century BCE or later). Glueck accepted Wellhausen's dating of the biblical sources, and thus he interpreted the biblical passages as a projection of a postexilic geography, i.e. the boundaries of Idomea. In a recent paper, Zucconi (2007) summarizes the arguments against this approach, based on archaeological and textual data, and concludes that independent Edom, already in the early Iron Age, extended on both sides of the Arabah Valley[11]. Most scholars today accept that Edom's territory included the southern Negev already in the early Iron Age (e.g., Rainey and Notley, 2006) (Fig.2.3), although issues such as when in the Iron Age Edom extended, the geopolitical situation in the early part of the period (12th – 9th centuries BCE) and the territorial battles and arrangements with the neighbors to the west and northwest (the United Monarchy and Judah, see Fig.2.3), are still open. Although Faynan is located in the lowlands of southern Jordan, it is part of the accepted territory of Iron Age Edom, and high resolution radiocarbon dates published recently support our claim that this

[11] Some of the arguments are based on the date of 'P' (the Priestly segments in the Old Testament); when accepting its early date (e.g., Zevit, 1982) the passages of Num. 34.3-4 and Josh. 15.1-3 depict Edom's western borders in the period from 722 BCE to 587 BCE, situated along the road from Arad to Kedesh Barnea.

economically significant region was the initial core of the Edomite polity, while only later the center moved to the highlands (Hauptmann et al., 1985; Knauf, 1995; Levy et al., 2004c; Ben-Yosef et al., 2010a, and chapter 10 below).

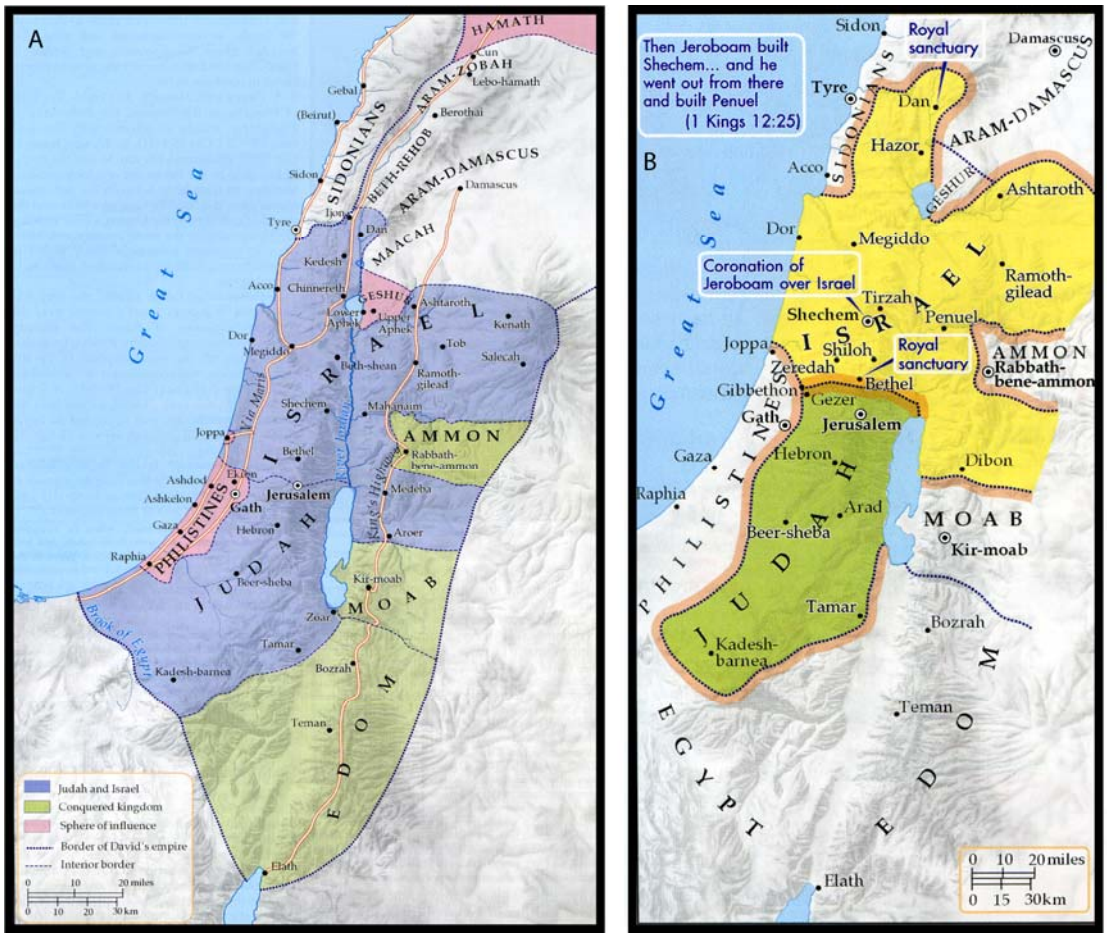


Fig.2.3: A) The territory of Edom in the days of David's Kingdom as depicted in Rainey and Notley's Atlas of the Biblical World (2006:162). Edom extends over both sides of the Arabah Valley and its territory includes Timna and the southern Negev. Although the authors are conservative about their interpretation of the biblical accounts, the wide geographic extent of Edom is widely accepted by biblical scholars and archaeologists (see text). B) The territory of Edom in the days of the Divided Monarchy (according to biblical historiography, after 931 BCE) as depicted in Rainey and Notley's Atlas of the Biblical World (2006:169). The enmity between Edom and Judah lasted for centuries and is well documented in the biblical accounts (Bartlett, 1989b; Dicou, 1994).

2.1.2 *Local and regional trade routes*

Faynan is located in the arid land on the margins of the populated zones of the Levant. Export of copper products from the mining and smelting areas was based on caravans of draft animals, most probably camels and donkeys that traversed the desert of the southern Levant towards the hill country of Judah, the coast of the Mediterranean Sea, or the northern states along the Transjordanian plateau. During the Iron Age, Faynan was probably connected to the regional road network of incense trade from the southern parts of Arabia (e.g., Finkelstein, 1988; Jasmin, 2006), and commercial traffic was at the core of the economy of the local Iron Age society.

In a recent study of regional and local Iron Age roads in the Faynan region, a reconstruction of the road network is suggested based on finds of a regional survey (FBRS, see section 3.2.5 below), topographic and textual analyses (Ben-Yosef et al., in press). The course of the trade routes is mostly dictated by geographical features, and illustrated in Figs.2.4 and 2.5. The Faynan region has a few local routes connecting the mining and smelting areas to the highland plateau to the east and to the central road station in the other side of the Arabah Valley at ‘Ain Hazeva (Arabic = Ain Hosb). The regional roads pass only through the outskirts of Faynan, and the Iron Age copper production centers of Wadi al-Ghuweiba were not part of any important route; the main east – west crossing road, connecting Busayra to the Wadi Arabah, passed through Wadi ad-Dahal to the north of Faynan and the main south – north road

passed through the western margins of the region (Ben-Yosef et al., in press). It is therefore not reasonable to explain any of the architectural features of the Iron Age sites of Wadi al-Ghuweiba as primarily related to road stations detached from the copper production enterprise, as been suggested recently by Finkelstein and Singer-Avitz (2009).

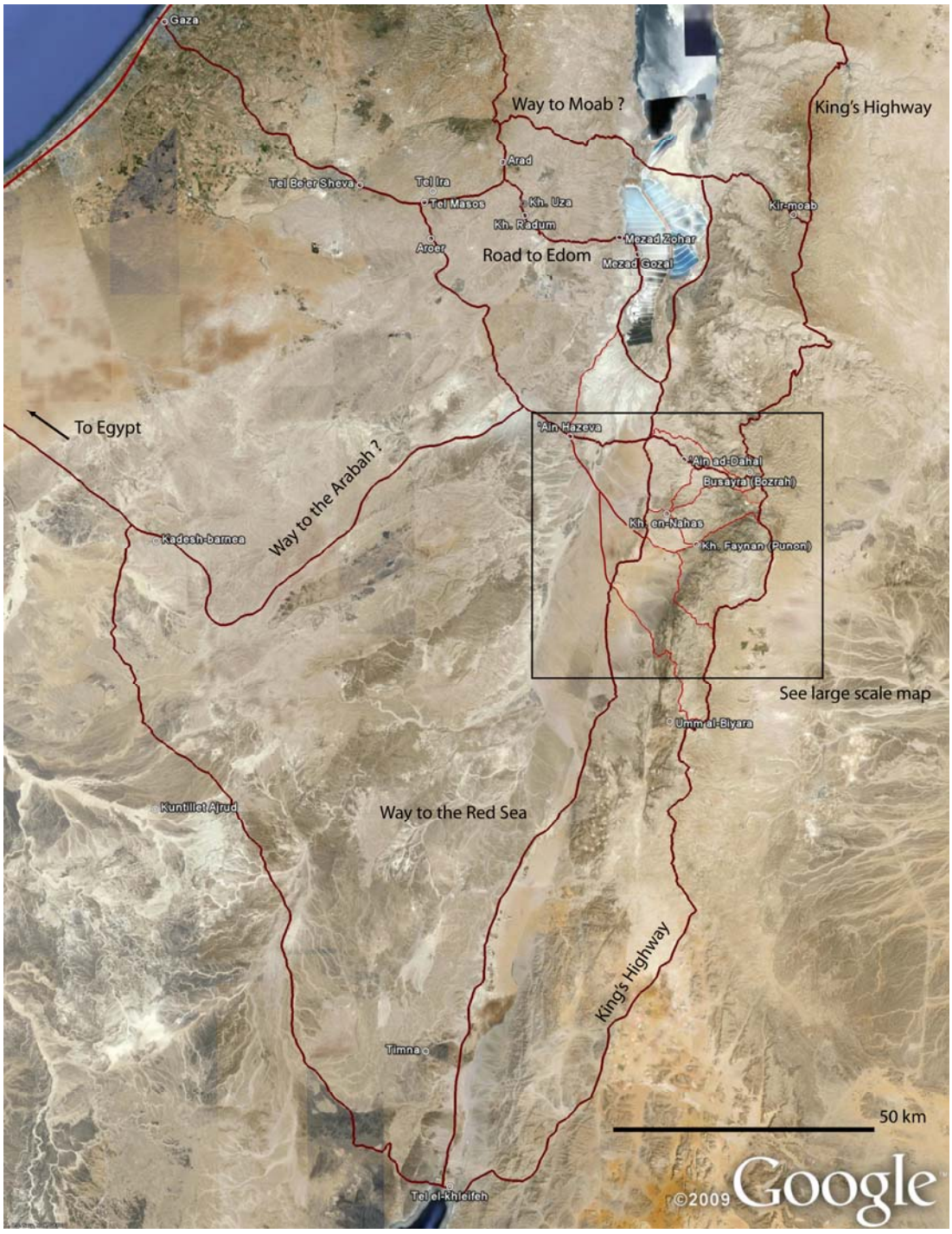


Fig.2.4: The ancient road network in the Negev,Arabah Valley and southern Jordan, including Biblical identifications (on Google Earth Satellite image, after Aharoni, 1979; Aharoni et al., 2002); for details see Ben-Yosef et al. (in press); for the Faynan region see Fig.2.5.



Fig.2.5: The ancient road network in the area of Faynan (on Google Earth satellite image). The two main north – south roads are the King's Highway (e.g., Num. 21:22) on the edge of the Edomite plateau and the "Way to the Red Sea" (e.g., Num. 21:4, 14:25, Deut. 1:40) (or possibly "The Arava Road" [e.g., Deut.2:8, 2Kgs.25:4]), here suggested to follow the water rich eastern margins of the Arabah Valley. The main east-west road from Busayra down to the Arabah and farther to the oasis of 'Ain Haseba is Naqb ad-Dahal; for details see Ben-Yosef et al. (in press).

2.2 Geology

A detailed overview of the geology of Faynan and its copper mineralization is available in Hauptmann (2007, chapter 4), Palmer et al. (Palmer et al., 2007:32-35), Heitkemper (1988, PhD dissertation, in German), and al-Shorman (2009:10-28, PhD dissertation). A detailed description of the geology of Timna Valley is available in Segev (1986), and for its copper mineralization in Segev and Sass (1989), Schlomovitz (1995) and Keidar (Keidar, 1984). For the diagentic connections between the copper mineralization of Faynan and Timna see in particular Segev et al. (1992). Recently, a comprehensive volume covering the geology of the Levant was published (Hall et al., 2005), and presents a good overview of the stratigraphy and structural features of the region.

The geological history of the eastern Mediterranean is complex and relates to processes along various tectonic boundaries. The area comprises the African-Arabian shield (or the Arabian-Nubian Massive) of Precambrian crystalline rocks exposed in the south, and sedimentary rocks of increasing thickness towards the north (Fig.2.6). An important boundary is the contact zone between the African-Arabian Plate and the Taurides and Iranides in eastern Anatolia. This folding area is part of the Tethyan Eurasian metallogenic belt ("TEMB"), (after Jankovie, 1997), and contains numerous ore deposits that were exploited in antiquity. The 'metallogenic belt' was formed in two major folding episodes, one in the Upper Cretaceous, connected to the obduction

of ophiolitic rocks (Yilmaz, 1993), and the other in the Eocene-Miocene, linked to the collision of the Arabian Plate and the Eurasian continent. Ophiolitic rocks occur in the Troodos mountain range in Cyprus, throughout the Taurides, along the Zagros Mountains in Iran and Oman. Copper ores embedded in these rocks were rich metal resources in Antiquity (Fig.2.6, Hauptmann, 2007:56).

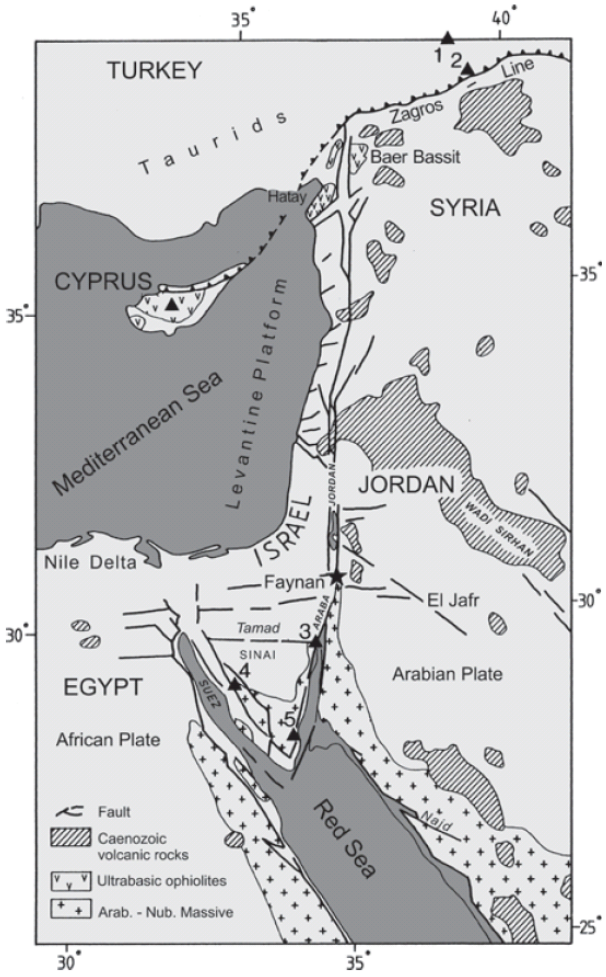


Fig.2.6: Structural map of the Eastern Mediterranean showing major fault systems, the exposure of the Arabian-Nubian Massive, the sedimentary cover (smooth gray zone) and copper ore mineralizations: (1) Keban and other ore deposits of the upper Euphrates; (2) Ergani Maden; (3) Timna; (4) Umm Bogma; (5) Wadi Tar and other ore deposits of southeast Sinai (from Hauptmann, 2007:56)

The geological landscape of Faynan and Timna is primarily the result of the Dead Sea transform, a left strike-slip fault system between the Arabian plate and the Levantine Platform (Freund, 1965) (Fig.2.6). This fault system is responsible for the morphological rift valley of the Arabah, for the uplift of the Jordanian plateau and for the uplift of the Timna region, resulting in the exposure of various rock units and the copper ore mineralization. The transform fault is a relatively young phenomenon, starting in the Miocene and demonstrating a lateral movement of ca. 105 km (Garfunkel, 1981). The Rift Transform stretches over 1200 km form the Zagros-Tauros subduction zone in southern Turkey; it is a northern (and younger) feature of a 6000 km geological structure that begins in the south in East Africa, and related to the formation and opening process of the Red Sea.

Because of the difference in uplifting between the eastern and western sides of the Arabah, the basement crystalline rocks are exposed in the eastern side along a ca. 50 km continuous strip (Fig.2.7). A faulting system of a geological Horst in Faynan is responsible for one of the largest and northern most outcrops of basement rocks in the Arabah Valley (Rabba', 1991; Rabba', 1994). The Faynan Horst consists mostly of andesitic rocks that have partly undergone zoned alteration. Various granitic rocks can be found in the wider surroundings of Faynan, which are covered by Cambrian and Cretaceous sediments in the north, south and east. A series of basaltic and andesitic-rhyolitic dikes cross the basement rocks, and are related to volcanic activities of the end of the Precambrian and early Cambrian. These dikes and volcanic rocks (the latter

are exposed in several locations along the eastern margins of the rift, including in the Abu-Khusheibah region) contain copper mineralizations, and are regarded as the primary source of ore deposits in the Arabah and the western part of Sinai (see below).

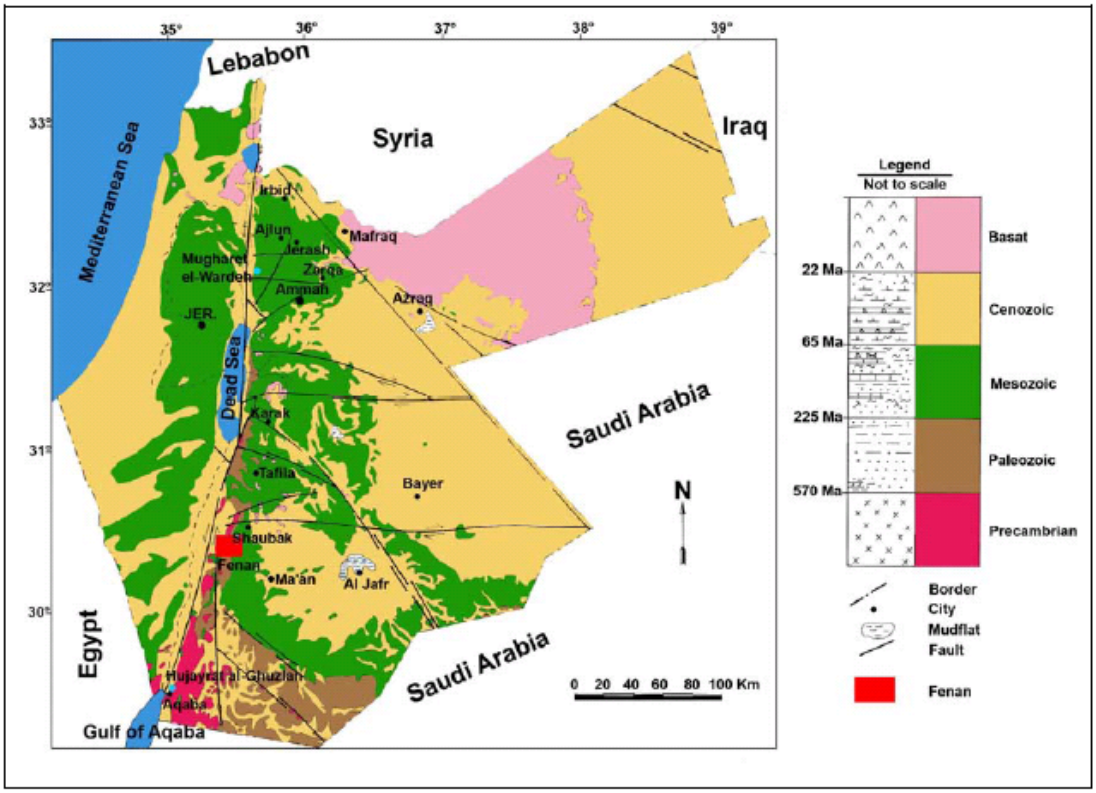


Fig.2.7: A simplified map of the geology of Jordan and Israel (Faynan is indicated in red). The basement crystalline rocks are exposed, together with other sedimentary layers of the Paleozoic, mostly along the eastern margins of the Arabah Valley (from NRA, 1996; through Al-Shorman, 2009).

The sequence of sedimentary rocks covering the basement andesites and granites span (not continuously) the Cambrian to Quaternary and are up to 1900 m thick (e.g., Neev et al., 1976). In general, the stratigraphic sedimentary sequence can be divided into three main units, according to rock types and occurrences (note that it is not a division by unconformities). The lower most consists mostly of sandstones,

commonly known as the *'Nubian Sandstones'* (Hirsch et al., 2005), including Cambrio-Ordovician to Early Cretaceous clastics of fluviatile and shallow marine origin. The sandstones are described by Weissbrod and Perath (1990). The lower part of this unit (Lower Cambrian and in Timna probably also Lower Cretaceous) is where the copper ore deposits are located. The second unit is composed of marine deposits. During the Cenomanian a transgression took place and limestone, dolomite, chalk and marl accumulated in a shallow marine environment; in the Negev and the area of modern Amman, phosphate deposits formed. The marl and limestone form the upper slopes of the Jordanian plateau (Fig.2.1). The uppermost stratigraphic unit is composed of conglomerates, sandstones and claystone formed during the Neogene. This includes the sediments that were deposited in the brackish water of the Lisan Lake. These deposits occur in patches along the Arabah and its margins, and in Faynan it is represented by Pleistocene terraces along Wadi Fidan and Wadi al-Ghuweiba and sand dunes in the southern part of the region (Barker et al., 2007a; el-Rishi et al., 2007; McLaren et al., 2007) (Fig.2.8). The wadis in Faynan drain an extensive region of the Jordanian plateau and contain various rock types of different sizes from sand and gravel to boulders in the alluvium of the wadi beds. This assortment of stone types (chert, limestone, dolostone, sandstone, granites, andesites, basalts, etc.), resulting from the exposure of numerous stratigraphic units along the mountain slopes, was a readily available rich resource of ground stones for various grinding and crushing activities in the smelting sites, and is reflected in the archaeological record (see Chapter 7 below).

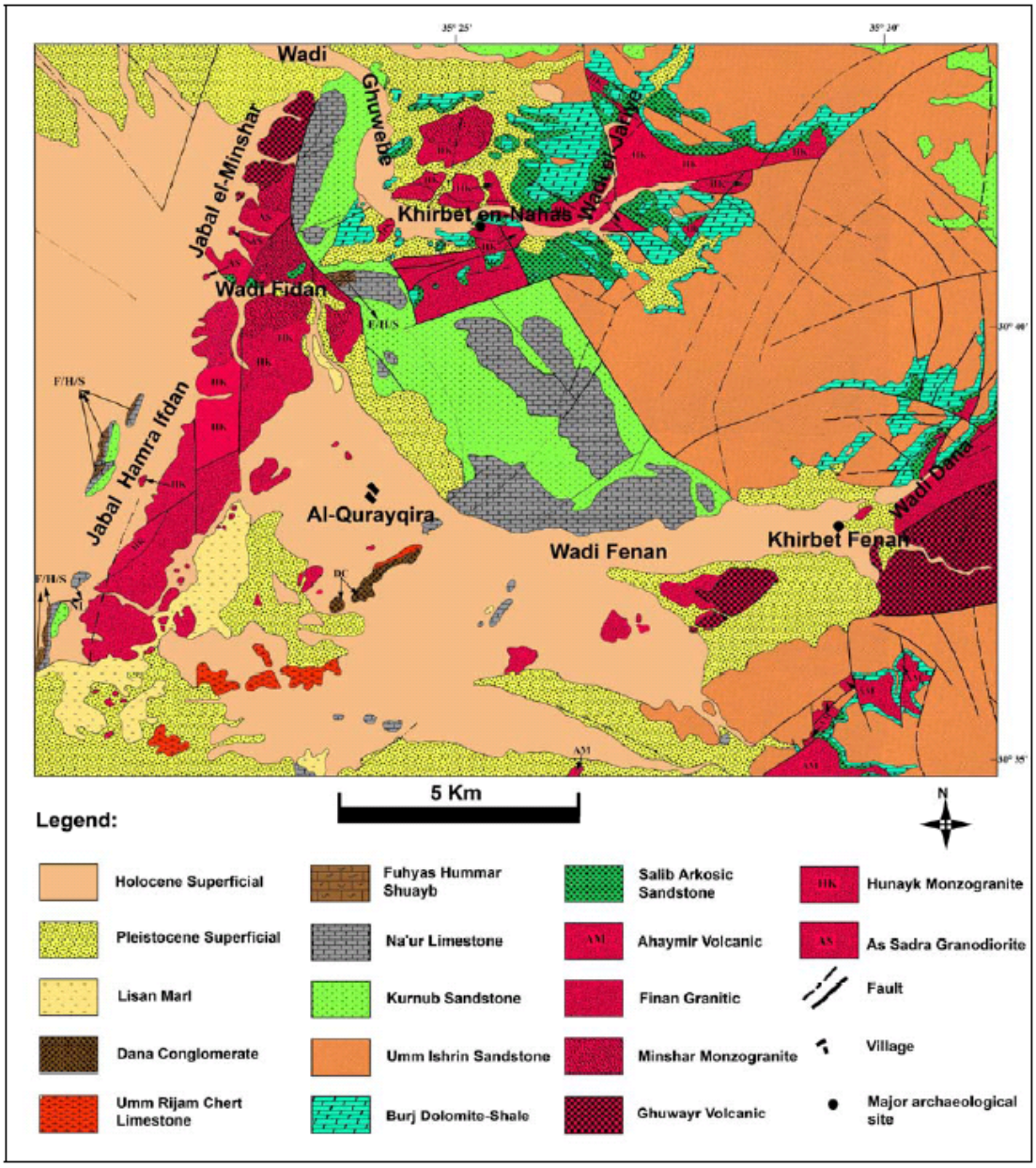


Fig.2.8: Simplified geological map of the Faynan area (from Al-Shorman, 2009:20). The map is based on the 1:50,000 geological map sheets of Al Qurayqira (Rabba', 1991) and Ash-Shawbak (Barjous, 1988). Note especially the rich variety of rock types and the distribution of the Burj Dolomite-Shale formation, the principal copper ore bearing unit. See also more detailed map and Iron Age sites in Fig.5.3.

2.2.1 *General overview of the copper ore deposits of the Eastern Mediterranean and the southern Levant*

Copper ore deposits are relatively abundant around the Mediterranean (Fig.2.9), and a few of the major ones are located in the eastern part of the region (Fig.2.6).

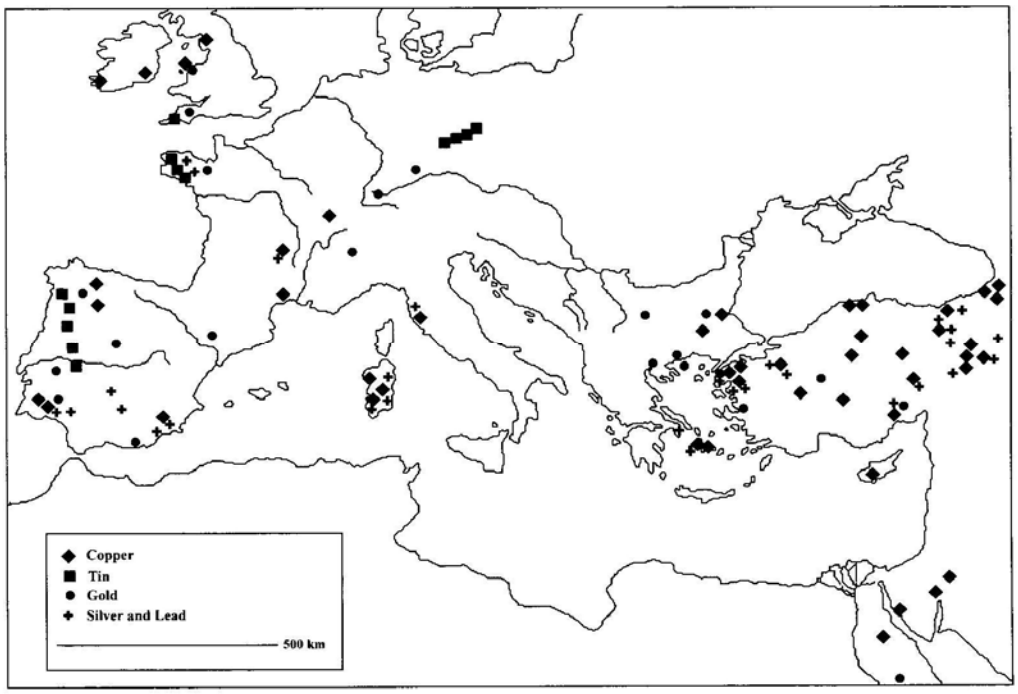


Fig.2.9: Distribution of major ore deposits in Europe and the Mediterranean (Kassianidou and Knapp, 2005, map drawn by V. Kassianidou). Note that the controversial tin mines in Anatolia, a possible source of tin in the Early Bronze Age, are not shown on the map (e.g., Muhly et al., 1991; Yener, 2000:71-109).

The copper ore bodies of the Arabah and Sinai are significantly different from most of the other ore sources. While the common appearance of copper minerals is associated with basic and ultrabasic rocks of ophiolite formations, and usually they are

part of massive sulphide deposits[12], the copper minerals of the southern Levant are a secondary deposition associated with sedimentary rocks and are overwhelmingly oxidic. This difference has direct implications on the ancient smelting process, as it is much easier to smelt oxidic copper minerals than sulphides (and see below).

The largest copper ore deposits in the Eastern Mediterranean are located in Cyprus and eastern Anatolia. In Cyprus, more than 30 major copper ore outcrops make the island the most important regional source of copper in antiquity. These ore deposits were intensively exploited from at least the Middle Bronze Age (early second millennium BCE, see Muhly et al., 1982), with one of the peaks of copper production between 1600 and 1200 BCE. This peak was followed by a considerable decline in the consecutive Iron Age period. Cyprus has a multitude of slag mounds (Bachmann, 1982a; Koucky and Steinberg, 1982), estimated to contain four million tons of slag material (Zwicker, 1986; cf. ca. 200,000 tons of slag in Faynan Hauptmann, 2007:147). The slag deposits in Cyprus are mostly located near the mining areas. In most cases they are not dated properly as the focus of archaeological research has been the coastal settlements, and future research may shed new light on the archaeometallurgical history of the island, including the poorly understood Iron Age. The ore deposits contain massive sulphides of volcano-sedimentary origin associated with the formation of mid-oceanic ridge (Sillitoe, 1972). They were tectonically moved together with oceanic crust form an ophiolite that comprises the Troodos

[12] An important exception is the major ore deposits in Sub-Saharan Africa (Bisson, 2000:95).

Mountains. Ore mineralization, associated with (ultra-) basic rock, occur in all litho logic units in the Troodos, and date to the Cretaceous period. However, the most important copper ore deposits are associated with the Pillow-Lava Unit, exposed as a belt around the Troodos ridges. The mineralization of this unit is rather monotonous and consists predominantly of pyrite (FeS_2) with erratic occurrences of Cu-Fe sulphides and occasionally sphalerite [(Zn,Fe)S] (Hauptmann, 2007:60). Cyprus has an important field evidence of ancient smelting of sulphidic copper ore, providing a 'model case' for studying the technology of smelting such minerals (e.g., Kassianidou, 1999; Kassianidou and Knapp, 2005). This technology consists of multi smelting cycles and the production of matte ('matte smelting', e.g., Craddock, 1995), and is still not well understood. The copper ore deposits of Cyprus are also associated with bright red gossans ('iron cap', a secondary deposition of the weathered ore body, above the ore body itself) that were extensively mined in antiquity. The gossans and cementation zones have rich copper sulphides (covellite [CuS], chalcocite [Cu_2S], bornite [Cu_5FeS_4])or cuprite (Cu_2O), sometimes containing up to 30% Cu or more (Stos-Gale and Gale, 1994). Some of the other mineralization zones of the Troodos, especially those associated with the gabbros and periodotites underneath the volcanic rocks were also exploited in antiquity at least since the Hellenistic-Roman period, although it is not clear to what extent (Hauptmann, 2007:61). The Cypriote copper ores contain only traces of Ni, As, Co and Pb (Constantinou, 1980).

Another important region of copper ore deposits in the Eastern Mediterranean is eastern Anatolia, and especially the mines of Ergani Maden (Fig.2.6) that were until 1994 the largest active modern copper mine in Turkey. The geological situation is similar to Cyprus; the copper mineralization also occurs in association with ophiolitic rocks, and the ore bodies has similar geochemistry making it difficult to differentiate between the two sources by means of lead isotope analysis (see section 2.2.2 below). The minerals of the ore body of Ergani Maden are also monotonous, with pyrite, pyrrhotine, chalcopyrite, magnetite, hematite and sphalerite (Hauptmann, 2007:61). The expansive modern exploitation of the mines destroyed almost the entire evidence of ancient mining and exposed outcrops, thus it is hard to assess the quality of the ore body as it was in antiquity and the intensity and chronology of human activities at the site. Nevertheless, it has been suggested that Ergani Maden is the most important prehistoric copper source in Anatolia, based mostly on its central location between eastern Anatolia and Mesopotamia, and the rich occurrence of native copper and oxidic copper ores (Tylecote, 1970). Some peripheral archaeological evidence of ancient mines do exist, but their dating is not secure (e.g., Seelinger et al., 1985). The suggestion by Tylecote (1976) that Ergani Maden was a source of arsenic and nickel copper ores for production of arsenic bronzes in the Early Bronze Age is debated (Hauptmann, 2007:61).

Minor copper ore deposits in the Eastern Mediterranean include a series of outcrops between Lake Van and the upper Euphrates in eastern Anatolia that may have

been the source of native copper during the Neolithic (Seelinger et al., 1985), the lead-silver deposit of Keban in the upper Euphrates that may possibly have been a source of As-containing copper and gold (Palmieri et al., 1993), and some small copper mining operations in northwestern Hijaz. The latter region is known primarily as a source of gold (Kisnawi et al., 1983), but traces of early copper production were reported, according to Hauptmann (2007:63) from three different sites associated with small sedimentary ore deposits in sandstones: Shim at-Tasa (Shanks, 1936), Imsayea and az-Zuwaydiyah at al-Disa (Kisnawi et al., 1983). The ore rich region of the Hijaz is poorly studied and probably contains much more archaeometallurgical evidence relevant to the history of metallurgy in the southern Levant. Another copper ore deposit close to the southern Levant is located in the eastern desert of Egypt (Fig.2.9). This ore deposit was probably exploited briefly in the Early Bronze Age with furnaces operated by wind on the local hills (Castel et al., 2008). Except from this evidence, no primary copper smelting activities are known thus far from Egypt during its long history (Ogden, 2000).

Most of the copper ore deposits of the southern Levant are fundamentally different from the common occurrences of copper ores such as those described above. Their copper minerals are usually oxidic, sulphides are rare, and they appear as secondary mineralization in sandstones or ore pockets in paleokarst. The most important of these deposits occur in Cambrian and Cretaceous sandstone and dolomite, and the most extensive outcrops are those of Faynan and Timna. In

southwestern Sinai there are similar ore deposits in the vicinity of Umm Bogma and Serabit el-Khadim (Figs.2.6 and 2.9). The deposits of Umm Bogma, which were mined in antiquity, contain Mn-ores, oxidic Cu-ores, and very low concentrations of trace elements (Hauptmann, 2007:62). The site of Bir Nasib, the largest smelting site in the Sinai Peninsula, is located near Umm Bogma and contains ca. 100,000 tons of slag (Rothenberg, 1987; Hauptmann, 2007:62). The Egyptian mining activities in Wadi Maghara and Serabit el-Khadim (Beit-Arieh, 1985; Weisgerber, 1991), were focused mostly on the extraction of turquoise, although evidence of smelting is present and dated to at least the New Kingdom (turquoise mining started as early as the beginning of the Old Kingdom, Petrie, 1906). Small ore deposits in southern Sinai are located in andesitic dikes and hydrothermal veins in the Precambrian basement, and were also exploited in antiquity (Early Bronze Age, see Beit-Arieh, 2003). A unique ore deposit with an ancient prospecting trench has been reported in Wadi Tar in southeastern Sinai. It contains copper-arsenic mineralization, native copper and copper-arsenides, and was suggested as a possible source for the arsenic copper alloys of the Chalcolithic and Bronze Age Levant (Ilani and Rosenfeld, 1994). However, results of lead isotope analysis ruled out this possibility (Segal et al., 2000) , and the exploitation of this deposit, as well as the origin of arsenic copper in the Levant, are still enigmatic (see also a good overview of early mining in Sinai in Avner, 2002). Currently there is no evidence of any copper mining and smelting in Sinai later than the New Kingdom period. However, the limited studies of the evidence in Sinai, uncertainties in dating methodologies (see Chapter 4 and 6 below) and a dominance of

the 'Egyptian paradigm' in the archaeological research (see section 3.2.2 below), suggest that further research may shed new light on the history of metallurgy associated with these deposits.

Although some other random occurrences of copper ores exist in the Negev and the margins of the Arabah Valley (Itamar, 1988) (Fig.2.10), only the ones of Faynan, Wadi Abu-Khusheibah, Timna and Wadi Amram were exploited in antiquity[13]. In Wadi Abu-Khusheibah (and the nearby Wadi Abu Qurdiya) sedimentary copper ores appear in sandstones of the Lower and Middle Cambrian, and evidence of some local mining and smelting exists in the form of large caves with pillars ('Umm al-Amad' in Arabic, meaning 'The Mother of Pillars'), a few galleries and scatters of slag (Kind, 1965). The entire archaeological evidence is dated to the Roman-Nabataean period without any earlier activities, an observation that was corroborated by a visit of the present author in March 2009[14]. The region of Wadi Abu-Khusheiba has been reported to have about 40μg g^{-1} gold in felsic volcanic rocks, including visible pieces in heavy washed minerals (http://www.nra.gov.jo). These occurrences of gold, together with historical descriptions from the Byzantine period of gold mining in the Arabah, were the basis of recent suggestion to see some of the ancient mines, and in particular those of the 'Umm al-Amad' type, as gold mines from

[13] Possible mining evidence in local copper mineralizations in the magmatic complex were reported from several locations. For example, in Wadi Khubat ca. 40km north of Aqaba, a cave with chisel marks and green deposits is described in a popular hiking book (Haviv, 2000:219) (visited by the present author in the December 2000). In addition, Rothenberg (e.g., 1973) mentions some mines south of Eilat, such as the one in Wadi Tueiba.

[14] In the visit (March 9 2009) also participated M. Najjar, T.E. Levy, A. Levy and 'Aweid Sayadin.

the Late Antiquity (Meshel, 2006). This interesting suggestion is still based on speculative evidence[15].

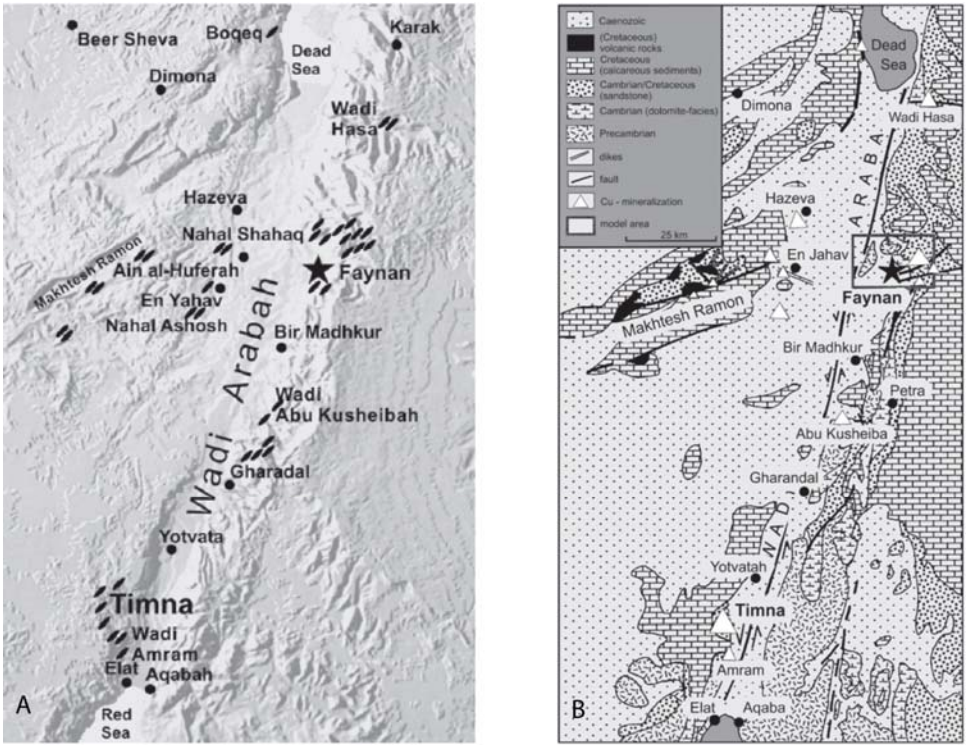


Fig.2.10: Locations of copper ore mineralizations along the Arabah Valley and in the Negev desert, on a shaded-relief map (A) and a schematic geological map (B) (Hauptmann, 2007:41,58). Only the ore deposits of Faynan, Wadi Abu-Khusheibah, Timna and Wadi Amram were exploited in antiquity (see text).

The copper ore deposits in the Cambrian sandstones and dolostones of Faynan are the richest in the Arabah Valley (Fig.2.8). They are diagenetically related to the smaller copper deposits of Timna and Wadi Amram (and the nearby Nahal Roded), located on the west side of the Arabah Valley, ca. 105 km to the south. Both copper ore deposits were formed in the same paleogeopraphic location prior to the tectonic movement of the Rift Valley (Fig.2.11). The origin of the copper ore deposits in

[15] Interestingly, archaeological evidence of gold production in the 10th century CE was reported from the geologically parallel region in the western side of Wadi Arabah (see e.g., Amar, 1997).

Faynan and Timna is complex, with gradual enrichment of copper and manganese through secondary deposition (Segev and Sass, 1989; Segev et al., 1992). The primary source of copper is Cu-Fe sulphide mineralizations in the late Precambrian volcanic rocks (part of the basement complex, 510-560 Ma). During the lower Cambrian, erosion of the volcanic rocks led to synsedimentary (stratiform) enrichment of copper in sandy or clayey dolostones in shallow marine environments. Migration and redeposition of copper occurred mainly as chlorides and here also synsedimentary Mn-ore-mineralizations were formed. The next stage of mineralization was epigenetic remobilization, and was connected to the formation of the Rift Valley, subsequent development of karst associated with faults and fractures at the top of the dolostone unit, and enriched concentration of secondary copper and manganese ores (the DLS unit, see below). The occurrences of copper ore deposits in the sandstone cliffs above the dolomite unit, the lower Umm-Ishrin formation in Faynan and the Amir/Evrona formation in Timna, is also related to the young epigenetic remobilization associated with the Rift Valley (Keidar, 1984), and/or to Lower Cretaceous volcanism evident in Timna (Beyth and Segev, 1983; Segev et al., 1992), or younger (13-15Ma) hydrothermal alteration of the Cambrian sediments associated with the Rift (Beyth et al., 1997). Some of the finds of the current research have the potential to shed new light on the relations between rich copper mineralizations of the sandstone units and volcanic/hydrothermal activities in the geological history of the Arabah (Beyth and Segev, 1983; Ilani et al., 1987; Segev et al., 1992; Beyth et al., 1997). During the 2007 FBRS survey (see section 3.2.5 below) we discovered an extensive pit mine fields that

probably was one of the richest culluviatile ore deposits in Faynan (Ben-Yosef et al., 2009b). The mine fields are associated with young dike and volcanic plug that cross the Salib and Burj formations (thus they are Cambrian or younger). Rock samples from the dike are currently being measured for Ar/Ar dating in the laboratory of Oregon State University. According to the regional geological history, the age of the dike is probably either Lower Cretaceous or Miocene and younger, and the results will help to correlate between field evidence in Faynan and Timna and to further understand processes related to ore formation and/or the Rifting. Further description and discussion appears below, in section 5.2.9.

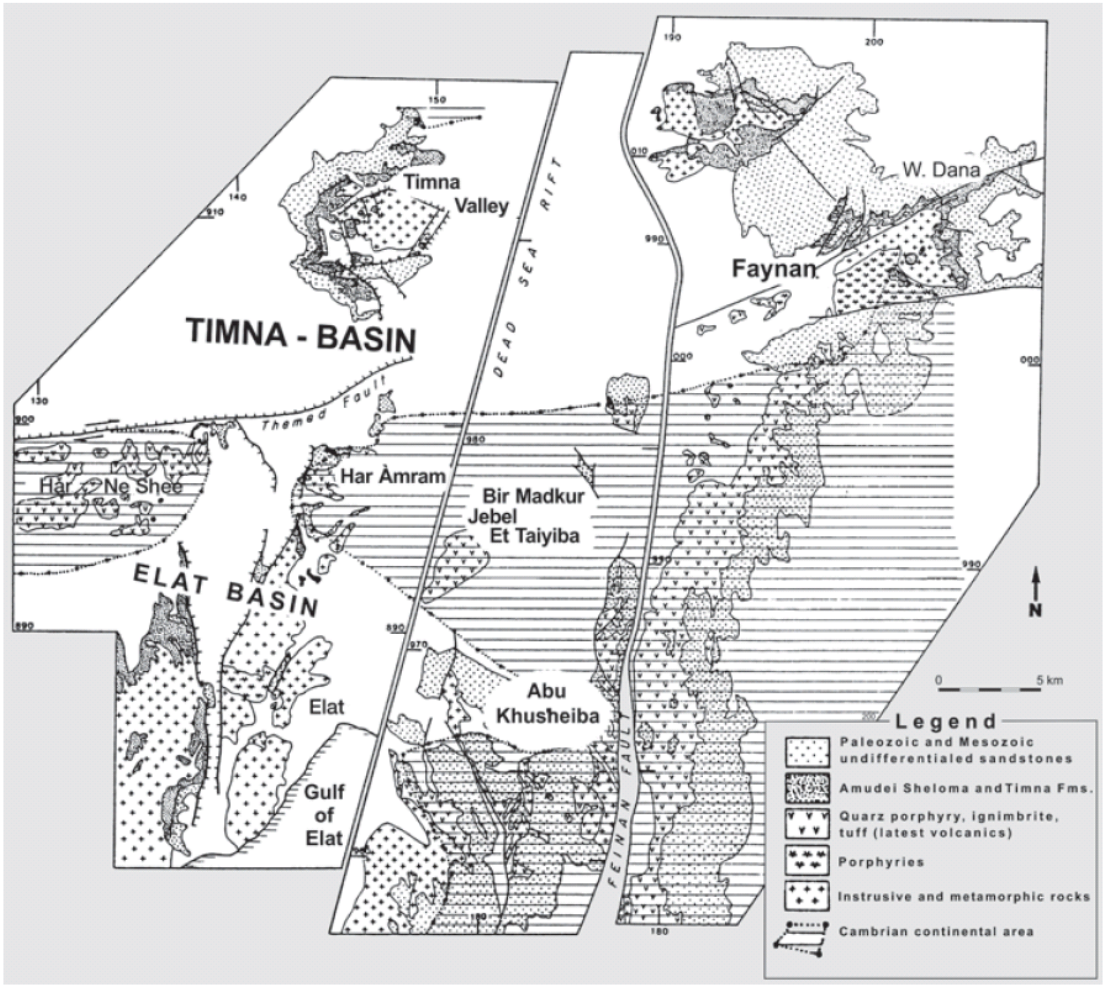


Fig.2.11: A reconstruction of the paleogeography of the Arabah region in the Cambrian. The reconstruction is based on shifting the Levantine and Jordanian blocks by ca. 105km. The copper mineral deposits of Faynan, Timna and Abu-Khusheiba are shown (after Segev et al., 1992; via Hauptmann, 2007:65).

2.2.2 *The host rock formations and the copper minerals of Faynan and Timna*

The raw material for copper production in Faynan and Timna occur in two major geological units with specific characteristics and minerals. The lower and richest unit is the Cambrian dolomite-shale formation, known as DLS (‘Dolomite-

Limestone-Shale Unit', although in Faynan and Timna limestone is not present) or Burj formation in Faynan, and Timna formation in the southern Arabah. The upper unit is part of the so-called 'Nubian' sandstone formations and is known as the Massive Brown Sandstone Unit (MBS) in Faynan, where it is part of the Cambrian Umm-Ishrin formation, and as Amir/Evrona (of uncertain age, but probably Lower Cretaceous) formations in Timna (Fig.2.12). Although the diagenesis of copper mineralizations in Faynan and Timna is similar (see above), the exposure of the host rock formations is different and consequently there is a difference between the two areas regarding the main ore sources exploited in antiquity.

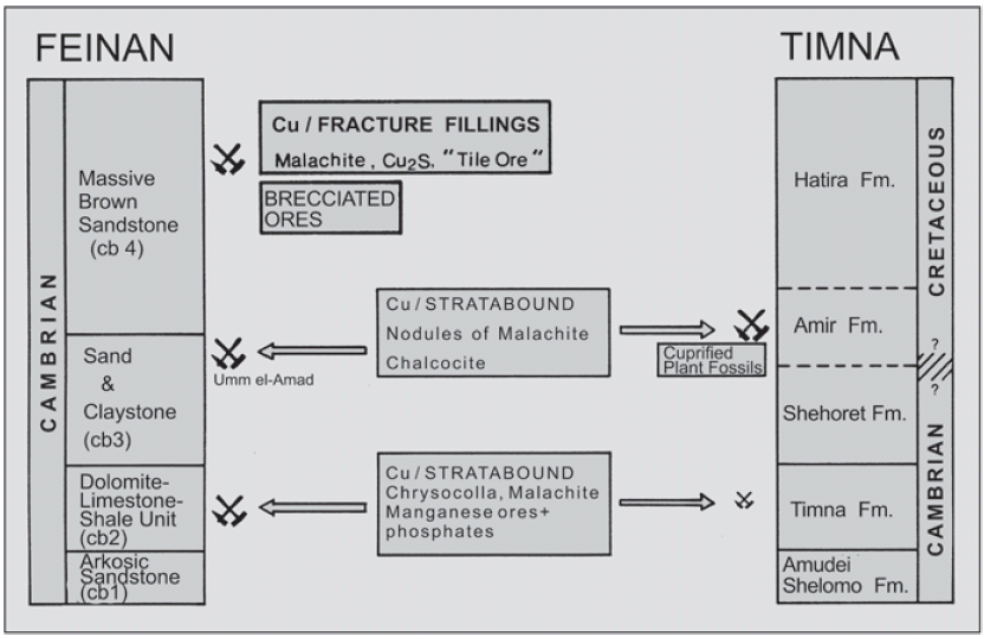


Fig.2.12: Simplified lithostratigraphy and copper mineralizations in Faynan and Timna (from Hauptmann, 2007:66). Note that the correlation showed here is of the ore deposits, and *not* of the lithostratigraphic units. In Faynan, the Arkosic Sandstone (cb1) is also known as 'Salib formation', the 'Dolomite-Limestone-Shale' as 'Burj formation' and the sandstone units cb3 and cb4 as the lower part of the 'Umm-Ishrin formation'. During the Iron Age in Faynan the main source of copper was the DLS Unit while during the Late Bronze – Iron Age in Timna the main source of copper was the mineralizations in the sandstones of Amir/Evrona formations. Geochemically the ore mineralizations are very similar and currently the only secure difference is the presence of cuprified plant fossils in the Timna ores (see discussion in section 2.2.3 below).

According to Hauptmann (2007:69) the copper ore of the Arabah can be precisely characterized because most of the outcrops were not destroyed by modern mining (as is the case in most ancient mining areas around the world), and prospection works done by the Natural Resource Authority of Jordan during the 1960s and 1970s exposed fresh deposits that most probably represent the ore quality as it was available in antiquity. Nevertheless, the new evidence described in this work indicates exhaustive mining activities in specific regions that may imply the presence of higher quality ores than those present today in locations where the ore was not exhausted (see section 5.2.9). In any case, like in any of the ancient mining region, the ore present today should be considered as representing the minimum quality of the available ore in antiquity.

The copper ore deposits of the Cambrian dolomite-shale unit (Burj and Timna formations in Faynan and Timna respectively) are located stratigraphically above ca. 60 m of non-mineralized arkosic sandstones (Salib and Amudei-Shlomo formations in Faynan and Timna respectively). The dolomite-shale unit is 20-40 m thick and is easily recognizable in the landscape by its prominent cliffs, terraces, plateau and dark-gray color (see Fig.5.77). The 1 – 1.5 m thick upper portion of the dolomite-shale unit is the ore-bearing layer, mostly composed of silt, clay and shales. The ore is located in pockets, as matrix mineralization and as vein fillings, and includes copper and

manganese minerals (Hauptmann, 2007:66-79, and references therein). In Faynan, this unit was the principal copper ore source in most of the archaeological periods; in fact, according to the research of the GMM group (e.g., Weisgerber, 2006; Hauptmann, 2007), only in the Chalcolithic and the Roman periods was the other mineralization in Faynan (namely those of the MBS, see below) exploited. During the Iron Age, the ores of the dolomite-shale unit were the primary source of raw materials for copper production in Faynan. The current research has found that the mining techniques in Iron Age Faynan were probably more varied than those described by the GMM researchers. Our new work has identified a previously undocumented major source that included ore nodules mined from culluvial/alluvial deposits derived from the DLS unit; this complemented mining of ore from the Burj rock unit itself (see description in section 5.2.9 and discussion in section 9.1.1). The situation in Timna is entirely different, probably because there are less exposed outcrops of the DLS unit (Timna formation). The only evidence of ancient mining in the DLS unit in the southern Arabah Valley is Site 250 (Rothenberg and Shaw, 1990a), a few pits at Givat Sasgon that were presumably the source of copper ore for the Early Bronze IV smelting Site 149 (for some reservations about the date and function of these sites see Avner, 2002, and section 6.2.4). Outcrops of manganese ore are located in the nearby area around Nahal Mangan, and in two other locations in Wadi Nehushtan, but it is not clear if they were exploited in antiquity (see section 7.2.1 below for further discussion). In addition, some DLS outcrops south of Har Timna were suggested by Segev and Sass (1989) to have been exploited in antiquity, however, modern open cast mining

activities destroyed any possible evidence of ancient mining. The difference in mineralization between the DLS and the other ore deposits, most notably the presence of rich manganese ores in the DLS, has implications on the smelting process itself and its remains in the archaeological record. In general, the presence of manganese ore, usually intimately related to the copper minerals, renders the smelting 'self fluxing', thus easier to prepare (no need to deliberately mine and add a fluxing agent). Furthermore, manganese minerals as a fluxing agent (in silicate-rich host rock such as those available in the southern Levant) are more efficient than the use of iron minerals, the common fluxing minerals used in Timna and associated with the upper sandstone units. The slag of a smelting process with DLS as the source of ore is usually rich in manganese, while the slag of a smelting process with the other copper deposits as the source of ore (MBS in Faynan and Amir/Evrona in Timna) is usually rich in iron, unless manganese ores were deliberately added as a fluxing agent, as is probably the case at the 9th century smelting of Site 30 in Timna described below (section 9.1.1).

The copper ore deposits of the upper sandstone units (MBS unit in Faynan and Amir/Evrona formations in Timna) are located between other sandstone units, ca. 50 m stratigraphically higher than the DLS (the intermediate sandstone and claystones includes some local copper and manganese ores, without almost any evidence of mining, probably because of their conspicuous hardness). In Faynan, the copper ore bearing unit is up to 250 m thick and has extensive mining evidence around Wadi

Khalid and Qalb Ratiye (Table 5.1 and associated figures). The copper mineralizations occur in fractures and veins and in places where it is associated with iron mineralization. This unit was the principal source of copper ore in Timna throughout the entire history of copper production there. In Faynan it was exploited only to a limited extent during the Chalcolithic and the Roman period (e.g., Weisgerber, 2006) with possible mining also in the Late Islamic period according to recent finds reported by the present author from Wadi Salmina (Ben-Yosef, 2009a). Here we discuss in some detail the different minerals found in the major geological units of the Arabah Valley because of their relevance to the analytic study presented in Chapter 8, and because the mineral composition has a direct implication on the smelting technology used in antiquity to extract metallic copper.

The predominant ores of the southern Levant are oxidic and silicate copper minerals that can be reduced to metal in a one step smelting process (without roasting and multistep smelting as in the case of sulphide ores, the dominant ores in Cyprus and Anatolia). Sulphies are rare and native copper is not present in the southern Levantine deposits.

The minerals present at the DLS unit are [after Hauptmann (2007:69-70) with references therein (primarily Wurzburger, 1970; Heitkemper, 1988)]:

- Malachite, $Cu_2(CO_3)(OH)_2$
- Paratacamite, $Cu_2(OH)_3Cl$

- Chrysocolla, $CuSiO_3 \cdot H_2O$
- Dioptase, $Cu_6[Si_6O_{18}] \cdot 6H_2O$
- Planchéite, $Cu_8[(OH)_2/Si_4O_{11}]_2$ (in shiny blue crystals)
- Pseudo-malachite, $Cu_5[(OH)_2/PO_4]_2$

The minerals listed above are usually 'masked' by abundant malachite. The following minerals were observed only under the microscope:

- Bornite, Cu_5FeS_4
- Chalcocite, Cu_2S
- Pyrite, FeS_2

The copper ores of the DLS unit appear as fist-sized hard nodules and chunks. They are intensively inter-grown with oxidic manganese ores (averaging 41-43% in Mn content). The manganese minerals include:

- Pyrolusite, β-MnO_2
- Hydroxi-manganomelane, (psilomelane, $(Ba, H_2O)Mn_5O_{10}$)
- Cryptomelane, $K_2Mn_8O_{16}$
- Hollandite, $Ba_{1-2}Mn_8O_{16}$
- Coronadite, $Pb_{1-2}Mn_8O_{16}$
- Ramsdellite, γ-MnO_2
- Manganite, MnOOH

The Mn-ore contains a considerable amount of iron. Analytical work on the ore showed an average of 8-10% Fe_2O_3. Enrichment of Fe oxides and hydroxides

(hematite, goethite) in the metallurgical remains of the Late Islamic site of el-Furn in Faynan even raised the possibility of iron smelting activities there (e.g., Hauptmann, 2007:120). However, the results of the current study show clearly that iron was an undesired byproduct of advanced copper smelting technologies even when the primary ore source was manganese-rich (and not iron-rich such as in Timna, and see Gale et al., 1990; Merkel, 1990 for further details on iron in copper in the southern Arabah)[16]. Further evidence and discussion about iron byproducts in advanced smelting of copper is presented in section 7.2.7 below.

The minerals present at the MBS unit (and similarly in the Amir/Evrona formations in Timna) are (Hauptmann, 2007:71):

- Malachite, $Cu_2(CO_3)(OH)_2$
- Cuprite, Cu_2O
- Chalcocite, Cu_2S and covellite, CuS
- Paratacamite, $Cu_2(OH)_3Cl$

The cuprite appears mostly intergrown with Fe-hydroxides. Some morphological appearances of the minerals are unique to Faynan (cuprite with relics of chalcocite and quartz as 'tile ore', brecciated fragments cemented with malachite) and made it possible for Hauptmann (1989) to identify the source of ore from the Chalcolithic site of Abu Matar in the Beer-Sheva Valley. In Timna, cuprified plant remains were

[16] The Iron Age technologies studied here are not different in their basic principles from the ones practiced in the later Roman and Late Islamic periods. We believe that the field evidence in el-Furn relates to the problem of iron as a byproduct in the smelting of copper, and not to the practice of iron smelting per se.

uniquely observed in the Amir/Evrona formation (they are missing in the MBS unit in Faynan) and they made it possible for Hauptmann (2009) to identify the source of ore from the Chalcolithic/Eaerly Bronze I site of Tall Magass near Aqaba (for further discussion about sourcing see section 2.2.3 below). Both the DLS and MBS copper ores are of a high quality and range in copper content between 15% and 45% (Hauptmann et al., 1992). Similar quality was reported for the copper ore of Timna (Bartura et al., 1980). These rather high concentrations of copper imply no need of complex beneficiation process besides manual sorting (a variety of processes whereby extracted ore is separated into mineral and gangue, the former suitable for further processing or direct use).

2.2.3 *Lead isotope signatures of Faynan and Timna – problems with provenance studies*

Provenance studies of metals are based mostly on lead isotope analysis (LIA) of ore, slag and metal artifacts (see e.g., Gale and Stos-Gale, 2000; Pollard et al., 2007:302-345), a complicated and controversial method (Budd et al., 1996; Knapp, 2000; Pollard, 2009; Ben-Yosef, 2010) that although established already in the late 1960s still presents difficulties of interpretation. The method is based on the geochemistry of lead, a common trace element in copper ore bodies. As the lead isotopes are daughters in the uranium decay chain, the ratio of these isotopes corresponds to the geological age of the ore deposit and can usually be used to

characterize ore bodies and to differentiate between ore sources of different geological history. Lead isotopes also do not fractionate throughout any of the stages of the metallurgical process, from the mining of ore through smelting, casting and production of metal objects. This is a fundamental principle in LIA studies, and the reason why measurements can be done on slag, copper prills and other metallurgical waste in addition to the ore itself for characterizing ore bodies. The method becomes more complicated when analyses of alloys or artifacts made of scrap metal are done, as the final products may include isotope signature from more than one source. Moreover, not all the ancient mines are known, and some studied mines have overlapping isotopic signatures. Thus, in general, it is easier to exclude an ore deposit as a potential source of an artifact than to securely assign one.

With the exception of defining the lead isotope signature of a specific mining district based on analysis of the ore body itself or local slag derived from it (see e.g., Hauptmann, 2007:254-304, for LI investigation of Faynan with references within), LIA is mostly done on ingots and metal objects from potential destinations sites in an attempt to find correlations between markets and copper sources. Investigation of a vast inventory of copper (and bronze) artifacts from Iron Age settlements in the Eastern Mediterranean and beyond is required to establish analytical evidence for the copper trade network in which Faynan played a role. Currently, only very limited number of LIA studies were published for Iron Age metal artifacts in the Eastern Mediterranean (e.g., Artzy, 2006; Yahalom-Mack and Segal, 2009; Yahalom-Mack,

2010), thus the reconstruction of trade connection and destination markets for Iron Age Faynan is rather difficult and based primarily on speculations and geopolitical/historical considerations (see section 9.1.4 blow). Although the question of trade destinations and market economies for the final products of Iron Age Faynan is important for understanding the society responsible of the production, it was beyond the scope of the current research to provide new field evidence regarding this issue. In fact, a better understanding of metal trade networks should be the result of constant research efforts by various groups investigating the Iron Age in the Eastern Mediterranean. Only cumulative provenance data based on well established methodology, similar to these available for the Late Bronze Age metal trade (e.g., Stos-Gale, 2000), could provide new field-based insights regarding metal trade in the Iron Age; if such methodology is indeed available is still debated (Ben-Yosef, 2010).

There is still a need to refine the available lead isotope database of the southern Levant, especially to clarify if any differences can be detected between the sub-regional ore bodies (Faynan, Abu-Khusheiba, Timna, Wadi Amram, Bir Nasib and southwestern Sinai). Although some publications in the past (and a few recently) were based on supposed detectable difference between Faynan and Timna (e.g., Hauptmann et al., 1999; Artzy, 2006), the distinction between the two ore districts is still questionable. According to a recent publication by Hauptmann et al. (2009), LIA cannot provide a decisive means to differentiate between Timna and Faynan. Furthermore, some of the LIA signatures from the Arabah overlap other ore deposits

(see below). On the other hand, recent work at the Geological Survey of Israel by Irena Segal and Dan Asael, using multi-collector ICP-MS, was able to show statistical difference between Timna and Wadi Amram, and demonstrate the potential of further LIA studies of the ore bodies in the southern Levant (Segal and Asael, pers. comm. 2010, and also Asael, 2010:51-81).

The results of LIA studies from Faynan (Hauptmann et al., 1992; Hauptmann, 2007:79-83) show that the Cu-rich and Mn-rich ores have similar signature and thus the isotopic composition of the copper product would not have been affected by the use of Mn ore as fluxing agents (Fig.2.13). Ores from the MBS unit have a different composition of a wider range, and its signature overlaps other ore deposits in the Eastern Mediterranean (Fig.2.14). LIA from Timna have been published by Gale et al. (1990) (Fig.2.13), and they are all inside the range of data from Faynan (there is virtually no data from the Timna formation, and the Amir/Evrona formations do not show the data range of the MBS in Faynan). The age calculated for the ores based on the LIA data corresponds to the history of mineralizations described above, with values representing the original mineralization in the volcanic units of the late Precambrian (excluding values for the MBS, Wadi Abu Khusheiba and one Fe-ore sample from Timna). The copper ores of the southern Levant are the most ancient so far in the Eastern Mediterranean, although some data from Oman overlap the Faynan/Timna field (but are mostly consistent with Cyprus as they also belong to the

ophiolitic complex) (Prange, 2001). LIA of ore deposits in Sinai (Hauptmann et al., 1999; Segal et al., 2000) show similar early ages as those from the Arabah.

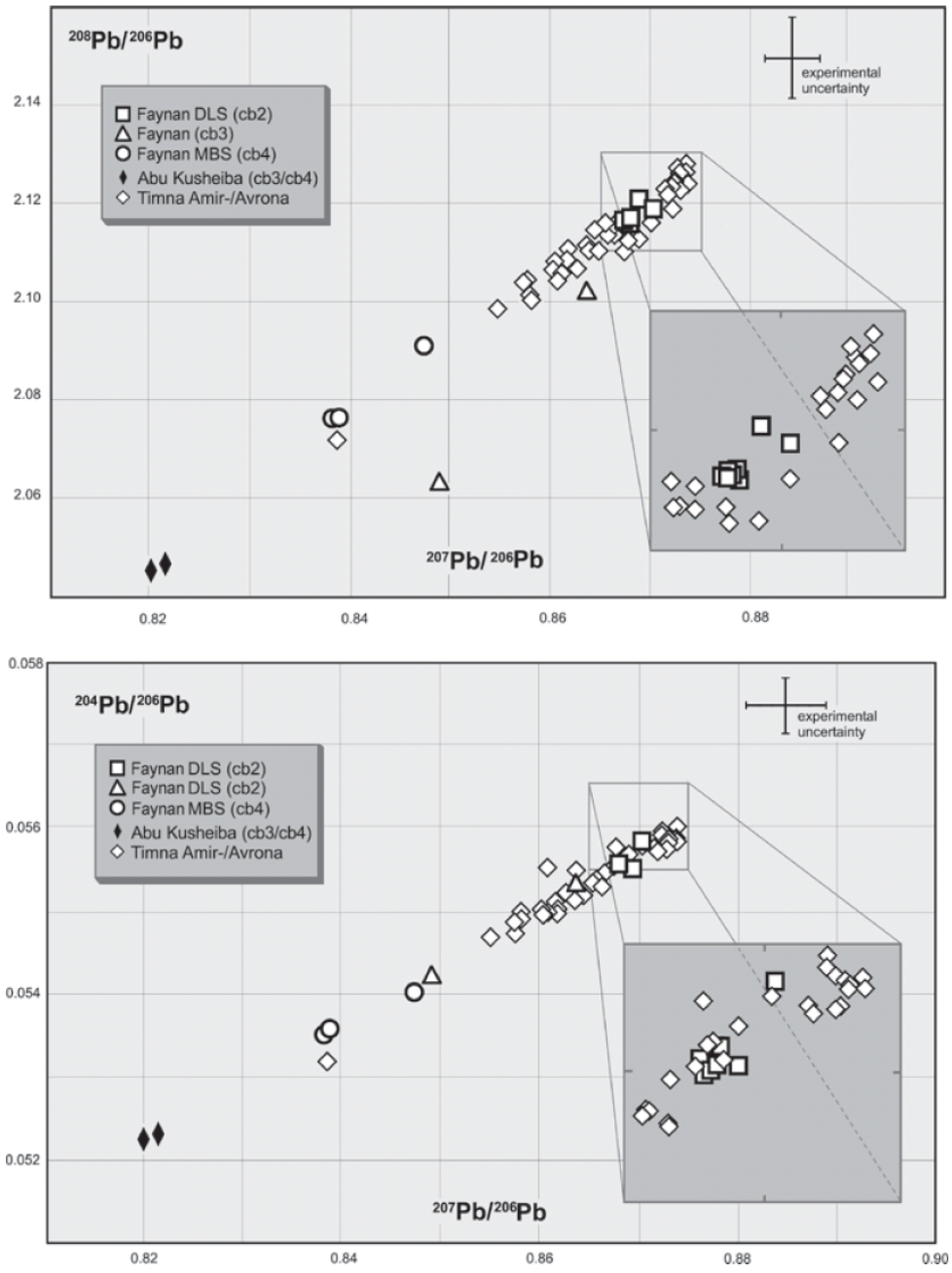


Fig.2.13: Lead isotope abundance ratios of Cu- and Cu-Mn-ores from Faynan, Timna and Wadi Abu Khusheiba; data for Faynan are from Hauptmann et al. (1992); data for Timna are from Gale et al (1990) and from the Oxford laboratory provided to Hauptmann for preparation of the this figure (from Hauptmann, 2007:80).

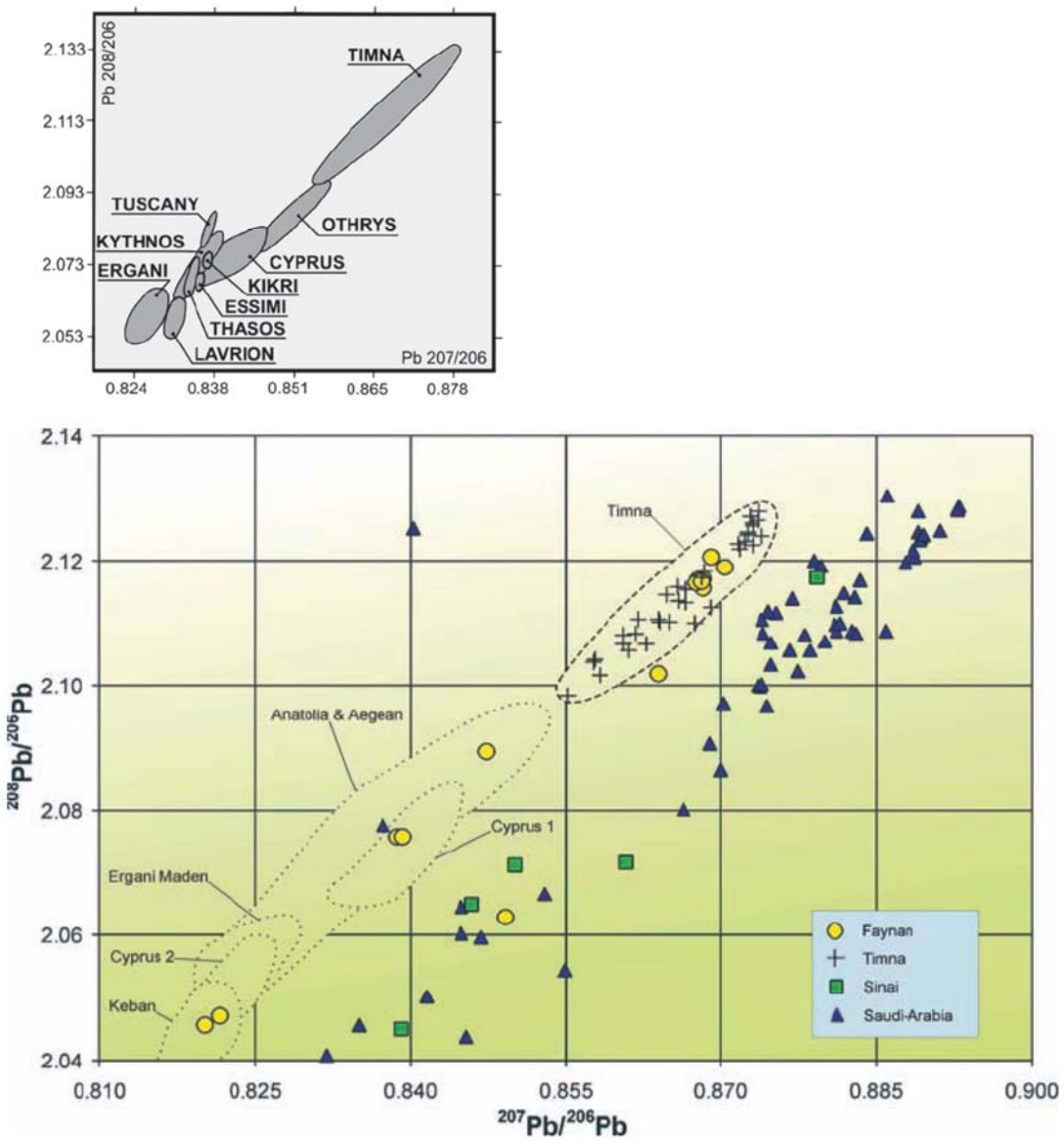


Fig.2.14: Lead isotope abundance ratios fields (Hauptmann, 2007:37, 83). The Timna/Faynan field compared to other mine fields in the Mediterranean (upper diagram) and compared to major mine field in the Eastern Mediterranean (lower diagram). The location of the Faynan/Timna field indicates its relatively old age. Note that the Timna/Faynan field includes data only from the DLS and the Amir/Evrona formations, and other values fall in the range of other mine fields (lower diagram).

In sites located far from the mining districts in the southern Levant, provenance studies of ore sources can be based on petrography, in cases ore fragments

are present in the archaeological record. The presence of cuprified plants or brecciated cuprite with chalcocite relicts are indicators of ore from Timna or Faynan respectively as described above.

Other methods for provenance studies of metals have been suggested, such as comparative analysis of slag inclusions in iron artifacts (Blakelock et al., 2009), trace element patterns and copper isotope signatures (Woodhead et al., 1999). However, these methods and others, including the widely practiced LIA method described above, still await further research to become a reliable tool in anthropological archaeology research.

2.3 Climate and vegetation

The climate of the Arabah Valley has had a direct impact on local societies that have inhabited the region throughout history. Subsistence resources, living conditions and some cultural customs are related to environmental factors determined mostly by the climate, especially in extreme environments such as the deserts of the southern Levant. For societies engaged in the copper production enterprise in Faynan and Timna, the climate conditions are crucial as they determine the availability of fuel sources, the ability to sustain large quantities of laborer and consequently to maintain stable and durable large scale organization of production.

The region of Faynan and the southern Arabah is part of the hot and dry climate of the Saharo-Arabian desert belt (Fig.2.15). It is separated from the Mediterranean climate zone by a distance of more than 100km (and by the morphological barrier of the Rift Valley). Significant local variations exist, especially between the lowlands of the Arabah and the relatively high Jordanian plateau to the east (Fig.2.1, 2.15). While the Arabah Valley is the driest and hottest area in the entire region of the Negev and southwestern Jordan, the higher parts of the Jordanian plateau have more moderate Mediterranean climate. The mean annual temperature in the lowlands (the Arabah) is 23°C to 24°C in the highlands it is 14°C to 16°C (Fig.2.16). In Faynan during the summer, maximum temperatures are around 45°C and during the winter, lowest temperatures at night may drop below zero (Bruins, 2006:30). The region is characterized by frequent western winds that are occasionally very strong (Rabba', 1994). Most rain in Faynan fall between December and March, and there is no precipitation between June and September. The annual rainfall is around 50mm in Faynan and even less in the southern Arabah (30mm in Aqaba, Bruins, 2006). In the plateau the annual rainfall exceeds 200mm (Amiran et al., 1970; Aresvik, 1976) (Fig.2.17). Rainfall in the Arabah is also extremely variable, ranging between 150mm in a wet year to 0 mm in a dry year (Amiran et al., 1970; Cohen and Stanhill, 1996; Bolle, 2003) (Fig.2.18). This inter-annual variability, common in arid zones, present problems for societies in the region; precipitation is unpredictable and it is difficult to prepare for droughts. Often the rain falls in short intervals, causing flesh floods in the local wadis.

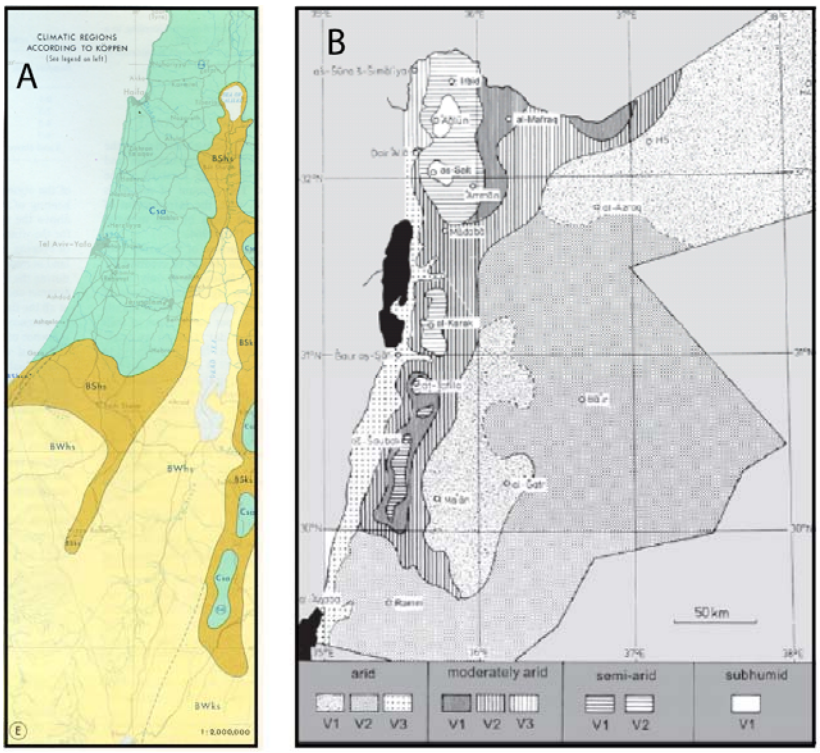


Fig.2.15: Bioclimatic zones in Israel and Jordan. A) The classic division of Koppen (1931; 1953), showing three major bioclimatic regions: desert (BW, yellow), Steppe (BS, ochre) and Mediterranean (Cs, green) (from Amiran et al., 1970); note the variability between the Arabah and the southern Jordanian plateau. B) More detailed bioclimatic zones of Jordan (after Kurschner, 1986; from Hauptmann, 2007:45).

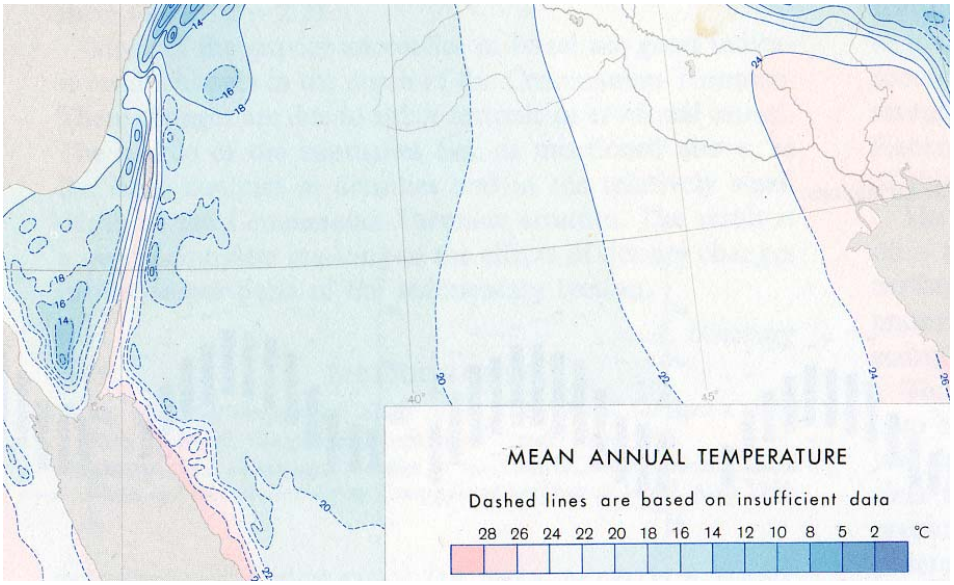


Fig.2.16: Mean annual temperature of the southern Levant (from Amiran et al., 1970). Note that the Arabah Valley (and the Dead Sea Rift Valley in general) is the hottest region.

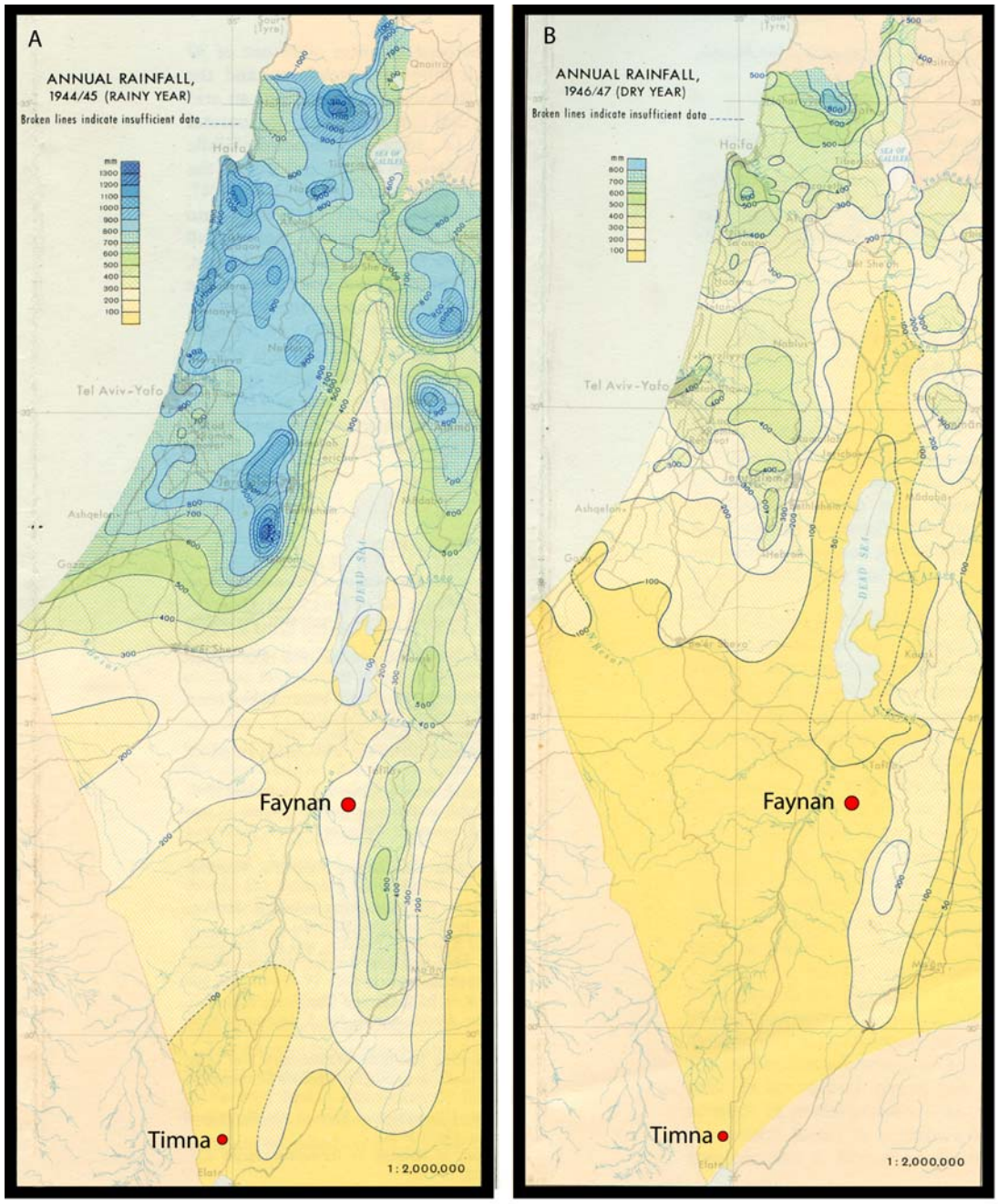


Fig.2.17: Annual rainfall in Israel and Jordan in rainy (A) and dry (B) years. Faynan is located between the 0 and the 300 isopleth (note that 300 is very rare) while Timna between 0 and 100 (from Amiran et al., 1970).

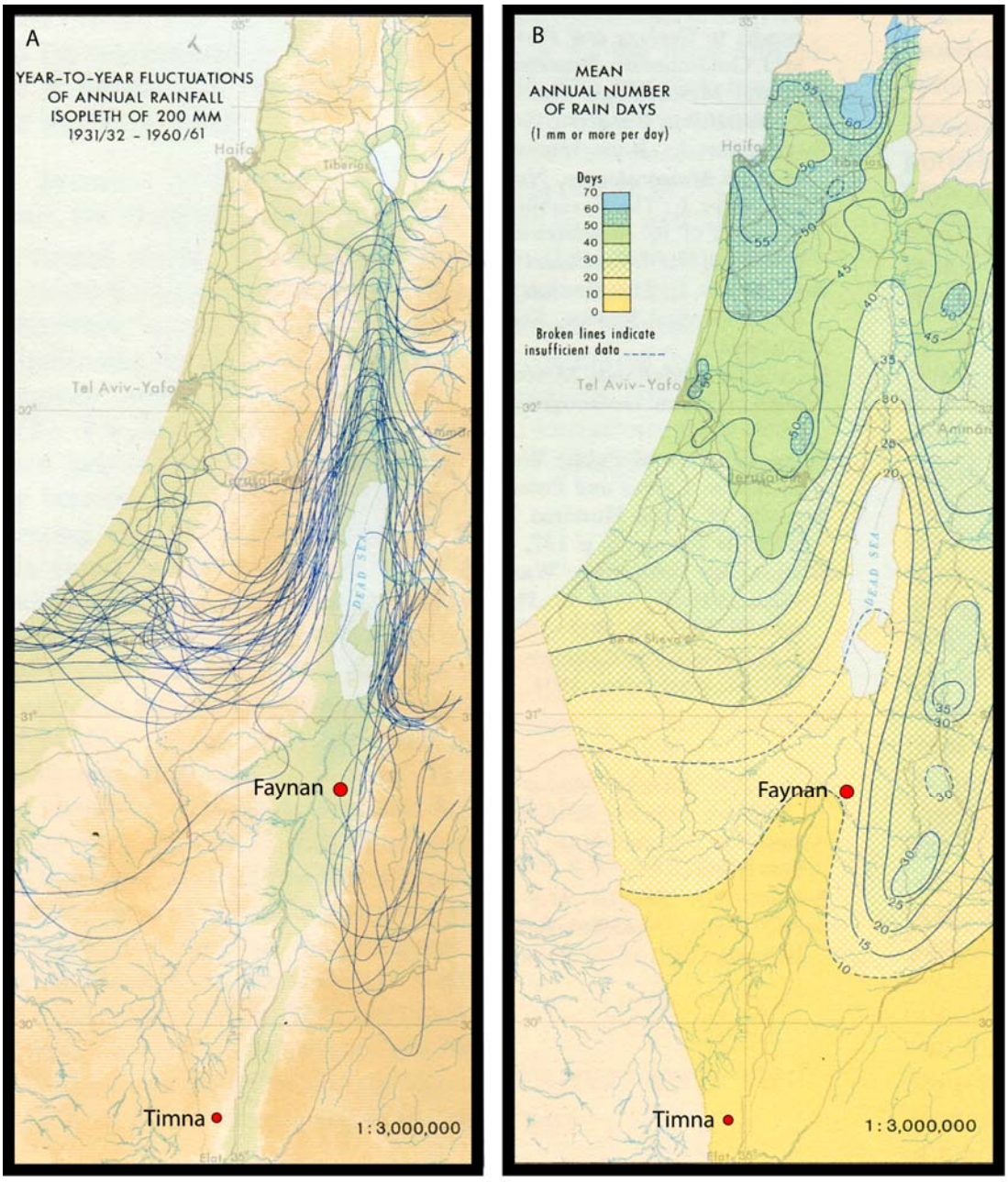


Fig.2.18: The arid zone of the Arabah has a varied and unpredictable rain pattern (A), with only a few rainy days per year (in average, less than 10 in Timna and less than 20 in Faynan, see B) (from Amiran et al., 1970).

The vegetation of the Faynan area was studied in details by a group of botanists from the Free University of Berlin (Kurschner, 1986; Baierle et al., 1989;

Frey and Kurschner, 1992, 1994), as part of the extensive archaeometallurgical research in the region headed by the German Mining Museum (see section 3.2.5 below). One of the principal aims of these studies was to evaluate sources of fuel for the ancient smelting operations (Engel, 1993; Engel and Frey, 1996). This issue, together with new data and insights regarding fuel supply in the Iron Age in Faynan and Timna, is discussed in details in section 7.2.3 below (see also sections 9.1.1).

The bioclimatic zones maps (Fig.2.15) show the contrast between the relatively homogenous desert environment of the southern Arabah and the varied environments in the vicinity of Faynan, with rapid changes towards the Jordanian plateau to the east. In addition, local springs and oases that create niches of hydrophilic vegetation are absent in the Timna Valley itself (and the wadis to the south), thus the vegetation near the mines of the southern Arabah is typical to the extreme steppe deserts, and include mostly acacia trees, ratema shrubs and other small bushes in the wadi beds. The variety in vegetation in Faynan and its vicinity is mostly the results of the substantial elevation differences, coupled with unique geological conditions. Fig.2.19 presents the distribution of major vegetation units in the Faynan region, and Fig.2.20 presents a cross section from the lowlands in the west to the highlands in the east with the corresponding vegetation units, elevation and precipitation; for detailed descriptions of the species represented in each vegetation unit, see Baierle et al. (1989).

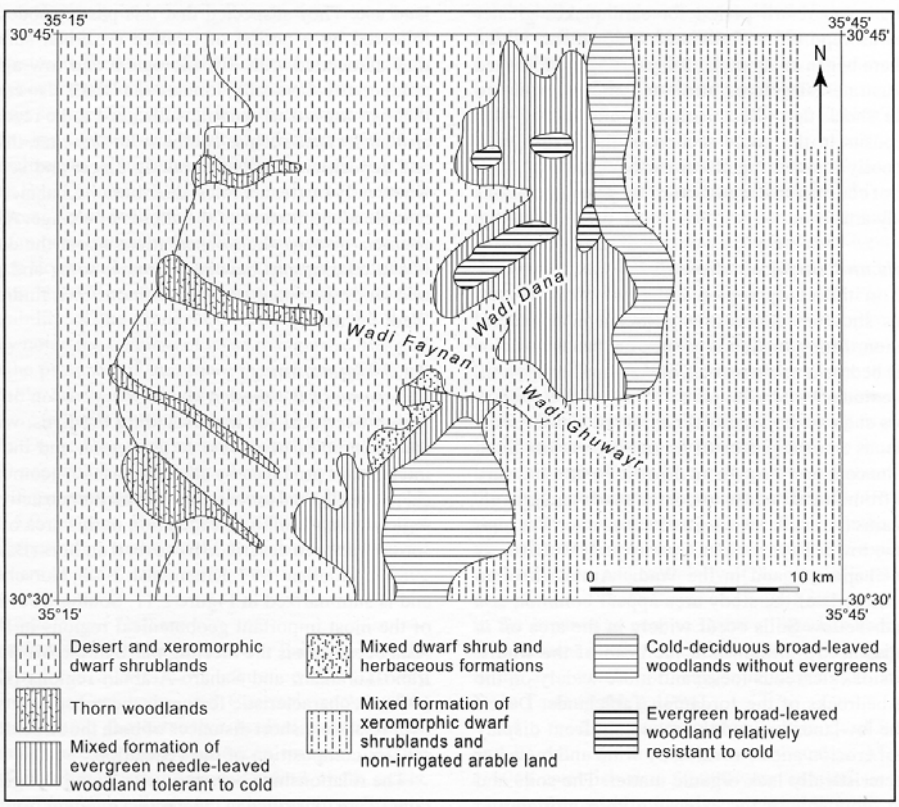


Fig.2.19: Distribution of vegetation units in the area of Faynan, Jordan (from Palmer et al., 2007:36). Note the high variability and the relative proximity of the woodland zones to the smelting sites in the lower Wadi Faynan.

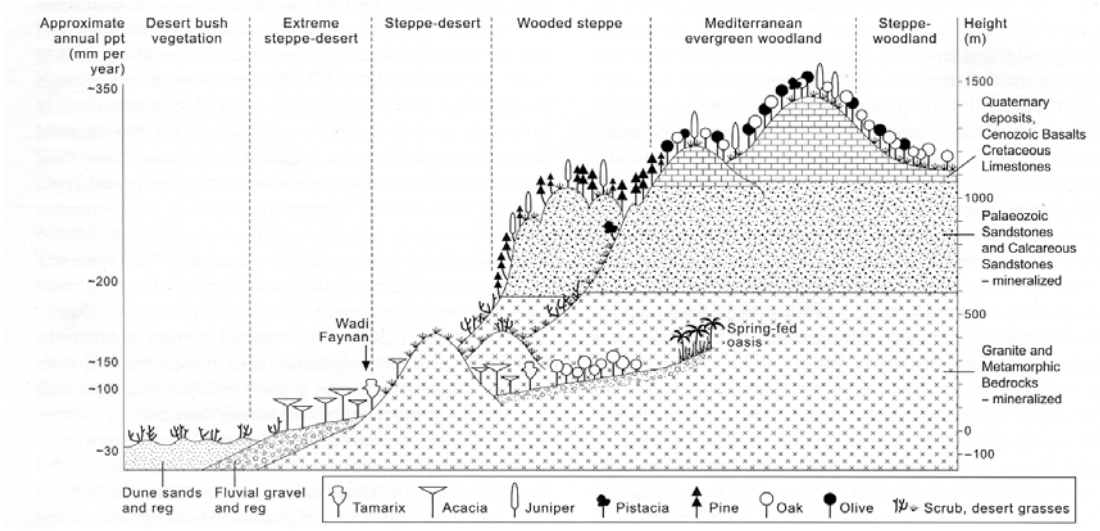


Fig.2.20: A cross section from the lowlands to the highlands in the region of Faynan showing vegetation units, approximate annual precipitation and elevation change (from Baierle et al., 1989; Palmer et al., 2007). For further details about the different species, see Baierle et al. (1989).

Previously, it was assumed that the local vegetation of the desert units (Fig.2.20) could not provide sufficient supply of fuel for smelting on the scale evident in Faynan and Timna, and the question of fuel sources has been debated since the beginning of research in the study area (e.g., Glueck, 1940c:65 and section 3.1 below). While in Faynan the (mostly juniper) trees of the wooded land on the slopes of the Jordanian plateau were available as a source for charcoal, in Timna the only wood available was from the desert vegetation. The study of charcoal from the smelting sites of the Arabah provides further insights regarding this question.

The arid vegetation units can sustain seasonal grazing of herds of sheep and goats. The local societies in the Arabah region during the last few centuries have been semi-nomadic Arab Bedouin tribes (Bienkowski and van der Steen, 2001; Palmer et al., 2007), engaging in pastoralism with seasonal migration between the lowlands of the Arabah (winter) and the highlands of the Jordanian plateau (summer). Only very limited agriculture has been practiced near local springs, and in a few places orchards of olives and pomegranates still exist (such as the fields of the Mana'ja tribe near 'Ain al-Ghuweiba). The social structure of the local Bedouin tribes, which is well adapted to the physical environment of the Arabah, was the basis of (or an influence on) some models for the Iron Age societies in the region (especially the concept of tribalism, see e.g., Gellner, 1990; LaBianca and Younker, 1995; Bienkowski and van der Steen, 2001; Levy, 2009b and in the Introduction above).

2.3.1 *Paleoclimates: the Arabah during the Iron Age*

Paleoclimate reconstructions are complicated and based on various scientific methods such as isotopic analyses, reconstruction of lake levels and vegetation history (usually using palynology), geomorphological studies, etc. Any reliable interpretation of the published data, which appear more frequently in recent years, must take into consideration the shortcomings and drawbacks of each specific method. It is even more complicated when trying to correlate between climate changes and cultural processes, and often such interpretations have been published hastily and without in-depth evaluation of the issues, usually by groups of scientists uninformed by anthropological research. For the southern Levant, two important syntheses were published recently by Rosen (2007) and Issar and Zohar (2007) (references to some additional studies in Jordan can be found in Cordova, 2007). The interpretation of data available for the Iron Age is still somewhat ambiguous, and some of the main datasets for climate reconstruction do not agree with each other. However, the general conditions and some trends can be identified[17].

Two of the main methods for reconstructing the climate of the southern Levant during the late Holocene are oxygen isotope analysis in cave sediments (Bar-Matthews et al., 1998) and modeling of the Dead Sea levels through sedimentary sequences

[17] As part of the new research project "*Reconstructing Ancient (Biblical) Israel: The Exact and Life Sciences Perspective*" of Tel Aviv University and Weizmann Institute of Science there is a new effort to reconstruct the climate of the Iron Age by pollen studies from Dead Sea cores. This study may provide additional, high resolution information in the near future (see Langgut and Neumann, 2010)

(Frumkin and Elitzur, 2002; Bookman (Ken-Tor) et al., 2006). The results of the two different methods show relatively good agreement, in particular the oxygen isotope record in speleothems published for the Soreq cave (Bar-Matthews et al., 1998) and the Dead Sea levels published by Frumkin, based on lake sediments in salt caves at Mount Sedom (1991) (Fig.2.21). Published climatic reconstructions for the Iron Age are slightly different, especially in regard to the Iron Age I (ca. 1200 – 1000 BCE), although they are based on the same records. Issar and Brown (2007) reconstruct a colder and more humid climate during the Iron Age I and more warm and dry climate during the Iron Age II (Fig.2.21):

> An abrupt change to a colder global climate took place towards the end of the second millennium BCE. The cold began around 1200 and peaked by 1100 BCE causing waves of people from Eurasia trying to settle down in new territories […] With the increasing cold, Egypt experienced a series of environmental calamities, most probably due to the weakening of the monsoon and penetration of most uncommon northwesterly rainstorms into Lower Egypt […] The paleo-climatic proxy-data show that after the spell of cold and humid climate around 1000 BCE came a warm and dry period with a low peak of humidity around 850 BCE. Then it steadily improved reaching favorable conditions from ca. 300 BCE until the 3rd century CE (Issar and Zohar, 2007:163-164, 193).

Their interpretation of climate and cultural interaction is extremely deterministic. For example, following Herzog (1990) they attribute the flourishing of Iron Age I settlements in the northern Negev to the amelioration of climatic conditions:

> The passage from a pastoral to an agricultural society can be seen in the nature and pattern of buildings at Tell Masos. From the end of the Late Bronze to the beginning of the early Iron Age, i.e. from 1250 to 1200 BCE, the people lived in tents or sheds […] Herzog found that the favorable climate conditions of the 11th century BCE had promoted the expansion of farming communities into the Negev's more arid highlands. He also attributes the desertion of these posts in the 10th century to the worsening of the climate, rather than to the anthropogenic causes suggested by Meshel and Cohen. Indeed, the Soreq Cave curve shows a steep decline in humidity at the end of the 10th century, but its impact in the Negev may have started earlier. (Issar and Zohar, 2007:185).

We believe that such a deterministic approach ignores substantial anthropogenic factors in the interpretation of social processes. Specifically regarding the Beersheva Valley in the Iron Age I, the flourishing mines of Faynan and the economic opportunity the copper trade provided to local societies were probably an important catalyst for the new settlement pattern in the region (Finkelstein and Piasetzky, 2008, and chapter 10 below). Especially because the climatic record is not very decisive in this period, any climatic-based interpretation of major social changes should be viewed as hasty.

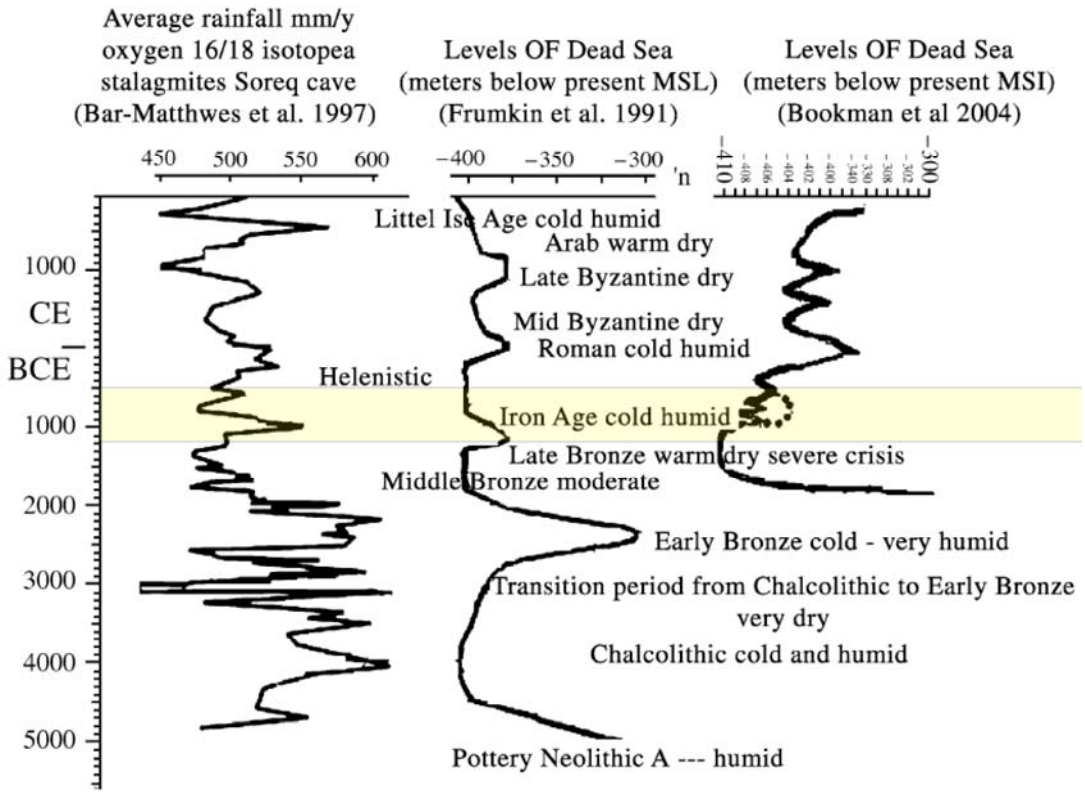


Fig. 2.21: Three datasets based to reconstruct the climate of the late Holocene in the southern Levant. The interpretation presented here (modified from Issar and Zohar, 2007) suggests a cold an humid climate in the first part of the Iron Age (see text for details).

Rosen (2007:101) also indicates a moist interval around 1200 BCE, without exact interpretation of duration and intensity. Rosen is also much more careful in connecting climatic trends to social changes, especially in periods where complex societies inhabited the region. Frumkin and Elitzur (2002) interpret the entire Iron Age (1200 – 500 BCE) as relatively dry, with low levels of the Dead Sea throughout the period and a completely dry southern basin at least between 1000 – 700 BCE[18]. This reconstruction concurs with the one published by Enzel et al. (2006), based on detailed study of the Dead Sea levels (Bookman (Ken-Tor) et al., 2006). The latter suggests gradual improvement of climatic conditions (more humid) throughout the Iron Age, after a severe drought in the end of the Late Bronze Age (Fig.2.22), but in general a dry phase in the entire period (Fig.2.23) (see also Bruins, 2006:32). The interpretation of climatic impact on social processes published on the basis of the reconstruction of the Dead Sea levels (Migowski et al., 2006) (Fig.2.23) also present a very deterministic approach.

[18] Frumkin and Elitzur (2002) also raise the intriguing possibility the "Valley of Salt" (gai ha-melach, the battle ground between King David, and later King Amaziah, and the Edomites, e.g., II Kings 14:7) is in fact the dried southern basin of the Dead Sea.

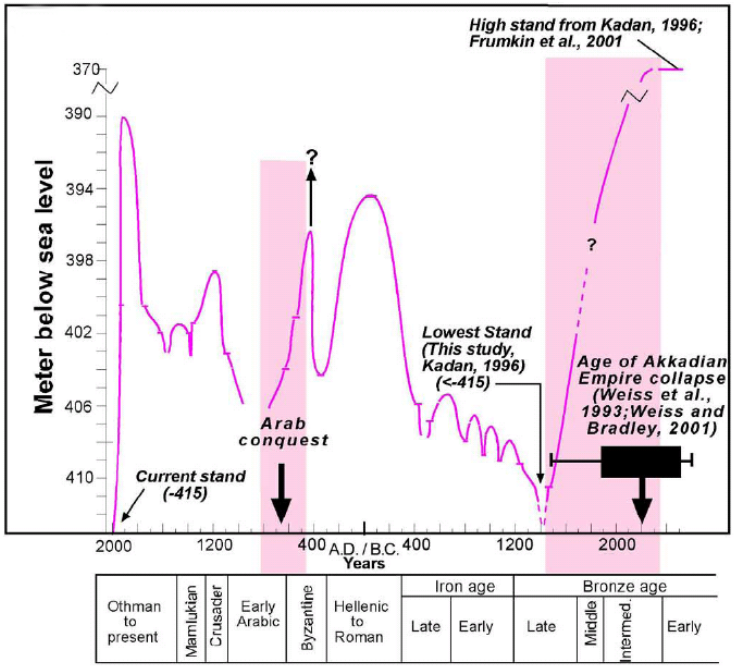


Fig.2.22: Reconstruction of Dead Sea levels based on ^{14}C-dated sequences of marine sediments (based partially on Kadan, 1997; from Enzel et al., 2006). In principle, as the Dead Sea is a terminal lake, high levels indicate more humid periods.

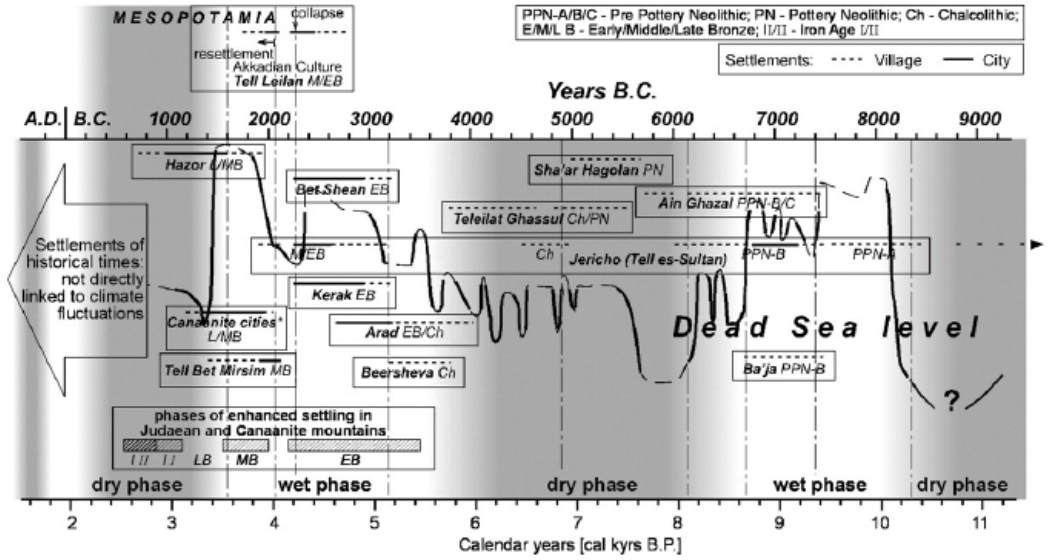


Fig.2.23: Dead Sea levels and cultural archaeological periods in the southern Levant (Migowski et al., 2006:421). According to Migowski et al. (2006) "the establishment of favorable climate conditions appears to parallel the expansion of villages into cities and the spread of farming communities into the Negev Desert. Deteriorating climate conditions are generally characterized by fewer settlements confined to the vicinity of water resources along the Jordan valley". Note that the Iron Age appears as a "dry phase".

Reconstruction of the Iron Age climate of the Arabah is important for evaluating the physical conditions that the local societies experienced, especially regarding availability of water sources, possibility of agricultural practice and its scale, seasonality of smelting operations, and availability of fuel sources. Even a small change in humidity can impact the hydrophilic vegetation in the wadi beds around the smelting sites, the main source of fuel in Faynan during the Iron Age (see section 7.2.3 below). From the data outlined above, there is supporting evidence of slightly better climatic conditions in the early Iron Age, during the resurgence in mining activities in the area. However, it seems that during the 10th and 9th centuries, the peak in copper production in Faynan, the climate was not better than today if not even slightly worse. Even with the available climatic data, it is still very hard to assess the availability of water in the local wadis. Higher water table will support more vegetation for fuel and a water sources such as *thmila* (dug depressions into the wadi gravel, exposing water for drinking and herds), wells and small springs.

Descriptions of early travelers in the Faynan region (see section 3.1 below) demonstrate the variation of water sources throughout time, probably as an impact of slight climatic changes. Glueck (1935:29) visited the region in March 1934 and described the area of Khirbat en-Nahas: "At the present time there is very little water in the immediate vicinity of Kh. En-Nahas. There is a small spring on the north side of Wadi el-Gheweibeh opposite it, which was, however, insufficient for our own needs." Today, there is no evidence of any spring or high water table in the close vicinity of

the site. Evidence for a higher water table near Khirbat en-Nahas in the early Iron Age is available in the form of an Iron Age well found by Levy and excavated in 2002 by the project of the University of California, San Diego (Levy et al., in press-b) (Fig.2.24). In addition, some of the extensive remains of field terraces along Wadi Faynan near Khribat Faynan (see Figs.3.7 and 3.8 below) recorded by the British projects (Wright et al., 1998; Barker et al., 2007b) may represent extensive Iron Age agriculture based on water from springs in lower Wadi Ghuweir. Although these fields were published mostly as Early Bronze Age, the area is abundant with small Iron Age sites (pottery scatters, etc.) that together with the inherent difficulty in dating terraces and fields suggest the possibility of Iron Age agriculture in this area. The extensive fields near Khirbat Faynan suggest that the region could attract people to settle around its oases, in addition to the mining activity or without direct connection to it (such as the Nabataean occupation of Khirbat al-Ghuweiba that still supports local orchards, see section 5.2.7 below).

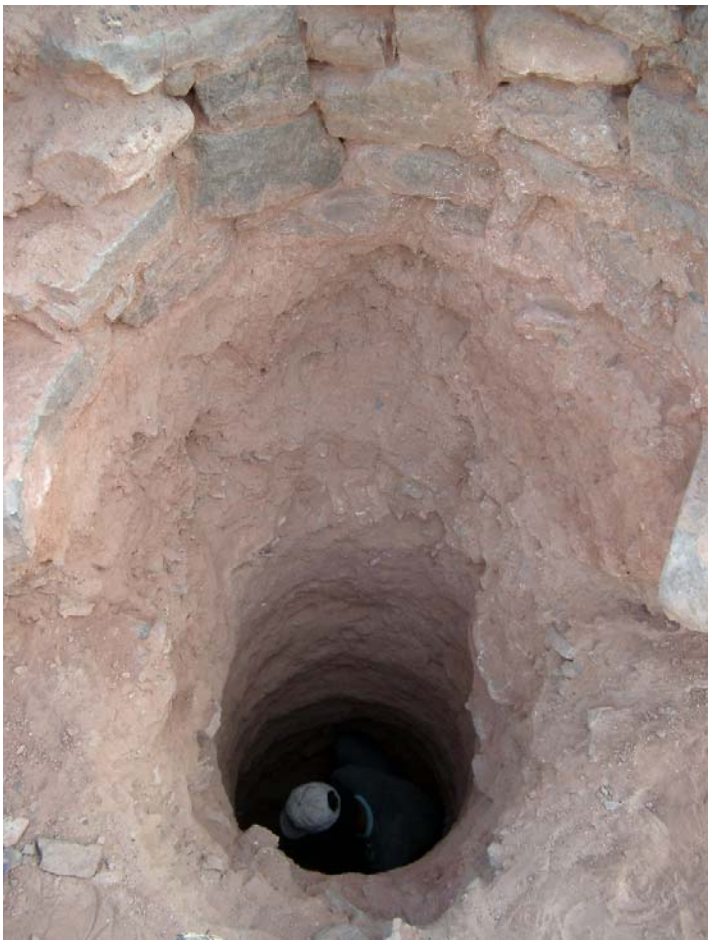


Fig.2.24: An early Iron Age well near Khirbat en-Nahas (excavated in 2002) suggests a higher water table in this period (note person for scale); photo courtesy of UCSD Levantine Archaeology Laboratory.

Paleoclimate 'insights' for the northern Arabah were published based on chronological patterns of plant species used as charcoals in the smelting sites of Faynan (Baierle et al., 1989:50-53; Hauptmann, 2007). For example, according to these studies, the presence of juniper trees in the charcoal record of the Early Bronze Age implies more humid climate during this period, and the absence of acacia in the charcoal record of the Iron Age implies that still the wadis carried more water than today. This approach ignores the anthropogenic quality of the record and presumes

simplistic relations between societies and their natural environment based strictly on pragmatic activities. Juxtaposing the patterns observed in Faynan with the paleoclimate records of the southern Levant, we believe that the differences in charcoal used for smelting reflect different social choices and values rather than climatic changes. In fact, the charcoal record in Faynan is an important source for insights regarding local societies and their structure (Ben-Yosef, 2009b, and see section 7.2.3 for further details and discussion). It is against this environmental background that the new research concerning Iron Age mining and metallurgy in the Arabah Valley is presented in the following chapters.

3. History of the research: investigations of Iron Age copper production in the southern Levant

The archaeometallurgical records of the Arabah Valley's Faynan and Timna regions are extraordinarily rich and easily noticeable, making it attractive to travelers and scholars for centuries. Special conditions make it also a unique 'field laboratory' for the study of ancient copper metallurgy (Rothenberg, 1990e). It was Israel's Timna Valley where the first systematic research of metallurgical technologies took place on the world scene, and where the sub-discipline of archaeometallurgy was established (Pigott, 1996). As Jordan's Faynan district has an even larger ancient mining and metallurgy landscape than Timna, more recent archaeometallurgical studies there have made it a touchstone for researchers interested in this subject. The unique situation in Timna and Faynan is the result of the natural environment and the history of settlement and mining in this region. The scarcity of precipitation and low humidity help preserve the sites and the lack of vegetation render the archaeological remains visible and easy to access. The sites are located far from populated centers and thus suffered very little from secondary use or robbery in antiquity. In addition, the modern exploitation of the ore deposits in Timna and the prospection activities in Faynan have resulted, relative to most of other ancient copper production centers, in very little damage to the archaeological remains. This extraordinary situation is one of the reasons for intensive research by various groups since the second half of the 20th

century, and it is also the reason for recent attempts to declare this region (especially Faynan) as a UNESCO heritage site (Levy and Najjar, 2007).

The intensive research in Timna and Faynan has resulted in a large amount of data regarding the Iron Age copper production activities in this region. These data, together with new information from excavations and surveys conducted as part of the current research, are the basis for growing comprehensive evaluations of the social, political and technological aspects of the copper production enterprise in the Iron Age southern Levant (e.g., Mattingly et al., 2007b; Levy et al., in press-a). Understanding the history of research in this region is therefore important for contextualizing the dataset itself. Moreover, in many cases typological errors and chronological misconceptions are the direct result of particular research paradigms used during different periods of investigations in this region. The following review highlights the major controversies and the current state of research.

3.1 Early travelers and explorers

The importance of the Arabah region as an ancient copper production center was recognized early on, as demonstrated by a map from 1732 by Bourguignon d'Anville (1897) (Fig.3.1), where Khirbat Faynan (there as Phenon) appeared together with a specific notation for copper slag (*Aeris Fodinae*). According to Weisgerber (2006:2-3) this notation is the first-ever mapping of slag anywhere, and probably

refers to the massive slag mounds around the Roman-Byzantine ruins of the Khirbah. Unfortunately, the actual source of information for the map is unknown.

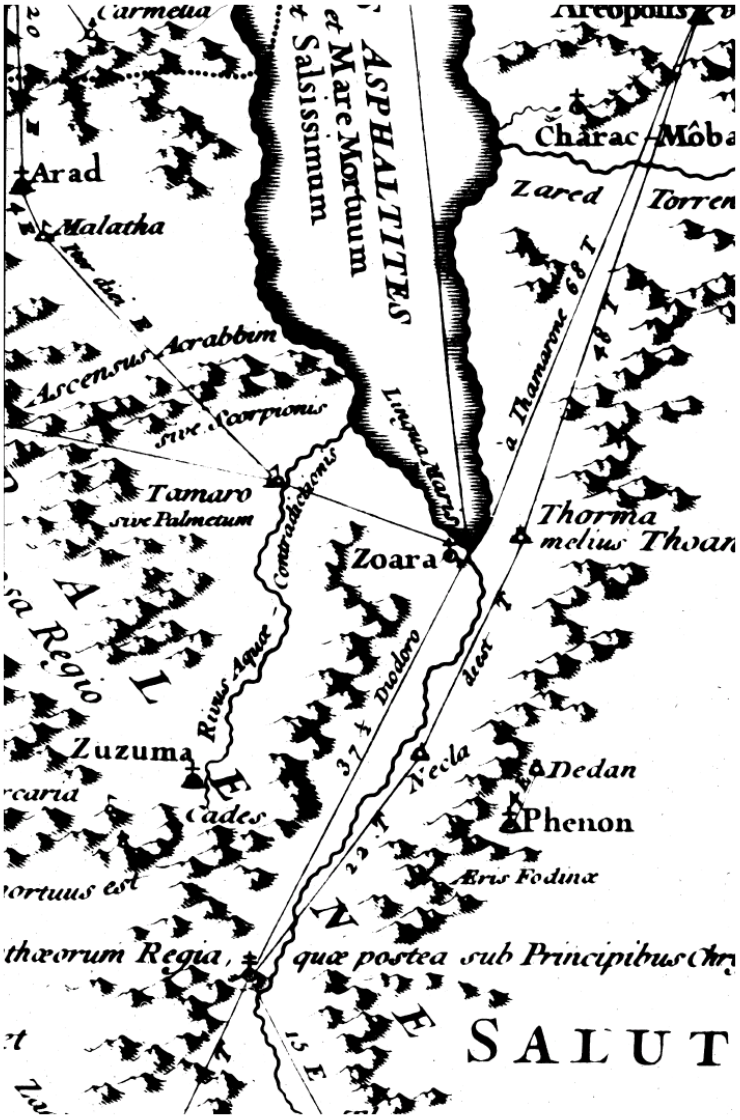


Fig.3.1: Map of the northern Arabah Valley from 1732 by d'Anville showing Faynan (=Phenon) and the first-ever mapped slag deposits (*Aeris Fodinae*) (after Weisgerber, 2006:3).

The first to report ancient metal workings in the southern Arabah was John Petherick (1861:37), a mining engineer from the British Consul at Khartoum who

visited the area in 1845[19]. In 1883 Major Horatio H. Kitchener's expedition of the Palestine Exploration Fund (PEF) traveled from Aqaba to the Dead Sea and reported an unnamed copper smelting site north of Faynan (Kitchener, 1884:214) (Fig.4.2), most probably the first report of the Iron Age ruins of Khirbat al-Jariya (Ben-Yosef et al., in press) (Fig.3.2). At the turn of the 19th century the Austrian-Czech orientalist and theology professor Alois Musil visited both Faynan (1898) and Timna (1902) and reported a few sites, including Khirbat en-Nahas (Musil, 1908). Regarding Timna ('al-Meneijje'), Musil mentioned a local Arab legend about the fate of the valley's ancient inhabitants, that later became an argument for identifying Ezion-geber there. The legend tells that the city of al-Meneijje (probably Site 34 of the Arabah Expedition, see below) was once a port and its dwellers possessed many ships. Because the inhabitants offended Allah, great floods destroyed the city and blocked the sea, relocating the shore line to its current location, ca. 25 km to the south (Musil, 1908:187). This story lead to the assumption that King Solomon's port, Ezion-geber, was actually in Timna itself (instead of an earlier suggestion to identify it with 'Ain Ghadian, see e.g., Phythian-Adams, 1933:137). The British scholars Alec Kirkbride, George Horsfield (Chief Inspector and Director of Antiquities in Transjordan, 1928-1936) and R.G. Head also visited the mining sites of the Arabah but did not write any significant reports (Glueck, 1935:29).

[19] According to Rothenberg (1988:2) the sites visited by Petherick should be identified as Site 4 near Eilat (Tell Hara Hadid) and Site 30 inside Timna Valley.

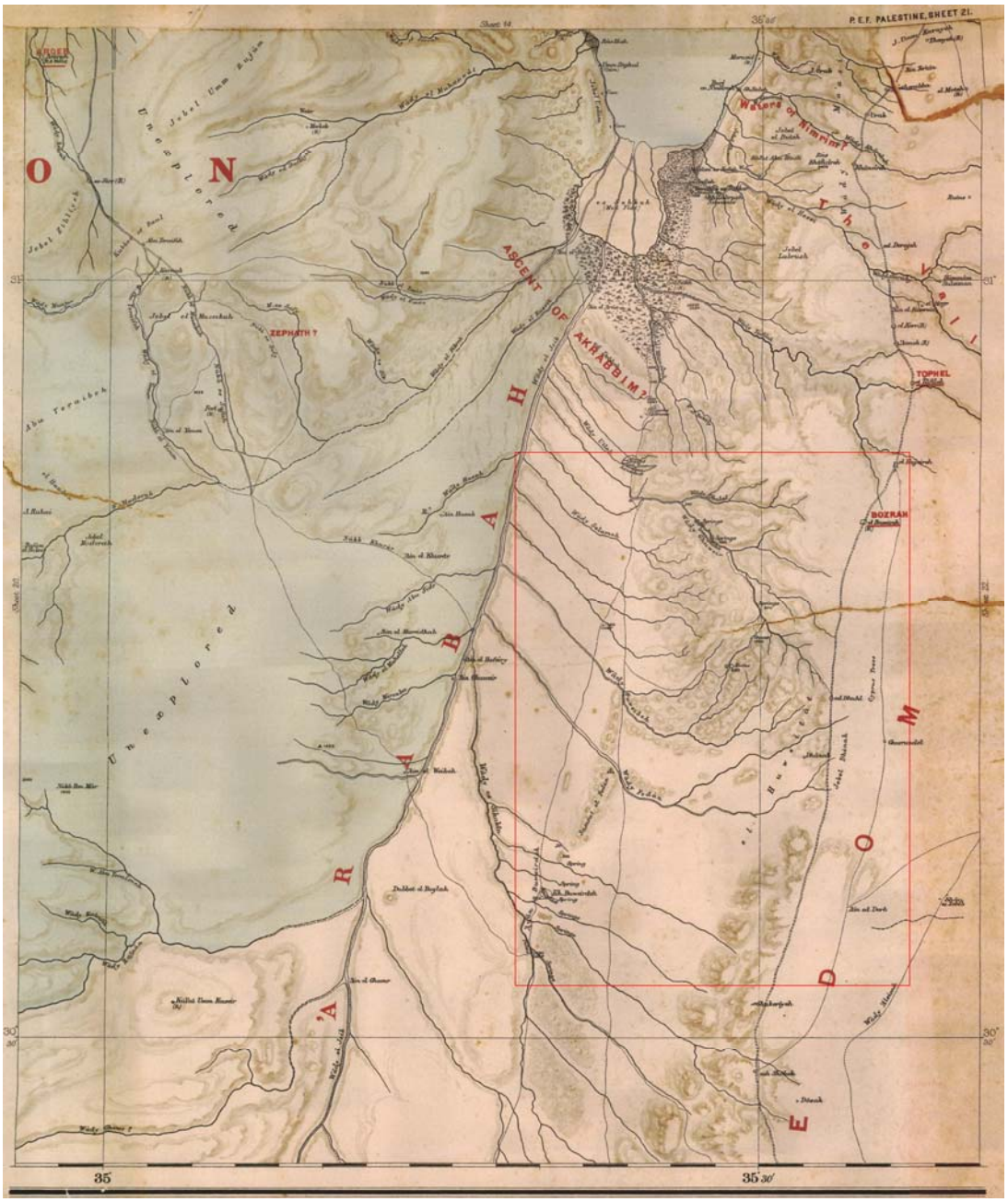


Fig.3.2a: Sheet 21 of the small scale Palestine Exploration Fund map series showing the northeastern side of the Arabah Valley. The map was published in the 1883 by Major H.H. Kitchener R.E. (Royal Engeneer) and is based on the survey of the 1883 expedition to the region (after Ben-Yosef et al., in press). For details of the Faynan – Busayra region, see Fig.3.2b. (Map courtesy of the Survey of Israel Historical Archives).

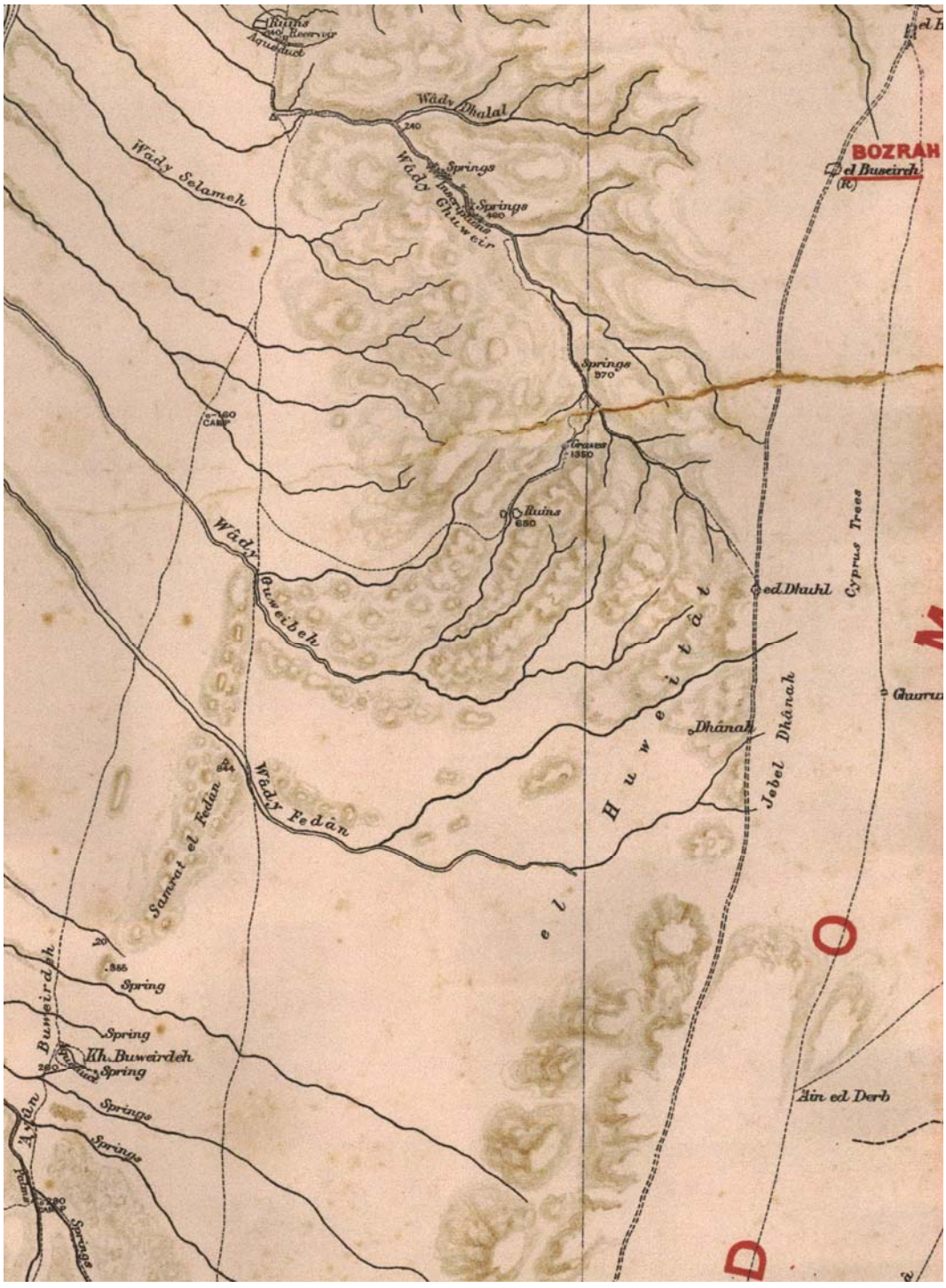


Fig.3.2b: The Faynan region in the 1883 Palestine Exploration map of Major H.H. Kitchener R.E. (see Fig.3.2a). The map depicts for the first time the ruins of Khirbat al-Jariya (and surprisingly not the major site of Khirbat en-Nahas) (after Ben-Yosef et al., in press). (Map courtesy of the Survey of Israel Historical Archives).

In the winters of 1932/33 and 1933/34 the German Templer Fritz Frank visited the Arabah and published detailed reports on numerous habitation, mining and smelting sites (Frank, 1934a, 1934b, 1935). Frank is considered to be the first modern explorer of the Arabah (Rothenberg, 1988:2), and his publications are still relevant as a reference in modern research. Frank was the first to discover Tell el-Kheleifeh, and to identify it with the Biblical port of Ezion-geber. Frank also described seven copper smelting camps in the Timna Valley, including the walled site of Timna 30 excavated also as part of the present research. Except from Tell el-Kheleifeh, Frank refrained from dating the sites or speculating on their historical significance.

Shortly after Frank's excursions in the Wadi Arabah, the American Biblical scholar and archaeologist Nelson Glueck visited both Faynan and Timna in March 1934 (Glueck, 1935:20-35, 42-45, respectively) as part of his journeys in Transjordan (see overview in Dever, 2000). Although Glueck's visits to the copper mining and smelting sites were short (at Faynan he spent two days and three nights arriving on March 24 and leaving on the early morning of March 27; his first investigation of Timna's smelting camps lasted only several hours, from 4pm of March 30 to early morning of March 31) his interpretations became the dominant voice regarding the Iron Age copper production operation in the Arabah for decades. Based on the ceramic findings Glueck dated the sites to the Iron Age II, from the period of Solomon (10th

century BCE) to the end of the Judean monarchy[20]. The association of the copper mines at Timna with King Solomon was published immediately after his first visit to Timna (Glueck, 1934), and was a major premise in Glueck's research and publications throughout his life, including in the second edition of *The Other Side of the Jordan* (Glueck, 1970:73) published shortly before he died in 1971. It was only after the British research in the Edomite highlands beginning in the mid-1960s (cf. Bennett, 1966) and the excavations of Rothenberg and the Arabah Expedition (cf. Rothenberg, 1972a) in the southern Arabah that Glueck's interpretations of the sites were thoroughly questioned and revised. In Faynan, Glueck's dating was reinterpreted as late Iron Age mining and copper production operations under Assyrian control and in Timna they were reinterpreted as Late Bronze Age operations under Egyptian control (see details below). These revised interpretations became, after a long scholarly debate especially regarding Timna, the accepted view in the archaeological/historical discourse until recent years. Copper production in the Arabah Valley during the Solomonic era, as well as any locally initiated copper mining and smelting in the Iron Age, were taken out from the archaeological and historical discussions, and Timna and Faynan are usually not mentioned at all in the basic text books of the Iron Age southern Levant (e.g., Mazar, 1990)[21]. As will be discussed below, the new UCSD

[20] In his first visit and early publication he dated the sites to the 13th – 8th centuries BCE based on 'Edomite' pottery (Glueck, 1935:138).

[21] In Mazar's text book *The Archaeology of the Land of the Bible – 10,000 – 586 BCE* Timna is mentioned as part of the Late Bronze Age chapter and briefly in regard to the Iron Age I; Faynan is mentioned only once in the entire book, in regard to the Iron Age I and in a speculative manner. This was the common case in publications regarding the Iron Age southern Levant until recently, when the preliminary results of the University of California San Diego research in Faynan, of which this research is part, were published.

Edom Lowlands Regional Archaeology Project (ELRAP) with its advocacy of high precision radiocarbon dating and digital archaeology methodologies has affirmed many of Glueck's original dating scheme for the Faynan district (e.g., Levy et al 2004, 2008) sparking scholarly debate amongst Iron Age specialists (cf. Finkelstein, 2005b; Levy et al., 2005a; Finkelstein and Piasetzky, 2006; Levy et al., 2006; Levy and Najjar, 2006a; Van der Steen and Bienkowski, 2006b; van der Steen and Bienkowski, 2006a; Finkelstein and Piasetzky, 2008).

In the Faynan area Glueck, following Musil, Frank and others, visited the sites of Khirbat en-Nahas and Khirbat Faynan; he believed that he was the first to visit the site of Khirbat al-Jariya ("hidden in a pocket between the hills", Glueck, 1940c:61), although the British PEF expedition of Major Kitchener reported the site as early as 1883 (see above). Glueck was the first to report Khirbat al-Ghuweiba, Nuqeib as-Samar and the small Iron Age watch tower of Rujm Hamra Ifdan that recently yielded some limited evidence of copper smelting[22]. In the southern Arabah, Glueck visited seven smelting camps in the Timna Valley itself (Sites 2, 12, 13, 15, 30, 34 and 35 of the Arabah Expedition, Rothenberg, 1988:2) and a few others near the Gulf of Aqaba, but did not report the ancient mines in this region. The main contribution of Glueck, who only made surface inspections of the ancient metallurgy sites, was the dating and interpretation of the copper production remains. Glueck's (e.g., 1940c) assertion

[22] In Glueck's report (1935:20-21) this site is mistakenly called "Khirbat Hamra Ifdan" and a different site named "Rujm Hamra Ifdan" was not identified in modern research (see discussion in Adams, 1992). The name "Rujm Hamra Ifdan" for Glueck's site of "Khirbat Hamra Ifdan" was given by the Jabal Hamra Ifdan Project (and see most recently in Levy et al., 2008a).

regarding Solomonic mining and smelting operations in the Arabah Valley had a strong impact on the flourishing Biblical Archaeology research at the time, and became an integral part of the conventional biblical and archaeological studies. Glueck's work in Transjordan and southern Arabah Valley contributed to the 'Golden Age' of Biblical archaeology (Moorey, 1991).

In 1938-39 Glueck conducted excavations at Tell el-Kheleifeh, following Frank's suggestion that this site is the sea port of Solomon, Ezion-geber (1 Kings 9:26, 22:48). Glueck interpreted the results of his excavations (see Chapter 6 below) in light of his 'Solomonic paradigm', and defined the site as an industrial center, "the Pittsburg of Palestine" (e.g., Glueck, 1940a, 1940c:94, 1940b), in addition to being an important port. A large brick building in the middle of the site was interpreted as a complicated copper smelting installation in which the copper ore from Timna (Wadi Mene'iyeh), after being roasted in the furnaces near the mines, were smelted into pure copper metal (Fig.3.3). Some large pots were interpreted as crucibles and some architectural installations were associated with the smelting process. Although this interpretation became an 'archaeological sensation' and was integrated in all contemporary text books (e.g., Albright, 1954), it was proved wrong by later research (e.g., Rothenberg, 1967a; Pratico, 1985). Samples labeled as 'slag' from Glueck's excavations at the site were found to be random rocks in the current research (see more details about the site below, in section 6.2.2).

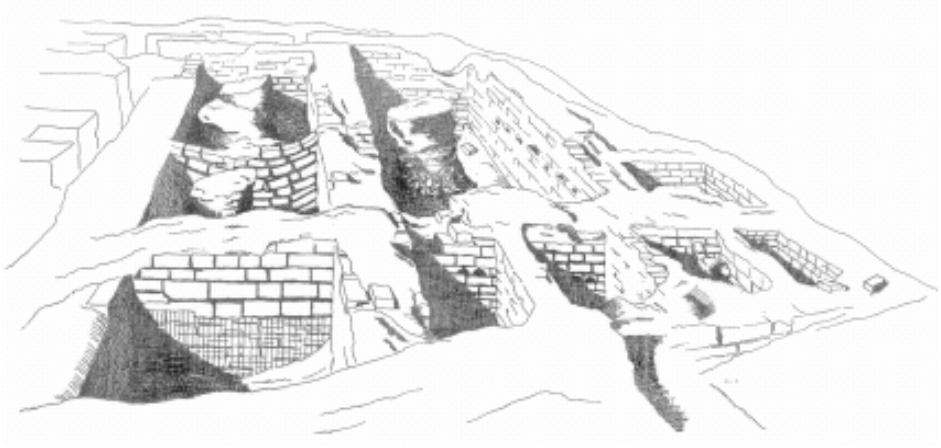


Fig.3.3: The complex "Smelting and Refining plant" at Tell al-Kheleifeh reconstructed by Glueck (1940c:95). Later research found this architectural complex to be no more than a series of burned grain storage spaces and architectural features (e.g., Pratico, 1985).

Although Glueck recognized the challenges presented by research of archaeometallurgical remains and the advantages of multidisciplinary investigations (e.g., Glueck, 1936b) he did not pursue any in-depth studies of the metallurgical remains and his basic interpretations of the field evidence for Tell el-Kheleifeh and what is now called Timna were basically wrong. For example, his assertion that the region of Timna is "the largest and richest copper smelting site in the entire 'Arabah'" (1935:42) has no support in the archaeological evidence (Faynan has more metallurgical remains in at least two orders of magnitude, e.g., Hauptmann, 2007), and Glueck's identification of the Iron Age furnaces in the Arabah Valley was completely erroneous (Fig.3.4):

> [Regarding Khirbat al-Jariya] Two small furnaces were found still fairly intact, a circular one, A, at the south end of the east side, and a square one, B, at the north end of the west side, with foundations of other furnaces visible, such as C, near the center of the west side, and another circular furnace near it. Furnace A is in the form of an irregular circle and measures 2.9 by 2.6 metres; […] Some of the smelting furnaces were two stories high, one compartment above the other. Just how the ore was smelted is unknown to us. It seems likely that a bellows of some sort or other was made use of…(Glueck, 1935:23-25)



Fig.3.4: Photograph taken by Glueck (1940:63) on March 25 1934 at the smelting site of Khirbat al-Jariya. Glueck misinterpreted the stone structure as a 'copper smelting furnace', probably after Petrie's (1906) research in the Sinai.

These installations, like others Glueck identified in Timna, have nothing to do with the ancient smelting process. While in Jariya they are probably related to storage or other domestic purpose (see Chapter 5 below), in Timna they were reinterpreted as the graves of the workers (Rothenberg, 1967a:12, and e.n. 49,79,154). The source of Glueck's misinterpretation is probably Sir Flinders Petrie's work in the Sinai Peninsula, where similar structures were also (mistakenly) interpreted as smelting installations (Petrie, 1906:242-243, Fig.172). Glueck raised many questions regarding the copper production industry in the arid region of the Arabah Valley, such as the source of fuel [suggesting import of charcoal made in the wooded area of the Edomite highlands (1940c:65)], seasonality of work [suggesting that all of the mining and smelting sites of the entire Arabah Valley, excluding Khirbat Faynan, were active only during the winter season where water was available (1935:25)], and source of labor

[suggesting *corvée* as the principal recruitment mechanism, and interpreting the fortress at Khirbat en-Nahas, and the walls at Timna Sites 30 and 34 as enclosures for controlling the workers rather than protection against external enemies, (1935:28)]. The current research attempts to reassess many of these issues and others, from an anthropological archaeology perspective and in light of substantial new data obtained since Glueck's work in the 1930s.

3.2 Modern research of archaeometallurgical sites in the southern Levant

3.2.1 *The Arabah Expedition*

For political reasons, Glueck (1957; 1959; 1965b) began widespread surveys in the Negev desert and the southern Arabah valley in the 1950s where he continued his search for evidence of Iron Age metallurgy. However, it was only when systematic research started in the Timna region by Beno Rothenberg and the 'Arabah Expedition' that the metallurgical remains were correctly identified and the copper production process was interpreted from the perspective of a multidisciplinary research endeavor (Rothenberg, 1999b; Rothenberg, 1999a). This pioneering project, starting in 1959, blazed the way for archaeometallurgical research world-wide and took an important part in establishing this sub-discipline as a distinct branch of archaeology (e.g., Pigott, 1996). The Institute of Archaeo-Metallurgical Studies in London (IAMS), one of the leading centers of archaeometallurgical research in the world

(http://www.ucl.ac.uk/iams/), was established by Rothenberg as part of the effort to create a research group that can handle questions related to ancient metals production and use, with scholars from the natural sciences, mining engineering and archaeology. Most of the research in the southern Arabah and Timna was done under IAMS, which also sponsored the publication of the two final reports of the Arabah Project published so far (Rothenberg, 1988, 1990e). Unfortunately, a significant portion of the research in the southern Arabah was not published, or was only partially published in short papers, including the planned volume on the survey results (Researches in the Arabah 1959-1984 Volume III)[23].

A detailed summary of the research activities of the Arabah Expedition appears in Rothenberg (1988:1-18). The project started with intensive survey of the Arabah, with a focus on Timna and the southern part of the Valley (1959-1961). The results of the initial survey challenged the well accepted chronological frame of Glueck (see below) and triggered further research and excavations. The first phase of excavations in the Timna area was in 1964-1970 (Sites 39, 2, 28 and 200), and the second (the 'New Timna Project') was in 1974-1976 (first excavations of mines [Site 212], investigations of the 'plates' [1976], excavations of Site 30, geomorphological survey and excavations of a 'Model Area'). The last phase, 'The New Arabah Project', was in 1978-1983 and included more surveys of the southern Arabah, archaeometric

[23] The surveys include more information on some Iron Age copper smelting and mining sites that is not yet available; see Table 6.1 and also Rothenberg and Glass (1992:152)

investigations of the finds and historical models and experimental archaeology related to the smelting process.

The experiments were done as part of the Arabah Project by Bamberger, Wincierz and Bachmann (Bamberger et al., 1986, 1988; Bamberger and Wincierz, 1990) and especially by John Merkel (1990) are still fundamental to our understanding of ancient copper extraction technologies (see e.g., Craddock, 1995, Chapter 5). They are also a key to understanding the new finds analyzed in the current research, as we found that the Iron Age evidence from Faynan represents similar technology to the one recorded in the southern Arabah[24]. The surveys of the Arabah Expedition resulted in approximately 300 new sites (Fig.3.5 and 3.6) (Wilson, 1983), of which about 50 were dated to the New Kingdom period (13th – first half of the 12th century BCE; only one was dated to the Iron Age II)(Rothenberg and Glass, 1992). These sites, especially in light of the chronological revision we suggest below, are probably directly related to the developments in the Faynan area and area an important part of assessing the technological impact on the Iron Age society of this region.

[24] The similarity in technological practice between Fayan and the southern Arabah corresponds to chronological revision we suggest for the sites in Timna that mostly represent the same period of occupation (see Chapters 5, 6 and 10 below).

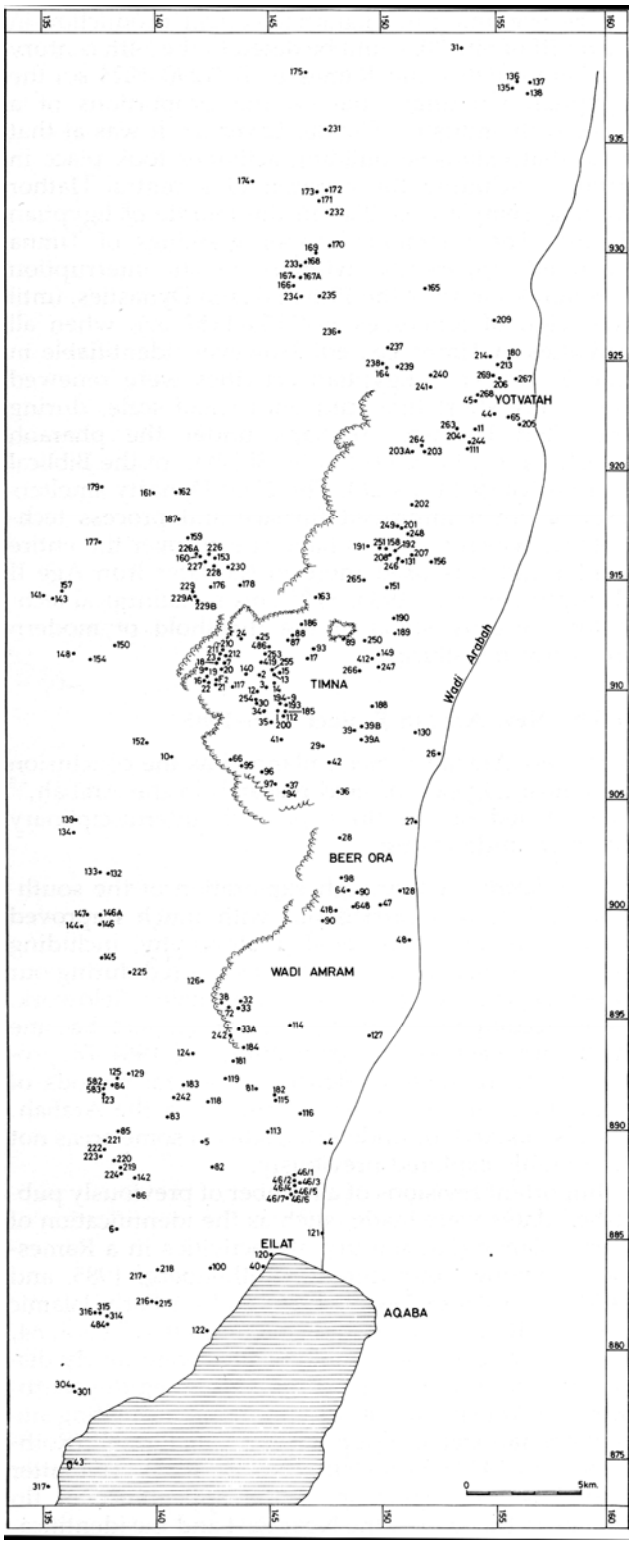


Fig.3.5: Distribution of archaeological sites recorded by the Arabah Expedition in the southern Arabah region 1959-1984 (Rothenberg, 1988:12).

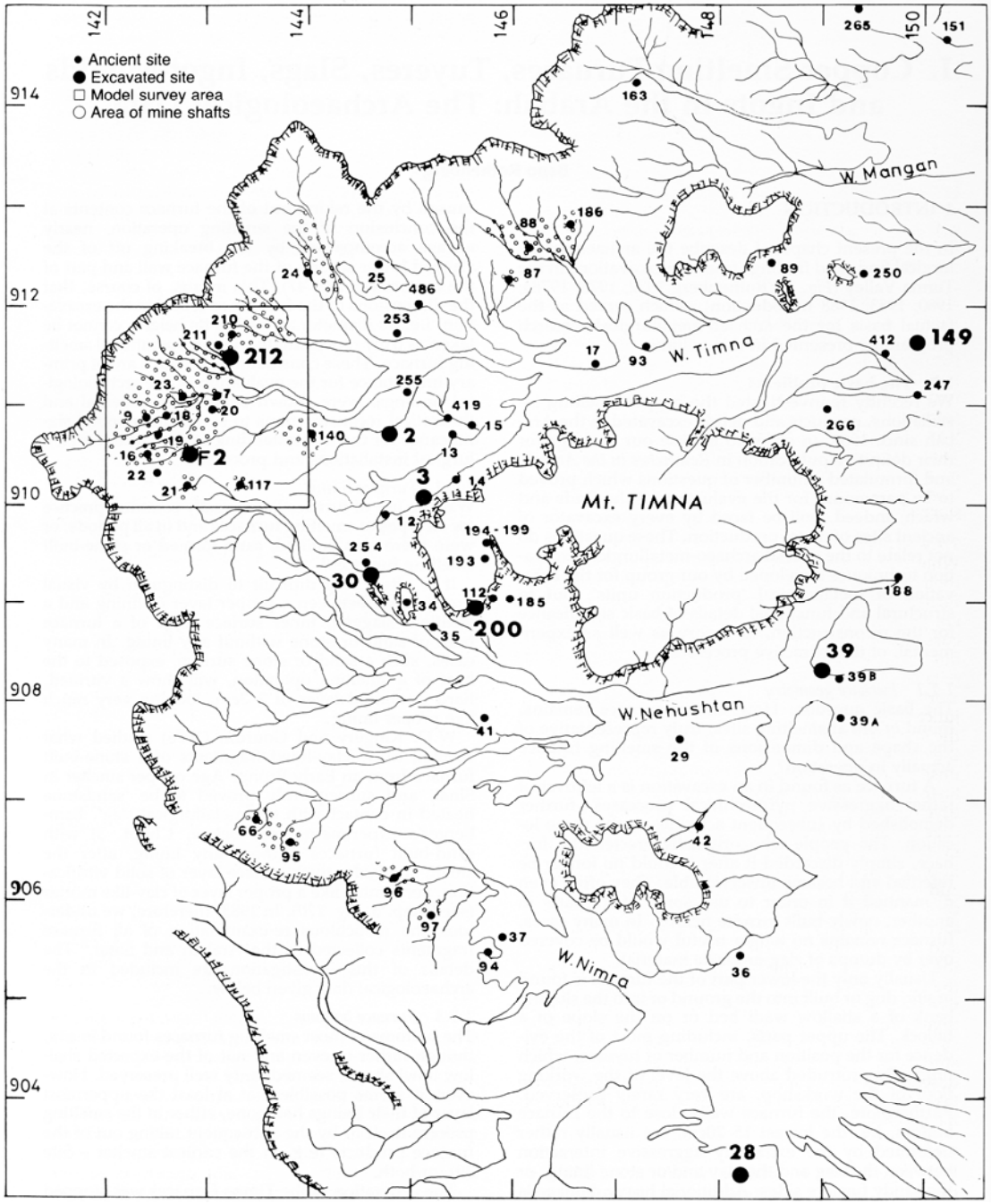


Fig.3.6: Timna Valley and the archaeological sites recorded by the Arabah Expedition (1959-1984). Note the 'Model Area' of detailed survey and excavations, the empty circles representing mine shafts/pits, and the excavated Sites 2, 3, 30 and 200 discussed below (from Rothenberg, 1990e:4).

3.2.2 *The chronological debate and 'King Solomon's Mines'*

Directly relevant to the current research is the debate around the chronology of the major smelting camps in Timna that took place during the 1960s and 1970s. As mentioned above, Glueck was the first to assign a date to copper production remains, both in Faynan and Timna. Based on ceramic finds and historical consideration he claimed that the major smelting sites should be dated to the Iron Age II, from the era of King Solomon to the end of the Judean Monarchy (Glueck, 1940c) based on the traditional chronological typology of the time. Glueck also identified Tell el-Kheleifeh with Ezion-geber, Solomon's Red Sea port (1Kings 9:26), and interpreted the site as a major industrial plant for production of final copper objects (e.g., Glueck, 1940b). With Glueck's research, the concept of 'King Solomon's Mines' was virtually created; there is no mention of such mines or copper mining activities in the Old Testament (or in any other historical sources), and Henry Rider Haggard's legendary 1885 book bearing this title takes place in East Africa and has nothing to do with copper mines (Haggard, 1885). The Iron Age date and the historical interpretation of the copper mines, especially in the southern Arabah, became the accepted research framework and appeared in all of the text books of the time.

The investigations of the Arabah Expedition first contested the accepted framework in 1962, when Y. Aharoni, the expedition's advisor on ceramic typology, claimed that none of the Arabah pottery should be dated later than the 11th century,

and most likely dated to the Iron Age I (12th – 11th centuries BCE, Aharoni, 1962). This new date was reassured after the excavation of Site 2 in 1964 (Rothenberg, 1966) but was immediately rejected by Glueck (1967; 1969) who was supported by Albright, the greatest 'authority' in Biblical Archaeology at the time (Glueck, 1969:54, and note 16) (regarding Albright, see Levy and Freedman, 2008).

The major revision in the chronology of the copper smelting sites of Timna happened only after the discovery (1967) and excavations (1969) of the Egyptian sanctuary in the central part of the valley (Rothenberg, 1972a, 1972b). The same pottery types found in the smelting sites were reported from the sanctuary and were associated with Egyptian finds and cartouches from the 19th and 20th Dynasties (Seti I – Ramesses V). As a consequence of these finds, all of what had hitherto been considered as 'Iron Age' sites in the southern Arabah were re-dated to the period of the Egyptian New Kingdom (Late Bronze – Early Iron Age, 13th – first half of the 12th centuries BCE), including the major smelting camps and the vast copper mine fields[25]. Glueck acknowledged the Egyptian finds in the second edition of *The Other Side of the Jordan* (1970:93-94), but still did not accept that his ceramic dating had been refuted, and insisted that the pottery represents the 10th – 6th centuries BCE (1970:73). While this was Glueck's last word on the subject (he died in 1971), Albright finally accepted the new chronology of the sites (Albright, 1971:4, also shortly before his death in September the same year). Thus, after some years of academic debate (see

[25] It is important to note that in the Expedition's publications, from the beginning of the Arabah Project in 1959 until the excavation of the Egyptian Sanctuary in 1969, there was not a single mention of Egyptian finds or an Egyptian presence in Timna, although a major excavation took place at Site 2.

e.g., Wright, 1961; Avigad, 1963; Yadin, 1965, 1966), the 'Solomonic paradigm' for the copper mines of the southern Arabah was entirely replaced by a new 'Egyptian paradigm'. The major copper production remains in the southern Arabah were now interpreted as another aspect of the Late Bronze Age Egyptian control over Canaan and its resources, and the option of Iron Age mining in the region (controlled by local social groups) was completely taken out of the archaeological and biblical scholarly discourse[26]. This stands in contrast even to the reports of the Arabah Expedition itself, in which Layer I at Site 30 was interpreted as an Iron Age II resurgence of copper production in the valley (also here under Egyptian control). The debate over the dating of the Iron Age sites in Timna, the confusion and disagreement regarding the date of many other earlier sites (especially Sites 39 and F2 see e.g., Muhly, 1984a; Ben-Yosef et al., 2008b; Ben-Yosef et al., 2010c), and some inherent problems in the dating methodologies and reference typologies of the Arabah Expedition (e.g., Avner, 2002; Ben-Yosef et al., 2010c, and chapter 4 below) probably contributed to the exclusion of Timna from almost any further discussion and research in regard to the Iron Age of the southern Levant. However, close scrutiny of the reports of the Expedition and the results of some later works (e.g., the reinvestigation of Glueck's pottery collection from the southern Arabah and reassurance of his dating, Baron, 1978, 1981) raise some challenges to the 'Egyptian paradigm' (see a good summary in Bimson and Tebes, 2009). The current research attempts to tackle some of the dating problems and

[26] See footnote 21 above.

to revisit the accepted chronological scheme for Timna (Ben-Yosef et al., 2010a, and see below, chapters 6 and 9)[27].

3.2.3 *The British research in Edom and its implication on the dating of Iron Age Faynan*

In 1960 the British archaeologist Crystal-Marie Bennett commenced a study of the Edomite settlement in southern Jordan that soon became the principal archaeological project of her career. Bennett excavated three key sites in the highlands, including Umm al-Biyara (1960, 1963, 1965), Tawilan (1968-70, 1982) and Busayra (1971-74, 1980), and dated them to the late Iron Age, with occupation starting not earlier than the late 8th century BCE (e.g., Bienkowski, 1992; Hart, 1992). Although some reservations were raised (e.g., Finkelstein, 1992), the new chronology of Iron Age sedentary settlement in Edom was widely accepted by archaeologists working in the southern Levant. Moreover, the results of Bennett's excavations were considered to represent correctly the chronology of the entire region, including revision of some survey results (Weippert, 1979, 1982; MacDonald et al., 1988)[28], and most importantly also the copper production sites in the Faynan region. While in the Timna region Glueck's dates were revised to an earlier period (see above), in Faynan

[27] The 2009 new excavations of Timna Site 30, directed by the author, were part of this attempt. A series of 11 high precision radiocarbon dates suggest a major revision in the accepted chronological scheme for Timna, and see below.

[28] Two of the 'Iron Age I' sites from MacDonald's survey in Wadi al-Hasa were later excavated by Bienkowski who showed no early Iron Age occupation there and further fixed the low chronological framework for Edom (Bienkowski et al., 1997; Bienkowski and Adams, 1999; Bienkowski, 2001).

the sites were considered now to represent a later period, and in both cases the role of the local society in the enterprise was replaced by external control: in Timna the Egyptians, in Faynan the Assyrians.

This 'low chronology' for Edom has become another research paradigm, embedded in multiple research models, two of which are still fundamental to our understanding of the Iron Age society of the region (see above, in the Introduction). The *core-periphery model* for the development of local polities in the Iron Age southern Levant, according to which the emergence of the Edomite state was tied directly to the Assyrian control of the region, was substantially supported by the new chronology (e.g., Porter, 2004). According to the low chronology dates, settlements in Edom started to appear only after the Assyrian conquest of the region in the second half of the 8th century BCE, thus the interpretation of the social evolution and economic development in the region fitted well a core-periphery model (rather than, for example, *peer-polity interaction model*, or other forms of locally initiated development of social complexity(rather than, for example, peer-polity interaction model, or other forms of locally initiated development of social complexity, cf. LaBianca and Younker, 1995; Levy, 2004).

The low chronology of Edom also supported the 'Low Chronology' suggested by Finkelstein to the Iron Age southern Levant (see e.g., Mazar, 2005, and above, in the Introduction), and played an important role in deconstructing the validity of the

Old Testament as an historical source, especially in regard to the 10th century BCE. If Edom was vacant during this period, or at most was occupied by dispersed nomadic tribes, the biblical narratives about King David's conquests in the area (for example) cannot have any historical basis. The results of the British research in Edom and other studies in Transjordan became a fundamental argument in the efforts of the critical movement in Biblical archaeology to separate the archaeological evidence and the narrative of the scripts. Beginning in the mid-1990s, the debate about the interpretation of the archaeological evidence still goes on and is in the core of our basic understanding of the Iron Age southern Levant.

The deeply entrenched chronological and research paradigms regarding the Iron Age archaeology of Edom were probably the cause that even when new radiocarbon dates from Faynan were published by the German Mining Museum team (Hauptmann, 2000, and references therein), indicating substantial early Iron Age activities in the Edomite lowlands, they were widely ignored by the archaeological community. A significant revision to the accepted chronology of lowland Edom took place with the publications of the Jabal Hamra Ifdan and the Edom Lowland Regional Archaeology Projects (Levy et al., 2004c; Levy et al., 2008a), who systematically showed early Iron Age high precision ^{14}C dates for the copper production sites in the Faynan region. Both works of the German Mining Museum and the JHF and ELRAP projects are further detailed in the next sections; the present research is part of the

ELRAP project, and the revision in chronology, both in Faynan and in Timna, is detailed in Chapters 4, and 5 and 6 below.

Although ELRAP and other studies have presented hard evidence regarding the dates of the copper production sites in Faynan, only gradually has the archaeological community accepted the new framework. Especially reluctant were scholars in support of the 'Low Chronology' paradigm, headed by Israel Finkelstein of the Tel Aviv University. In spite of the article by Levy et al. (2004c) and other publications, Finkelstein and Silberman wrote:

> […] Another important source of copper is the area of Wadi Feinan, on the eastern margin of the Arabah Valley….Recent studies by German, American, and Jordanian scholars have revealed evidence for continuous activity in the Iron Age, with one of the intense periods of mining and production dated to the late eighth and seventh centuries BCE. Like all other lucrative economic activities in the region, this industry was carried out under Assyrian auspices. (Finkelstein and Silberman, 2006:174-175)

In later publication Finkelstein acknowledged the new dates for the copper production (e.g., Finkelstein and Piasetzky, 2008), but is still unwilling to accept the dates of the massive structures associated with the smelting and refining activities (Finkelstein and Singer-Avitz, 2009). Recently, Levy and colleagues demonstrated Finkelstein's flawed methodology in approaching the Iron Age radiocarbon and other data from the ELRAP expeditions in Jordan (Levy et al., 2010a, 2010b). In this dissertation we present further archaeological evidence of the Iron Age copper production process in Faynan (and some new results from Timna), including the smelting remains, mines and associated structures (see Chapters 5 and 6), in light of robust dating methodologies (Chapter 4). Although the 'debate' is ostensibly still going on, we think

some of the recent arguments are beyond the scope of scientific argumentation and thus cannot be reciprocated.

3.2.4 *Recent research in Faynan*

In recent years intense research has been conducted in the copper ore district of Faynan, Jordan. The new data, some of which were the result of excavations and surveys conducted by the present author as part of ELRAP expeditions, are the focus of the current research. They should be contextualized in relation to the expansive modern research in the region that included surveys (mostly), a few major excavations and some small probes. The most relevant projects, the German Mining Museum surveys and the Edom Lowland Regional Archaeology Project of the University of California San Diego, are further detailed below (3.2.5), after the general overview.

Except from the brief surveys of H. Kind (1965, including a survey of the copper ore district of Abu Khusheiba) and Raikes (1980; 1985, working during 1967-9 and 1975-9), systematic research in Faynan began in the early 1980s. The major archaeological (and archaeometallurgical) surveys are summarized in Fig.3.7 and the major archaeological projects in Fig.3.8, including their years of activity and main references in the captions. Although significant water sources also attracted habitation in the region, the exploitation of the copper ore was part of probably the underlying aim of all the occupation periods in Faynan starting in the Neolithic (then as part of

bead production and procurement of pigments, cf. Hauptmann, 2000; Levy, 2007)Hauptmann 2000, Levy 2007). Thus a significant part of research in Faynan was devoted to understanding mining and metallurgy technology and the interaction between society and technology, and material on this topic can be found in many of the publications mentioned in this section.

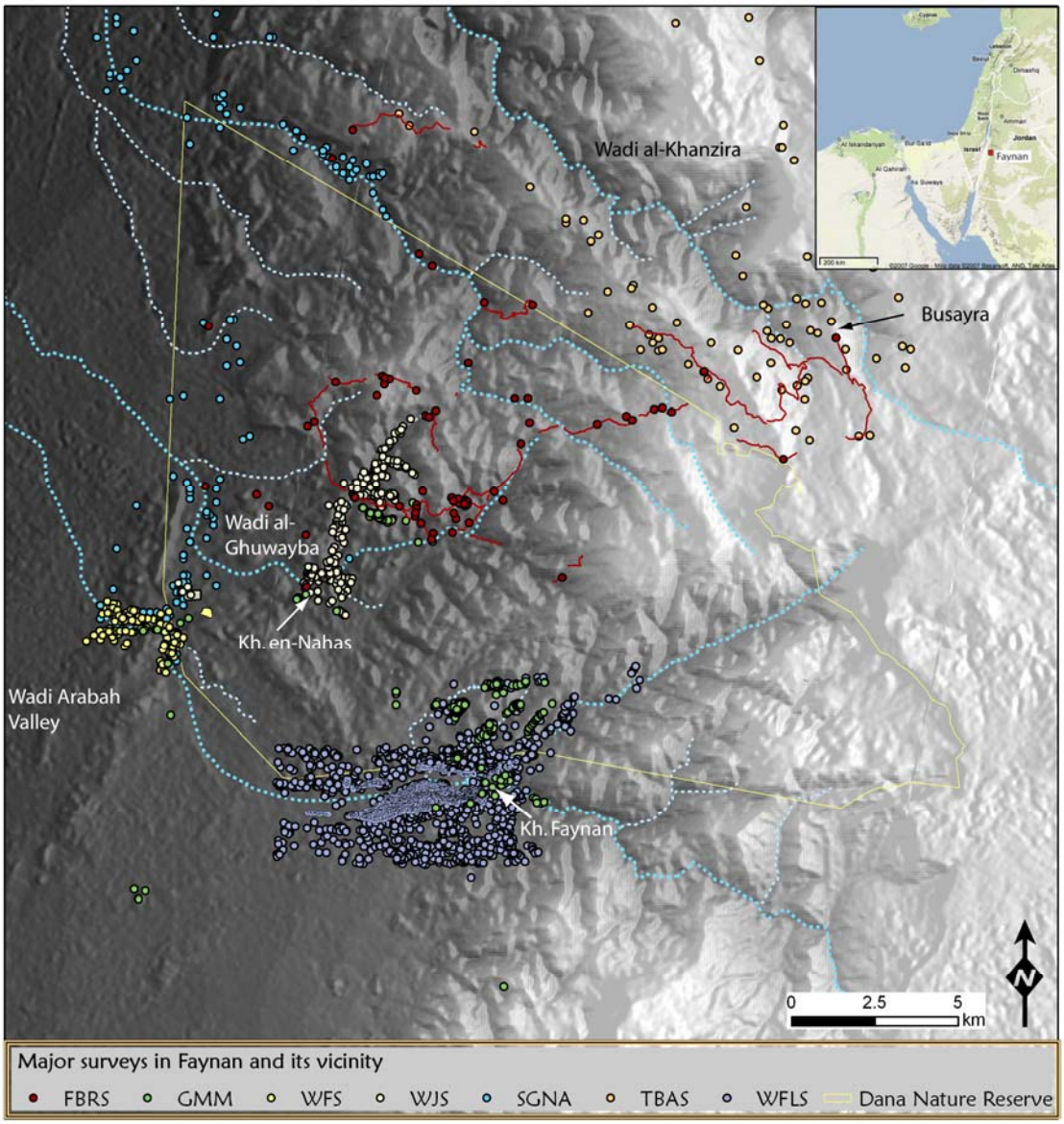


Fig.3.7: Shaded-relief map of Faynan copper ore district (Jordan) and its vicinity. Archaeological sites recorded by major surveys in the region are plotted, as well as the boundary of Dana Nature Reserve. Kh. = Khirbat ('the ruins of' in Arabic); FBRS = Faynan – Busayra Regional Survey, red lines are recorded road segments (2007, Ben-Yosef et al., in press); GMM = German Mining Museum archaeometallurgical survey (1983-1992, described partially in Hauptmann 2007 and references therein); WFS = Wadi Fidan Survey (field season of 1998 in Levy et al. 2001, field season of 2004, contiguous portion higher along the wadi, not published); WJS = Wadi al-Jariya Survey (season of 2002 in Levy et al. 2003 and season of 2007 in Knabb et al. this volume); SGNA = Southern Ghor and Northern Arabah Survey (1985-1986, MacDonald 1992); TBAS = Tafila – Busayra Archaeological Survey (1999-2001, MacDonald 2004); WFLS = Wadi Faynan Landscape Survey (1996-2000, mostly in Barker et al. 2007).

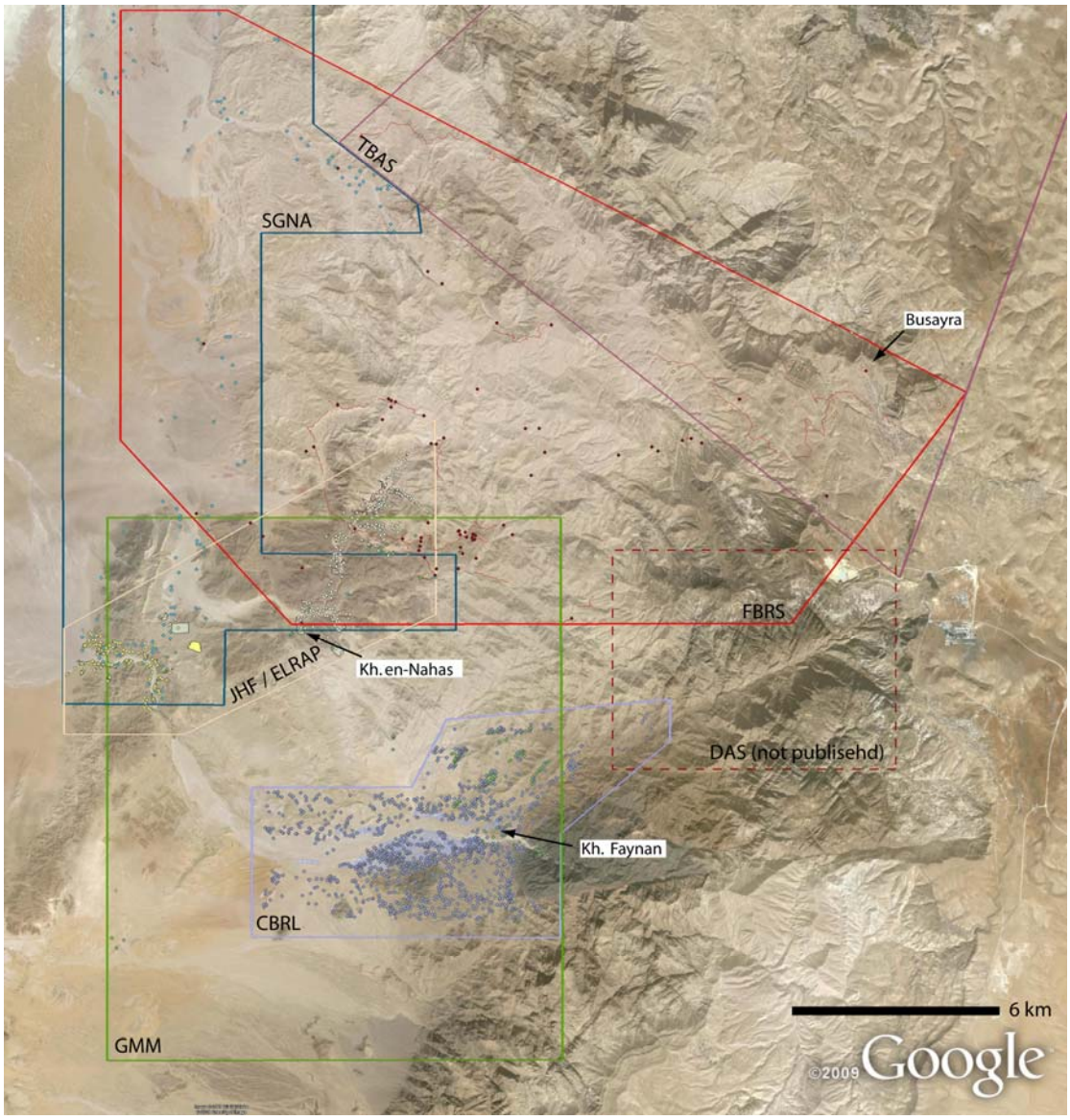


Fig.3.8: Satellite image (Google Earth) of the Faynan copper ore district (Jordan) and its vicinity. Archaeological sites recorded by major surveys in the region are plotted (cf. Fig.3.7 for key), as well as schematic delineation of main research areas. CBRL = Center of British Research in the Levant (formerly BIAAH, British Institute at Amman for Archaeology and History; see in particular Barker et al. 2007 [Wadi Faynan Landscape Survey], Finlayson and Mithen 2007 [The Dana-Faynan-Ghuwayr Early Prehistory Project], McQuitty 1998 [The Wadi Faynan Project], and Wright et al. 1998 [The Wadi Faynan Fourth and Third Millennia Project]); DAS = Dana Archaeological Survey (an extensive, unpublished survey in the Dana Nature Reserve conducted by George Findlater [also affiliated with CBRL]; exact extent is unknown); GMM = German Mining Museum (Deutsches Bergbau-Museum, Bochum; Hauptmann 2007 and references therein); JHF = Jabal Hamrat Fidan Project (University of California, San Diego and the Department of Antiquity of Jordan, Amman; see Levy et al. 2001, 2004); ELRAP = Edom Lowlands Regional Archaeology Project (University of California, San Diego, see Levy et al., 2008a; and papers in Levy et al., in press-d); SGNA and TBAS are regional surveys by MacDonald (see Fig.3.7 for details).

The 1980s research in Faynan is marked by the intense work of the German Mining Museum (Hauptmann, 2007, and see below) in addition to publications of archaeological work by King (1989) on the Byzantine churches of Khirbat Faynan. In the 1990s research centers developed around two areas, one near Khirbat Faynan and the other around Wadi Fidan and Wadi al-Ghuweiba. The research around Khirbat Faynan was declared as the flagship of the British Institute at Amman for Archaeology and History (BIAAH, later the Center of British Research in the Levant, CBRL, see McQuitty, 1998) and included numerous surveys and supported excavations, some directly related to the Wadi Faynan Project initiated in 1993 by William Lancaster with association to the establishment of the Dana Nature Reserve at the same year (e.g., Barnes et al., 1995; Ruben et al., 1997; Findlater et al., 1998; Findlater, 1999), and others were associated in some way with the CBRL, starting at 1996 (Freeman and McEwan, 1998; Wright et al., 1998; Barker et al., 2007b; Finlayson and Mithen, 2007; Grattan et al., 2007). A major survey of Wadi Dana and its vicinity was conducted by George Findlater of the CBRL, as part of the resource management of the Dana Nature Reserve of the Royal Society for the Conservation of Nature in Jordan (RSCN) and is yet to be published. In the same general area surrounding Khirbat Faynan, Najjar and colleagues conducted excavations in the Neolithic sites of Tell Wadi Faynan and Ghuweir 1 (Najjar et al., 1990; Simmons and Najjar 2006 respectively), the research in the latter is still ongoing.

Out of the many projects by British groups, three analytical themes occupy the majority of publications. One is related to the agricultural revolution in the Neolithic (Finlayson and Mithen, 2007, and refernces therein), the other to archaeology and desertification processes (Barker et al., 2007b, and references therein) and the third to ancient metallic pollution in the region (e.g., Grattan et al., 2007, and see chapter 9). In addition, mostly based on data from Khirbat Faynan area, Hana Friedman published her dissertation on the Faynan copper industry during the Roman-Byzantine period (Friedman, 2008).

In the area of Wadi Fidan and Wadi al-Ghuweiba research started with the Wadi Fidan Project (Adams, 1991) and developed in 1997 to be the Jabal Hamrat Fidan (JHF) Project (Levy et al., 1999; Levy et al., 2001a; Levy et al., 2001c). Since 2006 the research in this region is done under Edom Lowlands Regional Archaeology Project (ELRAP) of the University of California, San Diego (of which most of the current research is part, and see further details below). Based mostly on data from the early projects in this area of Faynan, Russell Adams published his dissertation on the development of the copper production activities in Faynan during the Early Bronze Age (Adams, 2002).

The surveys by Burton MacDonald and his colleagues covered an extensive landscape including parts of western Faynan region and adjacent areas: the northeastern Arabah Valley, the lower part of Wadi ad-Dahal and the terrain around

Busayra (MacDonald, 2007) (Figs. 3.7 and 3.8). These surveys provide invaluable archaeological data for the areas surrounding Faynan to the east and to the north, although the methodology was not consistent and the surveys were not comprehensive. The Southern Ghors and Northeast ʻArabah Archaeological Survey (SGNA, carried out in 1985-1986, MacDonald, 1992b) focused on sites along easily accessible routes (mostly dirt roads) and thus was likely to miss important sites that can be reached only by foot. The Tafila-Busayra Archaeological Survey (TBAS, carried out in 1999-2001, MacDonald et al., 2004) was based on a random square sampling method adjusted to fit three different topographical zones in addition to intensive survey of the hinterlands of Busayra (3-km radius from the citadel). Both SGNA and TBAS did not cover the upper parts of Wadi ad-Dahal and the important road that connects Busayra to the Arabah (Fig.3.7), although MacDonald was aware of it (MacDonald, 2006:86). This, in addition to the gap in the surveyed landscape between SGNA, TBAS and the intensive surveys of Faynan (Figs.3.7 and 3.8), was one of the incentives for conducting the Faynan – Busayra Regional Survey (by the present author under ELRAP, see Ben-Yosef et al., in press, next section below and Chapter 5).

Recently two new regional projects started in the Faynan area and its periphery, the Barqa Landscape Survey (BLS) lead by Russell Adams and John Grattan in the sand dunes around the site of Barqa al-Hetiye (http://russellbadams.brinkster.net/barqaproject.htm), and the Wadi Feid Survey, lead

by Kyle Knabb, Levy and Najjar in the vast area of this wadi basin, on the southern and southeastern periphery of the Faynan region. The latter complements the work initiated by Neil Smith in the highlands south of Shawbak (noted below, under ELRAP).

3.2.5 *The German Mining Museum and the Edom Lowland Regional Archaeology Projects: different perspectives on ancient technology*

The work of the German Mining Museum (GMM, or Deutsches Bergbau-Museum, DBM), headed by Andreas Hauptmann, is a landmark in the history of research in Faynan and the history of research of the archaeometallurgy of copper in general. The project is detailed in Hauptmann (2007:V-VIII), and its main publications (Hauptmann, 2000, 2007) are basic reference to any study about ancient production of copper, let alone the one recorded in Faynan. The project was initiated by a group of scholars that previously worked in Timna, including Hauptmann, Gerd Weisgerber (a mining archaeologist) and Hans-Gert Bachmann. The latter visited the region in 1982 and was the one suggesting starting there a major archaeometallurgical study. After a reconnaissance visit in September 1983, four field seasons were conducted in 1984, 1986, 1988, 1990, and the fifth and concluding one in 1993. The work included collaboration with various institutions and scholars, like the German Protestant Institute of Archaeology in Amman (GPIA, with Susanne Kerner as director), The Free University of Berlin (Wolfgang Frey, Uli Baierle, Thomas Engel and others,

mostly focusing on the archaeobotanical remains), Hermann Genz (the American University of Beirut) and Volkmar Fritz (University of Mainz), and various other students and scholars.

The GMM project focused almost exclusively on investigating the ancient technology of copper production throughout the millennia, and the main methodology used was field surveys (Fig.3.9), accompanied with sample collection for further laboratory analysis as well as ^{14}C dating. In a few locations, including the Iron Age copper smelting sites of Khirbat en-Nahas and Faynan 5, the team conducted small excavation probes into slag mounds and had unearthed a number of metallurgical installations (see Chapter 5 below). The narrow perspective on technological remains resulted in a fundamental contribution to our understanding of the development in copper production technology in the region, but other aspects of the archaeometallurgical remains, such as their historical, anthropological and cultural implications, were missing from the analyses of the GMM expedition. Exception to this approach was the work of Volmar Fritz, whose excavations at Barqa al-Hetiye and Khirbat en-Nahas in 1990 (Fritz, 1994a; 1996, respectively) contributed to a wider range of questions regarding the society of Iron Age Faynan (and see below).

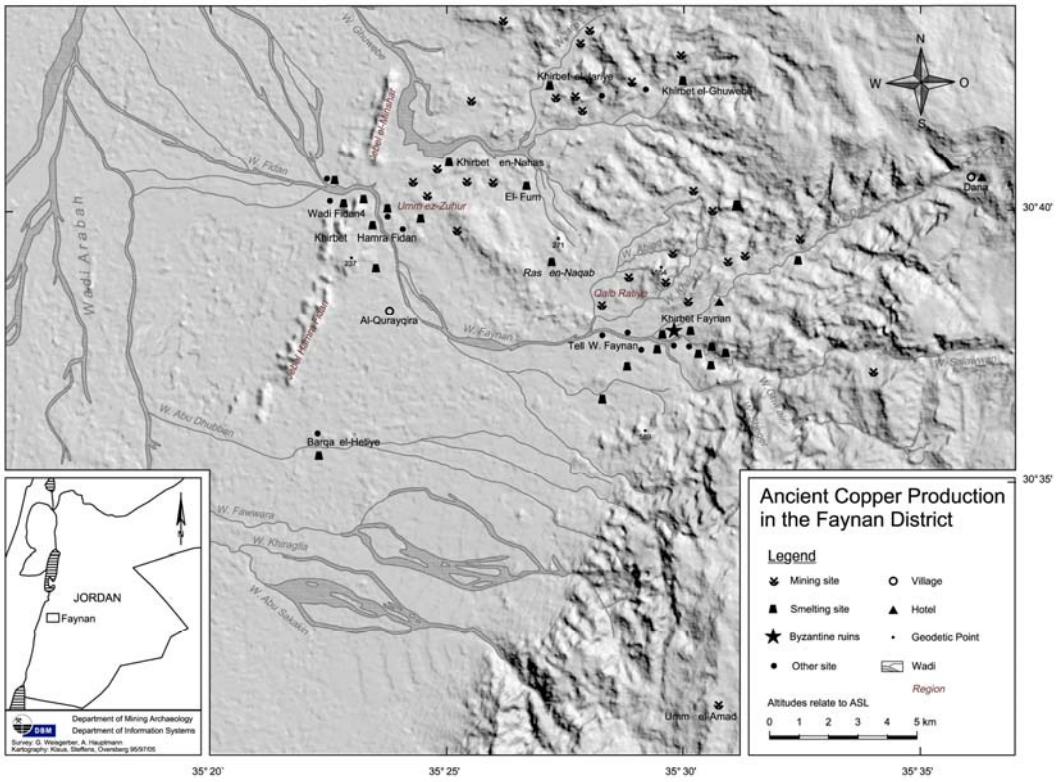


Fig.3.9: Major finds of the German Mining Museum Survey in Faynan, Jordan. Smelting and mining sites from various periods were recorded during their field work 1983-1993 (from Hauptmann, 2007:86) (cf. Figs.3.7 and 3.8).

The ongoing Edom Lowland Regional Archaeology Project (ELRAP, Levy and Najjar, 2007; Levy et al., 2008a) of the University of California, San Diego (UCSD), headed by Thomas E. Levy and Mohammad Najjar, started in 2006 as a direct continuation of the Jabal Hamra Ffdan (JHF) Project (1997-2002) in the western area of Faynan (Figs. 3.7 and 3.8) (for the latter, see Levy et al., 2001a; Levy et al., 2001c; , for an overview of UCSD project in Faynan see Levy, in prep.). This project, under which most of the data for the current research were collected, aims to *investigate the role of ancient mining and metallurgy on the evolution of societies, from the Neolithic period (ca. 8,000 BCE) to the Islamic times* (Levy and Najjar,

2007:97). A significant portion of both JHF and ELRAP was devoted to the investigation of the Iron Age of western and northern Faynan, including several excavations and surveys. The Iron Age excavations included the 1999, 2003 and 2004 excavations in the Iron Age cemetery of Wadi Fidan 40, the 2002 (Levy et al., 2004c), 2006 (Levy et al., 2008a) and 2009 seasons at Khirbat en-Nahas, the 2006 probes at Khirbat al-Jariya (Ben-Yosef et al., 2010a) and Ras al-Miyah East (Ben-Yosef et al., 2009a), and Rujm Hamara Ifdan (Levy et al., 2008a), the 2007 season at Khirbat Hamra Ifdan (including Iron Age slag mound), the 2009 probes in Khirbat al-Ghuweiba and Jabal al-Jariya-1 mine field (see Chapter 5 for more details). The JHF and ELRAP included also intensive, full-coverage archaeological field surveys. In 1998 and 2004 archaeological sites in Wadi Fidan were recorded (Levy et al., 2001c, results of 2004 are yet to be published) and in 2003 and 2007 surveys of Wadi al-Jariya and parts of Wadi al-Ghuweiba revealed "an Iron Age landscape"- a condensed scatter of Iron Age sites in this region of Faynan (Levy et al., 2003; Knabb et al., in press). In the summer of 2007 the present author conducted a thematic survey to record Iron Age routes and geographic features (such as springs) in the area between Faynan and Busayra as part of the ELRAP expedition to investigate lowland-highland relationships in Edom and ancient road constructions (the Faynan Busayra Regional Survey [FBRS], Ben-Yosef et al., in press). Some of the finds of the FBRS relate directly to the Iron Age copper production in the northeastern area of Faynan, and are part of the current integrative research (see Chapter 5).

As part of ELRAP, an evaluation of the social boundaries and development in Faynan during the Iron Age from the perspective of ceramic analysis was conducted as part of the Ph.D. dissertation of Neil Smith (Smith, 2009). Smith (2009; Smith et al., in press-b) also investigated the relationship between lowland and highland Edom through additional survey (L2HE) and excavation probes in the highlands between Ash-Shawbak to Petra. The current research aims to characterize the social evolution in Faynan in light of technological practices and to fuse together the archaeometallurgical evidence with anthropological approaches outlined in Chapter 1.

4. Challenges in dating of archaeometallurgical sites in the southern Levant: new approaches

Although accurate dating of the archaeological evidence is the foundation for any meaningful investigation into ancient societies and social development, the dating of archaeometallurgical sites in the southern Levant raised many controversies since the beginning of modern research in the region (see Chapter 3 above). In addition to the debates regarding the date of the Iron Age sites both in Timna and Faynan detailed above (sections 3.2.2 and 3.2.3 respectively), disputes over dating issues have been raised regarding other periods as well, and controversy over chronology seems to be a general attribute of the archaeometallurgical research in the southern Levant (Avner, 2002; Ben-Yosef et al., 2008b). A few of the more prolonged debates have concerned the Chalcolithic date of Wadi Fidan 4 in Faynan (e.g., Adams and Genz, 1995; Genz, 2000) and Site 39 in Timna (e.g., Rothenberg, 1990b; Ben-Yosef, 2006; Ben-Yosef et al., 2008b), the Neolithic date of Site F2 in Timna (Rothenberg and Merkel, 1995; Adams, 1997; Segal et al., 1998; Ben-Yosef et al., 2010c, and see below, chapter 6), and the Early Bronze Age of Site 149 in Timna (Avner, 2002; Ben-Yosef et al., 2008b).

The main reason for the difficulty in dating the archaeometallurgical sites in the southern Levant is that the material culture in most of the sites is usually scant and does not correspond to the well established typological scheme from the more

populated regions of the hill country. To try and overcome this difficulty, the Arabah Expedition developed a specific chronological/typological scheme for the southern Arabah Valley and Sinai that has less refined divisions than the common chronological scheme for the southern Levant and Egypt (Rothenberg and Glass, 1992) (Fig.4.1). “The Sinai-Arabah Copper Age”, with its three phases, covered the Chalcolithic to the Early Bronze Age IV, and the different copper production periods up to the Iron Age were characterized by local typologies of material culture and technology.

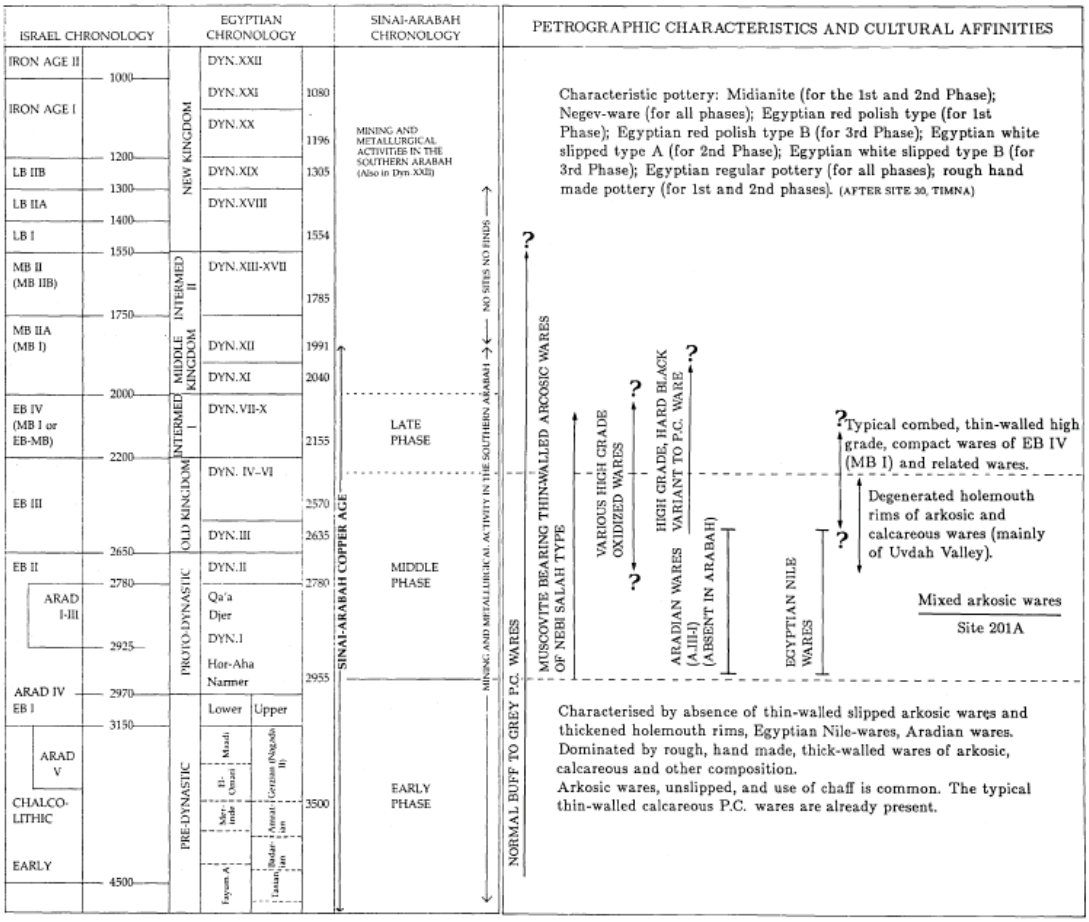


Fig.4.1: The chronological/typological scheme of the Arabah Expedition for the archaeometallurgical sites in the southern Levant, in comparison with (the much more refined) 'Israel chronology' and the Egyptian chronology (Rothenberg and Glass, 1992:149); note that all dates are BCE.

As the ceramic finds in the archaeometallurgical sites were usually very limited and often different from the known typological schemes, the Arabah Expedition often resorted to 'technological horizons' in dating metallurgical remains, a problematic approach (see Ben-Yosef et al., 2010c, and below) that led to erroneous interpretations of the archaeological record.

4.1 Technological typologies: critique of the simplistic approach to the development of technology in the southern Arabah Valley and implications for the current research

More recently, Segal et al. (1998:233) use the concept of '*technological horizon*' as a basic argument in dating Site F2 in Timna to the Pottery Neolithic period, and as the only means of dating Timna Site N3 to the Chalcolithic period. They state: "Inferences can be made about the relative level of sophistication of the processes used. Comparing two prehistoric sites in Timna – Site F2 and Site N3 – it is obvious that the smelting technology at Site N3 was more developed in the appropriate use of flux than at Site F2. […] The metallurgy of Site N3 had reached the 'technological horizon' of Chalcolithic copper smelting in the Timna Valley, dated by the archaeological evidence found in the excavations of Site 39." (ibid.). The same approach of dating archaeometallurgical sites according to the level of sophistication and advancement in technology as represented by the archaeological finds prevails throughout the pioneering research of the Arabah Expedition in the southern Negev (Rothenberg, 1990a:68; see in particular: Rothenberg and Glass, 1992; Merkel and Rothenberg, 1999; Rothenberg et al., 2006). The central paradigm underlying such an approach assumes a strict unilinear technological evolution throughout human history, in which less developed technology always predates the more advanced one. Adherence to this paradigm, even when ^{14}C dates became available and suggest a different story, has created confusion in the archaeological research of this key area for the study of ancient metallurgy.

Perceiving technological developments as a unilinear evolution is part of what Brian Pfaffenberger (1992) has termed the "Standard View" of technology, and is usually accompanied by the two other principles of "necessity is the mother of invention" and "form follows function and style, and meaning is a surface matter". To exemplify the unilinear evolution paradigm Pfaffenberger argues (ibid.):

> This record shows a unilinear progression over time, because technology is cumulative. Each new level of penetration into Nature's secrets builds on the previous one, producing ever more powerful inventions. The digging stick had to precede the plough. Those inventions that significantly increase Man's reach bring about revolutionary changes in social organization and subsistence. Accordingly, the ages of Man can be expressed in terms of technological stages, such as the Stone Age, the Iron Age, the Bronze Age, and so on (Pfaffenberger, 1992, the use of "Man" for "humankind" was deliberately done to emphasize the gender ideology accompanying the Standard View).

The socio-historical reality is much more complex, as the anthropological and archaeological records show consistently (e.g., Pfaffenberger, 1992, 1998; Dobres and Hoffman, 1999). Less developed technologies can reappear in the archaeological record (thus, 'technological horizon' can be used only as a *terminus post quem*, with caution), and technological knowledge can be lost and re-gained.

Reinvestigation of several archaeometallurgical sites in the southern Arabah Valley carried out as part of the current research (Ben-Yosef et al., 2008b; Ben-Yosef et al., 2010c, and see below, chapter 6) has found that several sites that were dated by the Arabah Expedition to early periods (Neolithic, Chalcolithic and Early Bronze), actually represent simple copper production technologies used in the Iron Age (similar

evidence was found in Faynan, see Chapter 5). This is an important insight regarding Iron Age copper production technological practice, the society in the region and its social structure. The simultaneous (or interchangeable) practice of using simple technologies along with a standard and advanced smelting operation probably indicates a complex reality of stratified society or segregated social groups (and see discussions below).

4.2 New approaches for dating archaeometallurgical sites in the southern Levant

As detailed above, material culture and technological typologies are problematic for precise dating of the archaeometallurgical sites that are located on the margins of the settled areas of the southern Levant. This includes Iron Age ceramic typologies that have been considered as the basic dating tool both in Faynan and Timna since Glueck's work in the region. The difficulty with ceramic-based dating in the Arabah Valley sites is evident by examining the history of research in the area (Chapter 4): even after more than 50 years of modern research there is no scholarly consensus regarding the Iron Age chronology of either Timna or Faynan, and prolonged discussions on ceramic typologies are still going on, especially in regard to the intensive research in Faynan (Smith and Levy, 2008; Finkelstein and Singer-Avitz, 2009; Smith, 2009).

The adherence to ceramic-based dating by 'traditional' archaeologists, even when absolute dating methods were available, has been the main reason for confusion and prolonged discussions throughout the history of research in the southern Levant. The scarcity of the ceramic assemblages in the archaeometallurgical sites, their idiosyncrasy and the often subjective interpretation of context and typology have made it easy for scholars to impose preconceptions on the archaeological evidence, whether it was the primary role of Timna in the history of metallurgy (Sites F2 and 39), the New Kingdom date for sites in Timna, or the Low Chronology as is expressed (or should be expressed) in Edom. One example of a long discussion regarding the ceramic of the south during the Late Bronze and Iron Ages relates to the so-called 'Midianite pottery' (or Qurayya Painted Ware, QPW) that was originally dated by Rothenberg to the 14th – 12th centuries BCE based on the finds from the Egyptian sanctuary in Timna (Rothenberg, 1988:201, 276, using high chronology for Seti, 1318-1304). Later on, when this pottery was found in the same context of late Iron Age ceramic (8th century BCE and later)[29], a lengthy scholarly discussion has started with arguments using the QPW as evidence for the an early date of a site (e.g., Fritz, 1994a, for the Iron Age I date of Barqa al-Hetiye) or conversely for a late date of the original Timna finds (e.g., Bimson and Tebes, 2009) (and see more discussion below, Chapter 6, section 6.2.1.4). Resorting to other, absolute methods of dating, will root

[29] Some of the sites where QPW was found in later contexts (or in context with later pottery) are Tell el-Kheleifeh (Glueck, 1967:10-11; Glueck, 1969:54, there mistakenly as 'Edomite pottery', see ; Rothenberg and Glass, 1983:75-76), Tawilan (Bienkowski, 2001:261-262), 'Ain al-Qudeirat (Fantalkin and Finkelstein, 2006:20; Singer-Avitz, 2008), Barqa al-Hetiye (Fritz, 1994a), Tel Masos (Yannai, 1996:144-145; Herzog and Singer-Avitz, 2004:222-223), and recently at the excavations of ELRAP in Faynan (Khirbat en-Nahas and Rujm Hamra Ifdan). See also discussion in Chapter 6, section 6.2.1.4.

such discussion in a firm ground and prevent preconceptions and accusations of deficient stratigraphic work to take a hold over the archaeological discourse.

Without ignoring the important role of ceramic studies in the investigation of the Iron Age society of Edom, including diachronic developments, spatial variations and craft specialization (e.g., Smith and Levy, 2008; Smith, 2009), we suggest relying on absolute methods of dating when adequate samples are available. The pottery finds and the insights drawn from them (typological, technological, social, etc.) should be framed according to the absolute dates, and not vice versa. As detailed above, this approach is crucial for accurate understanding of the archaeometallurgical sites in Faynan and Timna, and it was the one we applied in the current research in all of the excavated sites, as well as in some of the surveyed ones.

The primary absolute dating methodology we have used is high precision radiocarbon measurements. An emphasis on this dating technique coupled with stratigraphic excavation was first introduced in Faynan by the UCSD JHF and ELRA projects (see above), that have collaborated with the Oxford Radiocarbon Accelerator Unit to produce large suites of radiocarbon dates for the Iron Age sites in the region (Levy et al., 2004c; Higham et al., 2005; Levy and Higham, 2005a, 2005b; Levy et al., 2005a; Levy et al., 2005b; Levy et al., 2005c; Levy et al., 2008a; Ben-Yosef et al., 2010a; Levy et al., in press-b). The WFLS of the CBRL and the GMM projects in Faynan have also published important Iron Age radiocarbon dates that are integrated

in the current research. In Timna, although radiocarbon dating was part of the pioneering research of the Arabah Expedition, this methodology was secondary to the typological dating. Most of the radiocarbon dates for Timna and the southern Arabah were published as end notes, and many were ignored or excused when they did not show agreement with the main research paradigm of the Expedition (see chapter 6 and Ben-Yosef et al., 2010a). The new excavations of Site 30 in Timna, directed by the present author as part of the current dissertation research, was accompanied by a substantial dataset of radiocarbon dates (done at the NSF AMS laboratory at the University of Arizona), and revealed a different chronology that calls for a revision in the dating of many other sites in the Timna region.

Two other absolute dating techniques employed for this study have been improved considerably in terms of accuracy (and precision) in recent years and are useful for the investigation of archaeometallurgical sites in the southern Levant. Archaeomagnetism, and especially the record of the intensity of the geomagnetic field in archaeological artifacts, provides a useful tool for correlating ancient sites and in some cases, dating them (see below). One advantage of this technique is the direct dating of an artifact (in case it has suitable magnetic qualities; the date is of the last heating of the artifact above a certain temperature, usually in the range of 350°C-550°C). This can provide information regarding specific metallurgical debris that are important to our understanding of the Iron Age (see the case of Site F2 and others presented below). The other technique, optically stimulated luminescence (OSL)

provides the only solution thus far for dating pit mines. As far as we know, the current research, is the first time this kind of mining complex was dated using OSL, and the results are both promising and encouraging further research.

The entire set of radiocarbon dates presented in this work (see tables 5.2 and 6.2) was done by collaboration with different laboratories. The sample measurements of the other absolute dating techniques introduced here, archaeomagentism and OSL, were partially done by the present author, at the Scripps Institution of Oceanography paleomagnetic laboratory (directed by Lisa Tauxe) and the Israel Geological Survey OSL laboratory (directed by Naomi Porat), respectively. The following presents the principles of each technique and its applicability in the study of the Iron Age archaeometallurgical sites in the southern Levant.

4.2.1 *High precision radiocarbon dating*

The radiocarbon dating technique was introduced in the early 1950s (Libby, 1954, 1955) and is now well established and commonly used in archaeological practice (see overview in Tylor, 1987). In addition, the calibration curve for the last 10,000 years is fixed and no significant changes are expected (e.g., Ramsey et al., 2006). The dating used for JHF-ELRAP sites and for the new excavations at Timna Site 30, is based on accelerator mass spectrometry (AMS) analysis, in which all of the ^{14}C atoms in the sample are counted and thus it is more precise than the standard

techniques. AMS dating also requires smaller samples than the standard radiocarbon measurement techniques (50-100 microgram vers. 1-10 grams), thus if needed, only a portion of the sample can be measured (for example, the outer rings or bark of a charcoal sample, to avoid the 'old wood effect').

Charcoal is abundant in the archaeometallurgical sites of the southern Levant as they were the principal source of fuel in the smelting process. In many cases these samples present a dating difficulty, especially if the charcoal is of a long-lived tree (such as juniper and acacia in southern Jordan and the Arabah regions). This difficulty is known as the 'old wood effect', as the radiometric measurements dates the point in time in which the wood dies (stops exchanging CO_2 with the atmosphere), and may produce an age older than the actual usage of the charcoal up to a few hundred years (Bronk Ramsey, 2005). To overcome this difficulty, we try to collect short-lived samples, such as olive pits, grape pips, date and barley seeds, etc. In contexts where short-lived samples were not available we collected wood charcoals from trees and shrubs, trying to focus on twigs and thin branches. Such samples were further processed to minimize the old wood effect: the plant species was identified and when possible the AMS analysis was done on a portion from the outer bark/ring (e.g., Levy et al., 2008a). For the Iron Age Faynan, the most common charcoal were of hydrophilic vegetation (usually Tamarisk) that is fast growing, constantly rejuvenating (it probably was under intense harvesting) and relatively short-lived (see more below, in section 7.2.3 and Chapter 9).

As much as the radiocarbon dating technique is precise, the accuracy of the interpretation of the results depends first and foremost on the context, and the collection methodology, the recording system used and field observations are irreplaceable (see section 5.2.2 for details about the field recording system and excavation methods of the present research). Field observations and relative stratigraphy can be used to constrain sets of radiocarbon raw dates and to produce a more tight and accurate age determination. The method used for applying constraints of relative stratigraphy is Bayesian statistics (see a good overview in Buck et al., 1996); for ELRAP radiocarbon dataset we collaborate with Thomas Higham of the Oxford Radiocarbon Accelerator Unit[30], and for the results of Timna Site 30 we used the online software of the Oxford laboratory, OxCal (Ramsey, 1995) (http://c14.arch.ox.ac.uk/embed.php?File=oxcal.html).

Precise dating of the Iron Age archaeometallurgical sites contributes to the ongoing chronological debate regarding this period, and especially the 10th century BCE (see Introduction and Chapter 3 above) (Higham et al., 2005; Levy and Higham, 2005b). The calibration curve enables relatively high resolution dating (up to a few decades) in the time span of the 11th to 9th centuries BCE and much lower resolution (in the scale of a century or more) in the time span of the 8th to 6th centuries BCE. To

[30] For the ELRAP Faynan dates and analyses we are grateful to Tom Higham and Christopher Bronk Ramsey and the team at the Oxford Radiocarbon Accelerator Unit, Research Laboratory for Archaeology and the History of Art, University of Oxford.

increase the dating resolution (even in the early Iron Age) and correlate occupations phases between sites and excavated contexts, for the study here, we have complemented the radiocarbon results with archaeomagnetic study (see below).

As part of the investigation of Iron Age copper production sites in the southern Levant, we have compiled a list of all relevant radiocarbon dates published so far (Tables 5.2 and 6.2). All of the original dates (BP) were re-calibrated using the most updated version of OxCal 4.1 (©Christopher Bronk Ramsey 2010).

4.2.2 *Archaeomagnetic dating*

Although archaeomagnetic dating techniques have been available for almost a century (e.g., Sternberg, 1997), it is only in recent years that high quality reference data were published for young (Holocene) archaeological periods of the Levant (magnetostratigraphic dating of prehistoric sites, using reversals in the dipole direction as a reference, is applicable for dating sites in the scale of hundred of thousands and million years only). Published ancient geomagnetic intensity values for the last 8,000 years in the Levant (in short, "archaeointensity") have accumulated to a robust dataset that can be used, in some cases, as a dating reference (Genevey et al., 2003; Gallet et al., 2006; Gallet and Le Goff, 2006; Ben-Yosef et al., 2008a; for dating application see Ben-Yosef et al., 2008b; for a general overview and the state of archaeomagentic research see Gallet et al., 2009) (Fig.4.2). In addition, slag material was found to be

highly suitable for archaeointensity experiments, demonstrating a high yield of reliable results (Ben-Yosef et al., 2008a; Shaar et al., 2010; Shaar and Ben-Yosef, in press), thus the method is particularly applicable for archaeometallurgical sites. Slag (and many other types of materials, of which most commonly in use for archaeological periods are ceramics and other baked clay) records the properties of the ambient geomagnetic field at the moment of its cooling below the corresponding blocking temperature of its dominant ferromagnetic minerals (e.g., below 580°C for magnetite). As most slag (and ceramic) fragments are not found in their original orientation of the time of cooling, we can only retrieve the ancient intensity component and not the directional one (declination/inclination).

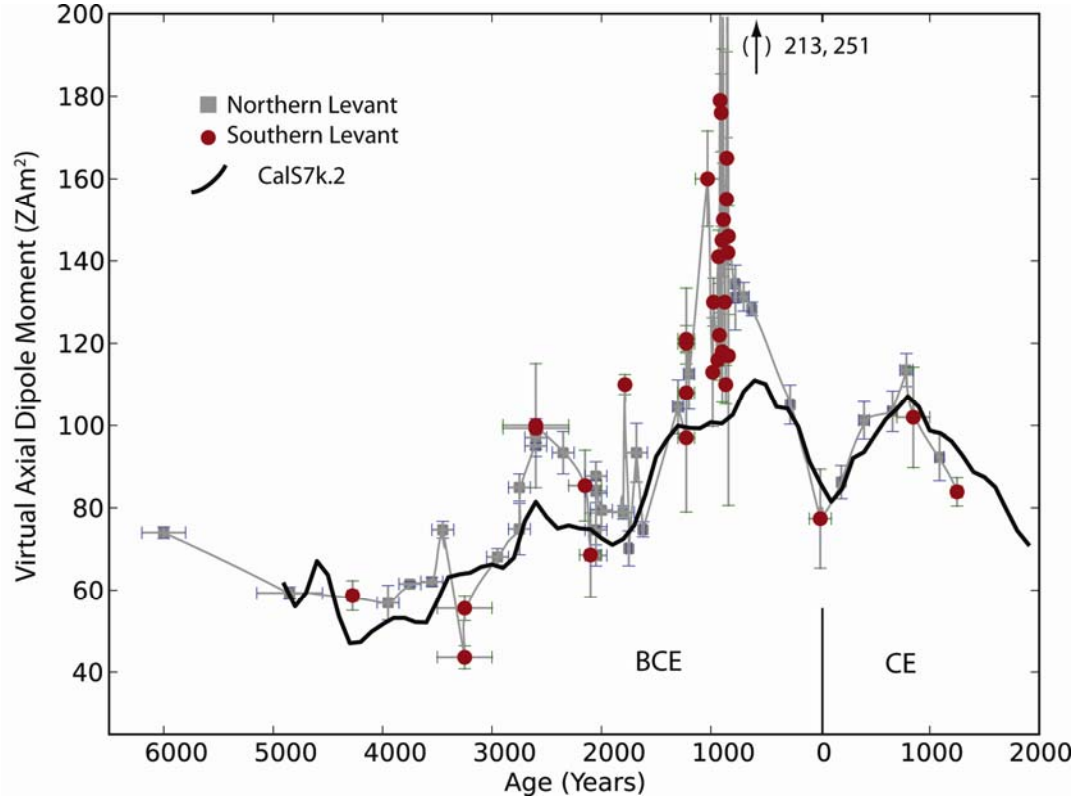


Fig.4.2: The geomagnetic intensity variations for the Levant, compiled by Ben-Yosef et al. (2009c). Data from the Northern Levant (Syrian data of Genevey et al., 2003 and Gallet et al., 2006) and from the southern Levant (Israeli and Jordanian data of Ben-Yosef et al., 2008a; Ben-Yosef et al., 2009c) are shown as squares and circles respectively. The reference curve (thin black line) is from the CalS7k.2 model of Korte and Constable (2005); figure modified from Ben-Yosef et al. (2009c).

The most common experiments for retrieving intensity values from a sample that recorded geomagnetic properties while cooling are based on some variant of the Thellier-Thellier method (Thellier and Thellier, 1959). The basic physical theory behind this method is that the magnetic intensity of the sample (natural remanent magnetization, NRM) is, in low fields like the Earth's, approximately linearly proportional to the ambient field at the time of cooling. Thus, by applying a known field on a re-heated sample in the laboratory and measuring the artificially acquired

intensity (thermal remanent magnetization, TRM), the constant of proportionality can be estimated and calculation of the ancient field is feasible. However, the original magnetic component of a sample may be complex (e.g., if the sample was later partially re-heated) and/or the mineralogy and texture of a sample may alter during the heating process, resulting in an unreliable proportionality constant. In order to assess the quality of the results, the experiment is divided into separate steps of gradually heating the sample in an oven with a controlled magnetic field, usually alternating between "in-field" and "zero-field" steps and repetition of selected temperature steps for checking constancy in the quality of magnetic recording. The experiments usually require several weeks, although many samples can be processed together (depending on the capacity of the oven). The data accumulated during the experiments are usually represented graphically as an "Arai plots" and "vector end-point diagrams" (see e.g., Figs.6.30 and 6.31), as well as quantitively by a suite of variables that characterize different aspects of the sample behavior (see Ben-Yosef et al., 2008a for a more complete description). Both kinds of data representation are used for quality control, and are the basis for accepting or rejecting results. A complete survey of the Thellier-Thellier derived experimental protocols can be found in Tauxe (Tauxe, 2010, Chapter 10).

The recorded properties of the geomagnetic field are directly dependent on the geographic latitude. Thus, for comparison of data from different locations, the laboratory result of magnetic intensity (in units of microtesla) is represented as a

Virtual Axial Dipole Moment (VADM) that simulate the same dipolar source of the field (Tauxe, 2010, Chapter 10). The small scale variations of the geomagnetic field (called "secular variations") are commonly taken to be more or less consistent over an area of up to 1000 km in extent, as they mostly represent non-dipole components (Valet, 2003). However, global models based on data collected world wide are still in use (e.g., Korte and Constable, 2005), although should be treated cautiously both for the robustness of the input data and for probable regional variations.

The archaeointensity results from the southern Levant (Ben-Yosef et al., 2008a; Ben-Yosef et al., 2008b; Ben-Yosef et al., 2009c; Ben-Yosef et al., 2010c; Shaar et al., in press) are used in the current research for dating several sites that earlier researchers identified with a 'primitive' technology in the southern Arabah Valley linked to the Pottery Neolithic to Early Bronze Age and we are able to re-date here to the Iron Age. In addition, we produced a high resolution archaeointensity curve for the early Iron Age ($11^{th} – 9^{th}$ centuries BCE), based on the high resolution sections of slag mounds in Khirbat en-Nahas and Timna Site 30 (Fig.4.3). This curve for the Iron Age represents a unique feature of the geomagnetic field of unprecedented high values of intensity. We used the rapidly fluctuating field of this specific period as a tool to correlate between excavated contexts (strata, and sites, see section 5.2.5.4 on Khirbat al-Jariya below). This curve can be used in future research as a dating reference for further refining the chronologies of biblical sites in the southern Levant (Shaar et al., in press).

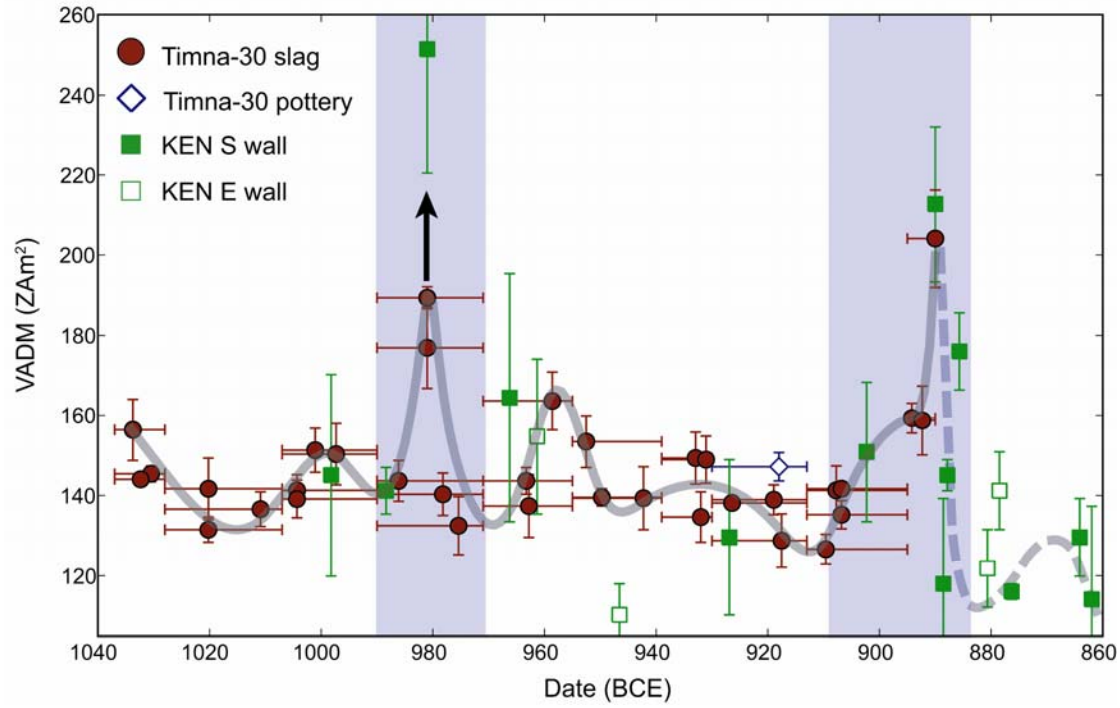


Fig.4.3: High resolution archaeointensity curve for 180 years in the Iron Age (I-II) in the southern Levant. The curve is based on samples from Site Timna 30 and Khirbat en-Nahas (KEN). Vertical error-bars represent standard deviation of sample means. Horizontal error-bars in Timna-30 represent the layer boundaries. The solid curve is constructed by a weighted cubic spline interpolation of the Timna-30 data points. The dashed curve is an interpretation of field behavior after the 9th century spike. Pale blue areas show the two geomagnetic spikes. Arrow marks a high spike value in KEN not captured in Timna. From Shaar et al. (Shaar et al., in press); see there for details about construction the curve and age determinations, and also under Timna Site 30 (section 6.2.1.5) below.

In some cases, archaeointensity research is applicable as a dating tool for archaeological (and archaeometallurgical) samples from the Levant, independent of their context or typological considerations. This is an advantage when the stratigraphic situation is not clear (such as in Site F2 where the total sedimentation is merely ca. 18 cm deep, Merkel and Rothenberg, 1999:Fig.7) and the material culture typologies (metallurgical or ceramic) are problematic or contested. Other methods for independent dating do exist, such as rehydroxilation of fired-clay (Wilson et al., 2009)

and thermoluminescence (Aitken, 1985; and see Lorenz, 1988 for TL dating of slag from Faynan), each with its own limitations and capabilities. Archaeointensity dating requires a relatively small sample size and in cases, like the one at Site F2, it is plausible to pinpoint a very narrow age range. The archaeointensity dating method also has the advantage of identifying post deposition re-heating (e.g., by a later campfire on the same spot), a potential complication in dating techniques that are based on exposure to heat (see Tauxe, 2010, chapter 10 and Fig.4 for details). As mentioned above, retrieving reliable ancient geomagnetic values is plausible for various types of archaeological materials, including ceramic, fired clay bricks, metal and glass slag and kiln walls and linings, although with different success rates. Ben-Yosef et al. (2008a) demonstrated the advantages of slag and other pyrotechnological ceramics (crucibles, furnace walls, tuyères, etc.) in archaeointensity research, including relatively high success rates and fewer contextual problems (like heirlooms or long usage span for ceramics). Recently, this was further corroborated by a through study of the magnetic properties of slag and the mechanism of TRM acquisition in such material (Shaar et al., 2010).

The accuracy and resolution of archaeointensity dating depend directly on the resolution and accuracy of the reference curve. Even when using only data obtained by rigorous experimental methods and strict selection criteria, the resolution of the Levantine curve is still low (Ben-Yosef et al., 2010c; Shaar and Ben-Yosef, in press). Nevertheless, more high quality archaeointensity data from well-dated sites in the

Levant are published frequently and improve the quality of the curve as a dating reference. The highly fluctuating intensity of the geomagnetic field presents difficulty even when a high resolution curve is available, as in some cases the extracted value can match more than one point of the reference. With the current state of the Levantine dataset it is easier to exclude dates than to assign exclusive ages to a sample (as in the case of Site F2, in which Neolithic to Early Bronze ages were excluded; the suggested 13^{th} -11^{th} centuries BCE date is based on supporting evidence). However, archaeomagnetic dating for the Holocene has further potential for precision when combining the directional components (declination/inclination) with the intensity (see for example Jordanova et al., 2004). This is feasible only with oriented samples, from regions where full vector curves are established.

The characteristics of the geomagnetic field dictate that the secular variation curves show consistency over an area of approximately 1000 km in extent, thus the applicability of the Levantine curve is spatially limited. High resolution archaeointensity data are available for Europe, North America and Central Asia (see e.g., Korhonen et al., 2008), but are scarce in other parts of the world, most notably India and Australia, from which there are virtually none. Establishing high resolution archaeointensity curves using samples from well-dated sites will not only benefit the archaeological research in the future, it is of great interest for geophysical research aiming at understanding Earth's magnetic field and related phenomena, one of the more enigmatic topics in geosciences.

The archaeointensity measurements for the various Levantine archaeomagnetic project mentioned above (of which some are part of the current research) were done at the Scripps Institution of Oceanography (SIO at UCSD) Paleomagnetic Laboratory by the present author and Jason Steindorf (directed by Lisa Tauxe), and at the Hebrew University of Jerusalem, Institute of Earth Sciences Paleomagnetic laboratory by Ron Shaar (directed by Hagai Ron). The present author took part in the interpretation of all measurements. All archaeointensity data produced so far by our group, as well as by many other studies (including directions and paleomagnetic data), are available online at the Magnetic Information Consortium (MagIC, http://earthref.org/MAGIC/).

4.2.3 *Optically Stimulated Luminescence*

Different archaeological phenomena require different dating methods. Accordingly, to date one of the Faynan pit mines discovered for this project and void of material culture, we applied Optically Stimulated Luminescence (OSL). This is another long practiced dating technique (Aitken, 1997, 1998) that was improved in recent years to provide higher resolution and more precise results (Porat et al., 2006; Wintle, 2008). The method is usually used for dating buried sediments (although it can be used to date burned artifacts as well such as pottery, flint and bricks). As part of the current research we have applied this method for dating pit mine fields discovered by us in 2007 that were suggested to represent intensive Iron Age mining activities (Jabal

al-Jariya Mine Fields, see Ben-Yosef et al., 2009b). Not only did the results have a relatively narrow error range and that they were in accordance with their stratigraphic context (see section 5.2.9.3 and 5.2.9.4 below), OSL seems to be the only dating method applicable to such significant archaeometallurgical features. The excavation of one of the pits yielded virtually no artifactual finds, including pottery or charcoals and a similar situation has been reported at Timna (e.g., Rothenberg, 2005). Our results encourage the application of OSL for dating other pit mine fields, including those of Timna (see discussion in Chapter 5 below).

The OSL measurements were done by Naomi Porat at the Luminescence Laboratory of the Geological Survey of Israel (GSI), Jerusalem. The present author collected the samples during ELRAP 2009 field season (November) and processed one sample in the IGS laboratory under the guidance of Porat (July 2010).

OSL dating is based on the measurements of energy released as luminescence from a sample of mineral grains when exposed to light (while in thermoluminescence the energy is released by heating). This energy is proportional to the time elapsed since the sample's last exposure to light (the age of the sample), and is the result of the release of entrapped electrons at defects in the crystal structure. The electrons were trapped as a result of exposure to ionizing radiation, and their release and recombination with the crystal structure is a process that emits energy in the form of light. Knowing the rate of environmental radiation (that the mineral grains were

exposed to) and the energy released as luminescence when the crystal are 'reset' (the electrons released from the traps), we can calculate the age of the sample.

$$\text{OSL age} = \frac{\text{Total energy accumulated during burial}}{\text{Energy delivered each year from radioactive decay}}$$

SI units for absorbed radiation is Gray (Gy) [Jkg^{-1}]; the total absorbed (radiation) dose of a sample, calculated from the luminescence of the sample in the laboratory, is called the *equivalent doze* (D_e); the amount of energy absorbed per year by the sample from the radiation in the environment surrounding it is the *dose rate*. Hence:

$$\text{OSL age (years)} = \frac{\text{Equivalent dose } (D_e) \text{ (Gy)}}{\text{Dose rate (Gy/year)}}$$

The dose rate can be evaluated by direct measurements of the amount of radioactivity in the field, or by chemical analysis of the surrounding material and calculating the radiation from the concentration of radioactive isotopes in it (most important of which are the ^{238}U, ^{235}U, ^{232}Th and their daughters, and ^{40}K). For the current project we have used the multi-spectral ICP-MS (Inductively coupled plasma mass spectroscopy, see e.g., Newman, 1996; Olesik, 1996) at the GSI laboratory to measure the radioactive isotopes for calculating the dose rate. In addition to the radiation from the radioactive isotopes [alpha particles (α), beta particles (β), and gamma rays (γ)] the calculation includes cosmic radiation that depends on the sample depth and the history of the magnetic field intensity.

Minerals used for OSL dating should have electron traps that can be easily emptied by exposure to sun light and that are thermally stable to retain all the entrapped electrons over the lifetime of the sediment. Quartz is the most suitable material for OSL dating and the single aliquot regenerative dose (SAR) is now the most commonly used protocol (and the one used in the current research). The sampling and measuring procedures are summarized in Fig.4.4 (see caption for details), the principles of the SAR protocol and the laboratory procedure are summarized in Figs.4.5 and 4.6.

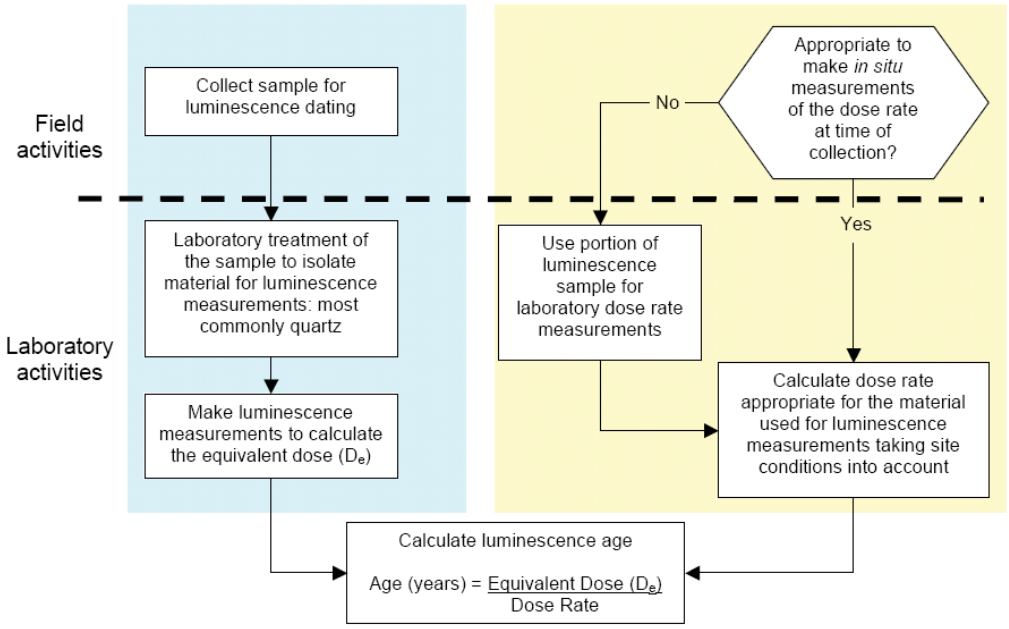


Fig.4.4: Flow chart showing the procedure for measuring the equivalent dose (D_e) (in blue, in the current research we used the SAR protocol in the laboratory) and the dose rate (in yellow, in the current research we used ICP-MS analysis to measure the radioactive isotope concentration in the sample) (from Duller, 2008:5).

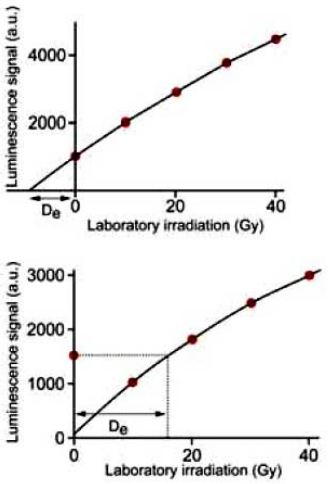


Fig.4.5: Two ways to calculate the equivalent dose (D_e): 'additive doze' (upper curve), giving laboratory dose on top of the signal acquired during burial (dote on y axis); the luminescence signal increases and mathematical function can be applied to estimate the radiation dose the sample acquired during burial prior to laboratory dosing. 'Regeneration' (below): measuring the intensity of the luminescence signal from the natural radiation dose (by exposure to light or heat); the D_e is then estimated by finding the laboratory radiation dose that gives the same luminescence signal as that found in the sample (after Duller, 2008:9).

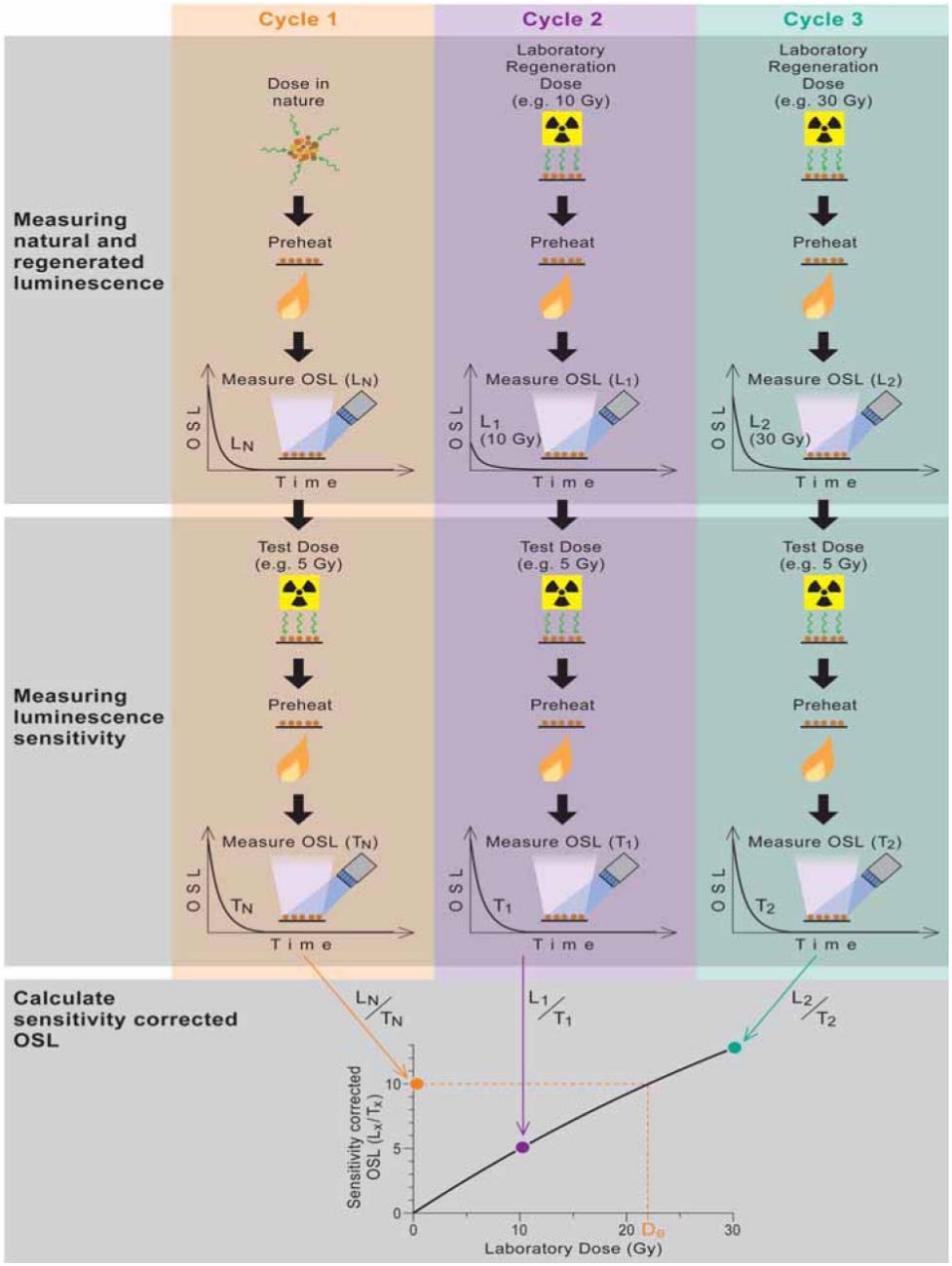


Fig.4.6: The SAR (single aliquot regenerative dose) protocol, used in the current research, as applied to quartz grains (after Duller, 2008:10). Characterizing the growth of luminescence signal is done by applying a number of laboratory doses (10Gy, 30Gy, etc.); after each step the luminescence sensitivity is measured by giving a fixed dose (5Gy in this example) and measuring the resulting signal (T1, T2, etc.). Changes in sensitivity can be corrected by taking the ratio of the luminescence signal (Lx) to the response to fix dose (Tx); the plot of the sensitivity-corrected OSL (Lx/Tx) as a function of the laboratory dose is used to calculate the equivalent dose (22 Gy in the example above) for that aliquot when the ratio of the initial measurements on the natural sample (L_N/T_N) is projected onto the dose response curve.

The quartz grains (in the range of 75/88-125 μm in diameter) from the sediment samples studied in the current research were separated at the GSI laboratory by wet sieving; carbonates were dissolved by hydrochloric acid (10 %) and heavy minerals removed by magnetic separation. Further etching was carried out by hydrofluoric acid (40%), to remove feldspars and the outer rim of the quartz grains. The purified quartz was mounted on discs for the luminescence measurements (using the SAR protocol). From each samples we measured 18– 24 specimens, for statistical evaluation of the results. A portion of the sample was pulverized and prepared for the chemical analysis for calculation of the dose rate. For further details on the sample collection in the field, the results and their evaluation, see section 5.2.9.3 and 5.2.9.4 below.

The OSL ages obtained in this study, ca 3000 years, are well below the limit of approximately 150,000 years for OSL dating caused by saturation of trapping electrons in crystal defects (see fig.4.5). We have shown the applicability of OSL in dating ca. 3000 years old pit mines in the southern Levant. This technique, as well as thermoluminescence (TL), can be used for dating archaeometallurgical artifacts themselves, and bear further potential (for the latter method, see e.g., Zacharias et al., 2006, for copper furnace walls; Hauptmann and Wagner, 2007a, for slag).

4.3 Summary

The major challenges for dating archaeometallurgical remains have been reviewed here with specific reference to the Arabah Valley study area. In this research, we have applied three fundamental dating tools: high precision radiocarbon dating, geomagnetic archaeointensity, and Optically Stimulated Luminescence (OSL) dating. The author played an active role in the original lab work and analyses of the archaeointensity and OSL samples. Together, for the first time, these three methods clarify the local (Faynan/Timna districts) and pan-regional Arabah Valley dating for the Iron Age. As will be shown in Chapters 9 and 10, the new chronometric data has important ramifications for understanding the social dynamics that underlie copper production during the late 2^{nd} – 1^{st} millennium BCE in the southern Levant.

PART II

ARCHAEOLOGICAL EVIDENCE OF IRON AGE COPPER EXPLOITATION IN SOUTHERN JORDAN AND ADJACENT AREAS

5. Iron Age copper production sites in Faynan, Jordan

5.1 General overview

To understand the dynamics of the changing role of Iron Age copper production in southern Jordan and adjacent areas it is essential to utilize the rich assemblage of archaeometallurgical research previously carried out in the southern Levant coupled with new large datasets produced for this thesis. The following chapter summarizes the data currently available for Iron Age copper production sites in the Faynan copper ore district, Jordan (Table 5.1, Fig.5.1, and Figs.5.2-5.11), with emphasis on sites investigated as part of the current research. Several sites dated to the Late Bronze Age are also included because of chronological uncertainties (e.g., Wadi Dana 1; see Chapter 4) and also as background to the metallurgical developments in the region during the Iron Age. In addition to evidence of mining and smelting, sites that are probably directly related to the copper production enterprise are also included, including Iron Age fortresses, cemeteries, campsites and road stations near the mining and smelting sites and along the local trade routes. This holistic regional approach to

south Levantine Iron Age copper production provides the foundation for developing anthropological models of technology and ancient society presented at the end of this study (Chapters 9 and 10).

Results of high resolution surveys in several areas in Faynan provide important data regarding Iron Age occupation and copper production activities. The definition of a site, the recording methods, the state of publication and details provided are different for each survey, thus comparison and general analyses should be made cautiously. For example, the recent publication of the German Mining Museum team provide details about different 'slag mounds' in the immediate vicinity of Khirbat Faynan (Fig.5.4). Although these mounds surround Khirbat Faynan and were all probably part of one extensive smelting site (now mostly covered by later remains of Roman and Byzantine age), they were given distinct site names (Faynan 3, 4, 5, 7, 14 and maybe 1, Table 5.1). On the other hand, the Iron Age mine clusters of Wadi Abiad (Fig.5.5), Wadi Khalid (Fig.5.6) and Wadi Dana (Fig.5.7) are described only in general, without specific details about each mine[31]. The area near Khirbat Faynan was intensively surveyed also as part of the Wadi Faynan Landscape Survey (WFLS), and as a result many of the sites were recorded twice and have different names (Figs.5.8 and 5.9). Also here, each 'slag mound' or small scatter of Iron Age remains was assigned a distinct site name. The WFLS sites are described only in general (Mattingly et al.,

[31] The German Mining Museum has an extensive collection of unpublished material from field work in the 1980s and early 1990s, some of it by the late mine archaeologist Gerd Weisgerber. The Museum is currently making an effort to publish the material about the ancient mines of Faynan (Hauptmann, Pers. Comm. 2010).

2007b), except for a few that were of more interest for the general landscape archaeology goals of that project (where ^{14}C dates or information regarding environmental impact were available). The surveys of the Edom Lowland Regional Archaeology Project (ELRAP) (Fig.5.10 and 5.11) have been partially published and include some brief descriptions of each site. Here we present more detailed descriptions of the Iron Age sites with emphasis on Iron Age copper production remains, and for the first time the Iron Age finds of the Wadi Fidan 2004 survey.

In the summary table (Table 5.1) the descriptions of the archaeological sites are presented with a focus on stratigraphy, chronology, function and primary architectural features based on previous research (and its methodology, e.g., survey vs. excavation, etc.). A comprehensive bibliographic reference list is provided and should be consulted for further details. The radiocarbon dates published thus far for the Late Bronze Age and Iron Age sites in Faynan are compiled in Table 5.2. These dates and their contexts provide foundations for the chronological framework of the Iron Age Faynan, partially replacing controversial relative dating based on material culture and in particular ceramic studies (see Chapter 4 for discussion). Nevertheless, when radiocarbon dates are not available, ceramic assemblages are still the most reliable data for dating. This relative dating method is common for sites recorded in archaeological surveys (indicated in Table 5.1) around the world. There are inherent dating difficulties (e.g., Banning, 2002) with survey data, and thus their assigned dates should be regarded as tentative. The ceramic assemblages of sites excavated or

surveyed as part of the current project are presented below (except for Khirbat en-Nahas, which is beyond the scope of this research[32]). Results of archaeomagnetic and OSL dating used in some cases to refine the dating resolution are also presented here.

[32] Recent in depth studies of Iron Age ceramics of Khrbat en-Nahas and northern Edom are presented in Smith (2009).

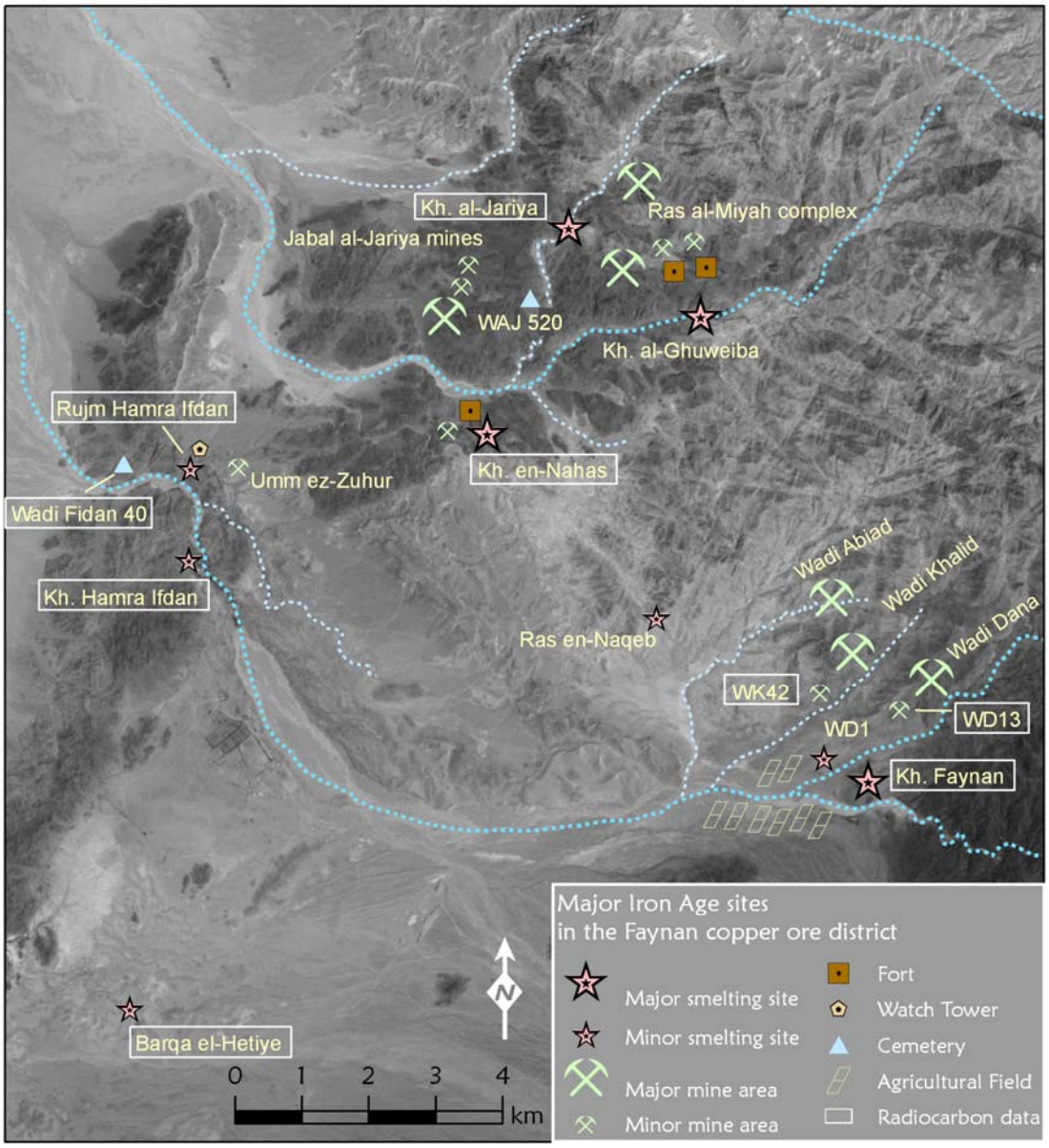


Fig.5.1: GIS map of the Main Iron Age sites in the Faynan copper ore district on a Spot satellite image. Small sites found in specific surveys appear in Figs.5.4 – 5.11 below. Cf. Table 5.1 for site descriptions and Table 5.2 for radiocarbon dates (sites marked with a white rectangle).

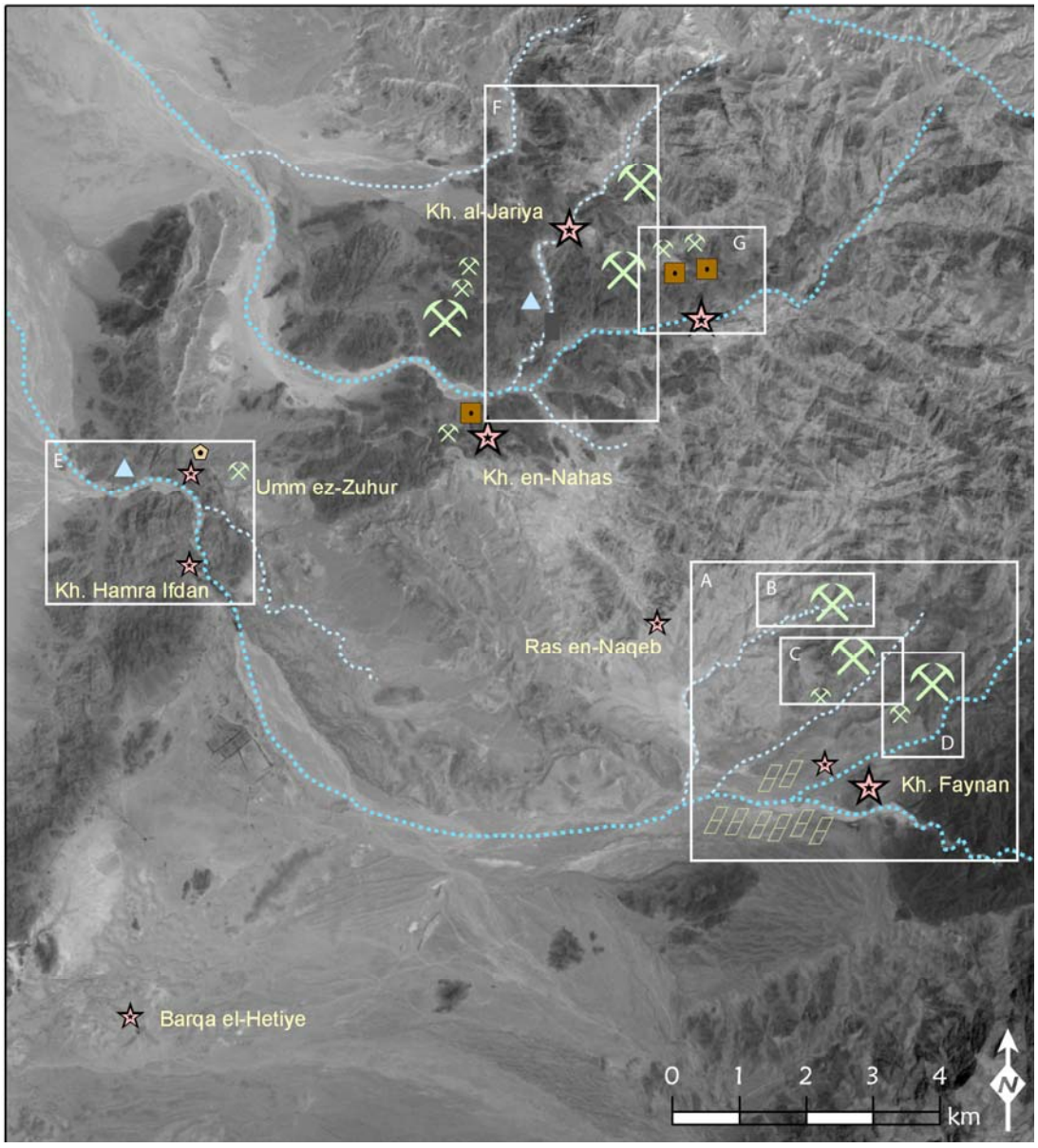


Fig.5.2: Faynan copper ore district, Spot satellite image. Main Iron Age sites (cf. Fig.5.1 for key) and location of detailed surveys with Iron Age finds: A) GMM (Figs.5.4) and WFLS (Figs.5.8-5.9); B) GMM mine survey in Wadi Abiad (Fig.5.5); C) GMM mine survey in Wadi Khalid (Fig.5.6); D) GMM mine survey in Wadi Dana (Fig.5.7); E) JHF Wadi Fidan 1998 and 2004 survey (Fig.5.10); F) JHF and ELRAP Wadi Ghuweiba-Wadi Jariya 2002 and 2007 surveys (Fig.5.11); G) Ras al Miyah Archaeological Complex, FBRS survey 2007 (Fig.5.75).

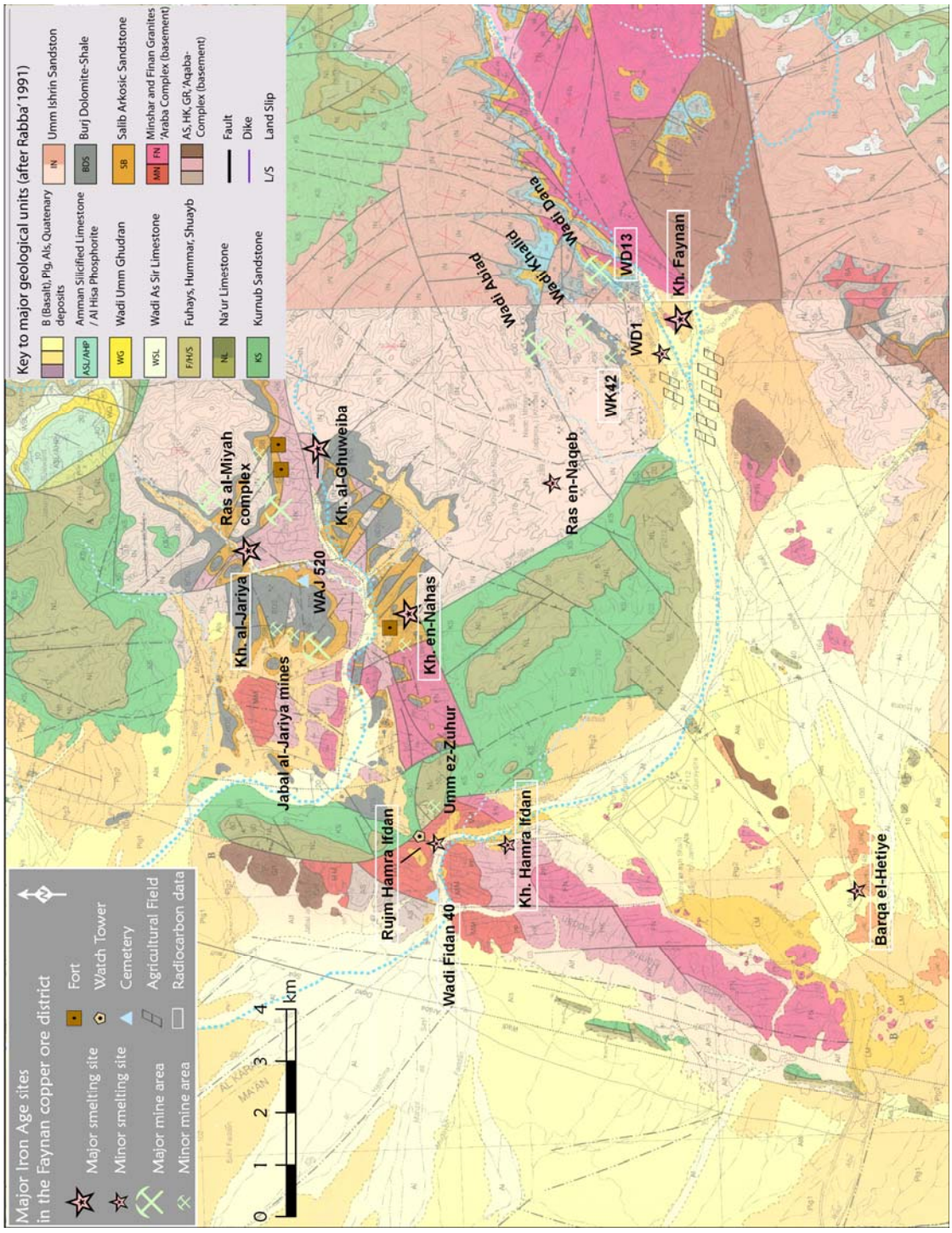


Fig.5.3: Main Iron Age sites in Faynan copper ore district depicted on local geological maps. GIS compilation of the al-Qurayqira sheet (left, Rabba', 1991) and ash-Shawbak (right, Barjous, 1988). Differences in coloration are on the original maps. Note the distribution of the Burj formation, the main copper ore body in Faynan.

Table 5.1: Summary of Late Bronze / Iron Age primary copper production archaeological sites in Faynan, Jordan; highlighted in blue are sites investigated as part of the current research and have more details presented below (section 5.2); also included are sites that are indirectly associated with the copper production enterprise

Site*	Description	References**
Khirbat Faynan WF1 30.626322N 35.493381E (central site) ☼	Khirbat Faynan is an extensive archaeological Tel with substantial remains of later periods (Roman-Byzantine, see in particular Mattingly et al., 2007a). In the immediate vicinity of the Tel and on the margins of the late occupation debris there are several slag heaps, numerous pottery scatters, agricultural fields and other features dated to the Iron Age (Figs.5.4, 5.7, 5.8). These Iron Age remains probably belong to one central production center that is mostly covered by the later remains. The GMM and the WFLS gave each individual 'slag mound' or other archaeological feature a distinct site name, and the recording of the two project is generally overlapping (WLFS recorded more sites, including non-metallurgical features). Only a few sites were published in some detail and those appear below.	(Hauptmann, 2007:94-110; Mattingly et al., 2007b) Related sites of the GMM and WFLS are not published yet.
Faynan 3 30.626322N 35.493381E ☼	Slag concentration visible underneath the Byzantine building at the southern slop of Khirbat Faynan; date based on pottery sherds and slag typology (Fig.5.4).	(Hauptmann, 2007:97)
Faynan 4 30.626322N 35.493381E ☼	Slag concentration visible underneath the Byzantine building at the southern slop of Khirbat Faynan; date based on pottery sherds and slag typology (Fig.5.4).	(Hauptmann, 2007:97; Al-Shorman, 2009:203-223)
Faynan 5 30.627053N 35.496558E 14C ☼	Smelting site, Iron II (probably also Iron I and possibly Persian) according to ceramic finds, slag typology and radiocarbon dates (Table 5.2, Fig.5.4). The site is located directly adjacent to and east of Khirbat Faynan. Hauptmann's estimation of surface slag, ca. 30,000 tons, makes Faynan 5 the second largest smelting site in the region (after Khirbat en-Nahas). It is probably part of an extensive copper production center (together with Faynan 3, 4 and 7) now mostly cover by archaeological deposits from later periods. Two types of slag were recorded, bubbled furnace slag with charcoal and ore inclusions and semi-circular tap slag up to 0.5 m in diameter and 57kg. Evidence of crushing (probably of both types) was found, probably done in order to obtain the remaining metal. Large number of tuyères fragments of two different sizes ('small' and 'large' were found, as well as clay pipes ('bellows tubes') (Hauptmann, 2007:Fig.5.10); they have been compared to finds from Timna and accordingly believed to represent different periods. This observation was confirmed and refined in the current research (see Chapter 7). The composite tuyères were studied also by Al-Shorman (2009:203-223). Several smelting installations were excavated in 1986 and 1988. One installation (locus 2) on the northern slope is dated to the early 8th century BCE and has a dome-shaped structure interpreted as the tap slag pit and a nearby pit interpreted as the bottom of the furnace itself. This installation is similar to the one reported from Timna Site 30 Stratum I locus 10 (see section 7.2.4.1 below). Another similar furnace installation was recorded in loci 1 and 4.	(Hart, 1992; Knauf, 1992; Hauptmann, 2007:97-103; Al-Shorman, 2009:203-223)

Table 5.1 continued

Site*	Description	References**
Faynan 7 Part of WF424 30.628694N 35.494478E ☼	A mound of approximately 5,000 tons of slag with similar metallurgical finds to those of Faynan 5 and Khirbat en-Nahas. Most of the slag is crushed to fine grain sand or gravel (Fig.5.4). Probably part of a larger copper production center around Khirbat Faynan.	(Hauptmann, 2007:103)
Faynan 14 Part of WF424 30.629447 35.497481 ☼	Heavily washed (alluviated) and disturbed slag field of ca. 100 x 15 m, between Faynan 7 and Wadi Dana (Fig.5.4). Ceramic finds and metallurgical typology indicate Iron Age activity. Probably part of the larger copper production center around Khirbat Faynan.	(Hauptmann, 2007:108)
Wadi Dana 1 30.631522N 35.4900E ☼	Smelting site in the 'Northwest cemetery' of Khirbat Faynan (Fig.5.4). Slag scatter and several slag heaps are located roughly 150-200 m from Faynan 7. Hauptmann (2007:122) states: "Thin plate slag found here had not been detected on any other find spot in Faynan. Similarly conspicuous are the tuyères which are also found here. With their interior width of ca. 1-1.5 cm, they are much smaller than their Iron Age counterparts. The impressions of reed on the tuyères' exterior are also very noticeable. They are identical to the type of 'small tuyères' from Timna Site 30 Stratum 2, dated back to the Late Bronze Age. The tuyères seem to be contemporaneous there with the mining activities, demonstrated for mine [Wadi Khalid] no. 42 in the LBA." New stratified data from KEN and KAJ show that this type of tuyères have also been in use during the early Iron Age, 12th – late 10th century BCE (Chapter 7).	(Hauptmann, 2007:122)
Wadi Faynan 30.625N 35.471E (central site) #	Extensive field terraces along Wadi Faynan include numerous scatters of Iron Age pottery sherds (Figs.5.8, 5.9). Although it is difficult to date the terraces and fields (Early Bronze Age and later finds are also present), they may represent Iron Age agricultural activity in the valley.	(Mattingly et al., 2007b)
Wadi Abiad 30.654N 35.494E (central site) □	Mining District. Fourteen blackish waste dumps on the valley bottom were recorded (Fig.5.5). They represents shafts dug into the lower Umm Ishrin formation to reach the ore bearing DLS formation below (this formation is not exposed here and it is located in an unknown depth). All of the mining waste dumps were dated to the "Iron Age II" by pottery finds.	(Hauptmann, 2007:115-116)

Table 5.1 continued

Site*	Description	References**
Wadi Khalid 30.645N 35.498E (central site) 	Mining District. Fifty six mines along the Wadi were recorded and studied (as a 'model area') by the GMM (Fig.5.6). Mines 42 and 7 were excavated (mostly Early Bronze activities). The target ore was the DLS, and in the Iron Age the shafts were dug from the lower parts of the Umm Ishrin formation to exploit the deeper occurrences of the ore. The visible outcrops of the DLS were exploited in earlier periods. The Iron Age shafts are usually double, one being sunk for climbing and the other for raising the ore. One of the deepest shafts is located on the upper part of the Wadi and is estimated to be 50-60m in depts.	(Hauptmann et al., 1985; Weisgerber, 1989; Hauptmann, 2007:116-121)
Wadi Khalid 42 30.639637N 35.490935E 14C	Excavated by the GMM in 1990 and 1993 (directed by A. Hauptmann). This mine represents mostly Early Bronze Age activity (according to pottery finds and contemporary smelting sites in Wadi Khalid). However, ^{14}C measurements of juniper wood spills (used for light) from the backfill of the mine yielded Late Bronze Age date (Table 5.2), and together with Middle Bronze sherds found in nearby mines (in particular in mines 11 and 18) the mine represent a continuous activity throughout the Bronze Age.	(Engel, 1992; Hauptmann, 2007:116-120)
WF 1422 Wadi Khalid 1 30.642916N 35.492923E 	Iron Age double mining shafts (one for climbing, the other for raising ore) and a Roman prospection shaft in the lower Umm Ishrin formation in Wadi Khalid. The Iron Age shafts are typical to Faynan and were dated by pottery. The Roman shaft was dated by pottery and coins (Vespasianic minting, 69-79 CE).	(Hauptmann et al., 1991; Hauptmann, 2007:121; Mattingly et al., 2007b:280)
Wadi Dana 30.644N 35.506E (central site) 	Mining District. Fourteen mines were recorded along the slopes of the mountain north of Wadi Dana (Fig.5.7). Pottery finds indicate Early Bronze Age and Iron Age mining, probably similar to the mining area of Wadi Khalid. This area was not studied in details by the GMM. It was recorded by the WFLS as well, but the data are not published.	(Hauptmann, 2007:122)
Wadi Dana 13 30.641904N 35.505281E 14C	A piece of wood from the tailing dump of the mine was radiocarbon dated to the end of the Late Bronze Age – Iron Age I (see Table 5.2).	(Hauptmann, 2007:89)
WF1431 30.649299N 35.530466E □	Small settlement in lower Wadi Dana, a building with enclosure (dated by ceramic finds).	(Mattingly et al., 2007b:282)

Table 5.1 continued

Site*	Description	References**
Ras en-Naqb 30.651944N 35.463333E ☼	The site located on a hill top, near the mountain pass of the main road connecting Khirbat Faynan and Khirbat en-Nahas. The 'slag mound' is dated by radiocarbon to the Early Bronze Age; thermoluminescense dating gave upper age constraint of 1740 years. No pottery was found with the main slag scatter. A heap of slag piled up by a bulldozer represents some 100 tons and can be dated to the Iron Age II by pottery and exterior typology of the slag. This was interpreted as a product of reprocessing and remelting of the Early Bronze Age slag in order to extract the remaining metal inclusions. Rectangular structures nearby may also be Iron Age. Hundreds of cup marks in the bedrock may represent the Iron Age slag crushing activity (although it may also be the result of slag processing in the Early Bronze Age).	(Hauptmann, 2007:123-127)

Table 5.1 continued

Site*	Description	References**
Khirbat en-Nahas (KEN) 30.679626N 35.436231E 14C ☼■	Khirbat en-Nahas (KEN) is the one of the largest smelting centers in the Levant (comparable to Khirbat Faynan and Bir Nasib). The site consists of dozens of 'slag mounds' with estimated tonnage of some 50,000 – 60,000 tons (Hauptmann, 2007:127), ca. 1000 of which are layers of fine crushes slag located in distinct areas on the slopes surrounding the site. The site is located ca. 6 km north of Faynan (Fig.5.1). The site is the centerpiece of the ELRAP and has been investigated by various teams, (Chapter 3). Extensive suite of radiocarbon dates, partially published (new dates will be published in the edited volume of Levy, Najjar and Ben-Yosef, *New Insights into the Iron Age Archaeology of Edom*), provides a solid and refined chronological framework for the Iron Age copper production activities in KEN, starting in the Late Bronze Age (13th century BCE) and ending quite abruptly at the end of the 9th century BCE. The site was first excavated in 1990 by V. Fritz who dated an elongated structure to the 9th century BCE; his report of later Assyrian pottery was not confirmed in later research. Intensive excavations took place in seven areas at the site as part of JHF and ELRAP in 2002, 2006 and 2009. The archaeometallurgical finds from Area M, a deep sounding into a 'slag mound' excavated in 2002 and 2006, provide the main reference for analyses in the current research (together with KAJ Area A, see Chapters 7 and 8). The ELRAP project at KEN recorded over 100 building complexes, including the 73x73m fortress in the north part of the site near Wadi al-Ghuweiba. The stratigraphic analysis and dating suggest a major rearrangement of the site at the end of the 10th beginning of the 9th centuries BCE, with decommissioning of the fortress' gatehouse (and construction of a metal workshop instead, Area A), leveling extensive areas of 'slag mounds' and construction of new building complexes. The current research suggests a major technological development associated with this rearrangement. The following areas were excavated as part of ELRAP: Area A = the fortress gatehouse (2002, 2006); Area F = metallurgical workshop at the fortress courtyard (2006); Area T = A massive building complex (2006); Area S = building complex (2002); Area R = A massive building complex and (associated?) metallurgical area (2006, 2009); Area M = 'Slag mound' and associated building (2002, 2006); Area W = building complexes (2009).	(Musil, 1908; Frank, 1934b; Glueck, 1935, 1940c:57-61; Kind, 1965; Bachmann and Hauptmann, 1984; Hauptmann et al., 1985; Knauf and Lenzen, 1987; Hauptmann et al., 1989; MacDonald, 1992b; Steinhof, 1994; Fritz, 1996; Levy et al., 2001b; Levy et al., 2004c; Finkelstein, 2005b; Higham et al., 2005; Levy and Najjar, 2006a; Hauptmann, 2007:127-130; Finkelstein and Piasetzky, 2008; Levy et al., 2008a; Smith and Levy, 2008; Al-Shorman, 2009; Ben-Yosef et al., 2009c; Finkelstein and Singer-Avitz, 2009; Levy, in prep.; Levy et al., in press-b; Levy et al., in press-d; Levy et al., in press-c; Smith and Levy, in press; Smith et al., in press-b)

Table 5.1 continued

Site*	Description	References**
Khirbat al-Jariya (KAJ) 30.70573N 35.452106E 14C ☼	An extensive Iron Age smelting site on both sides of Wadi al-Jariya (Kind's Wadi Se les-Sasar?), first reported by Kitchener 1883 expedition to the Arabah. The site has remains of ca. 15,000-20,000 tons of slag (with 100 tons of crushed slag concentrated in the southern part of the site) (Hauptmann, 2007:131). The investigation of the GMM suggested early Iron Age / Late Bronze Age beginning of copper production at the site (radiocarbon dates and tuyères typology). The site was excavated as part of ELRAP 2006 field season (Area A), and a new set of AMS radiocarbon dates indicates that the site was occupied from the late 12th century to the 10th century BCE; the site was abandoned sometime during the second half of the 10th century BCE, probably corresponding the major disruption and rearrangement reported at Khirbat en-Nahas.	(Kitchener, 1884:214; Glueck, 1935, 1940c:61-63; Kind, 1965; Hauptmann, 2007:131-132; Ben-Yosef et al., 2010a)
Wadi al-Jariya 30.710N 35.456E (central site) □ ▫	The areas of Wadi al-Jariya and parts of Wadi al-Ghuweiba were surveyed by our team in 2002 (JHF, Levy et al. 2003) and 2007 (ELRAP, Knabb et al. in press.). In addition to various Iron Age campsites and small cemeteries, we recorded a concentration of mines along wadi al-Jariya and its tributaries (Fig.5.11) (in 2002 with the help of the German Mining Museum team). About 50 mines have been recorded. In at least 26 mines some indicative Iron Age sherds have been reported. All of the Iron Age mines are dug in the lower Umm Ishrin formation to get to the ore bearing horizon of the DLS, and in many of them there is additional evidence of earlier, Early Bronze Age exploitation, similar to the situation in Wadi Khalid documented by the GMM team.	(Levy et al., 2003; Hauptmann, 2007:132; Knabb et al., in press)
Ras al-Miyah Complex 30.703N 35.486E (central site) ☼ ■ □	A dense concentration of Iron Age sites in the upper Wadi Ghuweiba and the vicinity of the oasis of 'Ain al Ghuweiba. The complex includes two Iron Age fortresses, a large smelting site, mine complexes, a unique cultic site and various architectural features. The fortresses and mines were reported briefly by Hauptman (2007:132) and Weisgerber (2006); the eastern fortress was excavated as part of ELRAP 2006 field season and the entire area was systematically surveyed as part of FBRS (see Table 5.15). Khirbat al-Ghuweiba (KAG) was sampled as part of ELRAP 2009 field season. While KAG is dated (by pottery finds, radiocarbon samples are being processed) to the early Iron Age, the fortresses and mining complexes are dated (by abundant ceramic finds) to the late Iron Age, not earlier than the 8th century BCE. The late activities in the RAM complex have no other clear parallels in Faynan (or in Timna) and present some difficulty of interpretation as contemporary smelting site is yet to be securely identified.	(Weisgerber, 2006; Hauptmann, 2007:132-133; Ben-Yosef et al., 2009a; Ben-Yosef et al., in press)

Table 5.1 continued

Site*	Description	References**
Khirbat al-Ghuweiba (KAG) 30.693455N 35.47568E 14C (in prep.) ☼	The site includes an extensive scatter of small fragments of slag on both sides of Wadi al-Ghuweiba and around the spring of 'Ain al-Ghuweiba. It was survey by Glueck and the GMM who suggested an Iron Age date. In 2009, as part of ELRAP field season, we excavated a building and an adjacent slag layers; the building was dated to the Roman-Nabataean period (pottery, glass) and the copper production debris to the Iron Age I-IIA (pottery).	(Glueck, 1935:22-23, 1940c:61; Hauptmann, 2007:132)
Ras al-Miyah East (RAM) 30.703212N 35.486475E ■ □	A massive fortress built of sandstone blocks located near a mining complex on the cliffs above Wadi al-Ghuweiba. The fortress is dated by abundant pottery to the late Iron Age (7^{th} – 6^{th} centuries BCE). It is related to a nearby mining complex. The archaeological evidence shows that the construction of the building was stopped abruptly. In 2006 we conducted small probes in the entrance corridor and one of the casemates.	(Weisgerber, 2006:15; Hauptmann, 2007:132; Ben-Yosef et al., 2009a)
Ras al-Miyah West 30.701085N 35.471208E ■ □	A fortress comprised of A tower, adjacent rooms and a courtyard built of the local dolomite stones. The fortress is dated by abundant pottery to the late Iron Age (7^{th} – 6^{th} centuries BCE). It is related to a nearby mining complex.	(Weisgerber, 2006:15; Hauptmann, 2007:132; Ben-Yosef et al., 2009a)
Wadi Fidan 30.669N 38.389E (central site)	Wadi Fidan is the western gateway to the Faynan region. In addition to the excavated Iron Age sites (WF40, WF4, RHI, and KHI), several other Iron Age sites were recorded in surveys only. The Wadi, from the 'Ain Fidan oasis to the Arabah, was surveyed by JHF project in 1998 (Levy et al., 2001c) and 2004 (first published here). The detailed surveys around the Wadi Fidan gorge resulted in documenting several Iron Age sites, including cemeteries, campsites and a few small copper production sites that demonstrate small scale smelting probably with simpler technologies than those utilized at the major Iron Age sites in Faynan. A similar phenomenon was found in the current research in Timna Valley (Chapter 6).	(Levy et al., 2001c; Hauptmann, 2007:133)
WF 601 □ ☼ ?	This site is situated on a level ridge below a steep hill. 1 large circular structure containing 1 stone circle and 2 tumuli. F. 5506, 5507. 3 more stone circles, F. 5508-5510, south of the large circular structure. F. #5504 (general): piece of slag.	Unpublished 2004 JHF survey
WF 604 □	This site contains miscellaneous structures on a moderately sloping shelf of the Pleistocene terrace. One large wall and one small wall are the most conspicuous. The rest are cairns and small structures dotting the shelf. Mid-Paleolithic flints and Iron Age pottery were found.	Unpublished 2004 JHF survey

Table 5.1 continued

Site*	Description	References**
WF 613 □ ☼ ?	The site is just east of Site 616 and south of S. 612, adjacent to the slag mound Site 614. Only 3 stone circles, two of them robbed were found. Here, the slag thins out, but ceramics from Iron Age to modern Gaza Ware were found. Roman/Byzantine was dominant. (Site 614, the 'slag mound', had associated Roman Byzantine pottery; these however may be related to the structures.	Unpublished 2004 JHF survey
WF 615 □ ☼ ?	Bedouin camp clearance east and adjacent to S. 614, slag mound. Included is the west slope of Site 625. One 2-course wide, L-shaped wall line was found close to this slope. Very small amounts of Iron Age slag and Roman/Nabataean ceramics were found.	Unpublished 2004 JHF survey
WF 630 □	4 medium-size oval cairns (ranging 3-4m in length and 2m in width) are on top of a high mound between 2 gullies approx. 100m from the west edge of the Wadi Fidan. 4 pottery shards, 2 of which were rim shards: maybe Iron Age Negabite Ware.	Unpublished 2004 JHF survey
WF 631 ☼	Cairn field with slag concentration, surveyed in 2004. On a Pleistocene shelf south of KHI, west side of Wadi Fidan. Several cairns and stone circles, slag scatter, pottery and flint.	Unpublished 2004 JHF survey
Khirbat Hamra Ifdan (KHI) Wadi Fidan 120, Raikes' Site F, GMM Wadi Fidan 3, JD_9 30.661394N 35.392700E 14C ☼	The majority of the excavated finds from this site date to the Early Bronze Age (II-IV) and represent an extensive settlement specialized in copper production. However, a large 'slag mound', clearly visible on the surface of the eastern part of the site, was excavated by our team in 2007 and dated by archaeomagnetic investigation to the Iron Age, probably parallel to the main production period at KEN. The new archaeomagnetic dating has confirmed previous suggestions of Iron Age date for the 'slag mound' that were based on the typology of the slag alone. The JHF project's excavations of 2000 in Area L at KHI have yielded two unpublished radiocarbon dates, one is from the Abbasid period and the other indicates Iron Age I (12^{th} – 11^{th} centuries BCE) occupation of the site. This area is mostly associated with the massive square structure (probably a caravansari) at the eastern edge of the site, dated probably to the Roman-Byzantine period; the date came from a deeper context, Stratum IIIA, dated by pottery to the Early Bronze Age IV. However, Iron Age samples are probably related to the smelting remains evident on the surface and may indicate that the EB finds were dumped in this location during the Iron Age along with some Iron Age artifacts. No direct evidence of smelting was found in this stratum. The source of copper ore for this site was probably the small mine district of Umm adh-Dhuhur (ez-Zuhur) located ca. 1.5 km to the north-north east from KHI (the ore source for the EB smelting may have been the area of Madsus , see below).	(Raikes, 1980; Adams, 1992; Levy et al., 2002a; Hauptmann, 2007:134-136)

Table 5.1 continued

Site*	Description	References**
Wadi Fidan 40 Raikes' Site D, SGNAS Site 14, GMM Wadi Fidan 9 30.673926N 35.381107E 14C ▲	Wadi Fidan 40 is the largest Iron Age cemetery site in Edom and situated on a Pleistocene conglomerate terrace that forms a low plateau overlooking the Wadi Fidan where it debouches into the Wadi Arabah. The cemetery marks the western entrance or 'gateway' into the Faynan district. The site is large and extends over an area of ca. 3,450 square meters. JHF – ELRAP and a DoAJ emergency project made extensive excavations here. A total of 287 tombs and graves have been excavated to date. The exact number of graves present in the site is difficult to estimate but may range from as low as 1500 to over 3000. The typical tomb consisted primarily of sub-surface cists lined with sandstone or cobble slabs accompanied by a circular stone-lined installation on the surface. The absence of settlement sites in the vicinity of the vast mortuary complex, the style of graves and the character of their burial remains has led to the suggestion that the cemetery belonged to a nomadic community – perhaps the Shasu nomads known from sixteenth to tenth century BCE ancient Egyptian texts. High precision radiocarbon dating indicates that most of the tombs date to the tenth century BCE. Preliminary toxic metal studies of the human remains from this cemetery suggest that some members of this community were actively engaged in smelting activities during the Iron Age (Beherec, Erel and Levy in prep). To date, the Wadi Fidan 40 cemetery provides the best dataset for linking a local human population to the mining and metallurgy activities carried out in Faynan during the Iron Age. The nature of this nomadic population – production relationship is just beginning to be investigated.	(Raikes, 1980, 1985; Adams, 1991; Levy et al., 1999; Levy and Adams, 2001; Levy et al., 2004a; Levy and Najjar, 2005; Levy et al., 2005b; Levy and Najjar, 2006b; Levy, 2009b; Levy, 2009a; Beherec, in prep.)
Wadi Fidan 4 30.671285N 35.384405E ▲	Wadi Fidan 4 is the best preserved Early Bronze I (ca. 3600 – 3300 BCE) village and metal-working site in the Faynan region. It is located on the south bank of the Wadi Fidan opposite the extensive Wadi Fidan 40 cemetery site. Several tumuli are located on the northeast edge of the site. Salvage excavations in 2003 carried out by the UCSD-DOAJ revealed that the tumuli were in fact isolated Iron Age tombs, not related to the EBI site. The material is currently being prepared for publication. Tomb 1 (a large cairn on top of capstones of a cist grave) a total of eight individuals were found with Egyptian amulets and other objects. It is possible that Wadi Fidan 4 was used during phase of the Iron Age when the main cemetery located at WFD 40 was abandoned.	(Adams and Genz, 1995:8; Levy, 2006; Beherec, in prep.; Levy et al., in press-a)
Umm adh-Dhuhur (ez-Zuhur) 30.673789N 35.399239E (central site) □	A small mine district consisting of 24 tailings of the DLS formation is located in the area between Wadi al-Ghuweiba and Wadi Fidan. The mines were dated by the GMM team to the Iron Age II based on 'archaeological evidence' and probably were the source of ore to the Iron Age smelting sites in the nearby area of Wadi Fidan. The mines here were shafts dug into the whitish local gravel, aiming to penetrate the DLS formation below. Some of the galleries were cut by erosion and are exposed on the slopes (similar to the situation in Timna). Mining with shafts and galleries conform to the general pattern observed for Iron Age mining technology in the region of Faynan.	(Hauptmann, 2007:130-131)

Table 5.1 continued

Site*	Description	References**
Madsus 30.671509N 35.410828E □?	In a small valley near Jabal Madsus there are 20-30 refilled pits (‘*Tellerpingen*’), somewhat similar in dimensions and geological location to the newly discovered JAJ mines. An early date for these mines has been suggested based solely on some finds of grooved hammerstones that show similarity to artifacts from the Early Bronze I site of Wadi Fidan 4. Furthermore, a small installation located nearby was accordingly dated to the Chalcolithic and interpreted as a smelting furnace (with slagless technology, see Craddock, 1995:128). The proximity of the mines to Khirbat en-Nahas suggests that they may date to the Iron Age, similar to the JAJ mines.	(Craddock, 1995:128; Hauptmann, 2007:130-131; Ben-Yosef et al., in press)
Barqa el-Hetiye 30.600460N 35.380410E 14C □ ☼	The area of Barqa el-Hetiye was excavated by V. Fritz in 1990 and 1993. In addition to Early Bronze Age II house and smelting remains, a large Iron Age ‘four-room’ house was unearthed (BH2) with ceramic dated by Fritz to the Iron Age I. The ceramic analysis was criticized by Bienkowski (2001) and a radiocarbon date indicates a 9th century occupation of the site. Midianite pottery was uncovered in the house and some (limited) smelting remains scattered around the site (and mostly to the west of it) were also attributed to Iron Age activities in the area. The closest ore sources are north of Wadi Fidan (Umm adh-Dhuhur and Madsus), some 7 km to the north. The location of the site, relatively far from the mines, suggests it served mainly as a road station along a route leading from Faynan to the Gulf of Aqaba via the Arabah Valley. A small oasis is located nearby and is probably the reason for the location of this road station in the middle of the sand dunes area.	(Fritz, 1994a; Fritz, 1994b; Bienkowski, 2001; Fritz, 2002; Adams, 2003; Hauptmann, 2007:141-143)
Rujm Hmra Ifdan (RHI) (Glueck’s Khirbat Hamra Ifdan) 30.672203N 35.390267E 14C ⌂ ☼?	During his surveys in the Edom lowlands during the 1930s, Glueck identified some structural remains on a small inselberg on the north bank of Wadi Fidan as an Iron Age watchtower. There has been some confusion over the name of the site (Adams 1992). The site is located on the confluence of Wadi Fidan with the secondary drainage known as Umm edh-Dhuhur, In 2006 ELRAP’s field season, two 5 x 5 m sondages were made at the site: a) just below the summit of the inselberg where Glueck had identified the foundations of a small watchtower and b) in an area adjacent to a large wall enclosure at the base of the site. The ^{14}C results are especially important because it is the only site in the Edom lowlands where evidence of both Iron Age IIA tenth c. BCE and Iron Age IIC seventh-sixth c. BCE occupations have been documented (except probably from Khirbat Faynan itself). There was a rich ceramic assemblage representing these two phases at the site.	(Glueck, 1935, 1940c:56; Adams, 1992; Levy et al., 2008a; Smith et al., in prep; Smith and Levy, in press)

Table 5.1 continued

Site*	Description	References**
Jabal al-Jariya (JAJ) JAJ-1 (central) 30.695061N 35.429852E OSL □ □	Mining District. Three fields of pit mines (*placer*) located in the colluvium/alluvium deposits of the DLS formation north of Jabal al-Jariya. The mines were discovered in 2007 as part of the FBRS survey and excavated in 2009 as part of ELRAP field season. OSL dates support Iron Age mining activity, and the vast area was probably the main copper ore source for the nearby Khirbat en-Nahas. JAJ-1 is the main mine field, consisting of hundreds of pits easily visible on satellite images. A nearby structure complex may be related to the copper mining activities (FBRS Site 37, 30.695715N, 35.436720E). JAJ-2 (30.701655N, 35.432040E) and JAJ-3 (30.704487N, 35.434889) are much smaller fields, but with similar characteristics of JAJ-1. All three fields are associated with a young geological dike (north end: 30.705619N, 35.432410E; south end and volcanic plug: 30.693691N, 35.433778E).	(Ben-Yosef et al., 2009b)

* Bold names = excavated sites; ^{14}C = radiocarbon date available (cf. Table 5.2); site names starting with "Faynan" were recorded by the team of German Mining Museum (Andreas Hauptmann et al.), and in many publications appear in different spelling (*Fenan, Feinan*); site names starting with "WF" (Wadi Faynan) were recorded by the Wadi Faynan Landscape Survey (WFLS), and some overlap those of the GMM. Symbol key: ☼ smelting; □ mining; □ buildings/settlement; ■ fortress; ▲ cemetery; ⌂ watch tower; ● campsite; # fields; + cultic; ○ point finds.

** Hauptmann (2007) is an updated English version of Hauptmann (2000), thus the latter is not cited here.

Table 5.2: Compilation of radiocarbon dates from Late Bronze Age – Iron Age copper production and related sites in the Faynan Copper Ore District (Northern Wadi Arabah); highlighted in blue are sites investigated as part of the current with more details below (section 6.2); for broader time frame covering all periods of the history of metallurgy in the southern Levant see Avner (2002), Weisgerber (2006:27), Hunt et al. (2007a) and Hauptmann (2007)

Site	Lab #	Radiocarbon Age BP	Cal. Age – 68.2% prob. (BCE)*	Context	Reference
Wadi Khalid, Mine 42	HD1492	3197±39	1500-1432	Backfilling, 17m inside entrance	(Hauptmann, 2007:89)
Wadi Dana, Mine 13	HD10578	2949±63	1262-1056	Waste dump in front of entrance, -0.6m	"
Khirbat al-Jariya (KAJ)	HD16351	2915±30	1192-1048	KJ2-4	"
	HD10990	2886±56	1191-979	Slag heap, wadi edge -0.3m	"
	HD16530	2839±22	1026-936	Base of slag heap, -0.75m	"
	See Table 5.12				(Ben-Yosef et al. 2010)
Khirbat al-Ghuweiba	Radiocarbon dates from 2009 ELRAP field season are being processed at the Oxford laboratory; two preliminary results that are probably of old wood are (OxA-23159, 2919±29 BP, 1192-1051 68.2% probability, Locus 30, and OxA-23159, 3288±28 BP, 1608-1526 68.2%, Locus 23				
Khirbat en-Nahas (KEN) Basal Strata	OxA17646	2871±26	1112-1005	Stratum M4: basal Stratum of 'slag mound', domestic and industrial mix	(Levy et al., 2008a:16463, here indicated as an 'outlier')
	OxA19040	2942±27	1254-1117	Stratum M5a: charcoal (*Retama r.*) near installation l.676	(Ben-Yosef et al. 2010)
	OxA19041	3026±27	1373-1260	Stratum M5b: charcoal from sediment above virgin soil	(Ben-Yosef et al. 2010)
	OxA12169	2899±27	1126-1026	Stratum S4: basal Stratum below industrial structure, domestic and industrial mix	(Levy et al., 2005c:149, including important discussion on context)
KEN, fortress, excavations at Area A	GrA25334	2910±50	1193-1016	Stratum A2A, l.21	(Levy et al., 2005c:135)
	GrA25318	2920±35	1193-1051	Stratum A3, l.89	"
	GrA25354	2880±50	1151-977	Stratum A3, l.89	"
KEN 'slag mounds'	HD14308	2876±38	1122-1002	KN-Eisen-5, -1.15/-1.25m	(Hauptmann, 2007:89) after (Steinhof 1994)
	HD14057	2905±40	1189-1016	KN-2, -0.85/-0.9m	Engel 1993:209
	HD14302	2880±28	1114-1012	KN-Eisen-2, -0.17/-0.2m	(Hauptmann, 2007:89) after (Steinhof 1994)
	HD14336	2895±35	1127-1014	KN-3, -1.15/-1.3m	Engel 1993:209
	HD14113	2864±46	1116-976	KN-Eisen-6, -1.65/-1.8m	(Hauptmann, 2007:89) after (Steinhof 1994)
KEN 10th – 9th centuries BCE	See published dates in (Engel, 1993:209; Fritz, 1996:5; Higham et al., 2005; Levy et al., 2005c; Hauptmann, 2007:89; Levy et al., 2008a; Levy et al., in press-b. for new results of areas T, R, and F); cf. also Table 5.11 for Area M				

Table 5.2 continued

Site	Lab #	Radiocarbon Age BP	Cal. Age – 68.2% prob. (BCE)*	Context	Reference
Khirbat Hamra Ifdan	?	2910±41	1192-1021	WF120, Stratum IIIA, Area L (2000), L. 3034, B.45344, RC23	**This study** (unpublished date from the JHF 2000 field season)
Khirbat Faynan (smelting activities)	HD10581	2726±102	1000-801	Slag heap 5, l.3, storage jar	(Hauptmann, 2007:89)
	HD10992	2664±74	910-786	Slag heap 5, -0.3m	"
	HD10582	2647±47	889-789	Slag heap 5, l.2, furnace (Locus 2)	"
	HD10580	2380±45	516-396	Slag heap 5, l.2, furnace (Locus?)	"
	Beta203407	2900±40	1188-1012	WF455, slag heap 9 or 7 (inconsistency in publications)	(Hunt et al., 2007b:1334; Mattingly et al., 2007b:282)
	Beta203406	2890±40	1129-1005	"	"
	Beta203409	2830±40	1039-923	"	"
	Beta203408	2790±40	1001-901	"	"
	Beta201410	2790±40	1001-901	"	"
	Beta203411	2680±40	894-803	"	"
	Beta110840	2630±50	841-771	WF5017, Barrage section, -2.4m (bulk sediment)	(Hunt et al., 2007b:1334)
	Beta110841	2630±50	841-771	WF5017, Barrage section, -2.6m (bulk sediment)	"
Rujm Hamra Ifdan (watch tower, minor smelting in Sounding A)	OxA14849	2747±28	914-842	Sounding A (hill top), charred date	(Levy et al.2008:online supplementary material)
	OxA14850	2849±28	1050-941	"	"
	OxA14851	2537±27	791-595	Sounding B (hill bottom), charcoal (*Tamarix*)	"
	OxA14852	2473±28	752-524	"	"
	OxA14853	2495±28	761-546	"	"

Table 5.2 continued

Site	Lab #	Radiocarbon Age BP	Cal. Age – 68.2% prob. (BCE)*	Context	Reference
Wadi Fidan 40 Cemetery	Beta111366	2800±70	1041-846	Grave 92, pomegranate seed, l.531	Levy et al. 1999:303
	OxA14233	2839±28	1050-970	Grave 59, pomegranate seed	Levy et al. 2005:482
	OxA14234	2819±26	1005-925	Grave 59, pomegranate seed	Levy et al. 2005:482
	OxA14235	2795±30	980-905	Grave 59, pomegranate seed	Levy et al. 2005:482
	OxA14236	2859±26	1070-970	Grave 59, pomegranate seed	Levy et al. 2005:482
	OxA14237	2863±27	1090-970	Grave 59, pomegranate seed	Levy et al. 2005:482
	OxA14238	2779±31	980-890	Grave 59, pomegranate seed	Levy et al. 2005:482
	OxA14431	2758±35	970-840	Grave 59, pomegranate seed	Levy et al. 2005:482
	OxA-14239	2784 ± 28	980-895	Grave 701, pomegranate seed	Levy et al. 2005:482
Barqa al-Hetiye (habitation, smelting activities)	HD13977	2743±23	908-843	House BH2, l.108 (Ceramic: Iron Age I [Fritz 1994b], but see Bienkowski [2001])	(Levy et al., 1999:305); the date obtained by Fritz was not available in time of the original publication of the site (Fritz, 1994a)

* All dates are calibrated using OxCal v.4.1, © Ramsey 2009; l. =locus; elevation is in meters (m) below surface.

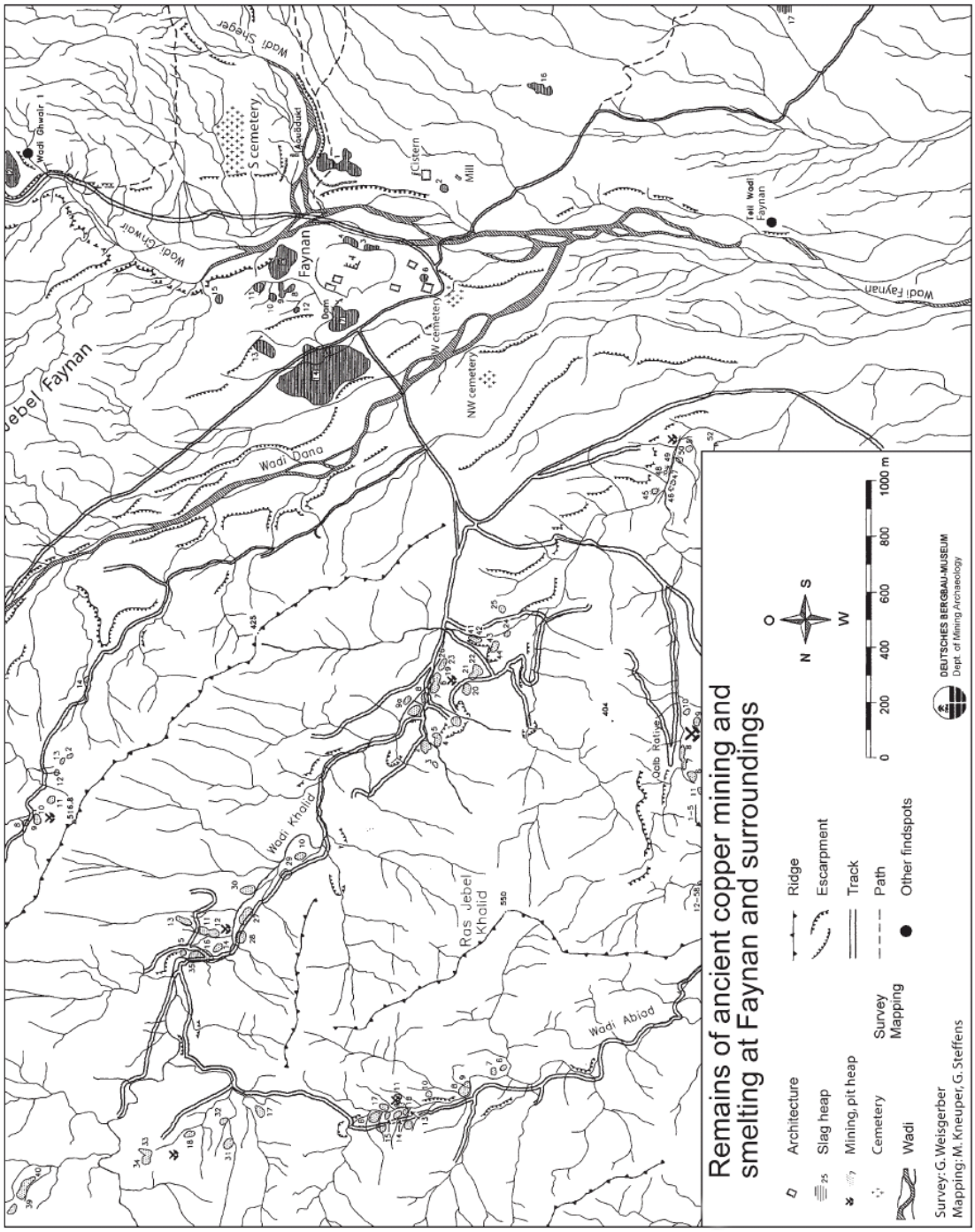


Fig.5.4a: Schematic map of sites recorded by the German Mining Museum in the vicinity of Khirbat Faynan (periods undifferentiated) (Hauptmann, 2007:93).

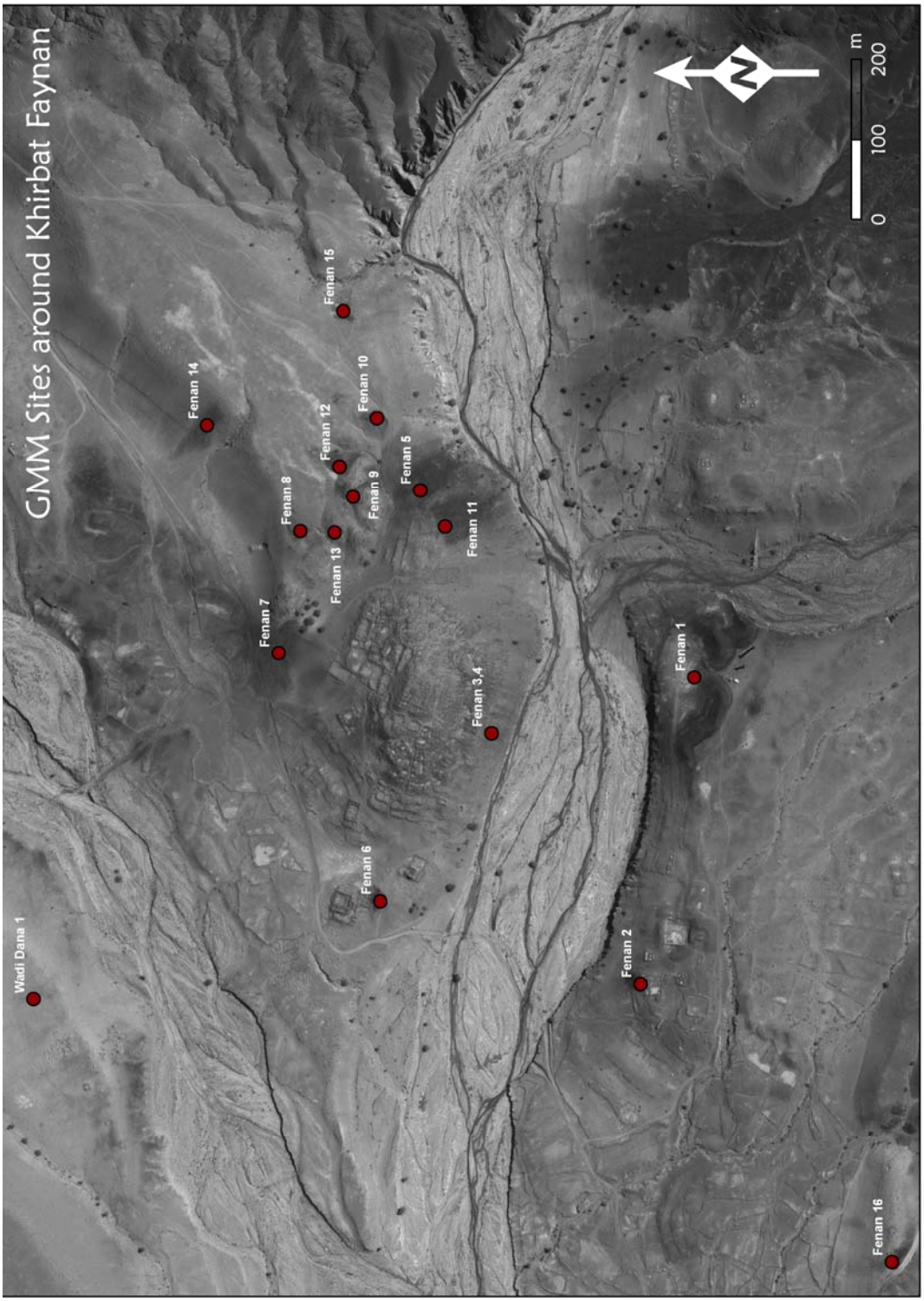


Fig.5.4b: Site recorded by the German Mining Museum near Khirbat Faynan on Ikonos Satellite image (data courtesy of A. Hauptmann and the German Mining Museum, Bochum). Wadi Dana 1. and Fenan 3,4,5,7 and 14 were dated to the Iron Age. Note the clearly visible Roman-Byzantine remains of Khirbat Faynan in the center, probably covering Iron Age remains of a large copper production center.

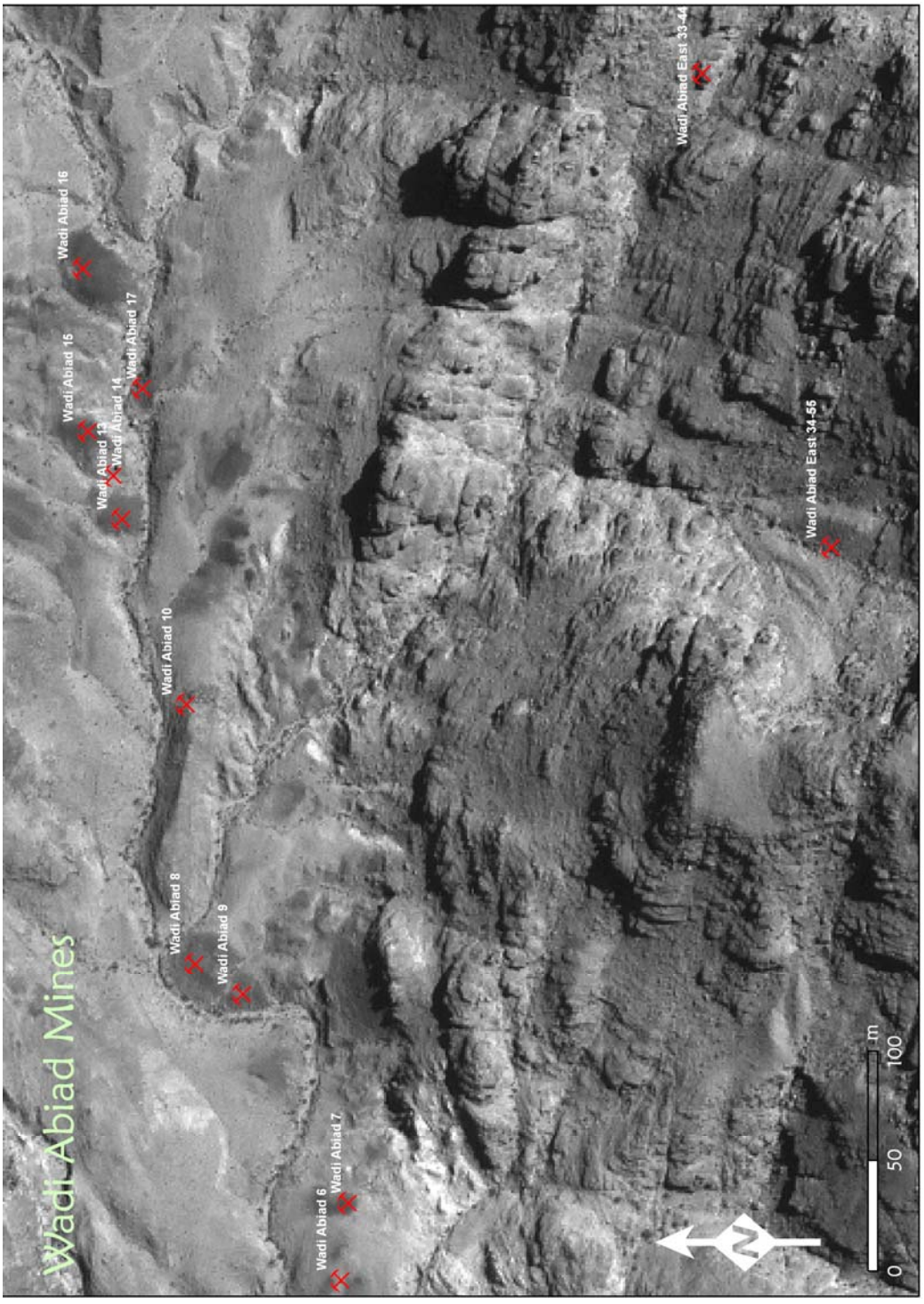


Fig.5.5: The mining district of Wadi Abiad (cf. Figs.5.1 and 5.4a) plotted on an Ikonos satellite image (data courtesy of A. Hauptmann and the German Mining Museum, Bochum). The dark sediments visible in the valley bottom are Iron Age tailings of DLS ore dressings; the ore was mined through shafts into the lower Umm Ishrin formation. The mines in the bottom left part of the image were dug into the MBS unit and are dated to the Chalcolithic and Roman period.

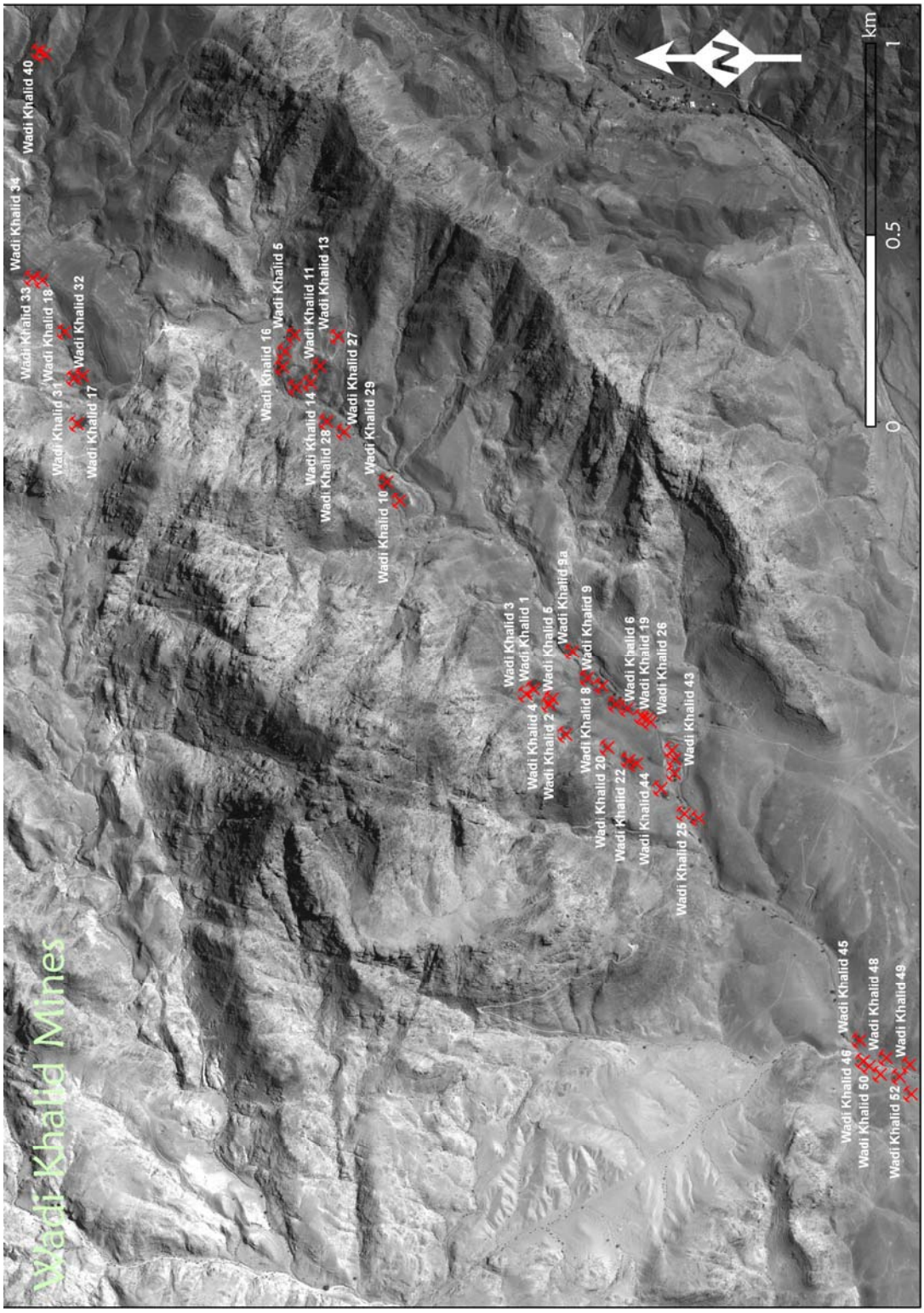


Fig.5.6: The mining district of Wadi Khalid (cf. Figs.5.1 and 5.4a) on an Ikonos satellite image (GIS data courtesy of A. Hauptmann and the German Mining Museum, Bochum).

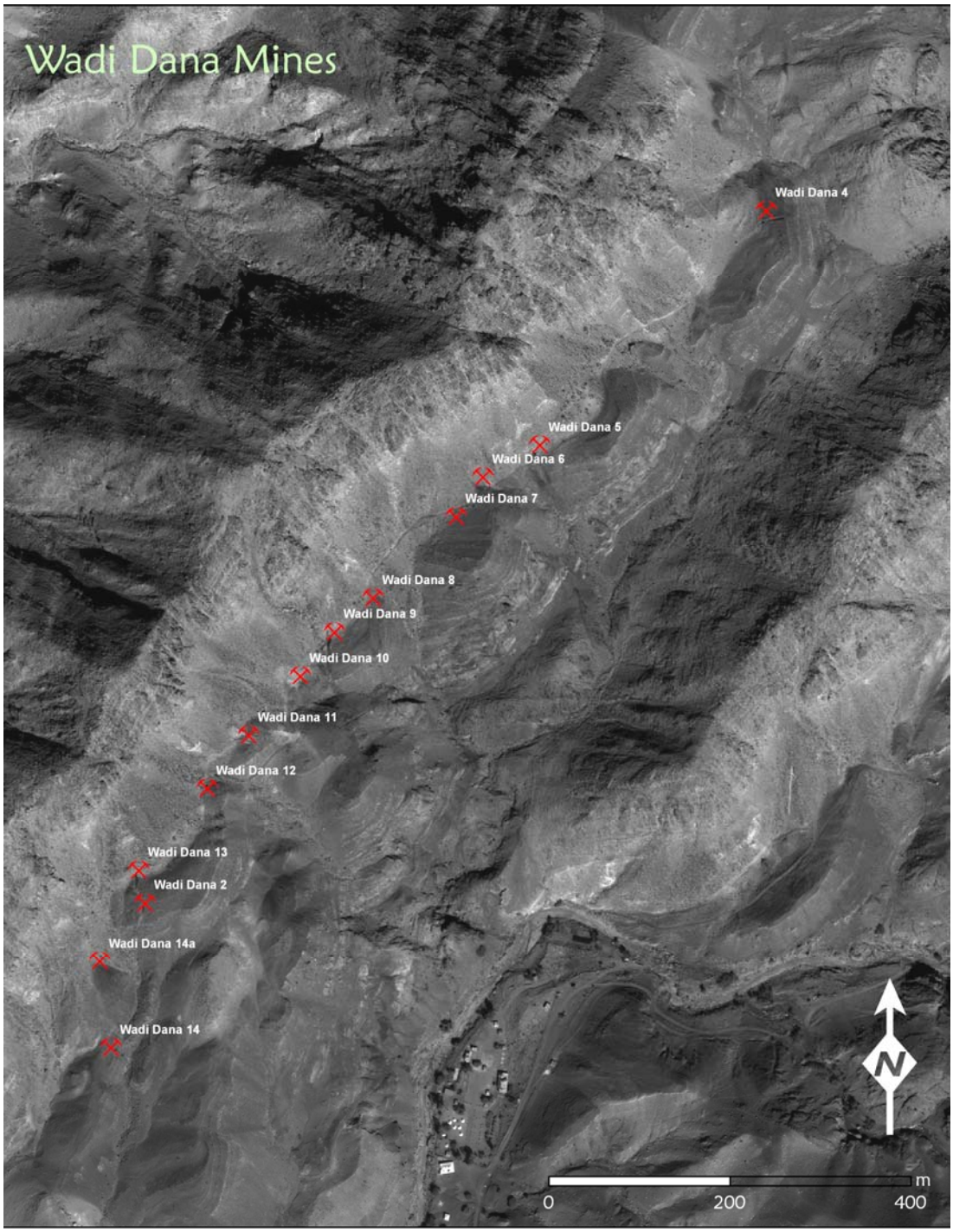


Fig.5.7: The mining district of Wadi Dana (cf. Figs.5.1 and 5.4a) on an Ikonos satellite image (GIS data courtesy of A. Hauptmann and the German Mining Museum, Bochum).

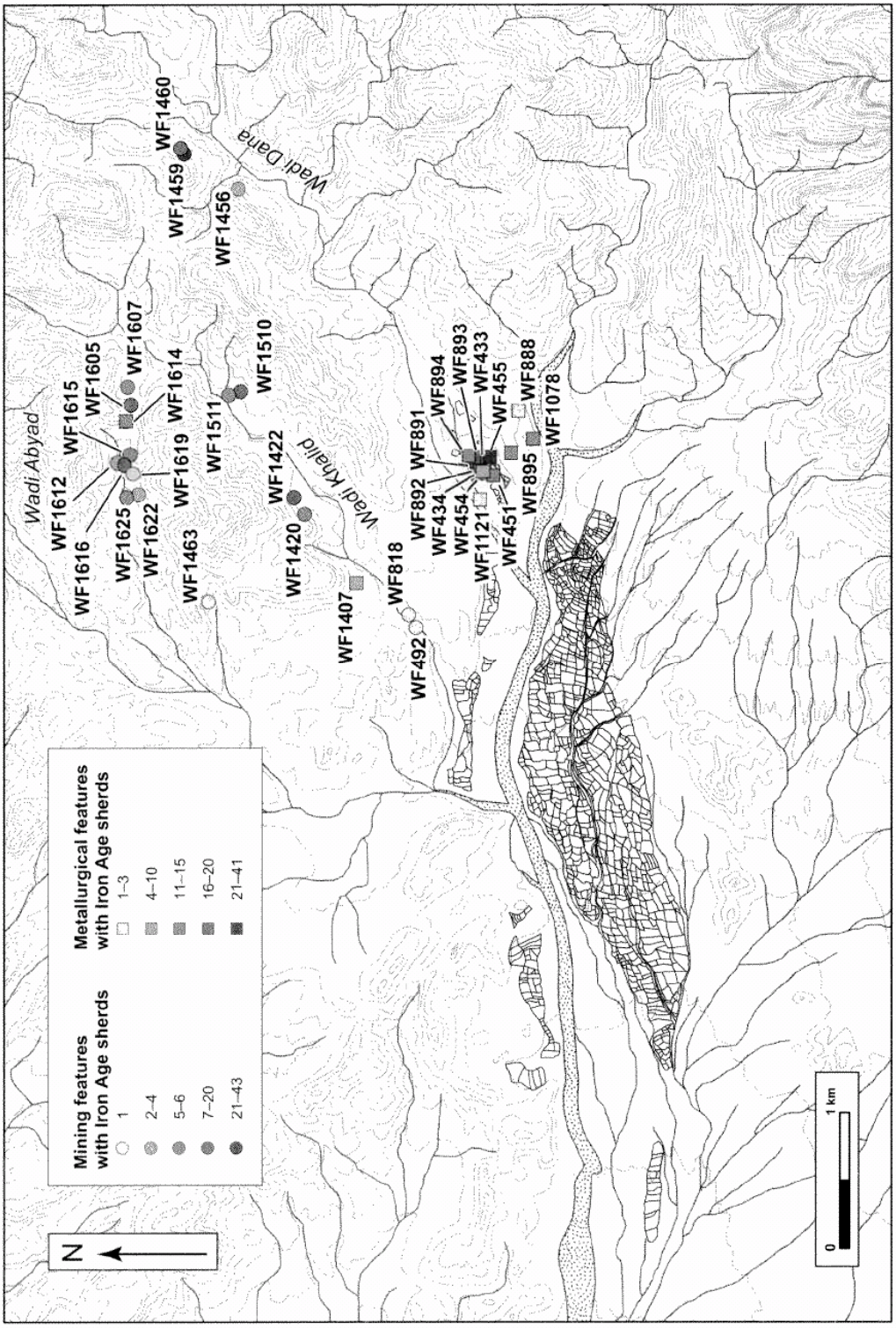


Fig.5.8: Mining and metallurgical Iron Age features recorded by the Wadi Faynan Landscape Survey in the vicinity of Khirbat Faynan (Mattingly et al., 2007b:276); note that many of the sites were recorded also by the German Mining Museum team (cf. Figs.5.4, 5.9).

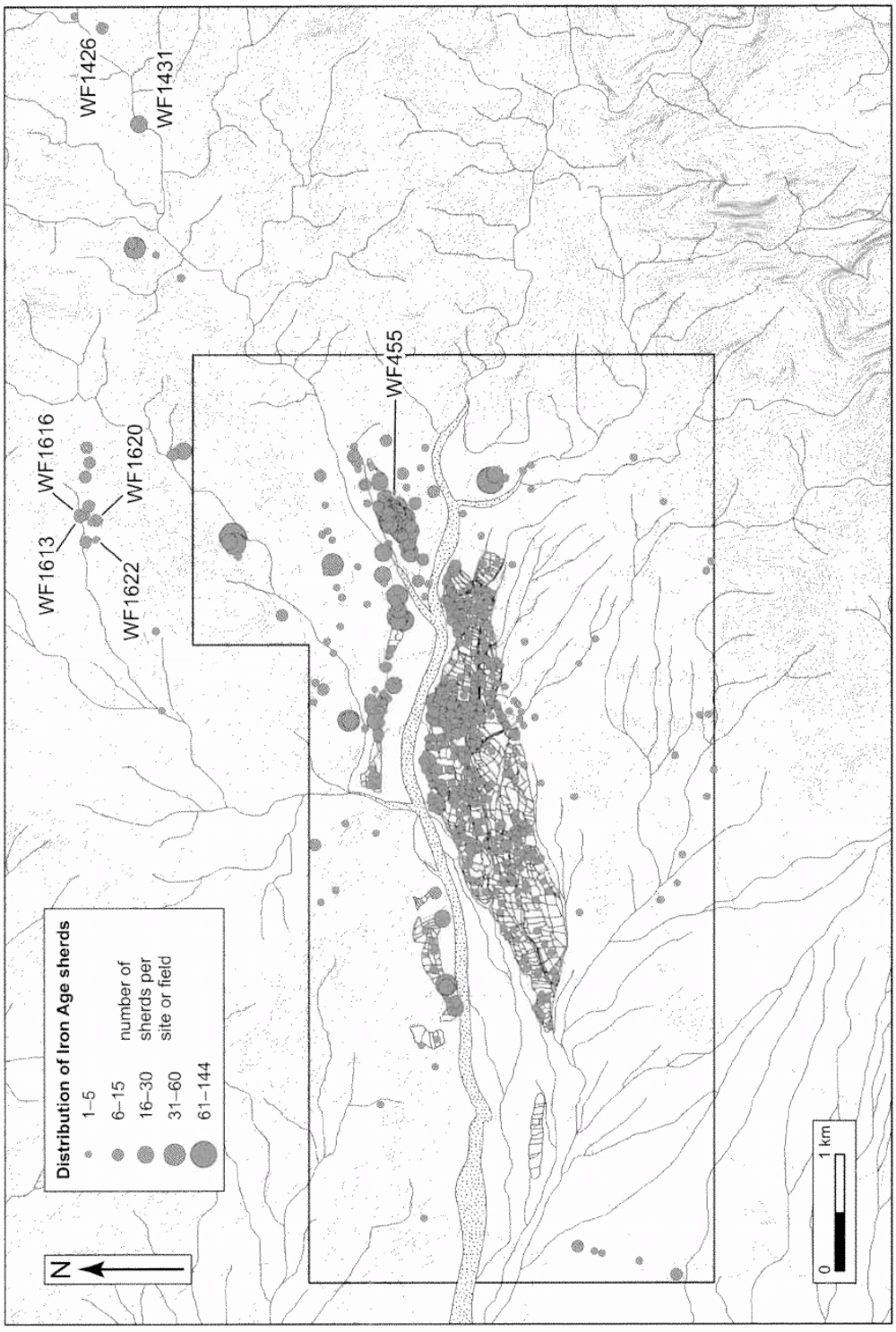


Fig.5.9: Iron Age pottery scatters recorded by the Wadi Faynan Landscape Survey (Mattingly et al., 2007b:280); note in particular the high concentration in the agricultural fields and near Khirbat Faynan (WF455); cf. Figs.5.4 and 5.8.

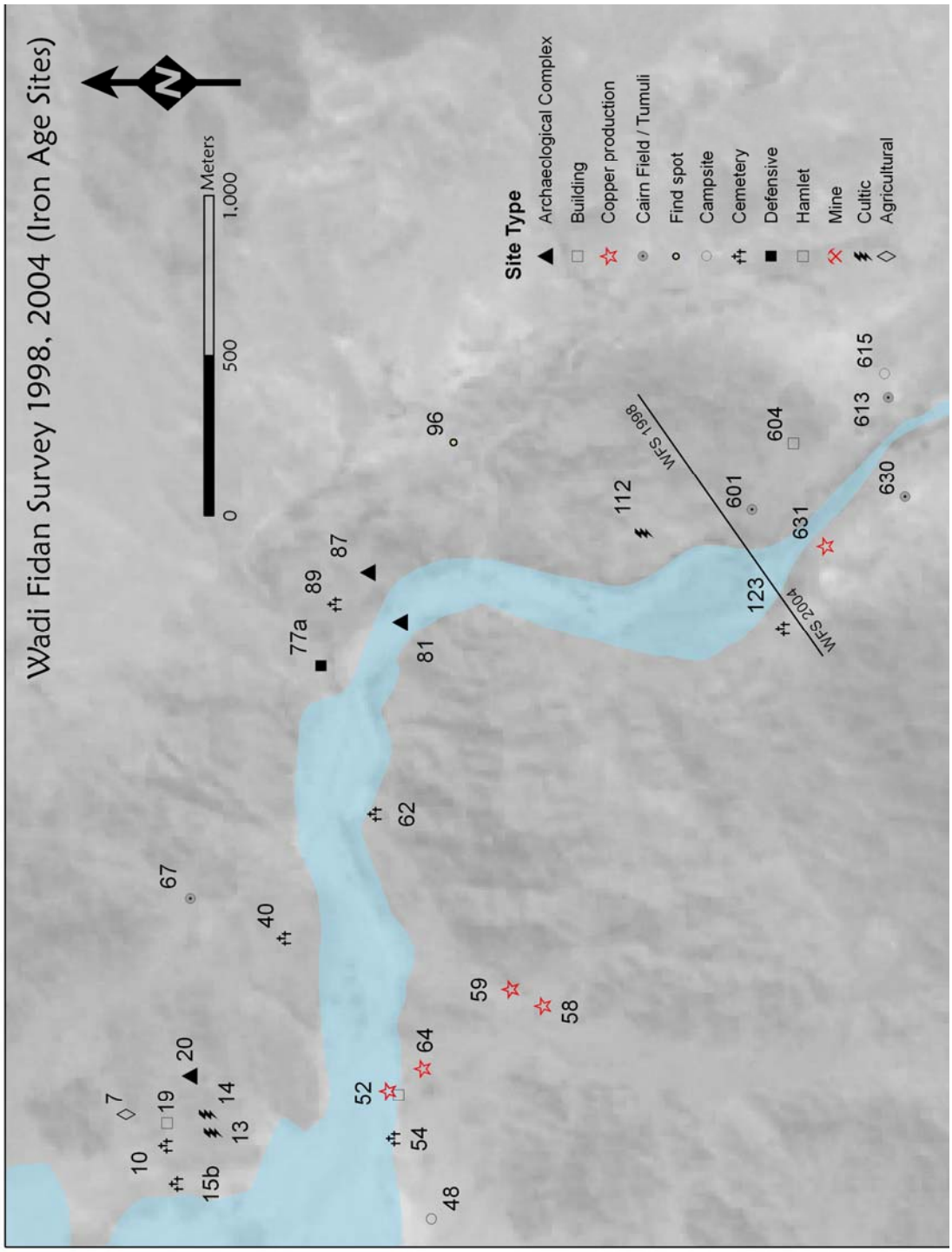


Fig.5.10: Iron Age sites of the Wadi Fidan Survey: the 1998 season (REF) and the 2004 season (not published). Note that Khirbat Hamra Ifdan (WF120) is not indicated here as an Iron Age site; the current research show that one of the major slag piles there is an Iron Age deposit (see section 5.2.8 below).

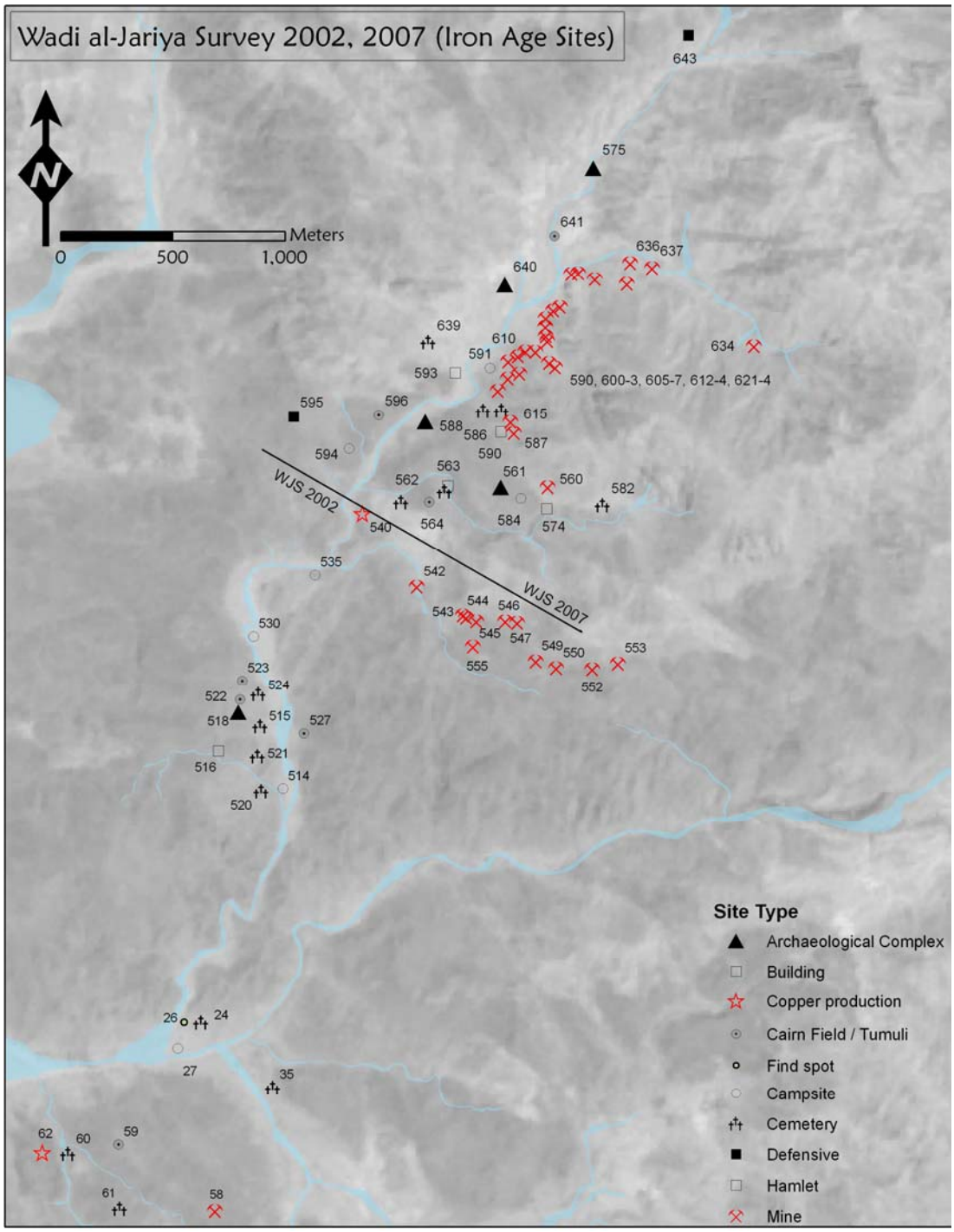


Fig.5.11: Iron Age sites of the Wadi al Ghuweiba and Wadi al-Jariya Surveys. Site 62 is Khirbat en-Nahas and Site 540 is Khirbat al-Jariya.

5.2 Description of the sites studied as part of the current research

The excavations of sites in the current research were part of the Edom Lowlands Regional Archaeology Project (ELRAP)'s 2006 (September – December), 2007 (July – August) and 2009 (September – November) field seasons in Faynan directed by Thomas E. Levy (PI and co-Field Director) and Mohammad Najjar (co-Field Director), except from the new excavations at Timna Site 30, conducted in April 2009 and directed by the present author (Chapter 6). The survey of Iron Age roads and sites (FBRS), which also contributed to the current research, was part of ELRAP 2007 field season. The excavations at Khirbat en-Nahas (KEN) Area M, Khirbat al-Jariya (KAJ), Ras al-Miyah East (RAM East), Khirbat al-Ghuweiba (KAG) and Jabal al-Jariya 1 (JAJ1), as well as the FBRS survey, were supervised by the present author (at KEN Area M together with Marc Beherec). The excavations and survey were designed to answer specific research questions related to society and technology in Iron Age Faynan, as detailed below.

The recording of archaeological remains in the current research is based on the digital archaeology system developed as part of the Edom Lowland Regional Archaeology Project (Levy et al., 2001d; Levy and Smith, 2007; Levy et al., 2010b; Levy et al., in press-c). Like any other basic archaeological practice (Hawkes, 1954; Renfrew and Bahn, 2004), the system is provides solution for three primary components: surveying, artifact and context recording, and photography. The

excavations and surveys databases are based on Geographic Information System (ESRI), associated digital forms (Microsoft Access) and digital photographs.

5.2.1 *Excavation methods*

Most of the excavations conducted as part of the current research were limited probes in different sites, with the main goals being to establish the stratigraphy and chronological framework, and to obtain representative reference metallurgical collections of artifacts. At KAJ, KAG, JAJ and Timna 30 only one or half a 5 x 5 meter square were carefully excavated from surface to bedrock, with a focus on detailed recording of the sections of these probes. At KAJ and KAG, structures believed to be associated with Iron Age metallurgical remains were entirely exposed to reveal floor levels. At RAM East we conducted soundings in one casemate and the main fortress corridor to try and clarify the chronology and function of the site. In contrast to these probes, the excavations at Khirbat en-Nahas, the largest copper production site in Faynan, have been the centerpiece of the ELRAP ancient metallurgy and Iron Age study project directed by Levy and Najjar. At KEN, seven areas have been intensively excavate during three expedition seasons (each ca. 10 weeks long), resulting in extensive exposures of metal production remains and architectural features. The large scale excavations at KEN comply with one of the main goals of the project, to investigate the impact of technological practice on society using anthropological approaches. The horizontal exposure is the basis for synchronic

reconstruction of the organization of production, and the stratigraphic sections in the deep soundings are the basis for assessing diachronic social and technological processes. The digital recording system basically eliminates the need for excavating in squares (except when stratigraphic sections are required), and in most cases the architectural features were entirely exposed with baulks left only in specific location for stratigraphic correlation and future reference. The basic excavation unit at KEN in open areas has been the 5x5 m square, a standard unit in excavation of biblical sites in the southern Levant.

The nature of excavation in archaeometallurgical sites is quite different than excavation in regular settlement sites (e.g., Rothenberg, 1980a). The metal production activities and especially the smelting process result in rather rapid accumulation of waste and 'slag mounds' can form in a relative short amount of time. Such metallurgical deposits consist of thin horizons (layers) that may represent a single smelting cycle. Often, especially in areas designated for disposal of metallurgical waste, these thin horizons often have initial strong inclination (see e.g., Fig.5.31A) that makes it difficult to delineate homogeneous loci and to interpret sections. The colorful interchanging horizons of clay, tuyère and furnace fragments and various types of slag are often disturbed by intrusive pits and sometime invasive installations built on top of the metallurgical waste; they demonstrate complicated three dimensional depositional structure and often consist of a variety of sediments that are difficult to interpret. Even with careful and precise recording of sediments and finds in

'slag mounds', the reconstruction of the metallurgical processes is limited. This complexity stems from the inherent quality of the metallurgical process itself, mostly from the fact that each smelting cycle ended with deliberate destruction of the (upper portion) of the furnaces to obtain the metal chunks and copper-rich slag materials. Meticulous work on the archaeometallurgical collection in the laboratory and some random finds of semi-complete installations (rarely in situ) are the key to technological interpretations. The initial approach of defining each horizon as a 'layer' in Area M during the KEN 2002 field season (supervised by E. Monroe) was abandoned in the 2006 field season (supervised by M. Beherec and the present author) in favor of larger scale excavation of the 'slag mound', more robust stratigraphic division, and more careful division into loci. The major stratigraphy in the excavation areas is based mostly on substantial changes in the sequence of the architectural remains. The accompanying radiocarbon dates helped to refine this stratigraphy (especially in the deep pit of Area M 'slag mound' where architectural features were scant) and to correlate between the noncontiguous excavation areas. High resolution radiocarbon dating is especially important when establishing stratigraphy and chronology of metallurgical 'mounds' because of the very nature of such deposits, which in addition to the rapid (or rather unknown and changing) and complex accumulation described above, usually lack rich repertoire of pottery and other material culture remains conventionally used to establish chronologies and correlations (see Chapter 4 for further discussion). The excavations at KEN, KAJ and Timna 30 provide a unique case in which accumulation rates of ancient metallurgical

debris can be estimated with a large and robust suite of high precision radiocarbon dates.

The location of artifacts, samples and loci (including architectural features) excavated in the current research and described below were recorded using a *Total Station* (also, *EDM – Electronic Distance Measurer*, Fig.5.12). The spatial information was recorded either as points (specific x, y, z - elevation) or as polygons (a closed plane representing a surface; it should include at least three *vertices*, i.e., different points that define the plane). Points are usually specific artifacts or ecofacts collected separately from general baskets, and polygons are usually the boundaries of loci, including walls and installations. When the spatial dimensions of a locus have changed throughout its excavation (a common case in metallurgical loci), a 'perimeter bottom' was also recorded. Regular pottery sherds, bones, flint and some of the archaeometallurgical artifacts were collected as general baskets associated with a specific locus and specific excavation day (basket were changed each day, regardless if their associated locus was close). Each recorded point, polygon, locus and basket has a unique number (points and polygon get an *EDM number*); these numbers are exclusive and do not appear more than once in the entire ELRAP excavations to facilitate identifying the context of the recorded feature.

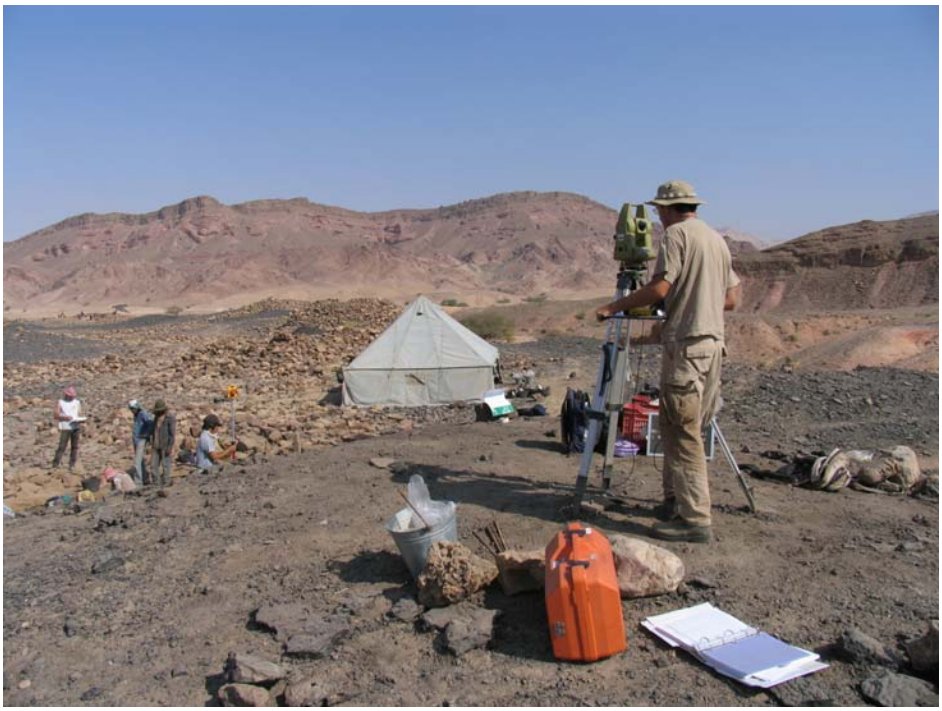


Fig.5.12: Recording points with a *Total Station* at Khirbat en-Nahas Area M (ELRAP 2006, supervised by M. Beherec and E.B.-Y.). The Total Station is located on the top of the 'slag mound' over a datum and directed towards the center of the prism on top of a metric rod or 'Pogo Stick'. The coordinates (of the bottom tip of the Pogo) are sub-cm resolution, assuming that the stick is held vertically (a bubble level is attached to the stick).

A hand-held Recon data collector with SoloField TDS Software transferred the data from the *Total Station* to a GIS format and enabled instant mapping of the loci and finds[33]. The GIS database is the basic medium for data collection, presentation and analysis used in the current research; it is the center of all aspects of recording and processing of the excavated (and surveyed) data as presented in Fig.5.13. The coordinates obtained with the *Total Station* were converted to the Universal Transversal Mercator (UTM) of Jordan (WGS84) with the help of the Royal Jordanian

[33] At Timna 30 we have used an old type of *Total Station* and recorded the coordinates manually; accordingly, the data are not converted to UTM; we plan to obtain GPS data and convert the recorded data, together with Rothenberg's information, into UTM.

Geographic Center (RJGC) (GPS survey conducted before the 2006 field season, see Levy and Smith, 2007:49).

All the associated information of the spatially recorded contexts, e.g., the excavation area, date, square, locus description, basket, special find descriptions, are stored in GIS as part of the shapefiles (the ESRI basic GIS file system) and as Access files (digital forms) directly linked with the spatial data. At the end of each excavation day the data are exported into ArcGIS on a GIS designated PC laptops. A 'daily map' with all the opened and closed loci of the day, together with all specific point-finds is drawn and serves as a graphic journal for the area supervisor. A key feature of the GIS recording system is that each artifact (or other recorded features) has its own recording symbol and can easily be graphically illustrated on the map (Fig.5.14).

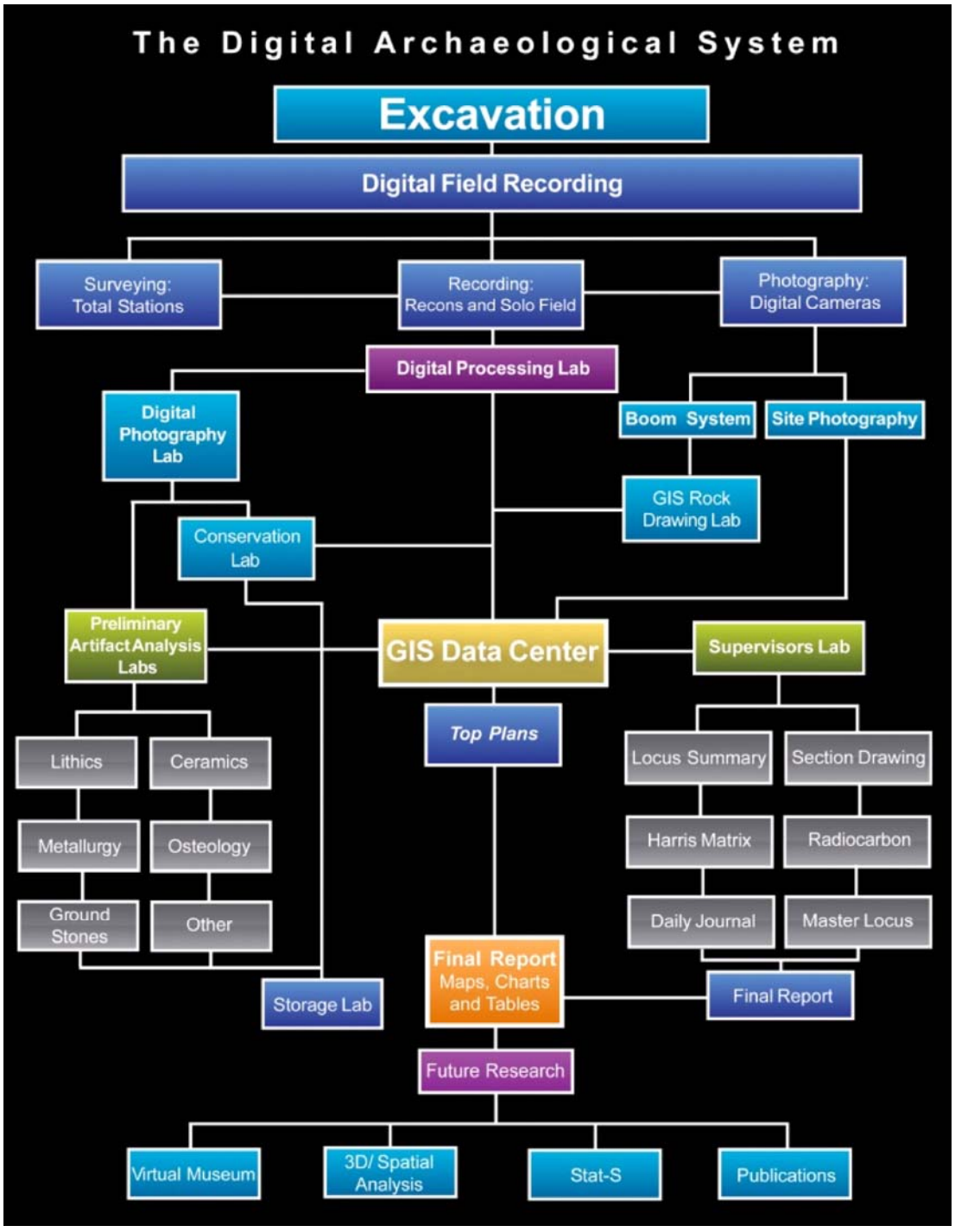


Fig.5.13: The digital recording system of ELRAP utilized in the excavations of the current research (see text for details; after Levy and Smith (2007).

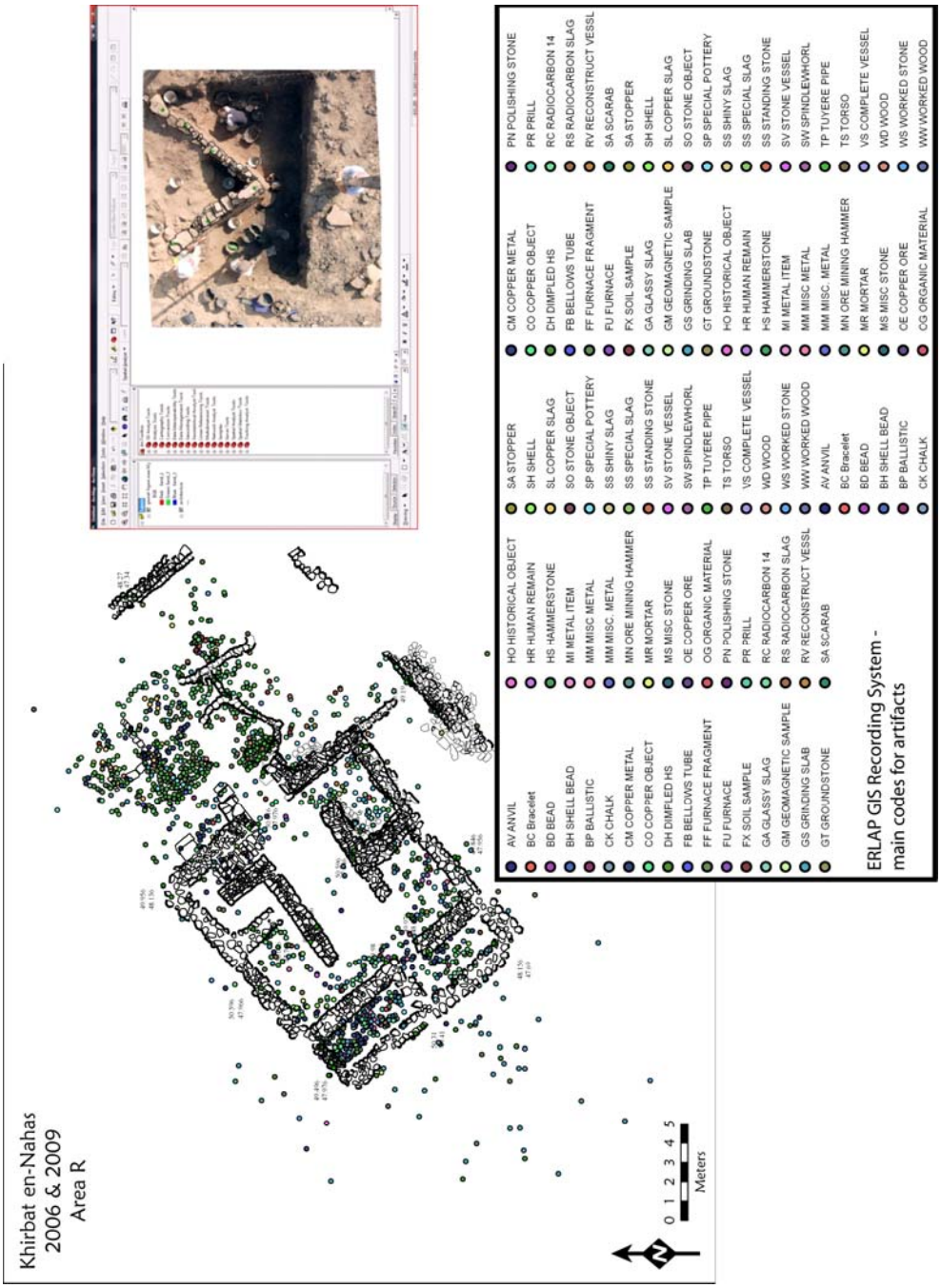


Fig.5.14: The GIS recording system of ERAP used in the current research. Each artifact (that is not collected in a general basket) is recorded with a *Total Station* and has a unique *EDM* number and a two letters code indicating its type (see the legend in the figure for most common artifact groups). The distribution of artifact can be easily plotted on a map, with the different codes converted to a visual symbol (on the map above, all the artifacts recorded in KEN Area R are plotted for illustration). The architectural features are drawn in GIS ArcView based on georeferenced 'boom' (or balloon in 2009 field season) photos taken from above, as demonstrated in the image at the upper right (a screen-shot of ArcView processing of wall photo from KEN Area M).

The digital recording system also uses geo-referenced digital photography shot in the field and digital photography of artifacts (also linked to the general GIS database) in the laboratory. Photographs taken in the field by the supervisor and directors were downloaded each day and the files were re-named systematically and linked to the general database. Photographs taken with a boom stick (Levy and Smith, 2007:51, 53) or a helium balloon (in ELRAP 2009 season, see Levy et al., in press-c) were georeferenced and used for drawing architectural features in the GIS laboratory (Fig.5.14). In addition, every artifact that was recorded separately in the field is photographed in the laboratory; with its unique *EDM number*, it is linked to the GIS database. This enables production of interactive maps in which the photos of the artifacts (and associated digital forms) can be presented to the user on the spot.

In ELRAP 2009 field season our expedition to Faynan utilized a portable XRF device (see sections 8.2.1 and 8.5.1 below) to obtain quick chemical analyses of material and small 3D scanners for documenting pottery sherds (Levy et al., in press-c). The chemical profiles of artifacts and the 3D images are also in digital formats that are linked to the GIS system.

The digital database includes thousands of spatial data points and digital images and hundreds of digital forms (*Access* files) and associated materials (*Excel* summary spread sheets, supervisor reports, etc.). In addition to fast and accurate graphic display, the GIS system enables powerful analyses and statistical

manipulations of the data in a way not possible with manual recording. Storing all the recorded information in one database helps sharing it with other scholars; the aim of the ELRAP system is eventually to make this material available on-line for the scholarly public. In addition, this recording system, coupled with the digital photography of each artifact, helps with later analyses of the finds after the end of each field season as most of the special artifacts have to be stored in their home countries (the Department of Antiquity of Jordan or Israel Antiquities Authority) and cannot be shipped to the foreign research universities such as UCSD. With the exception of special finds (such as metal tools, scarabs, etc.), most of the non-museum quality artifacts, including the bulk of the archaeometallurgical inventory, were shipped to the laboratories at UCSD.

5.2.2 *The archaeometallurgical recording system*

The extensive deposits of archaeometallurgical debris in the Iron Age smelting sites excavated as part of the current research required a specific recording method, with special attention to organizing a large inventory of artifacts and sediments related to the copper production process. The greatest challenge in developing such a method for the smelting sites of the Arabah is how to sort meaningful information out of the massive excavated material. In contrast to careful excavations at relatively small metallurgical workshops (e.g., the excavations of the iron smelting workshop and smithy at Tel Hammeh and Beit Shemesh, see Veldhuijzen, 2009), the project at KEN

unearthed over 8 tons of archaeometallurgical sediments focusing on large exposure rather than a detailed reconstruction of each installation, because these were rarely found intact in the excavations.. Nevertheless, when unique metallurgical remains were recognized (mostly intact furnace bases) a more carful excavation procedure was applied. As part of the ELRAP's 2006 field season, we developed a system for excavating, collecting and recording archaeometallurgical deposits[34] as described below.

The remains of the copper production processes include various types of materials and artifacts, some of which are found in huge quantities. A comprehensive list of metal-production related finds includes various types and sizes of slag (Bachmann, 1982b); fragments of technological ceramics (furnaces, tuyères, bellows tubes, crucibles, molds and other related installations); ash and charcoal; stones (portions of installations); chunks of copper, manganese and iron ore; copper prills; chunks of metal (copper and sometimes iron, products of the initial smelting); various ground stone artifacts for crushing and processing ores and slag (grinding slabs, hammer stones, pestles, mortars etc.); various sediments (mostly clayey soils mixed with ash, crushed slag, etc.); and some other related finds (see also Table 8.1).

The artifacts in most of the archaeometallurgical categories were recorded separately with and received their own *EDM* numbers and specific locations. Such

[34] The archaeometallurgical recording system was developed by the present author and was applied also in ELRAP 2009 season.

artifacts were catalogued in the expedition digital recording system (GIS-based, including photography). Slag, furnace fragments, and associated sediments were present in large quantities and were collected in bulks. . In certain cases also tuyère fragments, copper ore chunks, and charcoals were not collected individually and were assigned a general basket associated with specific locus and excavation day. Slag was documented in the field, classified, weighed and only sampled material was collected for the lab. Further documentation of the archaeometallurgical finds collected as bulk was done in the 'dirty laboratory' at the end of each excavation day. The following provides more detail on how the archaeometallurgy samples were collected and initially processed in the field:

(1) Slag

Slag slabs and fragments are the most abundant find in KEN, KAJ and other copper smelting sites in Faynan. For illustration, during the 2006 field season at KEN the total amount of weighed slag was 16,666 kg (from areas M, A, F, T, R and KAJ area A) and in 2002 field season it was 18,644 kg (from areas A, S and M). To deal with such large quantities without loosing essential data we developed a method of slag collecting and recording, ensuring sufficient description and sampling.

Most of the slag processing was done in the field and the rest in the "dirty lab" of the expedition after each excavation day. For each locus we collected all the slag pieces larger than a fist size (>~5cm) into buckets (*'gufas'*, Arabic for rubber buckets

made of recycled tires). Then the slag pieces were sorted by size into three groups (smaller than ~10cm, ~10cm to 20-25cm = "large", greater than 20-25cm = slag slabs), described (color, texture, inclusions), weighed (usually with a metric spring scale) and sampled. The samples, which we stored as part of the expedition collections, were made of 1 kg or more of slag pieces from each size type per locus. We also collected samples with characteristic features that were found during the sorting process (e.g. slag with charcoal, slag with ore, slag with copper metal, glassy slag, slag droplets etc.). To estimate the amount of small slag fragments (<~5cm) we sieved at least one plastic bucket (with a known volume) per locus with a ½ inch screen, weighed the remaining slag fragments and collected representative sample (knowing the concentration of small slag fragments from sieving a bucket of known volume, a rough estimation of the amount of small slag fragments in the entire locus was calculated, based on loci volume calculated with ArcView).

For each locus with slag remains we documented the following: (1) description of the slag according to their size distribution; (2) exact measurement of weight for slag pieces that are larger than fist size and an estimation of the weight for the slag pieces that are smaller than fist size; (3) 1 kg or more of slag fragments per each size type; (4) samples of slag with characteristic or unique features. The division into size groups corresponds to fine crushed slag (the smallest size), slabs of tap slag (the largest size) and broken furnace and or broken tap slag (the two intermediate sizes). In addition to the method described above, some unique slag pieces (e.g. slag droplets,

slag with copper ore, glassy slag, etc.) or slag pieces with important location inside the locus (e.g. slag with dateable charcoals, slag attached to furnace, etc.) were recorded as a point find with a *Total Station*.

All of the general samples of slag fragments (per locus per size) have been recorded also by taking two scaled digital photographs for each, one of the bulk collection of slag pieces and the second of one representative piece. This last stage of recording is aimed to produce a "slag library" made of digital photos.

The method of recording and collecting slag described above is more advanced and comprehensive than the one used in the season of 2002. Based on the experience acquired during the first season of excavation at the site, in 2006 we collected many more slag samples for further investigation. The slag sorting procedure was simplified and included less categories (in 2002 six categories were used: large furnace slag, small furnace slag, large tape slag, small tap slag, granulated and crushed). In 2002 season there was no systematic sieving per locus for documenting small slag fragments; instead, in Area M only, there was a designated 1x1m "control area", in which all of the sediments were sieved, and all of the slag pieces were sorted, weighed and collected.

(2) Furnace fragments

All of the fragments of furnaces were collected in general baskets except in cases when unique, well preserved, or concentrated assemblage fragments were uncovered and recorded as a point find with the *Total Station* (including photography). The hundreds of fragments recorded as point finds have been a key to reconstruct the metallurgical installations of KEN and KAJ. The furnace fragments collected in buckets were sorted in the "dirty lab" of the expedition after each excavation day. During the routine work in the field the designated 'furnace fragments' buckets filled up with miscellaneous technological ceramics. Most of the misplaced tuyère fragments were sorted out in the "dirty lab", but only during the work on the archaeometallurgical collection at UCSD in 2010 was it possible to distinguish between furnace fragments and fragments of what are probably crucibles, molds and other unidentified part of metallurgical installations (see Chapter 7 below).

Already during the field season (in the "dirty lab") the furnace fragments were divided into three groups: bulk chunks of poorly preserved furnace fragments; well preserved furnace fragments and indicative or unique furnace fragments (e.g., furnace rims and bottoms). The fragments from the three groups have been counted (estimation), described, weighed and measured (size range) per basket. The indicative or unique furnace fragments were photographed and stored separately; some were illustrated and presented here. Our experience shows that even careful excavation cannot replace the detailed study of the technological ceramic material in the

laboratory for the precise classification of the finds and establishing basic technological interpretations (similar experience was reported for the excavations in Timna by the Arabah Expedition, see e.g., Rothenberg, 1990a).

(3) Tuyère fragments

In the majority of the loci in the excavation at KEN, KAJ and KAG (and in all of the loci at Timna 30) tuyère fragments were collected separately; for ELRAP this was done as point finds recorded with a *Total Station* (including photography). The number of fragments coupled with their description (front or back parts, preserved diameter etc.) may be a key for estimating the number of furnaces (or the minimum number of furnaces) in a specific context, thus we counted and recorded them carefully (see section 7.2.5). In some loci where high density of tuyère fragments was found, (mostly in areas A, F, T and R), we collected the fragments in general baskets (corresponding to specific locus and excavation day). In addition, fragments of misidentified tuyères came out from the sorting of furnace fragments buckets in the "dirty lab". These were assigned a general basket numbers and stored separately.

Every fragment of tuyère, the ones that were collected separately and those that were collected as part of a general basket, were also documented in the "dirty lab". The sample was given a detailed description, including size (length parallel to the tube), color, inner diameter of the tube and minimum outer diameters (usually it is a fragment of a conical shape), material characteristics, and presence of attached slag.

Special attention was given to unique features such as residue of copper ore, charcoal or prills, textile or reed imprints on the clay, whether the sample was well preserved and if it had an unusual shape. Fragments with unique features found in the general baskets were stored separately. The entire inventory was carefully counted.

In the field, tuyères and clay bellows pipes were often confused by the student excavators. Only when we reinvestigated the archaeometallurgical collection in the laboratory was this corrected, although not in the digital database used for GIS analyses. The recorded information, especially in area F where bellows pipes were relatively abundant, may be not accurate in the current GIS database. The tuyères and bellows pipes were processed in the same way during the field season (counting, description and measurements). In general, bellows pipes are rare in KEN and completely absent in the recent excavations of KAJ, KAG and Timna 30. They probably represent an even more specialized and specific activity (see below).

(4) Copper ore, charcoal and sediments samples

The method of collecting copper ore fragments depended on their frequency. In contexts where ore fragments were abundant they were collected in general baskets (corresponding to the locus and excavation day), otherwise they were collected as point finds. In some cases, oxidized copper metal was confused as copper ore fragments; this was corrected only in the laboratory (and sometime even then it is not easy to distinguish between the two, especially when they are attached to slag).

Charcoal was collected mostly as point finds, but in contexts where they were abundant we collected them in general baskets for species identification and other investigations not related to radiocarbon dating. Sediment samples were collected as point finds and a representative sample was collected for each metallurgical locus or distinct context (identified primarily by color and texture).

The excavations resulted in a vast inventory of archaeometallurgical artifacts and ecofacts, digitally recorded as part of the GIS database and stored in the UCSD Levantine Archaeology Laboratory (most of the collection), in the storage facilities of the Department of Antiquity of Jordan and at the Institute of Earth Sciences at the Hebrew University of Jerusalem (artifacts from the new excavations at Timna 30; after final processing these objects will be stored with the Israel Antiquity Authority). The artifacts stored at UCSD constitute one of the most comprehensive archaeometallurgical collections currently available for research in the world. Only a small portion of these artifacts have been analyzed as part of the current research and the collection provides ample opportunities for future investigations. The organization of the metallurgical collection at UCSD is described in Chapter 8 below; finally, a number of future research questions are presented as part of the conclusions of this work.

5.2.3 *Survey methods*

Several important Iron Age sites investigated as part of the current research were recorded as part of the Faynan Busayra Regional Survey (FBRS) conducted in 2007 as part of ELRAP and supervised by the present author (see section 3.2.5 above, and Ben-Yosef et al., in press). The focus of this survey was to identify and record Iron Age roads in the region between Faynan and Busayra, therefore a recording system for routes was also included. In general, the recording method is tied directly to the GIS-based system of ELRAP described above (see also Fig.5.13), however, the *Total Station* is replaced by a differential GPS device as described below.

The accessible terrains of northeast Faynan region were surveyed by a team of four, with a 4-wheel-drive pick-up truck and by foot, sometimes backpacking and camping to explore remote destinations. Locations of FBRS Sites and Road Segments were recorded by a differential GPS system (Fig.5.15), with the base station located on a roof of a rented house in the village of Quraiqira[35]. Each GPS reading was assigned a unique number in a running order (1 to 12,501). The precision of the location records after correction is sub-centimeter both in the x-y coordinates and elevation, although technical problems during the field work sometime resulted in precision of up to a sub-meter resolution. For any practical and interpretational purposes a sub-meter resolution is adequate and is more than the commonly available resolution in

[35] The GPS antennas were connected to Recons (data collectors) with Interlock 1.0.2 software. Correcting the data was done using Spectra Precision 1.1. Thanks to Fawwaz Ishakat, Hashemite University and ELRAP digital surveyor for help in geo-referencing the differential GPS system.

archaeological surveys (until the 1990s location coordinates were obtained only from topographic maps). To check the accuracy of the system we established control points that were measured repeatedly and on different days (they were also used as a reference for the daily initiation of the GPS). The greatest benefit of a differential GPS system is that it enables recording architectural features relatively fast and 'on the fly', resulting in accurate architectural plans (e.g., FBRS Site 12 and 37, see section 5.2.9.2 below). For each site we recorded with the GPS system a point in the center, a polygon of its area and its architectural features. Site recording included also collecting pottery sherds and any diagnostic artifacts (if found), digital photography (almost 1,700 in total, including Road Segments) and detailed written descriptions (Fig.5.15A-B).

Road Segments were recorded by walking with the GPS antenna (Fig.5.15C) or in a few cases by holding it in the back of the truck. Sometimes only representative segments of a road were recorded (start/end, switchbacks, etc.). The roads were divided into six categories according to their accessibility level: current and old dirt roads and Goat, Donkey and Camel (and unidentified) (see further details in Ben-Yosef et al., in press).



Fig.5.15: Recording methods of Faynan Busayra Regional Survey (FBRS) include differential GPS measurements of site center and perimeter and road segments, collection of pottery sherds and detailed description of the sites. A) Collecting pottery sherds and recording a small Iron Age (?) watch tower at the Ras al-Miyah Archaeological Complex (Site 21); B) recording an artesian well in the Arabah Valley (Site 49C); C) recording a segment of the main road from Faynan to Busayra (Road Segment 6).

The data collected by FBRS is part of a Geographic Information System (GIS) and *Microsoft Access* database. A daily topographic journal was the basic method of collecting field notes, including the description of many archaeological features not recorded as a Site or a Road Segment. Field observations were noted on a printed large scale UTM map and additional data can be found there.

5.2.4 *Khirbat en-Nahas*

The recent excavations at Khirbat en-Nahas (KEN) (Levy et al., 2004c; Levy et al., 2008a; Levy et al., in press-b) provide substantial new data regarding the history of Iron Age occupation and copper exploitation in the southern Levant. Extensive collection of archaeometallurgical artifacts, detailed stratigraphic information and wide exposure of structures and installations constitute an empirical anchor for understanding the history, social context, tempo and role of copper production during the early Iron Age in southern Jordan (ca. 12^{th} – 9^{th} centuries BCE). These excavations form the centerpiece of the UCSD ELRAP directed by Levy and Najjar (see Chapter 3 above). The site was excavated during three field seasons in 2002, 2006 and 2009; the results of this work are reported in Levy et al (in press-b). As part of this project seven excavations areas were opened (Figs.5.16-5.17), including the four-chamber gatehouse of the fortress (Area A), a building located inside the fortress devoted to refining, re-melting and casting of copper metal (Area F), two large-scale buildings that may reflect elite residences at the site (Areas R and T), a building devoted to the processing

of slag (Area S), a deep-sounding through one of the site's many industrial slag mounds (Area M) and a structure complex of residential, storage and perhaps cultic function (Area W). The only other excavation at the site, conducted in 1990 by V. Fritz (1996), exposed a relatively small structure (building 200) dated to the 9th century BCE (Figs.5.16-5.17). The current research is primarily concerned with the deep stratigraphic section in the 'slag mound' of Area M, excavated in 2002 (small portion; supervised by E. Monroe) and 2006 (supervised by M. Beherec and the present author), with the general spatial distribution and characteristics of the *chaîne opératoire* components, and with specific metallurgical installations unearthed during the project. Information from previous investigations of the site, and especially from the archaeobotanic studies of the German team (e.g., Engel, 1993) is discussed in Chapter 7 below.

Khirbat en-Nahas has attracted the attention of scholars for more than a century (see Chapter 3 above). After Musil's visit in 1898 (1908:298) the site was visited also by Kirkbride, Horsfield, Head and Frank, but it was only Glueck that assigned (correctly) a date to the impressive ruins:

> Quantities of worn sherds were found on the surface at Kh. En-Nahas belonging to EI I-II [Early Iron I-II]. Almost all of them were from large, coarse vessels of various kinds, such as one might expect to find in a rude mining camp, where much of the pottery may have been locally made. (Glueck, 1935:29)

This observation was corroborated by the results of the German team and firmly confirmed by the recent ELRAP excavations after much scholarly debate (see section 3.2.5 above). With the exception of a metal production layers located at the base of the

deep sounding in Area M above virgin soil that dates to the 13th to 11th centuries BCE, the majority of the excavation areas at KEN date to the 10th and 9th c. BCE (Table 6.2).

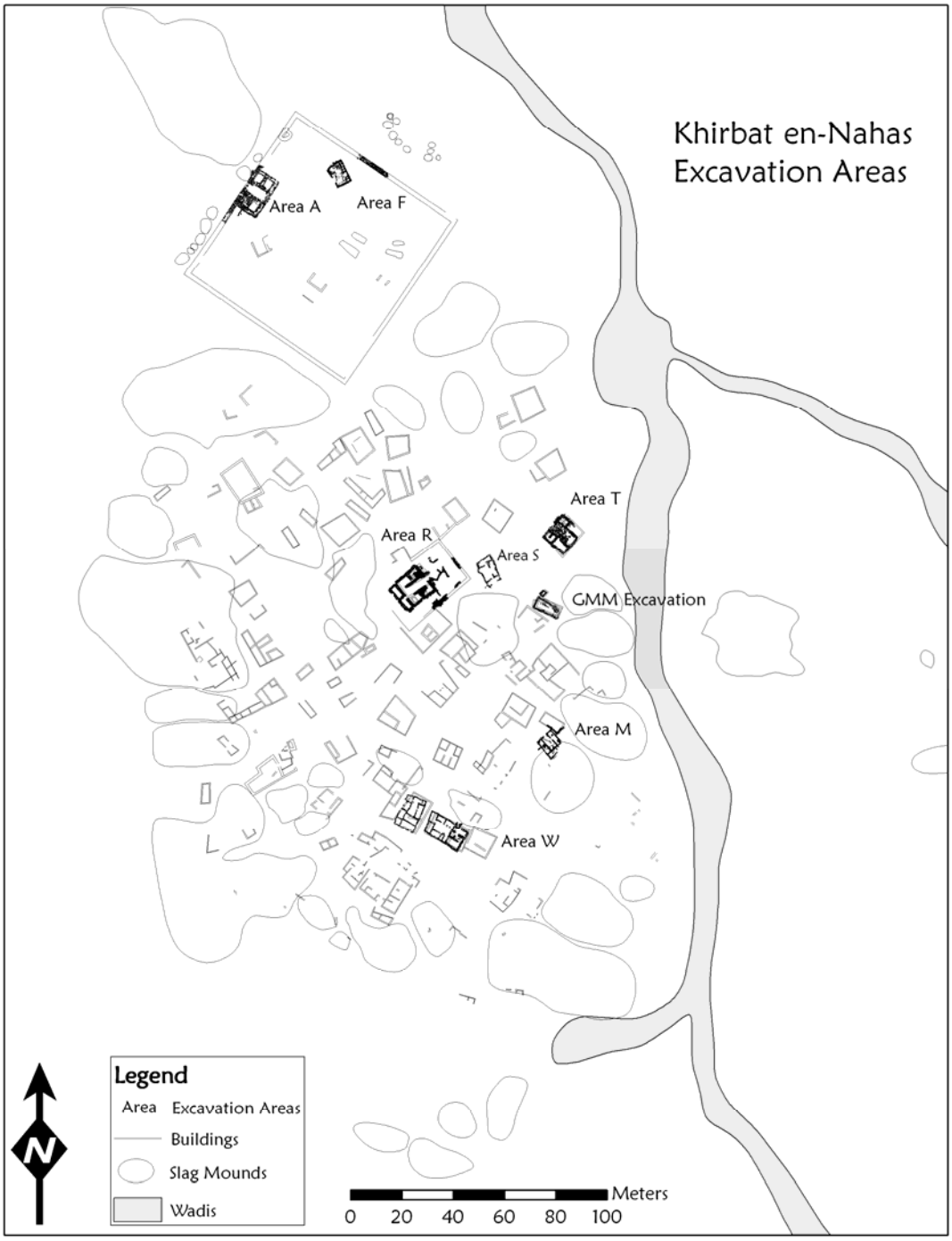


Fig.5.16: Khirbat en-Nahas and excavation areas of the GMM and ELRAP expeditions (map coutesy of UCSL-LAL).



Fig.5.17: An aerial view of Khirbat en-Nahas (taken with a helium balloon during UCSD ELRAP's 2009 field season; note the deep soundings into the 'slag mound' of Area M and the associated building (see text for details, photo courtesy of ELRAP-LAL).

5.2.4.1 General overview of the excavation areas

Khirbat en-Nahas is a ca. 10 hectare (100 dunam) site, with approximately 100 buildings visible on the site surface, including one of the largest Iron Age Levantine desert fortresses (Figs.5.16-5.17). All of the excavation areas at the site, as well as Area A at Khirbat al-Jariya (see section 5.2.5 below), are summarized in Table 5.3. The general stratigraphy across the different excavation areas at KEN presented in Table 5.3 is mostly based on a substantial suite of Accelerator Mass Spectrometry (AMS) high resolution radiocarbon dates (modeled with Bayesian analysis; n = 101 dates) from dozens of different stratigraphic contexts (Levy et al., in press-b). The excavations in various areas indicate that the archaeological accumulation is quite substantial. It is likely that much of the visible architecture at the site was founded on top of layers of crushed slag and other metallurgical debris. The deep sounding in Area M has more than 6 meters of archaeometallurgical deposits from surface to virgin soil, and in all of the areas substantial metallurgical deposits were unearthed (mostly in limited probes) beneath the layers with architectural features (Table 5.3). In the following we use the term "Layer" for the main stratigraphic units within excavation Areas and "Stratum" for main stratigraphic units that cut-across the entire site. We also use the term "horizon" to refer to series of thin and well-defined deposits within a major Layer of the excavation Areas.

Table 5.3 (next page): Correlation of Layers from all Excavation Areas at Khirbat en-Nahas and Khirbat al-Jariya (for the latter, section 5.2.5 below), represented by Strata (St.); the main tool for correlating contexts is high resolution radiocarbon dating (for Bayesian models and discussion see Levy et al., in press-b).
Unocc. = Unoccupied; Post-aband. = Post abandonment; year of field season indicated under the area.
Color key: white = unoccupied / post-abandonment features; orange = mainly smelting and other pyrotechnological activities; green = mainly architectural remains (buildings); blue = unexcavated contexts; pink = virgin soil.

St.	14 C	KEN -A	KEN-A description (2002,06)	KEN -M	KEN-M description (2002,06)	KEN -F	KEN-F description (2006)	KEN -S	KEN-S description (2002)	KEN -T	KE`N-T description (2006)	KEN -R	KEN-R description (2006,09)	KEN-W (2009)	KEN-GMM (1990)	KAJ-A	KAJ-A description (2006)
I		A1a A1b	Post – aband.	-	Post – aband.	F1a F1b	Post – aband, (Un-occupied)	S1a S1b	Post – aband.	T1a	Post – aband, (Un-occupied)	R1a R1b	Post – aband, (Un-occupied)	Structure complex; storage areas; cultic? Undated (14C samples are being processed) (un-published)	Small structure (similar in plan to Area S); dated by 14C and ceramic to the 9th c. BCE	KAJ A1a	Post – aband, (Un-occupied)/ Cu Prod?
II	9 th	A2a	Ephemeral metal prod. outside gate	M1 ; 1a	Smelting; (1a after building aband.?)			S1	Aband. possible corral								
	9 th	A2b	Intensive metal production	M2a	Intensive smelting, late phases in building			S2a	Minor extension-ns of main building							KAJ A1b	last phase of copper production
III	Ea. 9 th	A3a	Restruct. Gatehouse Residential?	M2b	First phase of building; Intensive smelting	F2a	Addition of small architectural units	S2b	Main building – casting/ slag processing	T1b T2a	2nd occupation phase floor	R2a	Some additions to structure			KAJ-A2	Building
IV	10 th	A3b	Building of Gatehouse	M3 [IV-V]	Industrial horizon: intense copper production	F2b	Main building w/ basins, refining	-	Unocc.	T2b	Main building phase, residential	R2b	Main building phase, residential		Not excavated	KAJ-A3; -A4	10th; copper product; activity-surface
V	10 th	A4a	Crushed Slag/ Below Gate			F2c	Crushed slag below building	S3	Sparse crushed slag	T3	Pre-building smelting	R3a R3b	Copper production complex	Metllurgi-cal debris			
VI	La. 12-11 th	-	Unocc.	M4	Copper production	-	-	S4	Small scale metal prod& domestic activities	-	Not excavated	-	Not excavated			KAJ-A5;	Copper Production
														Not excavated		KAJ-A6	Crushed slag
VII	13-12 th			M5a M5b	Installatio-ns; small scale production			S5	Unocc.								Unocc.
-	-	A4b	Virgin sediment	-	Virgin sediment	F3	Virgin sediment	S5	Virgin sediment							KAJ-A7	Virgin sediment

Below we summarize the main finds in each excavation area of ELRAP, with emphasis on metallurgical evidence (for further details see Levy et al., in press-b). A detailed report of Area M (section 5.2.4.2), a primary source for the original data and analytical work presented here, and a description of other archaeometallurgical features in the immediate vicinity of KEN (section 5.2.4.3) follow.

Area A: the fortress gatehouse

Three of the four chambers and the passageway of the gatehouse were excavated by ELRAP team in 2002 and 2006 (supervised by Y. Arbel). The fourth chamber was left unexcavated for future researchers. The gatehouse is located on the northwestern side of the square (73x73m) fortress, and has a façade of 16.8 m, 10.6 m (width/depth), and a 3.63 m passageway (Fig.5.18) (e.g., Levy et al., 2005a; Levy et al., 2005c). Two distinct building phases were observed: Layer A3b – the original 10th c. BCE construction of the gatehouse and fortification wall (KEN Stratum IV) and Layer A3a – a major 9th c. BCE restructuring of the gatehouse that included narrowing all the doorways leading into the various guard chambers, building balustrades in the gateway entrance to block the passage of wheeled vehicles and large animals, and closing the other end of the roadway that passes directly into the fortress with a well-built wall. Layer A3a probably represents a 'decommissioning' of the gatehouse from its former military function into a possible large residence or public building of some kind. Layer A2b is a phase that reflects a decision to change the use of the A3a

residence/public building, into a copper working facility. Layer A2a represents some ephemeral phase of metal production that took place only in the exterior of the gatehouse. Beneath the gate there is some evidence of copper production activities of the early 10th century or earlier (crushed slag, Layer A4, Table 5.3).



Fig.5.18: The gatehouse fortress (Area A) at the end of the 2006 field season (looking toward the exit). The doorway to the fortress courtyard was blocked by a well built wall and the inner complex was used as a metallurgical workshop (Layer A2, probably after a short residential function) (photo courtesy of ELRAP-LAL).

The remains of the industrial phase of the gatehouse (Layer A2) appear immediately beneath the collapse stones (Layer A1). It seems that this last phase of occupation ended with no trauma, and that the collapse relates to a later earthquake. The industrial activity is related to copper production and is evident both inside the gate complex and next to it (Fig.5.19). The space inside the gate was interpreted as an area of limited pyrotechnological activities and a designated dumping zone of

production waste (Levy et al., in press-b). The industrial waste is composed mainly of ashy layers containing slag and other related debris such as tuyère and furnace fragments as well as ground stones. The two northern chambers were packed with such debris. No sign of in situ furnaces or significant smelting or melting activities were detected in the main passageway between the guard rooms. This picture contrasts with that found outside the gate structure, in the southern probe (Probe 6). There the layer related to this stratum (L157) contained many pieces of slag along with furnace and tuyère fragments. Table 5.4 summarizes the loci of this layer; loci 170 and 171 are unusual concentration of compact ash on the benches inside the gatehouse.



Fig.5.19: The passageway of the gatehouse looking east. The ashy horizons of Layer A2 are clearly visible below the collapse and above the original surface and its benches. The metallurgical debris in the gatehouse was interpreted as a deliberate dump of metallurgical waste. On the southern bench an unusual compact ash concentration is clearly visible (locus 170).

Table 5.4: Locus list for KEN Area A Layer A2: industrial phase at the fortress's gatehouse (Levy et al., in press-b).

Locus	Description
A2a 157	Slag layer, Probe 6
A2a 168	Ashy fill, central passageway
A2a 170	Compact ash over southern "bench" - east
A2a 171	Compact ash over southern "bench" - west
A2a 187	Mixed fill, Chamber 4
A2a 189	Ash and slag layer, Chamber 4
A2a 190	Small furnace fragments concentration, by entrance to Chamber 2
A2a 192	Ash and slag fill around stone installation, Chamber 4
A2b 162	Secondary doorway to chamber 1
A2b 164	Western pilaster, gate passageway
A2b 174	Ashy fill, central passageway
A2b 178	Central pilaster, gate passageway
A2b 180	Slag layer in lower layer of access to Chamber 2
A2b 181	Ash fill sealed under compact ash layer L171
A2b 182	Ash fill sealed under compact ash layer L170
A2b 186	Southern pilaster, central passageway
A2b 193	Wall or later threshold remains in access to Chamber 2
A2b 195	Partial blocking at access to Chamber 4

It was difficult to distinguish the last phase of activity in the building from the metallurgical phase. The former is related to architectural changes as the narrowing of the gates (of the gatehouse and of the chambers) and was interpreted as primarily residential (probably of a supervisor or social elite, similar to Areas T and R) and the latter is deliberate discarding of metallurgical waste. The lower most ash pockets and lenses, located just above the passageway and benches (Fig.5.19) may be part of the earlier phase, and may indicate that the architectural changes were done for creating a confined metallurgical workshop.

Area F: a metallurgical workshop

Area F contains a small building located in the courtyard of the fortress and a small portion of the fortress's wall. The excavations unearthed a single occupation phase of the building. The architectural plan is unique (Fig.5.20) and consists of two main room and seven small installations (or cells). The excavations at the building (supervised by A. Muniz) yielded numerous artifacts, including large stone basins, ceramic, bones, unique technological ceramic, and other finds. Already during the field season we interpreted the building as some kind of a melting/casting workshop. This interpretation is strengthened and refined in the current research (see also Chapters 7 and 9 below). The unique architecture and the analysis of the archaeometallurgical artifacts, together with evidence from other metallurgical contexts at KEN, suggest that the Area F workshop was designated for refining of the raw smelting product into commercial pure copper ingots (see below).

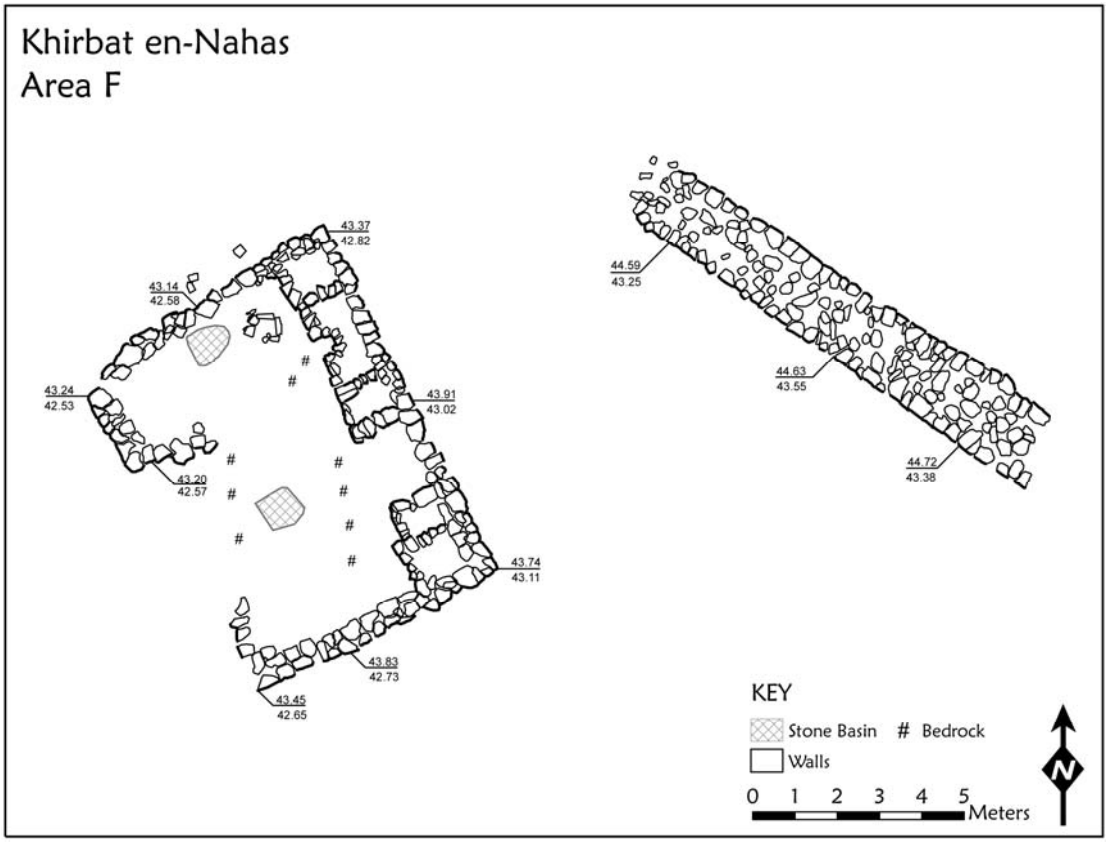


Fig.5.20: KEN Area F. A unique architectural plan related to specialized activities in a metallurgical workshop, most probably related to refining the raw product of smelting into pure copper, as well as melting and casting activities (production of ingots; see also Chapter 7 below). The wall in the east is part of the fortress (the workshop is located in the fortress's courtyard) (map courtesy of ELRAP-LAL).

The walls of the metallurgical workshop were poorly preserved. The building itself was constructed with two main rooms (without any division between them) and a series of cells along the eastern wall (Fig.5.21, Table 5.5). The remains of the occupation phase of the building are part of Layers F2b and F2a; the former represents a single surface and the main phase of activity, and the latter the accumulation of some ash pockets, installation and production debris. A total of five radiocarbon dates were processes for Area F (Levy et al., in press-b), and indicate that Layer F2b is late 10th century BCE (thus it was assigned to KEN Stratum IV, see Table 5.3) and Layer F2a

is early 9th century BCE (thus it was assigned to KEN Stratum III, see Table 5.3). Layer F1 represents collapse of the wall and the structure, and Layer F3 is related to the construction of the fortress wall (the relation between the construction of the workshop and the wall is not clear; the wall construction is not well dated). An additional context, labeled "Layer F2" in general, represents accumulation of slag abutting the workshop wall. This may reflect copper smelting in the fortresses courtyard that was contemporaneous to the activity inside the workshop.



Fig.5.21: The metallurgical workshop in KEN Area F. The two rooms (1, 2) and the seven small installations (3-9) are labeled (cf. Table 5.5) (photo courtesy of ELRAP-LAL).

Table 5.5: Area F, dimension and description of main installations

Installation/ Locus	Dimensions (m)	Interior depth (cm)	Function
3	0.88 x 1.01		Furnace
4	73.5 x 72		Metallurgical
5	1.57 x 1.18		Metallurgical
6	0.74 x .90		Unknown
7	1.99 x (s) .84, (n) .82 (c) .28		Unknown
8	0.97 x .86		Unknown/ Storage (?)
9	2.13 x 1.16		Metallurgical - melting
856	1 x 1.4	10cm	Basin
869	0.87 x 1.8	35cm	Basin
876	0.80 x 0.71	50cm	Rock Installation
898	0.39 x 0.86	10cm (w)	Installation
884	0.22 x 0.27	52cm	
884+pedestal	0.40 x 0.43	52cm	

Cells 3, 4, 5, and 9 were assigned to Layer F2a. The fill inside the first three cells consisted of a reddish sediment mixed with heavy traces of chipped shale followed by a compact layer of mud. All three cells appear to have been filled with the chipped stone sediment in antiquity. Few finds, mostly fragments of bellows pipes and tuyères were located in association with small pieces of copper metal. In cell 3, a furnace base was found along side partially complete pieces of bellows pipes and slag (Fig.5.22). In cell 4 (Loci 812 and 817) small pieces of copper metal, bellows tube fragment and one prill were found.



Fig.5.22: Area F, Cell 3, a possible furnace base (according to the area supervisor) and a clay bellows pipe.

Cell 5 (Loci 833, 875 and 878) has no wall separating it from the main rooms of the workshop. It yielded one furnace fragment and one piece of charcoal. Cell 9, also assigned to Layer F2a, had concentrated ash, and includes the best evidence of melting activity. The loci associated with this cell are Locus 842, Locus 883, Locus 895, and Locus 901. Many types of artifacts including copper metal, anvils, glassy slag, ceramics, special pottery (EDM 20413, 20593), tuyère fragments and worked stone were recovered from this area. Adjacent to the cell is a large rock-lined basin (Locus 869) and a stone installation (Locus 876) (Fig.5.23). The basin contained traces of copper and slag on the inside. Complete bellows pipe were recovered next to the

basin. A stone installation was located next to the basin, without any direct evidence of production or processing activity.



Fig.5.23: Partially exposed basin with evidence of copper melting (Area F, Cell 9). Note the fragment of bellows pipe located above the basin.

A separate activity area was around a basin located in Room 1 (Fig.5.21). The basin was situated next to a fire installation containing traces of ash. Significant pieces of copper metal and bellows pipes were recovered in-between the basin and the rock-lined installation.

Another set of installations was uncovered outside the main structure along the north wall. This consisted of two features, a fire installation (Locus 898) comprised of a poorly constructed semi-circular hearth and a standing stone (L 884). It is not clear

whether the two installations are related. The standing stone is unique and was interpreted as a possible altar or a specialized utilitarian surface and part of the metal working in this area. A unique pottery fragment from a fenestrated stand was found in Layer F2a has similar characteristics to the pottery from the 7th century BCE Edomite shrine of ‘Ain Hazeva. This may also indicate some kind of cultic activity associated with the Area F workshop. A similar fenestrated stand was found in Area A (Levy et al., in press-b)(Levy et al in press). Both samples are dated to the late 10th c. BCE. A similar fire installation to L. 898 was found in Room 1 (Locus 820) together with ash pockets, fragments of bellows pipes and ceramics. Nearby, a white sandstone basin with burning marks was unearthed (Locus 856).

Layer F2b is mostly represented in the main two rooms of the building. The working surface of the workshop was built by leveling up the original slope at this location with compact mud. Cells 6, 7 and 8 are associated with this layer. Although they had similar fills to cells 3, 4 and 5, they were part of the original construction of the building walls (Fig.5.24). The separation between Layers F2b and F2a probably represent slight changes in the organization of the workshop and some additions of installations and maybe intensification of activity.



Fig.5.24: Cell 7, one of the original installations of the metal workshop at KEN Area F (Layer F2b).

In summary, the metal workshop of Area F presents a unique architecture and artifacts that are different from all the other buildings excavated at KEN. The building was constructed on top of some slag layers indicating earlier smelting activities in this area or nearby (Layer F3). Slag continued to accumulate, in particular against the southern wall of the building, indicating continuous smelting activities adjacent to the workshop itself (Layer F2). The main phase of activity in the workshop was during the late 10th and early 9th centuries BCE and included the construction, initial working (Layer F2b), some organizational changes and the addition of installations (Layer F2a). These installations are unique in the entire excavated assemblage of KEN architectural features. This is augmented by the high concentration of clay bellows

pipes (they are extremely rare in the 'typical' metallurgical deposits or 'slag mounds'). This interpretation of the metallurgical work in Area F is based on field observations and the analysis of the artifacts themselves (see Chapter 7).

Area S: Rectangular building, slag processing?

The excavations at Area S (supervised by Lisa Soderbaum) exposed a rectangular building, metallurgical deposits surrounding it and some deeper layers related to copper production (Table 5.3). The Area is located near the GMM excavation Area and between the massive structures of Areas T and R (Fig.5.16). It was selected for excavation in order to retrieve a better stratigraphic record of this portion of the site (Smith and Levy, 2008).

The main use of the building is represented in Layer S2b, with minor changes and additions in Layer S2a. Layer S3 consists of crushed slag horizons which were the foundation deposits for the building, and Layer S4 consists of minor metallurgical activities and mostly domestic debris (cooking and other installations). Based on radiocarbon measurements (Higham et al., 2005) the building dates to the mid-9th century BCE, probably similar to the nearby structure excavated by Fritz (1996).

The building in Area S measures 15.4 x 8.4 m and was visible on the surface before the excavations (JHF, 2002 field season) (Fig. 5.25). The building is semi-

subterranean and consists of four rooms. The activities associated with the building were identified as metal processing including casting (clay casting mold of a goddess, maybe Hathor, copper chunks, copper prills), and crushing (various ground stones).

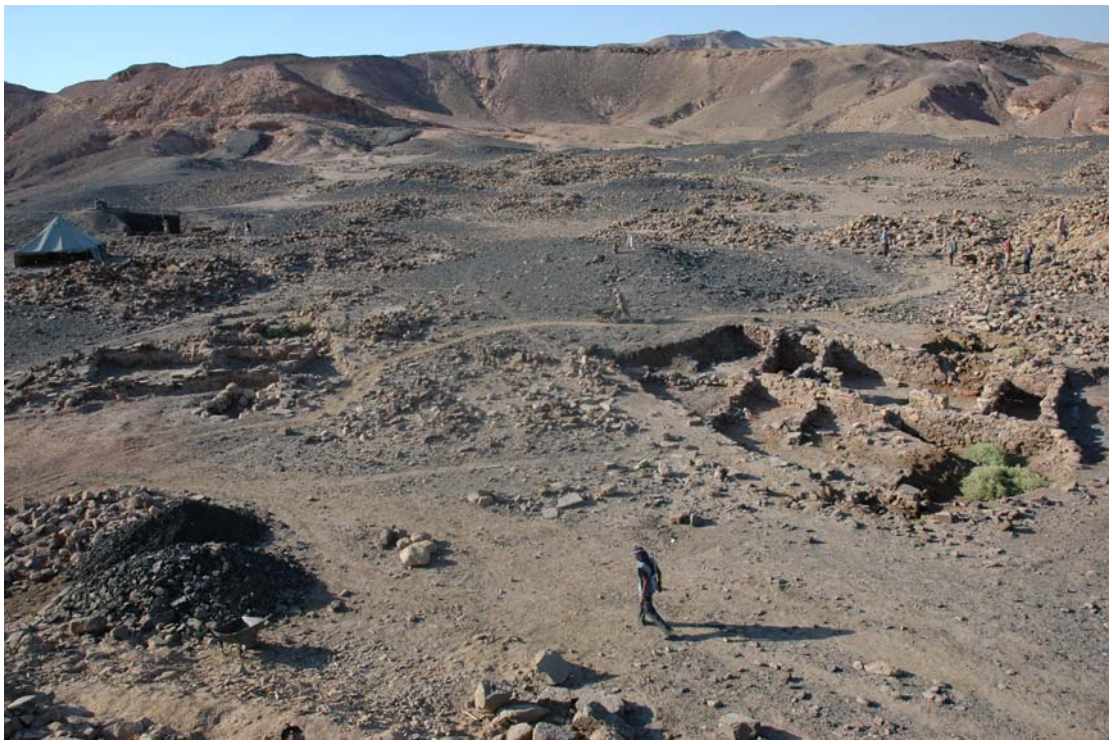


Fig.5.25: KEN Area S (right), a 9th century BCE building complex related to casting and other copper production activities. In the left side of the picture Area M (back) and the GMM excavations (front) are visible.

Area T: A large non-industrial structure; elite facility

A large Iron Age structure constructed with thick exterior walls encompassing five rooms (one of which is a stairwell probably for a 'tower' or second floor), and a large interior courtyard was unearthed during ERLAP 2006 field season (the excavations were supervised by A. Muniz) (Fig.5.26). The structure has two occupation floors with numerous samples of carbonized wood and seeds and minute

traces of metal production. The first phase indicates the structure was designed and constructed on a layer of crushed slag over an area that had previously been used in earlier periods (Fig.5.27). The second phase consists of paving stones covered with compact mud throughout the courtyard.



Fig.5.26: The large building of Area T, KEN (photo courtesy of ELRAP-LAL).



Fig.5.27: Thick layers of crushed slag and other copper production debris beneath the foundation of the large structure in Area T, KEN (photo courtesy of ELRAP-LAL).

The interpretation of the structure primarily relates to supervision of the metal working at KEN. Room 1, the stairwell that may have been a tower (Fig.5.28) overlooks the interior of the site of Khirbat en-Nahas and may have served as a lookout. Room 2, with its small area appears to have been a storage area, Rooms 3 and 4 are much larger in size and might have been living or administrative quarters. Room 5, at the far end of the courtyard, is enigmatic, and contains dark grey ash associated with a fire installation that may be related to some minor metallurgic or domestic activity. The courtyard was most likely the center of activity in the structure.



Fig.5.28: Area T, Room 1 ('tower'). A stairwell leading to a second floor is well preserved. The crack crossing the four lower steps (A) as well as other evidence indicates destruction by an earthquake (probably after the structure was abandoned) (photo courtesy of ELRAP-LAL).

The evidence-or lack of artifact evidence- indicates the structure, like all the others excavated at KEN, was abandoned before its destruction. Evidence from the walls, stairs and the main corners indicate that the structure was destroyed by an earthquake, probably after it was abandoned (Fig.5.28A). The majority of collapse from the walls appears to have fallen in an east to west direction.

Area R: A massive non-industrial structure (supervision?), and a metallurgical complex

Area R was excavated during ELRAP's 2006 (supervised by Y. Arbel) and 2009 (supervised by M. Beherec) field seasons. It consists of a massive structure that has been interpreted, similarly to the structure of Area T, to be related to supervision of the metal production activities at the site and/or a residential complex for a high ranked local person. This is one of the largest structures at the site, situated in a central position (Figs.5.16 and 5.17), and surrounded by a rectangular fence (Fig.5.17). A

deep probing in the courtyard (a strip excavated between the structure's gate and the exterior fence) revealed an intricate complex related to metal production (Fig.5.29).



Fig.5.29: Area R at the end of ELRAP's 2006 field season. In front of the massive structure a metallurgical complex was unearthed. In the foreground of the photograph is an unexcavated 'accumulation' (Locus 1850) that was subsequently excavated during the 2009 field season and found to be a dome-shaped installation, probably a furnace or a slag pit (see Chapter 7 for further details) (photo courtesy of ELRAP-LAL).

Layers R2a and R2b represent the main occupation phase of the building and Layers R3a and R3b the copper production complex excavated in the probing of the courtyard (Table 5.3). Both contexts, the structure and the metallurgical complex, were further exposed during the 2009 field season (Fig.5.30). The basic stratigraphic scheme still holds. The structure in Area R has similar characteristics to Area T, including a stair-well and other defensive / supervision elements. A unique bench

made of huge boulder has been exposed to the north of the doorway, attached to the exterior wall of the building.



Fig.5.30: Area R at the end of the 2009 excavation season; note the metallurgical complex at the front of the structure and the perimeter wall / fence (photo courtesy of ELRAP-LAL).

In fact, all excavated parts of Area R contained layers of copper production waste. Probes inside the main structure showed that it was founded on top of compact fine crushed slag (Loci 1829 and 1844). Crushed or broken slag have been exposed in all contexts of the courtyard, right below the surface, in addition to a scatter of large slabs of tap slag on the surface itself, and under the debris of the main structure's outer walls. The main probe in the courtyard area exposed a complex arrangement of walls and metallurgical deposits related to the smelting of copper. Its stratigraphic situation and its connection to the structure were not entirely clear: "No final conclusions could be reached regarding the exact stratigraphic and functional lay of the slag." (Levy et al., in press-b); however, the basic assumption has been that the metallurgical complex in front of the Area R monumental building represents an earlier phase of activity in this area, precluded by the construction of the massive structure (Table 5.3). A careful study of the metallurgical deposits conducted as part of the current research (Chapter 7 and 8) shows that the technology represented in the Area R probe is the most advanced and belongs to the last phase of Iron Age production (smelting) in the Arabah Valley during the 9th century BCE. Thus, we suggest here a different stratigraphic outline, in which the metal production debris relates to the last occupation phase at KEN, and is later than the final occupation phase of the structure. This conclusion entails a complicated stratigraphic layout in Area R, first suggested by M. Najjar based on field observations, that was formed by the Iron Age inhabitants digging pits designated for disposal of metallurgical waste. The radiocarbon data (Levy et al., in press-b) support either of the options.

Intact installations or bases of installations, probably furnaces, were unearthed very close to the surface level in the courtyard in front of the entrance to the monumental building (Figs.5.29 and 5.30). Numerous furnace fragments were unearthed in the probe, including many examples imprinted with the fingerprints of the builders, as well as pieces on which slag, charcoal and tuyère fragments remained attached. Large quantities of tuyères were also discovered, among them an unusual number of completely preserved artifacts, often with slag attached to the ends. In one relatively narrow locus (Locus 1847) tuyère fragments, several of them intact or nearly intact, comprised a substantial volume of the overall fill that also contained slag and large pieces of furnace fragments. Crucibles, molds and other melting/refining vessels were almost completely absent (similar to Area M).

Thick layers of slag of various types dominate the massive fill that covers an architectural complex (Layer R3b) also discovered below the surface of the Layer R2b courtyard. However, the sections in the probes show that the disposal of the slag was not random. The slag fill (Locus 1833, Locus 1845) within the irregular ("oval") chamber (of which three walls have been exposed) is arranged in diagonal layers, ca. 45 degrees declining from the northeast to the southwest (Fig.5.31).



Fig.5.31A: Well organized fills of slag and other metal production debris exposed in Area R. The walls of the compounds into which the waste was dumped are made of local small stones (and often pieces of large slabs of tap slag, like the wall in the far right side of the picture above). The new interpretation of the stratigraphy, based on technological insights, suggests these oval installations were deliberately dug into the ground in the 9th c. BCE (photo courtesy of ELRAP-LAL).

The distinct diagonal layers disappear outside the perimeter of the chamber, where the slag fill becomes random and mixed. Different type of slag fills has been noted in the opposite section. There fine layers of crushed slag dominate the area between the frontal wall of the Layer R2b building (Locus 1800) and wall Locus 1851, which cuts across the probe in the courtyard on a southeast-northwest axis (Fig.5.31). Beyond that point slag fill becomes again mixed and indistinct.



Fig.5.31B: Different types of slag fill in Area R. The ramshackle walls made of local stones and slabs of slag were used as retaining facilities to accommodate the metallurgical debris (photo courtesy of ELRAP-LAL).

The previous interpretation of the walls in the metallurgical deposits of Area R, as a kind of architectural complex that became obsolete and only then used as disposal area (Levy et al., in press-b) should be revised in light of evidence from other, contemporary archaeometallurgical sites, such as Timna 30 (Rothenberg, 1990a). At Timna 30 there is evidence for the deliberate construction of frail walls to create compounds for discarding of metallurgical waste, and the walls of Area R should be interpreted in the same way. The thin and roughly built walls, creating spaces of irregular shapes, were deliberately built for the well organized dumping of metallurgical waste. According to the new stratigraphic insights mentioned above, some of these compounds were dug into the ground. The intact installations were all

concentrated in one space delineated by the feeble walls; most of the installations were attached to these walls and it was clear that the ancient copper workers used the walls to support parts of the installations (see also Chapter 7). In light of this new interpretation, Layers R3a and R3b should be considered as a single context where R3b represent only a short construction phase of the walls and not a distinct occupational phase. The loci of both Layers are summarized in Table 5.6.

In a different context just opposite the designated area for crushed slag disposal there was a large concentration of tap slag, ca. 50 cm below the surface level of the courtyard. This has been suggested to be the source of the crushed slag, but probably the furnace slag were more adequate for this purpose, while the tap slag were left intact for other purposes (building, etc.). Non-smelting related finds from the metallurgical complex of Area R were overall poor. The assemblages from this context consist mainly of copper production related artifacts such as the waste materials and affiliated objects such as hammer stones (dimpled and plain), grinding slabs and mortars. Pottery was relatively scarce and consisted of sherds of rough container vessels, many of them locally made as indicated by the slag inclusions. The fine wear examples discovered on the superimposed surface of the Layer R2b courtyard totally disappear in earlier layers and may imply that the metal production took place *after* the building was abandoned.

Table 5.6: Locus summary of Layers R3a and R3b of KEN Area R – the metallurgical complex

Locus	Description
1810	Ashy fill with slag
1823	Ashy fill with slag
1828	Crushed slag layer
1829	Crushed slag layer
1830	Ashy fill with slag
1833	Slag layer inside round room
1842	Tap slag and crushed slag layer, courtyard
1844	Probe into slag layer in chamber
1845	Slag layer inside round room, probe
1846	Ashy fill with slag
1847	Copper industrial waste accumulation
1848	Ashy fill with slag
1849	Slag layer
1850	Furnace material concentration
1835	Wall, round structure
1836	Wall, round structure
1837	Wall, round structure
?	Wall, under courtyard level
1852	Wall, under courtyard level, connecting L1837-1851
1853	Compact ash lens

The sub-surface walls, previously considered as a separate occupation layer (Layer R3b), created an oval chamber (ca. 3.2 m in diameter) in conjunction with some rectangular spaces (delineated with ca. 5 m or longer walls, and connecting short walls in between). All walls consist of a single row made with local stones roughly laid and possibly with some clay consolidations in between. As might be expected with designated disposal areas for metallurgical waste, no surfaces were identified in the foundation levels or above them. A limited probe excavated below the walls revealed layers of crushed slag, probably representing an earlier phase of copper production at this area.

Within the bottom courses of the central part of wall Locus 1836 of the oval chamber is a rectangular vertical space ca. 60 cm tall consisting of three courses of building stones on each side and a flat stone serving as lintel. The resulting space is ca. 40cm wide. The outer outlet of this opening has not yet been exposed and the function of this element is not clear.

The wide exposure of smelting and metallurgical waste disposal in Area R help to reconstruct the spatial distribution of the smelting activities of the advanced technological phase, probably of the 9th century BCE. The well arranged space, including divisions by roughly built walls (preserved up to 10 courses high) and the distribution of the various types of metal production artifacts, suggest a well planned smelting workshop and a complex organization of labor at the site. Further discussions follow in Chapter 9.

Area W: A building complex

Area W was excavated during ELRAP's 2009 field season (supervised by A. Muniz). It is situated in the most southern portion of KEN and consists of three building complexes that seem to represent a range of functions including residential, storage and living space, and possibly some cultic activities as well (Fig.5.32). The eastern building (ca. 8.75 x 15.5 m) consists of three storage rooms with middle complex consisting of seven-room structure attached to it. These smaller rooms

surround a courtyard. The layout of this area coupled with special architectural elements and some cultic finds have led us to ascribe a ritual function to this part of the complex. The western most building is somewhat smaller (ca. 8.5 x 14.5 m) and is also dominated by a rectangular courtyard. Here the courtyard is surrounded by seven small rooms. The presence of domestic artifacts including an oven (tabun) and absence of metallurgical remains in both these building complexes, suggest that Area W was a residential area with minor cultic function - possibly for non-elites resident at KEN. A limited probe in the 'corridor' between the two building (Fig.5.32) exposed some metallurgical deposits including massive slabs of tap slag.



Fig.5.32: Area W at the close of ELRAP's 2009 field season. Two buildings and a probe in the 'corridor' between them are visible (see text for details).

5.2.4.2 Area M: Deep sounding of a ‘slag mound’, a building complex and stratigraphic key for KEN

Area M consists of a deep sounding into one of Khirbat en-Nahas’s typical ’slag mounds’ and a wide exposure of an adjacent building complex in the southeast of the site (Figs.5.16 and 5.17). The ‘slag mound’ was first excavated to a depth of about 1 m in 2002 (supervised by E. Monroe), and probed all the way to virgin soil in 2006 (supervised by M. Beherec and the present author). The main goal of the deep sounding was to examine Iron Age copper production through time by exposing artifacts from different diachronic contexts. Other goals were to clarify the chronological framework for Khirbat en-Nahas in general by exposing and dating fine sequences of culturally and ^{14}C-rich deposits from surface to the deepest layers. A corner of a room was exposed underneath the ‘slag mound’ already during the 2002 field season; in 2006 it was found to be part of a large building complex described below .

<u>The 2002 probe of the ‘slag mound’ in Area M</u>

The results of the 2002 excavations at Area M complement the data from the deep sounding of the 2006 field season. They are particularly interesting because they represent the latest phase of copper production at Khirbat en-Nahas and correspond to the most advanced Iron Age technological achievements (Chapters 7-9 below). The

original probe was a 2.5 x 5 m rectangle located on the northwestern slope of one of the large 'slag mounds' in the southeastern part of Khirbat en-Nahas (square GGG27 in the general grid of the site). An extension of 0.5 m to the east (square HHH27) was added during the excavation in order to fully expose a furnace feature. The original surface of the 'mound' was covered with large slabs of tap slag and fragments of tuyères, indicating extensive smelting activity in this area (or adjacent to it), corresponding to the last phase of occupation. Although the GMM team had dug limited probes into several such 'mounds' (e.g., Hauptmann, 2007) at the site (and in other Iron Age smelting sites in Faynan), this is the first time that an attempt to carefully examine the stratigraphy of such mound is done using state-of-the-art archaeological field methods[36].

'Slag mounds' constitute the primary type of archaeological deposits in the smelting sites of the southern Levant (and elsewhere) and thus investigation of their composition and formation processes is important for understanding the smelting sites in in both technological and socio-economic context. In particular, some basic assessments regarding the amount of processed ore and copper produced in the smelting sites are based on estimations of volumes and contents of such 'slag mounds', usually with the assumption that the main component of the mounds is slag material (e.g., Hauptmann, 2007). This assumption has been found to be incorrect (see below), and as will be shown here, the detailed investigation of the 'slag mound' in

[36] The GMM probes were shallow, roughly dug, and loosely recorded intended primarily to collect slag and charcoals for analysis in the laboratory.

Area M resulted in detailed descriptions of what we consider to be a 'typical' slag mound.

At the beginning of the 2002 field season, virtually every single artifact in Area M was recorded separately with the JHF-ELRAP digital recording system (see section 5.2.1 above), resulting in a very slow excavation. Only later in the 2002 excavation season was it decided to collect the bulk of the furnace and tuyère fragments in general baskets. In addition, the southeast corner of the probe was used as a control area for measuring the amount of slag in the area as a whole. Slag was collected from the entire excavated area and then sorted (large furnace slag, small furnace slag, large tap slag, small tap slag, and granule) and weighed. In the 1 x 1 meter control area, however, all of the sediments were sieved, and the sieved material was sorted. All of the slag from this control area was kept, including the very small pieces of crushed slag, and was subsequently weighed. This method was used in order to provide a better understanding of how much slag of all sizes was found in the area overall.

In order to differentiate distinct horizons of smelting activity, contexts with large tap slag fragments were used as a marker, assuming that each of such concentration represent one smelting cycle. This was more a convenience for separating the layers than a real reconstruction of activity, but it has proved itself useful. Utilizing this model, we were able to determine six distinct smelting horizons

throughout the excavation area as well as a seventh, lower activity layer of slag crushing.

Three preliminary 'contexts' were excavated in 2002 at Area M, of which context Ib represents the metal production debris and consists of seven different horizons[37]. Context Ia consists of two small installations, which are probably intrusive and later than the copper production horizons excavated in 2002. The production horizons, the fill directly underneath them, and the fill and rubble in Room 1[38] represent context Ib. The occupation layer of Room 1 represents context IIb. The fill under the surface of Room 1 represents context III.

Context Ia has two small stone installations visible on the surface in the northwestern part of the excavation unit. These were excavated as part of L. 506. Note that furnace debris associated with the third horizon of smelting activity and located in between these installations and W. 519 was also excavated in this locus. One installation was semi-circular with a diameter of ca. 60 cm. It was made up of six stones with one large flat stone in the middle. The stones and material surrounding the installation appear to have been burnt. A hammer stone was found associated with the installation (EDM # 80169) that possibly had charred ore attached to it. Tap slags were found that seem to have been part of the construction of this installation. Ca. 20

[37] We use here 'contexts' and 'horizons' to avoid confusion with the terminology of the 2006 field season. In the original field report of E. Monroe, 'context' is a Stratum and horizon is a 'layer'. As mentioned above, all of the 'contexts' and 'horizons' excavated in 2002 are part of Layers M1 and M2 of the 2006 excavations.

[38] In the original 2002 field report this is Room 5.

cm to the northeast of this installation was a line of five stones (ca. 40 cm. in length) that may have been used as a retaining wall. It appears from the excavation of the furnace debris to the east of the installations that these were later intrusive features, although it is possible that they are associated with one of the horizons of smelting activity (probably the third).

Context Ib has six horizons related to copper smelting and one horizon of crushed slag (Table 5.7, Fig.5.33). The smelting horizons were distinguished by high concentrations of furnace and tuyère fragments, slag, ash, and other artifacts related to copper smelting (Fig.5.34). Weights of tuyère and furnace fragments are summarized in Fig. 5.35. As mentioned above, tap slag fragments were used to distinguish the bottom of these horizons. The slag crushing horizon was a very hard patch of fine crushed slag with low a low concentration of metallurgical ceramics. Below this sequence, a fill horizon was distinguished by a relatively low concentration of slag, ash, and metallurgical ceramics, and a higher amount of pottery and bone than in the production layers above.

Table 5.7: Area M, 2002 excavations, metallurgical horizons in Context IIB (corresponding to Layer M1/M2a of the 2006 excavation season) (cf. Figs.5.33 and 5.34)

H.	Description
1	The bottom of the first smelting horizon was defined by the tap slags located on the surface of the excavation area. Evidence from the first smelting horizon was collected in L. 501 and 513.
2	The second smelting horizon consists of L. 502, 503, 505, 507, 514, and 515. The bottom of the smelting horizon was determined by large tap slags. Most of the furnace and tuyère fragments found were fragmented and not very well preserved. The southern part of the probe was somewhat ashier and had a higher concentration of metallurgical ceramics. Many of the furnace fragments were charred. Several large fragments were found in situ in the northeastern part of the probe, but these were unfortunately removed before they were properly recorded. These fragments were probably the in situ remains of a furnace that had been broken during the smelting process in order to extract the copper from inside.
3	The third smelting horizon consists of L.504, 506, 508, 509, 510, 517, and 518. The bottom of the smelting layer was determined by large tap slags. As in the second horizon, there was more ash and a higher concentration of metallurgical ceramics in the southern part of the probe. In the fourth horizon, separate loci were opened for the northeastern area and for the southern and western areas in order to show this differentiation. The northeastern part of the probe was excavated separately (L. 504) in order to attempt to discern more of the furnace that was removed in the locus above (L. 507). This was not possible, but another, better preserved in situ furnace was discovered directly to the south of the first one. This furnace and the furnace debris directly associated with it were excavated as part of L. 510. The intact part of the furnace was semi-circular in shape and had an interior diameter of ca. 70 cm. The walls of the furnace were 15-20 cm in width and preserved to a height of 20-30 cm. The furnace extended into the eastern balk of the probe, and accordingly the probe was extended half a meter east into square HHH27 (L.517). The furnace, however, was not preserved more than a few centimeters into square HHH27. Inside the furnace was an extremely high concentration of furnace fragments with almost no sediment. Under these was ashy sediment with a very high concentration of charcoal. Some wood was also found and collected (EDM # 80337). The bottom of the furnace was not found probably because it was ripped out after the smelting in order to extract the copper. Large tap slags were found directly under the furnace.
4	The fourth smelting horizon consists of L. 511, 512, 516, and 526. The bottom of the smelting horizon was determined by large tap slags. Separate loci were given for the northeastern (L. 512) and southern and western (L. 516) areas in order to distinguish the difference in ash and metallurgical ceramic concentration between the two (the southern and western areas appeared to have somewhat higher concentrations than the northeastern area).
5	The fifth smelting horizon was collected in L. 522, 524, 526, and 528. The bottom of the smelting layer was determined by large tap slags. The furnace and tuyère fragments in this horizon (and the sixth) were larger, less fragmentary, and better preserved than those from the later horizions above. In the northeastern area (L. 522) several cut stones were found similar to those used in W. 519 and W. 520. It is possible that these are rubble from W. 520 and represent the destruction of the wall. If this is indeed the case, L. 521, which is fill and rubble inside Room 1is probably contemporary with the fifth smelting horizon.
6	The sixth smelting horizon was collected in L. 523, 529, 530, 531, 535, 536, and 538. The bottom of the smelting horizon was determined by large tap slags. Because of difficulties in following the exact layers due to the slope of the unit and the layers within the unit, the western part of L. 531 and 536 probably represented the 5th horizon instead of the 6th. Horizon 6 was excavated in the western part as L. 538, although again due to difficulties determining the slope of the horizons, part of the 5th horizon was excavated within L. 538.

Table 5.7 continued

H.	Description
7	A horizon of fine crushed slag consists of L. 530, 533, 535, 537, 539, and 540. This horizon had a much lower concentration of metallurgical ceramics. A thin layer of ashy sediment with much looser crushed slag was found directly on top of a ca. 5 – 10 cm layer of extremely hard packed crushed slag. The crushing activity is more prominent in the southern area. There is some evidence of crushed slag in the northeastern part of the probe (L. 533), but none in the northwestern part. Directly under the crushed slag, a significantly greater amount of pottery and bone was found. Also, directly under the crushed slag in the 1 x 1 meter control area (L. 540) a thin lens of decomposed organic material was found. Several large fish vertebrae as well as small pieces of textile (EDM # 80711) were collected from this lens.
Fill	A fill horizon that does not seem to be directly related to production activities was found under the seventh production horizon. This fill consists of L. 532, 541, 542, and 543. The fill was a medium brown silt with some ash although much less than in the production horizons. There was significantly less slag and metallurgical ceramics than in the production horizons and more pottery and bone. Because this fill marked an end to the first levels of production in the excavation area, all excavation in the probe was ceased after excavating only ca. 10 cm into this horizon.

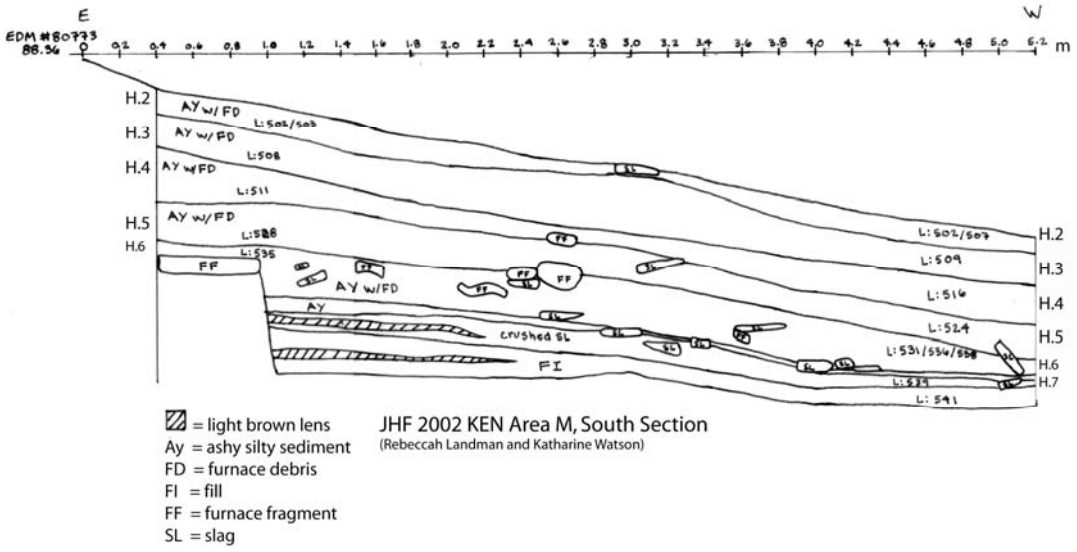


Fig.5.33: Section drawing of the upper portion of the deep sounding into the 'slag mound' of Area M. This part was carefully excavated during the 2002 field season (Context Ib) and seven horizons (H) of metal smelting cycles were identified (cf. Table 5.7). Note the intact furnace base on the east side of the section.

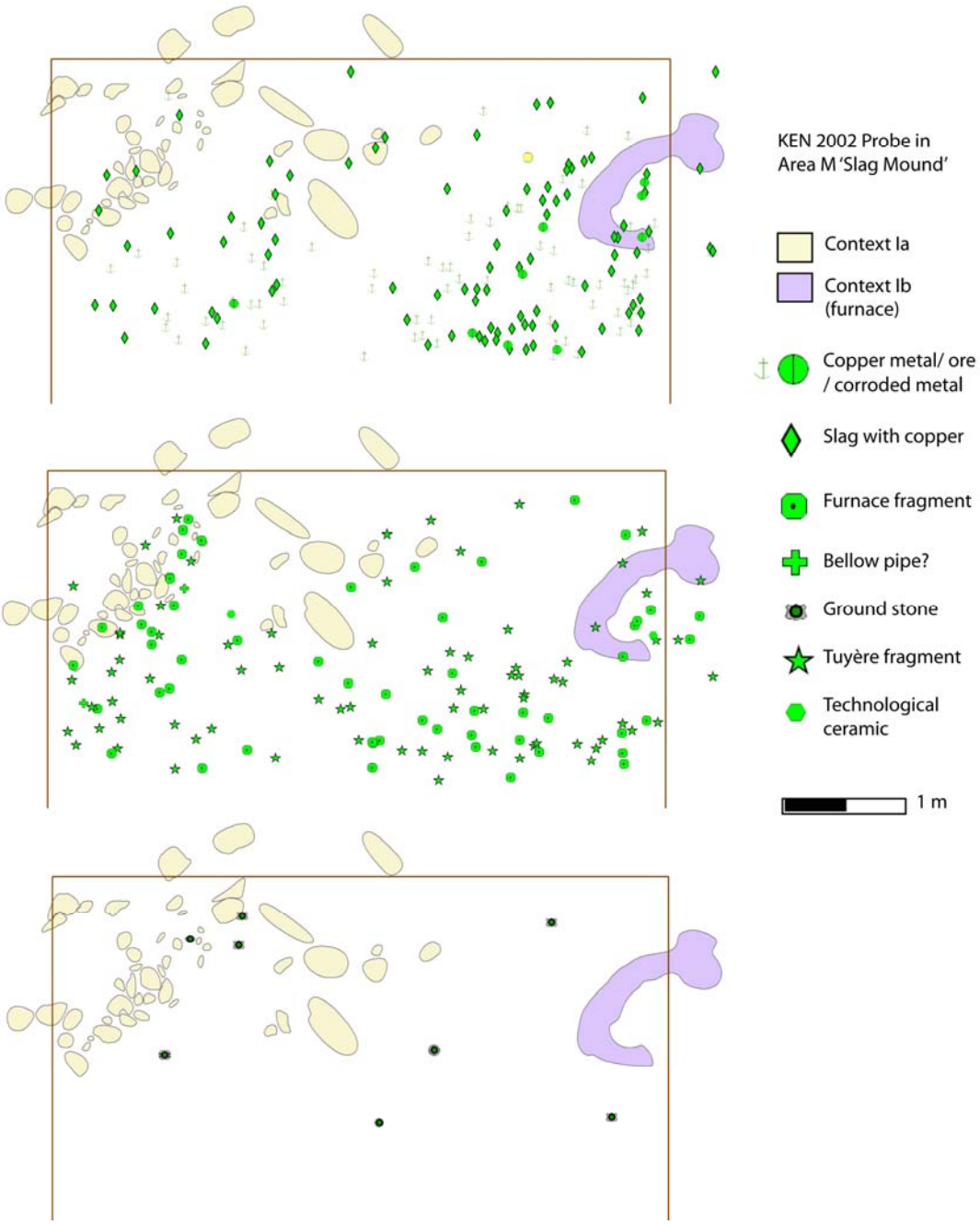


Fig.5.34: GIS map of the 2002 probe into the 'slag mound' at KEN Area M. The ephemeral installations of Context Ia and the furnace base of Context Ib are shown together with the distribution of various metal production related artifacts. Note that not all of these artifacts were collected as separate finds, thus the maps represent the upper horizons only (see text for detail) (figure prepared by E. Monroe).

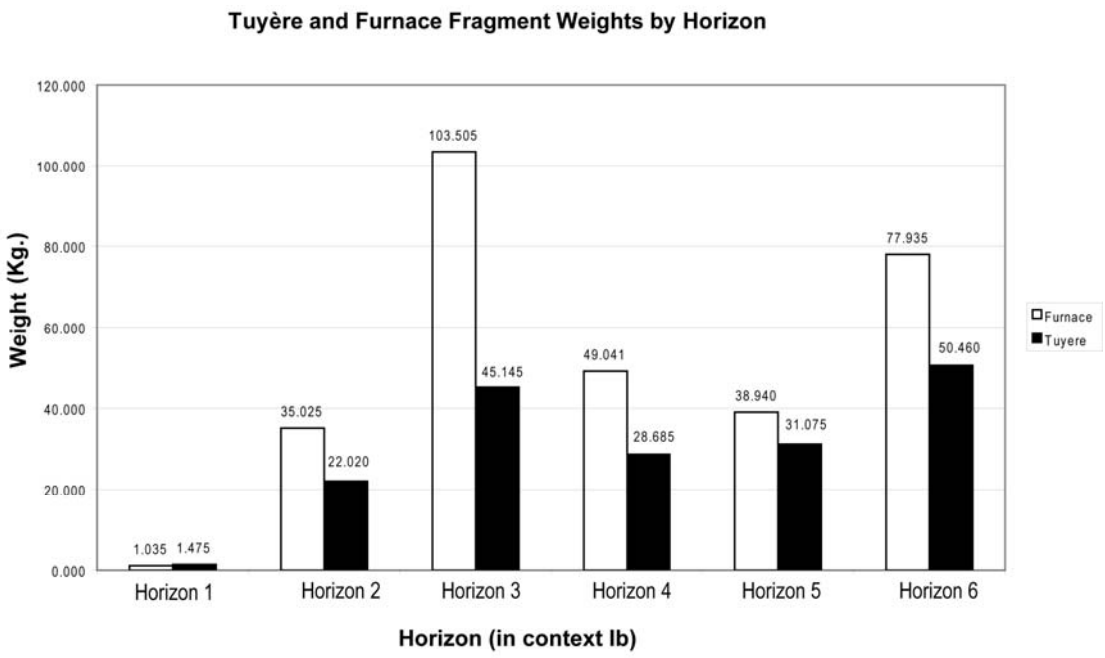


Fig.5.35: Weights of tuyère and furnace fragments by horizon (KEN, Area M, 2002 season); total weight of tuyère fragments = ~179 kg; total weight of furnace fragments = ~305.5 kg) (see also Chapter 7).

Context IIb of the 2002 excavations in Area M represents the occupation level of the structure, of which only one small corner was exposed (cf. Layer M2 below; Context II represents the collapse inside the room). Room 1 was defined by walls W. 519, W. 520. It has been concluded that the room pre-dates the production horizons (Context Ib) because of the wall collapse found in the 5th horizon of production and the fact that the occupation layer of the room is ca. 1 meter lower than the last production horizon excavated.

Wall 519 runs from northwest to southeast and meets with Wall 520 at its southern end to form the southern corner of Room 1. It is preserved in this location up to eight courses (ca. 1.05 meters in height) on its outer side and to up to twelve courses

(ca. 2 meters in height) on its inner side. It is ca. 1.90 meters in length and ca. 39 cm thick. The wall is primarily made of well-cut stones that range from ca. 16 x 11 cm to ca. 46 x 19 cm. A grinding slab (EDM # 80649) was found on the wall at its northern end. This was probably not part of the original wall, but was placed there later after the wall ceased to support the building. Wall 520 is preserved up to six courses (ca. 0.95 meters in height) on its outer side and up to eleven courses (ca. 1.85 meters in height) on its inner side. It is ca. 2.06 meters in length and ca. 37 cm thick. Like Wall 519, it is primarily made of well-cut stones. The size of the stones ranges from ca. 14.5 x 10 cm to ca. 57 x 16.5 cm. There is also one very large stone measuring ca. 84 x 30.5 cm.

The exterior of both walls of Room 1 appear to have been burnt as evidence for smelting extends right up to them and the stones demonstrate heat impact. Under the production horizons outside the room, reddish silt was found adjacent to both walls. This was excavated as L. 532 next to W. 520. There were almost no finds in this locus, and after ca. 10 cm of excavation, it became very hard and densely packed. It was thought that it could be a surface, but it only extends from the wall 15 – 20 cm. Another possibility is that it is part of a mud brick installation or a mud brick superstructure along the walls. A sample of it from west of W. 519 was collected to be analyzed (EDM # 80744).

Inside Room1 was a thick layer of buff, slightly ashy silt with much stone rubble. This probably corresponds (in time) to the production horizons excavated and may represent a deliberate infilling of the building. Underneath this layer was reddish silt that was a fill on top of an ashy hard and densely packed surface (L. 525 and 527). This surface corresponds with the bottom of the walls and is probably the only occupation surface for the room. Context III of the 2002 excavations in Area M is represented by the material under the occupation surface of Room 1. It consists of L. 534. The fill was very ashy with an extremely high concentration of slag but few other finds. It extended for at least a meter beneath the surface. Excavation was ceased when a large furnace fragment that extended into the north balk made further excavation impossible (cf. description of Structure 1, Room 1 and the Southern Probe from the 2006 excavation below).

The results of the 1 x 1 m 'control area' for precise measurement of slag (weights by basic types) are summarized in Table 5.8. The excavated volume is approximately 1 m^3 (the depth of the probe in the southeastern part is approximately 1 m). This volume contained 1152 kg of slag material. Given an average density of 3000kg/m^3 for slag material (more or less similar to solid basalt), out of the excavated volume (which consisted mostly from smelting debris, without 'fills' of domestic quality such as the one exposed beneath the lower horizon), only ca. 38% was slag (vol.-%). This calculation of slag concentration (volume) results in even lower values when the entire sounding is evaluated (see below).

Table 5.8: Weights of slag fragments (in Kg) per locus in the 1 m^3 'control area' of the 2002 probe in the 'slag mound' of Area M; note that type definitions is slightly different from the 2006 field season and include 'crushed' (patches of compact and hard fine-crushed slag), 'granule' (separate grains of fine crushed slag), furnace slag and tap slag in two different sizes.

Locus	Crushed	Granule	Furnace slag	Tap slag	Tap slab	Total
503		31.85	358.43	14.65	8.42	413
508		26.15	30.6	50.74	12.31	120
511		58.79	54.49	58.59	23.96	196
528		32.67	23	32.35	28.85	117
535		8.64	35.41	42.1	11.7	98
540	4.73	32.62	24.53	15.63	1.78	79
543		41.44	33.15	49.26	5.2	129
Total	4.73	232	560	263	92	1152

The ca. 1 m probe of 2002 provides well recorded data of the latest smelting phase at KEN (Fig.5.36). Artifacts obtained directly from the walls of the pit (the exposed sections) were analyzed as part of the current research and demonstrate an advanced technology that belongs to the latest smelting activities (Chapter 7 and 8 below). Radiocarbon samples from Loci 502/503, 511, and 539 (2746±35 BP) (obtained from the walls of the pit) were processed in the Oxford Laboratory and indicate 9th century BCE date for the 2002 excavation contexts (2764±25 BP, 2659±32 BP, and 2746±35 BP respectively); these dates were incorporated into the general age model of Area M (see below).



Fig.5.36: Area M at the beginning of ELRAP's 2006 excavation season. The 'metallurgical horizons' of the upper part of the 'slag mound' were excavated in 2002 and represent the latest phase of copper smelting at KEN. The uppermost horizons are probably later than the building (see text). The reddish sediment adjacent to the wall is Locus 708, possibly decomposed mud brick, was probably placed here to protect the building from the impact of the adjacent smelting activities to the south.

The 2006 excavations of Area M

The deep sounding of the 'slag mound' and the excavations of Structure 1 and parts of the adjacent Structure 2 resulted in the identification of five major layers, replacing the 2002 'micro' stratigraphic division of the 2002 excavation[39] (Tables 5.3, 5.8; Fig.5.37).

[39] In ELRAP's 2002 field season each metallurgical horizon was defined as a separate layer. In 2006 we used loci for such contexts. The excavated materials from 2002 belong to Area M Layers M1 and M2a in the 'slag mound' and M2b-M3 in Room 1 (see above).

Table 5.9: Major stratigraphic units at KEN Area M

2006 Layer	2002 Context	Description
M1a1	Ia	Surface slag, surface installations.
M1a	Ib	Post building abandonment, aeolian sediment accumulation, some metal production.
M1b	Ib/IIa	Post building abandonment, wall collapse and aeolian sediment accumulation, metal production.
M2a	IIb	Last occupation phases of structures, use of plastered outside work area, metal production.
M2b	IIb	'Slag mound' leveled and Structures 1 and 2 constructed.
M3	III	Remains of intensive metal production beneath structures.
M4		Intensive metal production, installation construction, followed by possible abandonment horizon.
M5a		Decommissioning of earliest installation (L.676), construction of new installation (L.673).
M5b		Earliest site occupation, founded on virgin soil. Installation construction (thin horizon of crushed slag).

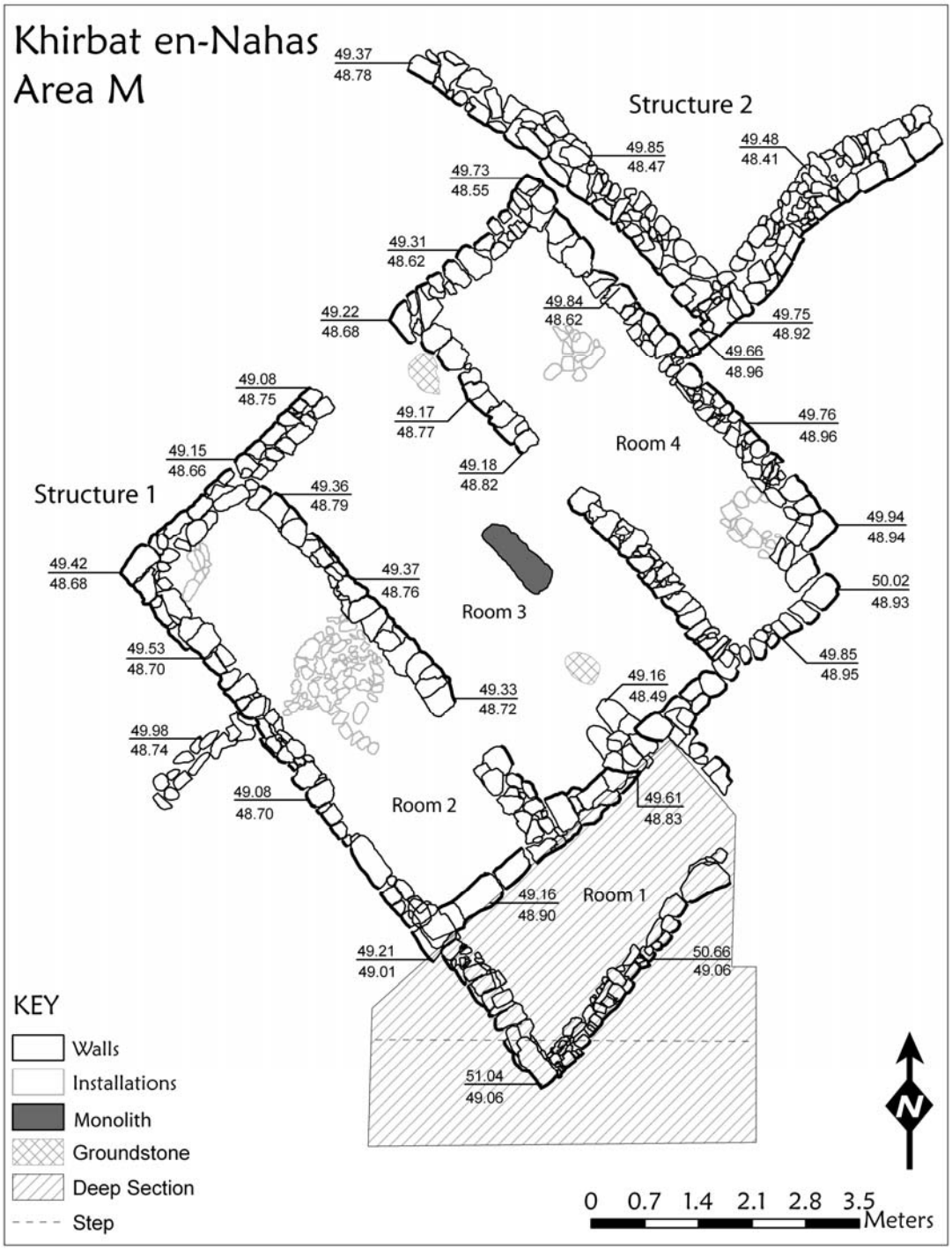


Fig.5.37: Final plan of Area M, Khirbat en-Nahas (2006). Structure 1 (center) is a large 'four-chamber' building with a central courtyard (Room 2). Room 1 was removed to enable extending the probe into the 'slag mound.' The southern portion of the probe (ca. 1.5 x 5m) was left as a 'safety step' as the probe became deeper. Only part of Structure 2 has been exposed.

The results of the 2002 excavations demonstrate that the final metallurgical horizons of the upper portion of the 'slag mound' represent activities that are later than Room 1 of Structure 1. It is not entirely clear whether the other rooms of Structure 1 were still in use simultaneously to the last phases of copper production in the area of the 'slag mound'; however, a blocking of the doorway to Room 1 suggests that it went out of use while the rest of the building was still occupied. Being adjacent to the smelting area, Room 1 suffered the most from heat damage and its walls caved in under the pressure of the accumulated production debris against its northeastern and southeastern walls. The uncovered walls had a steep inclination of more than 15 degrees inward, possibly representing their original dilapidated state while metal production still took place outside of the room and the rest of the building was still occupied. The room was blocked and seems to have become a designated space for dumping copper production waste.

The copper production remains that post-date Room 1 are part of Layer M1. Layer M1a1 is an ephemeral context of surface finds, relating to the very end of metal production in Area M. Huge slabs of tap slag littered the surface of the 'mound', and a fine dust of slag granules also sat atop the aeolian yellow-brown sandy silt and loess. These slabs cover the surface of the entire site and seem to represent a product of the latest production episode during which no further processing of the tap slag was required because of the high efficiency of smelting (Chapters 7-9). The snout of an

equine figurine (EDM # 91279) was found on the surface just outside of Area M and belongs to Layer M1a1.

Layers M1a and M1b correspond to the metallurgical horizons excavated in the 'slag mound' in 2002 (cf. Table 5.9). In the area of Room 1, Layer M1a consists of sediments accumulated after abandonment and of some remnants of metal production. The loci of this Layer (l. 603, 604, 609, 644, 645, 649, 663, 672, 681, 687, 694, 695, 701, 718, 724) consist mostly of aeolian sandy-silt. Layer M1a was excavated in arbitrary loci due to the lack of distinguishing characteristics. Layer M1b consists of wall collapse mixed with aeolian sandy silt inside Structures 1 and 2, often with tap slag mixed in (l. 607, 613, 614, 623, 626, 633, 645, 648, 649, 664, 679, 682, 683, 688, 693, 698, 699, 705, 706, 723, 724, 725). This Layer probably also represents a long period of abandonment, and was found in all of the rooms of both structures. The most interesting example of this wall collapse is in locus 649, in the northern part of Room 2, where several courses of wall locus 632 fell as one. Though the wall seems to have fallen here (an earthquake?), this situation was not replicated elsewhere in Area M. Large numbers of ground stones were uncovered in Layer M1b, in and around both Structure 1 and Structure 2. Most abundant were dimpled hammerstones which were found in great abundance mostly outside the structures.

In Layer M2, intense metallurgical activity resulted in the accumulation of large quantities of broken slag and furnace fragments around the structures. It is

difficult to establish the stratigraphy of these deposits and to precisely correlate them with the activity remains inside the structures. In general, the metallurgical horizons were excavated in arbitrary units, and with less care to minute details as was done in the 2002 excavations (see above). Without this approach, the 2006 team would never have reached virgin soil during the ca. 2 month excavation project. Two distinct metallurgical areas of Layer M2 were excavated. One, Locus 707 (Layer M2a), lay above the floor of Layer M2b working area Locus 717. The other is directly south of the structure, in the core of the 'slag mound'. In this area Layer M2 consisted of Loci 602, 605, 606, 608, 609, 610, 612, 615, 616, 617, 620, 622, 627, and 629. The separation into stratigraphic units in the 'slag mound' was less clear than in the excavations of the structures; loci were distinguished by color and characteristics of the sediments, including different concentrations of archaeometallurgical artifacts.

Near both the northeastern and southeastern walls of Room 1, the closest walls to the metallurgical activity area, there seems to have been an attempt to protect the building from the impact of the smelting process. A thick deposit (L.708) of buff or reddish sediment, relatively free of artifacts, was excavated directly next to the exterior of these walls. This seems to have been an insulation of sorts, perhaps originally mud bricks, and is not found along the other sides of the building (that are not oriented towards the metallurgical area, and neither along the interior of the walls), where metallurgy was not practiced or was practiced to a much lesser degree (Fig.5.36). Eventually the walls did suffer extreme damage from heat. Both wall Loci

618 and 632 were badly impacted, including cracking and discoloration of the stones. As mentioned above, Room 1 may have been abandoned in Layer M2a, with the construction of installation 634 (see Room 1 description below). After abandonment, Room 1 was used for metalworking or more probably as a designated space for dumping metallurgical waste (L. 619) which eventually spilled over the wall and on top of other deposits (L. 630). The use of Room 1 as a dumping space for metallurgical waste and the accumulation of fills on both sides of it are the reason for the good preservation of the walls which in their damaged state could not stand alone too long. The walls themselves became part of the 'slag mound' deposits.

Four similar installations were uncovered in the metallurgical deposits of Layers M2 (L.616, 643) and M3 (L.651, 678). They probably represent delineations of metal working spaces with lines of uncut (or roughly cut) stones, usually circular or semi-circular in shape (although all were exposed only to a limited degree because of the limits of the probe). Locus 616 (probably Layer M2a) consists of a line of four exposed boulders, each about 20-30 cm in diameter. The line abutted wall Locus 632 at a slight angle, and on the other side continued into the section (thus we were unable to determine its entire length) (Fig.5.38). There were no specific finds related to these installations and the precise function of them could not be determined.



Fig.5.38: Locus 616, a line of roughly cut stones in the probe of the 'slag mound' in Area M, probably delineated working spaces for metal production.

A similar installation to L. 616 was found in L. 643 (Fig.5.39). It is located about half a meter below L.616 and is probably part of Layer M2b.The stones of this installation were placed together more tightly than in L.616, but the placement next to wall l. 632 was almost identical. Loci 640 and 641 were excavated on either side of this feature, but also here no discernable difference in their deposits was detected.

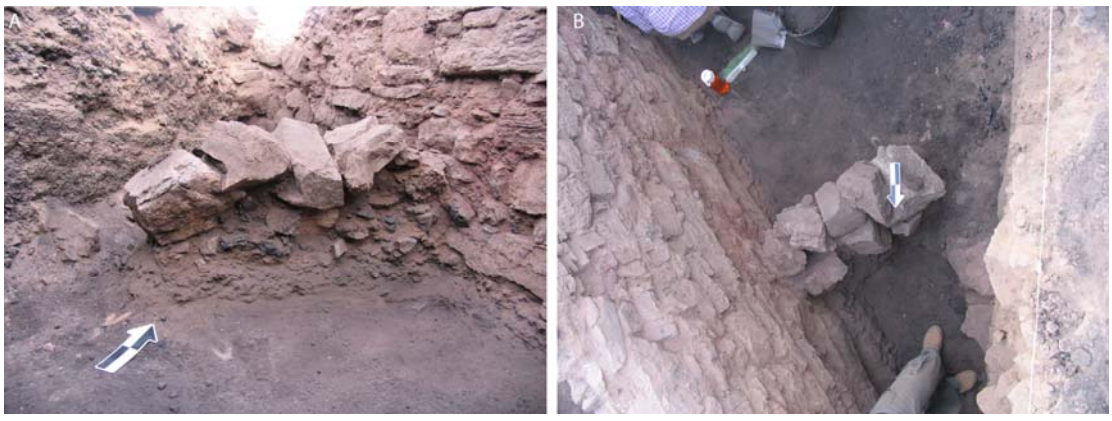


Fig.5.39: A side (A) and a top (B) view of Locus 643, a line of roughly cut stones in the probe of the 'slag mound' in Area M, probably delineated working spaces of metal production.

In the structure complex of Area M (Fig.5.37), Layer M2a represents a second phase of occupation and Layer M2b represents the original construction and occupation of the complex, including major preparation works of leveling up the rugged surface of ‘slag mounds’ and production debris.

Between the two structures there is a very narrow space (Fig.5.37) that probably was not easily accessible when the area was occupied. The excavations of this space, Locus 700, uncovered a large concentration of artifacts mixed with some aeolian dust (Layers M2a/M2b), including numerous pottery sherds and a few ground stones. Also found in Locus 700 were a diamond-shaped green bead blank (EDM # 12109) and a brown and black pendant-like bead (EDM # 12108) (Fig.5.40).

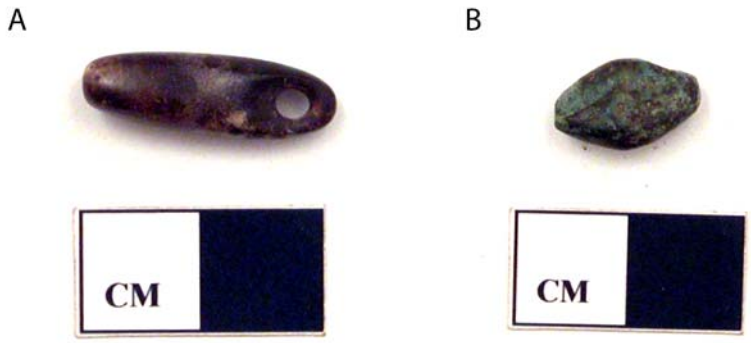


Fig.5.40: The bead (A, EDM # 12108) and bead blank (B, EDM # 12109) found in Locus 700 at Area M.

Layer M2b is situated on top of massive accumulation of copper production debris that was leveled up for the construction of the structures. This disruption of the local landscape is clearly visible in the walls of the pit in the ‘slag mound’ (see section

drawings below, especially Fig.5.56) where it is represented by horizontal thin deposits of aeolian dust and silty sediments. These deposits accumulated on a distinct surface corresponding to the first occupation phase of the structures, most probably an open space behind Room 1. On top of the leveled surface two buildings were erected, Structure 1, a building with three rooms surrounding a central courtyard was almost entirely excavated in 2006 (Room 1 was partially excavated in 2002, the northeastern part of this room was not exposed and is mostly covered by heavy metallurgical debris of the 'slag mound', see Fig.5.37). Structure 1 and its finds represent mostly domestic activities, although a high concentration of ground stone suggests some processing of slag or ore, perhaps in the courtyard. It is also clear that contemporaneous smelting activity took place just outside and to the south of Structure 1, and the interaction between the two different areas, including deliberate protection of the walls of Room 1 and maybe eventually decommissioning it (see above). Beneath one of the walls of Structure 1, a small, mostly intact dipper jug (EDM #90869) was uncovered, most likely a foundation deposit. Structure 2 was only partially exposed. It is more substantially built than Structure 1 and is probably more industrial in function.

Structure 1 consists of a courtyard (Room 3) with rooms opening to the south (Room 1), west (Room 2), and east (Room 4) (Fig.5.37, Table 5.10). As mentioned above, Room 1 has to be removed to allow for the excavation of the deposits beneath it (Figs.5.41, 5.42).



Fig.5.41: The three remaining rooms of Structure 1 after the 2006 excavation (view towards south). From the right (west), Room 2, Room 3, and Room 4. The place once occupied by Room 1 is now part of the deep sounding. The southwest wall of Structure 2 is in the far left of the photo (photo courtesy of ELRAP-LAL).



Fig.5.42: Area M, Structure 1, Room 1 before its removal. Also visible are parts of Rooms 2 and 3 (the north arrow lies on the upper floor level of the courtyard, Room 3). The southern corner of Room 1 was excavated already in 2002 (then as 'Room 5') down to the levels below the floors (Context III, the triangle shallow pit visible in the photo above) (photo courtesy of ELRAP-LAL).

Table 5.10: Interior walls of Structure 1 in Area M

Room #.	Locus numbers, measurements (m)					
1	North wall (637) Length: 3.85 Width: 0.40 Height: 0.90 Courses: 1x7	East wall (631) Length: 1.75 Width: 0.30 Height: 0.70 Courses: 1x7		South wall (618) Length: 3.70 Width: 0.35 Height: 2.10 Courses: 1x12	West wall (632) Length: 2.00 Width: 0.35 Height: 1.95 Courses: 1x14	
2	North wall (690) Length: 1.55 Width: 0.30 Height: 0.45 Courses: 2x2	East wall (N) (669) Length: 3.80 Width: 0.30 Height: 0.60 Courses: 1x5	East wall (S) (668) Length: 1.20 Width: 0.30 Height: 0.60 Courses: 1x5	South wall (637) Length: 1.75 Width: 0.40 Height: 0.65 Courses: 1x2	West wall (661) Length: 4.30 Width: 0.40 Height: 0.90 Courses: 1-2x8	
3	North wall (690) Length: 1.30 Width: 0.30 Height: 0.45 Courses: 2x2	East wall (N) (691) Length: 2.10 Width: 0.25 Height: 0.40 Courses: 1x3	East wall (S) (625) Length 2.70 Width: 0.50 Height: 1.15 Courses 1x6	South wall (637) Length: 2.80 Width: 0.40 Height: 1.00 Courses: 1x7	West wall (N) (669) Length: 3.80 Width: 0.30 Height: 0.60 Courses: 1x5	West wall (S) (668) Length: 1.20 Width: 0.30 Height: 0.60 Courses: 1x5
4	North wall (692) Length: 1.85 Width: 0.40 Height: 0.60 Courses: 1x5	East walls (684, 714) Length: 5.65 Width: 0.40 Height: 1.10 Courses: 1-2x 9		South walls (737, 714) Length: 1.70 Width: 0.30 Height: 1.00 Courses: 1x6	West wall (N) (691) Length: 2.10 Width: 0.25 Height: 0.40 Courses: 1x6	West wall (S) (625) Length: 2.70 Width: 0.50 Height: 1.15 Courses: 1x6

The central room of Structure 1 is probably an open courtyard, Room 3 (L. 711). Room 3 was a communal space in the structure. It was the only one connected

to the outside (through a 1.3 m doorway in the northeast) and the area connecting all of the other rooms (Fig.5.37). A large red granite monolith (L. 703), measuring 0.25 x 0.40 x 1.15 m, was found in the south center of the room. This is most likely a column which supported a roof of perishable material.

The floor level of Layer M3b in Room 3 (L. 756, 754, 631, only the northern half of the room was excavated to this level) yielded a few interesting artifacts: a large pot base (EDM # 91906) next to a round pestle (a dual-faced dimpled hammerstone, EDM# 90452) and a round mortar (EDM# 90451). Less than a meter away was a large grinding slab, perhaps a sharpener (EDM # 91885) (Fig.5.43). A figurine pendant was found at this level near these objects (Fig.5.44, EDM #90464).



Fig.5.43: The lower floor level of the courtyard (Room 3) in Structure 1, including a large grinding slab and a base of a large pot. The granite pillar lies at a higher level. The stones behind the grinding slag (and the arrow) belong to installation locus 634 (Layer M2a) that blocked the original doorway to Room 1 probably after the room was damaged by the intense metallurgical activity nearby and went out of use (see text).

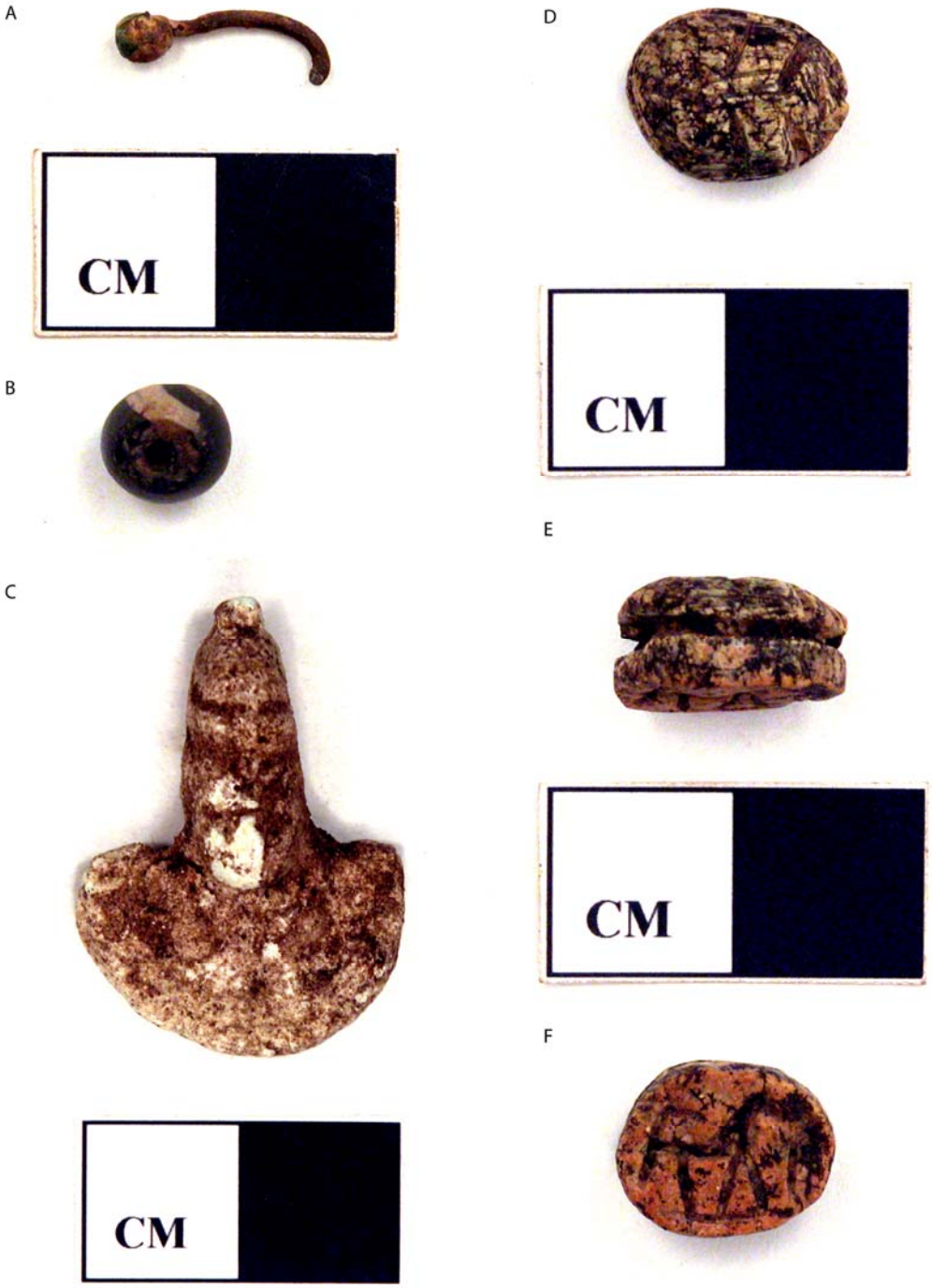


Fig.5.44: Some small artifacts associated with Structure 1 and 2 at KEN Area M discussed in the text. A) copper earring found on the surface and probably originally from L.717 (EDM #91774); B) a swirled glass bead from Room 4, L. 733 (EDM # 91706); C) Egyptian Aegis amulet (Structure 1, Room 3, l. 635, EDM # 90464) (Levy et al., 2008a); D)-F) A scarab seal (EDM #91464; ibid), found in metallurgical deposits (L. 707) (illustration courtesy of ELRAP-LAL).

To the south of Room 3 (the courtyard), Room 1 (Figs.5.42 and 5.45) was apparently entered through a doorway later blocked by an installation of Layer M2a (L. 634, Fig.5.43). It was difficult to delineate the original outline of the doorway, however, it appears to be relatively narrow (Fig.5.37). The blocking of the access to Room 1 indicates that the room went out of use during the second phase of occupation in Structure 1, most probably as a result of the damage caused by the heat of the smelting activities and the accumulation of heavy slag layer against its walls (L.632 and 618). A thick layer of reddish silty clay attached to the exterior face of these walls was likely a plaster (or mud bricks) applied in an attempt to protect the walls from the metallurgical production process, possibly from the building's very foundation (see above). The southern corner of Room 1 was excavated in 2002 (see above). The excavations in the 'slag mound' to the south of the room revealed no evidence of architecture and it seems that this area, towards the edge of the site and the local drainage, was an open space designated for metallurgical activities throughout the Iron Age occupation.

Room 1 has a beaten earth floor in Layer M2b (L. 635, 657). The floor of this room was hard packed, and buried within it was discovered a white spindle whorl (EDM # 90881). Many date seeds were also collected here. There were no installations, and there is little other evidence as to the function of this room. The floor of this room was founded upon the leveled-off slag of Layer M3 and may have been a residential area.



Fig.5.45: Room 1 before its removal, facing north. Arrow indicates location of a pot in partially-excavated Room 3 (Layer M2b) (photo courtesy of ELRAP-LAL).

To the east of courtyard Room 3 lies Room 2 (L. 712), accessed through a 0.80 m wide doorway in the southwest wall of Room 3 (Fig.5.37). The south wall of this room (L. 637) measured 1.75 m in length, and continued to form the south walls of Rooms 3 and 4. Its north wall (L. 690) measured 1.55 m. The interior of its west wall (L. 661) measured 4.3 m in length, and continued to the southeast to form the southwest wall of Room 1. The walls and doorway of its east side (L. 668, 669) measured a total of 5.8 m in length. Two patches of flat cobbles were uncovered, one around the center of the room (L. 748) and one at the room's northern edge (L. 747); these are likely the remains of pavements. The northern installation had a particularly large flat stone abutting the wall.

To the west of Room 3 is Room 4 (L. 710), which is accessed through a ca. 0.90 m wide doorway (Fig.5.37). Its northern wall (L. 692) measures 1.85 m long in the interior. Its southern wall (L. 637, 714) has a bend in it, likely associated with the unexcavated space to the south. The total length of the room's southern side is 1.70 m., but there is a 0.50 m long intrusion in the eastern corner of a 0.35 m thick wall at a right angle to the main wall (L. 714; see Fig.5.37). Most of the southern side is enclosed by the same wall that extends into Rooms 3 and 2. The total length of the eastern side of the room, including this wall intrusion, is 5.85 m. Room 4, like Room 2, apparently had a cobbled floor during Layer M2b represented now only by a few patches (L. 736 and 737 in the south, L. 740 in the north) that were covered over by the Layer M2a beaten earth floor.

The layout of Structure 1 recalls the '4-rooms' houses common in the Iron Age southern Levant, and usually attributed to the Israelites (e.g., Mazar, 1990; Herzog, 1992)[40]. However, it is now clear that the link between architecture and ethnicity is more complex and similar architectural styles may have been used by other ethnic groups (see discussion in e.g., Faust, 2006:chapter 9). It seems that Structure 1 was well-planned (although not entirely symmetric) and that the walls were constructed with substantial efforts. The stones used in the walls are often very large, sometimes requiring two people to lift. They are usually roughly cut and made of the locally

[40] Room 1 has a partition, dividing it into two unequal spaces. This suggests a '5-room' or an elaborated '4-room' plan.

available assortment of rocks, especially the flat blocks of dolomite (from the Burj formation). The latter usually breaks easily along cleavage planes and is found in a crumbly state.

Although only partially excavated, Structure 2 is a much larger and more substantially built complex to the north of Structure 1 (Fig.5.37). It was also founded on metallurgical deposits but at a slightly lower elevation than Structure 1, being further north of the majority of the slag accumulation of Layer M3. Two walls (of two rows of stones, 0.6-0.65 m thick) were partially excavated here; one running NW-SE (L. 696), of which 4.80 m were exposed (1.80 m high, up to 8 courses), and an intersecting wall running SW-NE (L. 715), of which 3.80 m were exposed (1.5 m high, up to 8 courses). The structure has the same orientation as Structure 1 (part of wall L.696 is parallel to wall L.684). The finds from the excavated portion inside the structure suggest an industrial function; it is also possible that the walls delineated an extensive working space rather than a roofed building (similar to the perimeter walls in Area R). Locus 732 in Structure 2 is associated with Layer M2b. It was rich with variety of ground stones, including hammerstones, dimpled hammerstones (one was a re-used rubbing stone), a small chalk mortar (EDM # 91765), and a large, dense, deeply cut red grinding slab with a lozenge-shaped cavity (EDM # 91745). Some evidence of metallurgical activity, such as furnace fragments, was also uncovered. Other artifacts were scarce and included some pottery sherds and an unique concentration of sulfurous sandstone.

East of Structures 1 and 2 is a partially-excavated courtyard with a plastered floor (Fig.5.46). A small wall (0.50 m long 0.25 m wide, 0.75 high one row of 5 courses) covered with thick plaster was constructed joining walls L. 715 and L. 684. Together with wall L. 761 (1.10 m long, 0.45 m wide, 1.50 high, one row of up to 6 courses), these walls formed the boundaries of the courtyard, while to the east the excavation was bounded by the arbitrary exaction square. In the south of the unit, running parallel to wall L. 684, a well-laid pavement (L. 749) was uncovered with a well-preserved portion of the plaster floor (L. 745) next to it. Further north, chunks of plaster and large stones were uncovered surrounding a reconstructable vessel with a trefoil spout (EDM # 91833). Plaster also adhered to the vessel, and it seems that a plaster and stone construction held this vessel in place on the plaster floor. Many metalworking items, including tuyère and furnace fragments and hammer- and ground stones were found here. In this courtyard some unique artifacts were found: a bead (EDM # 91762) and a small metal object, probably an earring (EDM # 91774, located near the excavation area; probably fell while carrying dirt to the dumping zone) (Fig.5.44A).



Fig.5.46: The Eastern Courtyard in Area M. Note the broken pot (EDM # 91833) and the pavement (L. 649) (photo courtesy of ELRAP-LAL).

Layer M2a represents the last occupation phase of Structure 1 and 2 and contemporary copper production activities in the south of Area M. The beaten-earth floors and several installations inside Structure 1 belong to this context, as does a wall added to the structure in the west. No clear floor was uncovered inside Structure 2, but a layer of aeolian sand above a slag layer is believed to be the work area associated with Layer M2a in that building.

Room 3, the courtyard of Structure 1, had a complicated stratigraphy. Layer M2a was excavated in several loci (741, 742, 743, 752, and 631). This floor was recognized by a thick amount of plaster with some embedded rocks located on the

western side. The granite monolith lay on this surface, as well as a well preserved hearth (L. 753) and an anvil (EDM # 91886). The anvil, a rounded blue diorite wadi boulder, lay right in front of the doorway. The hearth, lined with stones and slag chunks held together by plaster, surviving to about 0.60 m. in diameter, was likely used for domestic cooking. It lies in the corner of wall loci 690 and 669. A soil sample was taken from here for floatation, and charcoal (EDM # 91837) and a date seed (EDM # 91838) were collected for dating this occupation phase. Relatively few other finds were associated with this floor.

Room 1, the southern chamber, was probably not occupied in Layer M2a, and used for a designated space for dumping metallurgical waste. Installation L. 634, which blocks the doorway to Room 1, was likely constructed at the very beginning of Layer M2a. This consists of two large stones placed on their sides with smaller stones lying atop them.

Layer M2a in Room 2 contains an installation of unknown purpose, and the remnants of a storage installation. Some large ground stones were found in the fill above the floor (Layer M2a -L. 633), and it is likely that they were once associated with the occupation phase of this layer. The floor was hard packed earth and excavated in three loci (716, 719, and 735). A small white bead with a groove running down its center (EDM # 91717) was uncovered here, as was a red stone bead (EDM # 91774). Utilitarian items including a dimpled hammer stone and a plain hammer stone were

found here. Directly next to this northern pavement in the northwest corner was a roundish installation (L. 720) of unknown purpose rising about 0.60 m above the floor and about 0.60 m in diameter. It was made of flat cobbles held together in bright red clay. This red clay was also used in an installation in the southeastern corner of the room (L. 646). This installation consisted of a square layer 3-5 cm thick of fine red clay with film of bright yellow clay sealing the corner of walls L. 668 and L. 637. It made use of the bases of these walls that consist of very large stones. Small stones along the edge of the installation may be part of it, and although the installation was destroyed with wall collapse, remnants of it were visible on the southern wall exposed to at least 40 cm above the floor.

Layer M2a in Room 4 is represented by a floor of beaten earth (L. 726, 727, 731, 733, and 734) lying over the slag and pavement remains of Layer M2b. A black-and-grey swirled bead was uncovered within this floor (Fig.5.44B; EDM # 91706). A small plastered basin in the south-center of the room, L. 739, probably belongs to Layer M2a. This basin measured 46 x 63 cm and dipped gently to a depth of 5 cm. Some charcoal was embedded in the plaster, including a date seed that was collected from its edge.

As noted above, no floor was discovered in Structure 2 during excavation or in the section, however, fine aeolian dust with only small amounts of wall debris covering what is believed to have been the work surface was uncovered. These loci

(728, 732) were sieved through 1/8" screen and were notable for their overall lack of artifacts. A single bead, a white stone disc (EDM # 91647), was uncovered in Locus 723 just at the start of Layer M2a.

Layer M2a is represented in the eastern courtyard by a fill with remains of metal production debris. Much pottery and many ground stones were discovered in the metallurgical deposits, suggesting that this area had become a midden. Some decorative items were also uncovered here. A scarab seal with an apparent incised horse (Fig.5.44D-F) was found in locus 707 (EDM # 91464), as were two beads, both small greenish white stone discs (EDM # 91500 and 91475). In the upper part of Locus 708 another two greenish white stone disc beads (EDM # 12114 and 91459), and one worked shell bead (EDM # 91460) were found.

To the west of Structure 1, a poorly constructed wall (L. 662) was added in Layer M2a, perpendicular to wall L. 661. Only 1.70 m of its length was uncovered. It was 0.35 m wide and excavated to 0.40 m of its height in 3 courses two stones thick.

Layer M3 is located beneath Structure 1 (Room 1) and to the south of it in the 'slag mound' probe (L. 647, 651, 658, 659, 660, 665, and 666). This is almost entirely a series of metallurgical deposits, with a few installations probably associated with metallurgical activity. The original inclination of the metallurgical deposits, clearly exposed in the sections of the southern pit in the 'slag mound', indicates intentional

dumping of metallurgical waste. While the center of dumping was south of Structure 1 in Layer M2, the center of the dumping area, or 'the top of the slag mound', seems to be located where Structure 1 was later constructed, after leveling up the local landscape. In addition to the bulk of inclined deposits, we recognized several surfaces that may represent episodes of smelting activities that took place in the excavated locations themselves. The entire deposits of Layer M3 are located above a clear break in activity at this area, represented by a thick yellow-brown dust and ash of Locus 667.

Locus 651 in Layer M3 is another stone linear installation that is probably related to the metallurgical activities (Fig.5.47). The remains of this installation consist of a line of three exposed boulders, each about 30-40 cm in diameter, with one visible in the section.



Fig.5.47: Stone lineation, locus 651, found in the metallurgical deposits of Layer M3.

Another similar stone installation was found embedded in the north section of the excavation pit in the ‘slag mound’ (Locus 678). It consists of a wall-like pile of flat stones – four stones high (resembling L.643 and different from the linear installations L. 616 and 651, Fig.5.48).



Fig.5.48: The installation (L. 678) in the southern section wall of the deep-probe.

Layer M4 is capped by Locus 667, a thick level of ashy sandy aeolian silt without much charcoal or artifacts. Below this rests Locus 670, which started with some Aeolian dust but quickly became very hard sediment derived from mud, clay, and furnace fragments, with some crushed slag mixed into it. Locus 671, the lowest of Layer M4, has a similar composition, but began with a dense amount of crushed slag, particularly in the east. Here there are spots of sandstone fragments in the fill. It seems that copper smelting was less intense in Layer M4 in Area M.

The earliest occupation phase exposed in Khirbat en-Nahas is represented in Layer M5. This layer, located right above virgin soil (red wadi sands), consists of two installations stratigraphically separated from each other by a thin accumulation of soil. This separation is the reason for dividing this layer into M5a and M5b (Fig.5.49). In Layer M5a installation Locus 673 was found. This is apparently a hearth or an oven, made of a circle of local limestones. Bone and ash, but no slag, were found within it. Only part of it was excavated, as the rest extended into the section. About four courses of stones were laid upon each other to construct the feature. In the bottom level of installation L.673 was a thick layer of soft earth, mostly grey in color and with only small amounts of slag (Locus 674). In places, there are red spots derived from decomposed clay bricks. The installation itself was built upon Locus 675, a layer of grayish-black fill with many stones mixed into it covering Layer M5b.

The lowest levels excavated constitute Layer M5b.These rested on red virgin wadi sand. Locus 677 contained very little charcoal in its upper levels and then extended down into virgin sand. Founded upon this locus was an installation (Locus 676), a rectangular small structure of flat local limestones laid as a nice pavement and then covered with a layer of brown plaster about 2 cm. thick. The plaster spreads upwards, as though to act as a basin, forming upraised edges to about four or five cm height. On the southern side, a small, thin wall was preserved. It consists of some flat stones and one rounded stone plastered to the corner that protrudes upward like a horn (EDM # 91905). The form of the feature suggests that it is an altar (Fig.5.50). One

worked stone (EDM # 91245) and one hammerstone (EDM # 91246) were associated with this installation. Covering it, in Layer M5a Locus 675, was a pile of stones, apparently deliberately piled over the feature. Although very few finds related to metallurgy were found in this context, the sediments contain some fine crushed slag, suggesting that metallurgical activities did take place at the site already in its early stages of occupation.

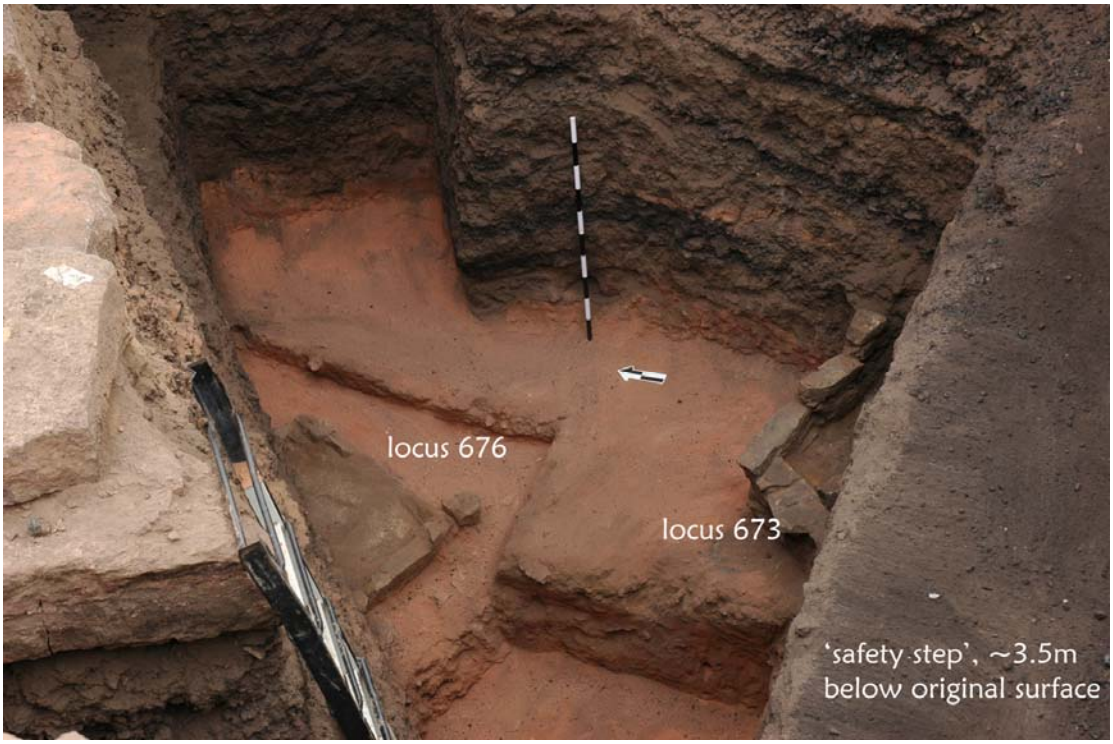


Fig.5.49: Area M, the deep probe into the 'slag mound' and the installations of Layer M5 (photo courtesy of ELRAP-LAL).



Fig.5.50: Area M, the ‘altar’-shaped installation on virgin soil at the bottom of the pit in the ‘slag mound’ (Locus 676, Layer M5b; the corner stone was originally attached to the installation with plaster) (photo courtesy of ELRAP-LAL).

The deep sounding of the ‘slag mound’ exposed more than 6.5 meters of metallurgical deposits (in five major Layers) and provides stratigraphic contexts for detailed studies of the Iron Age copper production technology at KEN. In addition to the careful excavation and recording of the different loci in the sounding, we documented and sampled the walls of the deep section for archaeomagnetic, radiocarbon dating and other future research (Figs.5.51-5.56). The material from the deep sounding and from its sections constitutes the basic reference for technological and socio-economic reconstructions and models presented in the current research (Chapters 7 and 8).



Fig.5.51: Working in the deep pit of the ‘slag mound’ in Area M.



Fig.5.52: Measuring the southern section in the excavation pit of the ‘slag mound’.



Fig.5.53: The six meters (+) pit in the ‘slag mound’ of Area M at the end of the excavation (looking south). The step was left for safety; Room 1 of Structure 1 was removed to allow the excavation of the pit (remains of the southeastern wall of the room are visible on the left).



Fig.5.54: The excavation in the ‘slag mound’ of Area M, east profile.

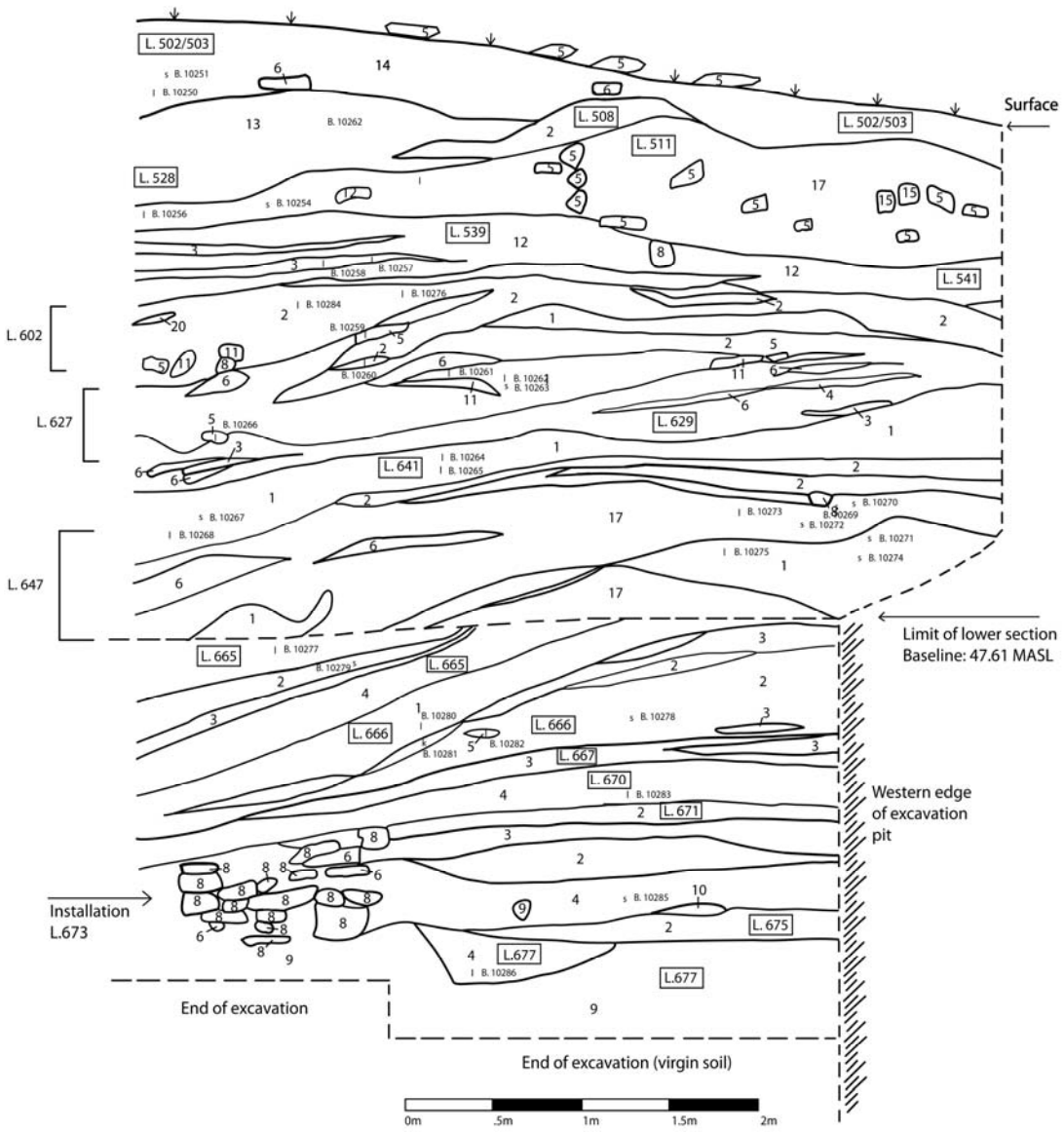


Fig.5.55: Detailed section drawing of the southern wall of the sounding in the 'slag mound' of Area M. Location of loci is approximated. For general division into Layers cf. Fig.5.56. Note the horizontal dashed line representing the location of a 'safety step' approximately 1.4 m wide (thus there is discontinuity in the section). Key: 1) broken slag fragment; 2) fine-crushed slag; 3) silt and ash; 4) ash with some slag fragments; 5) tap slag slab/fragment; 6) solid ash horizon; 7) animal bone; 8) stone; 9) wadi sand (virgin soil); 10) silty/clay; 11) furnace fragment; 12) crushed and broken slag, poorly sorted; 13) broken furnace and tap slag mixed with furnace fragments; 14) yellow/brown ashy loess with some slag fragments; 15) tuyère fragment; 16) red wadi sand; 17) compact crushed slag; 18) silt and ash with some crushed slag; 19) plaster; T) tuyère fragment (sampled); s) radiocarbon sample; l) slag sample.

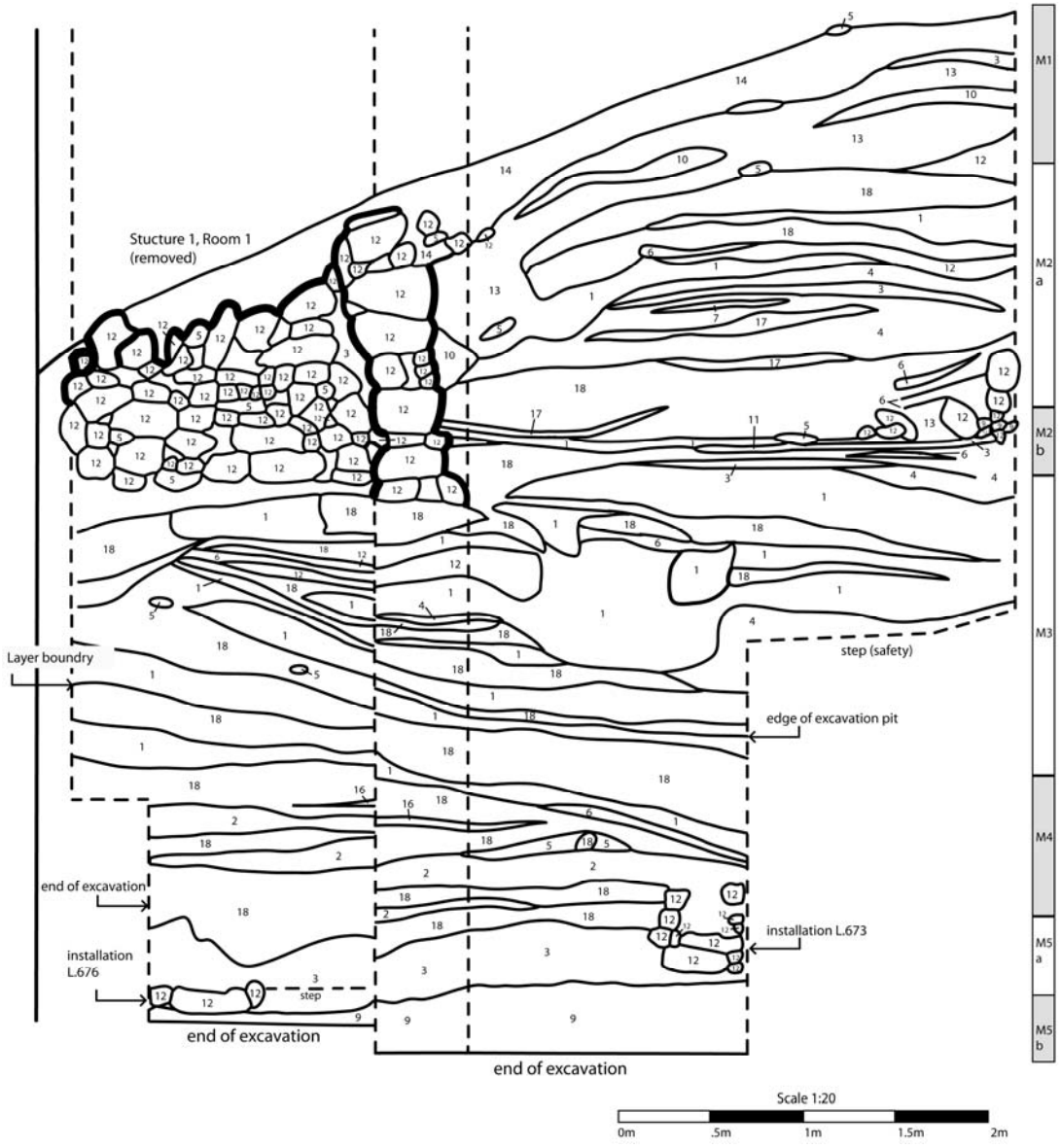


Fig.5.56: Detailed section drawing of the eastern wall of the sounding in the 'slag mound' of Area M. General division into stratigraphic layers is shown on the right and is approximated. For key see Fig.5.55.

Radiocarbon considerations – Area M KEN as Chronological Anchor (13th – 9th c. BCE)

From the excavations in Area M and in particular from the deep sounding in the 'slag mound' twenty two radiocarbon were published in Levy et al. (2008a) and additional two dates from the deepest stratigraphic context (Layers M4 and M5) were published in Ben-Yosef et al. (2010a). Two of the samples are from the 2002 excavations and the rest 22 are from the 2006 excavations. One sample (OxA 17646) dated to the 11th century BCE was considered as an outlier in the 2008 publication. However, re-examination of its context shows that it originated from Layer M4 and not M3 and its date corresponds well to its stratigraphic location. The new Bayesian model, incorporating all of the 24 dates, was first published in Levy et al (2010b:841) and is presented below (Fig.5.57), together with the original dates and their context (Table 5.11).

The results of the radiocarbon dating for Area M indicate that the original occupation of the site was probably already in the last phase of the Late Bronze Age (Layer M5b, 14th-13th centuries BCE, and M5a 13th-12th centuries BCE). As mentioned above, already in this context fine crushed slag fragments were found mixed with the wadi sands. The first substantial accumulation of metallurgical debris in Layer M4 dates to the 11th century BCE, and the massive production waste of Layer M3 to the 10th century BCE. The activities in the structures and the contemporary

metallurgical activity to the south of them (Layer M2) probably date to the early-mid 9th century BCE and the last phases of copper production in the site (Layer M1) probably date to the later part of this century.

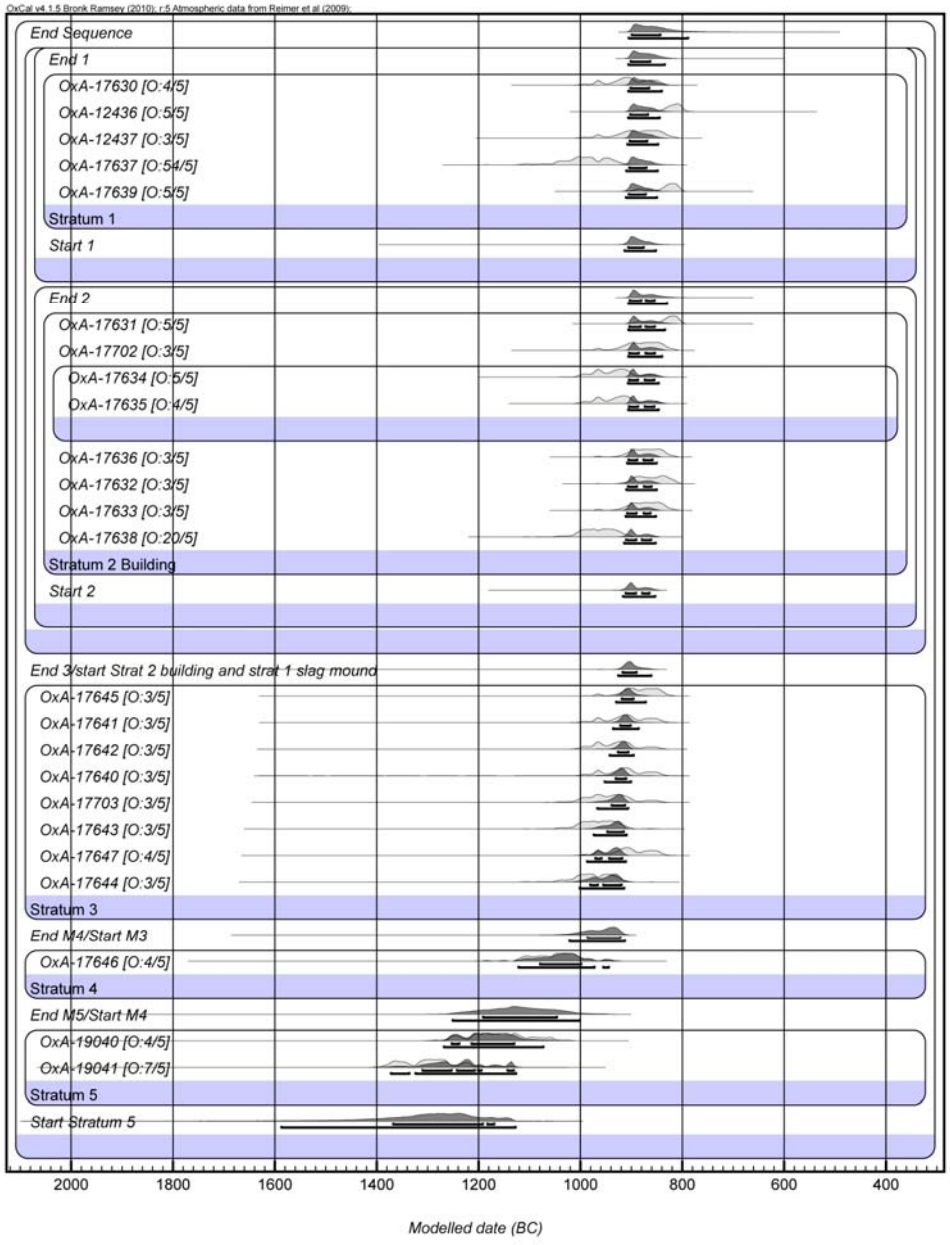


Fig.5.57: Modeled age diagram for KEN Area M (cf. Table 5.11; see text for details).

Table 5.11 (next page): Radiocarbon dates from Khirbat en-Nahas, Area M (see text for references)

									Cal date BC 68.2%		Cal date BC 95.4%	
OxA	Sample information			Layer	Material		Date BP	+/-	From	To	From	To
12436	-	KEN02	EDM80372	1	Charcoal	Tamarix?	2659	32	834	799	896	792
12437	-	KEN02	L539, B9039	1	Charcoal	Tamarix?	2746	35	917	839	976	815
17630	M1	KEN06	L535	1	Charcoal	Retama raetam	2764	25	969	846	977	835
17631	M3	KEN06	EDM91837	2	Seeds	Phoenix dactylifera	2676	26	841	803	896	800
17632	M4	KEN06	EDM91808	2	Seeds	Phoenix dactylifera	2713	26	896	828	908	811
17633	M5	KEN06	EDM91641	2	Seeds	Phoenix dactylifera	2734	25	900	841	925	819
17634	M6	KEN06	EDM90466	2	Charcoal	Haloxylon persicum	2783	25	976	900	1005	846
17635	M6	KEN06	EDM90466	2	Charcoal	Haloxylon persicum	2777	25	976	860	1000	844
17636	M7	KEN06	EDM90378	2	Seeds	Phoenix dactylifera	2732	25	899	840	922	819
17637	M8	KEN06	EDM90395	1	Seeds	Phoenix dactylifera	2836	26	1022	933	1110	913
17638	M9	KEN06	EDM91773	2	Seeds	Phoenix dactylifera	2814	25	1001	928	1038	904
17639	M10	KEN06	EDM91462	1	Seeds	Phoenix dactylifera	2678	26	841	804	896	801
17640	M11	KEN06	EDM91098	3	Charcoal	Tamarix	2770	25	972	851	996	840
17641	M12	KEN06	EDM90754	3	Charcoal	Acacia	2767	25	971	848	996	837
17642	M13	KEN06	B10279	3	Charcoal	Tamarix	2781	25	976	898	1003	846
17643	M15	KEN06	EDM91175	3	Charcoal	Tamarix	2813	26	1001	927	1041	903
17644	M16	KEN06	EDM91211	3	Charcoal	Tamarix	2824	25	1008	932	1047	912
17645	M17	KEN06	EDM90832	3	Charcoal	Tamarix	2747	25	913	843	972	827
17646	M18	KEN06	B10285	4	Charcoal	Tamarix	2871	26	1112	1005	1129	936
17647	M19	KEN06	EDM91192	3	Charcoal	Haloxylon persicum	2764	25	969	846	977	835
17702	M2	KEN06	EDM90181	2	Charcoal	Retama raetam	2740	30	906	841	972	816
17703	M14	KEN06	EDM90527	3	Seeds	Phoenix dactylifera	2792	30	993	906	1013	845
19040	-	KEN06	Near L.676	5a	Charcoal	?	2942	27	1254	1117	-	-
19041	-	KEN06	Basal layer	5b	Charcoal	?	2036	27	1373	1260	-	-

5.2.4.4 Archaeometallurgical features at the outskirts of Khirbat en-Nahas

On the slopes surrounding Khirbat en-Nahas from all directions (except in the north, where the site boundary is Wadi al-Ghuweiba) there are several locales with thick layers (up to 1.8 m high) of fine crushed slag (Figs.5.58 and 5.59).

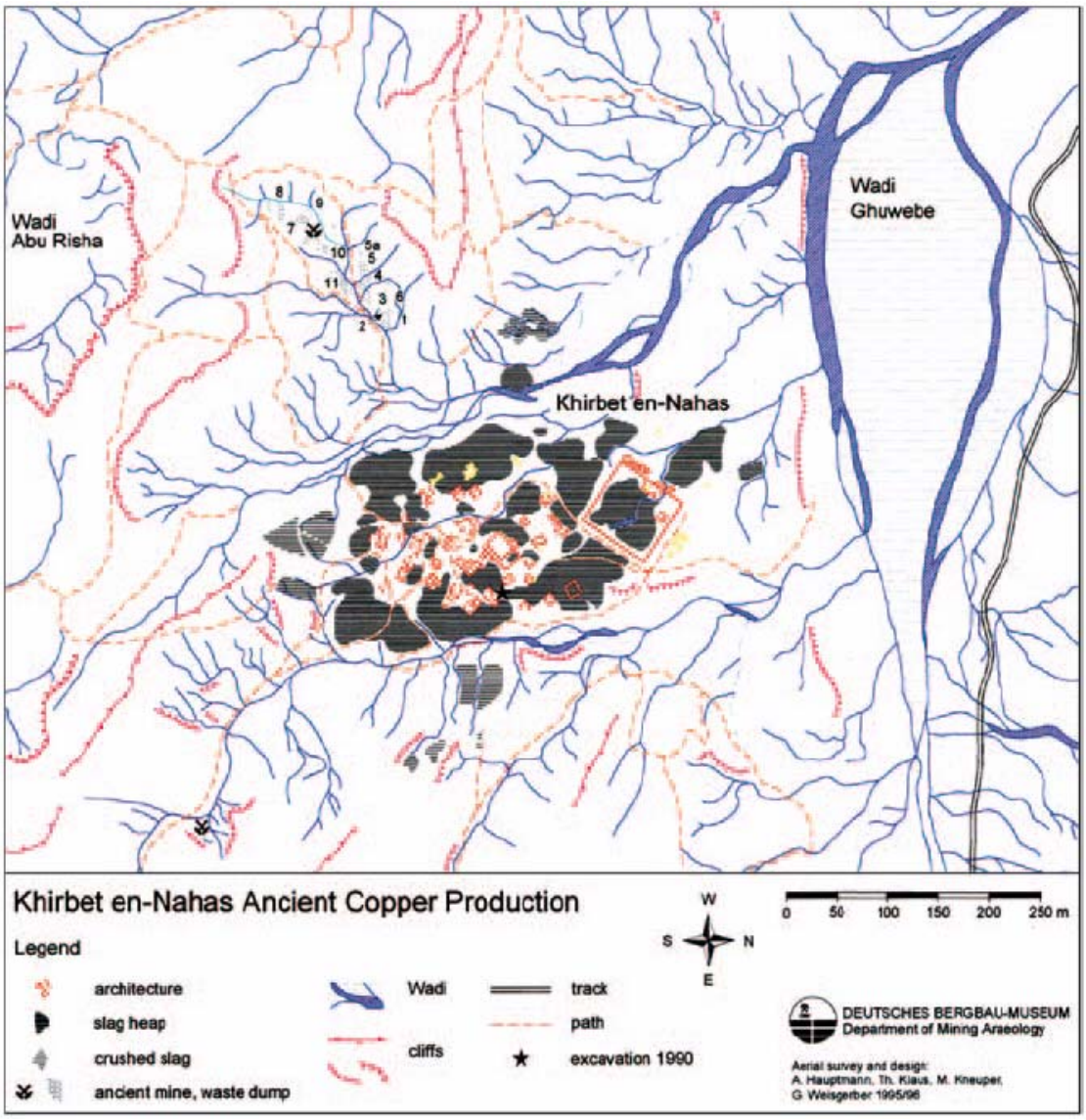


Fig.5.58: A map of Khirbat en-Nahas and its vicinity (Hauptmann, 2007:129) showing the location of the unique crushed-slag deposits on the slopes surrounding the site and the location of copper mines surveyed by the GMM team.



Fig.5.59: Thick deposits of fine-crushed slag on the slopes surrounding Khirbat en-Nahas.

The fine-crushed slag deposits are some distance from the main activity areas of the site and are not associated with any substantial architectural features. They consist of several thousands of tons of solid black granular slag with individual grain size of up to 0.5 cm. The depositional characteristics of these deposits, including condensed and cemented layers with flow patterns, raised the possibility that water was used in the crushing process for washing out and sorting copper prills (Hauptmann, 2007:129-130). This suggestion does not seem to be probable, if only because of the severe problem of water supply in this arid region. It is more likely that

the consolidation of these deposits relates to post-depositional processes and exposure to random rains throughout the millennia. In any case, the vast layers of fine-crushed slag testify to the importance of slag crushing in the copper production process at Khirbat en-Nahas (see Chapter 7 and 9).

In the immediate vicinity of Khirbat en-Nahas a number of mines were reported by the GMM team (Figs.5.58 and 5.60). Most of these mines concentrate in a small wadi to the west of the site and are represented by large waste/tailing piles. A few are located to the southeast of the site, in the small wadi connecting KEN and el-Furn (see also Fig.5.11). These mines penetrate the copper bearing horizons of the Burj formation and are probably similar (technologically) to the ones recorded by our team in Wadi al-Jariya (Levy et al., 2003; Knabb et al., in press). Until the discovery of the nearby Jabal al-Jariya mine fields in 2007 (see section 5.2.9 below) that are part of this doctoral research, it was assumed that these few mines around KEN were the main copper ore source for the site throughout the Iron Age; notwithstanding the recognized discrepancy between the vast evidence of smelting at KEN and the relatively minor evidence of mining near KEN and generally in Faynan (e.g., Hauptmann, 2006:128).

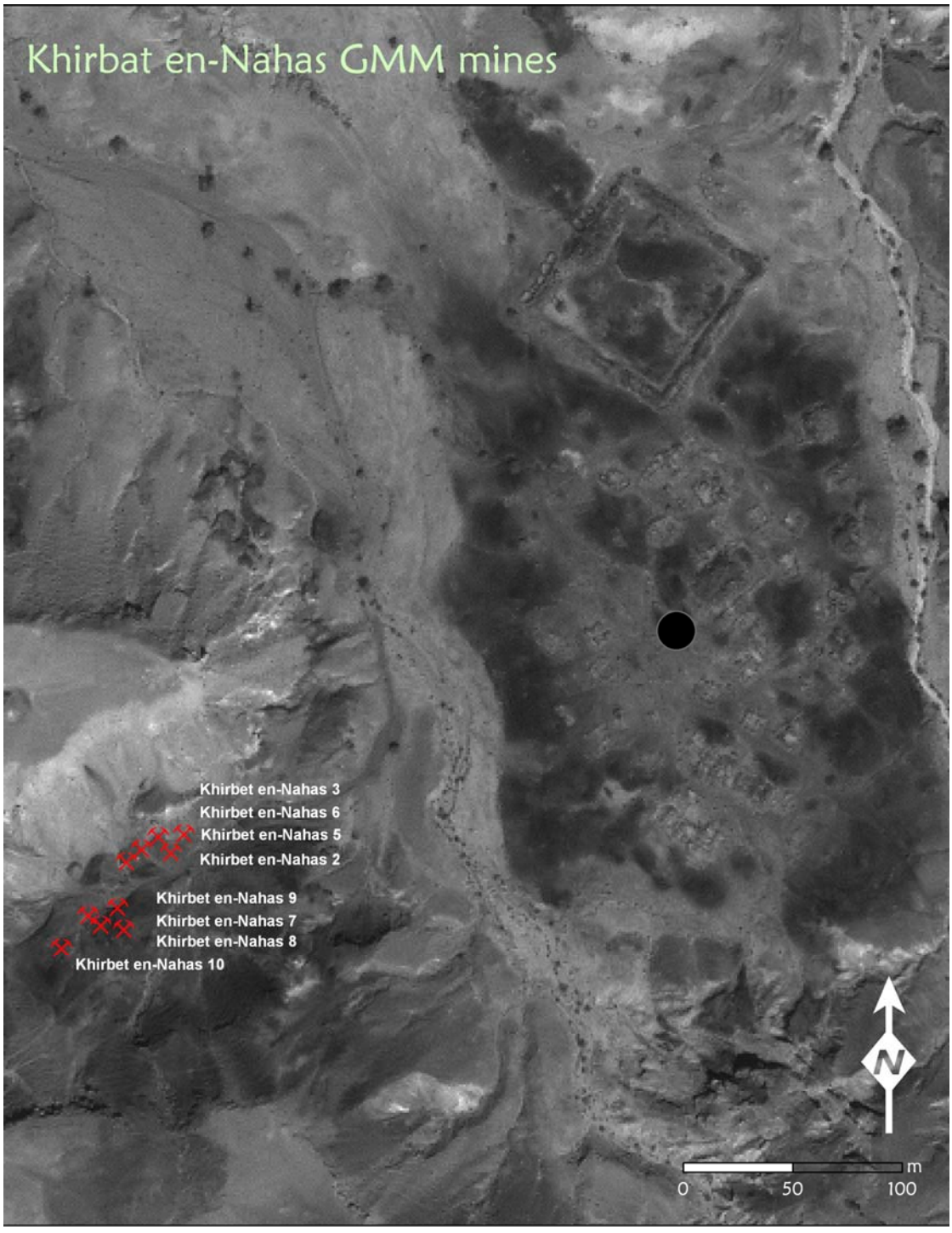


Fig.5.60: Satellite image of Khirbat en-Nahas and its close vicinity (Ikonos, Geoeye) showing the location of the Iron Age mines surveyed by the GMM team.

5.2.4.5 Khirbat en-Nahas archaeometallurgical remains: a summary

The site of Khirbat en-Nahas is located on an elongated shallow wadi terrace (or a spur) between Wadi al-Ghuweiba in the north and two local small wadis to the east and west (Fig.5.58). Field surveys and investigation of the maps (Fig.5.16, 5.58), aerial photographs and satellite images (e.g., Fig.5.17, 5.60) show that the 'slag mounds' are concentrated mostly around the perimeter of the site, probably because the edges of the occupied areas and the slopes of the local wadis were preferred locations for smelting activities and dumping of metallurgical waste. Khirbat en-Nahas is not surrounded by any wall or other defensive elements; however, the pattern of distribution of 'slag mounds', although not strict (many small 'slag mounds' are also located throughout the site) created a well-defined central area dense with structures of various size and function. In the north of the site near the entrance to the smelting complex from Wadi al-Ghuweiba a large, 73 x 73 m fortress was founded during the 10th century BCE on top of earlier layers of slag and other copper production waste (probably dated to the 12th-first half of 10th century BCE). Inside the courtyard of this fortress a unique refining and casting workshop was excavated in Area F. The radiocarbon dating of both the fortress's gatehouse and the workshop indicates that the structures are contemporaneous, suggesting that the fortress functioned as an enclosed compound for metallurgical activities, including probably the most specialized crafts of refining the raw metal and preparing it as final products. This interesting situation of having a metallurgical workshop and other metallurgical activities in the open space

of the fortress also suggests that the latter functioned not only as a defensive structure (or a compound for prisoners, cf. Glueck, 1935; or some kind of projection of social power, cf. Stein, 1998) but rather as a confining element separating the highly specialized metallurgical practice from the rest of activities in the site. Except from one room on the south side of the gatehouse, there are no rooms associated with the fortress's walls and the architectural plan is quite different from the "typical" Iron Age desert fortresses in the southern Levant. Most of the complex is an open space with abundant metallurgical remains. This space may also have been the storage of the final product of copper before shipment, via Wadi al-Ghuweiba, westward to Egypt, the Levant and the Mediterranean. The practice of highly specialized metallurgical activities inside a confined space has parallels in Timna Site 30 and 34 (see Chapter 6 below), in which the layout of the walls suggests even more a non-defensive function. Additional interpretations of these 'enclosures' have been suggested, such as compounds for keeping slaves from escaping the hard labor (Glueck, 1935:28, there the fortress at KEN is describes as "a large prison camp") (see further discussion in section 9.1.3).

The fortress of Khirbat en-Nahas continued to be used for copper production also after the decommissioning of the gatehouse and the blocking of its southern entrance. It seems that in this period the walls of the structures were robbed for constructing the 9th century buildings at the site, and entrance to the fortress courtyard was possible from any direction. This is indicated by the current conditions of the

walls: they are short and easily passable, and they lack sufficient collapsed stones around them to reconstruct a massive wall. The only reasonable candidates for the destination of the original stones are the nearby 9th century buildings. The last phase of activities in the gatehouse of the fortress was some sort of metallurgical workshop and/or a designated dumping of metallurgical waste. This probably suggests an exhaustive use of the available spaces at the site during the intense copper production activities of the 9th century BCE.

At least four massive structures with two stories and/or ('towers') that are located in the center of the site (Area R) and around its perimeter (Area T; a similar structure is located to the north of this area and another, a bit smaller, is located on the opposite side of the site, Fig.5.60 – all identified by Glueck 1940). The first phase of construction and occupation of the massive structures in Areas R and T is dated to the 10th century BCE, similar to the fortress (Levy et al., in press-b), and they are all founded on top of massive accumulations of metallurgical debris (e.g., Area T, Fig.5.27). These structures have been interpreted as houses of the local élite and important local persons who were responsible for possible supervision of the production activities at the site. The structures in Areas M, S and W are less massive and have been interpreted as residential, residential/industrial and residential/cultic respectively. In all of these structures metallurgical related artifacts and abundance of various ground stones have been recorded.

The excavations in the ‘slag mound’ of Area M resulted in exposing more than six meters of copper production related deposits, including interchanging horizons of various types of slag (fine-crushed, tap, and furnace in different sizes), clayey and ashy sediments mixes with tuyère and furnace fragments. Most of the accumulated material represents deliberate dumping of production waste (in particular primary smelting) at this location. In a few places working surfaces and installations, including a complete intact furnace base and a few stone alignments, were uncovered. The metallurgical horizons present an intricate stratigraphy derived from their complex depositional process which is fundamentally different from settlement sites. Thus, in addition to the detailed recording of the excavated material, we carefully studied the exposed walls of the pit. These sections provide invaluable information regarding the history of copper production at the site and are a basic reference for some of the analyses of the current research (Chapters 7, 8 and 9), and for our investigation of the chronological framework of the site (Levy et al., 2008a) and of the development of Iron Age copper production in Faynan (Ben-Yosef et al., 2010a). In addition, slag material from these sections was the basis for archaeomagnetic studies focused on reconstructing of the geomagnetic intensity during the period represented in Area M (Ben-Yosef et al., 2009c; Shaar et al., in press).

Basically, five major stratigraphic units were distinguished in Area M (Layers M1-M5, Fig.5.56). These were dated with a suite of 24 high precision AMS radiocarbon dates from well controlled contexts. The basal sediments and installations

belong to the last phase of the Late Bronze Age. Already in this context fine-crushed slag were present, suggesting copper production activities at the site already in its early occupation stages. Layer M4 (Iron Age I, 12th – 11th centuries BCE) and Layer M3 (10th BCE) represent copper smelting activities, while the latter in much more intense scale. The transition between Layer M3 and M2 represents a major change in the layout of this region of KEN. The mounds of debris were flattened to prepare the ground for a new occupation phase at the site, including the foundation of the structure complex. This transition dates to the end of the tenth century BCE and correspond to the approximate date of the Egyptian campaign of Shishak I to the southern Levant (Kitchen, 2003), suggested to be responsible for the observed disruption (Levy et al., 2008a:16461). Interestingly, at approximately the same time the sites of Khirbat al-Jariya and probably also the site of Khirbat al-Ghuweiba were abandoned (see below). The new phase of copper production at KEN, represented in Area M by Layers M2 and M1, also included intense copper production throughout the 9th century BCE. Sometime during this period we recognize a major change in the smelting technology with the introduction of larger installations (furnaces) and larger and different tuyères. This change has been observed in other sites (e.g., Faynan 5, Hauptmann 2007, Timna 30, Rothenberg 1980), but it is the first time we are able to precisely date this change in a well-stratified site and to thoroughly study the details of this substantial development (Chapter 7). The latest and most advanced technology is the one responsible for the huge slabs of tap slag visible on the surface of the site today. During this time the ‘slag mound’ of Area M became so high that the weight of the

debris and the heat of the smelting activities damaged the walls of Structure 1 and put at least one of its rooms out of use. Area M, like the rest of the site, was abandoned at the end of the ninth century BCE.

According to Hauptmann (2007:127) the site of Khirbat en-Nahas contains 50,000-60,000 tons of slag, an estimation based on calculation of volume of visible 'slag mounds' at the site, and the assumption that such mounds contain mostly slag material. However, the results of the detailed excavations of 'slag mound' contexts at the site, and in particular the 'slag mound' at Area M, demonstrate that such mounds contain only 40% or less of slag material (by volume, see detailed description of the excavations in Area M and the different deposits exposed in section 5.2.4.2 above; cf. also Tables 5.8 and 7.1). All of the excavated areas at KEN contain large amounts of copper production related artifacts; the industrial waste is found everywhere and 'penetrated' almost any context. These artifacts are discussed in Chapter 7.

Notwithstanding the extensive excavations in recent years described above, only a tiny fragment of the archaeometallurgical deposits and related architecture were uncovered at Khirbat en-Nahas. Most probably the data we obtained do not represent the entire metallurgical processes of Iron Age copper production in Faynan (for example, the discovery of the Area F workshop was a surprise; there are more than 90 unexcavated structures and some may represent other specialized workshops. However, the general pattern of the industrial scale copper production process, the

spatial distribution of its various components and diachronic changes in technology at Khirbat en-Nahas can be cautiously reconstructed. Together with detailed analysis of the archaeometallurgical artifacts (Chapter 7) and laboratory analysis of slag from various contexts (Chapter 8), the basic skeleton of the changing *chaîne opératoire*s can be established (Chapter 9).

5.2.5 *Khirbat al-Jariya*

Khirbat al-Jariya (KAJ) is located ca. 3 km northeast of Khirbat en-Nahas (30.707°N, 35.452°E, ca. 150 m above sea level, Fig.5.1) in an enclosed valley hidden in the rugged terrain of the eastern Wadi Arabah. It extends over both banks of Wadi al-Jariya and consists of shallow 'slag mounds', numerous architectural features, installations and some large structures preserved to a height of five courses and more (Fig. 5.61 and 5.62). Deepening of the wadi bed over the past three millennia has eroded the center of the site (ca. 3 ha) that was mostly situated on the western bank of the wadi (note the 'empty' portion in the middle of Figs.5.61-5.63). With the exception of several recent Bedouin graves and some robber trenches, the site was left relatively undisturbed since its abandonment in the Iron Age.

The first to report KAJ was Major Horatio H. Kitchener of the Palestine Exploration Fund (PEF) in 1884 (Ben-Yosef et al., in press) (see also section 3.1 above). In 1883, Kitchener led an expedition along the Arabah Valley, leaving 'Aqaba on December 3rd and traveling north along the eastern margin of the Valley, reaching Faynan region after several days. Their first campsite was at 'Ain al-Buweirdeh, a small oasis in the sand dunes of the southwestern part of the region[41]. The next day the

[41] Kitchener report rich archaeological remains near the springs, including "terraces of an old town of considerable extent," "numerous little mounds of artificial appearance" and "portions of an aqueduct" (Kitchener 1884:213). This area is yet to be properly surveyed, as it has not been included in the area of any of the modern research teams and has a great potential for archaeological discoveries because of its permanent water sources. In March 2009 the present author, together with T. Levy, visited the Buweirdeh springs in search of possible Iron Age fortress buried under the dunes. Although no fortress

expedition continued north, missing Khirbat Faynan (which is further to the east than their course of travel) and pitched a campsite near the mouth of Wadi al-Ghuweiba. While Kitchener himself explored the western side of the Arabah (although without reaching ‘Ain Huseib “owing to the want of knowledge of the locality by [his] guide”), G. Armstrong (Royal Engineer) explored the landscape to the east:

> Camp was pitched near the mouth of Wady Guweibeh, and I was extremely glad to find that a day’s halt was to be made in this locality. […] Armstrong explored the country towards the east, and found, six miles north-east of Feidan, the ruins of a small town in a valley, surrounded by bold and precipitous cliffs; the ruined walls are from a foot to 3 feet high, the stones roughly squared, and of no great size; some black heaps resembling slag heaps point out that very probably ancient mines may be found in the neighbourhood. (Kitchener 1884:213-214)

A study of the PEF map of this expedition (Figs. 3.2a and 3.2b) shows clearly that the small town is Khirbat al-Jariya, making this report to be the first to mention the site and to recognize this part of Faynan as an ancient mining district. The next passage is also interesting:

> A path leads from Wady ‘Arabah to this valley [of Khirbat al-Jariya], crossing the watershed into Wady Ghuweir, where it joins, leading up the valley in a south-easterly direction, a beaten and well-worn track: this was probably the pilgrimage road from Gaza to Mecca. Lower don in the Wady (Wady Ghuweir) are numerous springs of sweet water trickling out of the bed of the wady; and in a narrow gorge the rocks are literally covered with Bedouin tribe marks, Arabic inscriptions, &c., the work of pilgrims on their way to Mecca. (ibid. 214)

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was found in this visit, we recorded several sites including Roman-Byzantine small mound with remains of a short aqueduct (maybe the same as observed by Kitchener, UTM coordinates 72370/38545) and a condense scatter of Early Bronze Age slag and furnace fragments (UTM 72415/38650).

This unique description actually follows Naqb al-Jariya to Wadi ad-Dahal (here named Wady Ghuweir) and clearly indicates the importance of Naqb ad-Dahal as a central route connecting Wadi Arabah to the highlands for centuries and millennia.

The American archaeologist Nelson Glueck (1935:23) visited KAJ on March 25, 1934 after exploring the nearby Khirbat al-Ghuweiba. Glueck believed he was the first to discover the site and attributed his find to the seclusion of the ruins, mentioning that even the Czech explorer Alois Musil, who visited the nearby Jabal al-Jariya in 1898, could not find them. Glueck correctly assigned the site to the early Iron Age, but incorrectly interpreted certain structures as smelting furnaces (Glueck, 1935:23-25; 1940c:63, Fig. 28). This problem plagued Glueck's interpretations at other archaeometallurgical sites along the Arabah valley as he probably was following the misinterpretations of one of his mentors - Sir W.F. Petrie in Sinai (1906:18). At Timna, some of these same small structures were suggested to be the graves of the workers (Rothenberg, 1967a:12 and e.n. 49,79,154). In addition, Glueck's (1935:23) claim that "the two main sections of the site seem originally to have been enclosed with strong walls", probably relates to his supposition of servile labor in the smelting camps (e.g. Glueck, 1935:28), and has no support in current field observations.

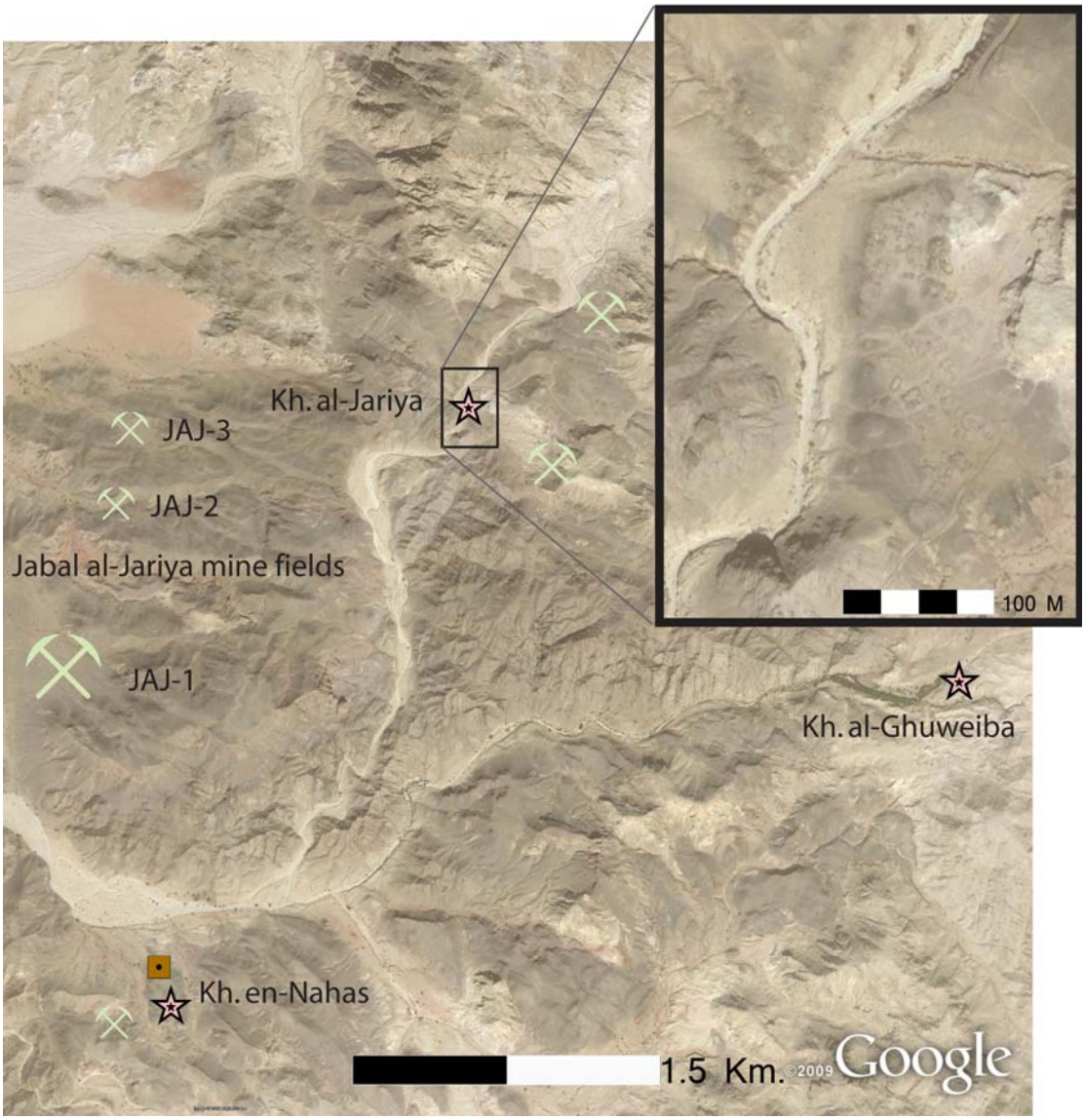


Fig.5.61: Satellite image of Khirbat al-Jariya and its vicinity; for key see Fig.5.1; (Reproduced using Google Earth Pro) (after Ben-Yosef et al., 2010a).



Fig.5.62: The Iron Age copper smelting site of Khirbat al-Jariya, looking toward the north (note people in Area A for scale). The site is bifurcated by Wadi al-Jariya whose deepening eroded a significant portion of the ~5 hectares ruins. Also visible are the relatively shallow 'slag mounds' and some substantial stone structures, probably dating to the 11 – 10 c. BCE.

After Glueck, KAJ was visited by the German Mining Museum (GMM) team (Hauptmann, 2007:131-132). They estimated the amount of slag at the site to be ca. 15,000-20,000 tons (cf. estimation for KEN = 50,000-60,000) and published three radiocarbon measurements from the upper portion of some 'slag mounds' that suggested an early IA I date (see Table 5.2 and Hauptmann, 2000). In 2002 our team surveyed and mapped the site (see Fig.5.63) together with some other small IA ruins and copper mines around Wadi al-Jariya (Fig.5.11) (Levy et al., 2003).

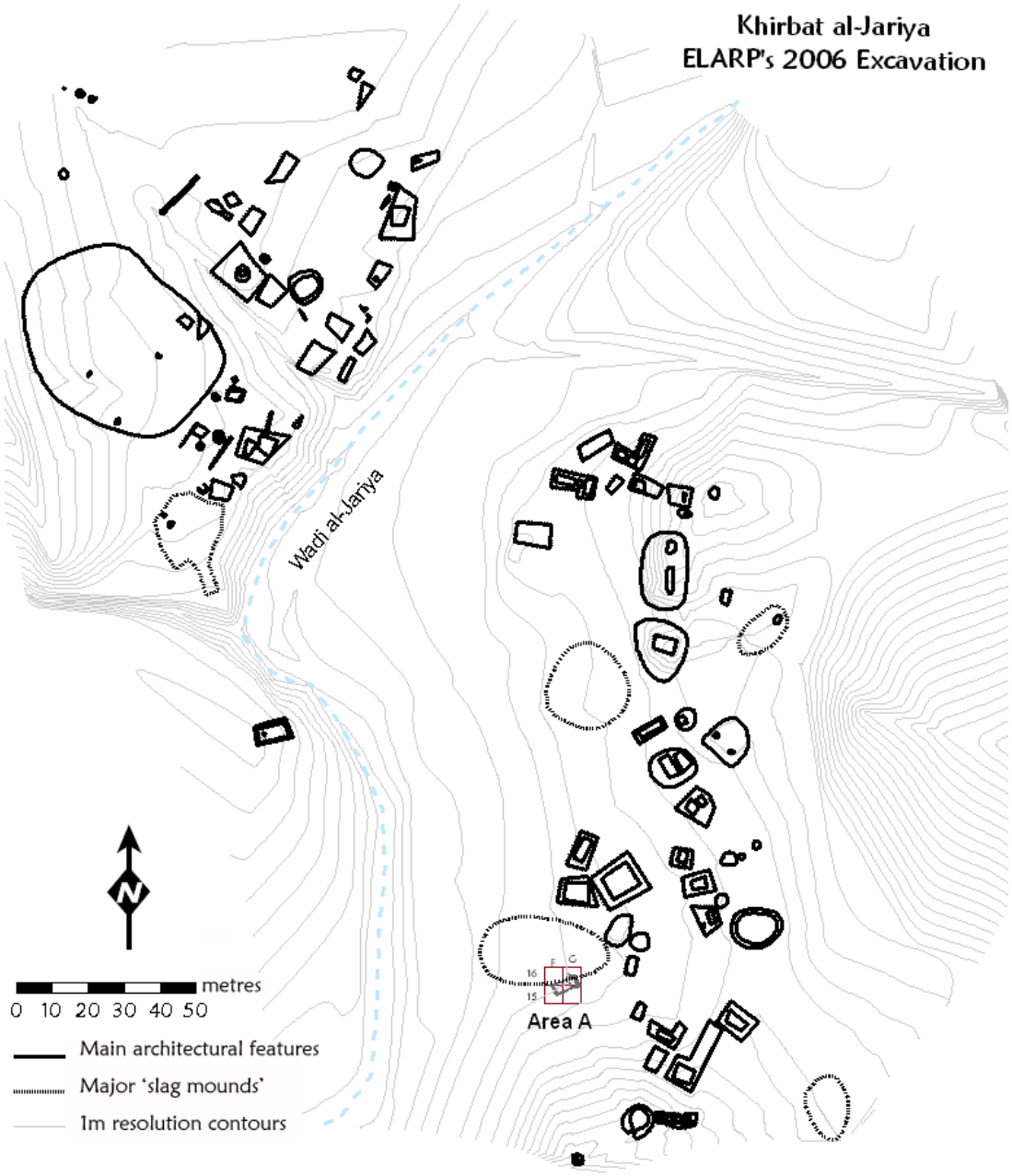


Fig.5.63: Architecture and 'slag mounds' in Khirbat al-Jariya (after Levy et al., 2003:274). The 2006 excavation Area A, including its grid and building 276, is indicated in the southeast part of the map. The 'empty' area in the center is a result of erosional processes (see text).

The first stratigraphic probe took place at KAJ November 13-27, 2006, aiming to clarify the chronology of the site and characterize diachronic changes in the copper industry by comparison with the large-scale investigation at nearby KEN (Fig.5.63) (Ben-Yosef et al., 2010a). Area A was selected in the southern portion of the eastern bank of the Wadi al-Jariya, where a rectangular structure (#276 from 2002 survey, see Levy et al., 2003) seemed to be associated with one of the larger 'slag mounds.'. This seemed to be similar to the situation in Area M at KEN (Fig.5.64) (Levy et al., 2008a). A grid of four 5 x 5 m squares was established over the 'slag mound' and structure. The building was exposed to its floor level and the western half of the 'slag mound' to bedrock (Square F-16) where the accumulation of archaeological material appeared to be the thickest (Fig.5.64) and six layers representing at least three occupation phases were recorded (Fig.5.65-67, Table 5.12). The distribution of loci is summarized as a Harris Matrix (Harris, 1977) in Table 5.13.

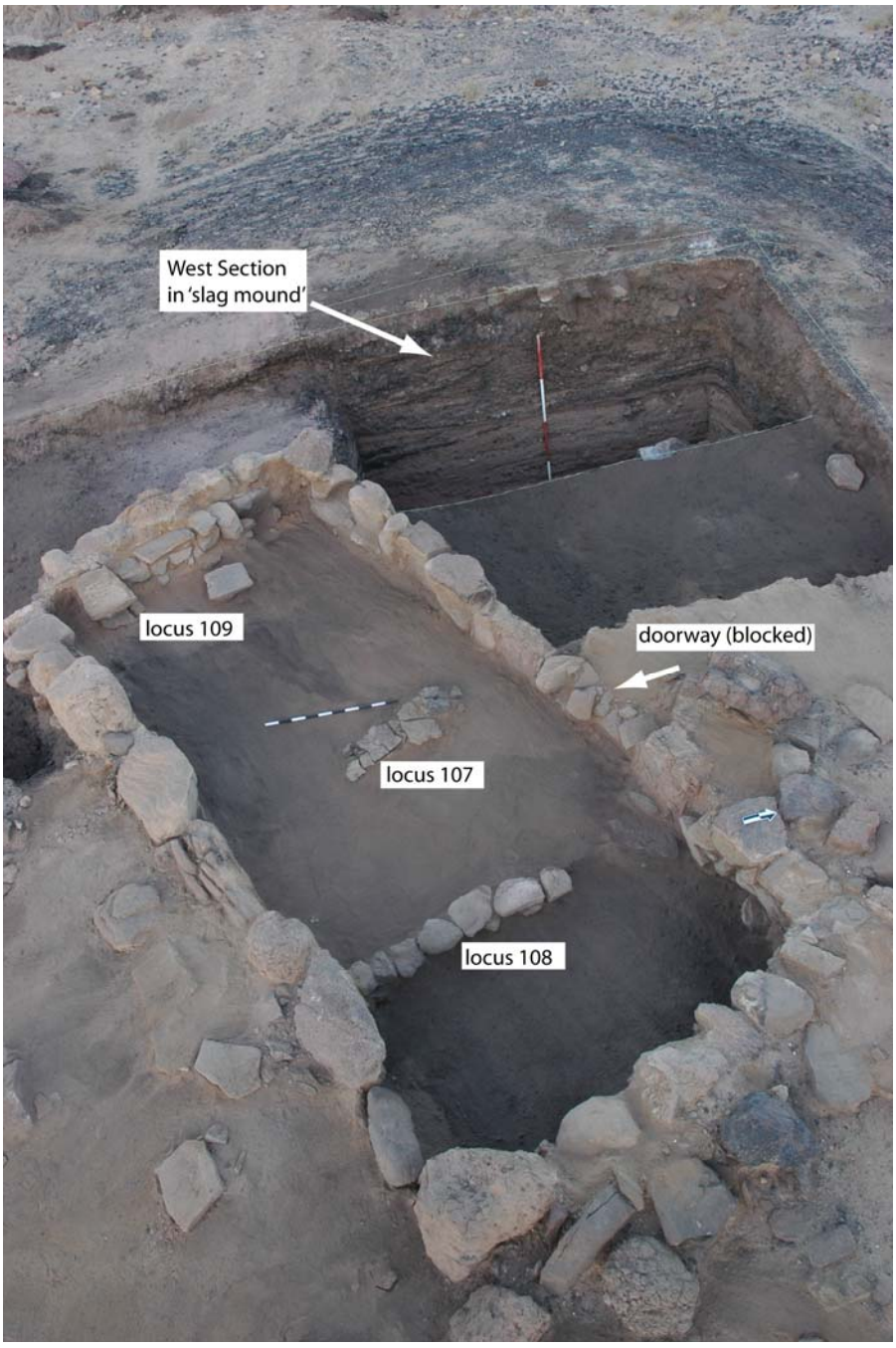


Fig.5.64: Khirbat al-Jariya, Area A, general view at the end of the 2006 season. The excavation exposed structure 276 to its floor level (hardened earth), revealing a stone-and-plaster 'bench' with a flat worked stone in front of it (locus 109), a patch of large tap slag close to the doorway (locus 108) and a partitioning stone line abutting one of the structure walls (locus 108). In half of square F-16 the excavation penetrated a 'slag mound' to bedrock, exposing stratigraphic sequence of waste and occupation layers (compare with Fig.5.65, a drawing of the West Section visible here) (after Ben-Yosef et al., 2010a).

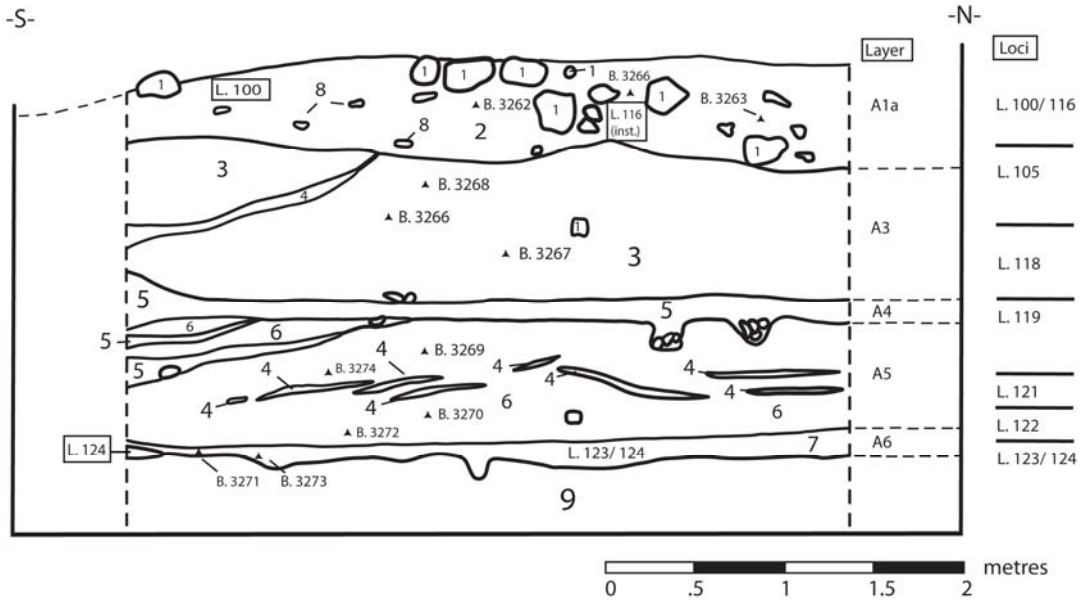


Fig.5.65a: Khirbat al-Jariya, Area A, schematic drawing of the west section in the 'slag mound' probe, representing the stratigraphic sequence of the site, from surface to bedrock (see Fig.5.64) (after Ben-Yosef et al., 2010a). (1) stones, (2) broken slag with ashy sediments, (3) broken slag with clay and silt, (4) light color ash pockets, (5) hardened ashy sediments, (6) light brown soil, domestic debris, ashy pockets, (7) fine crushed slag, (8) large slag fragment, (9) bedrock, (B) archaeointensity sample (slag/ceramic). For description of layers and associated ^{14}C dates see Table 5.12. Note that only the location of samples for archaeointensity research is indicated here, as they were collected directly from the western wall of the excavation pit.



Fig.5.65b: Khirbat al-Jariya, Area A, the west section in the 'slag mound' probe, representing the stratigraphic sequence of the site, from surface to bedrock (cf. Fig.5.65a).

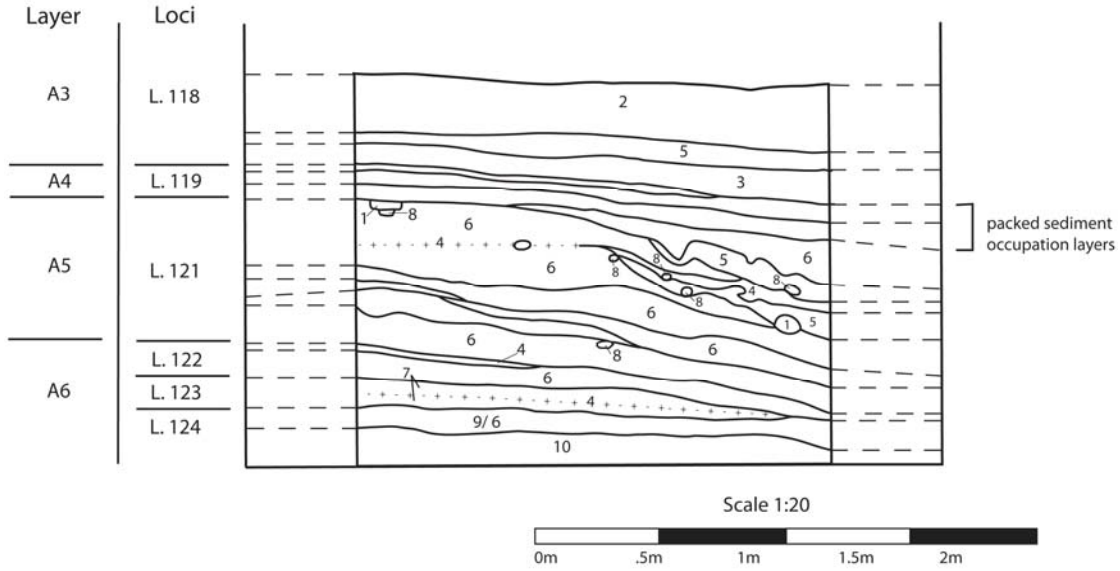


Fig.5.66a: Khirbat al-Jariya, Area A, schematic drawing of the south section in the 'slag mound' probe, representing the stratigraphic sequence of the site, from surface to bedrock (see Fig.5.66b). For key see Fig.5.65a.



Fig.5.66b: Khirbat al-Jariya, Area A, the south section in the 'slag mound' probe, representing the stratigraphic sequence of the site, from surface to bedrock (cf. Fig.5.66a).

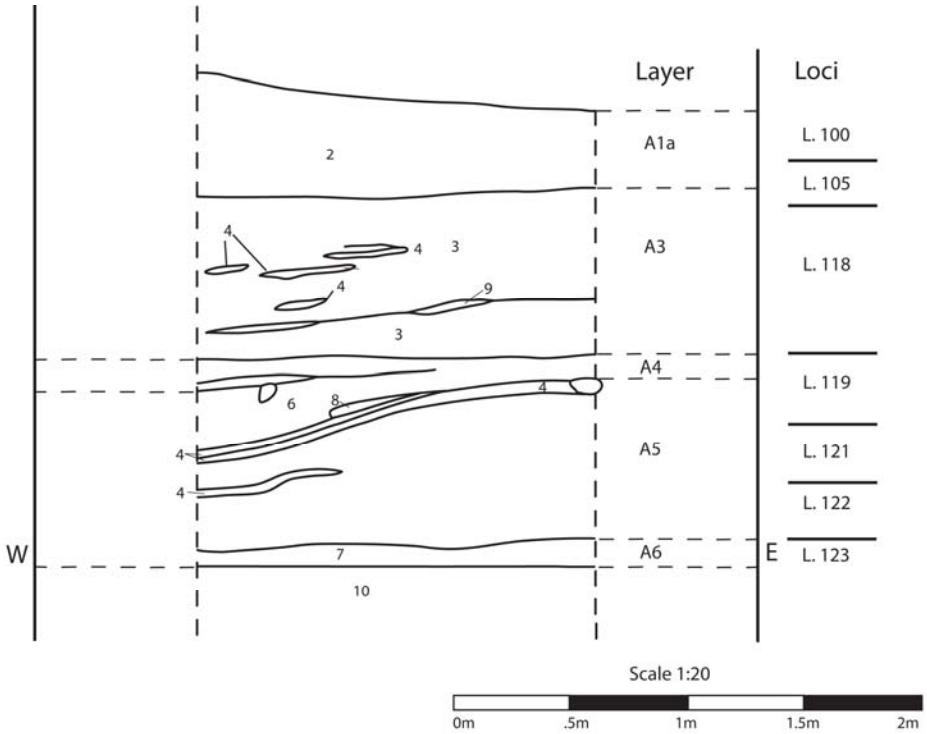


Fig.5.67a: Khirbat al-Jariya, Area A, schematic drawing of the north section in the 'slag mound' probe, representing the stratigraphic sequence of the site, from surface to bedrock (see Figs.5.64, 5.67b). For key see Fig.5.65a.

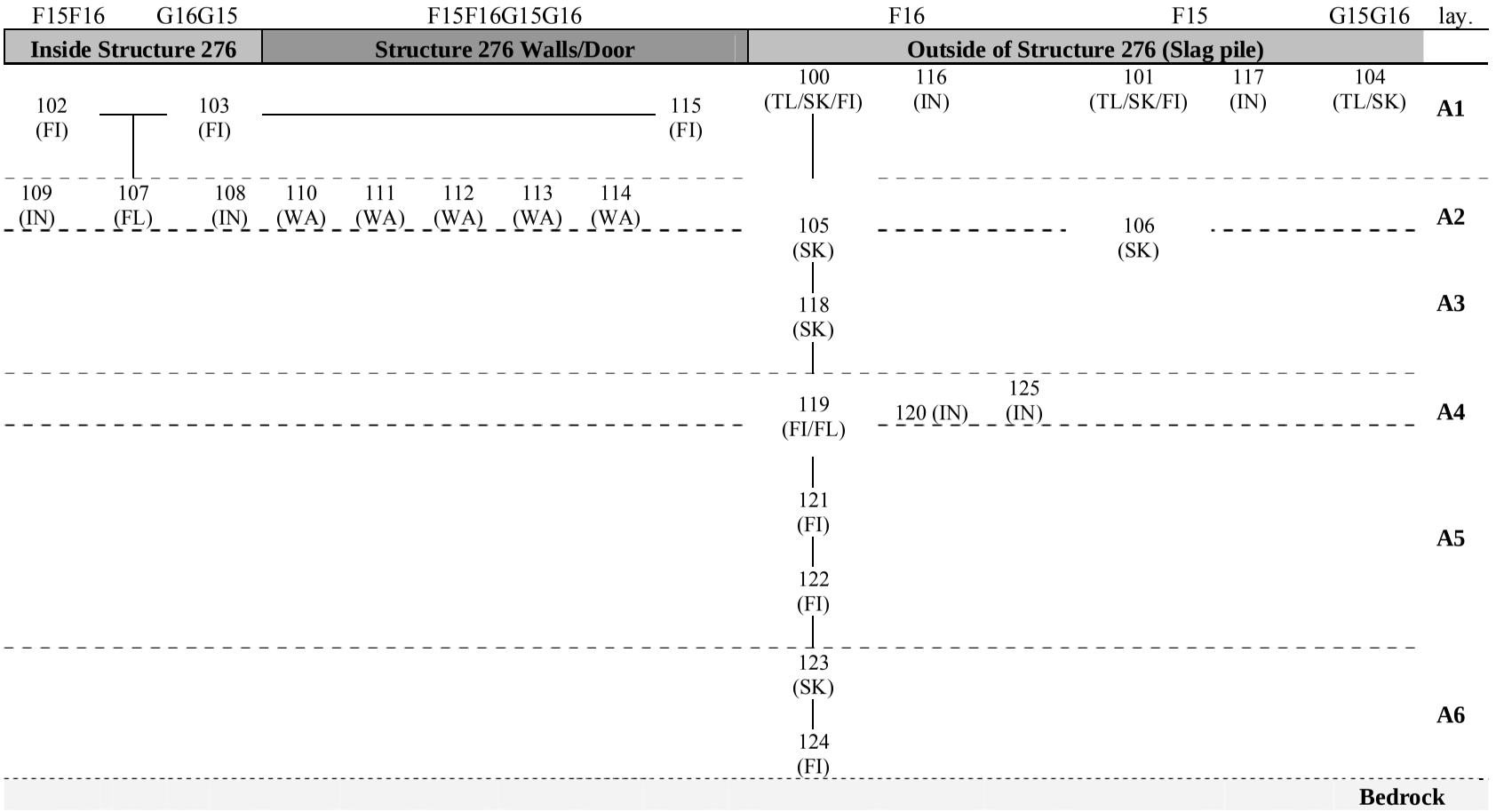


Fig.5.67b: Khirbat al-Jariya, Area A, the north section in the 'slag mound' probe, representing the stratigraphic sequence of the site, from surface to bedrock (cf. Fig.5.67a).

Table 5.12 (next page): KAJ Area A stratigraphy, radiocarbon and archaeointensity results (Cf. Fig.5.65 and Fig.5.68 for sample location, and Fig.5.72 for the Bayesian model of the results at 68.2 and 95.4% probability). N = number of specimens per sample; archaeointensity sample JS02b is from Ben-Yosef et al. (2008a)

Layer	Description	**14C results** (Calibrated with OxCal4.1 © Ramsey 2009)					**Archaeointensity results**				
		Lab#	Material	$\delta^{13}C$ ‰	Radiocarbon Age BP	Cal. Age – 68.2% prob. BCE	Lab#	Material	N	B_{anc} (μT)	VADM (ZAm^2)
A1a	Top sediments of the 'slag mound': copper production debris, aeolian dust and a few stone installations	OxA-19033	Charcoal Tamarix sp.	-24.54	2864 ±28	1113-997	JS02b	Tap slag and clay (slag attached to furnace fragment)	5	76.8± 8.7	149± 17
A1b	Fill inside structure 276, large boulders and stones	OxA-19034	Charcoal Retama ra.	-11.18	2898 ±28	1125-1026					
A2	Occupation phase of structure 276 and probably copper production debris at the top of the 'slag mound'	OxA-19087	Charcoal Indet.	-26.98	2797 ±26	995-912					
A3	"Fill": Accumulation of copper production debris, part of the 'slag mound'	OxA-19035	Charred seed Phoenix dac.	-22.92	2799 ±26	994-915					
		OxA-19130	Charred seed Phoenix dac.	-23.5	2851 ±36	1108-934	W032 68a	Ceramic	3	68±3. 1	131± 6
A4	Occupation phase: stone installations, leaving floors, tent dwelling?	OxA-19036	Charcoal Tamarix sp.	-22.54	2803 ±26	995-919					
A5	"Fill": Accumulation of domestic debris mixed with industrial remains	OxA-19037	Charred seed Phoenix dac.	-24.75	2902 ±27	1128-1026	W032 69a	Slag	3	63.3± 8.9	122± 17
A6	Occupation phase above bedrock: fine crushed slag, ore, ash pockets and pits dug into bedrock	OxA-19038	Charcoal Phoenix dac.	-26.7	2880 ±26	1113-1012					
		OxA-19039	Charcoal Indet.	-21.53	2884 ±27	1114-1016					

Table 5.13 (next page): Harris Matrix of the loci at Khirbat al-Jariya, Area A (loci definitions: FI - Fill; IN - Installation; WA - Wall; TL - Top Soil; SK - Copper Production debris)


F15F16
G16G15
F15F16G15G16
F16
F15
G15G16
lay.
Inside Structure 276
Structure 276 Walls/Door
Outside of Structure 276 (Slag pile)
102 (FI)
103 (FI)
115 (FI)
100 (TL/SK/FI)
116 (IN)
101 (TL/SK/FI)
117 (IN)
104 (TL/SK)
A1
109 (IN)
107 (FL)
108 (IN)
110 (WA)
111 (WA)
112 (WA)
113 (WA)
114 (WA)
105 (SK)
106 (SK)
A2
118 (SK)
A3
119 (FI/FL)
120 (IN)
125 (IN)
A4
121 (FI)
122 (FI)
A5
123 (SK)
124 (FI)
A6
Bedrock

5.2.5.1 The ‘slag mound’ sounding: copper production at Khirbat al-Jariya

Although commonly regarded in the literature as piles of slag, ‘slag heaps’ or ‘mounds’ are rarely composed of only slag material. At KEN, less than 40% (in volume) of the excavated material of the ‘slag mound’ in Area M was slag in various forms and types with the remainder of material consisting of decomposed furnace material, tuyères , charcoal, etc (see section 5.2.4.2) . At KAJ the situation is even more striking as only a very small volume of the excavated material was slag. The rest of the deposit consisted of fills with considerable amounts of domestic (*not* pyrotechnological) debris, including relatively large quantities of ceramic sherds, ash, and other material (see below). This observation should be taken into consideration when calculating production intensities by estimation of slag mass from surface observations, as is commonly done in archaeometallurgical research around the world (see section 9.1.3 below). The Area A ‘slag mound’ is 2.4 m deep, and includes three distinctive activity horizons (layers A6, A4 and A1a/A2, Fig.5.65-67), and two thick fill layers that accumulated as a result of deliberate disposal of waste in the direction of the wadi channel, which originally was a few meters to the west.

Above the red sandstone bedrock (Salib Formation, Rabb'a, 1994), is a layer that probably represents the initial occupation phase of the site (A6). Evidence for copper production-related activities were found here, including thin, cemented patches of fine crushed slag (Locus 123), small pits dug into the bedrock (related to crushing

activity? Fig.5.65), ash pockets and some copper ore fragments (Fig.5.69c) in a thin and noncontiguous layer of light brown sediment (Locus 124). This supports the supposition that the *raison d'être* of KAJ, like most IA archaeological sites in the extreme arid environment of Faynan, was the exploitation of the copper ore deposits. There are no water sources in the close vicinity of the site (the closest is 'Ain al-Ghuweiba, located across a steep ridge ca. 2.7 km to the southeast, Fig.5.1), but numerous IA copper mines are located a few hundreds meters up the wadi and its tributaries (Fig.5.11) (Levy et al., 2003:270) as well as ca. 2 km to the southwest, on the other side of Jabal al-Jariya (Jabal al-Jariya Mines, Ben-Yosef et al., 2009b) (Fig.5.1).

Above the horizontal basal layer was ca. 70 cm of 'fill' – mostly domestic debris, composed of light brown sediment rich in ceramic sherds, bone and ash pockets (A5). The scant copper production refuse included small fragments of furnace linings, slag and tuyères (cf. Fig.5.69g-h), copper prills (Fig.69i) and some chunks of copper metal (Fig.5.69j); nevertheless, the general characteristic of the fill is of domestic activities, mostly cooking, eating and storage of water and food (see the ceramic discussion below). The sequence of inclined fine layers was cut abruptly by leveling of the surface in preparation of a flat area for habitation and other activities represented in layer A4 (this transition is clearly evident in Fig.5.65). The latter is made of thin horizons of hardened light-brown earth with some charcoal and pottery sherds, stone installations, patches of stone pavement, and several pits dug into the fill

of A5 (Fig.5.65). Two of the pits were distinctive narrow (3-5cm in diameter) 'holes' in the ground; one was 23 cm deep with hardened blackish walls and a red clay plug in its bottom (Fig.69a) and the other, 0.5m to the NNW, was 10 cm deep (Fig.5.68). The holes may indicate the location of tent stakes or the base of a tripod. Coupled with the stone installations and other finds from layer A4, these may reflect tent habitation activities. Other finds from layer A4 include a copper pin (Fig.5.69k), several grinding stones (see similar examples in Fig.5.69d-f) and a mollusk fossil probably used as an ornament and similar to a worked fossil of a sea urchin found in Locus 118 above (Fig.5.69m). It is interesting to note the abundance of such fossils in the 8th through 6th c. BCE site of Busayra, approximately 15 km to the northeast on the Edomite plateau (Reese, 2002, including comparative discussion of this phenomenon). Similar worked fossil of sea urchin was found also in Khirbat en-Nahas, Area A (Locus 118, Basket 3210; EDM 20239).

After the Layer A4 occupation ceased, the area became a disposal zone again, but rich with archaeometallurgical remains (A3), including pieces of tap and furnace slag (2-10cm in diameter), ample charcoal remains, tuyère and furnace fragments and chunks of copper metal and ore in a matrix of ashy sediment and clay indicating decomposed furnace materials. Evidence of some domestic trash was present as well, including ceramic sherds and date pits. Layer A3 is truncated by a horizontal accumulation of copper production debris, representing the last phase of activity in this part of the site (A1a-A2). This top layer probably belongs to the same occupation

period of Structure 276, although some of it may be related to a post-structure abandonment phase, including some ephemeral stone installations close to the surface (Loci 116 and 117). It includes similar materials to Layer A3 only with larger pieces of slag (3-15 cm in diameter) and a yellowish horizon of aeolian sediment that accumulated below the slag fragments covering the surface. A few meters to the north of the 'slag mound' a huge sandstone basin (ca. 1.5 x 1.2 m; see fig.69b) was found on the surface, exposed by recent robbery. The basin also relates to the last phase of copper production, and was probably used to crush ore, flux, charcoal or slag as part of the copper smelting process. The large size of this ground stone mortar is similar to ones found in Area F at KEN that date to the 10th C. BCE and indicate considerable investment in metallurgical activities at this time (Levy et al., in press-b).

The evidence from the 'slag mound' in Area A indicates small scale copper production, considerably different from the massive enterprise at nearby KEN. The mound is relatively shallow (cf. 6.5 m of industrial layers at KEN Area M) and only partially represents copper production activities. All contexts show a mixture of industrial and domestic debris, and even in layers directly related to smelting procedures the archaeometallurgical artifacts indicate work in small installations and quantities indicative of limited production. The most notable technological difference between the sites relates to the size of the metallurgical installations. Furnace fragments and tap slag at KAJ are smaller than in most excavated contexts at KEN, and the tuyère are shorter and less sophisticated (Levy et al., in press-b). The latter

was first recognized by Hauptmann (2007:131-132) who points out the similarity between the small tuyères of KAJ and the Late Bronze Age tuyères of Timna, suggesting to date the beginning of the smelting activities at KAJ to the Late Bronze Age.

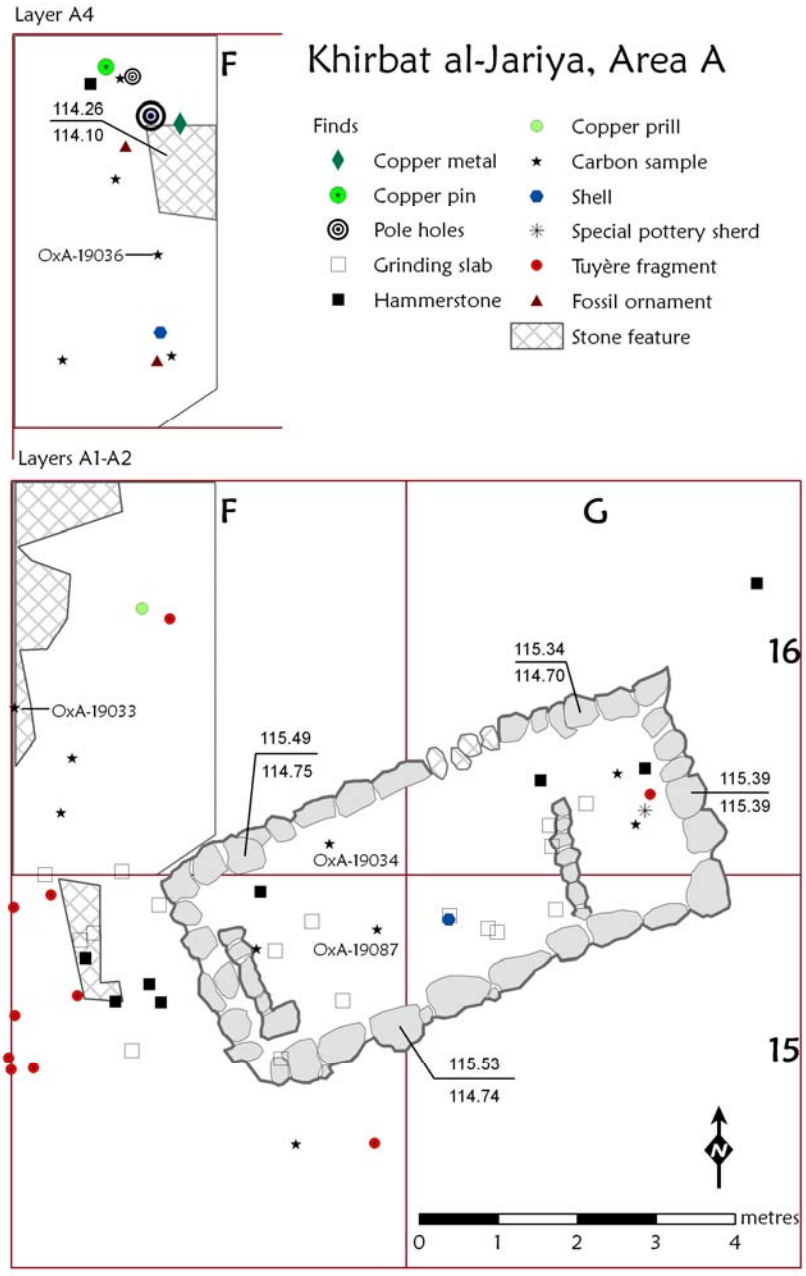


Fig.5.68: GIS map of Khirbat al-Jariya, Area A: layer A4 at the top and layers A1-A2 (including structure 276) at the bottom (see Table 2 and text for description of layers) (after Ben-Yosef et al., 2010a). The GIS-generated map displays the spatial distribution of artifacts and helps interpreting the occupation layers. For example, note the concentration of tuyère fragments in square F-15 layers A1-A2 that may represent a broken furnace in this location, the high density of hammer stones and grinding slabs inside the structure that may hint to its usage, the relative size and location of the 'pole holes' in layer A4 suggest a smaller construction than a tent (maybe a wooden frame for a churn?). Note the location of carbon samples; the ones used for radiocarbon dating are indicated with their laboratory numbers (cf. Table 5.12).



Fig.5.69: From ore to metal - finds from Area A excavation: A) 23cm hole in the ground level of layer A4 with a red clay plug in its bottom (L.120); B) Sandstone basin unearthed by robbers near the 'slag mound'; C) Copper ore from the manganese-rich dolomite-shale Burj formation; D) Hammerstone made of a chert nodule; E) dimples hammerstone; F) Grinding slab; G) Tuyère (front) with mat imprints on the clay; H) Tuyère (back) with a 'niche' for fixing the inner part the nozzle; I) Copper prill; J) A chunk of copper metal; K) Copper pin; L) Decorated pottery fragment; M) Worked fossil of a sea urchin used as an ornament (L.118) – (after Ben-Yosef et al., 2010a:736).

5.2.5.2 Structure 276 at Khirbat al-Jariya Area A

Structure 276 is a small, isolated, rectangular building with outer dimensions of 6.5 x 3.2 m and one doorway in its NNW broad wall (Fig.5.68). Its walls have only one course of massive local boulders and roughly cut stones of ca. 0.5 m in width, built on the truncated pile of copper production debris (A3). Limited finds from the occupation phase of the building (A2) came from an elusive floor level and included small quantities of pottery sherds, some grinding stones and charcoal, in addition to three interesting features: a line of stones perpendicular to Wall 111 (Locus 108) partitioning the inner space of the building; a pavement of large tap slag (in sizes not found in the 'slag mound' in the middle of the structure; and a bench-like installation abutting wall 112 made of flat stones, stuck together with plaster (Locus 109; Fig.5.70). Some 10-15 cm in front of the bench-like installation, on the floor level of the building, a flat, square, hewn stone with marks of intensive use was found. The building had a massive fill of heavy irregular stones (A1b) not indicative of wall collapse, but rather of an intentional blocking of the structure's inner space. Approximately 15 grinding stones of various types and a few pieces of charcoal were found in the fill.

Structure 276 presents difficulties regarding its interpretation. It was abandoned (or evacuated) prior to the deliberate filling of its inner space, resulting in scarcity of finds. It has substantial stone foundations that did not hold any substantial

walls, as well as a few intriguing installations. Whatever the interpretation of these may be, it does not seem that the building was an important industrial feature.



Fig.5.70: Installation Locus 109 abutting Wall 112 of Structure 276, Khirbat al-Jariya.

5.2.5.2 The ceramic assemblage of Khirbat al-Jariya

The ceramic assemblage of KAJ Area A was investigated by Neil G. Smith and the following short report is based on his observations in the UCSD Levantine Archaeology Pottery Laboratory. We present here only a basic ceramic plate for general reference with the intention of publishing a more thorough pottery analysis in the future[42].

[42] The main results of the ceramic analysis appear here with the kind permission of N.G. Smith.

Khirbat al-Jariya provides the first well documented stratigraphic evidence for the Iron Age I ceramic sequence in the lowlands of Edom. Although a few similar stylistic traits can be recognized in other regions, the ceramics recovered from KAJ appear indigenous to the area with the closest parallels found in Area M at KEN. A total of 113 diagnostic sherds from 1,158 collected ceramic fragments were recovered from the sounding. Similar to the findings at KEN (cf. Smith and Levy, 2008), a significant proportion of the ceramic assemblage was handmade (25.5%). These sherds should not be confused with 'Negevite' ware, the handmade vessels found at Iron I sites in the southern Negev (cf. Rothenberg, 1988; Meshel, 2002; Cohen and Cohen-Amin, 2004; Cohen and Bernick-Greenberg, 2007). Although petrographic studies and Instrumental neutron activation analysis (INAA) have identified several Negevite sherd's origins in Transjordan (cf. Gunneweg et al., 1991; Haiman and Goren, 1992), the hand made pottery found at KAJ uniquely contain slag inclusions indicating they were produced on site. In addition, they do not share the shaping techniques used in Negevite wares (see especially a recent typological study of the Negevite wares from Kadesh Barnea by Cohen and Bernick-Greenberg, 2007). The majority of our diagnostic sherds are wheel-made (n=102) and possess a well balanced distribution across vessel families (see Fig.5.71 for a representative sample of the wheel made assemblage from the site. These are representative forms for this period in Lowland Edom)[43]. Perhaps the most peculiar trait of the KAJ ceramic assemblage is

[43] The MNI count ('Minimum Number of Individuals') for each vessel family is: Cooking Pot (n=9), Bowl (n=19), Jar (n=25), Jug/Juglet (n=20), and Krater (n=22).

the absence of pithoi, which figure so prominently in the ceramic assemblage at KEN - however, this may be due to the small sample size. The equal proportion of cooking pots (cf. Fig. 5.71:12) and serving vessels (e.g. cups, bowls and kraters; Fig. 5.71:1-6) points to domestic activities practiced alongside metal production; debris of both activities often originated from the same context. There is a complete absence of painted sherds (including imported Midianite/ Qurayyah ware), with only a few diagnostic sherds decorated with grooves and incisions or slip (n=19); however this also may be attributed to the small sample. These data are similar to the earlier phases at Area M (KEN). Unique to the KAJ assemblage is the presence of small fine-ware carinated bowls with an incised stanza and applied knob decoration (cf. Figures 5.69:L; 5.71:1-2). Finally, a red horizontally burnished bowl was found in Layer A2/3 (cf. Figure 5.71:3). Thin-section analysis on this sherd indicates that it is made of loess soil originating from the N. Negev (Smith et al., in press-a). The evidence suggests that KAJ interacted with its western neighbors to some extent during the IA I/IIA period but was occupied by local potters.

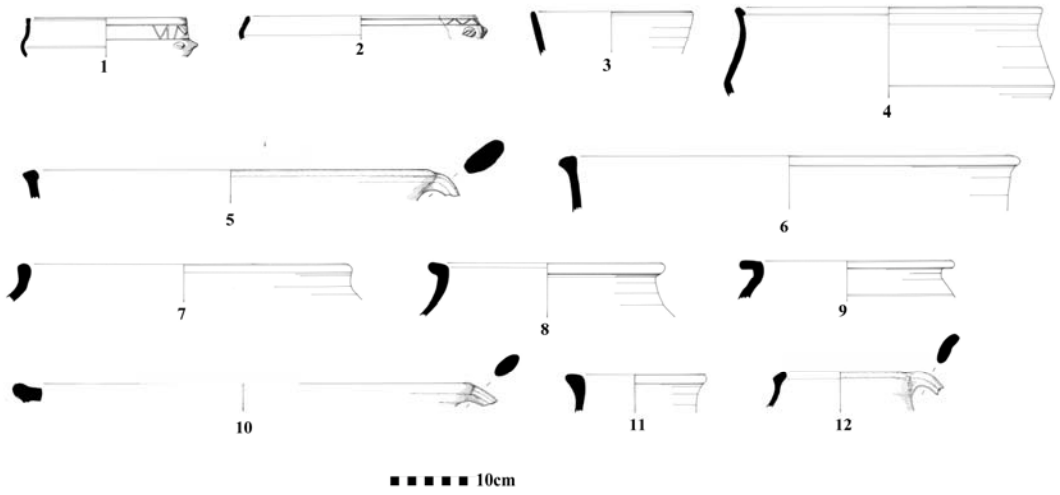


Fig.5.71: Some representative ceramic types of the copper smelting site of Khirbat al-Jariya, Jordan. The plate illustrates the predominant wheel-made vessel forms for depositional layers A1- A4 (Plate compiled by N.G. Smith, see Table 5.14 for details).

Table 5.14: Representative types of ceramic vessels from Khirbat al-Jariya, Area A (Table prepared by N.G. Smith, cf. Fig.5.71 for details); L.=locus, B.=Basket, Type = numbered vessel types represent parallel vessels found at Khirbat en-Nahas, cf. Smith and Levy (2008) and Smith (2009)

Fig.	Reg#	EDM	L.	B.	Layer	Vessel	Type	Description
1	394	20116	106	3105	A2/3	Bowl	BL18	Very pale brown (ext./int.) with red and black core; Incised Stanza and Applied Buttons
2	1451	20241	0	3212	A1a	Bowl	BL18	Very pale brown (ext./int.) with red and black core; Incised Stanza and Applied Buttons
3	938	20210	105	3196	A2/3	Bowl	BL16	Red (ext./int.) with redish brown core; Interior/Exterior Red Slip with irregular horizontal burnish lines
4	937	20210	105	3196	A2/3	Krater	KR27	Reddish Yellow with very pale brown core
5	928	20269	121	3231	A5	Krater	KR27	Reddish Yellow (ext.)/light red (int.) with very pale brown core
6	978	20227	118	3205	A3	Krater	KR26	Reddish Yellow (ext.)/light red (int.) with very pale brown core
7	929	20210	105	3196	A2/3	Jar	JR	Reddish Yellow (ext.)/light red (int.) with very pale brown core
8	975	20227	118	3205	A3	Jar	JR	Reddish Yellow (ext./int.) with very pale brown core
9	903	20125	107	3014	A2	Jar	JR	Light brownish gray with gray core

Table 5.14 continued

Fig.	Reg#	EDM	L.	B.	Layer	Vessel	Type	Description
10	908	20081	107	3072	A2	Jar	JR6	Pale Yellow (ext./int.) with white core
11	962	20244	119	3213	A4	Jar	JR	Pale Yellow (ext./int.) with pinkish-white core
12	974	20227	118	3205	A3	Cooking Pot	CP20	Light gray (ext./int.) with gray core; Cooking pot fabric

5.2.5.3 Radiocarbon measurements for Khirbat al-Jariya

The radiocarbon measurements of samples from Khirbat al-Jariya were processed in the Oxford Radiocarbon Accelerator Unit (Research Laboratory for Archaeology and the History of Art), by Thomas Higham (Ben-Yosef et al., 2010a).

Nine carbon samples from well defined contexts at KAJ are presented here (Fig.5.72, Table 5.12). Modeling of the results using stratigraphic constraints and Bayesian statistics (Ramsey, 1995; Buck et al., 1996) indicates that occupation of Area A started between 1092-1017 BCE (68.2% probability; 1147-1007 BCE 95.4%) (start of A6) and ended between 1002-933 (68.2% probability; 1016-904 BCE 95.4%) (end of A1-2) with an overall occupation span of 20.5-133.5 years (68.2% probability; 0-206 years 95.4%).

Similar to the situation in KEN, there is a conspicuous absence of Acacia charcoal in the archaeological record of KAJ (Table 5.12), which is in accordance with the general pattern of the Iron Age record in Faynan (e.g., Engel, 1993; Steinhof, 1994; Hauptmann, 2007:50-53) and was recently interpreted as reflecting the value

system of the local semi-nomadic tribal society rather than any significant ecological change (Ben-Yosef, 2009b). This issue is discussed in section 7.2.3.1 below.

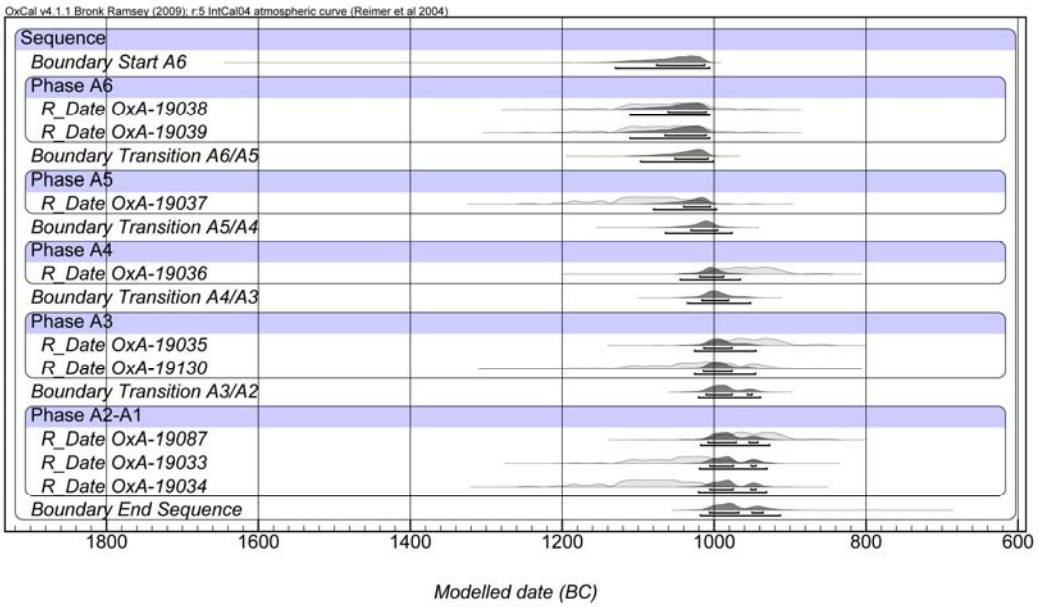


Fig.5.72: Bayesian Age Model of radiocarbon date distribution for Khirbat al-Jariya (see Table 2 for the uncalibrated and calibrated laboratory dates). The site spans the 11th and 10th centuries BCE (see text for details and Ben-Yosef et al., 2010a).

5.2.5.4 Geomagnetic archaeointensity investigation: Correlating KAJ and KEN

Absolute determinations of the rapidly changing geomagnetic field intensity may refine correlation between archaeological horizons by complementing datasets of material culture and radiocarbon dates from different locations (e.g., Ben-Yosef et al., 2008b, and chapter 4 above). Following the procedure of Ben-Yosef et al. (2009c) we obtained two new determinations from KAJ layers A5 and A3 in addition to the one published by Ben-Yosef et al. (2008a) for a sample collected from the upper portion of the same 'slag mound' (Table 5.12, Fig.5.65).

The archaeointensity data published here contribute supporting chronological data for correlating the radiocarbon evidence from KAJ layers A3-A1a and KEN Layer M3, probably to its early phase (Fig.5.73), and also for correlating between layers A5-A6 with KEN Stratum M4. As more absolute archaeointensity determinations become available, Table 5.12 will provide a useful reference for correlating KAJ and other sites in future research. The extremely rapid changes in field intensity values, or 'spikes,' during the IA (Ben-Yosef et al., 2009c; Shaar et al., in press) suggest that two statistically identical determinations from different sites indicate contemporaneity (up to a resolution of a few decades in certain time intervals).

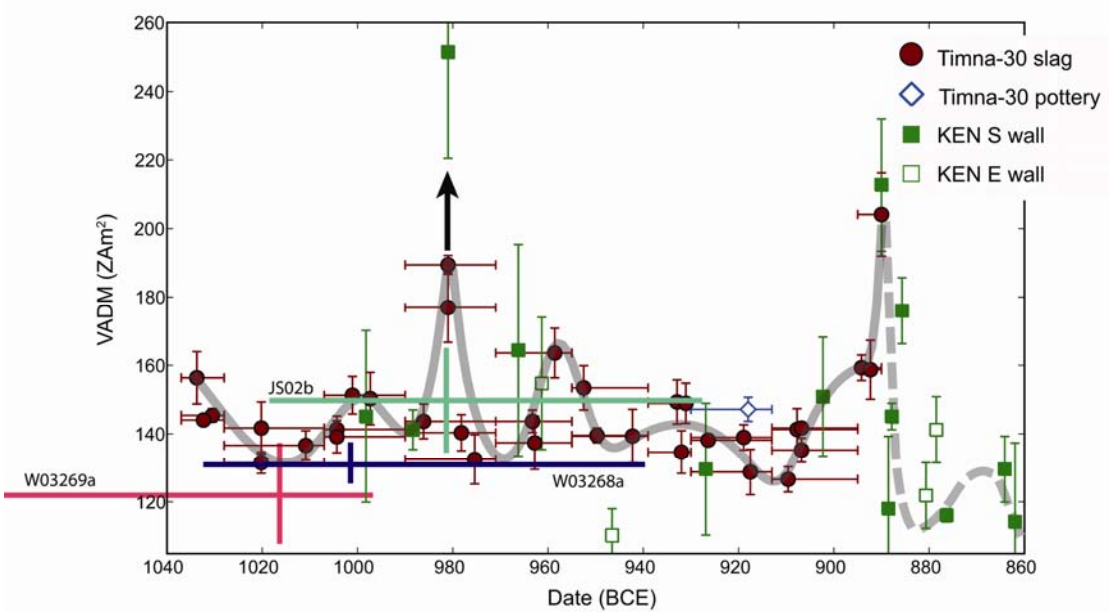


Fig.5.73: The geomagnetic intensity curve for the Iron Age IIA based on KEN Area M and Timna 30 (see Shaar et al., in press, and Chapter 4 above) and the archaeointensity results from Khirbat al-Jariya. Horizontal bars indicate modeled ^{14}C age of the stratigraphic layer; vertical bars are located in the highest probability of ^{14}C age and represent error range of intensity results. The oldest sample may represent intensity value not indicated on the present curve.

5.2.5.5 Khirbat al-Jariya – summary and discussion

After the collapse of Late Bronze Age state-level societies in the eastern Mediterranean (e.g., Bachhuber and Roberts, 2009), new socio-economic opportunities arose in lands on their periphery. A window on this process is provided at KAJ in the marginal Faynan copper ore district of southern Jordan. The stratified excavations there show that the site was first occupied around the mid-11th century BC and abandoned sometime during the mid to late 10th century BC – earlier than previously assumed. The sounding suggests that the substantial architecture visible on the site surface dates to the first half of the 10th century, and that earlier settlement was probably based on a more ephemeral use of the site. KAJ was established to exploit the copper sources in the nearby mines, and metal production developed gradually and opportunistically from the use of simple technologies for small-scale production to mass production with sophisticated large-scale installations. The peak in Iron Age copper production in Faynan, however, is evident at nearby KEN (e.g., Strata M3-M1, 10th – 9th centuries BCE) without parallel record at KAJ, and demonstrates a different and more complex social organization of production extending into the 9th c. BC - but no later.

Radiocarbon dates from three Faynan sites, including KEN, suggest small scale copper production activities starting already in the Late Bronze Age (with dates as early as the 15th c. BC, Table 5.2). At Timna, although there are fewer high

precision radiocarbon dates and sample contexts are not always secure, there is evidence for small scale copper production throughout the IA I – IIA sequence, *after* the end of 20th dynasty Egyptian hegemony in the region (Table 6.2 and Chapter 6 below). The resumption of copper production along the length of the Arabah valley during the early IA should be seen in light of "global" economic and political changes, especially the disruption of commercial connections between Cyprus and the Levant at the end of the 13th c. BC (Knauf, 1995; Fantalkin and Finkelstein, 2006; Finkelstein and Piasetzky, 2008) and the vacuum in political power in the region after the decline of Egyptian influence (Levy and Najjar, 2007; Levy et al., 2008a) that occurred in the Late Bronze Age – IA transition. Still, the questions of who or what triggered and organized this enterprise, what was the destination of its products and what social and political processes brought about the recorded technological changes within the IA remain open.

There is no evidence in the early stages of IA copper exploitation (before the end of the 10th century BC) for Egyptian or any other external control. The ceramic assemblages demonstrate local vessel types that later evolved into the late Iron Age (8th – 6th c. BCE)'Edomite' wares known from the highlands of Edom and Negev desert (see Smith and Levy, 2008 and above). In our view, the evidence from Faynan indicates that the resumption of copper production at the very end of the Late Bronze – Early Iron Age, was opportunistically initiated by local semi-nomadic tribal societies. These may be the "Shasu" tribes mentioned in ancient Egyptian documents and

suggested as having been responsible for the 10th c. BC cemetery at Wadi Fidan 40 in the Faynan district (Levy et al., 2004a; Levy, 2009b). Moreover, although the resumption of copper production may be related to the wider phenomenon of settlement intensification in the Negev highlands, and in particular interaction with the so-called "Tel Masos chiefdom" (Fantalkin and Finkelstein, 2006), we do not consider both regions to represent the same political or social entity. Rather, these Negev sites may have played a role in the copper exchange network emanating from Faynan. Thus, during the IA I, Faynan was part of the lowlands of biblical 'Edom' and provided the natural resources that enabled the beginning of processes that led to a local complex society such as a kingdom (Avishur, 2007) or chiefly confederacy (Levy, 2009b) described in the biblical accounts.

The geographical extent of Edom is poorly delineated in historical accounts (section 2.1.1 above). Most scholars agree that during the late IA (7th - 6th c. BC) Edom's borders extended to the west of the Arabah Valley, and according to Edelman (1995) and Zucconi (2007) the earliest references to 'Edom' may already encompass this larger area. Our IA research indicates that its borders oscillated through time with Faynan as its core during the 11th-9th c. BC and the highland plateau site of Busayra, most likely in the 8th-6th centuries BC.

KAJ was abandoned in the second half of the 10th century BCE, possibly coinciding with the date of the military campaign of Pharaoh Sheshonq I (biblical

Shishak) in the region (Kitchen, 1986:292-302). Levy et al. (2008a:16465) ascribe the disruption marked by the M3-M2 boundary at KEN (Area M) to the impact of this campaign on the organization of copper production at the site, while Fantalkin and Finkelstein (2006) attribute the prosperity evident in Tel Masos II and other changes in the archaeological record of the Beersheva valley to this event (contra e.g., Fritz, 2002). These researchers view the Egyptian endeavour as a positive intervention, fostering the copper industry and trade (and definitely not related to the end of IA IIA in the region). Although no definitive evidence of deliberate destruction was found at KAJ or KEN, the abandonment of the first and the re-organization of the second (that may have occurred decades after the year of Sheshonq's campaign itself) may suggest that Egypt attempted to strangle or simply disrupt the incipient industry, which eventually was revived in greater intensity by the local political powers independent of Egypt (Kitchen, 1986) by the early 9th c. BC. Nevertheless, we do not think that a decisive answer regarding the Egyptian role in the copper industry is currently at hand. Other explanations for the cumulative archaeological data are possible; for example, the abandonment of KAJ may relate to exhausting the local mines and focusing on the large copper ore-filled colluvial fields of Jabal al-Jariya (Ben-Yosef et al., 2009b), closer to KEN (for further discussions see Chapters 9 and 10).

5.2.6 *Ras al-Miyah Archaeological Complex*

Ras al-Miyah (Arabic for 'Head of the Spring' [transliteration: Rās al-Miyāh])[44], the area around 'Ain al-Ghuweiba oasis (Fig.5.74), is abundant with archaeological sites, mostly dated to the Iron Age II (Figs.5.1 and 5.75, Table 5.15). The largest site is Khirbat al-Ghuweiba, a dense, ca. 7 ha scatter of Iron Age slag located on both sides of Wadi al-Ghuweiba near the spring. Interestingly, the smelting activities at Khirbat al-Ghuweiba are dated to the Iron Age I – IIA (see section 5.2.7 below), thus they seem to represent a different occupation phase than the copper mines and fortresses recorded in this region (see discussion below).



Fig.5.74: An overview of Khirbat al-Ghuwayba (FBRS Site 1) and 'Ain al-Ghuwayba (Arabic for 'Spring of the Grove') from the fortresses area (the cliffs above the wadi). This is the head of the principal road to Busayra and a large Iron Age copper production site.

[44] When we visited the area in 2006 we could not track the local (Bedouin) name of the fortresses of the other ruins mentioned here, thus we named the sites after the general local name of this region.

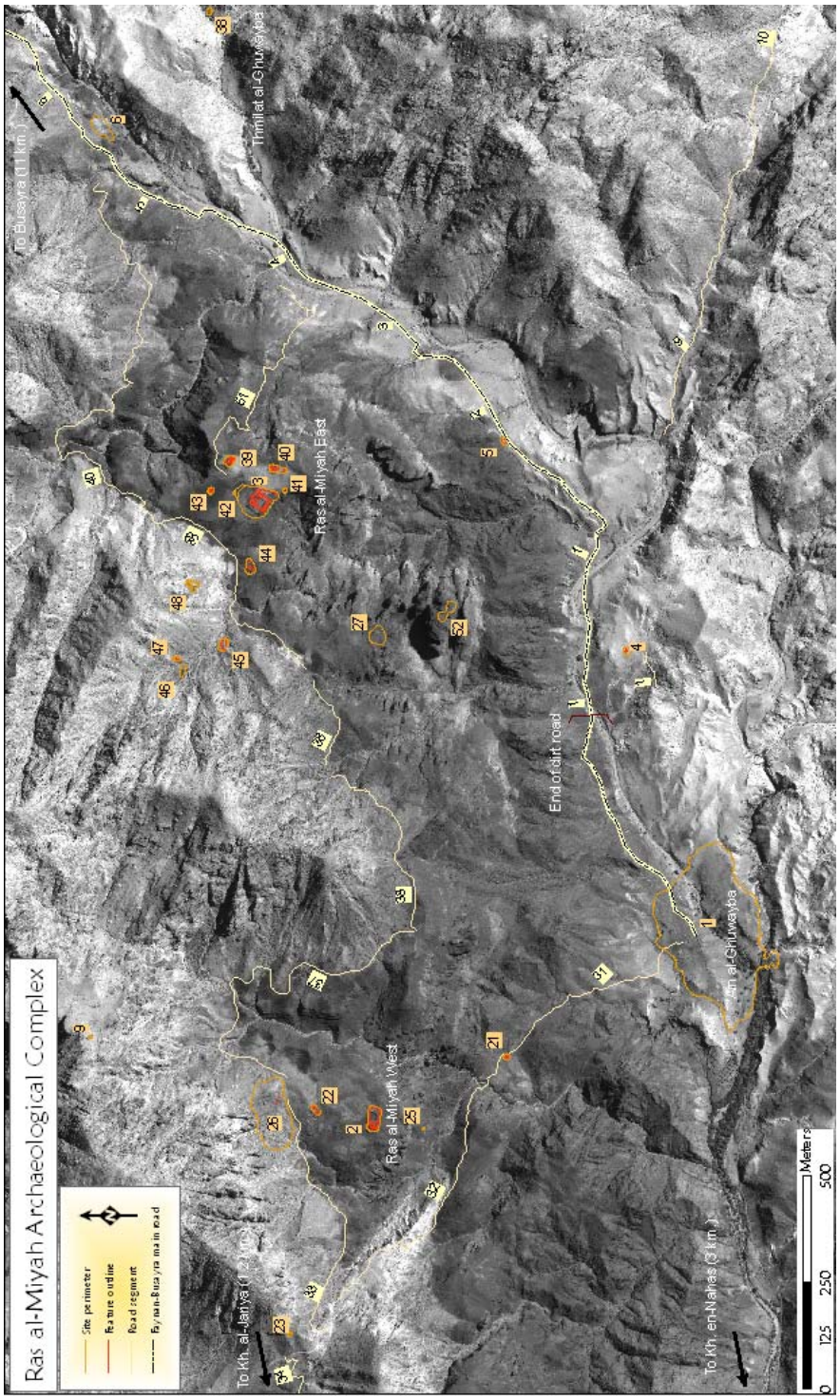


Fig.5.75: Sites and Road Segments recorded by FBRS at the Ras al-Miyah Archaeological Complex (high resolution satellite image, Ikonos, Geoeye). This area is the head of the principal road between Faynan and Busayra. The road climbs along the bank of Wadi al-Ghuwayba (Road Segments 1-6). All of the sites, except Site 52, are Iron Age or unidentified (Ud) (cf. Table 5.15) (for description of the Road Segments see Ben-Yosef et al., in press).

Table 5.15: Ras al-Miyah archaeological complex: sites recorded by FBRS (Ben-Yosef et al., in press) (cf. Fig.5.75); Kh. = Khirbat (in Arabic, 'ruins of')

* Site column contains (in the following order): site number; date visited; Wadi basin, map reference (in UTM WGS 1984 36N), elevation (in meters above sea level)

** Details column contains (in the following order): toponym (if any; Kh. = Khirbat [in Arabic, 'ruins of']), site type, site area (m^2), age (by ceramic identification, Ud = Unidentified).

Site*	Details**	Location	Description	Comments
1 7/7/2007 Ghuwayba 737153/3398 285 175	Kh. al-Ghuwayba Archaeological complex / Smelting site 70967 Iron Age, Nabataean (?)	Extensive archaeological complex sprawling on wadi terraces on both sides of Wadi al-Ghuwayba near the spring.	Small fragments of slag are scattered all over the site; structures and installation are visible on the surface. Modern Bedouin camp site is located in the middle of the north bank portion of the site.	The site was surveyed as part of SGNA (MacDonald 1992:76, site 161, "Iron Age II") and by the German expedition (e.g., Hauptmann 2007:132, "Iron Age"); more precise dating is needed, especially in regard to the mining complex of Ras al-Miyah. A few sherds were identified by our team as Roman.
2 7/7/2007 Ghuwayba 736692/3399 076 319	Ras al-Miyah - West Fortress 1656 Iron II	On the edge of the Burj dolomite plateau, ca. 150 m above 'Ain al-Ghuwayba.	Fortress built out of local dolomite stones.	See detailed description in Ben-Yosef et al. (2009).
3 7/7/2007 Ghuwayba 738148/3399 341 350	Ras al-Miyah East Fortress 5119 Iron II	On the edge of the Burj dolomite plateau, ca. 175 m above 'Ain al-Ghuwayba.	Massive unfinished fortress built out of brown sandstones from the nearby vicinity.	See detailed description in Ben-Yosef et al. (2009); A few sherds were identified as Nabataean.
4 7/7/2007 Ghuwayba 737799/3398 483 215	Camp site 264 Iron II	On a plain of a wadi terrace, ca. 30 m above Wadi al-Ghuwayba and about 800 m from the spring.	Elliptical courtyard (41x72 m inner dimensions) and a large concentration of collapsed stones (local brown limestone, brought from nearby the terrace plain). In the surrounding area there are other small stone features such as 1m in diameter semi-circles and small cairns. The site seems to be directly related to the nearby Kh. al-Ghuwayba and may have had a role in controlling the access to the smelting area from the east (the main road to Busayra).	There is no direct view from the site to either the wadi or the spring. Pottery sherds are scattered in courtyard and the site vicinity; copper ore was also collected. To the north, near the wadi bed, there are extensive remains of recent Bedouin occupation.

Table 5.15 continued

Site*	Details**	Location	Description	Comments
5 7/8/2007 Ghuwayba 738291/3398 771 240	Camp site 168 Ud	On a granite bedrock, adjacent to the main road of Naqb al-Ghuwayba where it crosses a local saddle ca. 120 m from the wadi bed.	Circular structure made of local lime/sand/dolo stones, 16m in diameter, one course, roughly built. One wall may be partially covered/ destroyed by the old dirt road.	
6 7/8/2007 Ghuwayba 739041/3399 726 283	Lithic scatter 1652 Ud	On a flat plain above wadi al-Ghuwayba.	Dense concentration of flint tools and flakes. There are also small stone structures scattered in an area of 20 x 20 m.	Flint nodules are available only in the wadi gravel, or outcrops of Cretaceous formations far from the site.
9 7/11/2007 Jariya 736888/3399 743 437	Leopard trap 46 Ud	On a saddle in the high MB sandstone ridge separating Wadis al-Jariya and al-Ghuwayba.	Small leopard trap build of local stones.	
21 7/18/2007 Ghuwayba 736841/3398 764 211	Fortlet 194 Ud	On a granite bedrock in a small valley between the spring of 'Ain al-Ghuwayba and the fortress of Ras al-Miyah West.	A small fortlet (5.2 m square) built of local stones (granite, dolomite, sandstone). Each wall consists of ca. 10-13 stones, only lower courses were preserved.	
22 7/18/2007 Ghuwayba 736712/3399 212 314	Structure complex 314 Iron II	on the top of a plateau made of the dolomite shale unit, just north of site 2.	A small rectangular structure made of the local shale-dolomite stones, fairly well preserved. Nearby there are remains of small circular structure.	

Table 5.15 continued

Site*	Details**	Location	Description	Comments
23 7/18/2007 Ghuwayba 736190/3399 275 348	Smelting site 69 Ud	On the slope ca. 20 m above and to the northeast of the saddle separating Wadi al-Ghuwayba and Wadi al-Jariya.	A copper smelting site with a concentration of solid small pieces of slag, but no discernable structure or installations; small pieces of slag are found all along the slope from the site center to the saddle below.	
25 7/21/2007 Ghuwayba 736672/3398 960 238	Retaining wall 15 Ud	On the Salib sandstone slope to the south of site 2 (below Ras al-Miyah West).	A small retaining wall built of massive dolomite stones; the construction characteristics seems to indicate that the site is not recent-Bedouin (part of a route up to the fortress? or part of a local terrace for other purposes?).	
26 7/22/2007 Ghuwayba 736718/3399 319 318	Mining complex 11991 Iron II	On the lower slope of the Massive Brown Sandstone formation, in the vicinity of site 2.	The slopes are covered with ample amount of archeological remains related to copper mines. The location of the shafts can be identified by the black tailings (residue of the shale unit). Below the tailings and other mining debris (which create artificial piles and shape the current slope), there are some constructions - small structures made of black dolomite in the lower part of the slope (not well defined in shape, maybe simple shelters for the miners). Above what seems to be the main shafts, there is a line of holes (about 18 and 12 cm in diameter) carved into the sandstone, probably part of the installation which helped with carrying out the dug material. Abundant ceramic all over the slope with concentrations near the mine shafts.	

Table 5.15 continued

Site*	Details**	Location	Description	Comments
27 7/22/2007 Ghuwayba 737832/3399 069 312	Cultic 1287 Iron II	On a ledge in the cliffs above Wadi al-Ghuwayba overlooking the fortress of Ras al-Miyah East and ca. 20 m below the route connecting the two fortresses of Ras al-Miyah.	Extensive pottery scatter, no architecture. More than 100 fragments were collected, more than 80 are identifiable. A small male figurine was found trapped in a crack between rocks.	GPS location of figurine - EDM 8000. The prominent sandstone dome facing the site (site 52) does not have clear Iron Age remains.
38 7/27/2007 Ghuwayba 739303/3399 463 255	Thmila 168 Ud	In a small tributary of Wadi al-Ghuwayba (200m from Wadi Ghuweiba itself). It is visible from Ras al-Miyah East.	A built thmila under a Ficus tree. Except for small constructions near the spring itself, there are no significant other ancient remains and no pottery.	Site center was recorded 6 m west of the spring due to the tree. Spring seems to be intensely used by local Bedouins. The wadi from the spring downward, is rich with water vegetation.
39 7/27/2007 Ghuwayba 738243/3399 415 350	Structure complex 534 Iron II	Structures located about 50-60m from the fortress of Ras al-Miyah East (site 3).	A small complex of dolomite structures composed of four rectangular spaces, the biggest of which is probably a courtyard. A small circular feature is adjacent to the northeast of the structure complex. In the courtyard, there is a broken sandstone slab. In some places the walls are preserved up to 5 courses.	
40 7/27/2007 Ghuwayba 738223/3399 307 357	Structure complex 581 Iron II	Situated on shallow residue of brown sandstone formation in the middle of the Dolomite plateau (Burj formation).	Structures constructed mostly of lousily built and lousily defined walls. Most of the buildings are of dolomite rocks, but in the center there is a structure composed mostly of sandstone. Most of the space of complex / line of structure was hard to define. The main complex is composed of 4-6 connected spaces. 10m to the south there is a smaller complex composed of 2 spaces. Abundant ceramic sherds. Manganese nodules were also collected from nearby the site (they are scattered all over the dolomite plateau).	

Table 5.15 continued

Site*	Details**	Location	Description	Comments
41 7/27/2007 Ghuwayba 738174/3399 285 351	Structure 108 Iron II	In close vicinity to the fortress of Ras al-Miyah East (site 3), on the edge of the cliff above Wadi al-Ghuwayba.	Structure is probably rectangular (we could identify some wall lines in its western and southern boundaries) and is rich with pottery. On other side of line feature of fortress site #3, there is another structure / pile of dolomite stones.	
42 7/27/2007 Ghuwayba 738170/3399 403 342	Tumulus 33 Ud	Located in a very shallow wadi in close vicinity of fortress site 3; seem to represent a different period than the fortress and structures.	A grave / tumulus, consists of a pile of massive sandstones. Robbery dig has exposed a rectangular grave chamber well defined by sandstone slabs on at least two sides.	Note the hidden location of the tumulus, uncommon with similar structure in the survey area.
43 7/27/2007 Ghuwayba 738174/3399 458 343	Structure complex 182 Iron II	On the dolomite plateau (Burj formation), close to the fortress site 3.	A single structure with a room complex made mostly of local small dolomite stones. The walls are preserved up to 3 courses. A few of the dolomite slabs are massive (up to 1 m in length).	
44 7/27/2007 Ghuwayba 737997/3399 364 329	Structure complex 647 Iron II	On the Burj dolomite plateau.	A complex of 3 small structures made mostly of small dolomite stones and small sand stones in some places. The central structure is the largest and is preserved up to 10 courses in some places.	
45 7/27/2007 Ghuwayba 737812/3399 431 332	Structure 508 Iron II	Located on the western bank of a small tributary of Wadi al-Ghuwayba and in close vicinity to copper mines (site 46). Around the site there are many small archaeological features.	Massive rectangular structure (enclosure) of local large brown sandstone.	From road segment 39 to the site and the mines (46, 47) there are many small archaeological features, retaining walls and stone piles, probably related to the mining activities in this region.

Table 5.15 continued

Site*	Details**	Location	Description	Comments
46 7/27/2007 Ghuwayba 737754/3399 525 346	Mine 304 Iron II	On the western side of a small tributary of Wadi al-Ghuwayba, a mine dug into the lower part of MBS formation.	This is the most visible mine shaft in the local tributary - blackish tailings visible from a long distance. Other mines may be present nearby buried under the sandstone talus. Abundant ceramic.	
47 7/27/2007 Ghuwayba 737781/3399 537 347	Mine 121 Iron II	On the eastern side of a small tributary of Wadi al-Ghuwayba, a mine dug into the lower part of MBS formation.	Copper mine shafts, including a possible mine tailing as well as two circular rock constructions (may represent shaft locations).	Ca. 15 m above the site there is a small cave where Edomite painted pottery sherd and a base with wheel markings were found, as well as a large mortar carved into the local sandstone.
48 7/27/2007 Ghuwayba 737952/3399 500 359	Archaeological complex / Watch tower 443 Iron II	On a hanging shelf overlooking the fortress of Ras al-Miyah East. In the lower parts of the cliffs of the MBS formation.	Massive structure stretching from edge of a cliff to the cliff face, probably rectangular. A few meters of a straight wall (the western side of the 'tower') is visible beneath the collapse and is composed of two courses of stones. On an upper rock shelf there are smaller constructions in front of a natural rock shelter / shallow cave. To the east of the massive structure carved into the sandstone cliff face, there is a slightly curved line of 7 holes, 10-15 cm in diameter, (about 3 m above the shelf, 'Feature 1' in GPS recording). Below the holes line a large sandstone block is etched with 22 notches about 2cm apart (decoration?). This area was the source of the building stones of the unfinished fortress Ras al-Miyah East. There may also be some copper mine shafts buried beneath the collapse, although no clear tailings are visible. The whole area has abundant pottery, especially in the collapse and along the slope below the building and cliff. Many diagnostic, extremely rich.	The holes line feature is similar to the one observed in site 26. Unique building whose purpose is not clear.

Table 5.15 continued

Site*	Details**	Location	Description	Comments
52 7/30/2007 Ghuwayba 737895/3398 895 328	Pottery scatter 902 EB?	On a prominent rock dome (Salib Sandstone) above Wadi al-Ghuwayba, facing both site 27 and Ras al-Miyah East. The access to the peak (including some rock climbing) is extremely hard and is possible only from the northeast side.	The site is mostly a scatter of pottery sherds in some pockets near the peak itself and to the east and south of it. There are some small cairns on the top of the peak; most of them seem to be recent. Small stone features to the northwest of the center point might be part of the old occupation.	We survey this peak because of a possible relation to the nearby unique site 27. The peak suffered extensive erosion and the site may have been more extensive. Body sherds seem to be Early Bronze.

The area of Ras al-Miyah was investigated by the German Mining Museum team, who in addition to Khirbat al-Ghuweiba reported two Iron Age fortresses ('hill forts') located near Iron Age mines (Weisgerber, 2006:13; Hauptmann, 2007:132). As part of ELRAP field seasons, we conducted a small probe in one of those fortresses (in *Ras al-Miyah East*, 2006), and a detailed survey (part of FBRS 2007, see sections 3.2.5 and 5.2.3 above). The results of ELRAP investigations are published in Ben-Yosef et al. (2009a) and Ben-Yosef et al. (in press)[45].

Ras al-Miyah is the closest Iron Age mining area to Busayra. It is located on the main road between the highlands of Edom and Faynan (Ben-Yosef et al., in press). In the Iron Age IIB-C, the heyday of Busayra as a regional administrative center (e.g., Bienkowski, 2002a), Ras al-Miyah was a center of various activities - probably all related to the mining operation in the cliffs above 'Ain al-Ghuweiba spring. Blocked mining shafts and tailings are visible on the lower slopes of the Umm Ishrin formation, and numerous small structures are located nearby (Fig.5.75). The most prominent architectural features are the fortresses, also located immediately in front of the mining complexes. Our detailed survey of both fortresses (*Rās al-Miyāh West* and *East*, or FBRS Sites 2 and 3 respectively) revealed a surprisingly high density of archaeological remains. Dense scatters of ceramic sherds indicate that both fortress sites date to the late Iron Age. In addition, our investigation shows that the

[45] The test excavation at *Rās al-Miyāh East* took place in December 4-5 2006 and the FBRS survey took place during July-August 2007. Both were supervised by the present author, and included archaeological students from UCSD and Bedouins laborers from the village of Quraiqira.

construction of the massive structure of *Rās al-Miyāh East* was never finished. The evidence concerning the fortresses and other archaeological features in their close vicinity stimulates new questions regarding the Iron Age human activities in Faynan in the Iron Age IIB-C.

The area has abundant pottery sherds, in places as dense surface scatters. They are of typical Edomite forms and clearly distinct from the common ceramic finds at Khirbat al-Ghuweiba, al-Jariya and en-Nahas. The representing assemblage is presented in the sections below, associated with the FBRS site numbers.

5.2.6.1 Rās al-Miyāh Fortresses – Geographic Settings

The two fortresses are located in the area of ‘Ain al-Ghuweiba, a small oasis and a the site of Khirbat al-Ghuweiba ('Khirbat al-Ghuweiba', see Hauptmann, 2000:89, 2007:132). Together with the surrounding remains of copper mines, small smelting sites, ancient road constructions, ancient encampments and numerous small installations, the area of ‘Ain al-Ghuweiba comprises a rich archaeological complex, situated in the upper basin of Wadi al-Ghuweiba, in the northeastern edge of the copper production district of Faynan (Fig.5.1 and 5.75). The main road connecting the region of Faynan in the lowlands of Edom with the late Iron Age administrative center of Busayra (Bozra, Bienkowski, 2002b) in the highlands passed through Wadi al-Ghuweiba, taking advantage of a relatively passable topographic path in an extremely

rough terrain. The eastern fortress and its surrounding copper mines is the closest copper production related site to Busayra, some 12 km to the northeast (as the crow flies) and approximately 800 m higher than *Rās al-Miyāh East*. It is reasonable to assume that this distance could have been traveled in one long day, and that ‘Ain al-Ghuweiba spring complex served as a major gateway, offering the first source of water in the desert environment of the Faynan district, and an efficient control point guarding both sides of the narrow valley. For those arriving from Busayra, the area of ‘Ain al-Ghuweiba also presents the first outcrops of copper bearing layers, exposed on the northern slopes of the wadi. The permanent spring still enables limited agriculture, practiced today by the Bedouins of the al-Man’ajah tribe with small orchards of olive trees and pomegranates located further downstream from the spring. This is the major water source for the entire basin of Wadi al-Ghuweiba, and probably one of the water sources for the largest Iron Age copper production site of Khirbat en-Nahas, located ca. 4 km (as the crow flies) to the east-south-east.

The fortresses are located on a distinct plateau of the Burj Dolomite-Shale formation (for the geological settings of the region see e.g. Rabba', 1994; Hauptmann, 2007:55-84) to the north of Wadi al-Ghuweiba (Figs.5.76 and 5.77). The plateau is a result of erosional processes that swept away the soft sandstone and shale of Umm-Ishrin and Burj formations, thereby exposing the hard dolomite layers and creating a well defined topographic step in the area’s landscape. This step is located several meters below the contact line between Umm-Ishrin and Burj formations. The contact

line itself, well defined by the colored shale of the upper unit of the Burj formation, forms a breaking point in the steep slopes and cliffs that enabled the construction of an Iron Age path connecting the upper Wadi al-Ghuweiba basin, the two fortresses, Wadi al-Jariya and Khirbat al-Jariya (Fig.5.78). In close proximity to the fortresses is the copper ore rich shale unit of the Burj formation, also referred to as the Dolomite Limestone Shale (DLS) unit where we identified Iron Age mines (Fig.5.77a and see below).

The oasis of ‘Ain al-Ghuweiba and the main road leading towards Busayra along Wadi al-Ghuweiba are visible from both fortresses, as well as the wide valley connecting Khirbat Faynan and Khirbat en-Nahas via Rās en-Naqb. Due to the wide vista available from the elevated location of the fortresses’ towers, guards could have been alerted for dealing with any unwelcome travelers or invaders approaching from the northeast or southeast. . However, caravans traveling from Busayra to Khirbat en-Nahas do not have to pass through the fortresses themselves, whose location does not indicate immediate concern with the road. Rather, it seems that the main interest in building the Rās al-Miyāh fortresses had to do with the exploitation of the copper ore deposits surrounding them. The position of the western fortress is one kilometer north of Khirbat al-Ghuweiba, and a ca. 150 m above the spring. The position of the east fortress is ca. 1.4 km northeast of the spring and ca. 170 m above it. This fortress is locally positioned for having a view towards the valleys in the west and not towards the road from Busayra, to the northeast.

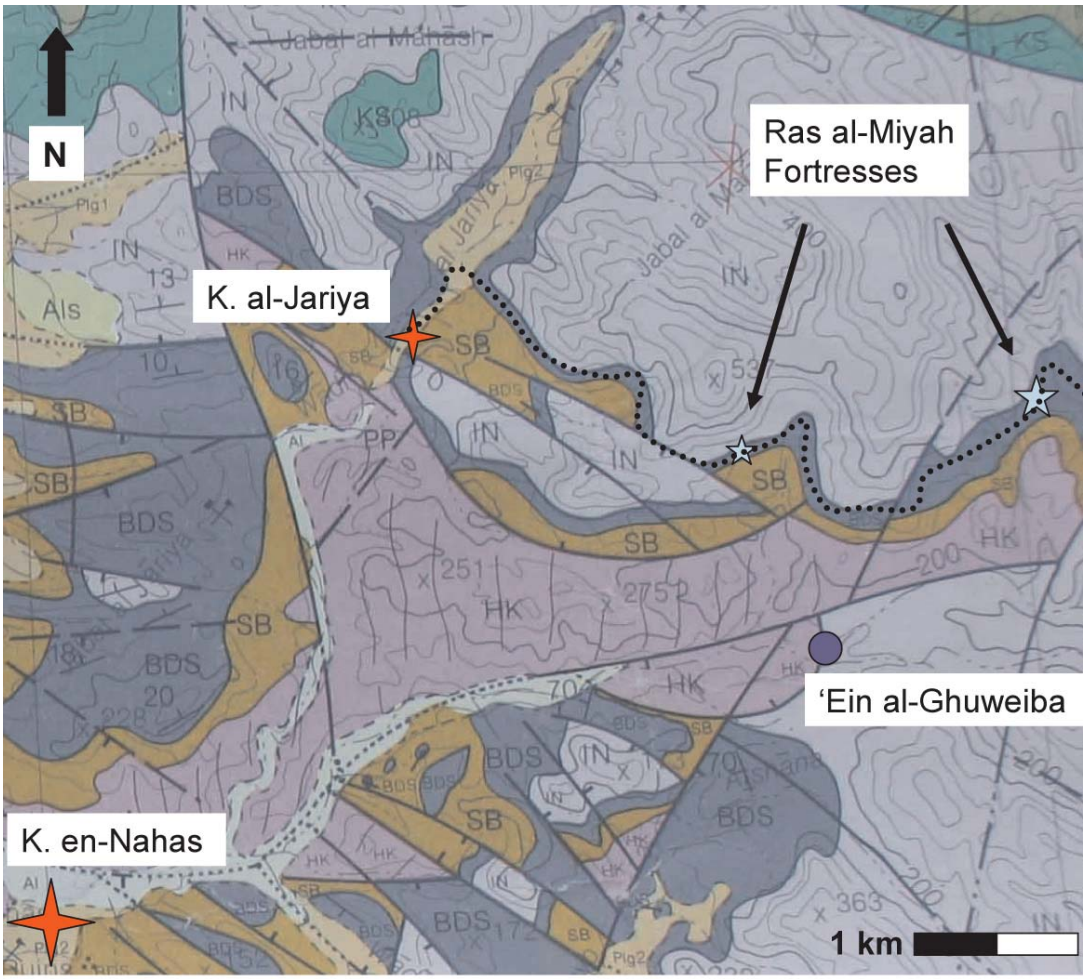


Fig.5.76: Geology map of Rās al-Miyāh Archaeological Complex (after Rabb'a 1994). HK= Hunayk Monzogranite; SB=Salib formation (arkosic sandstone); BDS=Burj formation (Dolomite-Shale; this is the main copper ore bearing formation in the Faynan district); IN=Umm-Ishrin formation (sandstone). Note the location of the fortresses and the local trail which connects them on the narrow outcrop of Burj formation (see text).

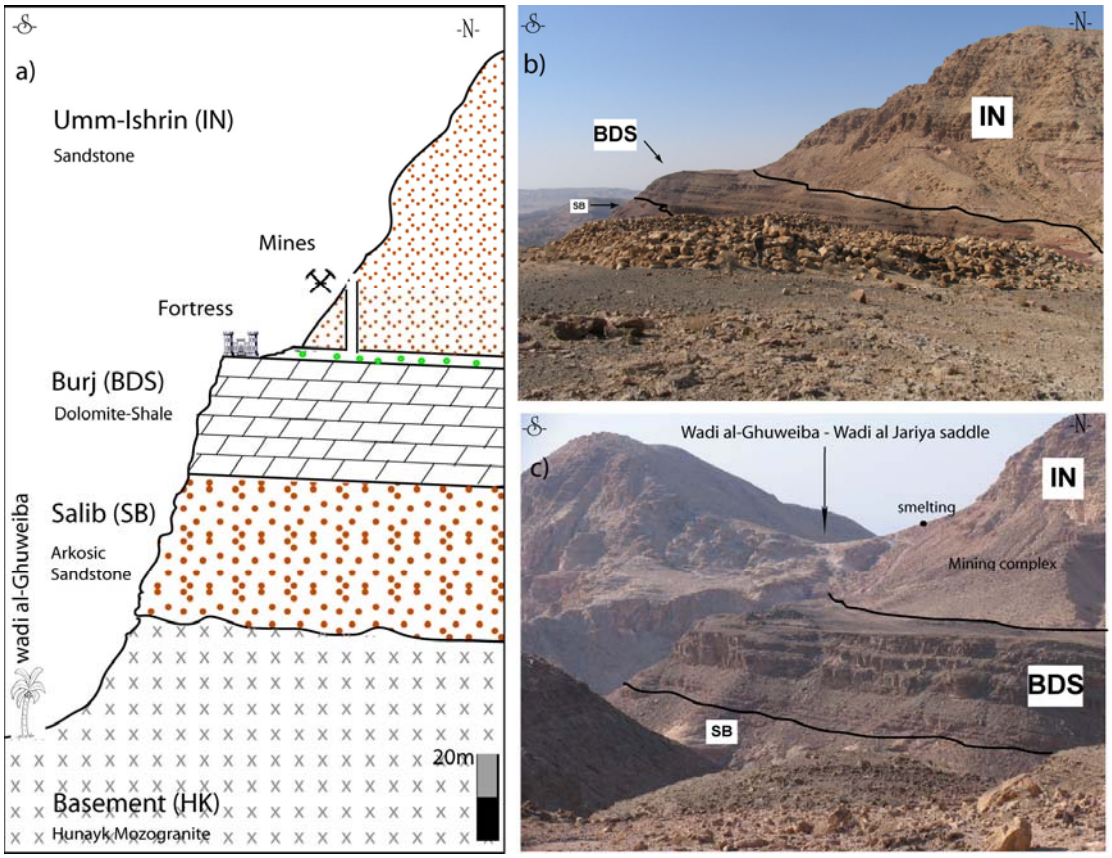


Fig.5.77: The geology of Rās al-Miyāh: a) a schematic section of the rock formations in the vicinity of the fortresses, looking west. Note the copper ore bearing horizon of Burj formation, the mining technique, involving shafts dug into the lower part of Umm-Ishrin formation and the topographic step caused by the erosion of the soft shale unit of Burj formation; b) *Rās al-Miyāh East* and the geological formations, looking west; and c) *Rās al-Miyāh West* and the geological formations, looking west.

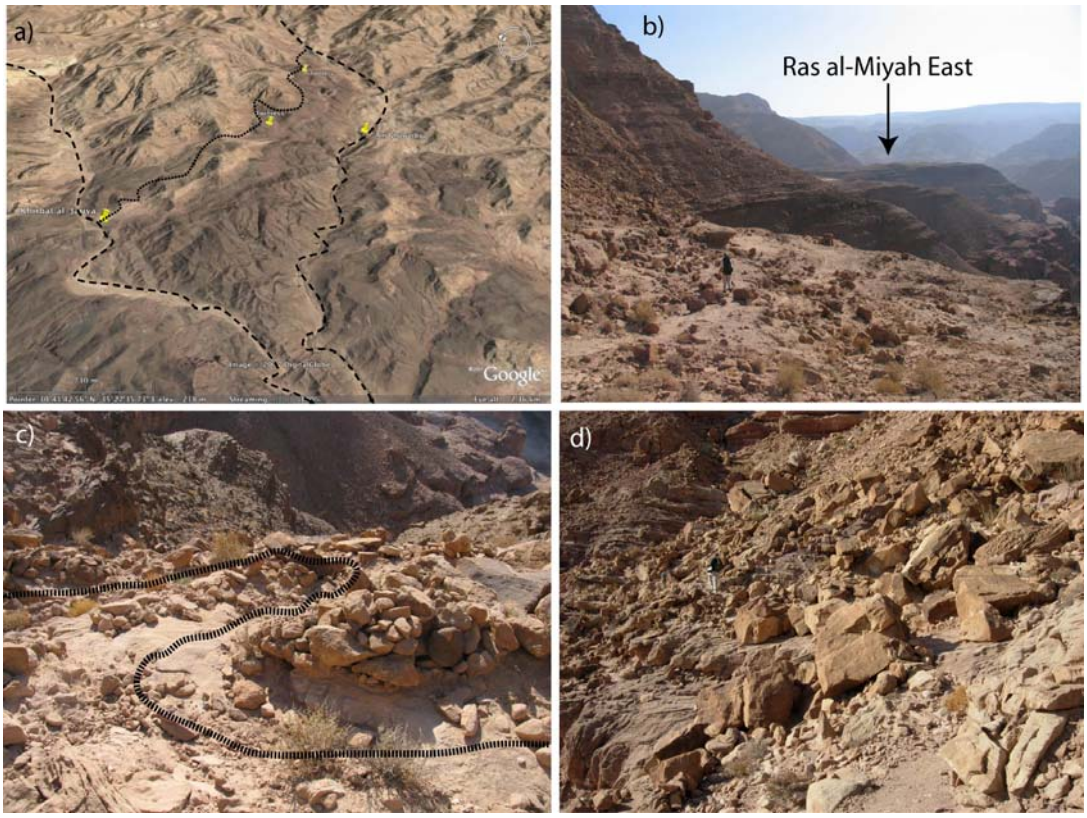


Fig.5.78: Local and principal trails in the area of Rās al-Miyāh: a) a multispectral tilted satellite image of upper Wadi al-Ghuweiba basin, looking to the northeast. The main road to Busayra passes through ‘Ain al-Ghuweiba and Wadi al-Ghuweiba; principle road to Wadi ed-Dahal passes through Khirbat al-Jariya and Wadi al-Jariya and a local road connects the two fortresses of Rās al-Miyāh with each other and with the basin of Wadi al-Jariya (image taken from Google Earth); b) the local trail connecting the two fortresses takes advantage of the topographic step of Burj formation (looking to the east). This trail shows constructions, typically in difficult passages (c); and d) the boundary between the sandstone of Umm-Ishrin formation and the shale unit of Burj formation is sometimes covered by sandstone talus. For scale, note the individual walking along the trail.

The water supply for both fortresses was provided by the nearby oasis at ‘Ain al-Ghuweiba but demanded considerable effort to haul water from the spring up to the fortresses. An additional small water source is located ca. 3 km upstream from the main spring, in a small eastern tributary of Wadi al-Ghuweiba (‘Thmilat al-Ghuweiba’, UTM 739302/3399462, FBRS Site 38). This is a small oasis with a dug pool that holds water permanently and currently has a garden consisting of fig and

palm trees and local vegetation indicating the high water table. Its proximity to the fortress of *Rās al-Miyāh East* (ca. 1 km 'as the crow flies') suggests that this was the primary water source of the fortress's occupants, assuming that a same pattern of springs prevailed in the area during the Iron Age. Building cisterns in the immediate vicinity of the fortress would require the use of mortar because the local rock does not hold water. With the exception of a possible incomplete attempt to construct a water drainage system in *Rās al-Miyāh East* (see below), no signs of any cisterns were found in our surveys around the fortresses.

5.2.6.2 Rās al-Miyāh West

The fortress of *Rās al-Miyāh West* (FBRS Site 2) is located at UTM 736691/3399076, ca. 320 m above sea level and 500 m from the saddle separating Wadi al-Ghuweiba and Wadi al-Jariya (Fig.5.1). The fortress is built out of local black dolomite stones, roughly cut into small slabs from the layered Burj formation (Fig.5.79). The structure is composed of two architecturally separate parts, a massive square tower and a rectangular enclosure divided into two main spaces (Fig.5.80). The enclosure and the tower represent distinct construction phases, as the enclosure walls abut those of the tower and do not constitute a continuous construction. The collapse walls of the tower rise ca. 4 m above the ground surface, surrounded by a massive collapse that gives it a circular layout (Fig.5.81a). However, some of the inner walls are still visible, revealing a rectangular chamber, ca. 4 x 8 m.

The enclosure walls are preserves up to 10-12 courses of stones and to a height of more than 2 m. These walls incorporate the tower forming a large rectilinear enclosure space (ca. 23 x 45 m) oriented as a west-east elongated shape. The tower dominates the northwestern part of the enclosure and does not protrude out of the rectilinear layout. The area to the south of the tower is divided into small spaces and consists of the highest remaining walls in the enclosure. This part might have been roofed, indicating several small chambers adjoining the wide open enclosure to the east. The main gateway to the fortress appears to be located in the western side, between the walls of the tower and those of the enclosure (Fig.5.80).



Fig.5.79: The fortress of *Rās al-Miyāh West* (view towards the west).

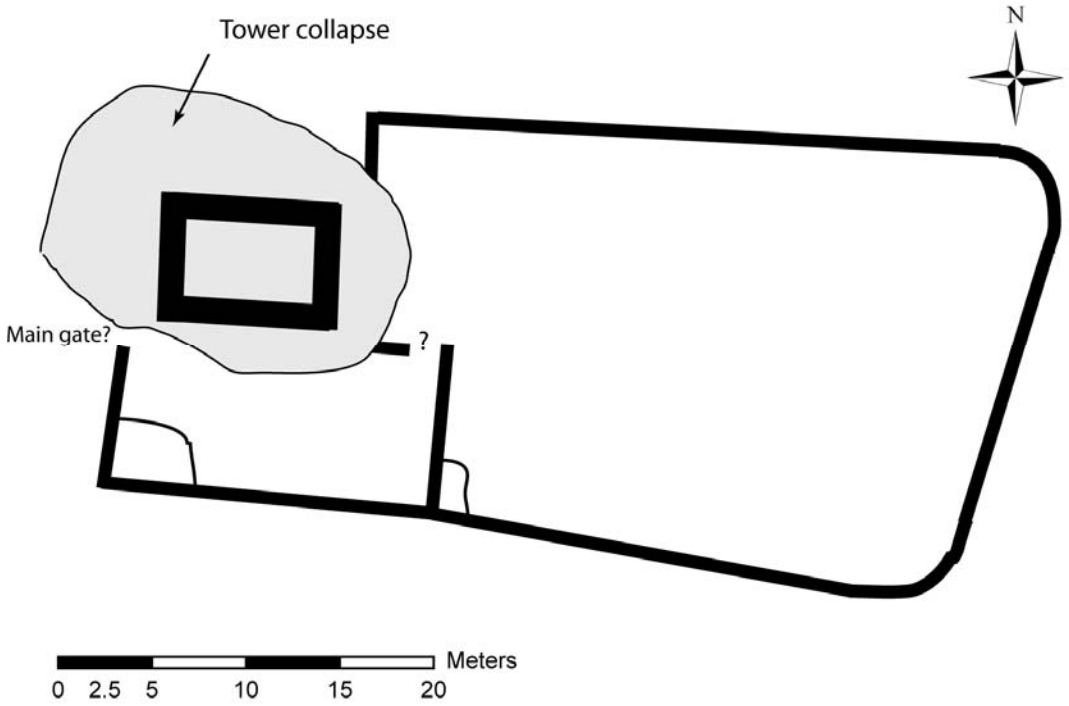


Fig.5.80: Wall plan of *Rās al-Miyāh West*. The width of the inner walls of the tower is approximate.

Although the fortress is roughly built from the local stones on a high and isolated plateau, it does not show similarity in its architectural plan to the other late Iron Age 'Edomite strongholds' such as Baja III (Lindner and Suleiman, 1987), Jabal al-Qseir (Lindner et al., 1996) and others (e.g. Ben-David, 2001)[46]. An interesting parallel is found in neighboring Moab, with an Iron Age fortress reported by Parker (1987:56, FIG.25, site 232; 2006:60, site 57. The fortress is called by the local Bedouins 'Rujm el-Abed') (FIG.8)[47]. The orientation, dimensions and architectural design of both fortresses are notably similar. They are both located on a leveled

[46] These 'Edomite strongholds' are typically built on isolated peaks along the western slopes of the Jordanian plateau. They show a variety of layouts and construction features according to the local terrain and rock formation (usually sandstone outcrops, but also on other types of bedrocks, see e.g. Hubner, 2004), thus their common denominator is primarily their location.

[47] We thank Chaim Ben-David for bringing this similarity to our attention. On the "Moabite" fortress and the road system in its vicinity, see Ben-David (2009).

plateau on the edge of a cliff; their elongate axis is in a west to east orientation; the towers are situated mostly on the northwest side of the courtyard and do not protrude from the rectilinear enclosures associated with them; the eastern side of the enclosures have somewhat rounded corners and finally, both structures are built from the local stone (in the case of Rujm el-Abed it is roughly cut basalt stones). The "Moabite" fortress is located on a cliff above one of the on a cliff above one of the southeastern tributaries of Wadi al-Mujib (biblical Nahal 'Arnon'), far from the track of the King's highway (located to the west), the principal north – south route along the Jordanian highland plateau. The massive structure is positioned on the edge of the eastern desert, not far from the location of the Roman limes line of fortifications (Parker, 2006) and probably on an ancient Iron Age road that crosses the topographic barrier of Wadi al-Mujib through an eastern alternative to the King's highway (see Ben-David, 2009). However, there are no remains of such a road or other fortification further east and north of the fortress. This suggests that the main objective of the site was to watch over the valleys below, where more plausible paths might have been in use for transportation between both parts of Moab (see especially Ninow, 2002, and Ninow, this volume)[48]. This suggests that *Rās al-Miyāh West* may also be a watch tower that guarded indirect routes in the valleys below.

[48] The use of a path along the valley below the fortress (Wadi Nukheila, a southern tributary of Wadi al-Mujib) during the Iron Age as one of the alternatives to the King's highway is supported by several major Iron Age sites found along the wadi, among them the site of Khirbet Medeinet 'Aliyā (e.g. Miller, 1991) and Qasr ed-Daba'a (Parker, 2006:74, site 194), located further up the wadi basin. Although the road along the ascent from the wadi to the fortress has impressive constructions, we should consider the possibility that its main target was the fortress itself, without an additional segment towards the north or east. Alternatively, one might date the massive road constructions to the Roman period, as a secondary access to the *limes* line.

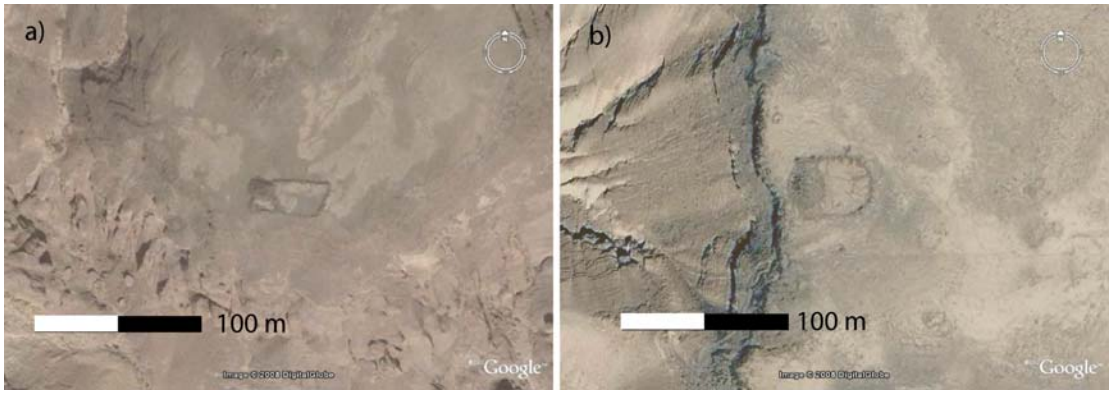


Fig.5.81: The Edomite Iron Age fortress of *Rās al-Miyāh West* (a) and the Moabite Iron Age fortress of Rujm al-Abed (b) show marked similarities in the architectural plan (images taken from GoogleEarth).

In close proximity to the *Rās al-Miyāh West* fortress, ca. 115 m to the north and near the northern edge of the dolomite topographic step, there are two relatively well preserved small structures roughly built from the local dolomite stones (FBRS Site 22, Fig.5.75; also Fig.82a). One is rectangular, ca. 7.5 x 5.5 m, and the other, situated ca. 6.5 m to the northeast, is a tumulus-shaped circular pile of stones. Some 20 meters to the north of the small structures is an extensive mining complex (FBRS Site 26, Fig.5.75), situated on the lower slope of the Umm-Ishrin formation and extending over an area of ca. 1.2 hectares (Fig.5.82b; for the mining technique see also Fig.5.77a). Only a few of the blocked entrances to the mine shafts may be identified today, nonetheless it is clear that many are buried under the collapse of the sandstone cliff as evidence by tailings. The mine shafts were dug into the lower part of Umm-Ishrin formation, in order to approach the copper ore bearing layer of the upper part of Burj formation (Fig5.77a) located below. From the location of one of the shafts entrances we can reconstruct the approximate depth of the mines to be around 15-20

m. Based on the extent of tailings we can presume extensive galleries were dug into the ore bearing horizon as has been documented by the German Mining team in many Iron Age locales in Faynan (Hauptmann, 2007). Iron Age copper mines with similar characteristics were reported from Wadi Khalid, in the vicinity of Khirbat Faynan (Hauptmann, 2007:116-121). The depth of the mine shafts in Wadi Khalid was up to 50-60 m (Weisgerber, 1989), and some of the excavated mines reveal long galleries (>30m) along the copper ore bearing layer (ibid).



Fig.5.82: Archaeological features in the vicinity of *Rās al-Miyāh West*: a) small rectangular structure made of local dolomite stones (FBRS Site 22); b) overview of the mining complex (FBRS Site 26). Note the blackish color caused by tailings; c) horizontal line of niches, 10-15 cm in diameter, located above a blocked shaft in the mining complex. A similar feature was found in the quarry area near *Rās al-Miyāh East* (d); e) open mining shaft dug into the shale unit of Burj formation; f) and g) copper slag deposit located near the saddle between Wadi al-Jariya and Wadi al-Ghuweiba.

A double shafts mine in the vicinity of Wadi al-Ghuweiba was reported by the German Mining Museum team and not recorded by us (Weisgerber, 2006:16; Hauptmann, 2007:132-133). It is one of the best preserved mines, with holes dug at

the edge of the shaft for placing a wooden winch (Fig.5.83). The double shaft mines are common in the Wadi Khalid – Wadi Abiad region and represent a common technology in the Iron Age of this region.



Fig.5.84: Double shaft entrance of a mine recorded in the area of Wadi al-Ghuweiba by the German Mining Museum team. This is one of the best preserved Iron Age copper mines, with evidence for the use of a winch. Three centrally positioned postholes indicate that a thin central beam was used to haul ore (and people) from the mine (Weisgerber, 2006:16).

The extensive copper mining activities are recognized primarily by the distinct remains of black manganese-rich tailings that are highly visible on the bright sandstone slopes (Fig.5.82b). The tailings originate from the copper ore bearing layer and were the result of removing rocks in order to create the shaft and galleries. They might also be the result of processing ore outside of the shafts after removing it from the ore body inside the hill. In addition, several small roughly built structures and installations located on the steep slope are another indication of Iron Age interest in exploiting the buried ore deposits. One particularly interesting installation is a horizontal line of rounded niches (ca. 10-15 cm in diameter) carved into the sandstone

cliff several meters above one of the major blocked shaft entrances (Fig.5.82c). The niches might have been the base for wooden scaffolding used in the process of raising ores (and perhaps miners) through the shafts, with the help of ropes. A very similar installation appears on the sandstone cliff near the fortress of *Rās al-Miyāh East* (FBRS Site 48; Fig.5.82d), although there it could also be related to stone quarrying activities (see below). We do not know of any parallels for such installations in the copper mining districts of the southern Levant (constituting mainly Faynan region and Timna valley), making this particular reconstruction speculative.

Two open shallow mining shafts were dug directly into the shale unit of the Burj dolomite-shale formation close to the boundary with the Umm-Ishrin sandstone and in close vicinity to the mining complex of the slope (not recorded by FBRS). One of these was excavated by the Natural Resource Authority of Jordan (NRA) possibly in the location of an ancient shaft, and the other (the eastern) is probably a collapsed ancient mining shaft (Fig.5.82e). If the Iron Age date of these shafts is correct, these mines are evidence for exploiting, or an attempt to exploit, copper ores directly from the Burj formation without the need of deep shafts. The disadvantage of mining copper directly from the outcrops of Burj formation without using the deep shafts described above is that these outcrops are stratigraphically located slightly below the richest copper-bearing horizon that was eroded in the region of the topographic step.

A strikingly large quantity of ceramic fragments, many of them identifiable, were recovered from the fortress, the nearby structures and the copper mining complex. The pottery sherds are scattered on the surface in a very high density relative to other Iron Age sites in the region. The large number of sherds may indicate a substantially long occupation phase and/or high intensity of activities in the last stage of the Iron Age II (probably the latter, see below; also possible is that the secluded location preclude constant collection of finds by archaeologists and travelers).

Four hundred meters to the west of the mining complex and ca. 20 m above the saddle between Wadi al-Ghuweiba and Wadi al-Jariya, there is a small deposit (ca.70 m^2) of broken slag (FBRS Site 23; UTM 736190/3399275) (Fig.5.82f and 5.82g; see also Fig.5.75 for location). We could not find any ceramics associated with this site, and although the technology is relatively simple we speculate that limited copper smelting took place simultaneously with the Iron Age copper mining activities in the area of *Rās al-Miyāh West*. Technological typologies based on the slag cannot be directly used as a chronological marker (Ben-Yosef et al., 2008b; Ben-Yosef et al., 2010c) as simple industries could have been practiced even after more innovative technologies were introduced during the Iron Age. In the case of this slag deposit, its proximity to the archaeometallurgical complex of Rās al-Miyāh may indicate dating the smelting activities to the late Iron Age. The Iron Age smelters may have selected this location some distance from the *Rās al-Miyāh West* fortress and nearby mines to take advantage of the high wind in the saddle. In Faynan area, the wind-based furnaces

are a common phenomenon in the Early Bronze Age II-III (Hauptmann, 2007). Distinguishing between Iron Age and Early Bronze Age slag can be achieved by archaeomagnetic investigation of the slag samples themselves, similar to what we demonstrate for the slag at Khirbat Hamra Ifdan in the current research (see section 5.2.8 below and Ben-Yosef et al., in prep.-c). It will be interesting to test the slag of FBRS Site 23 in the future. Similar remains of small scale smelting activities were found in the area of *Rās al-Miyāh East*, although the samples collected there are probably manganese ore and slag presence is not secure[49].

5.2.6.3 Rās al-Miyāh East

The fortress of *Rās al-Miyāh East* (FBRS Site 3) is located at UTM 738148/3399340, ca. 350 m above sea level and ca. 100 m above the stream channel of Wadi al-Ghuweiba (Figs.5.75 and 5.85). The fortress is quite different from *Rās al-Miyāh West*, both in building material and in architectural design. *Rās al-Miyāh East* was not built out of the local dolomite stones that can provide only relatively small slab blocks. Instead, the entire structure is built out of massive brown sandstone that originate from the nearby outcrops of the Umm-Ishrin formation. The thick layers of the sandstone in this formation can provide massive blocks of building stones with size limited only to transportation constraints and the architectural design. The

[49] If indeed this limited evidence dates to the Iron Age IIB-C, it will be one of the very few secure contexts with smelting activities in the entire Faynan region, and the only one in the Ras al-Miyah Archaeological Complex. This will indicate that the failure of copper exploitation in this area may have been due to lack of sufficient technological knowledge.

fortress's walls and tower were built with huge, typically well cut, sandstone blocks, sometimes exceeding 1 m in length (characteristic dimensions of stone blocks in the outer wall are ca. 80x40x30 cm, i.e. elongated blocks of about ca. 0.1 cubic meter) (Fig.5.86a). The distance to the quarry located in the sandstone cliffs to the north is relatively short (ca. 200-250 m). However, moving the massive sandstone blocks had to overcome both the lower steep slope of the Umm-Ishrin formation (a descent of some 30 m) and the moderate but longer slope of the Burj formation (an ascent of about 30 m).



Fig.5.85: An overview of *Rās al-Miyāh East*, looking towards southeast. The fortress is located on the dark Burj formation plateau and built almost entirely of bright sandstone. Note some of the small structures and the arrangement of building stones in front of the northwestern wall of the fortress. The size of this fortress is indicated by the two people standing along the southern corner of the structure.

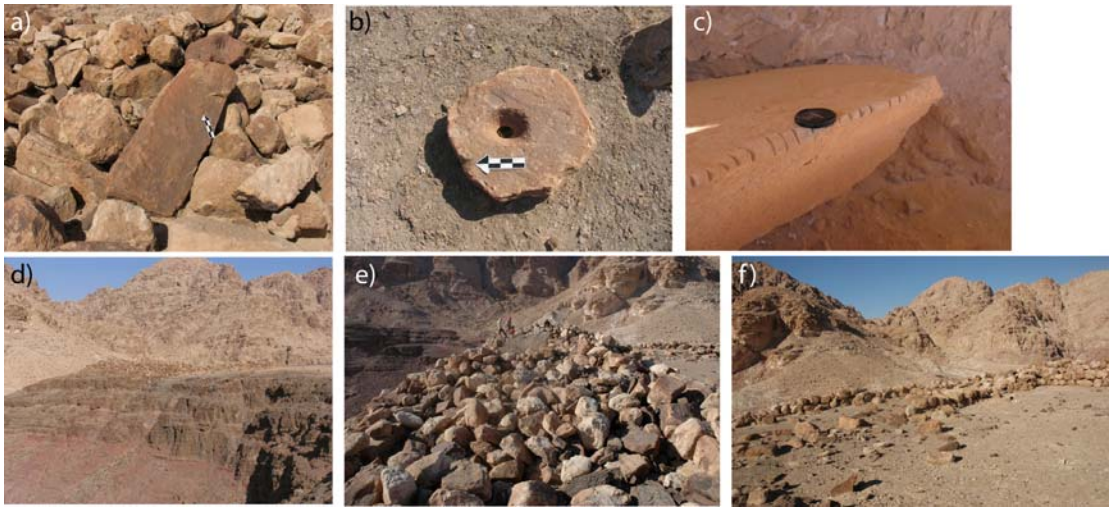


Fig.5.86: Details from *Rās al-Miyāh East* Fortress: a) massive sandstone ashlar is seen in the collapse of the eastern tower; b) carved hole in a sandstone found in the fortress's courtyard, probably a door socket; c) carved stone found in the nearby quarry, probably prepared the fortress; d) southwestern wall of the fortress, just above the edge of the dolomite plateau; e) southwestern wall of the fortress with semi-casemate rooms filled with rubble; and f) northwestern inner and outer walls of the fortress (view from the courtyard).

The outer dimensions of this fortress are ca. 42 x 35 m, with a northeast to southwest elongated axis. The walls are well preserved and the architectural plan is still clear, revealing small details of rooms and passages (Fig.5.87). The fortress has an inner courtyard of ca. 20 x 20 m, corridors on the northwestern and southeastern sides, a semi-casemate wall on the southwestern side and a double corridor with complicated maze of passages on the northeastern side. A massive tower (ca. 8 x 8 m, outer dimensions) protrudes form the fortress's eastern corner. Along the southern corner of the tower a line of small stones follows the moderate hill gradient towards the south until it reaches the edge of the cliff. An additional shorter line of small stones is located between the southern corner of the fortress and the cliff. The pattern of these installations probably implies an attempt to collect seasonal rain water, as they divert

the run-off into a local topographic drainage channel. However, there are no remains of a cistern at the end point of this system suggesting: a) an incomplete construction, b) a channel that was used by placing a jar at the end point to collect water, and/or c) a different use for these stone lines, such as diverting the run-off for protecting the foundations of the fortress walls.

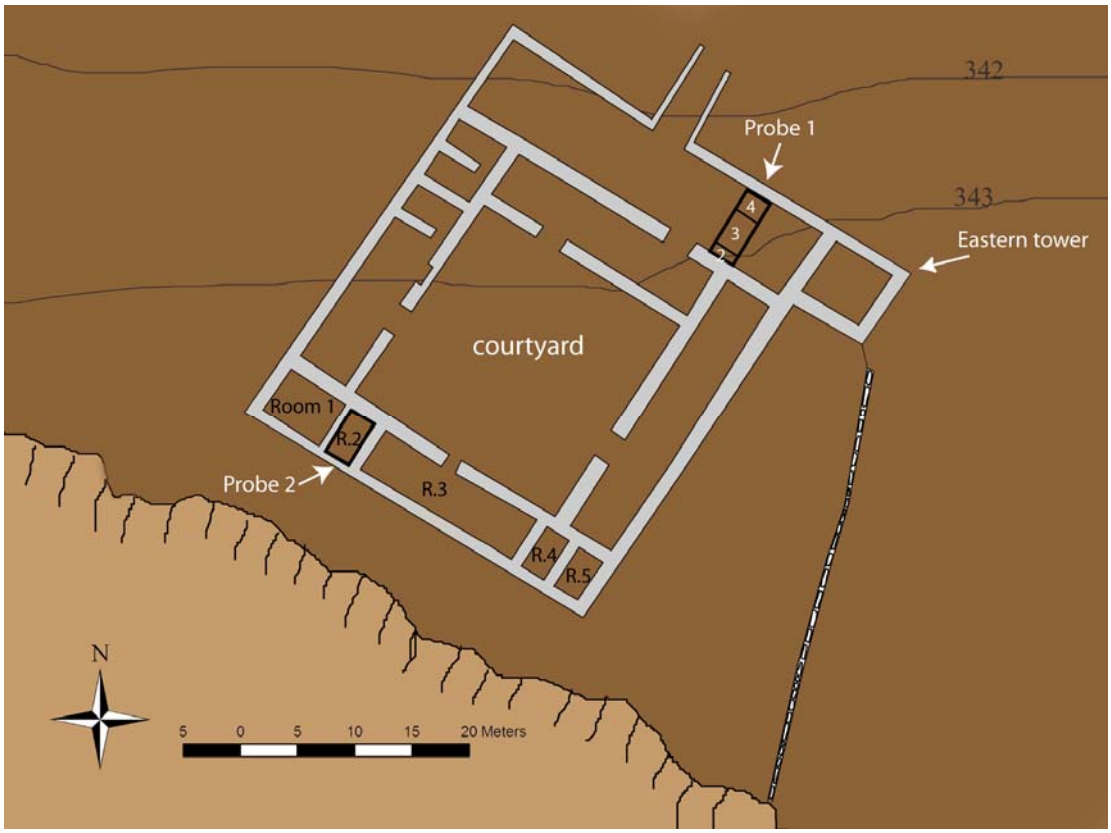


Fig.5.87: Wall plan of *Rās al-Miyāh East*. The location of the sample excavations are marked with black rectangles. Contour lines are approximate.

The gate of the fortress is located in the middle of the northeastern wall. It has a unique shape with two protruding walls which extend ca. 8 m toward the northeast. The width of the protruding walls is significantly smaller than that of the fortress's external wall (ca. 0.5-0.8 m vs. 1.2-1.7 m respectively) and their height decreases

gradually towards the outside. The protruding walls seem to be part of a short ramp that was constructed to overcome the elevation difference caused by the down sloping of the bedrock surface towards the north (Fig.5.87). The inner width of the ramp changes from about 2.5 m in the outside and 3 m in the inside. A similar construction, also interpreted as a ramp used to overcome local elevation difference, is reported from the Iron Age I-IIA fortress near Quseima in the northern Sinai Peninsula (Meshel, 1994). At that site, which is considered one of the so called "Israelite Fortresses" of the Negev, the ramp's walls extend towards the inner part of the structure (Fig.5.88).

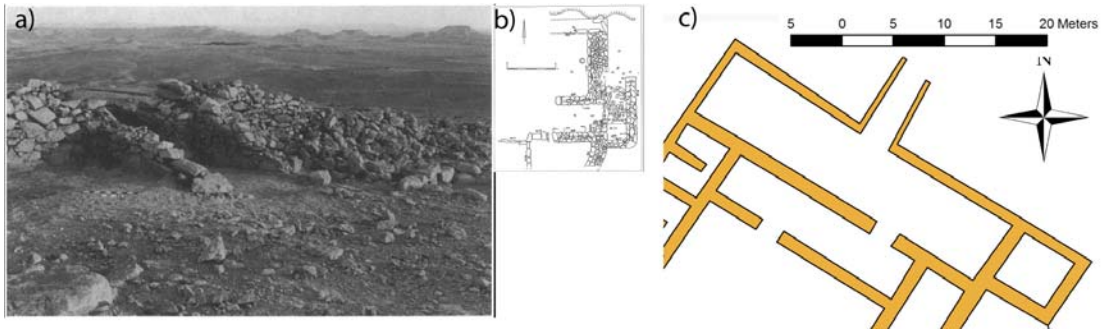


Fig.5.88: A picture (a) and a plan (b) of the gate complex of the so called "Israelite Fortress" of Quseima (after Meshel 1994: figures 7 and 8). The parallel walls are interpreted as being constructed for overcoming elevation difference, and are similar to in shape and purpose to those found in the fortress of *Rās al-Miyāh East*.

In the first corridor from the gate of *Rās al-Miyāh East* there are two small intrusive structures built out of small local dolomite stones. One is located in the northern part of the corridor and the other just in front of the gate area. Both of the structures have a circular, tumulus-like shape which suggests that these are later graves. The inner walls of the fortress are massive but short, consisting of to rows of

stones which stand up to a height of four courses (Fig.5.86f). There are almost no remains of collapsed stones in the close vicinity of these walls (see below).

The southwestern side of the fortress is the most fortified, consisting of an extremely wide semi-casemate wall (ca. 6.5 m wide including the casemates and inner wall; Fig.5.86d and e). The confined spaces within the wall (the 'casemates') are filled with a vast amount of rock and earth (excluding the central space, which has only partial remains of collapse). The fact that this side of the fortress is the most fortified is somewhat surprising giving the fact that it is the only side that is directly protected by the natural sheer cliff (dropping abruptly for more than 50 m) along the edge of the dolomite plateau (Fig.5.86e).

In order to gain more insights about the date and function of *Rās al-Miyāh East* we conducted two small test excavations in this fortress: Probe 1 at northeastern corridor and Probe 2 in one of the casemate room spaces along the southwestern fortified wall (Fig.5.87 and Fig.5.89). Probe 1 in the northeastern corridor was a narrow trench, ca. 1.5 x 6.15 m, and excavated between the outer wall and one of the inner walls of the fortress (Fig.5.89a and b). The higher surface elevation in this side of the corridor seemed to indicate the presence of occupational deposits and was one of the reasons for choosing this location. While excavating it became clear that the higher surface elevation was a result of the natural slope of the bedrock and that there was virtually no archaeological accumulation besides collapsed stones. We defined

three loci (2, 3, 4, see Fig.5.87) that represent the inner wall's collapse and wall foundation; the exposed bedrock in the center of the corridor; and the outer wall's collapse and foundation respectively (Fig.5.87 and 5.89a). The inner wall's collapse is meager and represented in Locus 2 by only two relatively small stones. It seems that the inner wall in this location is preserved to its original height (3 courses, ca. 1.35 m). Beneath the collapsed stones and directly above the bedrock was a thin layer of yellow aeolian dust with small amounts of ceramic sherds. This probe was excavated to bedrock (some Burj copper ore concentrations were found here) to expose the lower course of wall stones that was built into a shallow foundation trench (ca. 30 cm deep). The bottom of the trench was filled with relatively small stones (1500 cubic centimeters or smaller) (Fig.5.89b). This rough fill might indicate an intentional construction design for creating a more earthquake-resistant wall, as the small stones would give more flexibility to the heavy wall they support. We exposed a similar foundation trench (ca. 20-40 cm in depth) beneath the outer wall, after removing a massive collapse of wall stones (15 large stones in an area of ca. 1.5 x 3 m, Locus 4). Also here, a thin layer of yellow aeolian dust with few fragments of pottery was uncovered, and part of the trench was filled with relatively small stones. Between the collapsed stones of the two walls, as in the majority of the corridor's surface, the crumbly shale unit of the Burj formation was exposed (represented by Locus 3).



Fig.5.89: The sample excavations in *Rās al-Miyāh East*: a) probe 1 in the northeastern corridor. An area of ca. 1.5 x 6.15 m was opened between the outer and inner walls (view to the northwest); b) foundation trench beneath the inner wall. Excavations into bedrock exposed the base of the wall (note the small copper nodules and the brittle shale of the upper unit of Burj formation); c) an overview of the casemate room 2 before its excavation; and d) the excavated casemate room at the end of excavation, view towards southwest. Bedrock was not reached in this probe.

Probe 2 in the southwestern wall of the fortress was aimed at exposing one of the casemate rooms (Room 2, Fig.5.87; Fig.5.89c and d) to reveal a possible occupation layer beneath the collapse. Although bedrock was not reached, the result of the excavation indicates that the so-called “collapse” is probably an intentional fill as part of the fortress’s construction. Thus, the divided spaces between the inner and outer southwestern walls were probably planned as a frame for constructing a massive and wide wall with the use of a fill made of sediment and roughly cut stones.

The casemate room is an elongate space perpendicular to the fortress's external wall (ca. 4.6 x 2.5 m inner dimensions; see Fig.5.87). The outside wall of the fortress consists of two rows of stones, ca. 1.5 m in width, with a sharp bulge towards the outside of the fortress that was most likely the result of the massive pressure caused by the casemate's fill. The wall stands to a preserved height of ca. 1m (the base of the wall is not exposed; FIig.5.89d). A massive stone collapse is found outside of the wall, on a narrow step between the fortress and the cliff of the dolomite plateau. The inner wall of the fortress, standing to a height of ca. 2 m, is made of two rows of stones, ca. 1.2 m in width. It has sharp inclination towards the fortress courtyard, similarly the result of the intense pressure of the fill. The crudely built long walls of the room consist of one narrow row of roughly cut small stones (ca. 30-40 cm in thickness) with at least 10 unstable courses and some gaps of missing stones (the upper 2 m of these walls were exposed; Fig.5.89d). The poor building quality of these walls suggests that they had never stood by themselves and that they were erected together when the fill was poured inside the confined casemate spaces. A doorway between casemate rooms 2 and 3 is represented by a gap of ca. 1 m between the southeastern long wall and the outer wall of the fortress. A similar doorway is located between the northwestern long wall and the inner wall of the fortress, connecting room 2 with room 1, although there the excavation is only 1.15 m deep and the gap is less clear.

Before the excavation of Probe 2 was carried out, the long walls of the casemate were visible in only a few places. The southwest side of the fortress appeared as a continuous and massive pile of stones, confined only by the inner and outer walls of the fortress (this excludes the central space that has much less fill; Fig.5.86d and Fig.5.89c). The fill is a mixture of sandstone, dark dolomite stone and a large quantity of fine earth (in places more than 0.5 m deep). The nature of this fill lends additional support for assuming an intentional blocking of the casemates: a) the dolomite stones do not appear elsewhere in the construction of the fortress; b) there is a mixture of two stone types, and both are roughly cut in a manner not suitable for quality building found in the rest of the fortress; and c) the large quantity of sediment excavated here does not seem to be aeolian in origin.

The evidence from *Rās al-Miyāh East* shows that the construction of the massive fortress was never finished. Although some of the indications are speculative, putting them all together presents a clear picture of an abrupt abandonment in the middle of the building process. The fortress's features that indicate unfinished construction are: 1) a possible unfinished water system; 2) a possible unfinished filling and fortifying the southwestern semi-casemate wall; 3) the well designed architectural plan of the fortress suggests a symmetric layout, especially for the northwest and southeast corridors. However, only the northwest corridor is divided into inner spaces, and even this division seems to be incomplete. The intended construction might have been two similarly arranged corridors or even two blocked semi-casemate walls as the

one found in the only naturally fortified side (southwest); 4) the inner walls are short although their massiveness and foundation trench indicate an intention to build high walls, a building effort that never took place. In close proximity to these walls there are almost no indications of collapse, and there is no evidence of robbing these walls; 5) no significant occupation layer or cultural debris was found in the probe (No. 1) in the northeast corridor. In addition, the surface finds in the entire area of the fortress are scarce, including ceramic sherds. This stands in sharp contrast to the abundant surface ceramic both in the nearby copper mining complex and in the fortress's satellite small structures (see below). The latter structures may have been the dwellings of fortress's construction workers and/or the project management; and 6) an almost 'laid out' arrangement of building stones outside the northwest side of the fortress and in the direction of the quarry (Fig.5.85 and 5.90) represents preparations for construction (that was never finished), rather than a collapse.



Fig.5.90: Multispectral satellite image of the fortress of *Rās al-Miyāh East* and its vicinity (cf. Fig.5.75; image taken from GoogleEarth).

In close proximity to *Rās al-Miyāh East* fortress are abundant archaeological remains, most probably from the same period (excluding a small sandstone tumulus, ca. 40 m to the north of the fortress) (Figs.5.75 and 5.90). On the dolomite plateau five groups of small, roughly built structures are located between 30 to 120 m from the fortress. Most of the structures have rectangular shapes and some comprises several rooms. They are very similar in characteristic to the small structures near *Rās al-Miyāh West* fortress (Fig.5.82a), including dimensions and building quality. These may also have been associated with the Iron Age miners and/or builders responsible for the construction of the fortress.

A deposit of small black samples was found near the highest point of the dolomite plateau (Fig.5.90), possibly slag (some of the examined fragments were found to be nodules of manganese ore). The Iron Age II pottery fragments collected from the surface suggests a similar date for the smelting process (if such indeed occurred at this location), despite the simple technology that was practiced. Similar satellite site was found close to the *Rās al-Miyāh West* fortress (there the presence of slag is secure, see discussion above). At both sites we did not find any remains of furnaces.

A copper mining complex was found ca. 400 m northwest of the fortress, in both sides of a small valley and on the lower slope of the Umm-Ishrin formation (FBRS Sites 46 and 47, UTM 737754/ 3399525) (Figs.5.75 and 5.91). This area is directly related to mining activities and extends over an area of ca. 500 m^2. It includes several blocked mining shafts associated with black tailings (of the DLS formation) that are visible from a long distance (Fig.5.l91b). The layout of the mining complex is similar to the one located near *Rās al-Miyāh West* and discussed above. The mining shafts of *Rās al-Miyāh East* appear to be deeper, as they are located in a higher stratigraphic elevation and the distance between their entrances to the boundary between Umm-Ishrin and Burj formations is longer (more than 30 m). In the lower part of the valley, ca. 100 m southeast of the mines, a large trapezoidal enclosure was found (ca. 13 x 19 x 8 m) built out of massive local sandstone (FBRS Site 45;

Fig.5.92). The pottery in the vicinity of this structure was scarce and its dating is insecure. It is important to note that the organization of mining activities at both fortresses is remarkably similar.

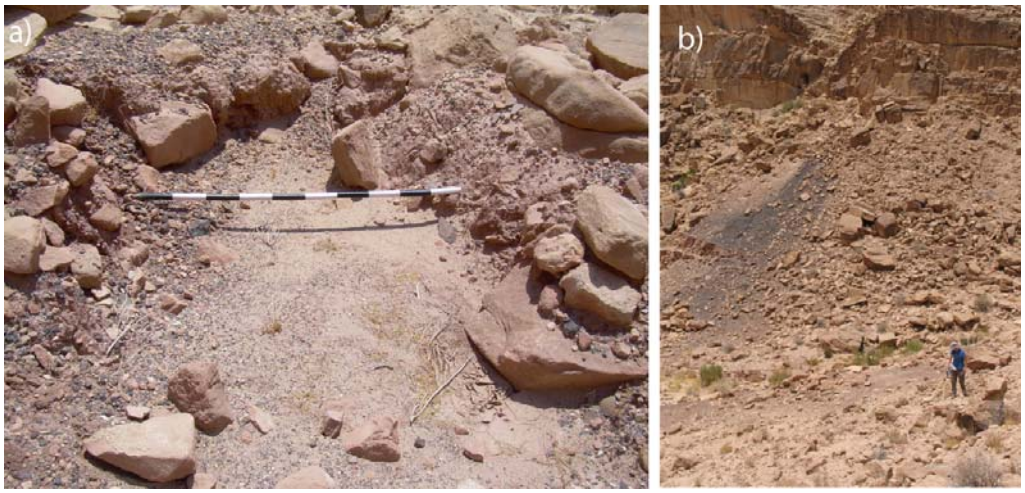


Fig.5.91: The copper mines near *Rās al-Miyāh East*: a) blocked shaft; b) black tailings, easily visible on the bright sandstone slope, indicate the location of an ancient mining shaft.



Fig.5.92: A large (13 x 19 x 8 m) Iron Age enclosure made of the local sandstone in the vicinity of the copper mines near the fortress of *Rās al-Miyāh East*.

On a narrow step high in the brown sandstone cliffs of Umm-Ishrin formation a massive tower was found with adjacent small structures (Fig.5.93). The tower is located ca. 220 m ('as the crow flies') northwest of the fortress and ca. 40 m above the dolomite plateau, in the vicinity of the sandstone quarry. The construction of this unique structure on the extreme location of the sandstone cliff is admirable even today. The layout of the tower, visible only in part beneath the massive collapse (Fig.5.93b), is probably rectangular. The western wall constitutes a straight line that can be identified for a length of ca. 8 m (Fig.5.93c). Thus, the dimensions of the tower might be 8 x 8 m or larger. The building stones comprise mostly the local

sandstone although blocks of black dolomite stones are also part of the collapse. The tower remains include numerous fragments of pottery, many of which are identifiable. The abundant pottery sherds all over the slope below the sandstone step are derived from the archaeological remains of the tower and the adjacent small structures. Between the collapsed stones of the tower we found a fragment of a basalt grinding stone (ca. 35 x 20 x 10 cm) indicating food preparation activities or initial processing of copper ores (Fig.5.93d).



Fig.5.93: *Rās al-Miyāh East* - remains of a tower on the sandstone cliffs: a) overview; b) massive collapse of the main structure; c) face of the western wall of the tower; d) basalt grinding stone found in the collapse of the tower; e) massive sandstone building block in the collapse of the tower; and f) construction remains on the upper shelf.

On a narrow shelf above the tower is a small roughly built structure in the opening of a shallow cave (Fig.5.93a and f). Below the tower and ca. 15 m to the northeast of its center, is a line of rounded niches (ca. 10-15 cm in diameter) carved

horizontally into the sandstone cliff (Fig.5.82d). A similar installation was found in the copper mining complex of *Rās al-Miyāh West* (see above), although there it is associated with a copper mining shaft. We associate the niches near the tower of *Rās al-Miyāh East*, together with other remains on the slope, with the sandstone quarrying activities that were part of the fortress's construction. However, even though there are no visible remains of mining activities on this slope, we cannot completely dismiss the possibility that such remains are buried under the eroded sandstone cliffs. Small installations, such as carved mortars located on the slope further to the west of the tower, suggest copper ore related activities (crushing and grinding). Just below the line of niches we found nicely carved cornice-like sandstone block with a line of grooves that might have been a simple decoration (Fig.5.86c).

Many ancient activities took place in the area of *Rās al-Miyāh East*. Although scant amounts of pottery fragments indicate a limited ephemeral Nabataean presence at the site, the vast majority of the pottery indicates late Iron Age II activities. However, we cannot discern whether the copper production activities (mining and possibly small scale smelting) were done simultaneously with the project of quarrying massive sandstone and constructing the fortress or earlier (assuming that the abandonment of the fortress construction marks the end of the area's occupation). This question, together with revealing the exact function and date of the various structures and installations, stays open; however, a few speculative suggestions are suggested below (see also Chapters 9 and 10).

5.2.6.4 Dating the fortresses

In the current stage of the research we consider the ceramic assemblage collected in both areas of *Rās al-Miyāh West* and *East* to represent one period without subtle distinction into different occupational phases[50]. The ceramic assemblage in general is typical to Edom in the 7th and 6th centuries BCE (Iron Age IIB/C). A limited sample of indicative pottery sherds from the two fortresses and the nearby mines (including a fragment of an oil lamp) are presented in Fig.5.94. Pottery from various different sites of Ras al-Miyah is presented in Figs.5.95a and 5.95b and 5.98.

[50] Excluding the scant Nabataean pottery collected in the area of Rās al-Miyāh East and mentioned above.

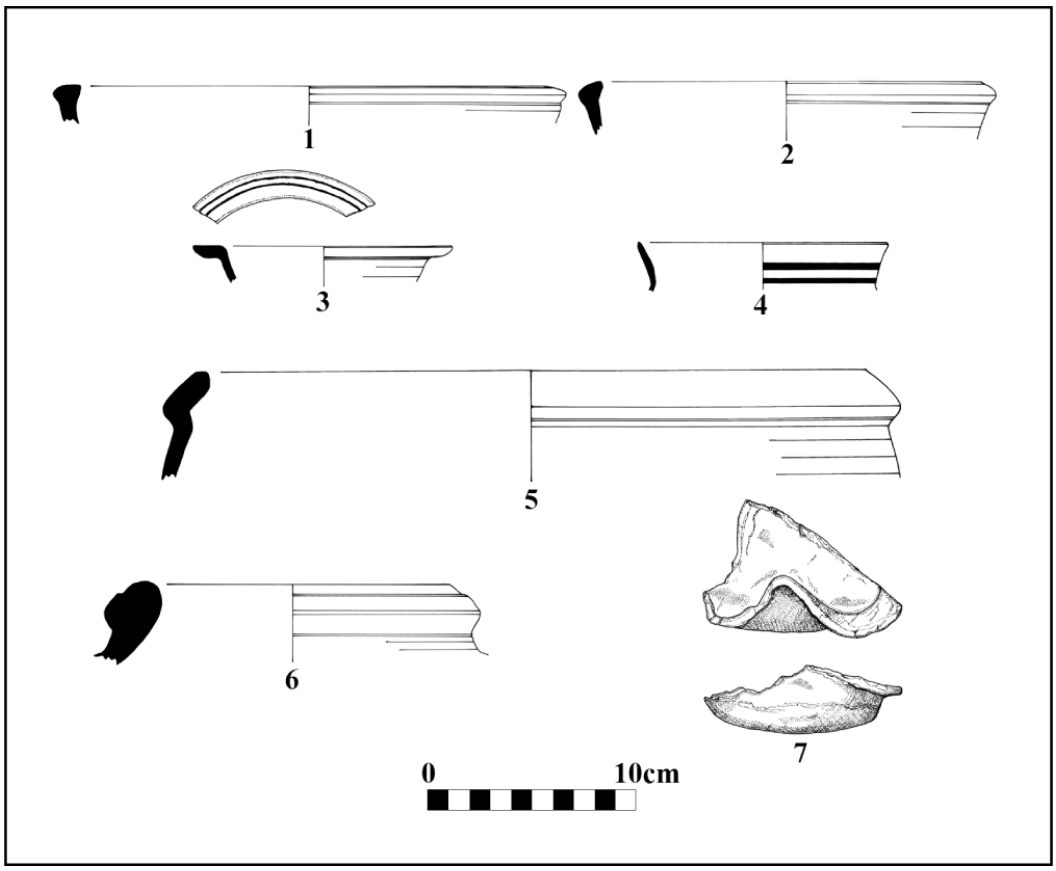


Fig.5.94: Representative Iron Age ceramics from the fortresses of Rās al-Miyāh and their vicinity: 1) Bowl, *Rās al-Miyāh East* (EDM 8137, Reg. 56); 2) Bowl, *Rās al-Miyāh West* (EDM 5663, Reg. 160); 3) Bowl, copper mining complex of *Rās al-Miyāh West* (EDM 6549, Reg. 51); 4) Bowl, copper mining complex of *Rās al-Miyāh West* (EDM 6549, Reg. 268); 5) Krater, the tower on the sandstone cliff near *Rās al-Miyāh East* (EDM 11259, Reg. 73); 6) Jar, copper mining complex of *Rās al-Miyāh East*, near western shafts (EDM 11152, Reg. 211); 7) Lamp, copper mining complex of *Rās al-Miyāh West* (EDM 6549, Reg. 52).

If the dating of the pottery sherds found at the two sites and their associated installations is correct, the Iron Age sites in the region of Rās al-Miyāh were occupied approximately one hundred years or more *after* the peak in early $11^{th} – 9^{th}$ c. BCE copper production activities in Khirbat en-Nahas and Khirbat al-Jariya (Levy et al., 2004b; Higham et al., 2005; Levy et al., 2005c; Levy et al., 2008a). There is no evidence of large scale sophisticated copper smelting industry such as that found at

Khirbat en-Nahas and Khirbat al-Jariyeh associated with these Ras al-Miyah fortress sites. The organization of metallurgical activities around these fortress sites is quite different form earlier Iron Age metal production in Faynan. However, the interest in exploiting the copper ore in the region of Rās al-Miyāh fortresses is evident, and the question is where the smelting process took place. A good candidate was the nearby large copper smelting site of Khirbat al-Ghuweiba. Until recently, this site was dated only generally to the 'Iron Age' (Hauptmann, 2007:132) without more precision. However, our recent excavations at the site (section 5.2.7 below) indicate that this site was occupied only in the early Iron Age, probably similar to the chronology of Khirbat al-Jariya. Thus, the major mining works of Ras al-Miyah have no appropriate smelting counterpart in the near vicinity and probably in the entire Faynan region. This observation corroborates the unsupported general claim of Weisgerber (2006:15) that "…the mining activities there [near the fortresses] seem to have been unsuccessful."[51]. The implications of the archaeological evidence from Ras al-Miyah to our understanding of the organization of metal production in Faynan throughout the Iron Age are further discussed in the following chapters.

[51] But Weisgerber continues: "Nevertheless, from a technical point of view the best twin shaft assemblage ever seen was documented there." (see Fig.5.84).

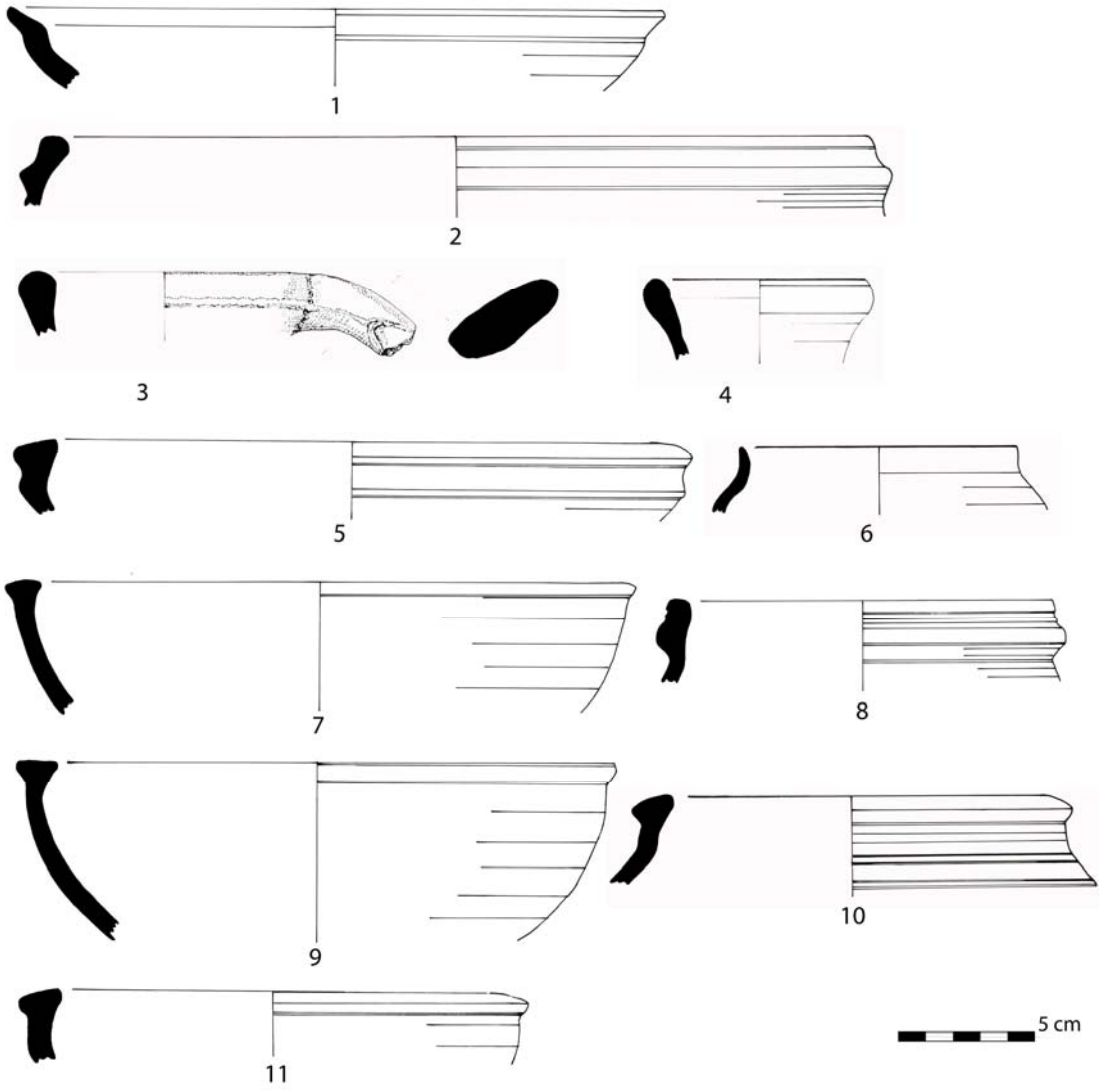


Fig.5.95a: Iron Age IIB-C ceramic from the Ras al-Miyah Archaeological Complex collected by FBRS (cf. Fig.5.75 and Table 5.15 for the location and description of sites): 1) FBRS Site 2, R. 161; 2) FBRS Site 2, Rg.131; 3) FBRS Site 3, Rg. 59; 4) FBRS Site 4, Rg.4; 5) FBRS Site 22, Rg.185; 6) FBRS Site 22, Rg.176; 7) FBRS Site 22, Rg.193; 8) FBRS Site 22, Rg.167; 9) FBRS Site 26, Rg.251; 10) FBRS Site 26, Rg.54; 11) FBRS Site 40, Rg.224.

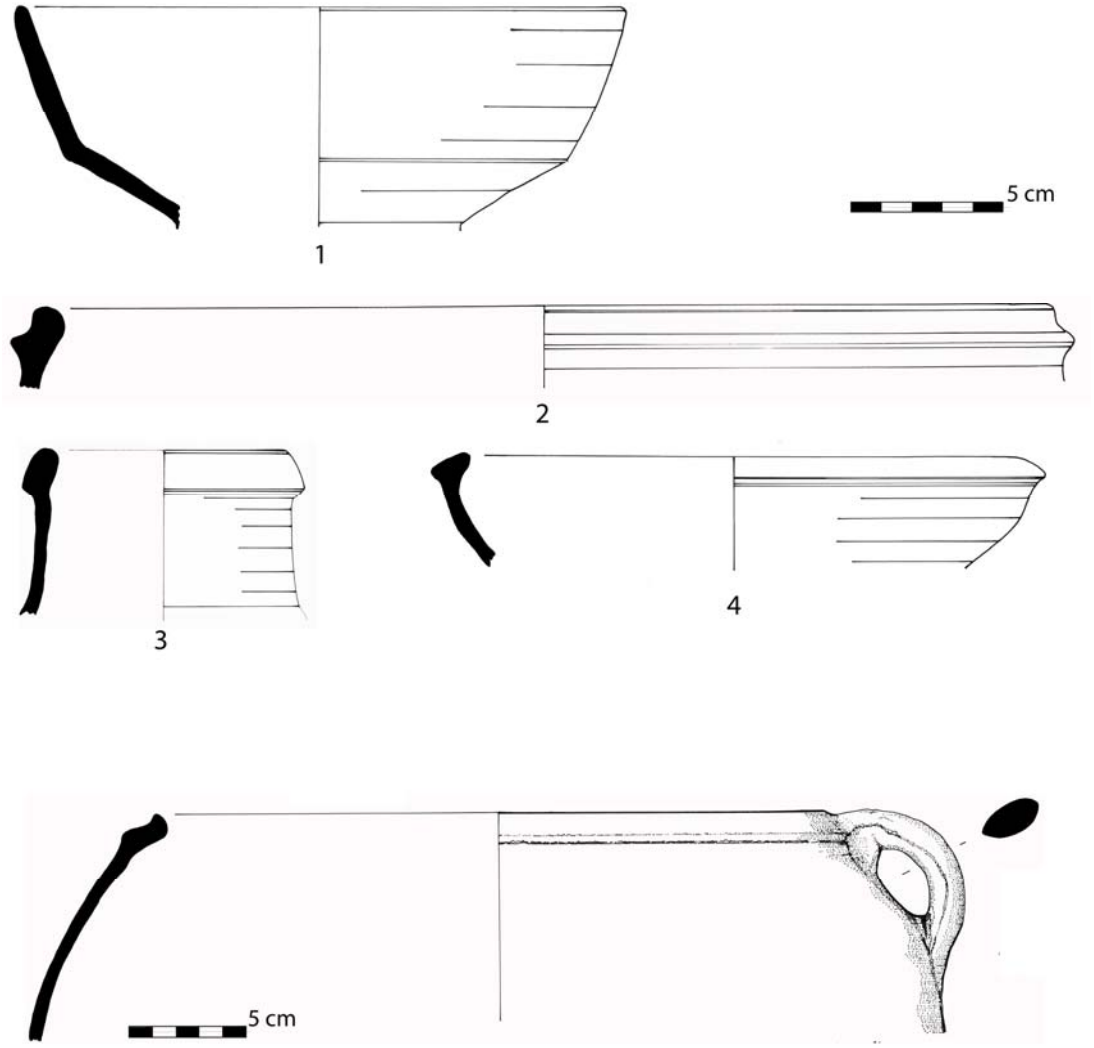


Fig.5.95b: Iron Age IIB-C ceramic from the Ras al-Miyah Archaeological Complex collected by FBRS (continues) (cf. Fig.5.75 and Table 5.15 for the location and description of sites): 1) FBRS Site 45, Rg.231; 2) FBRS Site 37, Rg.281; 3) FBRS Site 48, Rg.80; 4) FBRS Site 48, Rg.78; 5) FBRS Site 26, Rg.233.

5.2.6.5 A unique cultic site (FBRS Site 27) in the RAM complex

An enigmatic pottery scatter (FBRS Site 27) was recorded by us in the cliffs to the northwest of the fortress of Ras al-Miyah East[52] (Fig.5.75). The site is located on a flat shelf of the Salib dark red sandstone overlooking Wadi al-Ghuweiba and a prominent topographic dome of the same rock formation (Fig.5.96). It is not directly associated with any route, and even the constructed path that connects the two fortresses of Ras al-Miyah (FBRS Road Segments 37-39, Fig.5.75 and description in Ben-Yosef et al., 2009a) passes on a higher shelf more than 100m away. The dense pottery scatter spreads over an area of ca. 0.3 acres in addition to abundant fragments that were found below the sheer cliffs and in rock cracks surrounding the site. The pottery sherds are relatively well preserved and represent typical Iron Age IIB-C Edomite vessels (Fig.5.97). No architectural remains are associated with the site.

[52] The site was discovered already in 2006 by chance. The excavation team of Ras al-Miyah East explored each day a different path to get back to the truck parking near ‘Ain al-Ghuweiba. In one of these occasions E.B.-Y. noticed a dense pottery scatter in the unique location. In 2007 the site was carefully surveyed as part of FBRS.



Fig.5.96: FBRS Site 27 in the area of Ras al-Miyah Archaeological Complex. The site is a dense scatter of well preserved Iron Age II pottery sherds (see Fig.5.97) on a remote and high sandstone cliff (the figure in the photo stands in the center of the site). The unique location and the male figurine found in a shallow crevice (Figs.5.97 and 5.98; and see inset above, showing the figurine and its broken hand [below the arrow] in situ, arrow is 20cm) hint to a cultic function of the site. A survey of the conspicuous sandstone dome opposite the site (seen clearly in the picture, and having only one extremely hard access path) yielded only Early Bronze Age pottery sherds (FBRS Site 52).

In a shallow crevice underneath a rock in the center of the site we found a male clay figurine (inset to Fig.5.96 and Figs.5.97 and 5.98). The figurine was found without its head and is ca. 13 cm tall. It has broken hands, one of which was found nearby and was restorable. The left hand is holding something (now broken), probably a staff or a sword, and on its back a gown-like extension supports the figurine and enables it to be free-standing. The unique location, the lack of architecture and the presence of a figurine strongly suggest that the site represents cultic activity, maybe an

open shrine for worshiping Qos, the main Edomite god (e.g., Bartlett, 1989b). The interpretation of FBRS Site 27 as a cultic site triggered us to survey the prominent rock dome located immediately in front of it (but separated with a chasm of 50m+). After a very difficult climb through narrow cracks in the only passable path to the summit we found only a sparse scatter of Early Bronze Age pottery sherds and a few ephemeral architectural features (FBRS Site 52).

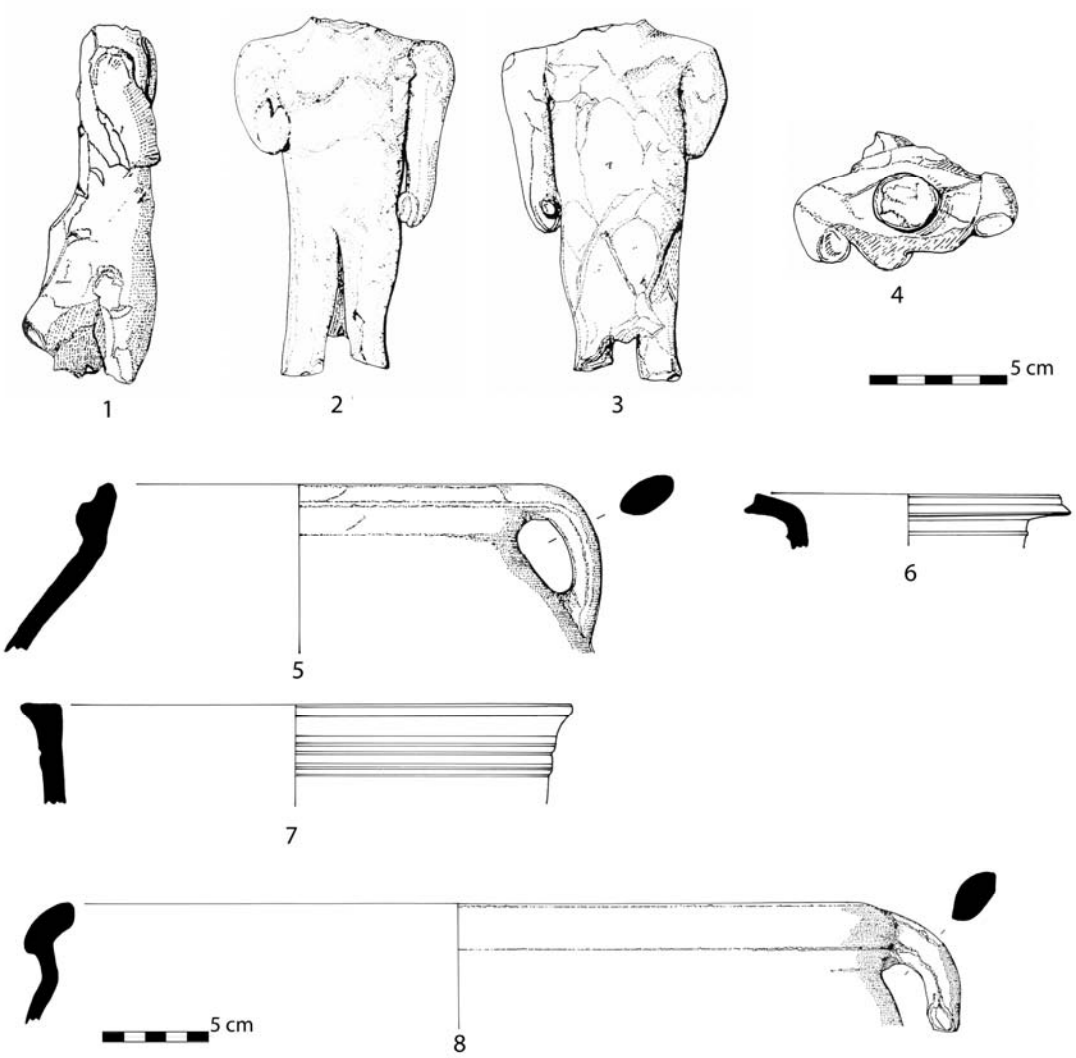


Fig.5.97: Male figurine and representative vessel types from the cultic site FBRS 27. 1) – 4) Figurine, different views (EDM 8000, cf.Fig.5.98); 5) Rg.46; 6) Rg.43; 7) Rg.40; 8) Rg.44.



Fig.5.98: Male clay figurine from FBRS Site 27.

5.2.6.6 RAM archaeological complex - summary

The archaeological complex of Rās al-Miyāh is extremely rich in Iron Age remains. Two massive fortresses are associated with copper mining activities in the northern slopes of Wadi al-Ghuweiba. The fortresses were probably also connected with a defense system around the oasis of ‘Ain al-Ghuweiba, which controlled the northeastern gateway to the entire region of Faynan. The rich ceramic assemblage of the Rās al-Miyāh fortresses and associated complex of sites is dated to the Iron Age IIC. These complexes of Iron Age sites are situated on top of the Burj formation relatively high above the main Iron Age copper production sites of Khirbat en-Nahas and Khirbat al-Jariya that date mostly to the 11th – 9th centuries BCE (Levy et al.,

2005c; Hauptmann, 2007; Ben-Yosef et al., 2010a). The late Iron Age date for the newly described fortress complexes indicates perhaps the latest phase of Iron Age copper production activities in the Faynan district, which was considerably smaller in scale and probably much less successful than the industry of the Iron Age IIA in Faynan (and Iron Age I). The evidence may suggest that the advanced technology of massive production displayed in Khirbat en-Nahas and in Khirbat al-Jariya may have been forgotten, and/or the social organization in the Iron Age IIC was not adequate for organizing such industrial activities on a scale comparable with the earlier years of the Iron Age. However, more probable is that the area became a tense conflict zone over its natural resources and that none of the local polities could establish there a viable and permanent infrastructure of organization of production, and a large scale exploitation of the copper ores could not have been achieved. This is supported by the need to build fortresses in association with the mining complex, with the fact that the building process of one of them was never finished and also the more general phenomenon of Edomite 'strongholds' known in southern Jordan at the exact same period (e.g., Ben-David, 2001). These 'strongholds' suggest refuge shelters, and strong defense strategy, indicating tension probably with the neighbors from the west, the rivals over the copper resources of the northern Arabah. During the late Iron Age, the overland trade in commodities from Arabia and other regions probably was of much greater importance to the economy of Edom than copper production. The flourishing of Arabian trade, probably on the expense of the former practice of copper production, is integrated with and related to the developments observed in Faynan.

As the Rās al-Miyāh fortresses are located on a high plateau in a rough mountainous region, these defensive sites might be considered as part of an the late Iron Age 'Edomite pattern' of 'high places' and 'mountainous strongholds' sometimes associated with the biblical passage of Jeremiah 49:16 and sites such as Sala, Umm al-Biyara and other highland locales (e.g. Lindner, 1992; Lindner et al., 1996; Hubner, 2004). However, besides the location and the surrounding rough terrain, the architectural similarities between the Rās al-Miyāh fortresses and other Edomite strongholds and high-places are meager, probably because of the peculiar function of the former, having to do with copper mining. The defensive phenomenon is similar, and suggests a time of regional conflict (see above).

The fortresses are distinct from each other in size, material and architectural plan. *Rās al-Miyāh West* is relatively small and has an interesting parallel in the region of Moab (Rujm el-Abed). This parallel should be taken into consideration when estimating the differences and boundaries between the Iron Age polities of Cis-Jordan. The fortress of *Rās al-Miyāh East* is a massive, well planned structure with no clear archaeological parallels. The huge labor effort manifested in the construction of the structure together with the details of the architectural plan suggests a centralized and well organized society in Edom during the late Iron Age. The fact that actual metal smelting activity was meager or non-existent just when tremendous expenditures were invested in the construction of these fortresses is intriguing. The construction process

at the *Rās al-Miyāh East* fortress was never finished. It ceased abruptly, perhaps for the reasons discussed above.

5.2.7 *Khirbat al-Ghuweiba*

The site of Khirbat al-Ghuweiba (Figs.5.1, 5.75 and 5.99) was first visited by Nelson Glueck (1935:22-23, 164 Plate 162), and was surveyed as part of SGNAS (MacDonald, 1992b:76, Site 161), GMM (Hauptmann, 2007:132-133) and ELRAP's FBRS project (Ben-Yosef et al., in press, Site 1) (see section 3.1 above). Glueck (1935:22-23) dated the smelting remains at the site mostly to the early Iron Age:

> On the surface of the site we found numerous sherds of rather coarse type belonging to EI I [Early Iron Age I] and to the first part of EI II. A few Nabataean sherds were also found. The considerable quantities of copper slag testify to intensive mining and smelting activities during the Early Iron Age. We did not actually find the copper bearing rock by *Kh. El-Gheweibeh*, but we did find large quantities of such rock a few kilometers away.

It is interesting to compare Glueck's observation with the comments of Weisgerber (2006:15): "Nearby at Khirbet el Ghuweiba was another, seemingly unsuccessful, smelting site. Perhaps the yield in copper ore there did not meet expectations." Indeed, the extensive scatter of slag on the surface is rather thin and less substantial than either KEN or KAJ. The large slabs of tap slag, abundant on the surface of KEN, are completely absent and there are no substantial 'mounds' like in most of the other Iron Age smelting sites in Faynan.

As part of the ELRAP 2009 field season we have conducted small soundings in Khirbat al-Ghuweiba in order to contextualize and date the copper production remains that dominate the site. The excavations took about three weeks and were conducted during November 2009. The field work included a small team of UCSD students, local Bedouin workers and a volunteer[53]. We applied the same excavation methodology and recording procedures as of the main project (ELRAP, see section 5.2.1 above), using a *Total Station* and a GIS-based database, with Microsoft Access forms for locus summary and ArcView for producing top plans and artifact spatial distribution maps (all material are available in ELRAP's digital database).



Fig.5.99: Khirbat al-Ghuweiba, an overview of the excavation area (Area E) during the 2009 excavation season.

[53] The excavations were supervised by the present author with the assistance of Kathleen Bennallack.

The site extends over 7 hectares (70 dunams) on both sides of Wadi al-Ghuweiba, just near the spring of ‘Ain al-Ghuwayba that holds water all year round and supports lush vegetation of tamarisks and other hydrophilic plants, as well as some orchards of the local Man’aja tribe. Although the site is quite extensive in area, the archaeological accumulation is rather shallow and in most places is composed of only thin scatter of broken slag (especially on the southern bank). Some substantial structures are visible on the surface, and a few are concentrated on the northern bank just near a seasonal active Bedouin encampment (during this season of excavation the encampment was vacant, although remains of the habitation and pens were visible).

We chose an area of relatively thick slag accumulation and some surrounding structures in the northern bank of Wadi al-Ghuwayba (“Area E”, Fig.5.100). The main goals were to date the copper production activities in the site, to characterize the technology (to the degree possible in a small probe) and to check the function of a nearby structure that may have been related to the copper production activities. Clarifying the chronology of the site was of a particular interest to our general investigation of the oscillation in copper production activities throughout the Iron Age. As the nearby mining sites of Ras al-Miyah (section 5.2.6 above) were dated by abundant ceramic to the late Iron Age (Iron Age IIB-C), we speculated that Khirbat al-Ghuweiba was the smelting counterpart of the mines and also dated to the late Iron Age (Ben-Yosef et al., 2009a). In the near vicinity of the mines, and probably in the

Faynan region in general, there are no good other ‘candidates’ for smelting sites associated with these mines.

5.2.7.1 Mapping Khirbat al-Ghuweiba

With the aid of ELRAP surveyor Fawaz Ishakat of the Hashemite University, we produced a topographic map of the site with the main architectural features (Fig.5.100). This general map helps to contextualize the excavated probe (“Area E”) and demonstrates the extent of the site. The map has topographic contours of less than half a meter resolution, emphasizing the topography and the location of the main structures (mostly on the north bank of the wadi). As clearly indicated by the map (cf. Fig.5.75 for general location and exact boundaries of the site mapped by FBRS), most of the slag scatter is not associated with substantial structures and the southern bank is almost completely vacant of architectural features (except small installations, not mapped). The spring of ‘Ain al-Ghuweiba is located between the two banks of the wadi; a mall cemetery is located to the northwest of Area E (not shown on the map; and the fortress of Ras al-Miyah West is visible from the site, located almost directly to the north of it (Fig.5.75).

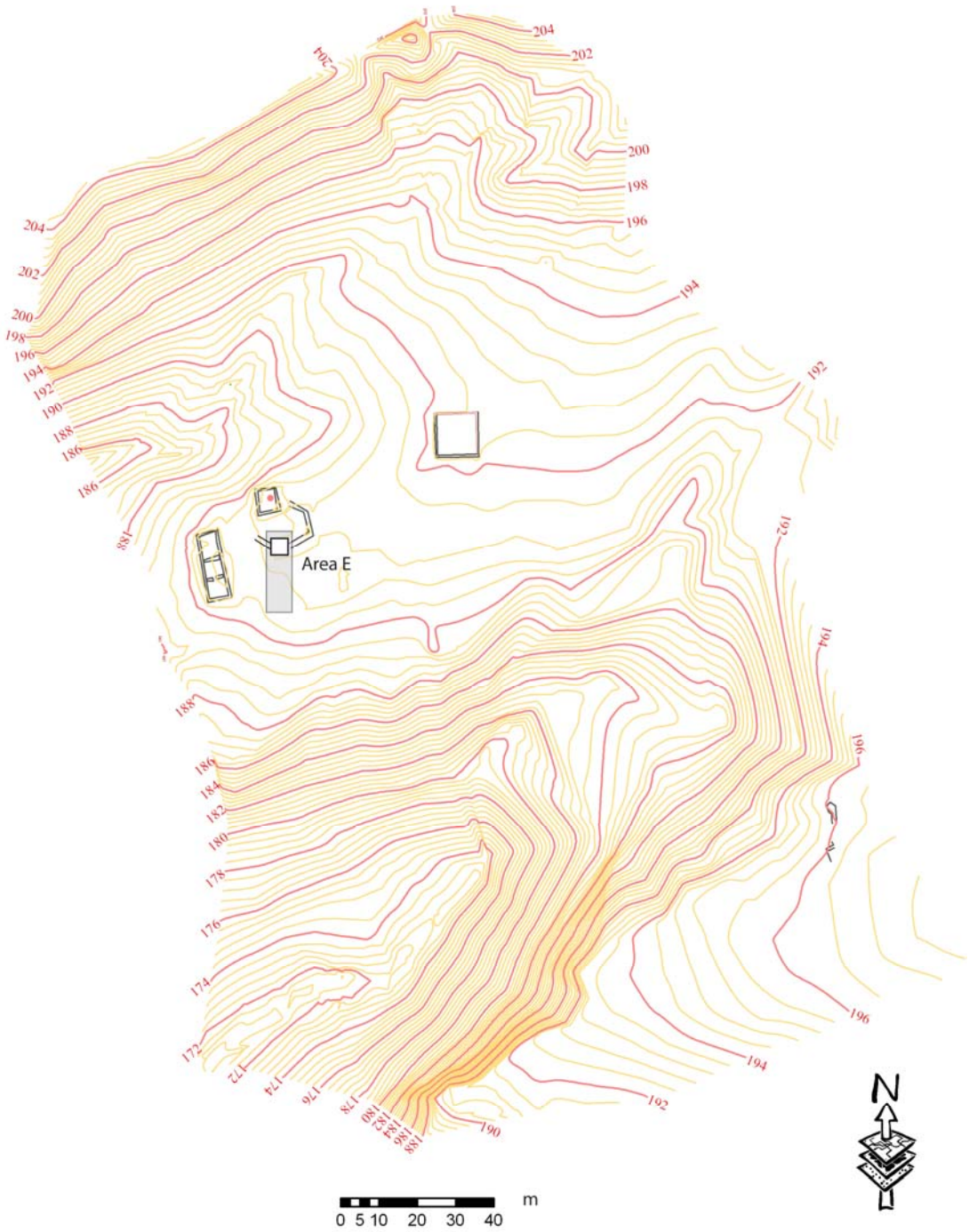


Fig.5.100: Khirbat al-Ghuweiba on both sides of Wadi al-Ghuweiba. The site extends over a 7 ha area, and consists mostly of a shallow scatter of slag fragments. Note the main architectural features and the location of the excavation probe ("Area E"): a small structure and half a 5 x 5 m square in metallurgical deposits were excavated.

5.2.7.2 KAG Area E: the structure

The excavation of the small square structure in Area E concluded in the exposure of a room dated to the Roman-Nabataean period based on the glass and pottery assemblages and small finds. The room contained several hearths and abundant carbon samples were collected from the floor levels. The structure was initially filled with collapse and windblown loess to the top of the walls, a depth of less than 1m (Figs.5.101-5.103). The truncation of the walls may suggest that the stones had been removed to use in later structures. Beneath the fill we found several hearths and ash pockets with large accumulations of charcoal, in addition to a large quantity of glass fragments, pottery sherds and one playing die (Table 5.15).



Fig.5.101: The Nabataean structure at KAG Area E before excavation.



Fig.5.102: The Nabataean structure at KAG Area E during excavation (Locus 3 – fill).



Fig.5.103: The Nabataean structure at KAG Area E during excavation, just below the fill (Locus 5).

Table 5.16: KAG Area E, Harris Matrix for loci associated with the structure

Main Building				Building walls	Probe below foundations	Courtyard(s) walls
7	3	15	16		24	25, 26, 27
				18,19,20,21,22	28	
13	5				29	
	6	14				
	32 FL	33 FL	36, 37			
		35				

The building technique is different from the Iron Age structures at Khirbat en-Nahas and Khirbet al-Jariya, reflecting the chronological difference. The construction of the structure at Khirbat al-Ghuweiba is finer and more regular, consisting of courses of large stones of uniform thickness with courses of small stones between the larger courses. In addition, we observed two walls to the north of the building which abutting the walls of the structure and curving outward and to the north, creating a rectangular courtyard with rounded corners (Fig.5.100). Since these walls abut, but do not interdigitate with, the walls of the structure, we can conclude that they are from a separate (possibly later) building phase; the fact that they are also higher than the foundation of the structure walls suggests that the courtyard is indeed from a later period (Late Islamic?) (Figs.5.104 and 5.105). The courtyard walls probably abut another structure located to the north (Fig.5.100); this building is probably also from the Nabataean period, as well as the elongated structure to the west. There is a doorway in the northern wall of the structure, facing the courtyard (and from which we did not remove the blockage). We also uncovered a third curved wall to the south; its upper courses may have been accidentally removed during the excavations while removing the fill and collapse. This wall abuts the southern wall of the structure

(although it ends abruptly to the south of the structure), and it may have been part of a wall which delineated a southern courtyard.



Fig.5.104: The courtyard wall abuts the eastern wall of the structure; its foundation is much higher, probably indicating that it was built in a later period (maybe with secondary use of the stones of the Nabataean structure).

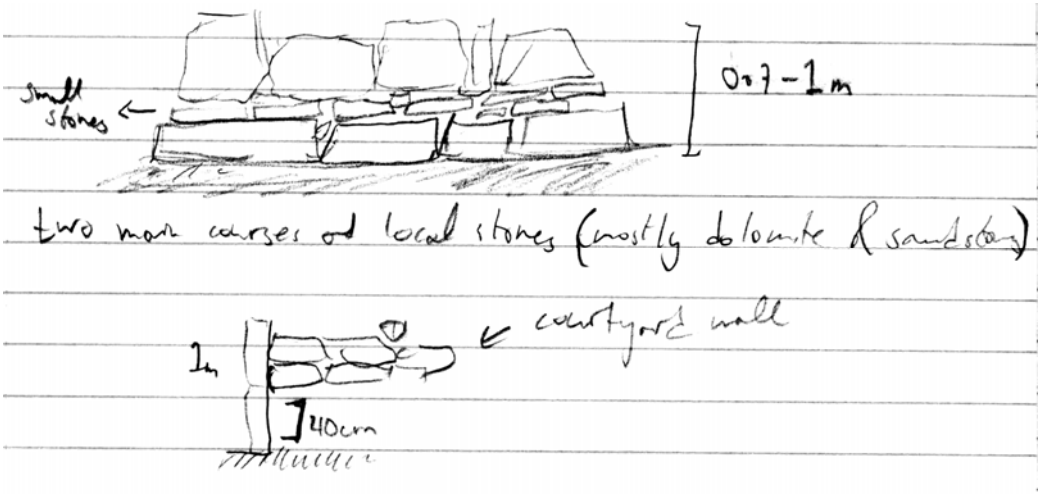


Fig.5.105: A sketch of the eastern wall of the building (top) and the relations between the courtyard wall and the eastern wall of the building (bottom) at KAG Area E.

Inside the structure we found several hearths and ash pockets (Fig.5.106). They were mostly located around the edges of the room, but some very thick deposits of ash, stones and large charcoal were located near the center of the room. A single carved stone die was found in the northwestern corner of the room. Some of the well defined hearths were recorded as separate intrusive loci (see Tables 5.15 and 5.17). The floor of the building was not more than compact dirt, but the finds, and mostly the hearths, made this level very distinct and well defined.



Fig.5.106: Example of one of several hearths found on the floor level of the Nabataean structure at KAG Area E (Locus 37).

Both inside and outside the walls we found several grinding slabs and hammerstones in the fill. Below the fill (both outside and inside) we found many

fragments of pottery and translucent glass fragments of fine vessels dated to the Roman-Nabataean period (found in several different locations).

In the southeast corner inside the building we penetrated below the floor level to check the relation of the wall foundation and the floor, and to make sure there is only one floor level (locus 35). Just below the floor level some copper production remains were exposed, and it was clear that the floor is in one main level, with some minor accumulations in areas where hearths were in intense use (Fig.5.107). The general characteristic of the floor indicates quiet abandonment of the building, and not rushed or traumatic desertion.



Fig.5.107: KAG Area E, excavating the floor level of the Nabataean structure.

In the southwestern outside corner of the building we dug a small probe to virgin soil (Fig.5.108). There is distinct metallurgical layer just beneath the wall foundation and the collapse, but in contrast to the situation in the excavated square to the south, the accumulation here was very thin and was mostly made of crushed slag ash and charcoals.

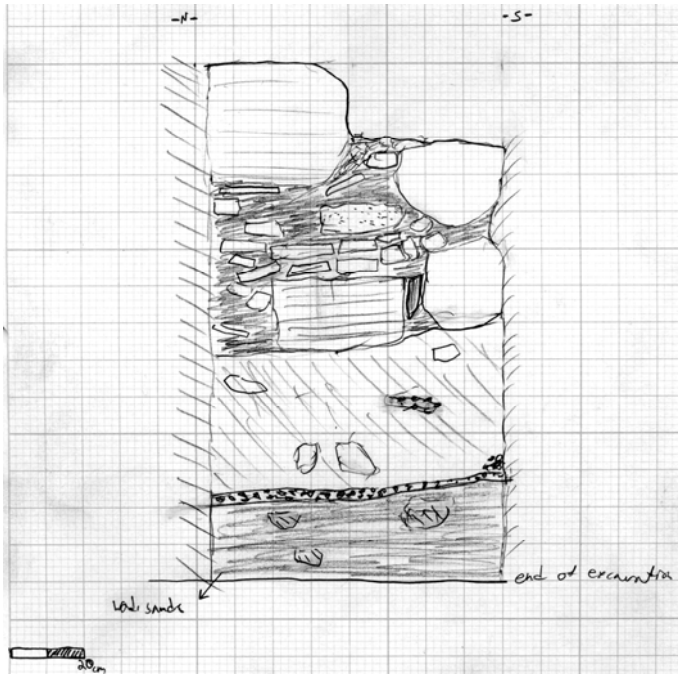


Fig.5.108: Drawing of the section of the southwestern outside corner of the Nabataean structure at KAG Area E. the Iron Age metallurgical layer is represented here mostly by a thin layer of fine-crushed slag (dotted horizon, second from the bottom). Scale bar is 20 cm.

5.2.7.3 KAG Area E: the probe in the metallurgical deposits

To the south of the structure we chose an area which appeared to be a dense metallurgical layer for sounding (Fig.5.109, Table 5.17). In the center of the square was a stone feature which resembled an Iron Age grave documented in other locations

in Faynan (Fig.5.10). The surface of this probe was a layer of slag mixed with a few sherds of (probably late) pottery, “floating” on a layer of windblown aeolian dust. The surface slag was black, matte, and relatively small, containing no charcoal or copper prills. Beneath the slag on the surface was a thick layer of accumulated ashy dust relatively sparse in finds. We found no charcoal in this layer, but did find a few tuyère fragments, pottery, and ground stones. We also found one copper object which may have been an earring. No bone fragments were recovered from beneath or near the “grave,” and there was no cist beneath the surface feature; most likely it was either not a grave, or if it was, the remains have decomposed completely enough to leave no trace.

Table 5.17: KAG Area E, Harris Matrix for loci associated with the probe in the metallurgical deposits; blue indicates locus with radiocarbon measurements

	1 (slag scatter)			2 (stone feature)	
9	12	4		11	10
		8	17		
		23			
		30			
		31			
		34			



Fig.5.109: The 'slag mound' at KAG Area E before excavation. Note the stone feature near the scale stick thought to be a grave (Locus 2)

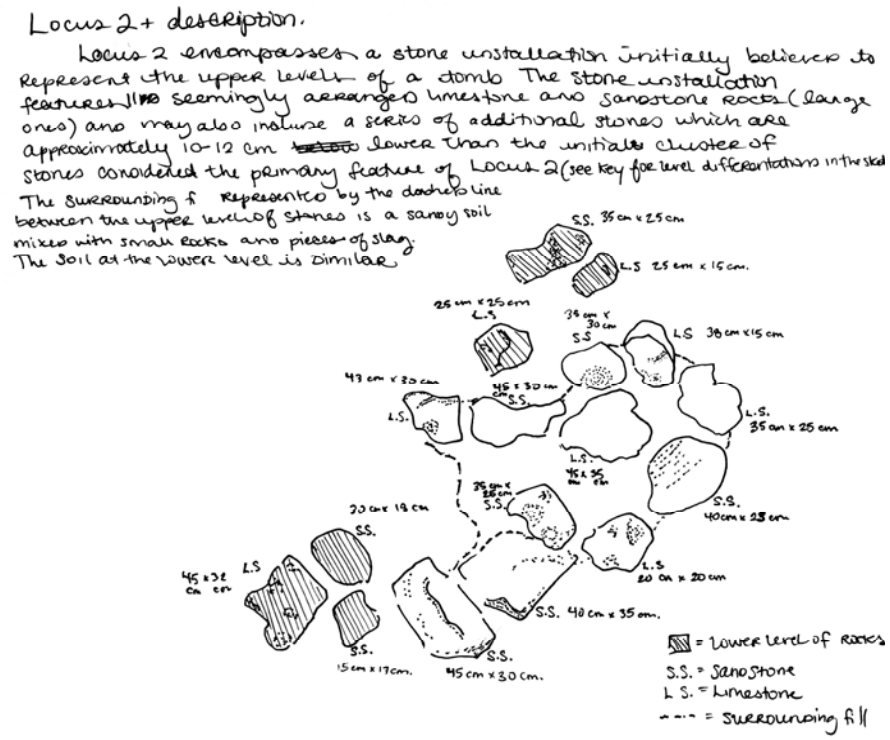


Fig.5.110: A sketch of the 'tomb' like installation and associated stones (KAG, Area A, Locus 2).

Below the fill, metallurgical remains became more predominant and the ashy dust less so. Additionally there were patches here of compact clay containing crushed slag. In this layer we also uncovered two, round (possibly circular, although we only uncovered the portions contained within the square) stone features: one in the northeastern corner and one in the southwestern (Figs.5.111 and 5.112). The northeastern ring was filled with crushed slag and metallurgical debris (tuyère fragments, some small charcoal, and a copper prill) but we could not excavate deeper than a few centimeters into this feature as only a tiny portion of the interior was exposed. The stone ring appeared to be only one course at first, but as we excavated deeper into the square it appeared to have several possible layers of stones below it; they were not arranged in clear courses and extended beyond the original ring, so they may have been a sort of support, or possibly collapse. The southwestern ring we did not excavate, except to uncover the surface feature, although it appeared to contain crushed slag similar to the northeastern feature. It had one clear course of stones and may have more, but the outside remained almost entirely covered by a baulk which was our entrance and exit to the probe once it was too deep to climb in and out of. Finally in this level there was a small installation of stones to the north of the southwestern ring, and which may have been contemporary or related to the same construction phase.



Fig.5.111: KAG, Area E, metallurgical installations in the probe on the 'slag mound', looking south.

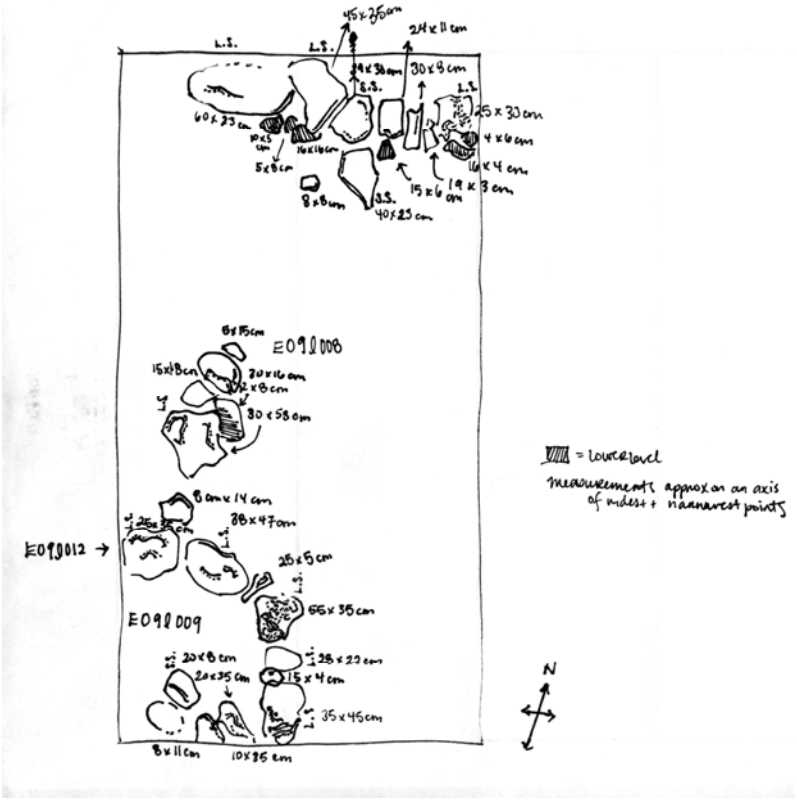


Fig.5.112: A sketch of the two installations exposed in the metallurgical deposits (compare with Fig.5.111).

The deposits became richer in metallurgical related materials below the layer of mixed fill and slag; the slag became more prevalent, and tuyère fragments, pottery, hammer stones, and charcoal became abundant, as well as ashy pockets of sediments. Just below this layer, the metallurgical remains abruptly became very sparse and the fill became characterized by orange and yellow wadi sands which represent the nature of the natural sediments in this location. However, although the metallurgical remains were very sparse here and may represent only very early phases of activity, this was not a level of virgin soil, as there were still some clear ash pockets and a large amount of charcoal. Below this level the ash and charcoal decreased almost completely but did not disappear, and as there was a grinding slab in this level it could not be called pre-occupation. The lowest layer of the probe contains virgin wadi sands; it does contain a few ashy pockets, but they are likely the result of animal burrows which can clearly be seen in the section drawing (Fig.5.113).

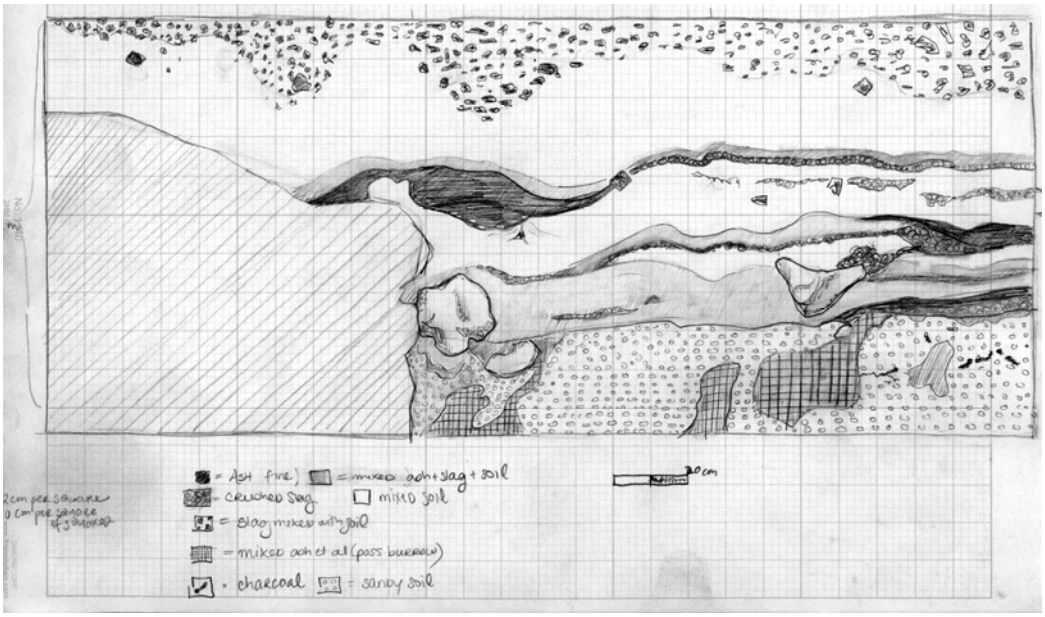


Fig.5.113: Drawing of the eastern wall of the excavation pit in the 'slag mound' at KAG, Area E.

5.2.7.3 ELRAP's excavations at KAG Area E: chronology and summary

The probe at Khirbat al-Ghuweiba Area E consisted of two main contexts – a small structure and a shallow 'slag mound'. The excavated loci are summarized in Table 5.18, with indication of the areas as 'metallurgical' or 'structure'. We exposed a small Roman – Nabataean structure, probably related to peasant activity near the oasis of 'Ain al-Ghuweiba or to some sort of military outpost in this region (maybe indicated by the arrow head and the die found in the floor level of the structure). Adjacent structure (the courtyard compound) may be of the same period or possibly later. It is not clear if there are any Iron Age structures at the site at all. Below the structure and stratigraphically older, there are remains of metallurgical activities of copper production, very thin under the structure itself, and more substantial to the south of it, where we opened half a square and excavated to virgin soil. The ceramic associated with the metallurgical context indicates early Iron Age occupation, and the assemblage has some similarities to the pottery from KAJ (Fig.5.14, and see section 5.2.5.2 above). This also corroborates Macdonald's observations (MacDonald, 1992b, there the site is dated to Iron Age I). Radiocarbon samples are currently being processed at the Oxford Radiocarbon Accelerator Unit (Research Laboratory for Archaeology); preliminary results that arrived shortly before the submission of the current work indicate indeed an early Iron Age date. Two charcoal samples were measured, one from Locus 30 (OxA-23159, 2919±29 BP, 1253-1016 Cal BCE 95.95.4% probability, 1192-1051 68.2% probability, OxCal2010, IntCal09, ©

C.B.Ramsey) and the other from Locus 23 (OxA-23159, 3288±28 BP, 1632-1497 Cal BCE 95.95.4% probability, 1608-1526 68.2% probability, OxCal2010, IntCal09, © C.B.Ramsey); three other samples from the excavations were identified as *Juniper sp* thus it is probable that these numbers are affected substantially by the 'old wood effect'.

The early Iron Age date is also supported by similarities between the technological finds between KAG and Khirbat al-Jariya. In general, the copper production activities in KAG were lower in intensity than the peak presented at KEN in the 10th and 9th centuries BCE. Utilization of the most advanced technology recorded in KEN and represented mostly by large tap slag is not evident in KAG. Given the new dating of the smelting activities at KAG, the complementary production site of the Ras al-Miyah copper mines is still unknown, or do not exist – these mines have ample ceramic sherds of the late Iron Age (8-6th centuries BCE, see above) and no substantial production site is clearly associated with them.

Table 5.18: Locus list of KAG 2009 Probe in Area E

Locus	Square	Definition
1	metallurgical	Metallurgical layer / surface fragments
2	metallurgical	Stone feature
3	structure	Fill and wall collapse, surface finds from square structure
4	metallurgical	Ashy fill (accumulation of dust in a metallurgical context)
5	structure	Floor level (and a bit above), secondary?
6	structure	Hearth
7	structure	Wall collapse / fill
8	metallurgical	Metallurgical layer / fill
9	metallurgical	Fill
10	metallurgical	Slag layer
11	metallurgical	Stone feature / installation / wall
12	metallurgical	Wall / Installation
13	structure	Ash layer
14	structure	Ash pocket
15	structure	Fill / wall collapse
16	structure	Fill / Wall collapse
17	metallurgical	Stone feature (intrusive to locus 8)
18	structure	Wall (eastern wall of structure)
19	structure	Wall (southern wall of structure)
20	structure	Wall (western wall of main structure)
21	structure	Wall (northwestern wall, by the doorway of main structure)
22	structure	Wall (northeast wall of structure)
23	metallurgical	Metallurgical layer
24	structure	Fill (a bit metallurgical layer)
25	structure	Wall
26	structure	Wall (part of courtyard wall, northwestern side of structure)
27	structure	Wall (southern courtyard wall?)
28	structure	Metallurgical layer
29	structure	Metallurgical layer (scant remains of the above locus) / fill / virgin soil
30	metallurgical	Fill
31	metallurgical	Fill / virgin soil
32	structure	Floor
33	structure	Floor
34	metallurgical	Virgin soil
35	structure	Fill (bottom of floor)
36	structure	Hearth
37	structure	Stone feature / hearth?

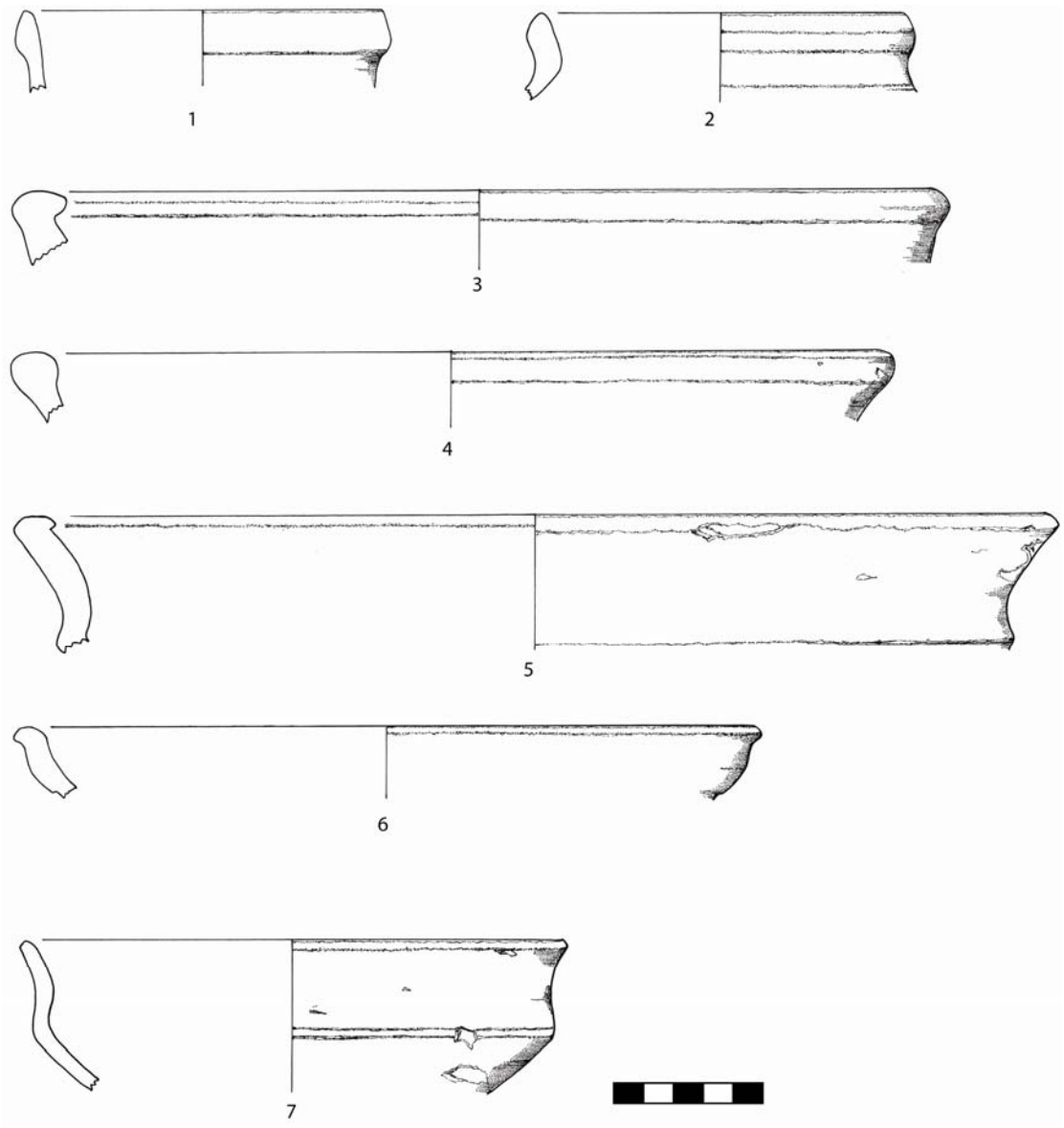


Fig.5.114: Some representative ceramic types from the metallurgical context of KAG area E. The ceramic indicates early Iron Age copper production activities at the site, and shows similarity to the assemblage of KAJ (see section 5.2.5.2 above). 1) EDM 0100, L.008, B.0087, R.457; 2) EDM 0100, L.008, B.0087, R.461; 3) EDM 0100, L.008, B.0087, R.458; 4) EDM 0662, L.008, B.0051, R.537; 5) EDM 0148, B.0130, R.474; 6) EDM 0181, L.030, B.0156, R.470; 7) EDM 0100, L.008, B.0087, R.463.

5.2.8 *Khirbat Hamra Ifdan*

Khirbat Hamra Ifdan (KHI, WF 120) is located on the south bank of Wadi Fidan near the small oasis of ‘Ain Fidan. It was investigated by various scholars, including extensive excavations of the Early Bronze Age settlement specialized in metal production by the JHF project in 1999 – 2000 (Levy et al., 2002a). In 2007 we conducted another season of excavations at the site focusing, in addition to the EB remains, on the large ‘slag mound’ on the southern side of the site (part of ELRAP field season, supervised by A. Muniz, metallurgical collection at the “dirty lab” organized by the present author). The excavations of the ‘slag mound’ were part of Area E, and the basic results, with emphasis on the Iron Age remains, are presented here. They are partially based on the field report of A. Muniz.

The goals of the 2007 excavations at Area E were two-fold: elucidating the chronology of the slag mound and collecting slag samples for paleomagnetic studies. The typology of the slag visible on the surface of the site was the main reason for ascribing them to the Iron Age by previous researchers (e.g., Hauptmann, 2007:134, there 'Iron Age II'), although such a link is tentative at best (e.g., Ben-Yosef et al., 2010c). An Iron Age date for some of the archaeological remains in this area of KHI is also supported by a radiocarbon date from the 2000 excavations at Area L, located to the northeast of Area E in and near a late (Roman?) square massive foundations of a structure visible on the surface. This date, published only recently (Levy et al., in

press-a), came from a mixed context of Early Bronze Age IV pottery, bones and loose sediments, interpreted as a refuse disposal area (2910±41 BP; 1192-1021 BC 68.2% and 1261-995 95.1% probability; OxCal v.4.1, © Ramsey 2010; Stratum IIIA, L. 3034, B.45344, RC23, Table 5.2). The archaeomagnetic investigation of slag samples from Area E clarified the chronology of the 'slag mound' and confirmed the Iron Age date of the upper most layer at this location (below).

5.2.8.1 Description of the 2007 excavations of the 'slag mound' at KHI Area E

During the five week excavation season, the members of the excavations at Area E removed 2036.88 kilograms of slag (most of which from the Iron Age occupation context) and approximately 48.99 cubic meters of wind-blown sands and miscellaneous fills. The Excavations followed the methodology applied by ELRAP (section 5.2.1 above). The results (Table 5.19) indicate two phases of copper production were conducted at this section of the site. Further, the probe revealed an Early Bronze Age occupation phase buried beneath the slag mound (only briefly discussed here).

Table 5.19: Strata identified during the 2007 probes at KHI- Area E

Stratum	Description	Date
Stratum I	Surface	Post Iron Age
Stratum IIa	Slag- Large Tap	Iron Age (?)
Stratum IIb	Fill	Abandonment
Stratum IIc	Slag-Crushed	Iron Age (?)
Stratum IIIa	Fill	Abandonment
Stratum IIIb	Architecture	Early Bronze Age III
Stratum IV	Bedrock	

Excavations for the 2007 season at Khirbat Hamra Ifdan centered on the southwestern center of the site. The area chosen for sampling represents the highest point on the 'slag mound'. On the surface (Fig.5.115) throughout this area, varying sizes of tap and crushed slags are found. Removal of the surface material (L. 3002, 3050, 3074) revealed layers of windblown sediments mixed with ash resulting from embedded carbon in the slags and cultural materials from different time periods including Roman and Islamic.



Fig.5.115: The 'slag mound' situated on the southeastern part KHI (photo courtesy of ELRAP-LAL).

Immediately beneath the fills of filtered sand and ash, the layer representing the main smelting phase is found. These layers are recorded as L. 3005, 3004, 3053, and 3076. The layers consist of large size tap slag and contain a large concentration of

carbonized wood. Water and sand had filtered through the layers of slag creating a conglomerate of slag, sand, ash, and other minerals throughout the layers (L.3010, 3079, 3077, and 3078).

Directly below the conglomerate, a lens of light color fill (L. 3013, 3018, 3090) and ash was found. The fill layer is depicted in Figure 5.116 towards the bottom of the slag layer. The light color fill is composed of light colored sands containing large traces of ash from leeched from the layers above. The accumulation of fill directly beneath the tap slag layer suggests two different production phases. Directly beneath this fill is a layer of crushed slag (L. 3017, L. 3019, L. 3056, 3100). The layer contains small pieces of slag and does not contain the conglomerate found in the tap slag layer above, making it distinctly different.



Fig.5.116: The profile of the slag mound found at KHI (photo courtesy of ELRAP-LAL).

With the exception of a few small walls found associated with the slag mound, the majority of the architectural remains at Area E belong to the Early Bronze Age III (3 rooms and 2 courtyards). The profile seen in Fig.5.116 provides a detail view of the stratigraphic layers at this part of the site, together with the section drawings in Figs 5.117 and 5.118 below. Fig.5.119 presents the Harris Matrix of Area E with preliminary pottery identifications.

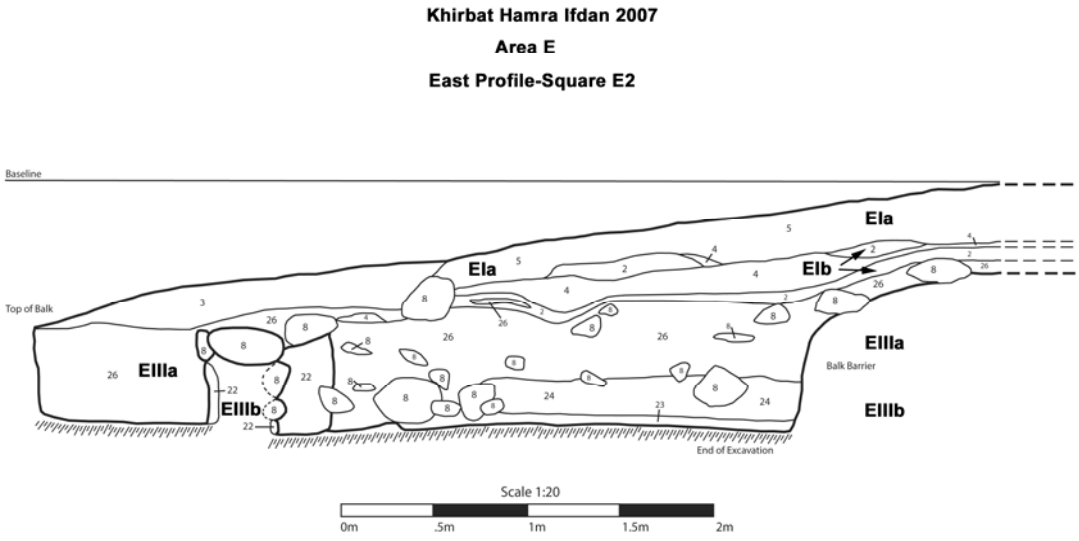


Fig.5.117: a drawing of the eastern wall of the excavation square E2 at KHI Area E with clear stratigraphic division into the copper production deposits (EI) and the Early Bronze Age architecture (EIII) (drawn by A. Muniz). See Fig.5.118 for legend.

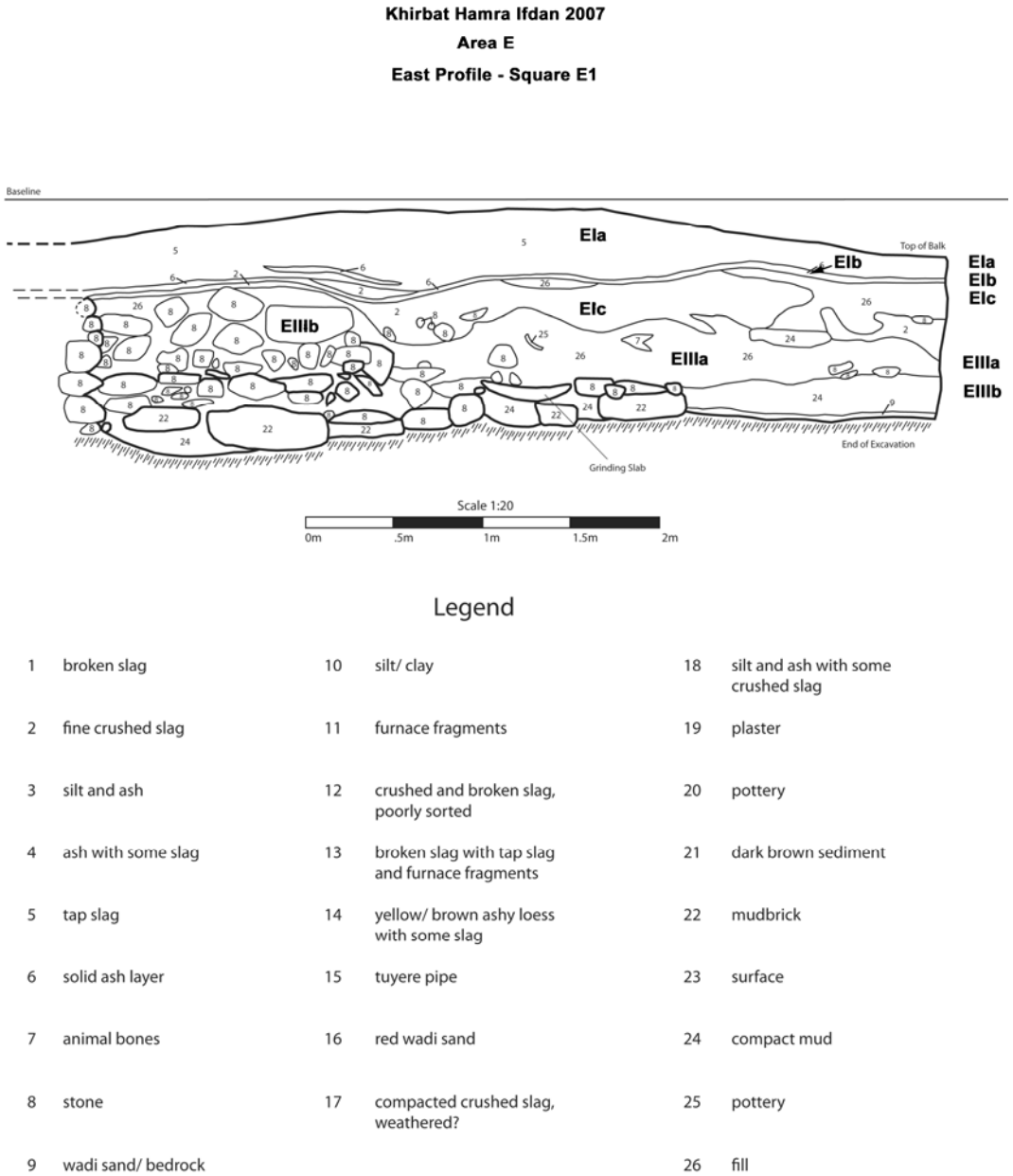


Fig.5.118: a drawing of the eastern wall of the excavation square E1 at KHI Area E with clear stratigraphic division into the copper production deposits (EI) and the Early Bronze Age architecture (EIII) (drawn by A. Muniz; UCSD ELRAP).

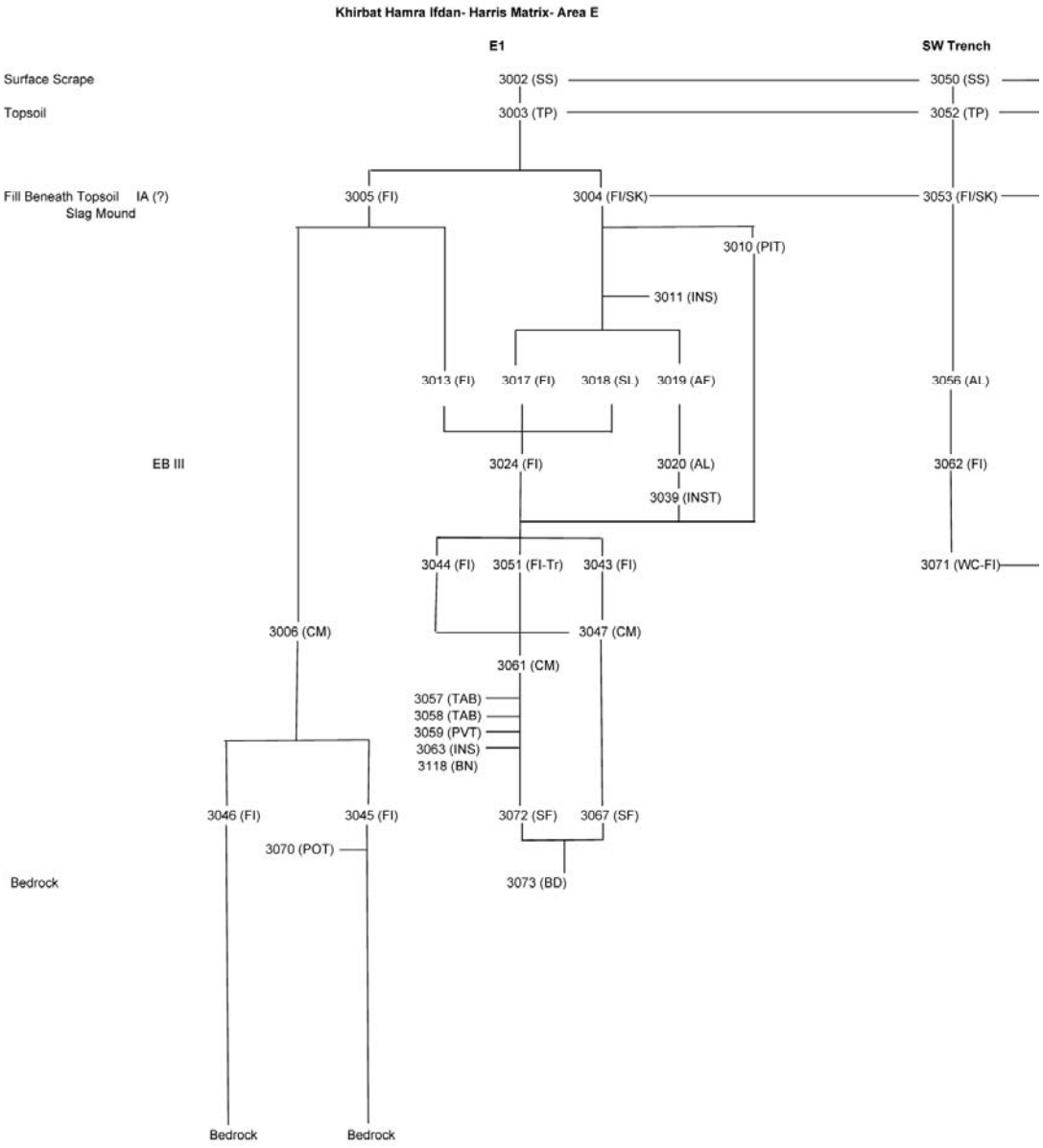


Fig.5.119A: The complete Harris Matrix of the 2007 excavations at KHI Area E (A. Muniz, UCSD ELRAP) (cf. Fig.5.119B).

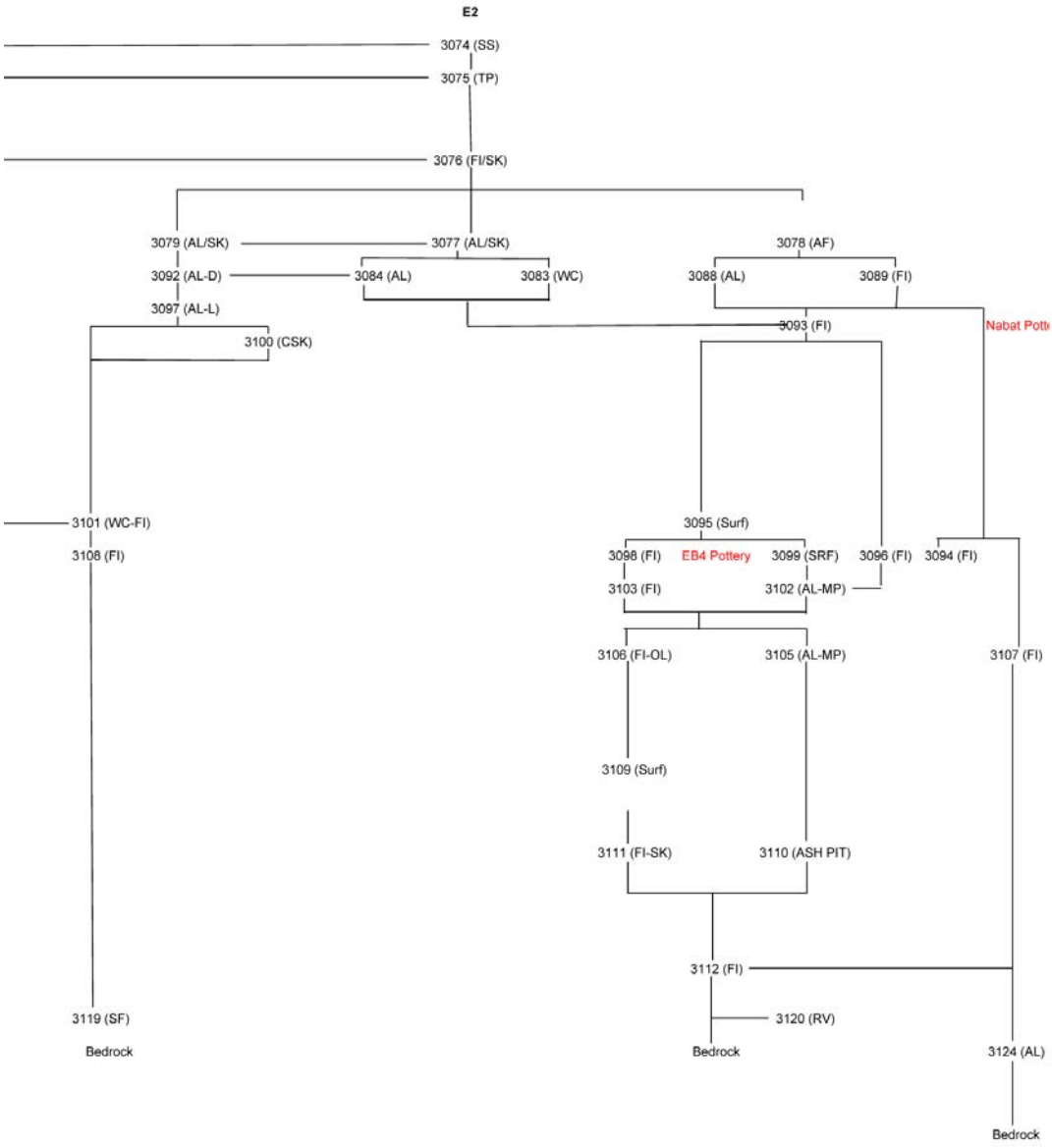


Fig.5.119B: The complete Harris Matrix of the 2007 excavations at KHI Area E (A. Muniz, UCSD ELRAP) (cf. Fig.5.119A).

5.2.8.2 Dating the 'slag mound' at KHI Area E

The context of smelting remains visible on the southern surface of KHI is not clear. Ceramic identifications from the 2007 excavations at Area E are mixed (Late Islamic, Roman-Nabataean), with no clear finds of Iron Age pottery. This situation makes it useful to apply a direct dating technique targeted at the slag fragments themselves (Ben-Yosef et al., 2010c, and section 4.2.2 above).

Samples from both the Early Bronze Age and later metallurgical deposits were measured by us in the paleomagnetic laboratory at SIO[54]. We applied the IZZI protocol and the selection methodology of Ben-Yosef et al. (2009c). The results are summarized in Table 5.20 and Figs.5.120 and 5.121.

[54] Intensity measurements were done by Jason Steindorf. This project was funded by NSF grant # xx to Lisa Tauxe and Thomas E. Levy. Interpretation of the results was done by L. Tauxe and the present author. The final publication of this project will appear in Ben-Yosef et al. (in prep.-c)

Table 5.20: Archaeointensity results from Khirbat Hamra Ifdan, Area E (latitude: 30.663°, longitude 35.393°) (cf. Fig.5.119 for stratigraphic location, and Fig.5.121 for the Levantine archaeomagnetic intensity curve); in green – values corresponding to the Iron Age, in orange – values corresponding to the Early Bronze Age, in blue – mixed locus (?)

Sample	Locus	N	Intensity [μT]	Intensity σ %	VADM [ZAm^2]	VADM σ
b62356a:b62391b	3053	2	77.9	6.7	151.0	10.1
b62448a	3056	3	84.5	4.2	163.8	6.9
b62492a	3062	2	53.5	25.9	103.7	26.9
b62610a	3077	2	116.5	3.0	225.8	6.9
b62610a:b62614a:b62628a	3077 [all]	3	79.3	41.3	153.6	63.5
b62015a	3079	2	58.6	4.7	113.5	5.3
b62425a	3079	3	48.5	2.5	93.9	2.3
b62015a:b62425a	3079 [all]	2	53.5	13.3	103.7	13.8
b62630a	3083	2	74.6	12.4	144.5	18.0
b62655a	3083	2	78.8	2.8	152.6	4.2
b62656a	3083	3	58.1	10.0	112.7	11.3
b62630a:b62655a:b62656a	3083 [all]	3	70.5	15.5	136.6	21.1
b62685a	3097	2	40.5	10.1	78.5	7.9
b62723a	3108	4	55.3	2.5	107.1	2.7

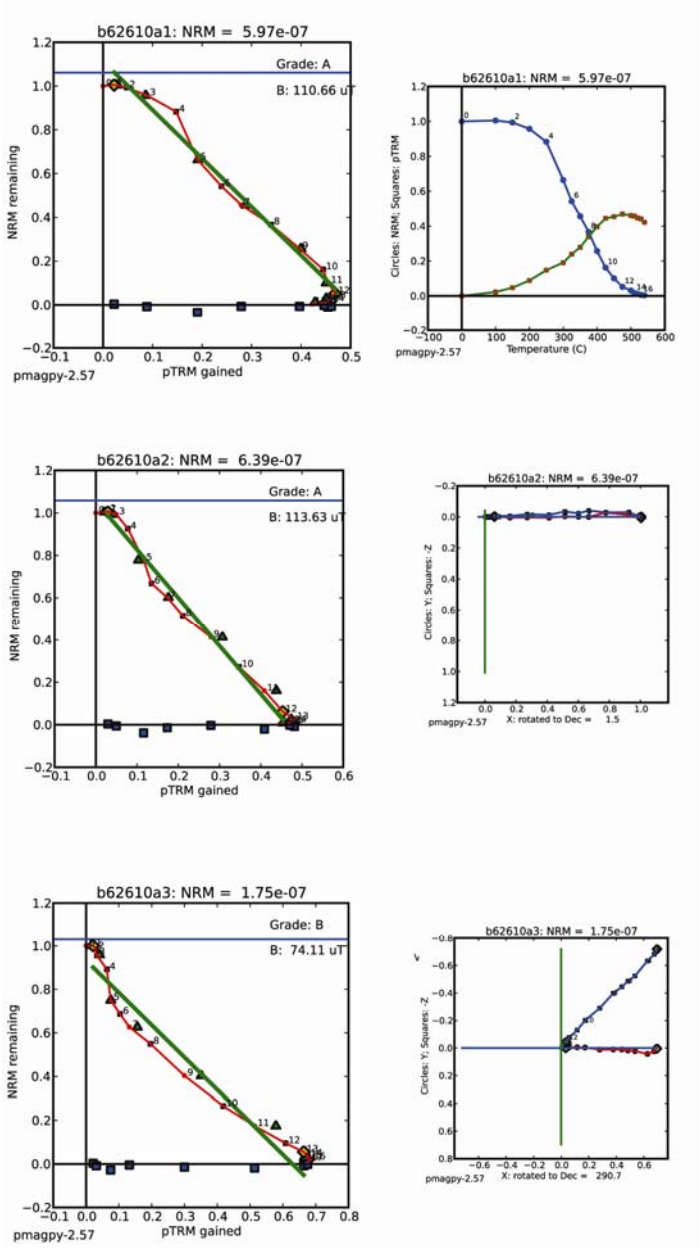


Fig.5.120: Example of results from archaeointensity experiments on slag sample from KHI. The three pairs of diagrams show results from three specimens obtained from one slag sample. The two upper specimens demonstrate excellent behavior throughout the experiment (Grade A), in contrast to the lower specimen that was rejected because of its low quality (Grade B). The two specimens indicate a very high intensity value (cf. Fig.5.121 and Table 5.20 there in VADM units = 226 ± 7 ZAm^2), probably one of the two spikes identified by Ben-Yosef et al. (2009c) in the slag deposits of KEN Area M. These are the highest intensity values discovered so far in the paleomagnetic record of the Earth. The results above are presented in Arai plots (left) and currently known only from the Iron Age and is probably one of the geomagnetic spikes first identified. The left plots are Arai diagram and the right plots are vector end-point diagrams. For details about the method see section 4.2.2 above; for explanation of these plots and their meaning see Tauxe (2010); for key, cf. Figs.6.24 and 6.30.

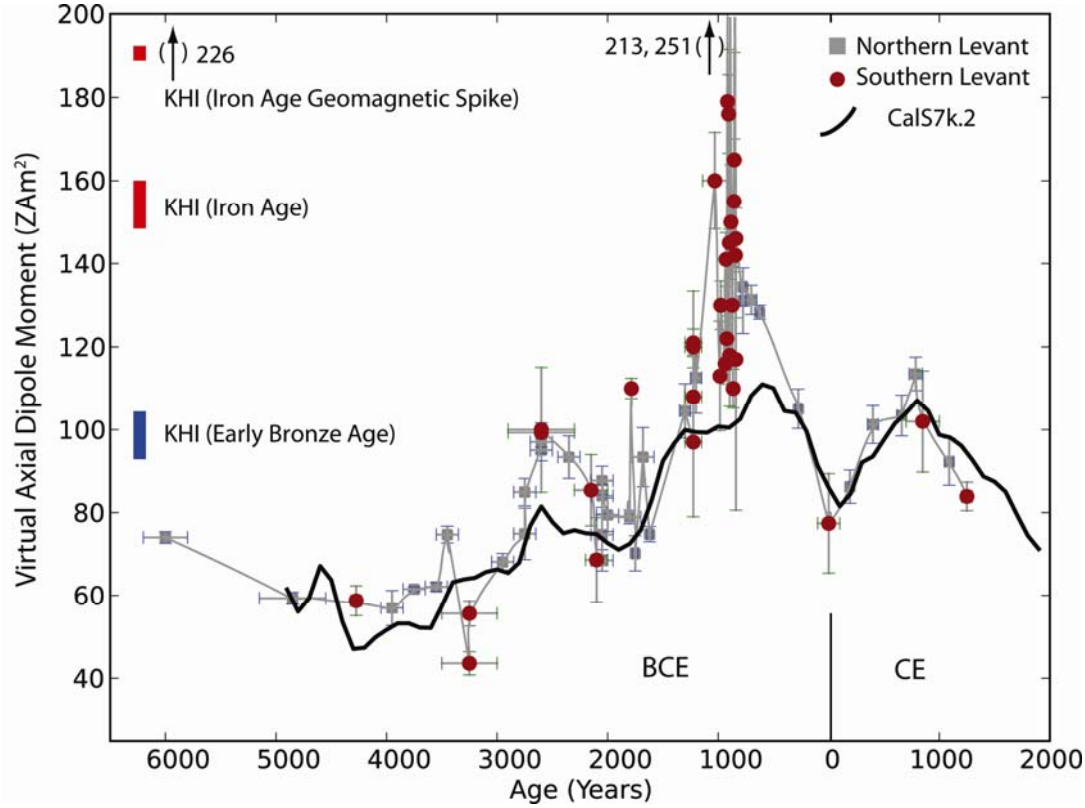


Fig.5.121: Archaeointensity results from KHI plotted against the Levantine archaeointensity curve (Shaar et al., in press). Two distinct groups of intensity values correspond well to stratigraphic context and demonstrate metallurgical activities at the site both during the Early Bronze Age and the Iron Age (cf. Table 5.20). One sample (b62610a) yielded extremely high intensity values (cf. Fig.6.120) that most probably correlate with one of the geomagnetic spikes identified by Ben-Yosef et al. (2009c) in the Iron Age southern Levant (based on slag samples from KEN-Area M).

The archaeointensity results strongly support an Iron Age date of the slag from the 'slag mound' of KHI Area E (Stratum EI). There is an excellent agreement between stratigraphic location and geomagnetic intensity values (except from Locus 3083 that probably represents a mixed context). The upper samples, associated with the main 'slag mound' visible on the surface of the site, yielded high values while the lower samples (Stratum EIII) yielded lower values. Such high values are so far unique to the Late Bronze Age / Iron Age period in the southern Levant. Sample b62610a from Locus 3077 yielded extremely high values that probably correlate with one of the

geomagnetic spikes identified by Ben-Yosef et al. (2009c) during the 10^{th} – 9^{th} centuries BCE (based on slag deposits from KEN-Area M, cf. Fig.4.2 above). The discovery of this short-lived phenomenon is now supported by results from three *different* sites (KEN, Timna 30 and KHI), making this observation substantial and important for various geomagnetic models based on intensity. These extreme high values also indicate that the Iron Age activities at the site were prolonged and not an ephemeral incident of smelting. The prolonged Iron Age activities are indicated also by the presence of two different type of slag from this period (observed in the 2007 excavations), which may correlate with the technological change recognized in this research (Chapter 9 and regarding slag material see section). Further discussion on the Early Bronze Age metal production and correlation between KHI and other smelting sites in the northern Arabah, including the enigmatic Ashalim site, will be published in Ben-Yosef et al. (in prep.-c).

5.2.8.3 Conclusions – Iron Age smelting activities at KHI

The archaeomagnetic evidence from the 'slag mound' at KHI, together with other indications (smelting technology not available prior to the second half of the 2^{nd} millennium, one radiocarbon date from a nearby context, some pottery fragments from mixed contexts) indicate Iron Age smelting activities at the site of Khirbat Hamra Ifdan, most probably during the early part of the period (12^{th}-10^{th} century BCE, radiocarbon date and archaeomagnetic data). The fine stratigraphy of the metallurgical

deposits indicates two phases of production within the Iron Age, with a break between them evident by a layer of aeolian deposits (‘fill’) and change in the stratigraphic layout (e.g., Fig.5.118). The younger phase is represented by tap slag and the older by crushed slag.

This small scale production, not associated with any substantial architectural features, represent a more ephemeral smelting than the main production centers along Wadi al-Ghuweiba and Wadi Faynan. The site belongs to a wider phenomenon of small sites documented in the current research (additional sites in Wadi Fidan and in the southern Arabah, see section 9.1 and Chapter 10 below).

5.2.9 *Jabal al-Jariya mine fields*

5.2.9.1 The discovery of the JAJ mines and general observations

Vast pit mine fields were discovered by the present author and the team of the FBRS project in the summer of 2007 (for the survey see section 3.2.5 above) (Ben-Yosef et al., 2009b). The striking similarities between these mines and the well-documented pits in the Timna Valley attracted our attention when visiting FBRS Site 37. The latter is a structure complex located on a narrow low ridge in the Jabal al-Jariya area; we found it by studying the UTM-IL topographic map (1:50,000) of the region, where the walls of the structure are indicated by black lines. After leaving the dirt road and climbing the narrow ridge we could observe the hundreds of pits below us, probably missed by others because when driving the road in the lower part of the valley these features are not visible. Furthermore, the link between these shallow depressions and mines are not easily recognized. It took many years of research in Timna to correctly associate similar features there with mines (among other options, they were interpreted as designate locations for ore processing, see e.g., Rothenberg, 1967a). The pioneering work of Rothenberg and the Arabah Expedition in the southern counterpart of Faynan has facilitated our investigations in the latter, including the interpretation of the Jabal al-Jariya mines.

The hundreds of plate-like depressions are approximately 7 meters in diameter on average, densely scattered in an enclosed valley of ca. 30 hectares that penetrated into an extensive gravel terrace at the base of Jabal al-Jariya (JAJ-1, 30.695°N, 35.430°E) (Fig.5.1, 5.122). They are similar to the mines found in survey areas A, C and G in Timna (Conrad and Rothenberg, 1980; Rothenberg, 2005), in which *placer* mining of copper ore nodules took place (Fig.5.123). In both contexts, the copper bearing formation is located in a higher topographic location and the ore was mined from the eroded material as already broken fragments (Figs.5.3, 5.124). Tracking the prominent signature of the Faynan mine scars on satellite imagery available on Google Earth (Fig.5.125) we located two similar mine fields approximately 0.5 km (JAJ-2, 30.701°N, 35.432°E) and 1 km (JAJ-3, 30.704°N, 35.435°E) to the north, sprawling over ca.0.25 and 1 hectares respectively.

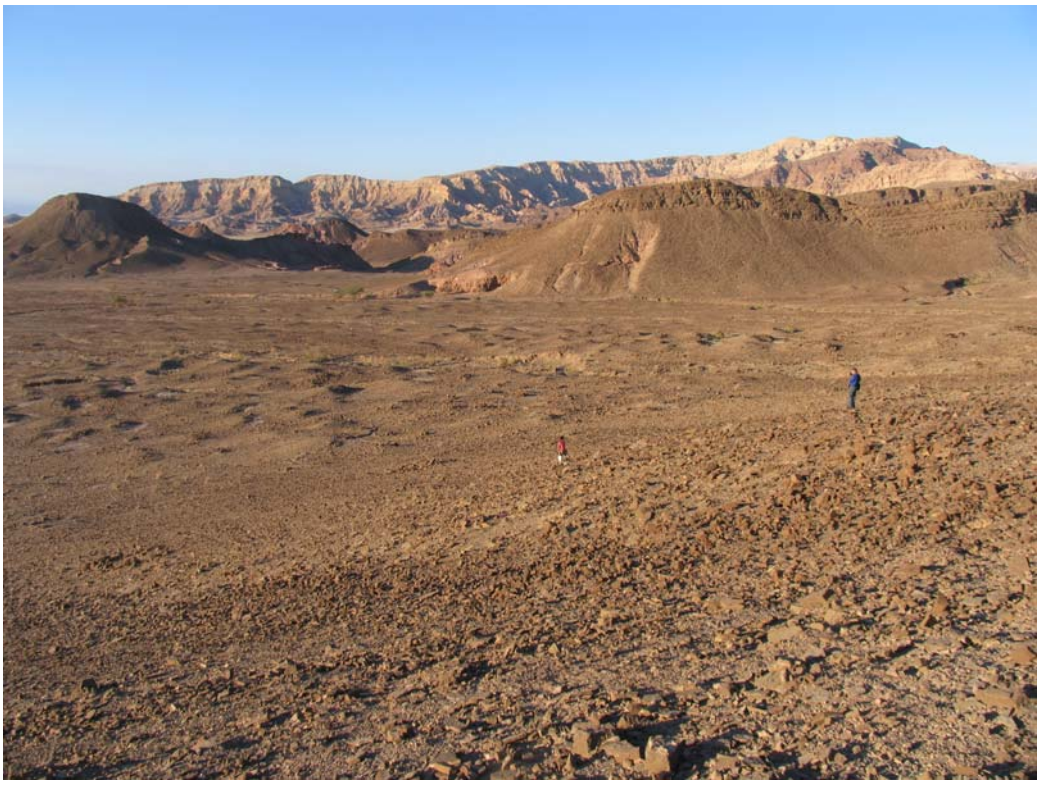


Fig.5.122: An overview of the large copper pit mine field (JAJ-1), view to the north. The disturbed surface is densely covered with depressions marking the location of the ancient mining pits. The depressions are identified as pit mines based on the comparison to the well-studied mines in the Timna Valley, and their geological location.



Fig.5.123: The ‘plate-features’ in the Timna Valley; more than 9,000 such features have been recorded by the Arabah Expedition (photograph courtesy of Rita Mendes-Flohr). After years of research the Arabah Expedition found evidence that most of these features are blocked mine shafts, and that some are open pit mines (in Areas A, C and G). The mines and resulting landscape are similar to the area discovered in the current research in Faynan (JAJ).



Fig.124: Jabal al-Jariya, a view from Wadi al Ghuweiba. The JAJ mines are located in the valleys behind the mountain into which the ore-bearing upper horizon of the DLS formation has been eroded; the local dip of the formation and its exposure layout in this area provided a ‘natural trap’ for ore with erosion processes functioning as a natural beneficiation mechanism.

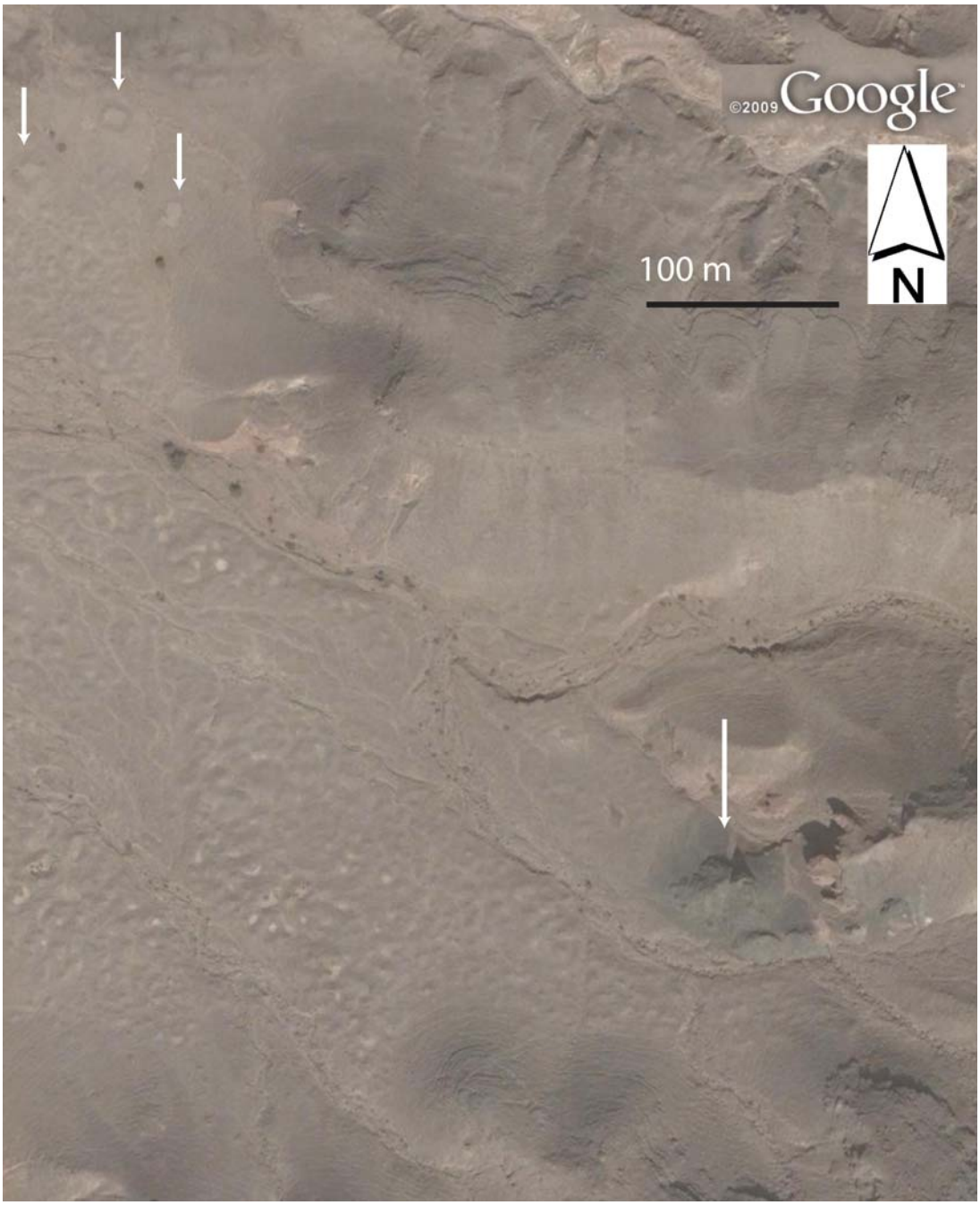


Fig.5.125: Satellite image of the eastern portion of the southern pit mine valley (JAJ-1). The three left arrows indicate the location of shallow rectangular encampments, two of which are possibly contemporaneous with the mining activities. The right arrow indicates the location of a magmatic plug, part of Phanerozoic magmatism exposed in the vicinity of all three mine fields.

In the Timna Valley, the previously enigmatic depressions were, until now, unique in the entire landscape of the Levant. The scarcity of archaeological finds in such mine fields and the exhaustive exploitation of ore made the interpretation of the 'plate-like' features in Timna difficult; even excavations of some of these features yielded very little artifactual evidence (Rothenberg, 2005). The situation in the JAJ area is similar: surveying the mines yielded only few fragments of ore (Fig.5.126), no pottery at all and, surprisingly, no securely identified ground stone[55]. The absence of ground stones is possibly explained by the quality of ore in this location. Very limited evidence show extremely high quality of ore in a very small nodules or attached to small fragments of the host rock (e.g., Fig.5.126A), saving the need to further beneficiate the ore by dressing with ground tools. The lack of ore, even in the excavated area (see below) indicates that this region was completely exhausted in antiquity. This situation is different from other mine locations in Faynan, where ore is still evident today and, according to Hauptmann (Hauptmann, 2007), probably represent the same quality available in antiquity. This supports our supposition that the ore of JAJ was of a higher quality than of other deposits in Faynan[56].

[55] In the placer mines of Madsus which appear to represent similar mine type and mining technology (Table 5.2) there are frequent ground stones (hammerstones and hand stones) and also more ore fragments. Hauptmann (Pers. Comm. 2010) recalled finding such tools in the vicinity of Jabal al-Jariya. In both regions, he suggested to date the mines to the Early Bronze Age I, based on the presence of these tools which are similar to some finds in the site of Wadi Fidan 4 (for Madsus, see Hauptmann, 2007:131). This dating should be regarded as tentative only, as technology, especially of mining in open pits, cannot be a secure chronological marker.

[56] It is intriguing to link evidence of young magmatic activities in the JAJ area recorded by our team (see below) and probably related to the copper mineralization with our supposition that the ore quality in this location was higher. This is, of course, a speculation that probably could not be approved, as the region is completely depleted of ore.

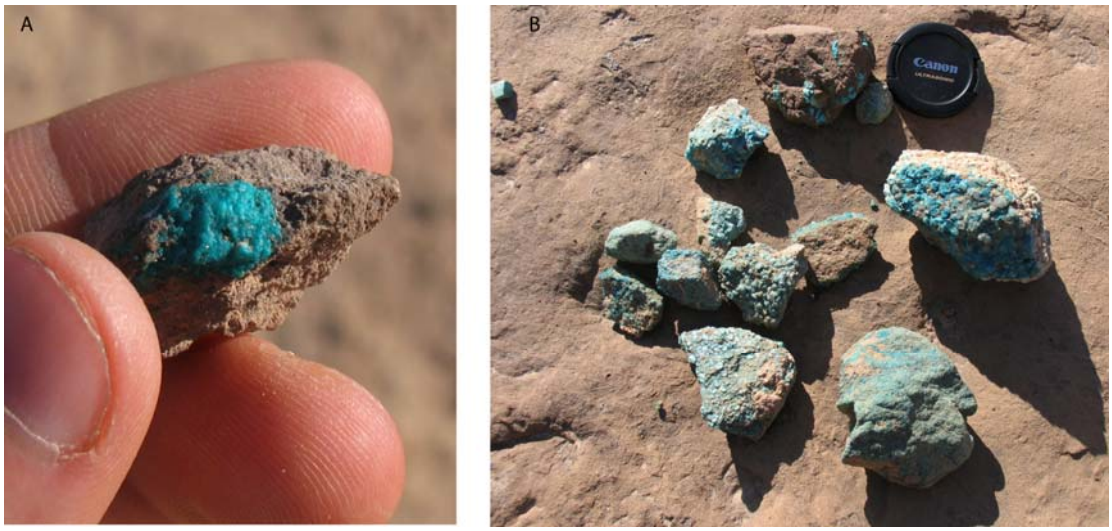


Fig.5.126: Copper ore from JAJ-1 (A) and JAJ-3 (B). The ore fragments are extremely rare today thus it is hard to evaluate the quality of ore available in the Iron Age. The lack of 'leftover' ore at this area (in contrast to most of other mines in Faynan) and some very limited finds (such as the fragment in A above) suggest exceptionally high quality ore in this region, probably in the form of small nodules mined by hand from the culluvial deposits (similar to the fragment A above) (see text).

The large plate-like depressions marking the location of the ancient pit mine have served as traps for bright wind-blown loess sediment that today enhance the visibility of the pits in contrast to the black dolomite rocks in the surrounding area (Fig.5.125). Some depressions are used today by the local Bedouins for limited horticulture (tobacco?, Fig.5.127) by taking advantage of the natural trap for runoff water and the accumulation of fine soil (roughly dug channels are constructed to divert the water from the slopes in the few rainy days during the winter).



Fig.5.127: A small ‘garden’ taking advantage of the natural trap of running water created by the mine scars at the region of JAJ-1. A few of the depressions of the pit mines are used by the local Bedouin for growing plants, probably tobacco.

After we recorded the mines in 2007 we have suggested, tentatively, dating them to the early Iron Age, based on their proximity to the well-dated copper smelting sites of KEN and KAJ (Fig.5.1) of the same period. In addition, the lack of significant copper related sites from other periods in the close vicinity of the JAJ mine fields (Hauptmann, 2007) and the “Iron Age landscape” identified by Levy et al. in this region (Levy et al., 2003) added further weight to this interpretation. In 2009 we conducted excavations in one of the pits; OSL dating strongly supports the ascribed Iron Age date (see sections 5.2.9.3 and 5.2.9.4 below). These mines constitute one of

the largest mining fields of the ancient Levant, and most probably represent one of the most important Iron Age mining fields in the Faynan region.

The discovery of the JAJ mines provides an explanation for what has been until now a noticeable discrepancy in the archaeometallurgical evidence from Faynan and Timna: while Faynan has much more evidence of Iron Age smelting activities, Timna had, until now, many more recorded mines. The difficulty of interpreting the contrasting archaeological evidence is well indicated in Hauptmann (2006:128):

> At Faynan the situation is different [from Timna]. Neither a comparable number of filled shafts nor a large number of tailings seems to indicate extensive underground mining. But this does not mean that the extent of copper exploitation was less than at Timna. The contrary is the case. The amount of slag produced at Faynan suggests metal production on the scale of several thousand tons over the millennia […] At Timna, the slag heaps indicate considerably less than this amount. There are two main reasons for the less visible evidence of ancient mining at Faynan. The first is the exploitation of ores at a greater depth, which led to more extensive underground mining activities. The second is that that exploited parts of the mineralization were backfilled so that not much of the waste was unloaded on the surface.

Hauptmann attempts to explain the discrepancy by suggesting a deeper and more elaborate mine shafts and galleries in Fayan; the lack of consequent enormous tailings is explained by re-filling of galleries and shafts after a mine was exhausted. The new mines provide the 'missing link' as they probably were the most important copper ore source in Iron Age Faynan.

The ancient pit mine operations have dramatically changed the local landscape in this part of the Faynan district (Fig.5.125). Unlike the numerous Iron Age shaft and tunnel mines found by the GMM team (Weisgerber, 2003; Hauptmann, 2007) and the UCSD projects (Levy et al., 2003; Knabb et al., in press) in the region, the new pit

mines are remarkably different. The pits were excavated into the colluvial slopes of the valleys in order to extract copper nodules eroded from the Cambrian ore-bearing Burj-Dolomite formation that accumulated in the gravels (Fig.5.126). The open pits were refilled with the gangue of the adjacent active mines to maximize the exploitation of the exposed copper-rich colluvium - a well delineated and easily accessible source of naturally broken copper ore. A nearby post-Precambrian magmatic plug and associated north-south dike of more than 1.5 km in length (Figs.5.125, 5.128, 5.129), the only Phanerozoic magmatism known in the Faynan region to date, may imply that the richness of the copper mineralization in this specific locale was influenced by this magmatic feature. The geological history of the secondary copper mineralization of the Arabah is directly related to magmatism at least in its later phase (Ilani et al., 1987), and the dike exposed near JAJ is probably part of this phenomenon (see section 2.2.1 above)[57]. Rock samples from the dike are currently being measured for Ar/Ar dating in the laboratory of Oregon State University (preliminary results indicate a relatively yourng age, ca. 7m.a.). According to the regional geological history, the age of the dike is probably either Lower Cretaceous or Miocene and younger, and the results will help to correlate between field evidence in Faynan and Timna and to further understand processes related to ore formation and/or the Rifting.

[57] The volcanic plug and dike recorded by our team in the area of JAJ provide significant information related to the geological history of the region. It is probably dated to one of two documented magmatic events, of the Lower Cretaceous (regional magmatic activity) or the Cenozoic (relating to the development of the rift system); it may also provide data for better understanding the copper mineralization process, the connection between Faynan and Timna deposits and the movements along the Dead Sea Transform.



Fig.5.128: The location of the ca. 1.5 km dike in the vicinity of the JAJ copper mines (on a Google Earth image). The dike is indicated by the white line; JAJ-1 is delineated near the southern end of the dike and JAJ-3 near its northern end; also indicted as pins are KEN (note the close proximity to JAJ-1) and KAJ, and in black the site of FBRS 37 located on a narrow ridge above the JAJ-1 valley.



Fig.5.129: A Phanerozoic dike located in the area of JAJ mines (cf. Fig.5.128). In this location the usually narrow (in places less than 0.5m in width) and single segment dike has a multisegment appearance and a 'jump' in trend.

Contemporary small-scale mining activities in the Bisie region of Congo, recently reported on in the New York Times (Polgreen, 2008), provide an important model for how pit mines may have functioned in Iron Age Jordan. Extraction of Congo tin ore was achieved from pits dug into gravel deposits. As seen in Fig.5.130, the disturbed terrace surface in the Congo show similar features to the 3,000 years old mine fields in both Faynan and Timna. The modern open pit mining in Congo is not limited to tin; in a recent visit to the country, the geologist Ram Ben-David recorded pit mines of copper in the country, resulting in a similar impact on the landscape as the one observed in JAJ region (Figs.5.131 and 5.132).



Fig.5.130: Pit mine in the Congo. Renegades are exploiting tin ore fragments from the gravel by digging large pits similar in shape (though larger) to the 3,000 years old pits recently discovered in Faynan, Jordan (Photo courtesy of Johan Spanner).



Fig.5.131: Copper pit mines in Congo (photo courtesy of Ram Ben-David). The disturbed landscape has similar characteristics to the pit mines in Faynan.



Fig.5.132: Copper pit mines in Congo (photo courtesy of Ram Ben-David). Note the great efforts done by sieving to exploit every ore fragment available. Same efforts were probably done in the JAJ mines, resulting in entirely depleting the area from ore.

5.2.9.2 FBRS Site 37

Site 37, recorded by FBRS, is located on a narrow ridge overlooking the pit mine valley of JAJ-1 (UTM reference: 733392/3398407, 150 m above sea level, Fig.5.128). It is a structure complex (Fig.5.133), extending over approximately 6,000 m^2 build of the local dolomite stones of the Burj formation. The complex consists of four separate units (‘features’ in the field report) (Fig.5.134). 'Feature 1' is the largest concentration of structures, made up of over 10 different rooms. Walls are made of a double line of stones and preserved up to 5-6 courses high in some places. 'Feature 2' is the second largest and is made up of about 5 rooms. 'Feature 3' is a single rectilinear/circular structure with a small chamber on its west side. 'Feature 4' is a rectilinear structure. A few body sherds were collected, none were identifiable.

The location of the site just above the vast mines of JAJ suggests that it is related to them, functioning as some sort of supervision facility. Except from three large shallow encampments (Fig.5.125), one of which is probably remains of a Bedouin camp, and some tumuli/grave-like features on the upper slopes of the mine valley (Fig.5.135) the entire area of the mines has no other substantial architectural remains (including the small valleys of JAJ-2 and JAJ-3).



Fig.5.133: The structure complex of Site FBRS 37 on the ridge overlooking the valley of JAJ-1.

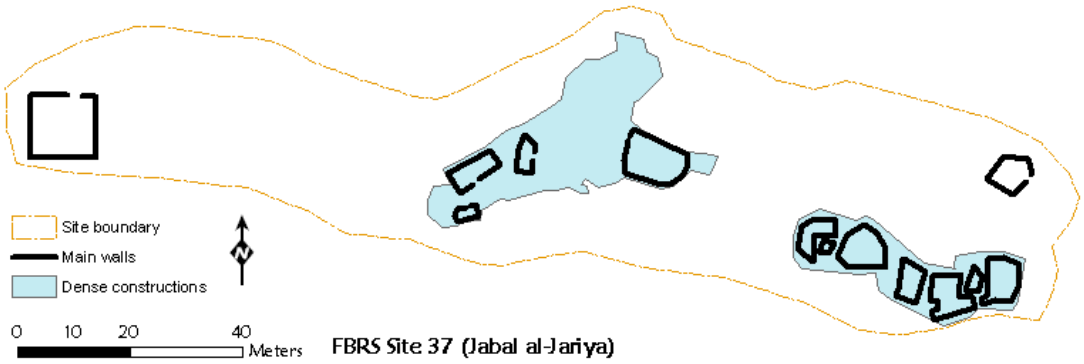


Fig.5.134: The structure complex of Site FBRS 37; five separate 'features' are visible (see text).



Fig.5.135: One of several tumuli located on the upper slopes of the JAJ-1 mine valley (not dated, may represent graves contemporaneous to the mining activity).

5.2.9.3 The 2009 excavations at JAJ-1 and sampling for OSL dating

As part of the ELRAP 2009 field season we conducted a probe in one of the pits of Jabal al-Jariya 1 mine field[58]. The goals of the probe were to find evidence of the mining activities and technology, to determine the shape and dimension of the original pit, and to expose deposits for Optically Stimulated Luminescence (OSL) dating.

We have used the same methodology and recording procedures of the main ELRAP project, using a *Total Station* and a GIS-based database. There were almost no finds, and most of the samples (soil samples, OSL samples, etc.) were taken directly from the walls of the excavation pit and are indicated on the main section drawing. The excavation took five days in early November, and the OSL sampling took place on the 24th of November.

A well defined and relatively small depression (or 'plate-like' feature) was chosen for the excavations, as we wanted to make sure we are able to reach the original surface of the pit and to expose its entire middle section during the timeframe available to us (Fig.5.136). The area around the excavated pit was mapped by us during the excavation; it represents various sizes of pits and the small mounds of mines material ('bumps') between them. The flat part of the depression was an ellipse

[58] The excavations were supervised by the present author. Participating in the excavations: Kathleen Bennallack (assistant supervisor), Conor Buitenhuys, Shannon Groves, Yusuf 'Azazmeh, and Mohammad 'Azazmeh.

measuring ca. 3.3m x 5m). We extended the excavation area itself outside of the flat ellipse by approximately 1m on either side, in order to expose the margins of the pit and define its boundaries. The section measures 5.51m across, and 1.6m deep in the center (Fig.5.137).



Fig.5.136: The 'plate-like' feature, representing mining pit, before excavation. Note the small stone feature to the right.

Using the ELRAP digital archaeology system (based on Total Station measurements) we mapped the sampled mining pit and the surrounding depressions to contextualize the excavation probe. In addition to the exact dimensions of the excavated feature, the excavation limits and the surrounding pits, the map demonstrates the density of the mining depressions. There is no undisturbed space

between them, the mounds separating one from the other are the result of the sorted material dumped during the mining. The sampled pit and its vicinity can be seen using Google Earth images that can help to further contextualize the excavation probe. Near the excavated pits, two small stone features were recorded. These seem to be some ephemeral installations, but may represent some activity connected to the last phase of mining in this area (Fig.5.138).

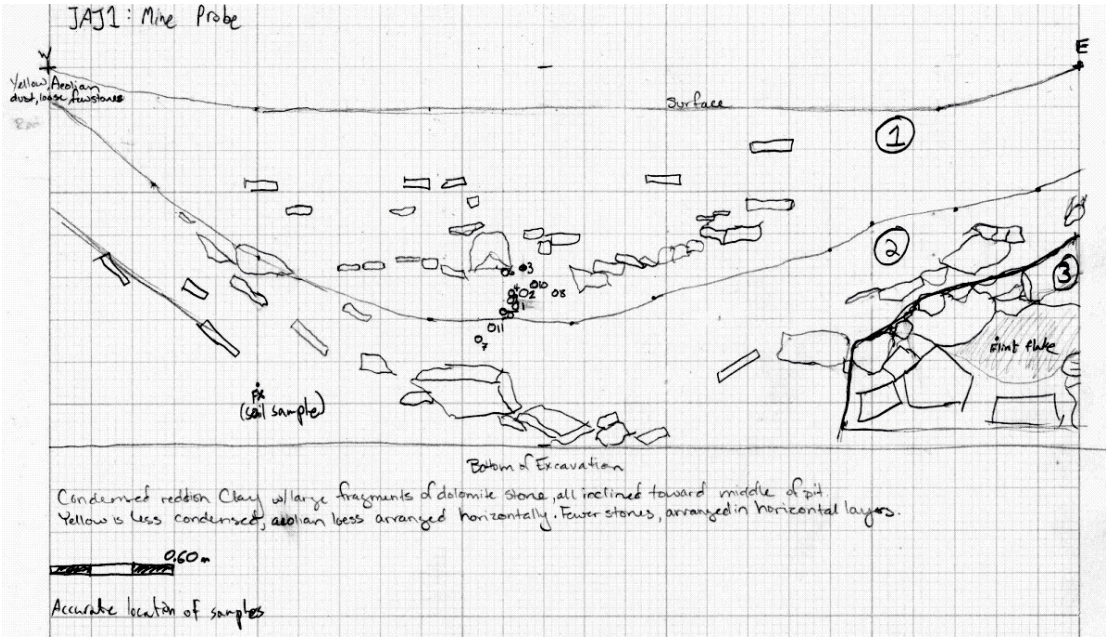


Fig.5.137: Drawing of the central section of the pit mine excavated in 2009. Three main units have been distinguished (marked as 1, 2, and 3, see text for details). Note the location of the OSL samples in the middle and the flint find in unit 3. FX represents the location of a soil sample taken for further studies.



Fig.5.138: Stone features on the edge of the excavated pit.

The bowl of the mine itself was filled in with relatively loose, horizontally deposited yellowish aeolian dust and some small stones (also lying horizontally), while the surrounding original margins of the pit consisted of condensed reddish clay with large fragments of dolomite stone, all inclined toward the center of the pit (Fig.5.137). We did not uncover any clearly anthropogenic finds inside the mine pit itself or on the surface, except of one fragment of flint (see below). Some small fragments of copper ores were found. These ores are in the shape of nodules and (usually) not attached to gangue (in most Iron Age mines in Faynan the ore is embedded in the blackish dolomite or shale stones and requires further processing).

The nodules seem to be composed entirely of copper minerals of bright blue color, with high concentration of copper in them. This is a very important observation: the reason for the extensive mines in this location was most probably this type of ore, which seems to be especially rich in copper and without the need to dress it (separate it from the host rock). This observation may explain the lack of digging/cutting tools of any sort on the surface or in the excavated area: the ore was already in the form of small, easily transported nodules.

In an 'air pocket', an area of loose sediments with relatively large rock fragments marked in the section as #3 (Fig.5.137) we found what appeared to be a flint flake. Flint cannot be explained by the local geology as naturally occurring in the colluvium, and it has to be anthropogenic. Its location indicates that the margins of the pit were also the result of human mining activities; it probably consists of the dump of a nearby pit after the ore was sorted out.

It was impossible to precisely separate unit 1 and 2 during excavation, and they should be regarded as part of the same locus. However, careful study of the section (Fig.5.137) reveals a significant and clear difference between these units; there were some areas of intermixing, but overall we could see a contact line between the yellow layer and the reddish one. Unit 3 was also easily recognized in the section as a distinct area with large loose rocks in one side of the pit margins (Fig.5.137).

The excavation revealed three distinct units of sediments (Figs.5.137, 5.139-5.140). The upper most (unit 1 in the section) is the yellowish dust with horizontally aligned small stones; the next unit, which we believe constituted the exposed surface inside the pit after it was abandoned, is reddish clay with larger fragments of stones with inclinations towards the center of the pit. This unit is the result of sediments transferring as part of the mining activity. The third unit is also part of the original margins of the pit and is exposed only in one side of the pit. It is composed of large rocks, held by loose soil with some 'holes' in between them.



Fig.5.139: Excavating one of the 'plate-like' features of JAJ-1.



Fig.5.140: The excavated pit at the end of the excavations; there units of sediments are visible (cf. Fig.5.137).

Once we had determined that we had excavated below the bottom of the original surface of the pit (i.e. all of the sediments had turned red) we sampled the sediments above and below the Unit 1 – Unit 2 boundary for OSL dating. The dating project was done with Naomi Porat of the Geological Survey of Israel (GSI) who provided instructions also for the sampling process. It is worth noting here that we probably did not penetrate 'virgin soil' – colluvial sediments that were not interrupted by human activity, as indicated by the flint flake and the similar characteristics of the clearly artificial pit margins and the bottom of the excavation (however, it was not clear if we can find any clear boundary or indication of this elusive 'virgin soil' and the pit was deep enough for characterization of the different sediments and for

sampling it for OSL – as we were interested in the deserted surface and the accumulated aeolian dust just above it, for dating the last activity phase in the mines). In order to avoid contamination, the samples for OSL cannot be exposed directly to sunlight, so we worked before the sun directly hit the section and used foil-covered PVC pipe to contain them (ca. 30cm in length, and 5cm in diameter). We chose eleven points from the lower levels of the pit (Unit 2) and the upper levels (Unit 1) of what we believed has naturally accumulated since the desertion of the mines. At each point we used a hammer to insert a sharpened PVC pipe plugged at the outside end with aluminum foil (Fig.5.141). Once all 11 samples were inserted, we removed them, keeping both ends covered and making a map of where each came from (Figs.5.142 and 5.143). In addition, we took four soil samples from the region surrounding the OSL samples. All this was done before direct sun hit the section (on the morning of the 23rd of November).



Fig.5.141: Sampling the section of the pit for OSL dating.

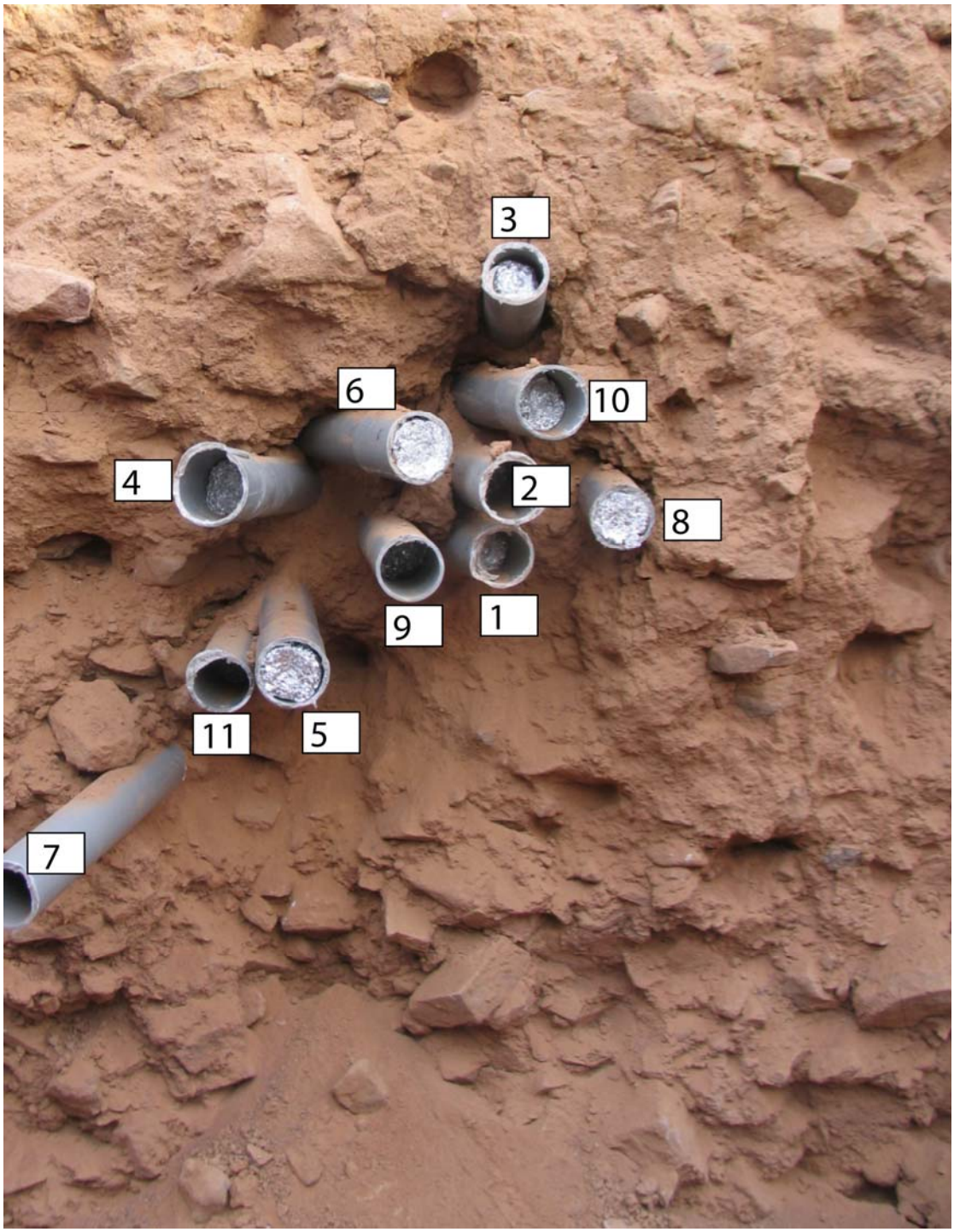


Fig.5.142: The location of the 11 OSL samples in the section (cf. Fig.5.137).

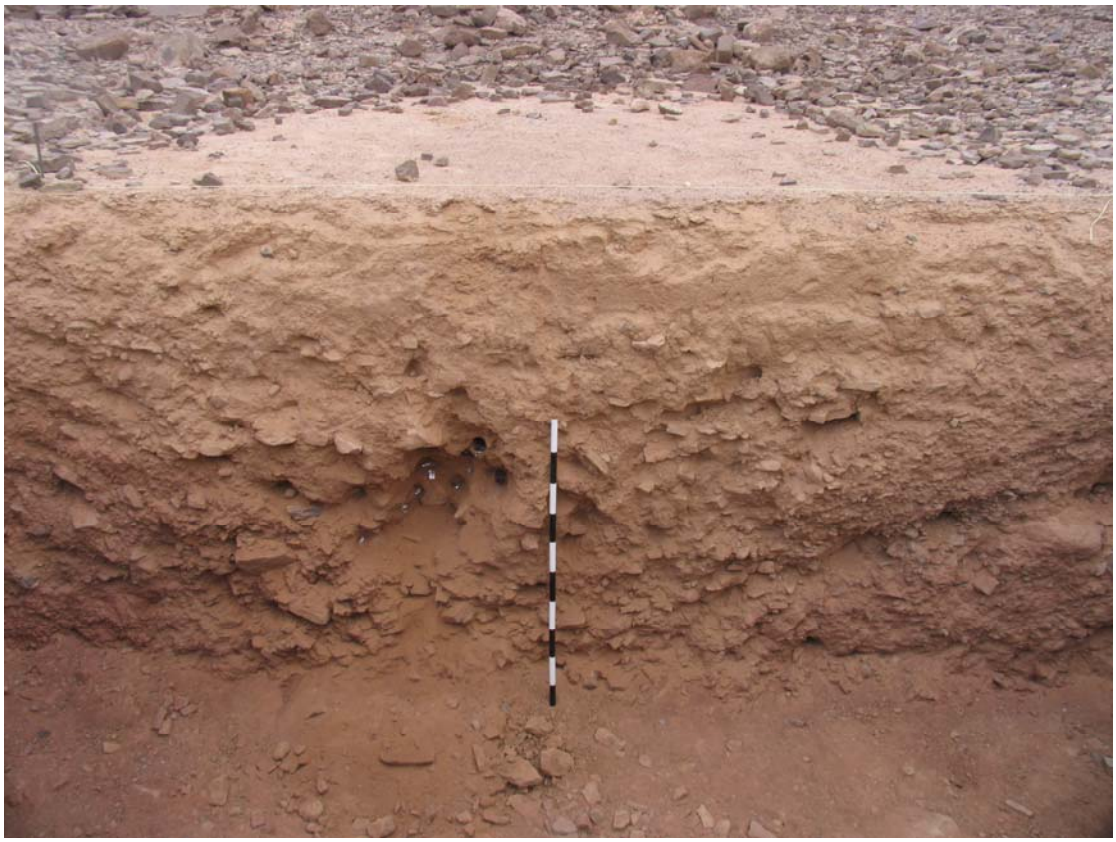


Fig.5.143: The section of the pit after sampling.

The excavation probe in one of the pits of JAJ-1 mine field has yielded the following observations:

1. The entire landscape of the valley is the result of human activity: the pits themselves as well as their margins.
2. The original bottom of the pits, as deserted after the mining activity, was approximately 1 m below the surfaces visible today. The pits were filled with aeolian dust and some alluvial deposits (stone fragments, silt) since they were deserted.

3. The miners were probably sorting out ore nodules of the kind collected by us: extremely rich small and easy to pick fragments copper minerals. These did not need any further dressing, and were collected without the need of any special tools. It is very hard to estimate the original richness of the mine field and the quality of the original ore, as probably the bulk of the ore was collected in antiquity and the finds are only the residues (a common problem in ancient mining sites). As noted above, it seems that we did not excavate any 'virgin' or original colluvial area that may indicate the original ore content – the whole sediments, including those exposed at the bottom of the pit, seemed to be the result of human activity.
4. The flint flake close to the bottom of the pit (see section) is a strong indication that even the pit margins and the heaps in between the pits are the result of human activity.
5. Further investigation of the ore fragments collected in the survey and the excavation is needed for precise identification of the minerals ant their quantitative quality. Moreover, these minerals visually seem to be richer in copper than the common minerals exposed today in other mine locations in Faynan; a better characterization of this difference may help to identify the destination of the JAJ ore, tentatively assumed to be KEN (and maybe KAJ, see below).

5.2.9.4 Results of OSL dating from JAJ-1, 2009 excavations

Five of the 11 OSL samples from the excavated pit of JAJ-1 were processed in the Luminescence Dating Laboratory at the Geological Survey of Israel by Naomi Porat[59], the director of the laboratory (Ben-Yosef et al., in prep.-a). The present author assisted in preparing two of the samples (#11 and #7) during the month of July 2010 in the laboratory in Jerusalem, with the guidance of Porat. The optically luminescence dating technique is detailed in section 4.2.3 above. The material yielded results with relatively high precision (Table 5.21). They are in excellent agreement with their stratigraphic location (Figs.5.137 and 5.142) and in general, they corroborate our tentative interpretation of the mining activities at the site.

The three middle samples, JAJ-6, JAJ-5 and JAJ-11, are basically of the same age, and average at about 2540±100 before 2010, i.e., 530±100 BCE. According to our interpretation, this age represents the first phase of sediment accumulation *after* the original pit was abandoned (mixed aeolian and alluvial deposits, see above, Unit 1). The upper most sample, JAJ-3 represents a later phase of natural deposition in the abandoned pit (2220±90 before 2010, 210±90 BCE).

The lowest sample, JAJ-7, came from Unit 2 (see above) and is more difficult to interpret. Given the low sample size (n=1), it is possible that this sample is an

[59] The author is grateful to Naomi for her help in this project.

outlier. Even if this age is *not* an outlier, there are still at least three possible interpretations. If our field observations are correct, the date represents the actual time of the mining activities. Based on the stratigraphy and finds we interpreted the sediments of Unit 2 as representing a dump of gangue material after the ore nodules were sorted out to be transported to the smelting sites; it seems that we did not penetrate an undisturbed 'virgin soil', thus we assumed that the original depth of the pit before it has been deliberately refilled could not be determined. However, the date of sample JAJ-7, coming from this context (3890±150 before 2010, 1880±150) suggests a Middle Bronze Age mining activities, which does not have any corresponding smelting evidence in the entire Faynan district, unless considering the upper margins of this age and correlating these mines to the Early Bronze Age IV large scale smelting evident in several sites in Faynan, including the large smelting site of Khirbat Hamra Ifdan (Levy et al., 2002a) (although also here, the closest EBIV smelting site is located far from the vicinity of the mines, 3 km to the south or more). Two other interpretations should be considered until further data is available. One is that the date of JAJ-7 represents the age of the final stage of the colluvial deposits formation, thus, with mining activities that did not expose the sediments to enough light, the date of the mines should be between JAJ-7 and JAJ-6,5 and 11, possibly the early Iron Age. Another interpretation is that we did not expose the original abandoned surface of the pit, and that the mining activities were earlier than JAJ-7, probably Early Bronze or even Chalcolithic. These all are speculations, and as mentioned above, we cannot base any conclusions based on one date only.

In the current stage of our OSL-based investigation of the pit mines the bulk of the data suggest early Iron Age mining activities. Nevertheless, this date is only tentative, and further research (more dates from the lower units of the excavated pits and more excavations in other pits) is required.

While the attempt to pinpoint the exact date of the JAJ pit mines is important, additional merit of the present research is the demonstration of the applicability of the OSL dating method to such mines. As far as we can tell, this is the first time OSL dating technique has been applied to date pit mines world-wide. Our results show the great potential of this method and encourage its application to additional pit mines not only in the southern Levant, but to other similar ancient mines around the world. Given the chronological challenges that still exist in the research of Timna (Chapter 4), new excavations and OSL dating of the pit mines *and* the blocked shafts will be an important contribution to our understanding of the Iron Age copper exploitation history in this area. We believe that many of the so-called 'Late Bronze Age' blocked shafts in the Timna Valley are in fact Iron Age (I-II) mines. Although the precision of the OSL technique may not allow dating in high enough resolution for distinguishing between two consecutive periods, it is worth trying as also in the Timna mines the material culture remains are scant. Moreover, the few pit mine fields in the valley, dated to very early periods (see above), may also represent a later activity, as mining

technologies are not a good chronological markers (they might be used only as a *terminus post quam*).

Table 5.21 (next page): Luminescence dating results from the 2009 excavations of the mine pit at Jabal al-Jariya 1 (measured and analyzed by Naomi Porat at the Geological Survey of Israel, 2010)

Lab No.	Depth (m)	K (%)	U (ppm)	Th (ppm)	Ext. α (μGy/a)	Ext. β (μGy/a)	Ext. γ (μGy/a)	Cosmic (μGy/a)	Total dose (μGy/a)	Aliquots used	Over-dispersion	De (Gy)	Age (years)
JAJ-3	0.8	1.33	2.1	5.5	10	1320	804	190	2324±35	21/22	16	5.2±0.2	**2220±90**
JAJ-6	0.9	1.33	1.6	4.3	8	1226	693	187	2114±34	16/19	12	5.3±0.2	**2510±90**
JAJ-5	0.95	1.33	1.9	5.3	9	1289	773	186	2257±35	20/22	10	5.7±0.2	**2550±80**
JAJ-11	1.0	1.33	1.7	4.2	8	1241	699	185	2133±89	22/24	15	5.5±0.2	**2560±130**
JAJ-7	1.1	1.00	1.3	3.2	6	937	530	183	1656±32	15/18	17	6.4±0.2	**3890±150**

Notes:
Grain size: 88-125 μm (samples 3,5, 6) or 74-125μm (samples 7,11). Dose rates were calculated from the radioelements and the cosmic dose estimated from burial depth. Water contents estimated at 2±1%. 'Aliquots used' is the number of aliquots used for calculating the average De from those measured. Over-dispersion is an indication of the scatter in the sample. Ages are in years before 2010. The central age model (Galbraith et al., 1999) was used to obtain the most representative De values and errors.

5.3 Discussion – new data and perspectives on copper production and Iron Age archaeological sites in Faynan

The Faynan district provides an extraordinary and well-preserved archaeological evidence for the history of copper exploitation technology and the organization of production *throughout* the Iron Age (ca. 1200 – 500 BCE). The evidence is based both on the spatial distribution of various types of sites, recorded in intensive surveys, and on technology-related materials from stratified contexts, exposed in large scale excavations and several probes. Many of the surveyed and excavated sites have been recently dated with high resolution radiocarbon measurements as part of the UCSD ELRAP research, providing a robust chronological framework to model the technological and social developments in the region that are presented here.

The Iron Age sites in Faynan spread over an extensive area, from Barqa al-Hetiye in the south and the mines of Wadi al-Jariya in the north, the cemetery of WF40 in the west and the mines of Wadi Dana in the east. The mining and smelting sites are concentrated in two main clusters, basically dictated by the spatial exposure of the main copper ore-bearing formation (DLS). One main cluster is located at and around Khirbat Faynan, with smelting sites at the Khirbah (ancient site) itself and its vicinity, and mining sites at the nearby wadis (Dana, Khalid and Abiad). These mines are typical to the Iron Age, usually comprising of double shaft dug into the MBS unit

and galleries in the DLS unit. The second cluster is along Wadi al-Ghuweiba and its tributaries. It includes three extensive smelting sites (KEN, KAJ and KAG) and several mining areas (near KEN, at upper Wadi al-Jariya and at Ras al-Miyah) that also often present typical Iron Age mining technology. Additional nearby and extensive mining area is the recently discovered Jabal al-Jariya pit mine fields. These have been tentatively dated to the Iron Age, based on their proximity to Iron Age smelting sites and preliminary OSL results. If indeed these are Iron Age mines, they represent exploitation of a different ore source (a *placer*) and thus a different mining technology. Additional, minor Iron Age smelting sites were recorded along Wadi Fidan. The ore for smelting in these sites was probably dug at the nearby mines of Um adh-Dhouhur. Some of the Iron Age smelting sites of Wadi Fidan and probably also those reported for Barqa al-Hetiye present a simple technology, different and much less advanced than the one practiced in the main smelting centers of Faynan. This marginal phenomenon has been observed also in the southern Arabah, and probably indicates social stratification and/or boundaries (see section 6.2.3.3 below).

In general, the Iron Age smelting sites in Faynan are located in a short distance from the mines (usually right near the mines and in some cases up to 3 km away), indicating an effort to reduce transportation costs. The other important factor in choosing a location for a large scale smelting operations was probably the availability of water and associated plants. Availability of water was crucial for any activity in the climate of Faynan, even if it took place on a seasonal basis (i.e., only during the

winter). In addition, the fuel for Iron Age smelting was based mostly on hydrophilic plants that grow in oases. This factor explains the location of Khirbat Faynan (near to the springs of Wadi Ghuweir), Khirbat al-Ghuweiba (around the oasis of 'Ain al-Ghuweiba), and probably also Khirbat en-Nahas (section 2.3.1) and Barqa al-Hetiye where current vegetation indicates a high water table.

In addition to sites directly related to mining and smelting activities, Iron Age Faynan includes three fortresses (Khirbat en-Nahas, Ras al-Miyah East and West, a 'watch tower' (Rujm Hamra Ifdan), an extensive cemetery (WF40) and a large 4-room building that may represent (part of) a road station or caravansari (Barqa al-Hetiye). Numerous small Iron Age sites have been recorded in several surveys, and include possible evidence of agricultural activity near Khirbat Faynan, small cemeteries, and a large number of *campsites* along the wadis (mostly wadi Jariya, Ghuweiba and Fidan).

The recently established chronological timeframe for Iron Age Faynan reveals several major patterns: (1) there is (limited) evidence of copper production already in the Late Bronze Age (KEN, Khirbat Faynan, Wadi Dana 1, Wadi Dana 13); (2) Many copper production sites have been abandoned in the late 10th century BCE (KAJ, KAG and associated mines; probably additional sites that are not yet radiocarbon dated); (3) All of the copper production sites have been abandoned in the late 9th century (ca. 800 BCE, or some years before), with a possible exception in Khirbat Faynan (indicated by limited radiocarbon dates, Table 6.2); (4) a serious attempt to rekindle copper

production in Faynan during the 7th – 6th centuries BCE is evident in the mines of Ras al-Miyah Archaeological Complex (see also Weisgerber, 2006:15, and detailed discussion above). This attempt was probably not successful as up to date no smelting counterpart has been found anywhere in Faynan. There is also clear evidence of interruption and abrupt stop in the construction process of the fortress of Ras al-Miyah East.

The new high resolution dates from stratified contexts also enable, for the first time in the southern Levant, to estimate rates of accumulation of metallurgical debris in 'typical slag mounds'. Although the stratigraphy of metallurgical deposits is rather complex, a superimposed high resolution stratigraphic sequences have been exposed as part of the current research in 'slag mounds' at Khirbat en-Nahas (Area M) and Khirbat al-Jariya (Area A, and cf. Area S in Timna 30, section 6.2.1 below)[60]. The results confirm that the only way to estimate deposition rate in 'slag mounds' has to be based on absolute dating methods. The dates indicate high variability in deposition rates, from about 2 meters in 100 years (KEN Area M, 10th century BCE) to about 1.5 meters in 300 years (Timna 30 Area S). Notwithstanding the rigorous datasets we have obtained from contexts of metallurgical deposits, extrapolation of the data for

[60] Our ELRAP stratigraphic observations in metallurgical deposits, including clear evidence of superposition, have been challenged (or more accurately, dismissed) by Finkelstein et al. (e.g., Finkelstein and Piasetzky, 2008; Finkelstein and Singer-Avitz, 2009), with no real basis. Radiocarbon dates, archaeomagnetic data and material culture (technological) typologies all correlate well with field observations and strongly confirm (fine) superposition in 'slag mounds' (e.g., Higham et al., 2005; Levy et al., 2005a; Levy et al., 2005c; Ben-Yosef et al., 2008a; Ben-Yosef et al., 2009c; Ben-Yosef et al., 2010a). Thus, layers exposed in excavations of 'slag mounds' can be interpreted as representing consecutive time intervals, with careful attention to difficulties stem from the three dimensional complexity of such deposits.

estimating *intensity of production* on a site (or a regional) level is not always valid. The spatial organization *within* a smelting site could have (and probably have) changed through time: areas designated as dumps of smelting debris are leveled-up to construct new buildings while architectural spaces went out of use and have been replaced by designated metallurgical dumps, areas of active smelting levels would demonstrate lower rates of material accumulation than dumps, and so on. Although estimates of *intensity of production* are important for social and historical reconstructions, there is a real challenge in getting accurate values, and each stratigraphic context should be interpreted cautiously and with respect to its specific attributes. There is definitely no place for simplistic data manipulations, such as the one recently published by Finkelstein and Piasetzky (2008) for Khirbat en-Nahas. Theses scholars simply used the frequencies of radiocarbon dates from the site per each 50 year time interval throughout the Iron Age (I and II) as a direct proxy for the intensity of production, completely ignoring stratigraphic and contextual considerations. Variations in *intensity of production* throughout the Iron Age are evident in the archaeological record, but the evidence is more qualitative than quantitative in the current stage of research. Even the decrease in number of smelting sites that took place sometimes in the late 10^{th} – early 9^{th} centuries BCE is not an indication for the decrease in *intensity,* if this is measured by the scale of exported products. A new and more advanced technology is associated with the new spatial organization of production (Chapters 7 and 8). This technology was more efficient; the decrease in number of sites may even stand for the increase in intensity of production,

resulting from more centralization, standardization and control over the smelting process. Certain measures like *intensity of specialization* (Chapter 1) are easier to estimate because they are technology-dependent and not directly linked to comprehensive assessment of the entire archaeological record. These issues are further dealt with in Chapter 9.

The slag amount in the entire Iron Age smelting sites in Faynan is estimated to be in the range of 100,000 – 130,000 tons (cf. 150,000 – 200,000 tons for all periods together, and a few thousands tons for all periods in Timna), indicating production of about 6,500 – 13,000 tons (Hauptmann, 2007:147). This numbers are based on field surface observations and rough estimation of slag represented in 'slag mounds' at the Iron Age smelting sites. We have shown above that a typical 'slag mound' consists of less than 40% of slag (in volume, see also section 7.2.10 below). Thus, it appears that the total slag weight for Faynan is on the upper end of the possible range, however, the copper estimates are on the lower range, given that the ore quality was probably more than 10% Cu, and that the smelting processes were rather efficient and exhaustive. As mentioned above, estimates of quantities of slag and copper products for different phases *within* the Iron Age cannot be directly derived from the materials excavated so far.

As we demonstrate in this research, there are temporal and technological parallels between Faynan and Timna, the other (smaller) copper ore district in the

Arabah, located ca. 100 km to the south. Thus, to complement the study of the Iron Age Faynan, in the next Chapter we investigate the published data regarding Timna and introduce results of new excavations in one of the major Iron Age smelting sites in this region.

6. Contemporary Iron Age copper production sites from the southern Arabah and Sinai

6.1 General Overview

The main smelting sites in the southern Arabah were considered by early scholars as the southern counterpart of the record in Faynan, representing the same 10th century BCE time frame and technologies (e.g., Glueck, 1935). Only later research "pushed" the Timna record earlier to the 14th – 12th centuries BCE and the Faynan record later to the 7th – 6th centuries BCE, and the two archaeometallurgical records became disconnected (Chapter 3 above). Our recent research, based on a large suite of radiocarbon dates, suggests that the copper production activities in Faynan and Timna are in fact continuous (Faynan representing the later activity), and mostly contemporaneous. Thus, for contextualizing Iron Age copper production in Faynan and for better understanding the societies responsible for this activity, it is necessary to discuss our current knowledge about the situation in the southern Arabah at the end of the second and the first half of the first millennia BCE.

The southern Arabah and in particular the Timna Valley were intensively investigated by the Arabah Expedition between 1959 and 1982 (Chapter 3). The results

of the Expedition's surveys were never published as a final report[61], thus many sites lack important information except for their assumed date (Rothenberg and Glass, 1992). However, the principal archaeometallurgical sites were published in different formats and a substantial amount of archaeometallurgical data are now available (e.g., Conrad and Rothenberg, 1980; Rothenberg, 1990e). This research of the Arabah Expedition introduced a major revision in the dating of the main smelting sites of the region, replacing the commonly accepted Iron Age II dates (e.g., Glueck, 1940c) with the Late Bronze Age – Iron Age I (14^{th} – first half of the 12^{th} centuries BCE) and concluding that they were operated under Egyptian control (in particular Shaw, 1998a; Shaw, 1998b, and section 3.2.2 above). Only Layer I of Site 30 in Timna was published as remains of Iron Age II smelting activities (Rothenberg, 1980a), suggesting that copper production at this Timna site was contemporaneous with the peak in production recorded in Faynan during the 10^{th} and 9^{th} centuries BCE . This, together with Timna as a possible immediate precedent to the record in Faynan, triggered our interest to re-investigate Site 30 and the copper production record in this region. The recent results of our excavations at Site 30 were surprising and suggested a new revision of the chronological framework for the southern Arabah, this time a shift towards the Iron Age II. In any case, our results demonstrated the fragility of the previous dating methods and accepted chronology, which are crucial for evaluating relatively rapid social processes in the transition periods of the Late Bronze Age – Iron

[61] The results of the surveys of the Arabah Expedition were supposed to be published in the third volume of "*Researches in the Araba 1959-1984*"; the current status of this publication is unclear. Some of the materials of the Arabah Expedition are now at the Israel Antiquity Authority (Y. Dagan, Pers. Comm. 2009).

Age I – Iron Age II, let alone for correlating the Faynan and Timna archaeological records. Because of the ambiguity of the LB/IA dates published thus far for the southern Arabah sites and the possibility that some of the sites do represent a precedent record to the one in Faynan, all the Late Bronze Age sites published by the Arabah Expedition, including Late Bronze Age sites from the Sinai Peninsula are discussed here (Table 6.1, Fig.5.1).

The complexity of the chronological framework for the sites in the southern Arabah becomes clear also when scrutinizing the radiocarbon dates published so far for sites in this region (Table 6.2, Ben-Yosef et al., 2010a). The dates, presented mostly as endnotes in the publications of the Arabah Expedition, indicate Iron Age II activities in various sites in addition to Late Bronze Age occupation in the region. Adding to the complexity are the results of recent archaeomagnetic dating of several sites previously considered to be much older because of their 'primitive' technology. The new archaeomagnetic studies, also part of the current research, surprisingly indicate that some of these sites belong to the end of the second millennium BCE (Ben-Yosef et al., 2008b; Ben-Yosef et al., 2010c). The dating challenge is even greater when attempting to determine the age of the mines themselves in the Timna region. The shafts, galleries and open pits have yielded very little (if any) material culture, let alone datable remains (e.g., Rothenberg, 2005, and see section 5.2.9 above). The mining technology, often used to determine the age of the mines, was probably similar throughout the end of the second millennium and the first millennium

BCE. There is growing evidence that at least some of the Timna mines previously published as Late Bronze Age (Egyptian New Kingdom) are in fact remains of Iron Age II copper exploitation efforts.

The main Late Bronze / Iron Age smelting sites are located in the inner part of the Timna Valley (Fig.6.1), in the vicinity of the mines but not immediately near them. An Iron Age fortress (at Yotvata) and some smaller smelting sites are located in the western margins of the Arabah Valley, to the northeast of Timna and near the only spring in the region (‘Ain Ghadian). One site with a considerable amount of tap slag was reported to be located on the eastern side of the Arabah, just opposite to the northern part of the Timna Valley and in the vicinity of the Jordanian village of Rahmeh (Holzer, A. and Avni, Y. pers. comm. 2010). The tap slag suggests the possibility that the site dates to the Late Bronze / Iron Age (although a later date is also possible). The location of the site far from the Timna mines is unique; together with a small copper mine in the magmatic basement rocks reported by Haviv (2000:219) in Wadi Khubat near the Jordanian village of Rahma, the other side of the southern Arabah presents intriguing evidence awaiting further research.

The reasons to include archaeometallurgical sites from the Sinai Peninsula in this overview are the chronological uncertainties mentioned above that are possibly applicable to some of these sites, the direct connection to Egypt attested by the Arabah Expedition to the copper production enterprise in the southern Arabah during the final

stage of the Late Bronze Age, and the possibility of Egyptian influence on the development of copper metallurgy in the region at the end of the second millennium BCE. The ore deposits of southern Sinai were probably mostly a source of gemstones for Egypt, with quarries for malachite and turquoise at Bir Nasib (29°02'N, 33°24'E), Wadi Maghara (28°54'N, 33°22'E), Serabit el-Khadim (20°02'N, 33°28'E) and Wadi Ba'ba/Wadi Kharig (29°02'N, 33°25'E) (Aston et al., 2000:15, 43-44, 62-63). The interpretation of the mines in Sinai is problematic because many of the Egyptian inscriptions are not clear about whether turquoise, malachite (as a resource in itself, a gemstone or a dying material) or copper were primarily being sought by the Egyptian expeditions; even when the object of the expedition is clearly stated as the procurement of *mfk3t* ['mafkat'], the common interpretation of this term as turquoise (and not malachite) is still a matter of some debate (e.g., Levene, 1998). Turquoise (hydrated phosphate of copper and aluminum, $CuAl_6[PO_4]_4[OH]_8 \cdot 4H_2O$) was used by the Egyptians primarily for jewelry from the Predynastic to the Greco-Roman period (Aston et al., 2000:60), although Ogden (2000:150) claims it was used mostly for glazes in powdered form. The mines at Wadi Maghara were dated to the Old and Middle Kingdoms only (Petrie, 1906; Chartier-Raymond, 1988), while the mines at Serabit el-Khadim (Barrois, 1932; Starr and Butin, 1936; Giveon, 1978; Bonnet et al., 1994; Chartier-Raymond et al., 1994; Castel et al., 2008) from the Middle Kingdom until at least the Late Period of Egypt (and see Beit-Arieh, 1980 for possible Chalcolithic mining evidence there). At Serabit el-Khadim there is a temple complex dating to the Middle and New Kingdoms (ca. 2040 – 1070 BCE) and dedicated to

Hathor in her aspect of *nbt mfk3t* ('Lady of Turquoise') and the god Soped, 'guardian of the desert ways.' Some remains of smelting activities were found during the Israeli investigations of Serabit el-Khadim between 1967 and 1982 (e.g., Giveon, 1972; Beit-Arieh, 1985) raised again questions about the primary goal of the Egyptians in Sinai, with the possibility that it was primarily the exploitation of copper with turquoise as a desired byproduct (e.g., Rothenberg, 1987; Levene, 1998). Aston et al. (2000:62) note that surviving examples of turquoise as gemstone form "a quite minor component in Egyptian jewelry, compared with the vast quantities implied by the numerous adits, shafts and stelae at Wadi Maghara and Serabit el-Khadim." (but compare with Ogdon's suggestion of turquoise as a glazing supplement mentioned above). The largest copper production site in southern Sinai is Bir Nasib near the mines of Umm Bugma (Site 350) (Rothenberg, 1970; Rothenberg et al., 1979; Rothenberg, 1987; Castel et al., 2008). The site consists of a huge heap of some 100,000 tons of slag (Petrie, 1906:27; confirmed in Rothenberg, 1987) near the desert oasis and in close proximity of extensive copper mines (at Jabal Umm Rina and Jabal Umm Bugma; the former has evidence of slag heaps). The slag represents the production of about 5,000 tons of copper and is manganese-rich, probably indicating deliberate (?) fluxing with manganese ores (Bachmann, 1980; Rothenberg, 1990a:52-54). The dating of this site and some others reported by Rothenberg (e.g., 1987) are problematic, with some similar difficulties present in his research of the Arabah[62]. The copper mines in this region are dated from the Chalcolithic to the Nabataean period "and perhaps also

[62] The final report of 15 field seasons of "the Arabah Expedition's Sinai survey 1967-1978" was never published, although the original publication year was supposed to be 1988.

later" (Rothenberg, 1987:4). The slag heap was dated first by pottery sherds and an Egyptian stela (and three proto-Sinaitic inscriptions, Site 351) in the nearby mines to the 18th – 15th Dynasties and Nabataean – Byzantine periods (Rothenberg, 1970:17-18). Only in 1978, after excavating several trenches in different parts of the slag heaps was the slag deposit dated to the New Kingdom by a scarab, a glass bead and new kingdom potter sherds (Nile ware and locally manufactured pottery with Egyptian shapes, never published). There were no indicative finds for dating the lower layers, however, they were tentatively dated to the Middle Kingdom by the stela and inscriptions located in the nearby mines (Rothenberg, 1987:7). If intensive copper production did occur at the site in the Middle Bronze Age (Egyptian Middle Kingdom), the remains are an important link for understanding the development of 2nd – 1st millennium BCE metallurgy in the southern Levant; the regions of Faynan and Timna lack almost any evidence of Middle Bronze Age copper exploitation[63].

The following summary tables (Table 6.1 and 6.2) present Late Bronze and Iron Age copper production sites in the southern Arabah and the Sinai Peninsula. In addition to evidence of mining and smelting, major sites that are probably directly related to the copper production enterprise are also included, such as Iron Age fortresses, campsites and road stations in the vicinity of the mining area. The descriptions of the sites focus on stratigraphy, chronology, function and main architectural features in the context of their previous research (survey vs. excavation,

[63] There is only one copper production site dated so far to the Middle Bronze Age in the entire Arabah Valley ('Beer Ora Hill', see Avner, 2002).

etc.). A comprehensive bibliographic reference list is provided and should be consulted for further details. The radiocarbon dates published thus far for the Late Bronze Age and Iron Age sites in Timna and its vicinity are compiled in Table 6.2. These dates are based on early publications and in many cases the context is insecure, thus they should be considered with caution and as an additional aspect of the chronological problems of the sites from the LB/IA in the southern Arabah. The relative dating of sites investigated only by survey (indicated in Table 6.1) should be regarded even more as tentative, because of the inherent dating difficulties of surveys in general (e.g., Banning, 2002). The main site excavated as part of the current research is dated with a large set of high precision radiocarbon dates presented below; the scarce new ceramic are finds also published here. We re-dated some sites by archaeomagnetic techniques and investigated two samples labeled 'slag' from Glueck's collection of Tall el-Kheleifeh housed at the Semitic Museum at Harvard University[64]. Our findings are discussed below.

[64] Special thanks to Drs. Joseph Green and Adam Aja of the Semitic Museum, Harvard University, for providing access to the ASOR Nelson Glueck Archive.

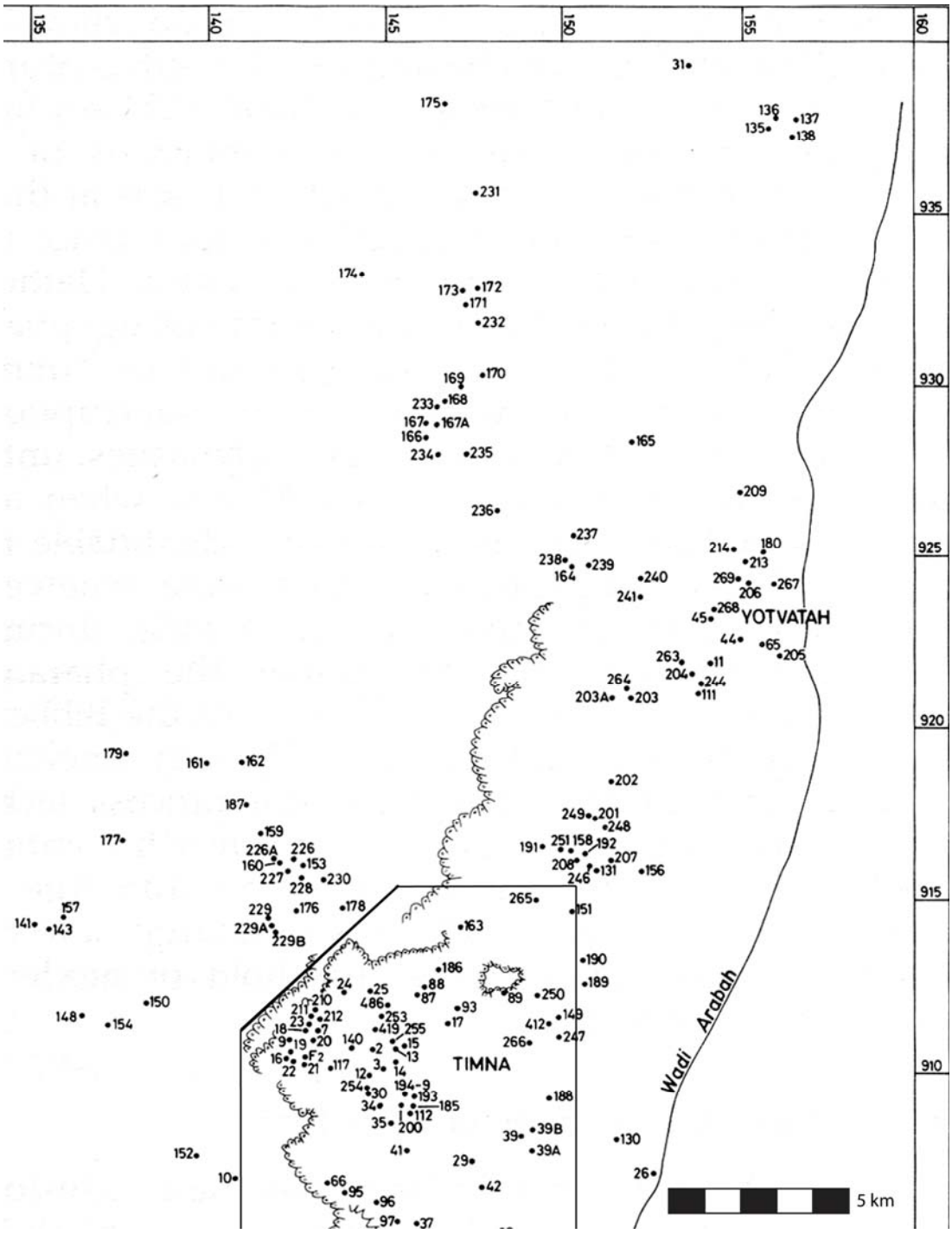


Fig.6.1A: Sites recorded by the Arabah Expedition in the southern Arabah (cf. Fig.6.1B and 6.1C); (from Rothenberg and Glass, 1992:153).

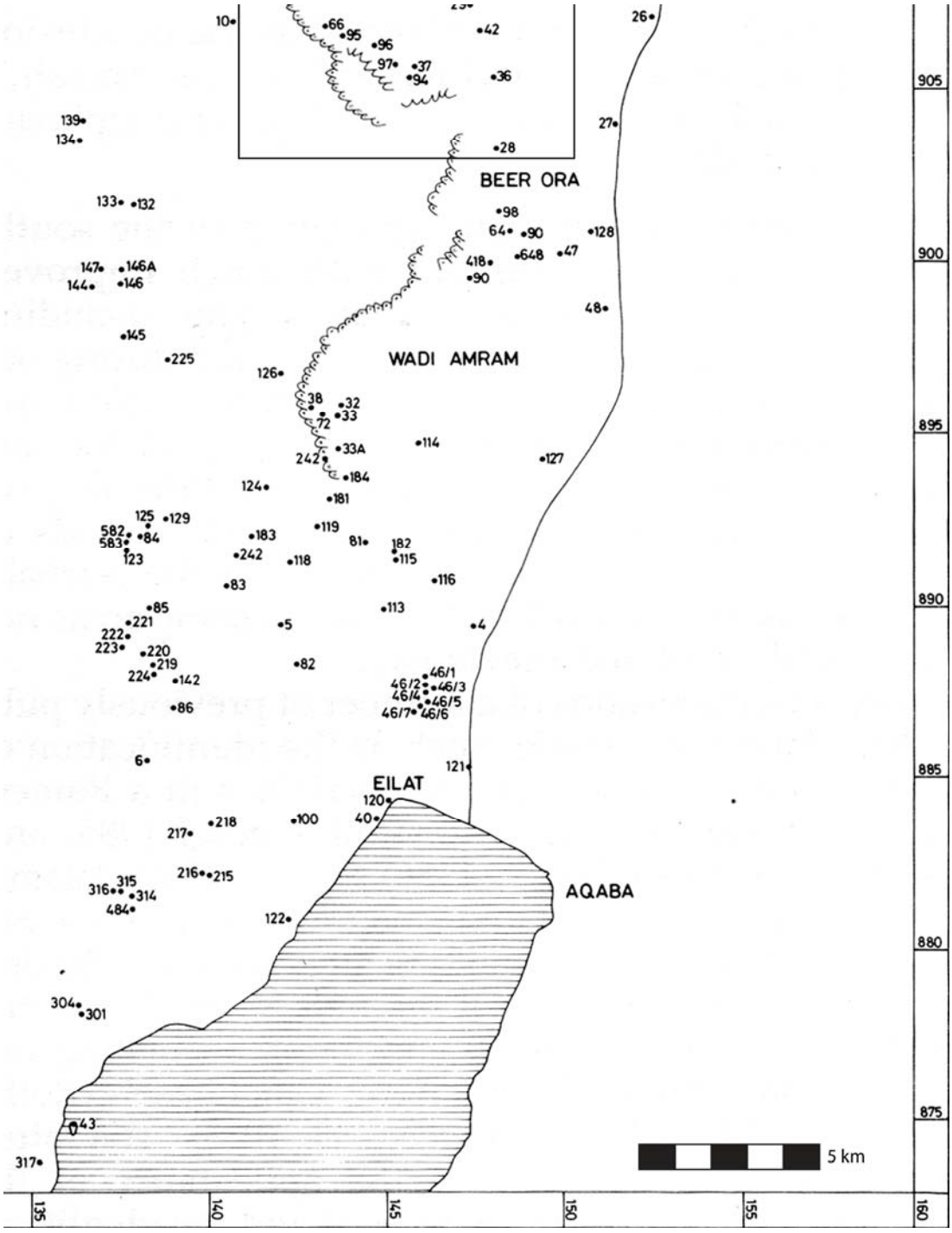


Fig.6.1B: Sites recorded by the Arabah Expedition in the southern Arabah (cf. Fig.6.1A and 6.1C); (from Rothenberg and Glass, 1992:152).

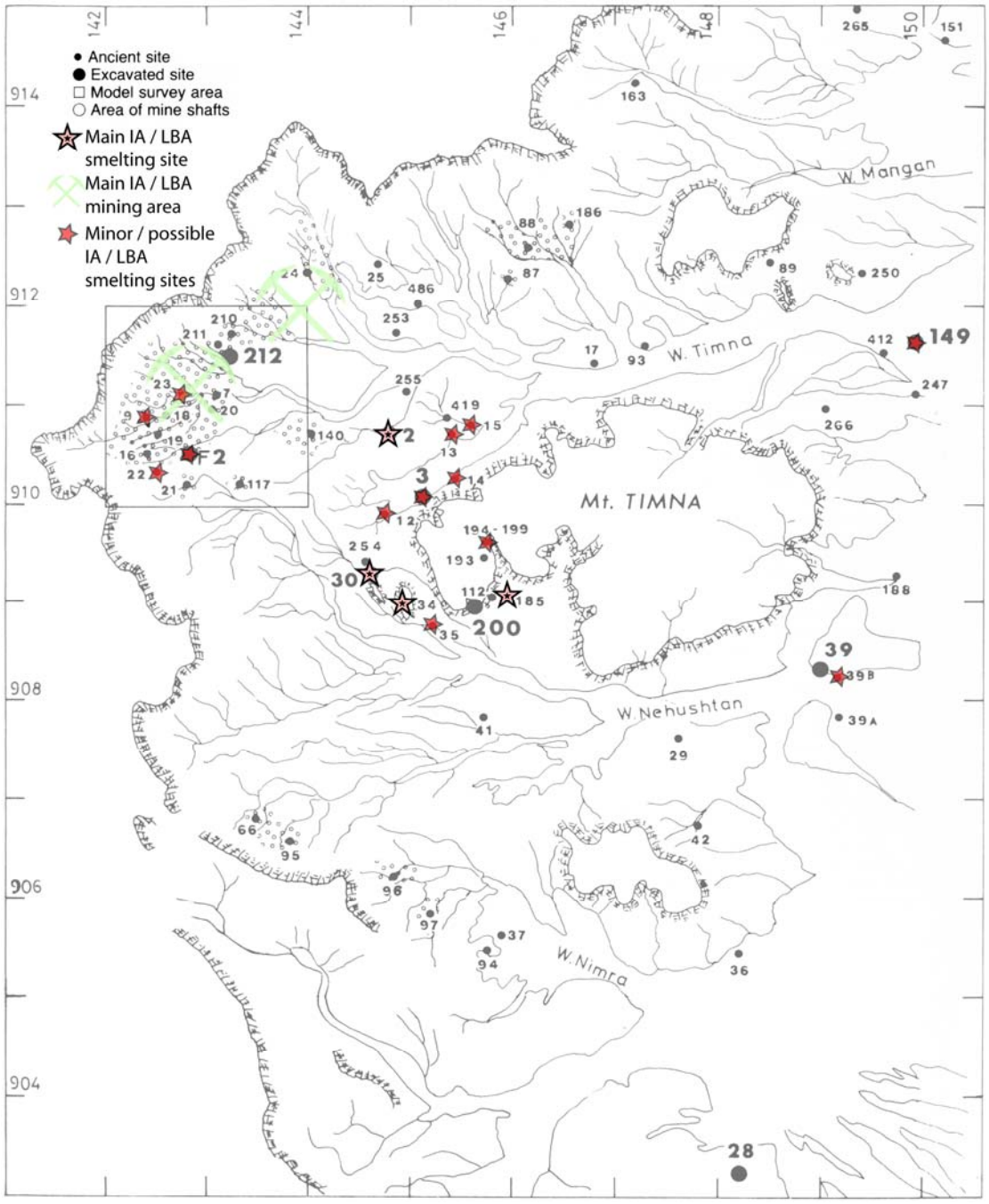


Fig.6.1C: Sites recorded by the Arabah Expedition in the Timna Valley; Late Bronze Age and Iron Age copper production sites are emphasized (cf. Fig.6.1A and 6.1B); (based on Rothenberg, 1990e:2).

Table 6.1: Summary of Late Bronze / Iron Age primary copper production archaeological sites in the southern Arabah (and southern Sinai); highlighted in green are sites investigated as part of the current research and have more details below (section 6.2) (The none metallurgical Sites 52, 53, 68, 102, 104, 105 and the mining Site 103 were recorded by the Arabah Expedition at the central and northern Arabah and are not included here; they are also dated to the Late Bronze Age)

Site*	Description	References
Timna and the southern Arabah		
Timna 2 29.783978N 34.9477354E ☼ □	The site was found in 1959 and excavated in 1964 and 1966 by the Arabah Expedition. It spreads over 150 x 180 m and includes architectural remains and some shallow 'slag mounds'. Furnaces, workshops, storage spaces and cultic/worship installations have been exposed in these excavations. There are several dating difficulties and stratigraphic problems, especially regarding the many furnace bases excavated in the site. We believe that at least some of these furnaces should be dated to much later periods (Early Islamic, see section 7.2.4). Here we briefly present the results of the Arabah Expedition regarding technology and other aspects. Area C: A large 'mound' of *ring slag* (35 cm in diameter with a hole in the middle), and associated furnaces. One of the furnaces (Fu IV, Layer I) is well preserved; it is a shaft dug into the ground (40 cm diameter and depth) with a lining of a 'clay-like mortar' and a dome with opening for inserting the smelting mixture. Tuyère was found in situ and the location of another two was reconstructed as well as a tapping hole. A somewhat different reconstruction has been suggested for another furnace from the same layer (Fu I) which is cylindrical and without a dome. The tuyères from this context are considered to be 'the most sophisticated in the archaeological record so far' (Rothenberg, 1999a:153) In Layer II, below the context of Furnace IV, there were different slags, broken pieces with flow texture, also of tapping technology although less advanced (than the one represented by the ring slag). No intact furnaces have been found in this layer, but it correlates with Timna 30 Layers II and III. Most of the other furnaces in the site belong to one of the two main types, 'cylindrical' and 'domed'. According to Rothenberg each type represent 'a different group of people' working simultaneously at the site, one Egyptian and the other 'Midianite'. An exceptional furnace at Area Z has attributes of *both* types and represent, according to its excavator, collaboration of the two groups of workers to create an installation that takes advantage of the two different technologies (Rothenberg, 1999a:155). Besides the dating problem, the 'technology equals people' approach as used in this case is too simplistic in our view (see Chapters 9 and 10). Most slag at the site are fayalitic (Fe-rich), and some are of the knebelite type (Mn-rich); the latter indicate deliberate fluxing with manganese and iron ores, sometimes together (Bachmann, 1980). Iron objects found at the site are among the earliest of their kind, and were the basis for connecting copper smelting technologies and the development of iron smelting (Gale et al., 1990). Areas D and K are structure complexes, used as working and storage areas. One of the rooms was used as a refining / casting workshop, with finds of crucibles and particular furnaces. Based on ceramic ('Midianite', 'Negevite', and 'Nilotic') and a scarab of Ramesses II were the basis for	(Rothenberg, 1972a; Bachmann, 1980; Rothenberg, 1990a:71-111, 1999a:151-158; Ben-Yosef et al., 2010a)

Table 6.1 continued

Site*	Description	References
	the dating (Layer I to the 13th – 12th century, and Layer II to the 12th century BCE). In December 2005 Tali Erickson-Gini conducted limited excavations as part of the construction of a visitor's center. For new radiocarbon dates from these excavations see Table 6.2.	
Timna 3 29.7785732N 34.951885E ☼ □	One large building has been partially excavated; for general description, see Timna 12, 13, 14, 15 and 35 in this table. Smelting evidence is very limited and little amount of slag was found (interpreted as casting/ refining activities). The site is more a residential and storage area.	Excavation results were not published (see (Rothenberg, 1990a:e.n.56)
Timna 9 ☼	One of the minor smelting camps in Timna. Interestingly, like Site 22, 23 and F2, this small smelting site is located *within* the mining area (Fig.6.1C). Unfortunately, the site has never been published.	(Rothenberg and Glass, 1992)
Timna 12 Timna 13 Timna 14 Timna 15 29.785798N 34.9560043E Timna 35 ☼□	These sites are groups of stone buildings, some consisting of one or two rooms only, others containing several rooms. The walls stand today up to 1.5 m high; dry stone walling with rough field stones. In all of these sites or on the slopes nearby only very small quantities of slag were found. Rothenberg (1972a:65) concludes that "it is obvious that no copper smelting took place here, but there could have been some casting activities. The stone tools, pottery and installations found indicate that, besides being simple quarters for the smelters working in the neighboring smelting camps, many of these stone houses must have served as workshops and storehouses. In fact, stores of ready smelting charge, charcoal and decayed foodstuffs were found inside some of the buildings."	(Rothenberg, 1972a:65; Rothenberg and Glass, 1992)
Timna 34 'Givat Haavadim' Mene'yia I ☼ □	One of the main Late Bronze – Iron Age smelting sites in the Timna Valley. The site has never been excavated. It is located on a top of a mesa, surrounded by cliffs and a short fence. It is accessible only from one side (a 'slag mound' is located also at the bottom of the hill, near the trail that climbs up). On one of the edges of the hill an exposed rock has been interpreted as a 'high place', a cultic installation for worship.	(Glueck, 1935; Rothenberg, 1972a)
Timna 35 ☼ □	A structure complex, 'worker village', with very little evidence of smelting. The site has never been excavated.	(Rothenberg and Glass, 1992)
Timna 185 29.7704678N 34.9591442E ☼	The site was not excavated. This is one of the main Late Bronze Age smelting camps in the Timna Valley, located in a short distance from the 'Egyptian sanctuary' (Site 200). One intact furnace base was recorded on site by the Arabah Expedition (see in particular Rothenberg, 1990a). There are no signs of a wall or a fence at the site.	(Rothenberg, 1990a)

Table 6.1 continued

Site*	Description	References
Timna 200 +	Also called the Hathor Temple; discovered in 1967, excavated in 1969; for a different interpretive approach, see Avner (1999). The temple became an anchor of the chronology of the entire Iron Age smelting sites in the southern Arabah (see discussion in section 6.2.1.4). The site has five strata, I is Roman-Nabataean (; ("a melting-casting furnace right in the courtyard of the abandoned temple", Rothenberg, 1972b:17-19) and V is Chalcolithic. Strata II – IV are related to the Egyptian New Kingdom activities in the region (the material culture there is mixed with local elements): **Stratum IV**: Foundation of the sanctuary. Rothenberg dated this phase to the time of Seti I (1294-1279 BCE) (or in higher chronology: 1318-1204, also used in places by Rothenberg), based on a bracelet with a cartouche of this Pharaoh. Geraldine Pinch (1993:67) pushed it back to the 18th Dynasty by stylistic arguments of the votive offerings (the time of Amonhotep III [1391-1358 BCE]); Kitchen (1976) suggested to read a partially effaced cartouche as that of Thutmose [which?], but was rejected by A.R. Schulman (1988:115-116), the Egyptologist of the Arabah Expedition. Rothenberg rejected Pinch's suggestion on stratigraphic ground (Rothenberg, pers. comm. in Bimson and Tebes, 2009), but the whole situation is problematic and complex (the bracelet does not necessarily represent the date of the foundation of the structure, only when it was active, and votive objects has also hereditary quality). **Stratum III**: A major reconstruction of the sancutary. Rothenberg suggested this renovation was done by Ramesses II (1279-1213 BCE); A.R. Schulman attribute it to Ramesses III (1184-1153 BCE); Geraldine Pinch Ramesses II as the builder, and Ramesses III is responsible only for a sub-phase of the structure (adding the pronaos). The latest cartouche is of Ramesses V (1147-1143 BCE) (Schulman, 1988:144-145); This phase has been destroyed by an earthquake and/or rockfall. **Stratum II**: Worship at the sanctuary was renewed with little or no break; temple was not restored, instead: "Semitic tented desert shrine" (Rothenberg, 1988:277). No signs of Egyptian presence, and no longer dedicated to Hathor; QPW is still present at the site (relatively large quantity). Also this phase was ended by a rockfall; it is not clear how long the tent-shrine had been in use, but Rothenberg considers it to have been "only a short-lived, makeshift establishment" (Rothenberg, 1988:278), and almost for sure was abandoned before Egyptians returned to Timna Site 30 because of the absence of QPW at Layer I of the latter site (Rothenberg, 1988:54).	(Rothenberg, 1972a:125-207; Kitchen, 1976; Rothenberg, 1988; Schulman, 1988; Pinch, 1993; Avner, 1999; Bimson and Tebes, 2009)

Table 6.1 continued

Site*	Description	References
198 +☼	Located 50 m from Site 199; a standing stone, 55 cm high and 30 cm wide with carefully rounded top. A flat stone with a very shallow cup mark was lying right at the foot of a 'table' rock, the base of the standing stone. Decorated Midianite sherds were found and several stone tools and a small quantity of slag and charcoal. Was interpreted as a small shrine, connected with the burial site 199, with a *massebah* standing on an 'offering table', and a libation bowl right next to it. Defined as a "Midianite funerary shrine"; the slag fragments, tools and charcoal found could belong to some kind of ritual casting, like those at Area F in Site 2.	(Rothenberg, 1972a:119)
199 ▲	(General map reference 14579094) Located on top of the red sandstones of 'King Solomon's Pillars' in Timna, between rocks and crevices, a scatter of human bones and complete, large Negev-type cooking pot and a beautifully decorated Midianite jug. Related to the "Midianite funerary shrine" Site 198.	(Rothenberg, 1972a:118)
Timna Sites 14, 24, 25A, 32, 43, 86, 193, 194, 196, 224, 304, 317, 419, 484, 486 (non-metallurgical function)	Site 43 is Jazirat Far'un, a small island in the head of the Gulf of Aqaba, identified by Rothenberg as Ezion-geber (see 'Tell el-Kheleifeh' below). The other sites have been surveyed, but never published.	(Rothenberg, 1967a; Rothenberg and Glass, 1992)
Timna Sites 18, 19, 21, 23, 25, 38, 88, Area S Other mines (general) □	Several of the mine sites in the Timna Valley that were dated to the Late Bronze Age by the Arabah Expedition.	(Conrad and Rothenberg, 1980; Hauptmann and Horowitz, 1980; Rothenberg and Glass, 1992; Rothenberg, 2005; Shaw and Durucan, 2008)
Timna Sites 22, 33, 33A, 112, 188, 254, 255 ☼	Several minor smelting sites recorded in the surveys of the Arabah Expedition. Most are located in the Timna Valley. Except from their assigned date, they have never been published.	(Rothenberg and Glass, 1992)

Table 6.1 continued

Site*	Description	References
Tell el-Kheleifeh ■ ☼?	Glueck, following a suggestion of Frank (Frank, 1934a), identified the site with the biblical Ezion-geber, Solomon's Red Sea port 1Kings 9:26, as well as biblical Elath (1940:92-94). Excavated in the end of the 1930s by Glueck; 5 levels, numbered from the bottom up: IV: Edomite inscriptions and Assyrian-influenced pottery = 7th-6th c. BCE I-III: 10th-8th c. BCE (conviction of identification; identified a refinery and similarities in pottery to Timna and Wadi Amrani/Wadi Amram) 1982: (Gary Pratico) - ASOR launched a reassessment project (1993): None of the pottery is older than the 8th c. BCE. Two main phases: casemate (earlier) wall and a larger-area surrounded by an offset-inset wall. 1999: Mary-Louise Mussell's excavations reversed the order of the two walls (Mussell, 2000). A revision in dating has been suggested already by Rothenberg, who, consequently, suggested identifying Jazirat Far'un as Ezion-geber (Site 44).	(Frank, 1934a; Glueck, 1940a, 1940b, 1940d, 1940c; Pinkerfeld, 1942; Glueck, 1967; Meshel, 1975; Pratico, 1985; Koucky and Miller, 1993; Pratico, 1993b; Pratico, 1993a; Mussell, 2000)
Timna 30 29.7713463N 34.9467336E ☼ □	One of the major smelting sites in the Timna Valley; the site is fenced (or 'walled'), and has been extensively excavated during the 1970s. The site was re-excavated in 2009 as part of the current research. A survey of the previous excavations and their results is found in section 6.2.1.1 below.	(Bachmann and Rothenberg, 1980; Rothenberg, 1980a, 1990a; Ben-Yosef et al., 2008b; Ben-Yosef et al., 2010b; Ben-Yosef et al., in prep.-b; Shaar et al., in press)
Timna 30A and 30H ☼	Timna 30A is a small copper smelting site on the top of the hill above the large smelting camp of Site 30. It was not excavated, but was dated to the main copper production phase of Site 30 (Layer II). Site 30H is not published.	(Rothenberg, 1980a)
F2 ☼	A small metallurgical workshop (smelting) near the mines in Timna Valley. The site was published as Neolithic, but later research have shown that it belongs to the Late Bronze – Iron Age, and represents a simple technology practiced at the same period of the advanced copper production in the main smelting camps.	(Segal et al., 1998; Hauptmann and Wagner, 2007a; Ben-Yosef et al., 2010c)

Table 6.1 continued

Site*	Description	References
Timna 39B 29.7624093N 34.9943182E ☼	The site is located on a hilltop on the margins of the Arabah Valley. It has evidence of simple smelting technology that was interpreted as Chalcolithic. The early date has been in the middle of a long lasting controversy. In the current research we have applied archaeomagnetic methods and found that the site is has been used for smelting in more than one period, probably including the Iron Age.	(Rothenberg, 1978b; Rothenberg et al., 1978; Rothenberg, 1985, 1990a; Rothenberg, 1990b; Rothenberg and Glass, 1992; Rothenberg and Merkel, 1998b; Rothenberg, 1999b; Ben-Yosef et al., 2008b)
Yotvata Hill N3 29.8851689N 35.0458221E ☼	The site is a scatter of small slag chunks on a hill in the margin of the Arabah Valley. It was considered to be Early Bronze Age (according to slag/archaeometallurgical typologies) but magnetic investigation done as part of the current research indicate a later date, probably Iron Age.	(Ben-Yosef et al., 2008b)
Hai-Bar 29.874337N 35.040663E ☼	The site is located 3 km south of Kibbutz Yotvata on the margins of the Arabah Valley. It consists of a large 'slag mound' of small fragments of mostly furnace slag. The site was recorded first by A. Avner and A. Naor and was mapped with a magnetic survey by S. Atkis. It has not been published yet. Ceramic and flint suggested an Early Bronze of Chalcolithic age (A. Avner, Pers. Comm. 2004, 2006; A. Holzer, Pers. Comm. 2006), but magnetic investigation done as part of the current research indicate a later date, probably Iron Age.	(Ben-Yosef et al., 2008b)
Timna 149 ☼	This smelting site has two main areas, one on the top of a hill and the other on its bottom. It was dated to the Early Bronze Age IV, but archaeomagnetic data indicate that the smelting on the hill top belong to a younger period, probably the Iron Age.	(Rothenberg and Shaw, 1990a, 1990b; Rothenberg and Glass, 1992:144; Rothenberg, 1999b:84-86; Ben-Yosef et al., 2008b)

Table 6.1 continued

Site*	Description	References
N. Amram / Givat Yocheved ☼ □	Located south of Timna in Wadi Amram, this smelting site has indications of Roman and probably Late Bronze / Iron Age smelting. The site includes several structures and 'mounds' of large tap slag. This is a different mining area than the Timna Valley itself that has a different lead isotope signature (see Chapter 2). The Arabah Expedition dated the site to the New Kingdom (a date supported by radiocarbon measurements, Table 6.2); however, other scholars argue for an Early Islamic smelting activities, a date that is also supported by a radiocarbon date (Burleigh and Hewson, 1979, 818±49 cal. BCE). Near the site there are extensive mines, one of which (#38) is in a total length of 3 km (Willies, 1990), and the others are probably in the same scale (recently some of these mines were mapped by the Cave Research Unit [CRU] of the Hebrew University, Amos Frumkin, pers. comm.. 2008). Ceramic evidences show that the most intensive mining took place in the Early Islamic period (probably correlates with smelting at N. Amram Site and Beer Ora). The closest mine to the N. Amram Site, number 13, was dated by ceramic and lithic finds to the Chalcolithic and Late Bronze Age only (Willies, 1990:12). Archaeomagnetic results support a multi-period use of the site.	(Rothenberg, 1967a:41-50; Burleigh and Hewson, 1979:350; Rothenberg, 1990a:71; Avner and Magness, 1998:42, 57)
Yotvata Fortress 29.8896938N 35.0582381E ■	An Iron Age fortress (Iron Age I?) located on a prominent hill near the oasis of Yorvata ('Ain Ghadian). Excavated by Z. Meshel in the 1970s. A casemate wall is located on the east and north, and the other directions are protected by steep cliffs.	(Glueck, 1957; Meshel, 1990, 1993) For the early smelting evidence nearby see (Avner, 2002; Rothenberg et al., 2004a)
Sites in the Sinai Peninsula		
Serabit el-Khadim (central coord.) 29.033333N 33.4E □☼?	Some (limited) evidence of Late Bronze Age smelting. There is uncertainty about how much activity focused on exploitation of turquoise vs. copper (see text above for details).	(Barrois, 1932; Starr and Butin, 1936; Giveon, 1978; Beit-Arieh, 1985; Bonnet et al., 1994; Chartier-Raymond et al., 1994; Aston et al., 2000; Castel et al., 2008)

Table 6.1 continued

Site*	Description	References
Bir Nasib (central coord.) 30.033333N 33.466667E ☼□	The largest smelting site in southern Sinai. More than 100,000 tons of slag located near a small oasis and a mining area. Dated mostly to the Late Bronze Age, and probably also to the Middle Bronze Age. The site might be a key to our understanding of technological developments in the region throughout the second millennium BCE.	(Petrie, 1906; Rothenberg, 1970; Rothenberg et al., 1979; Rothenberg, 1987; Aston et al., 2000; Castel et al., 2008)

* Bold names = excavated sites; 14C = radiocarbon date available (cf. Table 6.2); site names are based on the reports of the Arabah Expedition; unfortunately the final report of the surveys was not published yet and some sites have only their supposed date and no further details. Most of the sites indicated as Iron Age in Rothenberg (1970:7) appear as New Kingdom (Late Bronze Age – Iron Age I) in Rothenberg and Glass (1992:152); in the latter, no site is dated to the Iron Age II. Symbol key: ☼ smelting; □ mining; ▫ buildings/settlement; ■ fortress; ▲ cemetery; ⌂ watch tower; ● campsite; # agricultural fields; + cultic; ○ point finds.

Table 6.2: Compilation of radiocarbon dates from Late Bronze Age and Iron Age copper production and related sites in the southern Wadi Arabah (Timna and its vicinity)
For broader time frame covering all periods of the history of metallurgy in the southern Levant see Avner (2002), Weisgerber (2006:27), Hunt et al. (2007a) and Hauptmann (2007)

Site	Lab #	Radiocarbon Age BP	Cal. Age – 68.2% prob. (BCE)*	Context	Reference
Timna 30 (smelting site)	Ham216	3340±60	1689-1531	(Charcoal) from Layer I, slag heap	(Scharpenseel et al., 1976:287)
	BM1598	2785±50	1003-851	Charcoal from metallurgical debris, Layer III – II	(Conrad and Rothenberg, 1980:201; Burleigh and Matthews, 1982:165)
	BM1162	2480±35	756-539	Charcoal associated with 'slag cake' from Layer I	"
	See Table 6.5				**THIS STUDY** (and see also Ben-Yosef et al., in prep.-b; Shaar et al., in press)
Timna S28	HAM212 Bonn2361	2780±90	1027-827	Copper mine	Scharpenseel et al. 1976:287 confused in (Conrad and Rothenberg, 1980:179)
Timna 2 (smelting site)	BM2382	3220±50	1530-1430	Slag heap, Layer II	(Rothenberg, 1990e:71)
	Pta4121	3090±60	1430-1294	Area Z, bottom of slag heap	"
	GrH4493	3000±50	1370-1131	Area F, Layer II	"
	H3625-2782	2940±50	1257-1056	Furnace IV, Layer I	"
	Pta4123	2880±60	1189-943	Slag heap, Layer II	"
	BM1115	2840±51	1109-919	Area E, Layer I, Furnace I	"
	RTT5276	3125±35	1441-1322	Area C, l.100, B1	pers. comm. T. Erickson-Gini 2009
	RTT5277	2920±35	1193-1051	Area A, l.500, B20	"
	RTT5278	2965±35	1260-1129	Area A, l.501, B23	"
	RTT5279	2965±40	1263-1127	Area A, l.1001, B27	"
N. Amram	Pta4127	2920±60	1212-1021	Smelting camp, the date came from the *bottom* of the 'slag mound'	(Rothenberg, 1990e:71)
Timna S27	HAM208 (Bonn2357)	2910±60	1210-1012	Copper mine	Scharpenseel et al. 1976:286-287 confused in (Conrad and Rothenberg, 1980:179)
	HAM207 (Bonn2356)	2910±70	1252-1008		"
Timna S18	HAM210 (Bonn2359)	3050±70	1411-1215	Copper mine	Scharpenseel et al. 1976:287 confused in (Conrad and Rothenberg, 1980:179)
Timna 200	BM1117	2779±55	999-847	Sanctuary	(Burleigh and Hewson, 1979:349)

Table 6.2 continued

Site	Lab #	Radiocarbon Age BP	Cal. Age – 68.2% prob. (BCE)*	Context	Reference
Timna F2 (smelting site)	BM1368	3030±50	1386-1215	Furnace remains, charcoal, square 3, l.3	(Burleigh and Matthews, 1982:165)
Timna S19	HAM211 (Bonn2360)	2640±60	895-774	Copper mine	Scharpenseel et al. 1976:287 confused in (Conrad and Rothenberg, 1980:179)
Timna Tomb	Gro938	2655±65	896-790	Tomb	(Avner Pers. Comm. 2010; source unknown)

* All dates are calibrated using OxCal v.4.1, © Ramsey 2009; l.=locus; elevation is in meters (m) below surface

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6.2 Description of the sites studied as part of the current research

6.2.1 *Timna Site 30*

Site 30 in Timna Valley (Rothenberg, 1980a) is one of the largest 'smelting camps' in the southern Arabah. It extends over ca. 0.5 ha bellow a small hill in the center of the valley, a few hundred meters from the 'Egyptian Sanctuary' Site 200. The site is surrounded by a semi-circular wall with a north-facing gateway approximately in its middle. The southern side of the site is protected by the natural steep slopes of the hill, on which the wall climbs approximately 20 meters before it abuts the cliffs. On the top of the hill, a small smelting site (Site 30A) was reported by the Arabah Expedition; it was dated to the Late Bronze Age and associated with the main period of copper production at Site 30 below. Site 34, known as "The Slaves Hill", is located on a flattop hill about a hundred meters to the east (Fig.6.1, Table 6.1). Almost all the rich archaeological remains of Site 30 are located within its perimeter wall except from an extensive thin scatter of broken slag to its north, and a series of shallow walls and two mortar-like features to its southwest. The former are part of the earlier phase of smelting in the site (Layer III), and the latter was interpreted as an installation built to divert the water of a small local wadi that passes through the site (for protecting the site against flash-floods, and perhaps for collecting drinking water; the mortar-like features are probably related to crushing activities).

The first to report Site 30, one of the more noticeable smelting sites in the Timna Valley, was John Petherick who visited the southern Arabah in 1845:

> At Riguel Hadid [Site 4 of the Arabah Expedition = Tell Hara Hadid] and Wadi-il-Muhait [Site 30], on the west side of Wadi Arabah, are two very interesting spots, where copper ores were formerly smelted; the slag still remained, which contained a large proportion of copper. The latter of the two must have been the most considerable smelting locality, judging by the quantity of slag lying there, the whole of which, comprising a large area, is enclosed within a dry-stone wall; the greater number of stones, being lime-stone, were probably brought there as a flux for the reduction of the ores. But from whence those ores, or the fuel with which to smelt them, were derived, or who were the operators, are questions which the Arabs could not answer, nor myself divine. (Petherick, 1861)

In Frank's report (1934b:234), seven smelting camps are mentioned in the Timna Valley, one of them, described as a "*brandstatte* surrounded by a semi-circular wall with a diameter of 70-80 m…", is probably Site 30. Interestingly, he noted two distinct types of slag at the site, small and thin (1-2 cm) and large and thick (5-10 cm), an observation that was later confirmed and linked to different technologies (below). Glueck (1935:42-45) also reported seven smelting camps in the southern Arabah (according to Rothenberg, 1988, these are Sites 2,12,13,15,30,34 and 35 of the Arabah Expedition), and described Site 30 (there "Khirbat Mene'iyyeh II") as follows:

> Inside of the walls are the ruins of houses and furnaces and great black heaps of slag, with numerous pieces of EI I-II pottery strewn about. The nature of this large enclosure, with its thick walls of tumbled masonry, suggests that it too was used as a prison camp [as the Slaves Hill, the Arabah Expedition Site 34, and as the fortress of Khirbat en-Nahas in Faynan], in which the members of the corvée were held to their arduous tasks. (Glueck, 1935:44)

The wall (or fence) surrounding the metallurgical remains is a prominent feature of Site 30. Rothenberg did not accept this interpretation, and has attributed to the wall a

defensive function (Rothenberg, 1980a). There are other ways to interpret the walls, or confining features, in the archaeometallurgical sites of the Iron Age southern Levant, such as boundaries used to segregate the specialized metallurgists from common miners and passersby. This question is discussed also in Chapter 9.

Site 30 was investigated by the Arabah Expedition (section 3.2.1 above) mostly during the 1970s. We revisited the site as part of the current research in April 2009 for a 10-days long excavation, mainly focusing on chronological clarifications and technological comparison with our archaeometallurgical assemblage from Faynan.

6.2.1.1 The research of the Arabah Expedition at Site 30

Site 30 and its metallurgical remains were thoroughly investigated by the Arabah Expedition. It was studied during the surveys of 1959 (Rothenberg, 1962:19-20) and 1969 (Rothenberg, 1973:68f) and was excavated in 1974 and 1976 (Bachmann and Rothenberg, 1980; Rothenberg, 1980a). The archaeometallurgical finds from the site comprise the bulk of the Late Bronze – Iron Age technological discussions of Rothenberg (1990a), and were used as the basis for experimental reconstructions of the smelting process (Bamberger et al., 1986, 1988; Bamberger and Wincierz, 1990; Merkel, 1990). Site 30 has never been published in the format of a ‘final report’; general overview and ceramic plates from the 1970s excavations are available in

Rothenberg (1980a), and description of the technology and the archaeometallurgical material culture is available in Rothenberg (1990a).

The wall (Rothenberg calls it "defense wall") of the site was mapped and measured by the Arabah Expedition; it is about 1 m wide and 1.5-2 m high with a gateway flanked by two 'watch towers' (the wall was reconstructed as part of the Timna Park development in the 1990s, without carefully marking the original remains) (Fig.6.2). Through the site, between the area of the main archaeological accumulation and the slopes of the hill, passes a small wadi; this is where the excavated earth was disposed in 1974 and 1976 (and 2009) (Fig.6.3).



Fig.6.2: Site 30 in the center of the Timna Valley during the new excavations (April 2009), looking northwest. A prominent 'slag mound' is clearly visible close to the center of the site; the stone built fence was partially restored as part of developments of the Timna Park during the 1990s.

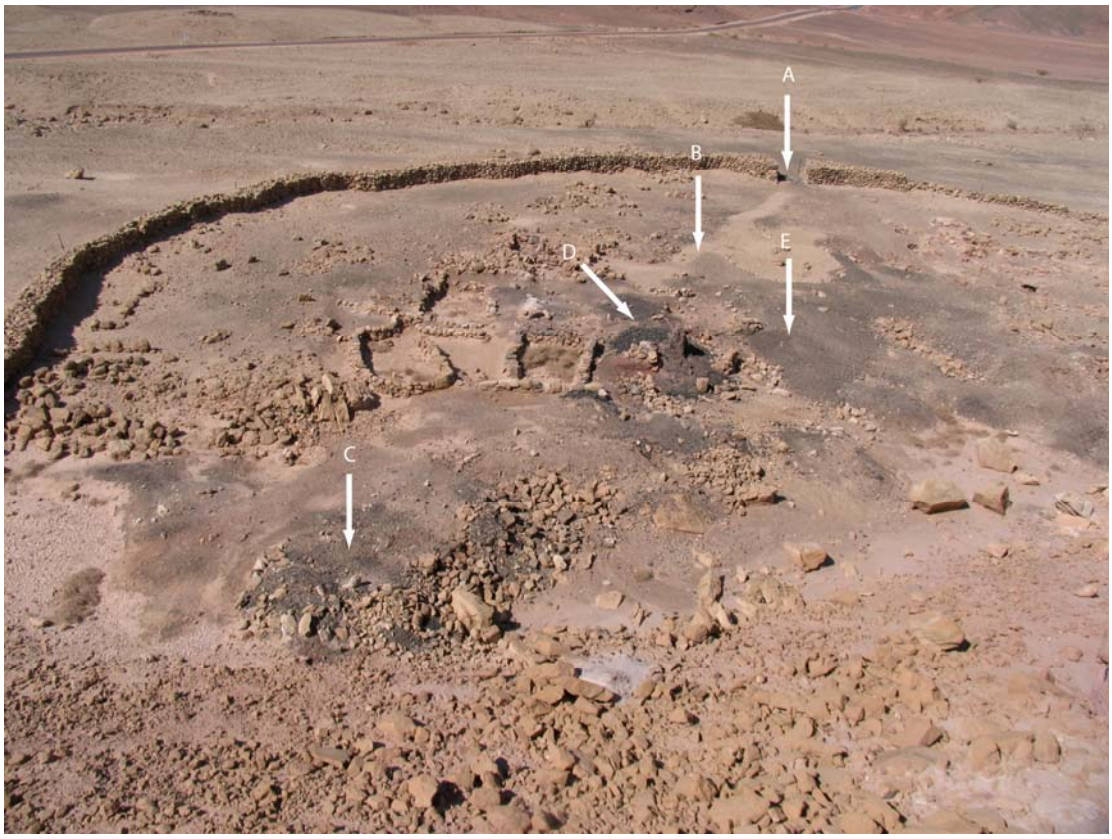


Fig.6.3: An overview of the western part of Site Timna 30 before the 2009 excavations (looking north). The site is poorly preserved and is heavily disturbed by unsupervised restoration works. A) The gateway in the restored fence flanked by two 'watch towers'; B) the bright earth represent a modern path leading from the gateway to the 'slag mound' and backfills of some excavation pits; C) the location of earth disposal from the excavations of 1974 and 1976, the small wadi is filled with the excavation waste; D) the central 'slag mound' studied in the current research. The eastern face of the mound was exposed in the 1970s and had retreated about 1 meter since; the western side (where the edge of the arrow is located) was damaged by unsupervised restoration works; the mass of large black tapping slag seen in the photo were returned to this spot after part of the upper portion of the mound was dug to be used as a backfill in the 1990s. The new excavations avoided the disturbed contexts.

The Arabah Expedition work at Site 30 is the largest excavation conducted in the archaeometallurgical sites of the southern Arabah. The stated goals of the project were to clarify the stratigraphy, to establish correlation with the Egyptian sanctuary (excavated in 1969), and to achieve a large exposure of remains for reconstruction the organization of production in the site. The entire area was divided into a 10 x 10 m grid and excavated mostly along straight transects (Fig.6.4). Rothenberg (1980a:189-

192) describes the challenges in establishing stratigraphy and chronology for Site 30 (and for metallurgical sites in general):

> The technological and chronological sequence of a metallurgical site has a very different nature [from ancient settlement sites]: every metallurgical process generates slag, which often accumulate to notable mounds around the smelting area. Each smelting procedure, even as short as a few hours, produces enough material around the smelting area and creates a new working level, on which the varied raw materials and waste products accumulate. This working procedure leads to the fast formation of many thin layers that have very limited chronological meaning. The challenge then is to understand the smelting procedure that appears in the excavation as a colorful, irregular and often very disturbed strip of lines […] the stratigraphic location of the remains of buildings [in Site 30] was of great importance to the chronology of the metallurgical site […]By exposing extensive and mutually-dependent plots in which ceramic sherds and other small findings were found adjacent to ruins of buildings, and by their meticulous correlation to the stratigraphically important remains… chronological criteria for Site 30 could be formulated. *The correlation of these criteria to the findings of the Mine-Temple leads to absolute dating.* (translated from the German by Maayan Shalev; emphasis E.B.-Y.)

The chronology of Site 30 was based mostly on the findings of Site 200, the so-called 'Egyptian sanctuary'. This is a crucial point, as the absolute dating of Site 30 has direct implications on our understanding of the metallurgical development in the Arabah at the end of the second and the beginning of the first millennia BCE.



Fig.6.4: Plan of Site 30 in Timna showing the excavated areas of 1974, 1976 and 2009 (adapted from Conrad and Rothenberg, 1980). The 2009 project focused on two areas, the sections in the 'slag mound' (S) and a metallurgical area (Square L).

The Arabah Expedition distinguished three major layers at the site (Table 6.3, Fig.6.5), spanning the 14th – mid 12th and 10th – 9th centuries BCE.

Table 6.3: The stratigraphy of Site 30 in Timna according to the Arabah Expedition (Bachmann and Rothenberg, 1980; Rothenberg, 1980a, 1990a); L.=Layer; cf. Fig.6.5

L.	Description	Main finds	Date
I	Tap slag of completely different type (than Layers II-III), located in two 'mounds' (areas E4-West and C5-Southwest), was the best indicator for this limited layer In general, representing little activity, possibly only a few weeks. Most of the structures of Layer II remained intact, some were re-used in Layer I, like Locus 171 (C6-SW) where a small chamber was used for storage of manganese ore pieces and smashed bulbs of copper. No substantial newly built architectural features were attributed to this layer.	Much bigger tuyères and smelting installations than the lower levels; except from small provisional stone features, there was no architecture; Negevite ware; no Midianite ceramic; no complete furnaces or furnace bases found in situ, but an interesting dome-shaped installation was recorded (L.10) and probably related to the smelting process. "22nd Dynasty Egyptian ceramic."	22nd Dynasty (Egypt); 10th – 8th centuries BCE. Representing "a short and rather limited revival of Pharaonic Egyptian activities in Timna."
II	The site is divided into metallurgical area around the central 'slag mound', with a sequence of thin layers of metal production debris and working platforms, and an architectural complex, located mostly in the eastern side of the site. In the metallurgical area, a series of relatively broad (1-1.5m wide) working surfaces, including a 'typical smelting workshop' (L. 50) and a smelting installation (L. 219), that was re-used as a potter workshop (still in Layer II) with two large stone basins (L.194, 163) for clay preparation and small kiln (L. 177) were found.	Small pieces of thin (2-3cm) tapping slag fragments; furnace slag with embedded charcoal; small tuyères and furnace fragments; Negevite, Midianite, Egyptian and 'normal' ware were unearthed.	13th – mid 12th century BCE, the main phase of copper production in Timna Valley.
III	Thin layer (a few centimeters) with small slag fragments, charcoal and pieces of burned clay; representing an open metal production area without any architecture; extending beyond the wall (Layer II) mostly to the north.	A few storage pits; Negevite ware; QPW; local "normal" ceramic; Egyptian red-polished ceramics of Nile clay (the basis for dating, three sherds were published in Rothenberg (1980a:Fig.2.11.13,12,13).	14th century BCE, Egyptian New Kingdom, *before* the construction of the Egyptian Sanctuary (Seti I). The Egyptian red-polished Nile ware was found only in this layer and was not present in the Egyptian sanctuary.



Fig.6.5: The section in the main 'slag mound' at the end of the 1976 excavations. The three main layers are indicated on the original photograph (Rothenberg, 1980a:197).

6.2.1.2 The 2009 excavations at Site 30

In accord with the goals of the current research, the recent evidence from ELRAP's Iron Age work in Faynan called for reinvestigation of the evidence from Timna Valley, the southern counterpart of the Jordanian mining district. The only context that has been reported as having Iron Age II metallurgical remains in the entire

southern Arabah region is Layer I at Site 30 (see above). For this we planned a short field season at the site designed to answer specific questions, mostly regarding chronology and metallurgical technology. The site had already been thoroughly investigated by the Arabah Expedition, thus our main goal was to contextualize the previous research in light of a better established chronological framework, based on high precision radiocarbon dates. In addition to the archaeological/anthropological questions, we investigated the magnetic properties of slag from the site (Shaar et al., 2010) and conducted a comparative archaeointensity study on the slag from the main section (see section 4.2.2 above, and Shaar et al., in press), mostly in order to find parallels to the unique geomagnetic feature recorded in the main section at Khirbat en-Nahas, Area M (Ben-Yosef et al., 2009c). The archaeomagnetic investigations will be described here only briefly, as they are not directly related to the scope of this dissertation. The main archaeological advantage of the archaeointensity results for this study is the combined age model and the fine temporal correlation between the archaeological record of Timna 30 and KEN- Area M.

The excavations took place April 9 – 17 2009[65] and focused on two areas, a section in the main 'slag mound' of the site (Area S) and a probe in metallurgical deposits (Area L) (Fig.6.4). The first day was dedicated to reconstructing the old grid

[65] The new project at Timna Site 30 was initiated by a multidisciplinary team and had a twofold goal, archaeological/anthropological and geophysical. It was directed by the present author (license # G-38/2009), with the help of Ron Shaar from the Institute of Earth Sciences at the Hebrew University of Jerusalem. It was partially supported by the US-Israel Binational Science Foundation grant #2004198. We would like to thank Lisa Tauxe and the volunteers, especially Uri Davidovich, Hai Ashkenazi and Eli Cohen, for their invaluable help in the field. We are also grateful for the support of the Timna Park management throughout the excavations, and to Hagit Gal and Michael Lavie for their help.

of the Arabah Expedition (some of the original 'rebars' were still intact, and most of the installations could still be recognized in the field), and to find a spot for probing. The latter was not an easy task as we were interested in metallurgical debris which has not been previously excavated or disturbed and that were not part of a backfill or the artificial mounds of dumped excavated sediments. We used photography of the pre- and post- 1970s excavations to make sure we penetrate unexcavated sediments[66]. It appears that most of the excavated sediments from the 1970s were dumped in the small wadi that passes through the site in its southern part. This area was also used by us for dumping the excavated earth.

The excavation methodology followed the basic system of ELRAP described above (section 5.2.1), except that our *Total Station* did not have an attached data collector and all locations were recorded manually on excel sheets that were converted into GIS shapefiles only later[67] (Fig.6.6). Our grid corresponds to the squares of the Arabah Expedition and to the same relative elevation system, which is not an absolute geographic reference[68]. All the excavated sediments from Area L were sieved in a 2x2 cm screen, and most of the artifacts were recorded as point-finds (except from general carbon samples for species identification, slag from Area L and in cases ore

[66] Some of the photos were from the private collection of Beno Rothenberg. We thank him for his support of the new project and advice along the way.
[67] We thank Yehuda Enzel from the Institute of Earth Sciences and Tamir Grodek from the Department of Geography of the Hebrew University of Jerusalem for their help with the *Total Station* used in the Timna 30 excavations.
[68] Our coordinates and elevation data, as well as those published by the Arabah Expedition, can be easily converted to the real geographic reference if reference points will be recorded with differential GPS in the future. This was not available to us at the time of excavations. However, our measurements are comparable to those published by the Arabah Expedition, and thus provide a good reference for any practical analyses.

fragments; those were collected as part of general baskets). The section (Area S) and all of the artifacts collected directly from it were recorded by a vertical grid (50 x 50 cm) and precise drawing on a millimetric graph paper. The artifacts are currently stored at the Institute of Earth Sciences and the Conservation Laboratory of the Institute of Archaeology both in the Hebrew University of Jerusalem.



Fig.6.6: The new excavation at Timna 30 (2009): Area S (right shade), Area L (central shade), location of sieving and dumping of excavated material (left shade), location of the *Total Station* (near the table).

Our investigations at Site 30 resulted in a new and different chronological framework for the site than the one proposed by the Arabah Expedition. Because this revision originates from differences in basic research methodologies, the new chronological framework has broad implications beyond Site 30 itself, and it can

probably be applied, to some degree, to other sites in the southern Arabah. The full report of the 2009 excavations, the interpretation of the finds, and discussion on the implications of the new data on our understanding of the copper production in this region at the end of the second and beginning of the first millennia BCE are also presented in Ben-Yosef et al. (in prep.-b).

Area L

Area L is a half 5 x 5 excavation square located ca. 5 m east of the 'slag mound' (Area S). The surface of the square was covered with broken small fragments of slag (Fig.6.7) with a few large rocks visible; most of these were found to be 'floating' on a layer of ashy dust and silt (Fig.6.8). The metallurgical deposits were excavated from surface to bedrock. 17 loci were defined and four major layers were recognized (Tables 6.4a and 6.4b). The entire accumulation of metallurgical debris in this area is no more than 1.25 m, representing a complex stratigraphic layout. The archaeological layers are described in the following from the oldest to the youngest.

Table 6.4a: Harris Matrix of the 2009 excavations at Timna Areas L and S; correlation between the two areas is tentative and based on field observations and ^{14}C dates (see text). Note that in Area L, locus 809 and the ones to the south of it are intrusive; loci 810 and 812 are relatively thin activity surface, paralleled by the more considerable accumulation of metallurgical debris in the area of the section.

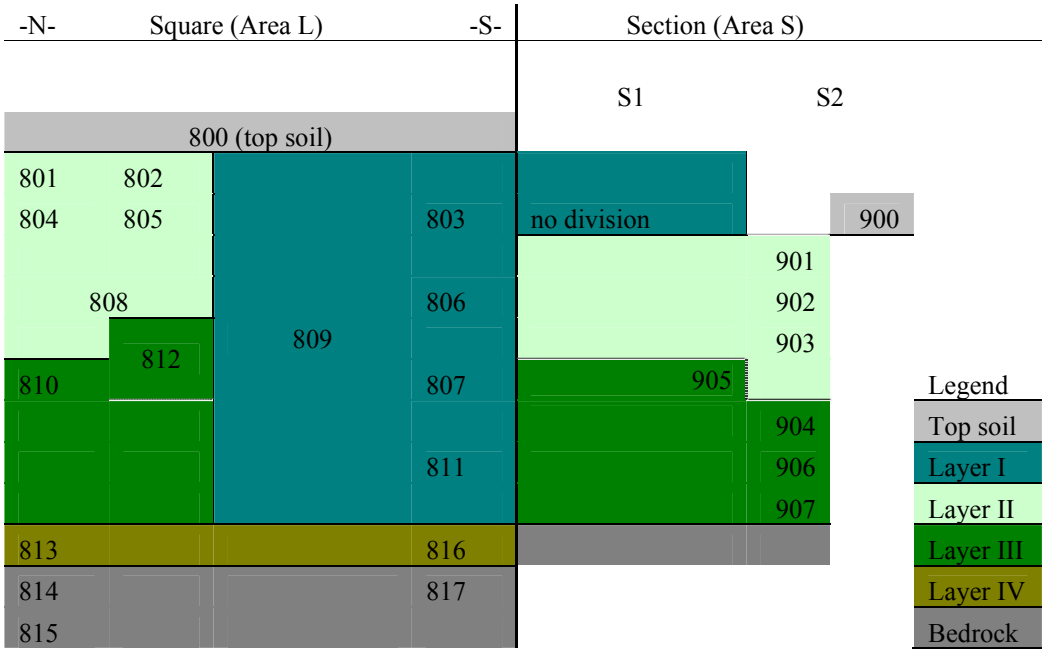


Table 6.4b: Locus list of Areas L and S of the 2009 excavations at Timna 30; elevation is in relative measurements and corresponds to the system used by the Arabah Expedition (cf. Table 6.4a).

Locus	Top (m)	Bottom (m)	Description
Area L – excavations in metallurgical deposits			
800	0.85	0.64	Top soil of square L; locus bottom quite arbitrary, by elevation and because of sloping surface (sloping towards the southeastern corner of excavation square); ingot mold came from this context
801	0.65	0.52	Northern locus of square L, darker soil, blackish sediments; part of the 'slag mound' debris
802	0.66	0.51	Middle of the square; contains thin layers of fine bright dirt (the other two adjacent loci contain slag and charcoal)
803	0.65	0.49	Southern part of the excavation square, metallurgical debris
804	0.48	0.33	Northern locus in square L, dark earth with many slag fragments, homogeneous material in the 'slag mound'
805	0.50	0.33	Part of the 'slag mound', metallurgical debris; dark layer with charcoals and slag material; similar to locus 804
806	0.45	0.30	Top material from the inside of the installation defined by locus 809; contains burned stones (collapse of 809?)
807	0.42	-0.20	Yellowish sediments (loess, fine dust), not clean - fragments of slag and other materials (part of installation defined by wall 809?)

Table 6.4b continued

Locus	Top (m)	Bottom (m)	Description
808	0.34	0.10	Slag mound' material, debris of copper production (blackish, plenty of loose slag fragments); in the middle part there is a cemented patch of red clay (this patch is a substantial feature that probably correlates with locus 818 in the southeastern part of the excavation square - thus the red clay is older than the structure/wall 809 and younger than most of locus 808 and 800 (and the ones in-between); See photos of eastern section of excavation square for some problems--> the red soil is much more cemented than the slagish layer above it, and contain dark-red clay, slag and charcoals
809	0.55	?	Wall collapse. Line of stones marking clear separation of loci. Made of irregular stones and 'slag cakes'; part of small structure / pit. Mostly sandstones, some of which went through heating trauma
810	0.135	0.00	Was first defined as 'bedrock' and 812 as 'charcoal and fire remains on bedrock' (hearth); later on, locus 813 proved to contain remains of smelting activity (small chunks of slag) - see relevant description
811	-0.20	-0.19	Bottom of the deposits inside the intrusive installation defined by stone feature locus 809
812	0.18	0.13	Shallow rounded pit, burned layer of a hearth / firing place (50-70cm in diameter) that is located on the top of locus 810; this surface is a well defined occupation / activity area; the pit contained charcoals (collected separately)
813	0.00	-0.34	gravel, course sand, mixed with brown soil, small fragments of charcoals and tiny pieces of slag
814	-0.34	-0.13	bedrock (wadi terrace, gravel)
815	-0.13	-0.40	bedrock (wadi terrace, gravel)
816	-0.01	-0.35	Similar to locus 813 (coarse sand, brown soil and charcoals, but in the southern part of excavation square)
817	-0.27	-0.54	Lower most part in the 'installation' area
Area S – section in the ‘slag mound’			
900	0.72	0.03	Top of fill on east side of Area S (section collapse)
902	1.04	0.94	Loci within section and corresponding materials in the collapse
903	0.94	0.80	
904	0.65	0.40	
905	0.68	0.64	Installation: storage pit of crushed ore
906	?	?	
907	?	?	
other	2.10		Top of slag mound (highest point in site)



Fig.6.7: Area L before the 2009 Excavations. It is one of the few undisturbed contexts left at Site 30; the surface has small broken tap slag fragments and a few large stones. The 'top soil' seems to derive from material of Layer II and aeolian dust and fine soil.



Fig.6.8: Top soil of Area L. Stone features found to be 'floating', slag fragments found to be on top of aeolian fine deposits (looking south).

The lowest most archaeological deposit, Layer IV, was exposed in very limited areas and is represented by Locus 813 in the north of the square (Fig.6.9) and Locus 816 in the south of it. It is located below the hard surface of Layer III, first thought to be the bedrock, and was found in small probing that were intended to check the characteristics of the supposed bedrock. The finds from Layer IV are scarce, but include firm evidence of copper smelting activities probably in the close vicinity of this location: tiny fragments of slag and charcoal (up to 1-2 cm in diameter) were found mixed with coarse sand and pebbles, about 35 cm thick and more or less evenly distributed across the excavation unit. Fragments of ore were also found. Layer IV is situated on top of gravel/wadi-terrace that had no anthropogenic finds in it (small fragments of ore in L.814 and L.815 were considered part of the natural deposit). It seems that Layer IV represents re-deposition of limited smelting/slag processing debris from the earliest phase of occupation in the site (or its immediate surroundings). It is not probable that the anthropogenic samples from this context resulted from post-depositional processes of infiltration and repositioning of artifacts, as the upper boundary of Layer IV seems to be firmly sealed by the thick and hard surface of the occupation horizon above it (Fig.6.10). From this reason we believe this Layer is not reported in the publications of the Arabah Expedition. We first assumed that it represents a much older phase of copper production, possibly corresponding to one of the two early radiocarbon dates published for the site: a Middle / early Late Bronze Age date (HAM216, 3340±60 BP, 1689-1531 BCE 69.2% prob. OxCal v.4.1, © Ramsey 2009, Layer I, charcoal, see Table 5.2) and an Early Bronze Age (HAM 215,

4020±100 BP, 2856-2409 BCE, OxCal v.4.1, © Ramsey 2010), both dates appear in Scharpenseel et al. (1976:287). The context of the second date is not clear; in Scharpenseel et al. (1976:287) it is reported as ‘charcoal, mining site, slag pile, Cut 25, Layer 2, with no direct reference to Site 30 (but cf. radiocarbon table in Avner, 2002). In any case, the results of our new radiocarbon measurements preclude a pre-Iron Age date of this layer (see below).

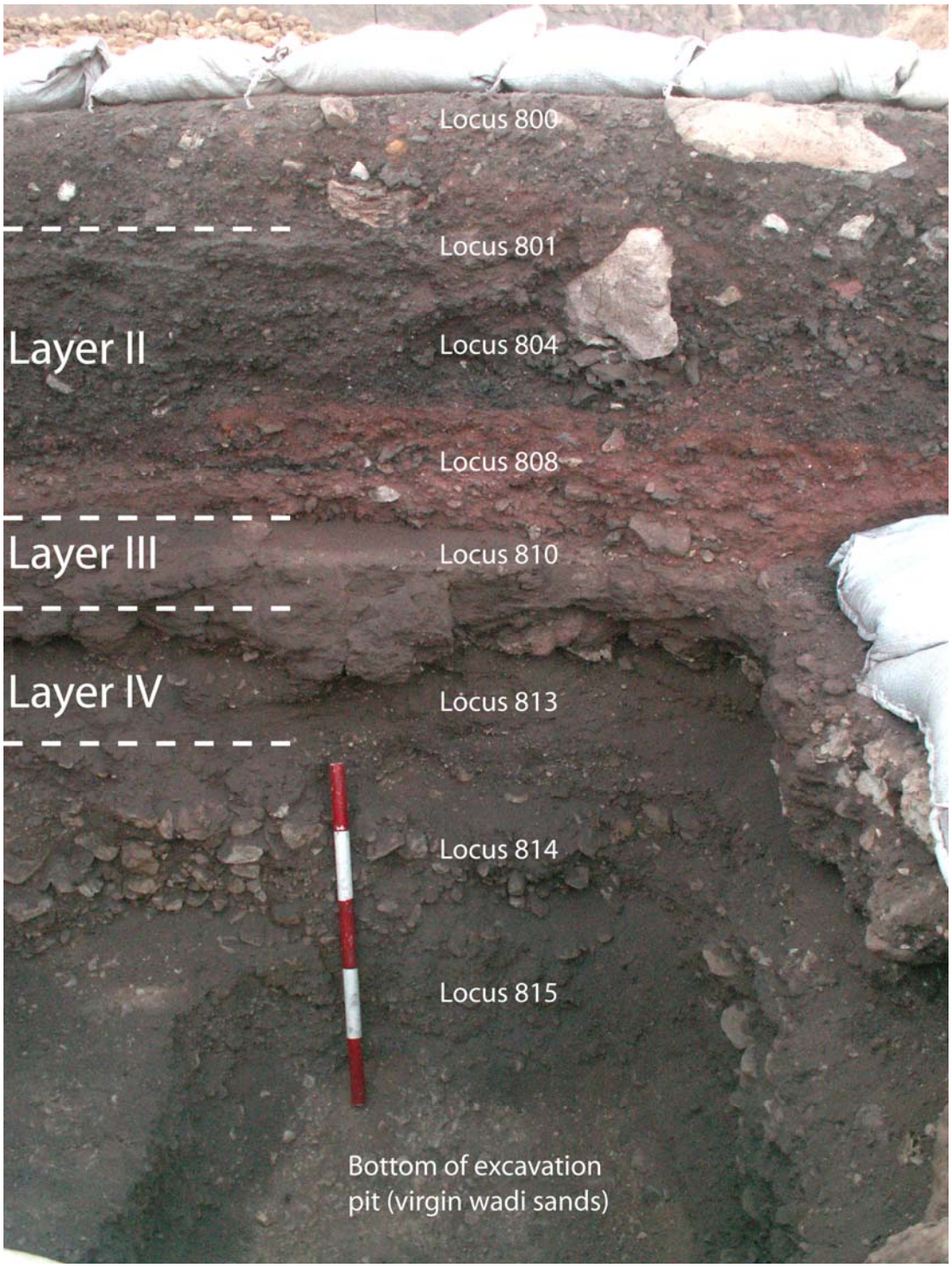


Fig.6.9: A photo of the north side of the eastern wall of the excavation square in Area L, Site 30, indicating excavated loci and layers. Layer I is presented only in the 'intrusive' installation in the southern side of the square.



6.10: Probing through the hard surface of Locus 810 (cf. Fig.6.9).

Layer III is represented in Area L by a distinct activity surface (L.810). The surface is so compact that we first defined it as ‘bedrock’, and only later, in limited probes, found out that it is situated above sediments with anthropogenic samples (Layer IV). Clear marks of a hearth / fire place are found on this surface at the northern side of the square (L.812, Fig.6.11). The finds from this layer were scarce, and probably some where confused with the loci above as being part of the debris of

Layer II. We suggest correlating this layer with Layer III of the Arabah Expedition. It seems that such features were thought to represent the earliest phase of occupation at the site, and that it is a clear occupation horizon below the characteristic thick accumulation of Layer II (of both the Arabah Expedition and the current project). A charcoal sample from the fire place was dated (below).

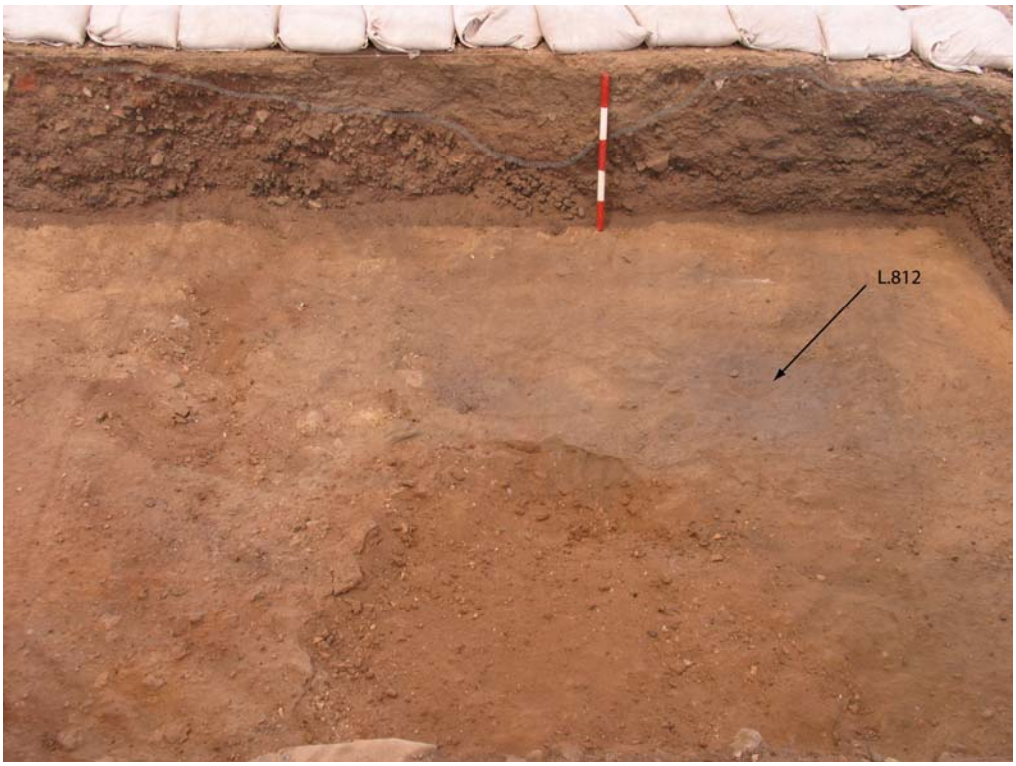


Fig.6.11: The occupation surface of Layer III in Area L, and the location of a fire place (hearth, L.812). We first considered this surface to represent the top of the local virgin soil, but probing below it reveals remains from Layer IV. Note the western wall of the excavation square, showing the original heaps of copper production debris (emphasized with a dashed grey line).

Layer II is a rich accumulation of copper production related debris (Fig.6.9), probably deliberately dumped in this location. The layout of the deposit as heaps, or small 'mounds' of production waste, is visible on the walls of the excavation sequare (Fig.6.11). We did not find any in situ installations, but many fragments of tuyères,

charcoals, slag and ore were collected. No large fragments of furnaces were found, and the identifiable furnace-ceramics were surprisingly scarce. A patch of red clay mixed with stones, slag and small artifacts (Fig.6.9, part of L.808) was identified right on top of the surface of Layer III, creating a pile-like feature in the eastern part of the excavated square. It is derived from deliberately accumulated clay related to the smelting installations (probably decomposed after dumping, although it is also possible that such clay piles had been gathered and prepared to be used [or re-used] in the construction of installations). Similar to the 'slag mound' of Area S, the preservation of organic material in Layer II was extraordinary. Long uncharred branches of acacia, as well as several twigs were uncovered, reinforcing the possibility that wood, and not (only?) charcoals, were used in the smelting process (see Chapter 7). Ground stones of several types were also present, as well as several large pieces of bones. It is interesting to note that camel bones were reported from this context by the Arabah Expedition (C. Grigson, pers. comm. 2009, and see also in Jasmin, 2006). If we accept the original date of Layer II (mostly 13th c. BCE), it is quite early evidence for the use of camels in this region; however, these finds should be now looked at in the context of the new chronological framework provided here (see below). Layer II is also the context from which most of the very scarce ceramic finds came (total of three rims, and a few body sherds, Fig.6.12). The scarcity of ceramic finds is a crucial point for the chronological discussion that follows. In the middle of the 'dump' of Layer II we have found a sherd of Qurayya Painted Ware (EDM 188b, Locus 808, for the chronological/ ethnical significance of this ware see section 6.2.1.4 below). A shell

fragment from the Red Sea and a large piece of ore from this layer are presented in Fig.6.3.

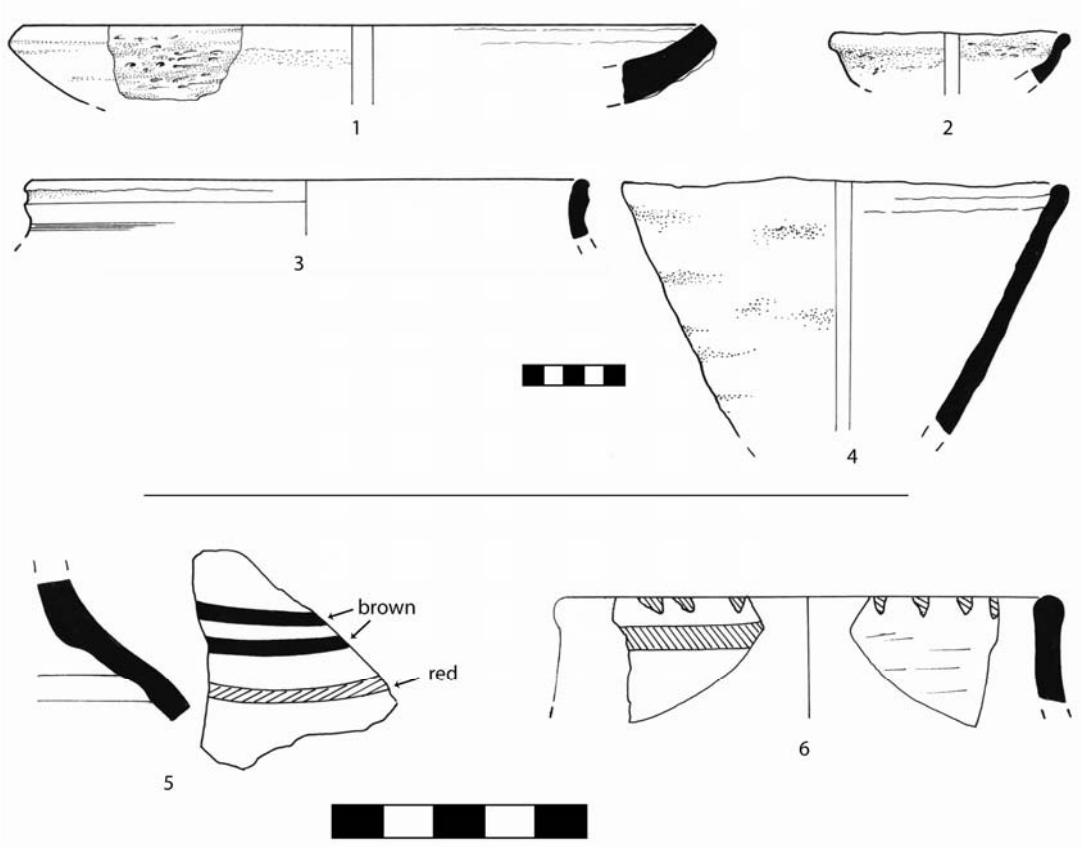


Fig.6.12: Ceramic plate showing *all* of the identifiable sherds found in the 2009 excavations at Timna 30: 1) L.802, B.1107, bowl, Negevite Ware; 2) L.808, B.156, bowl, Negevite Ware (?); 3) L.803, B.155 (cooking pot?); 4) L.804, B.1107, bowl; 5) EDM 188b, L.808 (cf. Rothenberg, 1988:Pl.8.2), QPW; 6) EDM s-1-pF10, upper most horizon of Layer II., QPW; for 5) and 6) cf. Fig.6.23.



Fig.6.13: Various finds from the 2009 excavations at Timna 30. A) EDM (section reference) S1-P2; bottom of a base, probably of Negevite ware, bearing textile imprints (of a mate? used in the making of the vessel, cf. e.g., Cohen and Bernick-Greenberg, 2007); B) Large fragments of ore, Layer II; C) EDM 129, L.801, B.173, shell.

Layer II of the 2009 excavations equals Layer II of the Arabah Expedition. It has similar iron-rich slag and the same characteristics of the various metallurgical finds. The context investigated in 2009 is in the more 'metallurgical' part of the site (or pyrotechnological, as most of the architectural remains of Layer II also in other parts of the site are related to copper production, such as storage pits and crushing areas), in the vicinity of smelting workshops and furnaces recorded by the Arabah Expedition (Table 6.3, Fig.6.4). The material from 2009 indicate a designated dumping area of metallurgical waste, just adjacent to the workshops themselves, with a probable first phase of storing clay material to be used in the workshops.

Layer I in Area L is represented by an intrusive installation dug into Layer II (and III) only partially exposed in the southern part of the excavation square (Fig.6.14). It is defined by the semi-circular wall L.809, made out of local stones (mostly sandstones) and large plate of tap slag, of the type that appears only in the latest phase of copper production in the site. The tap slag were used here as part of the wall that defined the installation.



Fig.6.14: Area L at the end of the 2009 excavations, looking north. Note the probe into the hard surface of Layer II (L.810) in the north part and the Layer I intrusive installation at the southeastern part of the square. The wall of this installation (L.809) is made of local stones and slabs of tap slag.

Although many artifacts related to the smelting process were found in the context of Layer I in Area L (slag, tuyère, charcoal), inside the installation defined by wall L.809, the bulk of materials were ashy bright sediments with a thin layer of fine

crushed ore in the middle of it. The wall seem to define some sort of a working area that was lower than the surroundings, maybe designated for crushing or some other non-pyrotechnical activity. Layer I of the 2009 excavations corresponds to Layer I of the Arabah Expedition.

Area S

The excavations in Area S, located in the 'slag mound' excavated by the Arabah Expedition (Fig.6.5), aimed to clarify the old section and re-expose the different layers of metal production debris. The section is a key feature for the entire site as it contains the three main stratigraphic layers defined by the Arabah Expedition - one on top of the other in the same locale. It took us several days of excavations before we realized that the section's face was not the original one. After cleaning the collapse, the original face of the section had been distinguished in the north side of the area, in a perpendicular section to the slag mound itself (Fig.6.15). It was found that in the 31 years that elapsed since the end of the excavations of the Arabah Expedition the original face retreated about a meter and the slag mound suffered from severe erosion[69]. In the collapse, probably corresponding to Layer II, a relatively large

[69] It seems appropriate to mention here the miserable conditions of Site 30. The site is unprotected, as is the main slag mound discussed here. Although rains are rare in this region, when storms do occur they are relatively strong; severe erosion is evident in Area S, as mentioned above. This situation is quite regrettable, as at this rate the small 'slag mound' will soon disappear and with it an invaluable record of the history of metallurgy. The preservation of different types of slag (and technologies) in one sequence, furnace fragments, tuyères, molds (?) and other archaeometallurgical artifacts, together with rich organic materials (textiles, hide, ropes, grape, date and other seeds) is unique on a worldwide scale. The new project at Timna 30 demonstrates how research methods and analytical technologies change

fragment of a copper casting mold was been found. It has a unique shape, and was probably used for casting ingots. This rare find (as molds, usually made of unfired clay, are poorly preserved in the archaeological record) is discussed in detail in Chapter 7.



Fig.6.15: A perpendicular view to the main section in the 'slag mound' of Timna 30, Area S (looking north). The sharp vertical contact represents the location of the original (1970s) face of the section, and the material to the right of it the collapse (indicated by an arrow).

After the section was cleaned (Fig.6.16), ten different horizons (thin layers) of metallurgical debris have been distinguished (numbered 0 – 9 from top most to bottom; Fig.6.17). The total height of the exposed section, from the top of the 'mound'

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and progress as generations replace one another; as it is now, at Timna 30 nothing will be left for the next one.

to bedrock, was about 1.5 m. For convenience of recording and because of the disturbance caused by installation L.905 (see below) the section was divided into two parts, S-2 in the south, which includes only layer 0 and represents the top most part of the entire ‘slag mound’, and S-1 in the north, which includes horizons 1-9. The metallurgical debris contained mostly slag fragments, usually small broken pieces of tap and furnace slag, with the exception of larger slabs in the highest horizon (0, section S-2). The slag are mixed with tuyère and furnace fragments, abundant charcoals (many of which are embedded in the furnace slag), ashy and clayey sediments, and some ore pieces.

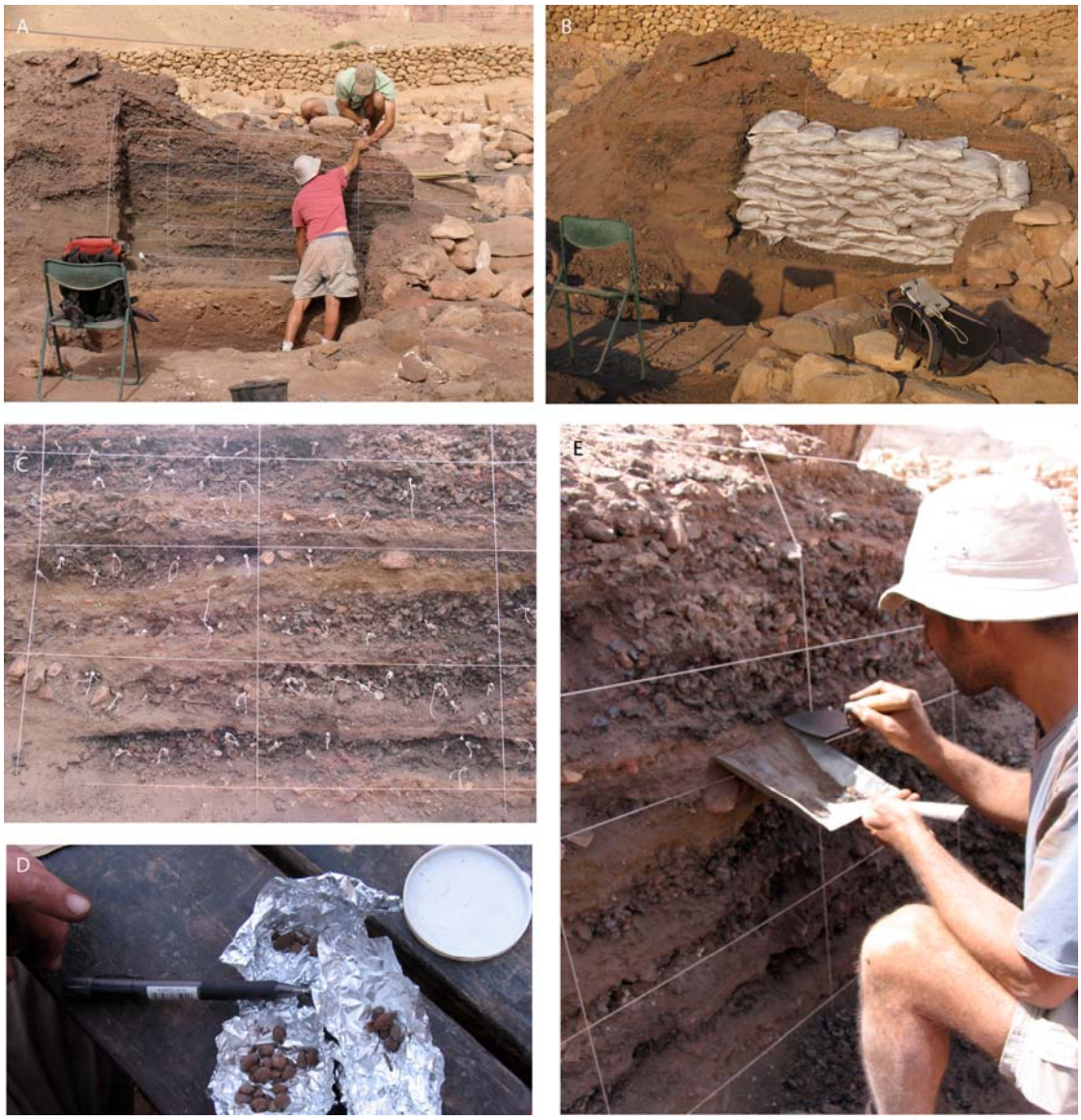


Fig.6.16: Working on the section at Site 30 Area S (cf. Fig.6.4). A) setting up the vertical grid; B) trying to temporarily preserve the section at the end of excavations until a more permanent solution can be built; C) sampling part of the section – each nail represent the exact location of a slag sample (95 samples were collected from this part of the section); D) example of the extremely rich (usually uncharred) organic materials sampled from the greenish horizons between the metallurgical layers (here, mostly olive pits); E) sampling organic materials from the section.

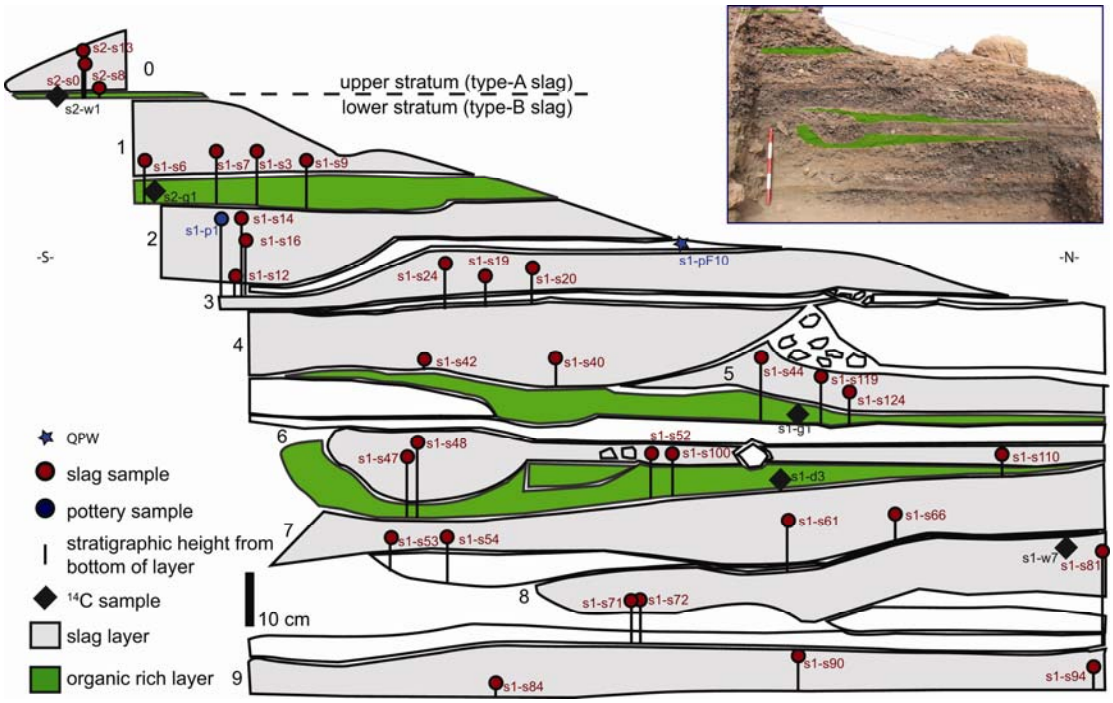


Fig.6.17: Area S, section drawing of the profile in the 'slag mound' (S-1, main section, and S-2 to the left); except from s1-pF10 (QPW = Qurayya Painted Ware) and the ^{14}C samples, all samples shown on this drawing are only the ones that yielded successful archaeomagnetic intensity results. More than a hundred slag fragments were sampled from this section, together with dozens of well-preserved organic samples (see text). Section drawn by R. Shaar.

The slag fragments from the 'slag mound' of Area S were investigated by Bachmann and Rothenberg (Bachmann, 1980; Bachmann and Rothenberg, 1980; Rothenberg, 1990a), and recently by Shalev et al (2009). Two distinct types of slag are present. The visible difference was recognized already by F. Frank who visited the site during the 1930s (see above), while the chemical difference was the focus of the later research. In the current research, samples collected from the mound in 2008 were subjected to mineralogical and magnetic investigation, and the difference was characterized also by distinct magnetic properties (Ben-Yosef et al., 2008a; Shaar et al., 2010). These differences are discussed in more details in Chapter 7. More new analytical data of chemical compositions (XRF) and mineralogy (XRD), as well as

some new insights from petrography (thin sections) are presented in Chapter 8. In essence, one type consists of relatively large fragments (or slab) of Mn-rich tap slag, sometimes more than 20cm in diameter, and the other consists of small fragments of Fe-rich tap slag; both have corresponding furnace slag, and both correspond to distinct stratigraphic location[70]. The large slabs are present only in the latest phase of copper production at the site (Layer I of both the Arabah Expedition and the 2009 excavations, in Area L represented in horizon 0 only), and the small fragments are found in Layer II and III (of both excavation projects). The slag types also correspond to a major difference in smelting technology, expressed by much more comprehensive collection of artifacts from Faynan. A very similar pattern has been discerned in the Iron Age archaeological record of Faynan as part of the current research (although there both types are Mn-rich). The technological change, the similarities between Timna and Faynan, and the new chronological anchor of Timna 30, all have significant implications to our understanding of the organization of production and the society responsible for this enterprise. These implications are discussed in Chapter 7, 9 and 10.

In between the metallurgical horizons in Area S, a few horizons of extremely rich and well-preserved organic materials have been exposed (Figs.6.17, 6.18). The preservation of organic materials in the Timna Valley is unique and does not have any

[70] Similarities between the slag of Layer I and slag of much later periods and the advanced smelting technology represented in this archaeological context caused Avner and Magness (1998) to suggest an Early Islamic date for the large slag at Timna 30. We have clearly demonstrated that those are Iron Age slag; however, the critique by Avner and Magness regarding the Islamic date of '*ring slag*' from Timna 2 is still valid (see section 7.2.6).

parallels in Faynan. Pieces of cloth, ropes and other textile were collected, as well as hide, various seeds (olive pits, grape and date seeds, barley [?], pistachio and more), and wood, including small twigs of acacia trees. Most of those are not charred. A similar inventory of organic materials, including the same variety of seeds, was reported from Site 200, the 'Egyptian Sanctuary' (Rothenberg, 1988, see in particular plates 131-133). The short-lived seed samples have been the basis for AMS radiocarbon dating of the 'slag mound' (section 6.2.1.3). Some of the textile and/or hide were probably part of some of the copper production related activities, including the preparation of tuyère and the use of them. In many artifacts we can still identify the imprints of textiles used in their preparation (parts of tuyères and furnace fragments). Here we have a unique case in which the actual materials used have been preserved (see below).

The Arabah Expedition reported the section in the 'slag mound' as representing the entire stratigraphic sequence of Site 30 (Figs.6.4, and 6.17). We agree that the three main layers are represented in the section (our I, II and III, which correspond to I, II and III of the Arabah Expedition); our Layer IV were not found in this location (only in Area L), and the upper boundary of Layer III is defined quite arbitrarily. We could not recognize any ceramic or technological difference between Layer II and III (neither could the Arabah Expedition), and flowing previous research Layer III in the 'slag mound' has been defined as the lowest occupation phase, lowest metallurgical horizon, and a corresponding installation that is situated on the bedrock

and is associated with the lowest deposits. This installation, L.905, is a rounded storage facility (Fig.6.19) that only a quarter of it was exposed (and removed) in the section. Inside there was a thick accumulation of fine crushed copper ore. We believe the installation was used as a pit for gathering crushed ore as preparation for the smelting process, and that this size of ore grains (a few mm or less) represents the actual size used for smelting. The issue of grain size of ore (and charcoal, flux etc.) was mostly discussed in regard to smelting experiments, and not field evidence that is, as expected, rare; we do not consider this state of ore to be a result of decomposing or natural fragmentation process, as not-crushed and not 'decomposed' ore fragments were also found in other contexts, and the layout of the installation indicates a deliberate storage. The installation that was higher than the activity surface of Layer III, created a 'disturbance' in the section as the fine metallurgic and organic horizons accumulated around it. It is located almost in the center of the original 'slag mound', and right above it is also the highest location of the mound, with remains of the youngest layer. This is the reason for separating S-2 from S-1 (see above). We consider all of the horizons between 8 and 1 to be part of Layer II, although as mentioned above this boundary is somewhat arbitrary.



Fig.6.18: Examples of well preserved organic materials from the non-metallurgical horizons in section Area S. A) rope; B) date seed, C) textile/cloth, D) animal hide (?).



Fig.6.19: Section S-1 in Area S and Installation L.905 in the bottom (part of Layer III). This feature represents a quarter of a rounded storage facility for fine-crushed copper ore (see text).

6.2.1.3 New radiocarbon dates from Site 30

As part of the archaeointensity research a preliminary set of charcoal samples were processed before the 2009 excavations and additional 8 samples were processed after the field work. We sent three charcoal samples embedded/associated with specific slag fragments (collected during 2008), to the NSF AMS laboratory at the University of Arizona. The results are summarized in Table 6.5 and their location is indicated in Fig.6.20. Because we have obtained after the excavation a set of short-lived samples and the control over context was better, the preliminary results are not included in the age model for Area S. Comparing the two sets, however, clearly

demonstrates the "old wood effect", a common problem in charcoal-based dating (see section 4.2.1 above). This difference can be used cautiously as a reference to gauge the possible error from such effect, especially in Timna where acacia trees were the most commonly use source of fuel (in Iron Age Faynan charcoal was usually made of rapidly growing hydrophilic plants, mostly tamarisk, see section 7.2.3). For example, sample IS26-S2-W1 of a twig (average 2sigma = 860) came from just below the charcoal sample IS26C (average 2sigma = 1023); the twig has a younger age in about 160 years from the charcoal, even before modeling. IS26I came from or just near installation L.905 and may represent the age of Layer III.

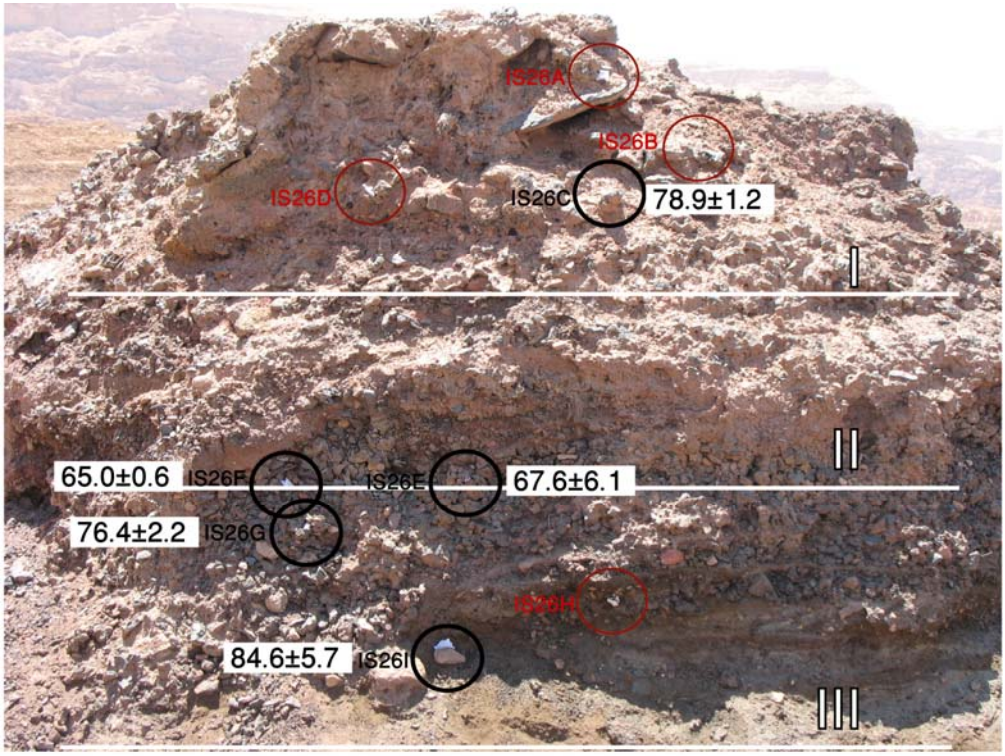


Fig.6.20: Area S before the 2009 excavations (reconnaissance work, 2008). The Layers roughly correspond to the division of the Arabah Expedition (based on Rothenberg, 1980a, but note that the section has severely eroded since). IS26C, IS26F and IS26I were slag with embedded charcoals that were sent for radiocarbon measurements. Cf. Table 6.5 and Fig.6.17 for ^{14}C results and fine stratigraphy. The numbers on a white background are the intensity values of the preliminary stage of research (μ Tesla) (Illustration and intensity measurements, R. Shaar).

Table 6.5 (next page): New radiocarbon dates for Site Timna 30 (calibrated and modeled by OxCal v.4.1, © Ramsey 2010); for explanation about stratigraphic height see section 6.2.1.4 below

Sample name top → bottom	Material	Age BP	1σ cal. BCE	2σ cal. BCE	1σ Modeled	2σ Modeled	Strat. Height	Comments
Area S – post excavation (cf. Fig.6.17)								
IS26-S2-W1 AA86520	wood-twig	2705±35	895-816	915-804	912-836	970-808	152	Layer I (bottom)
IS26-S2-g1-h AA86519	olive pit	2814±34	1006-921	1070-847	971-910	1006-894	135	
IS26-S1-g1-b AA86518	grape seed (?)	2819±35	1011-921	1113-896	1009-946	1037-920	71	
IS26-S1-d3a AA86517	date seed	2893±39	1129-1008	1252-941	1057-981	1101-938	57	
IS26-S1-w7 AA86516	wood bark	2859±34	1111-946	1129-919	1108-1009	1130-943	28	
Area S, pre- excavation (see text, cf. Fig.6.20)								
IS26C AA84739	charcoal	2852±50	1112-934	1208-899				AA86520 was just below this sample
IS26F AA84740	charcoal	2882±38	1124-1006	1209-933				
IS26I AA84741	charcoal	2855±39	1111-939	1188-911				Installation L.905?
Area L (cf. Fig.6.17)								
IS26-EDM188 AA86521	charcoal	2872±34	1116-1003	1192-928	1021-931	1051-917		Layer II, near QPW sherd (EDM 188)
IS26-EDM261 AA86522	charcoal	2858±34	1111-943	1128-920	1033-946	1072-930		Layer III Bottom of fire pit, L.812
L813-B1604 AA86523	charcoal	2803±34	1000-916	1047-847	1050-976	1112-940		Layer IV, oldest context

From the excavations of 2009, 5 short-lived samples from Area S and 3 charcoal samples from Area L have been processes in the NSF AMS laboratory at the University of Arizona (Table 6.5). We used the OxCal. 4.1.6 program (Ramsey, 2009; Reimer et al., 2009) for calibrating the ^{14}C ages as well as for Bayesian analysis. The Bayesian age modeling of the mound (Area S) and the metallurgical area (Area L) follows the methodology described in Levy et al. (2008a), and presented in Fig.6.21 and 6.22.

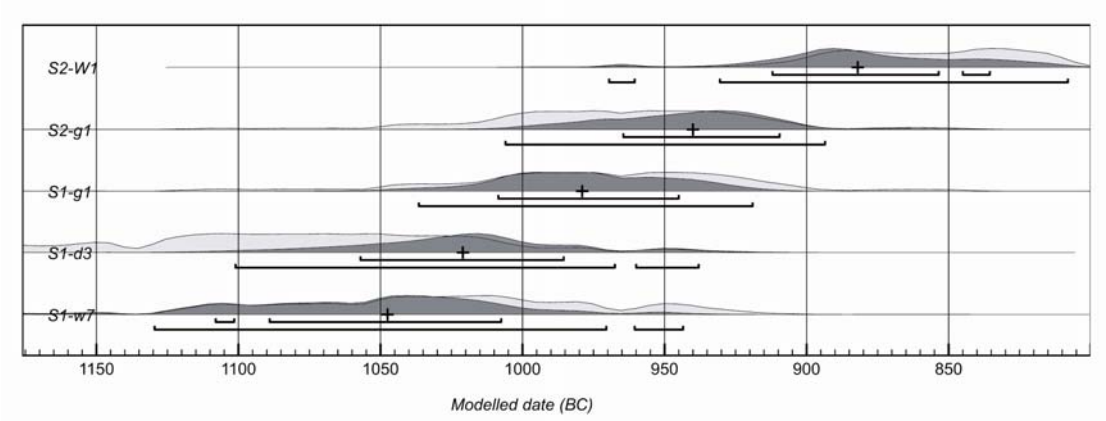


Fig.6.21: Distribution functions of the ^{14}C ages of Timna-30 (Area S), calculated using Oxcal4.1.6 program (Ramsey, 2009; Reimer et al., 2009). Pale grey is the unmolded age. Dark grey is the Bayesian modeled age assuming a stratigraphic order of the samples. Horizontal lines show 2σ and 1σ confidence intervals. Crosses mark the mean (cf. Table 6.5 and Fig.6.17 for locations) (from Shaar et al., in press).

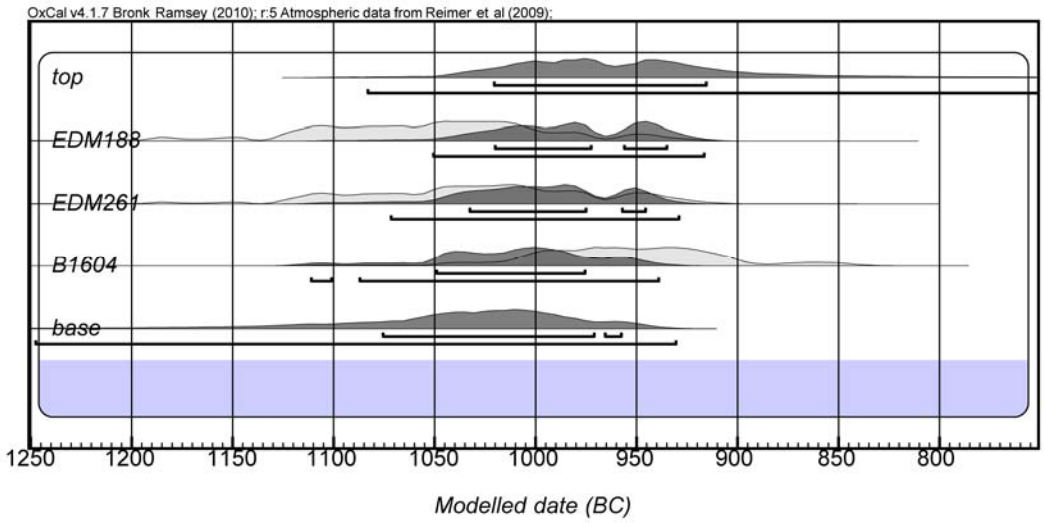


Fig.6.22: Distribution functions of the ^{14}C ages of Timna-30 (Area L), calculated using Oxcal4.1.6 program (Ramsey, 2009; Reimer et al., 2009). Pale grey is the unmolded age. Dark grey is the Bayesian modeled age assuming a stratigraphic order of the samples. Horizontal lines show 2σ and 1σ confidence intervals. (cf. Table 6.5).

The reference for dating Site 30 should now be *only* the post-excavation dates from Area S and L; the preliminary dates from Area S should be regarded only as general support of the age frame, but they are given here mostly as a reference for assessing the old wood effect as mentioned above (in any case, even these dates which evidently are affected by the 'old wood effect' are much younger than the previous chronology of the site). Basically the entire archaeological accumulation at Site 30 spans the late 12th to 9th century BCE, without any date from the Late Bronze Age period, including the lower most Layer IV. The results present a completely different chronological picture than the one suggested by the Arabah Expedition.

In summary, the occupation of Site 30 started in the 11th century BCE, and probably only in the second half of this century as demonstrated by the radiocarbon

data from the charcoal samples of Area L (Fig.6.22) (these ages must represent a lower limit given these samples may be subjected to the 'old wood effect'; these results are in accord with the short-lived samples of Area S, Fig.6.21). The beginning of human occupation at the area of Site 30 is represented by ephemeral copper-production related activities (Layer IV). This phase was succeeded by a more substantial occupation of the site, represented by the hard working surfaces of Layer III and dated to the second half of the 11th – first half of the 10th century BCE. The main copper production phase in Site 30, represented by a sequence of metallurgical debris both in Area L and Area S (Layer II), is dated to the end of the 11th– second half of the 10th centuries BCE. The end of this phase, in the second half of the 10th century, correlates with the date of the Egyptian military campaign to the southern Levant, conducted by Pharaoh Shoshenq I (reigned ca. 945-910 BCE). The last phase of copper production at the site, represented by Layer I with a more advanced smelting technology, is dated to the 9th century BCE. The occupation at the site ended in the end of this century and was not revived after that.

Thus, the new chronological framework for Site 30 shows a striking similarity to the developments of the copper production enterprise in Faynan (Chapter 5). The small scale beginning in the Iron Age I, the peak in production during the 10th century BCE, a major technological change at the end of this century or first part of the 9th, and a wide scale abandonment of Iron Age II copper production sites around 800 BCE were also observed in Faynan. This important observation and its implications on our

understanding of the Iron Age society and historical events in this region of the Levant are further discussed in the following chapters.

6.2.1.4 Timna Site 30: chronological issues in light of the new ^{14}C dating framework

In light of the Arabah Expedition's research at Site 30, Rothenberg (1980a:210) concludes that:

> …the excavations of Site 30 delivered extensive proof that the sites in Timna are not 'King Solomon's Mines' but a mining and smelting establishment of the Pharaohs of the New Kingdom of Egypt. From a historical and geographical point of view, Timna was a part of the vast Egyptian mining area of the Sinai Peninsula – in a time when the Pharaohs ruled Palestine as well.

This conclusion is mostly (or only) based on the ceramic finds from the site. The ceramic assemblages have been used not only as a chronological reference, but also as a means to identify ethnic identities. All of the three main ceramic types reported from the "New Kingdom" smelting sites in Timna have been found in Site 30:

1. "Negebite" (or "Negevite"): coarse handmade vessels (Glueck's "Amalekite ware"), "Negeb-type", or "Negev/Negebite ware".
2. Qurayya Painted Ware (QPW) (Rothenberg and Glass, 1983; Rothenberg, 1998; Tebes, 2007a): polychrome, decorated with geometric designs, stylized birds, animals and human figures; wheel-made, pink-buff ware with a heavy cream-colored slip, decorated in brown, reddish-brown and black (some handmade, majority slow wheel). Glueck did not distinguish it from "Edomite Pottery" (QPW differs from Edomite Pottery by having more sophisticated motifs and grits in section, and fewer types). QPW was found in 1968 in

Qurayya, Hejaz, 70km NW of Tabuk (Parr et al., 1970), where six ceramic kilns indicate that the production of this ware was done at the site. INAA and petrographic analyses in many publications have also confirmed that the Hijaz is the region of this ware. Rothenberg first followed Glueck's ('Edomite') identification, however, after Parr's discovery he termed the pottery "Midianite" after the biblical people described to be living in the Hijaz, while Parr preferred a more neutral term, "Qurayya Painted Ware" (Parr, 1988:74).

3. Wheel-made pottery 'normal types' (Egyptian or locally made). This was the main dating tool in early investigations of the Arabah Expedition (esp. the shallow carinated cooking pots with small folded rims and no handles).

The so-called 'Egyptian pottery' has been used as a key chronological and correlative element. Revisiting the published 'Egyptian pottery' from the site is beyond the scope of the current research. However, we present here the conclusions of the Arabah Expedition in the context of the history of research and the new chronological framework established for the site by our team.

During the first ten years of intensive research in the southern Arabah, including extensive excavations at Site 2 (Table 6.1), the Arabah Expedition did not report the discovery of *any* Egyptian related artifacts from this region. The only chronological concerns that had been raised during this period came from the Iron Age pottery assemblage, and specifically the shapes of some cooking pots that suggested an earlier date *within* the Iron Age than the accepted chronology at the time (suggested

by Glueck); the main claim was that the sites should be dated to the 12th – 11th centuries BCE (and not the 10th and later) (e.g., Aharoni, 1962). It was only with the excavations of Site 200 (the 'Egyptian Sanctuary' - Table 6.1) in 1969 (it had been discovered in 1967) that a new chronological framework has been imposed on the entire Iron Age smelting sites in Timna and the southern Arabah. The stratigraphy and chronology of Site 200 (Table 6.1) became an anchor for correlations and dating, even though they present many complications and discrepancies. Moreover, as the new excavations at Timna 30 demonstrate, the non-metallurgical material culture assemblages and especially ceramic finds, are meager; chronology based on comparative studies of thin inventories of artifacts has a weak basis, and should be done cautiously, if at all. Reviewing the history of research in the southern Arabah (sections 3.2.1 and 3.2.2 above) indicates that a strong "Egyptian" paradigm was behind the conclusions of the Arabah Expedition. The research of the Arabah Expedition was structured around the presumption that Egyptians were involved in all of the copper production activities in the region (at the period under discussion).

Based on the finds from the 'Egyptian Sanctuary' of Site 200, Rothenberg dated the QPW to the late 14th – middle 12th century BCE (Rothenberg, 1988:201, 276, using high chronology for Seti, 1318-1304 BCE). The lack of QPW in Layer I at Timna 30 was the principal argument for the claim that this type of ceramic ended in the 12th century BCE and does not appear in Iron Age II contexts. This created considerable confusion in the research of the southern Levant, as sherds of QPW have

been found in later contexts, including 10th century Khirbat en-Nahas, Rujm Hamra Ifdan (Smith and Levy, in press), and Barqa el-Hetiye (Fritz, 1994a) in Faynan, Tell el-Kheleifeh (Rothenberg and Glass, 1983:75-76), Tawilan (Bienkowski, 2001:261-262) and Edom in general (e.g., Finkelstein, 1992), Tel Masos (Yannai, 1996:144-145; Herzog and Singer-Avitz, 2004:222-223) and ‘Ain el-Qudeirat (Fantalkin and Finkelstein, 2006:20; Singer-Avitz, 2008). Already Singer-Avitz raised concerns about mixed stratigraphy in Site 200, and suggested that QPW is not earlier than the 12th century BCE (but suggested a short-lived phenomenon, see Singer-Avitz, 2004).

In the new excavations at Timna 30 we uncover two fragments of QPW, one from Area L (EDM 188b, L.808, Layer II) and the other from Area S (sample s-1pF10, Fig.6.17; upper part of Layer II; this sample was collected in a visit to the site in February 2010) (Figs.6.12 and 6.23). Both samples are from well-dated stratigraphic contexts. EDM 188b is associated with radiocarbon measurement AA86521 (1021-931 1σ modeled age, Table 6.5) and s-1pF10 (Fig.6.17) is in between radiocarbon measurement AA86518 (1009-946 1σ modeled age) and AA86518 (971-910 1σ modeled age) and closer to the latter. This suggests a 10th century date for the QPW of Timna Site 30.



Fig.6.23: Two sherds of QPW ('Midianite pottery') found during the new excavations of Site 30 in Timna. Both came from well-dated contexts (cf. Fig.6.12). Right: EDM 188b, L.808 (cf. Rothenberg, 1988:Pl.8.2); Left: EDM s-1-pF10, upper most horizon of Layer II (cf. Fig.6.17).

Our results, coupled with the published radiocarbon dates from other sites (Table 6.2) call for revision of the chronology of the major smelting sites in the southern Arabah. The new radiocarbon dates from Site 30 strongly suggest that other smelting sites are also dated to the Iron Age II and that the Egyptian New Kingdom presence in this region was much more limited than previously thought. A revision of the stratigraphy and chronology of Site 200 also seems to be necessary; the assemblages should be looked at again, and their context reinvestigated. It will not be surprising if Singer-Avitz (2004) was correct and the stratigraphy of the 'Egyptian sanctuary' is mixed, and the QPW finds there are *not* associated with the Egyptian phase[71].

[71] If the QPW at Timna Site 200 is indeed associated with Egyptian New Kingdom artifacts, and if the "Egyptian pottery" published for Site 30 by the Arabah Expedition (Rothenberg, 1980a:Pl.211) indeed represents New Kingdom artifacts, it will be tempting to adopt one of the radical suggestions for very low Egyptian chronologies (e.g., James et al., 1991, [and updates in http://www.centuries.co.uk/index.htm]; Rohl, 1995; and see intriguing arguments from the Arabah in Bimson and Tebes, 2009). However, cursory investigations of the publication of the Arabah Expedition suggest that the research in the southern Arabah has been confused: the "Egyptian Pottery" is not represented by any classic types known for the New Kingdom in Egypt and in the Levant (thanks for A. Mazar and M. Martin for their comments), the stratigraphy of Site 200 is problematic, Egyptian artifacts

6.2.1.5 Archaeomagnetic research in Timna Site 30 and correlation with KEN Area M

Further support for the correlation between the archaeometallurgical records of Timna 30 and Faynan has been found in the magnetic intensity values extracted from slag samples in Area S (Shaar et al., in press). To synthesize the radiocarbon data and the archaeointensity values from the section at Site 30 together with those of KEN-Area M (section 5.2.4.2 above, and Ben-Yosef et al., 2009c) we have proposed an age model that is based on stratigraphic height of both radiocarbon and archaeointensity samples from the two sites, and correlation with intensity values of the unique archaeointensity 'spike' features also found in both sites. The age model and its results are described in the following.

Ninety five slag samples from section S-1 and 13 from section S-2 were collected, and their context has been precisely measured with respect to the 50 x 50 cm grid, and documented on a scaled sketch at a resolution of 1 cm. In addition, we took over 50 short-lived organic samples from 16 different locations in the section, five of which were measured for radiocarbon age (Table 6.5).

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outside the 'sanctuary' are scarce, the ceramic assemblages in smelting sites are inherently meager, etc. It is much more plausible that the research of the Arabah Expedition was wanting than a firm foundation for a major revision in the well accepted Egyptian chronology (especially considering the recently published radiocarbon project of Egypt, see Ramsey et al., 2010, whose results support the accepted chronlogy for Egypt [although this paper deals only with Pre/Early dynastic Egypt]).

Fifty-two slag samples, a pottery sample, and a tuyère sample (high-temperature baked-clay nozzle of the bellow pipes) were analyzed from Timna 30 for absolute paleointensity. The measurements were performed at the paleomagnetic laboratories of the Institute of Earth Sciences, the Hebrew University of Jerusalem, and Scripps Institution of Oceanography, University of California, San Diego, for inter laboratory quality cross check[72]. At least three specimens per sample were prepared by isolating small chips, 1 to 5 mm in size, from the glassy outer margin of each slag sample. The chips were wrapped by glass microfiber filters and glued inside 12-mm diameter glass vials using potassium-silicate glue (KASIL). NRM measurements were used as a selecting criterion, rejecting specimens with NRM < 10^{-7} Am^2.

The absolute paleointensity experiments followed the IZZI protocol of Tauxe and Staudigel (2004) and Tauxe (2010), using an oven field of 75 μT or 80 μT (as close as possible to the expected field intensity). Routine checks of the reproducibility of partial thermal remanence acquisition (pTRM checks) were applied every second temperature step. Paleointensity estimates were corrected for anisotropy using anisotropy tensor, which was calculated through the acquisition of TRM or ARM in six positions (x, -x, y, -y, z, -z) in the specimen's coordinate system. Anisotropy of TRM (ATRM) procedure was monitored by comparing intensities acquired at opposite positions, while specimens with a difference larger than 6% were rejected. Non-linear TRM (NLT) behavior (Selkin et al., 2007; Shaar et al., 2010) was checked whenever

[72] The bulk of the measurements were done by R. Shaar as part of his PhD dissertation research. He spearheaded the archaeomagnetic research of Site 30 briefly presented here.

the difference between the calculated ancient field and the oven's field was –exceeds 10 μT. Alterations of the magnetic properties during the ATRM and NLT procedures were monitored by additional TRM acquisition tests at the end of each procedure. Cooling rate correction was applied to the pottery specimens following the procedure described in Genevey et al. (2002), using a slow cooling rate of 10 hours, and fast cooling rate of half an hour at a temperature of 600°C, assuming an ancient cooling rate of 24 hours. The final calculations were accepted or rejected according to a set of accepting criteria parameters, with threshold values listed below.

In this study we follow Shaar et al. (2010) that calculated cutoff values of paleointensity statistics from a set of laboratory-produced samples that were used for testing the paleointensity methodology. Here we define cutoff values for the same paleointensity statistics parameters, and apply them as acceptance criteria. The cutoff values are listed in Table 1, and they were chosen to be as close as possible to the values obtained from the laboratory-produced slag. The cutoff values are strict with respect to similar published paleointenisty studies, and they allow us to accept only specimens that display a stable NRM [MAD < 6°, (Kirschvink, 1980)] with highly linear Arai plots [β< 0.05, (Coe et al., 1978; Selkin and Tauxe, 2000)] over segments of at least 80% of a uni-vectorial paleomagnetic vector [(Fvds > 0.8, (Tauxe, 2010); DANG < 6°, (Tauxe and Staudigel, 2004)]. Sample means were calculated using at least three successful specimens, whereas samples with standard deviations higher than 6% where rejected. In cases where at least 5 specimens passed the selecting

criteria, but the standard deviation was higher than 6% due to one anomalous specimen, we ignored the anomalous specimen in the calculation.

Fig.6.17 shows a scaled cross-section drawing of Timna-30 slag mound. The cross section reveals 10 distinct layers of slag debris, as well as 3 soil layers rich in organic material (see description in section 6.2.1.2 above). The field relations demonstrate a clear depositional sequence of the layers. The locations of slag samples that passed successfully the paleointensity experiments, as well as the locations of ^{14}C samples are displayed on the scaled sketch.

In order to describe the stratigraphic as well as chronological relations between samples within the section, we assigned a stratigraphic height for each sample using the following procedure: we first measured the maximum thickness of each layer, and calculated a composite stratigraphic height of the whole mound using the sum of all thicknesses. Then, a stratigraphic height of each sample was calculated by the cumulative stratigraphic height of the bottom of the layer plus the height of the sample within the layer (shown as a vertical short line in Fig.6.17). This was also the basic methodology used in Ben-Yosef et al. (2009c) for relative stratigraphy of archaeointensity samples from KEN-Area M.

Fig.6.24 shows representative behavior of the slag material in the paleointensity experiments, displayed as Arai plots (Nagata et al., 1963). Fig.6.24a

shows the typical behavior of type-A slag, demonstrating blocking temperatures below 400°C [NRM carrier is Jacobsite, see (Shaar et al., 2010)], and Fig.6.24b shows a typical behavior of type-B slag, demonstrating blocking temperatures between 500°C and 550°C [NRM carrier is non-stoichiometric Magnetite, (Shaar et al., 2010)]. Fig.6.24c shows a behavior that cannot be classified as type-A or type-B according to blocking temperature spectrum, demonstrating an interval of 400°C to 550°C. Such samples resemble the appearance of type-B, and in this study we assign this behavior as type-B slag.

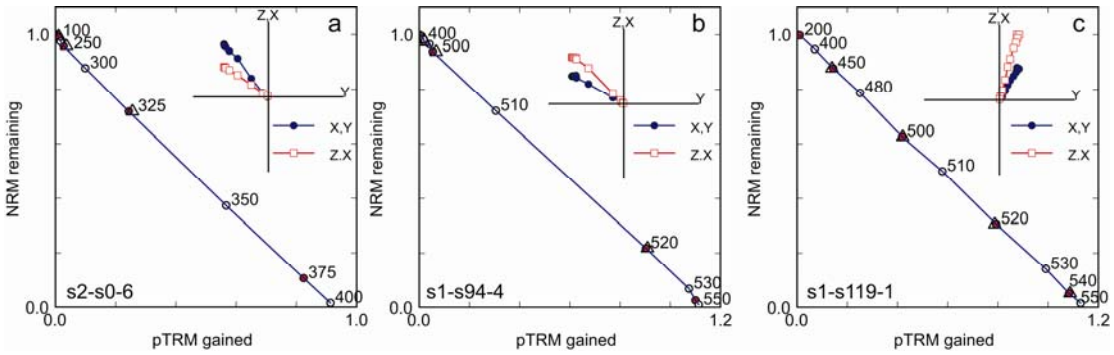


Fig.6.24: Selected Arai plots demonstrating the high quality of the slag samples (from Shaar et al., in press). Open (closed) circles are the Infield–Zerofield (Zerofield–Infield) steps of the IZZI experiments [see (Tauxe, 2010) for details]. pTRM checks, performed every second temperature step are shown as triangles. All plots are highly linear. Orthogonal projections of the zerofield steps, showing convergence toward the origin, are shown in the insets. Red squares (blue circles) are projections on the XZ plane (YZ plane) in the specimen coordinates.

The final paleointensity calculations of a total of 35 samples (3 of type-A slag, 31 of type-B slag, and 1 pottery) that passed the selection criteria listed in Shaar et al. (Shaar et al., in press). Fig.6.25 displays the paleointensity results according to the stratigraphic height of the samples, whereas horizontal error-bars represent the boundaries of the layers in which the samples were found, and vertical error-bars represent the standard deviation of the samples means. The results demonstrate

excellent grouping of paleointensity estimates within closely spaced stratigraphic heights, with exceptionally high values observed in layers (or 'horizons', see Fig.6.17) 0 and 5-6. The same behavior was observed in the archaeointensity dataset of similar age by Ben-Yosef et al. (2009c), describing double-peak geomagnetic spikes. We therefore attribute the Timna-30 anomalies to the Jordanian geomagnetic spikes, and provide a correlation between the two datasets.

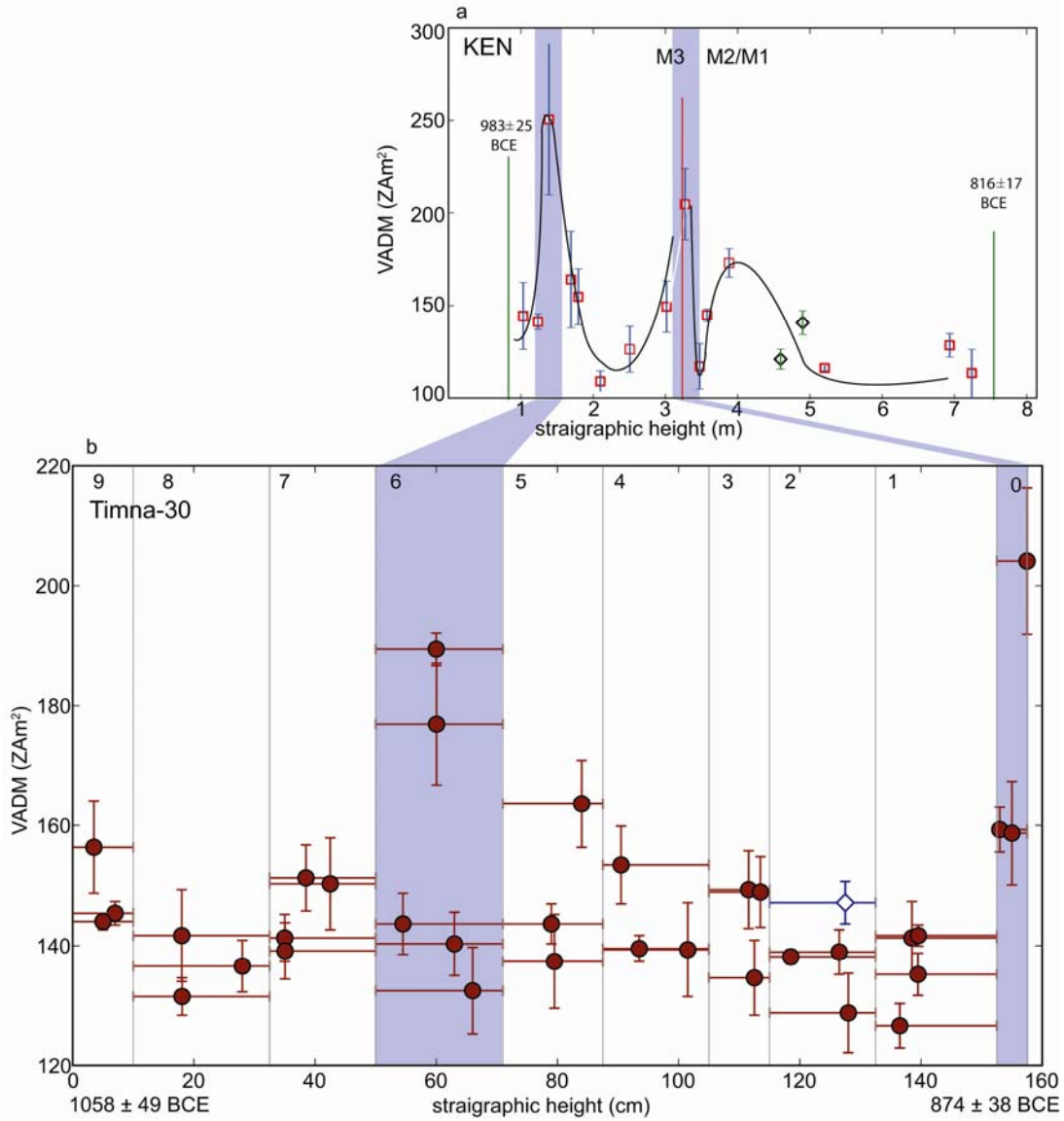


Fig.6.25: a) VADM versus height curve of site KEN (Ben-Yosef et al., 2009c). b) VADM versus height curve of site Timna-30 (Shaar et al., in press). Vertical lines show heights of the layer boundaries, red circles are slag samples, blue diamond is a pottery sample, vertical error-bars are the standard deviation around the sample's mean, horizontal error-bars represent the boundary of the layer. The geomagnetic spikes in both records are highlighted in pale blue. Ages at the boundaries represent the 1σ confidence-boundaries of the section, inferred from Bayesian models of each site.

As described above (section 6.2.1.3), five short-lived samples from different horizons in the section (Fig.6.17) were radiocarbon dated (Table 6.5, including the

output of Bayesian statistical model that assumes consecutive age order of the samples). Fig.6.21 (above) plots the distribution functions of the Bayesian modeled ages. The 95% confidence interval (2σ) and the 67% confidence interval (1σ) of the whole cross-section, inferred from the Bayesian analysis, are 1108-836 BCE, and 1130-808 BCE, respectively. The ^{14}C analysis indicates that the age of the Timna-30 'slag mound' is partly of the same age as the section analyzed in Ben-Yosef et al. (2009c) and Levy et al. (2008a).

Fig.6.25 shows the archaeointensity results from Timna 30 and Khirbat en-Nahas (KEN). The two datasets together demonstrate a behavior of two short-lived double-peak geomagnetic spikes. To further constrain the chronology of this behavior we correlate the two datasets towards a composite age model using a Bayesian analysis of the ^{14}C ages. The assumptions of the Bayesian model, illustrated in Fig.6.26 are as follow: 1) The early geomagnetic spike in KEN is of the same age as the spike found in layer 6 in Timna-30, 2) The late geomagnetic spike in KEN (M3-M2/M1 boundary) is of the same age as the spike in layer 0 in Timna-30, 3) The stratigraphic order of KEN ^{14}C samples are as listed in Levy et al.(2008a) and Ben-Yosef et al. (2009c), and Table 6.6) The stratigraphic order of Timna-30 ^{14}C samples are as illustrated in Fig.6.17.

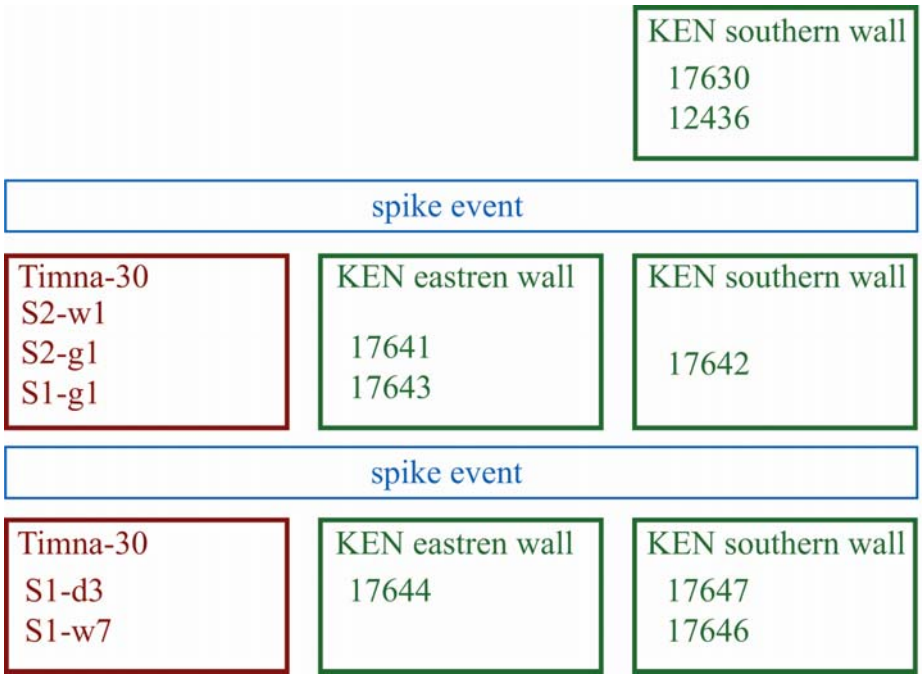


Fig.6.26: The basic assumptions used for the Bayesian model of radiocarbon ages for KEN Area M and Timna 30 Area S (from Shaar et al., in press). The relative stratigraphic order of the samples is taken from Ben-Yosef et al. (2009c:Fig.4) and Fig.6.17, and the T30 – KEN-M correlation is based on the assumption that the two geomagnetic 'spike' events recognized in both sites are the same.

The KEN dataset was split in this study into two sections: eastern wall section and western wall section [see Fig. 4 in (Ben-Yosef et al., 2009c)] in order to enhance the robustness of the model and obtain a better resolution. We used a total of 13 ^{14}C samples from both sites for the model, rejecting two samples that showed an anomalous old age. Sample #17637 resulted in low value of parameter A in the Oxcal program, which is probably biased by an old-wood effect (Levy et al., 2008a), and sample #17647 reduces drastically the overall value of A parameter. The resulting statistics of the combined Bayesian age model are listed in Table 6.6.

Table 6.6: Bayesian modeled ages of Timna-30 and KEN[a]

Sample ID	modeled age BCE (1σ)	modeled age BCE (2σ)	Mean (BCE)	Median (BCE)
17630[b]	886 - 846	902 - 832	866	867
12436 [b]	896 - 866	906 - 836	876	880
spike	908 - 874	923 - 846	888	890
S2-w1	917 - 886	937 - 862	902	901
S2-g1	949 - 909	981 - 899	935	932
S1-g1	980 - 926	1004 - 915	957	955
17641[b]	932 - 897	972 - 877	916	915
17643[b]	973 - 920	998 - 911	950	947
17642[b]	969 - 902	992 - 891	932	928
spike	1012 - 941	1026 - 925	978	980
S1-d3	1033 - 981	1066 - 936	1007	1009
S1-w7	1053 - 995	1105 - 941	1025	1023
17644[b]	1026 - 976	1048 - 942	999	1001
17646[b]	1047 - 993	1086 - 938	1016	1016

[a] Calibrated using Oxcal 4.1.6 program (Ramsey, 2009; Reimer et al., 2009). The stratigraphic model is illustrated in Fig.6.27.
[b] Data is from Levy et al. (2008a).

Fig.6.27 displays the normalized stratigraphic heights of the ^{14}C samples and the paleointensity samples for each dataset. Boundaries of layers are displayed as horizontal lines (4 layers in KEN, and 10 layers in Timna-30). The distribution functions of the modeled ages are plotted according to their stratigraphic heights, and their medians are marked as open circles. We connected the medians of the two spikes in a straight line in order to obtain a linear age-height model for Timna-30 and stratum M3 in KEN. Since the upper stratum of KEN (i.e. M1/M2) is characterized by a different deposition rate (Levy et al., 2008a), we applied a similar approach for M1/M2, connecting the medians of the earlier spike and the most upper ^{14}C sample in a straight line.

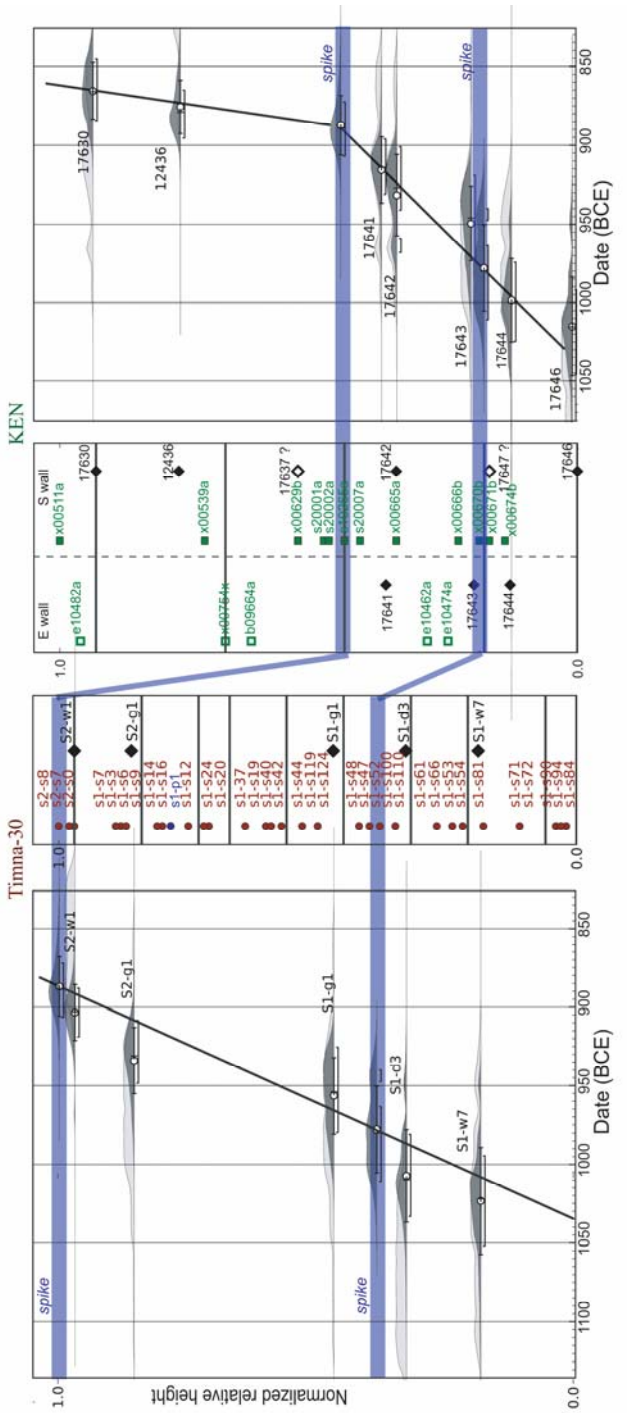


Fig.6.27: Combined age-height model of KEN and Timna-30 (from Shaar et al., in press). Horizontal lines represent relative stratigraphic height of strata boundaries. Red circles represent stratigraphic location of slag samples in Timna-30. Green filled (open) squares represent location of paleointensity samples in KEN southern (eastern) cross- section. Distribution functions of the calibrated radiocarbon dates (Bayesian modeled dates) are colored in gray (black). Linear age-height model of each section is represented as a straight line connecting the medians of the distribution function of the spikes events (pale blue horizontal lines), and the upper most sample in KEN.

The combined archaeointensity curve of Timna-30 and KEN is plotted as VADM versus age in Fig.6.28. An important output of the combined model is that the two datasets agree remarkably with each other, even though they were constructed independently using different materials (type-A slag and type-B slag in Timna-30, and Mn-rich slag, a potsherd, and a furnace fragment in KEN). Only two samples show a difference from the general trend: The early spike recorded in KEN shows a higher value than recorded in Timna-30. This may be a result of the different material used (a furnace fragment versus slag), or simply because the peak of the spike, which may be as short as few years, was not captured by the slag analyzed in Timna-30. Sample e10462a in KEN yields a low value with respect to the curve. Yet, it is hard to provide a possible source for this difference.

The large number of highly accurate paleointensity determinations, sequentially distributed over a short period of probably 200 years, enables a construction of a quasi-continuous archaeointensity curve of unprecedented resolution. Fig.6.28 displays the final curve, at a time-resolution of decades or better, and at an intensity resolution of 6%. This unique curve covers the growth and the decay of two dramatic geomagnetic spikes. The fine description of these spikes places new upper limits for two of the most fundamental properties of field behavior: amplitude and frequency of intensity variations. During the geomagnetic spike between 910 to 890 BCE, the field intensity changed rapidly from a VADM of 127 ± 4 ZAm^2 to 204 ± 12 ZAm^2 in about twenty years. Similar behavior is observed around 980 BCE when the

VADM soared from 143 ± 4 ZAm^2 to 190 ± 2 ZAm^2 (possibly as high as 250 ZAm^2, as indicated in KEN) and then dropped again to 133 ± 8 ZAm^2 over an interval of less than twenty years. We therefore re-define here the maximum VADM variability as >70 ZAm^2 in a few decades and raise the maximum VADM value to at least 204 ± 12 ZAm^2.

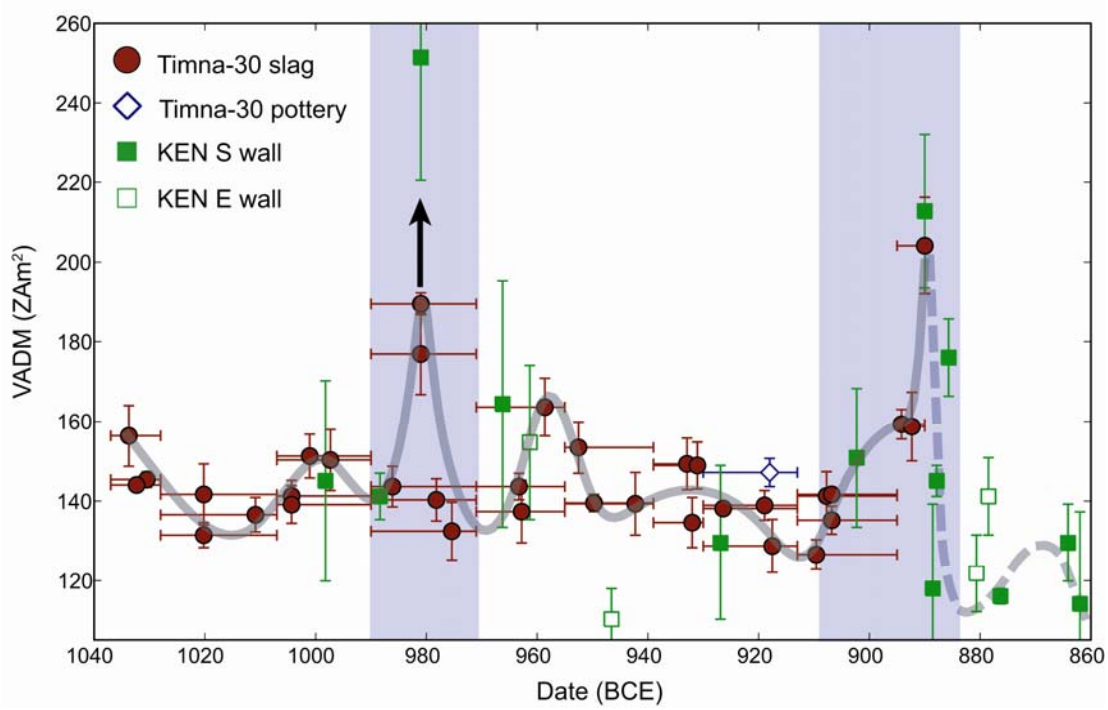


Fig.6.28: VADM curve of the southern Levant from this work. Timna-30 slag (pottery) is marked as red circles (open diamond), KEN (Ben-Yosef et al., 2009) southern (eastern) wall are marked as filled (open) green squares (from Shaar et al., in press). Vertical error-bars represent standard deviation of samples means. Horizontal error-bars in Timna-30 represent the layer boundaries. The solid curve is constructed by a weighted cubic-spline interpolation of the Timna-30 data points. The dashed curve is an interpretation of field behavior after the 9th century spike. Pale blue areas show the two events of geomagnetic spikes. Arrow marks a high spike value in KEN not captured in Timna.

The age model and reference curve (Fig.6.28) enables pinpointing almost the exact year of the technological change observed both in Faynan and Timna archaeometallurgical records. The technological change is much easier to discern in the slag record of Timna 30 as it involves a change in the basic chemistry and

mineralogy of the material (from Fe-rich to Mn-rich; in Faynan, all types are Mn-rich, see Chapter 8 below). The last three samples from Timna 30 in the combined model (Fig.6.28) are from the advanced technology. Thus, the transition occurred between 905 and 895 BCE. Given it is only a model we can refer to this technological transition at occurring around 900 BCE (see Chapter 10 for further implications of this date).

The resulting high resolution curve of changes in archaeointensity (1040-860 BCE) is a useful reference for dating other archaeometallurgical (and also non-metallurgical) sites in the southern Levant. The unique feature ('spikes') recorded for the Iron Age enables using archaeointensity values alone, without corresponding directional values, for dating sites with problematic contexts (section 6.2.3 below) or for achieving finer correlation between stratigraphic sequences of archaeological sites of the early Iron Age.

6.2.2 *Tell el-Kheleifeh*

Tell el-Kheleifeh is an archaeological mound located near the head of the Gulf of Aqaba, approximately 500 meters north of the modern shore line (in Jordanian territory, just near the modern border with Israel). The principal investigator of the site was Nelson Glueck, who, following a suggestion of Frank, identify it with Ezion-geber, Solomon's Red Sea port (1Kings 9:26), as well as biblical Elath (Glueck,

1940a, 1940b, 1940d, 1940c). Glueck defined five different levels at the site, numbered conversely to the accepted system in archaeological research, from top to bottom. Level IV, close to the surface of the mound, had indicative finds from the late Iron Age (7^{th} – 6^{th} centuries BCE), including Edomite inscriptions and Assyrian-influenced pottery. Levels I – III were dated by Glueck to the 10^{th} – 8^{th} centuries BCE and include a fortress (of two consecutive different architectural plans) and an architectural feature that Glueck wrongly interpreted as a refinery of copper, directly related to the mines in the Timna Valley and Wadi Amram to the northwest of the site. The functional interpretation, which had substantial impact on biblical archaeology research at the time ('the Pittsburgh of Palestine', a huge plant for smelting the ore which were only roasted at the sites near the mines, etc.), was rebutted early on by the pioneering research of the Arabah Expedition (see also section 3.1 above). The so-called crucibles of Glueck were found to be crude Negebite cooking pots; his 'flues' the location of decomposed construction beams and the hole structure a granary (e.g., Rothenberg, 1967a) or a stronghold (Pratico, 1993b:24-25, following Y. Shilo). Glueck accepted this critique (1965a); nevertheless, some evidence of copper production probably exists at the site (below).

In 1982 Gary Pratico started a reassessment project ending in a final publication (1993b). His main conclusions were that none of the pottery from the site is older than the 8^{th} century BCE and that the casemate fortress is earlier than the larger offset-inset fortress. New excavations conducted in 1999 (Mussell, 2000) seem

to support Pratico's observations about the date of the ceramics, although the chronological order of the two fortresses was found to be reversed (the off-set in-set wall was found to be *earlier* than the casemate wall).

Because of its strategic location, the stratified Iron Age fortresses found at Tell el-Kheleifeh at the head of the Gulf of Aqaba played a significant role in the regional trade at the time of its occupation. Until further research is done and new information is available, we should accept the late date of the site, and assess the role of the fortress(es) in light of the regional picture during the Iron Age IIB-C. Currently there is no firm evidence of any substantial copper production during this period either in Faynan or in Timna (Tables 5.1 and 6.1), and the relations of the fortresses at Tell el-Kheleifeh to copper production and trade is not clear.

Copper slag (and some ore) has been reported from Tell el-Kheleifeh (Glueck, 1937:13; Glueck, 1938:5, 1940c:93, 1965a:75; Glueck, 1970:115). Six large pieces of slag and many smaller ones, as well as four large fragments and several other pieces of copper ore were collected. The study of Koucky and Miller (1993) showed that some of the slag were fayalitic (iron oxides, see Chapter 8 below) as the majority of the slag in sites Timna 30 and Timna 2. They contained 10% Cu content, thus demonstrate poorer technology (less efficient) than this in Timna itself (Koucky and Miller, 1993). Ore found to be similar to those of Timna (Koucky and Miller, 1993:65), but this observation is not sufficient to eliminate Faynan as a possible source (for provenance

of ore fragments from a nearby Chalcolithc/Early Bronze site, see Hauptmann et al., 2009); nevertheless, Timna would be the simplest assumption.

As part of the current research we had the opportunity to investigate two pieces from Glueck's excavations that have been considered to be slag fragments[73]. One was labeled "Slag, 3/17/38, Surface" and the other "Surface Kheleifeh, 3/17/38, black stone". The first is one fragment, 2 x 1 cm in size, of shiny black and grey material, the second consists of two 1 x 1 cm fragments of mat black material. Both were found to be natural rocks, rich in manganese (possibly used as manganese ores) (Fig.6.29).

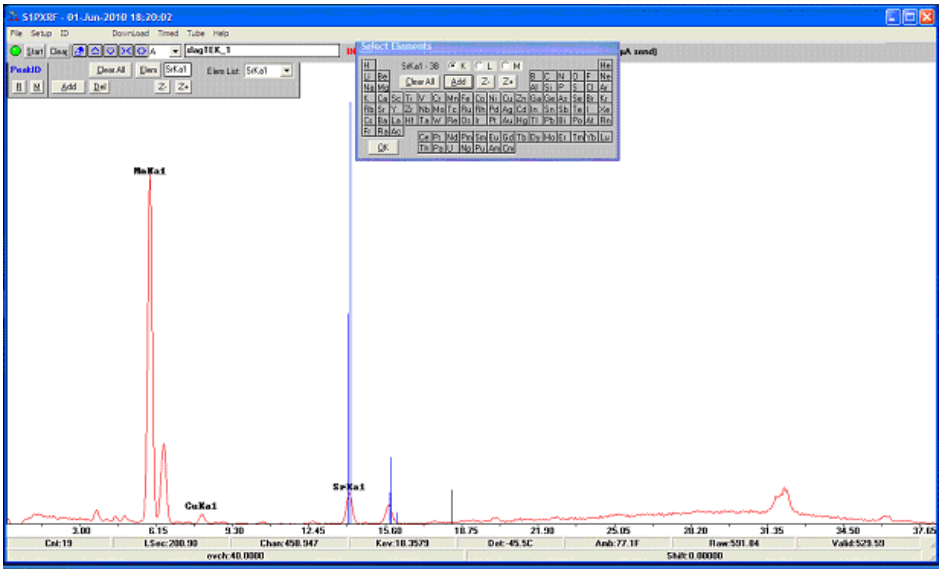


Fig.6.29: XRF reading of sample labeled "Slag 3/17/30 Surface" from Tell el-Kheleifeh excavations. The energy levels show no silicon (Si), a key component in any slag. The reading of the second sample was similar. For explanation see section 8.2.1 below.

[73] The samples were found in the Glueck's collection at the Semitic Museum, Harvard University, by T.E. Levy. They were borrowed for investigation with the kind permission of Adam Aja, Assistant Curator of Collections.

Our results demonstrate that a common confusion in material identification (manganese ore with slag) was part of the early research at Tel el-Kheleifeh. Nevertheless, other samples reported by Koucky and Miller (1993) seem to represent small scale, simple technology copper production at some context of the site. If the late dating of Tell el-Kheleifeh is correct, this simple technology may correspond to the possible late Iron Age smelting sites reported in the current research from Ras al-Miyah in Faynan (section 5.2.6.2 above) and represent a loss of know-how and return to a less sophisticated practice after the sharp break at the end of the 9th century BCE (Chapter 10).

6.2.3 *Timna Site F2*

6.2.3.1 Overview

One of the most contentious ancient metallurgical sites in the Timna region is Timna Site F2. In contrast to the major smelting camps in Timna Valley described above (see e.g., Rothenberg, 1999a, and see Table 6.1 above), Site F2 is located in close vicinity to the copper mines themselves, on the edge of a large pit mine field (Area G, Fig.5.1). It was found and excavated in 1976 by the Arabah Expedition (Rothenberg and Merkel, 1995) as part of a systematic ca. 4 km^2 "Model Survey" of a representative ancient mining landscape. The site is described as a smelting workshop and consists of a few working tools, slag scatter (Segal et al., 1998:Fig.7), fragments

of small tuyères (Rothenberg, 1990a:Fig.14-15), iron-rich copper ore nodules, rough coil-made ceramic sherds and numerous flint tools and debitage. No architecture or stone-built installations were found. In one of the excavation squares, at some distance from the workshop itself, a copper needle and an ash and charcoal pocket (described as "intrusive") were unearthed (Merkel and Rothenberg, 1999:152). Charcoal from this pocket yielded a radiocarbon date of 3030±50 BP (1386-1215 cal. BCE [OxCal2009], Burleigh and Matthews, 1982:165, and Table 6.2 above).

The various finds and the analytical results of the slag fragments (chemistry and mineralogy) were interpreted as representing a "very primitive smelting technology" based on a "trial and error" method in a period when deliberate fluxing was unknown and self-fluxing ore was in use (Segal et al., 1998:233). The smelting installation was not more than a "hole in the ground" powered by simple below pipes (reeds?) whose nozzles were protected by the very small clay tuyères (ca. 2 cm in diameter). The excavated ash and charcoal pocket was interpreted as an intrusive melting furnace, used for re-melting the copper-rich slag by the much later occupants of the site (Merkel and Rothenberg, 1999:152-153).

The proposed Pottery Neolithic age of the site is based primarily on the ceramic finds whose typology and petrography were thought to be similar (except for the matrix) to the Qatifian ware (Merkel and Rothenberg, 1999), a cultural horizon defined for sites in southern Gaza Strip and dated by radiocarbon to (calibrated) mid

6th and most of the 5th millennium BCE (Gilead and Alon, 1988). According to the original research team (Arabah Expedition) of the site, the early date is also supported by (1) the "primitive" (or "incipient") metallurgy, indicated by the extremely inhomogeneous furnace slag ("not yet slag in the true sense of this term", Rothenberg, 1999b:78), lack of stone-built installations, abundance of copper prills, lack of deliberate use of flux (suggesting lack of fluxing know-how), and the "most primitive" tuyères; (2) the "primitive" quality of the pottery (even without the proposed identification of Qatifian ware); (3) the proximity to "primitive pit mining"; (4) scattered flint tools of "prehistoric" date (not published). It appears that the basic guideline in dating the site was what Segal et al. (1998:233) termed as "technological horizon", a concept that embodies the *Standard View* of technology (Pfaffenberger, 1992, and see section 4.1 above) and is based on the supposition of unilinear technological evolution, always from simple to complex.

The early date of Site F2 challenges the common view of the beginning of copper smelting technology. As Hauptmann and Wagner (2007a:69) states, "the proposed dating… not only would predate the beginning of extractive metallurgy in the Levant by a few millennia, it also would raise the know-how of earliest metallurgical techniques in the entire Old World to a hitherto unknown level of sophistication, unparalleled by any other findings." Moreover, such a date calls into question a widely accepted model of the organization of production for the early stages of copper smelting technology in the southern Levant (and possibly world

wide), according to which the smelting activities were conducted by communities of experts inside settlements and *far* from the ore source (Levy and Shalev, 1989a; Hauptmann and Wagner, 2007a, although misunderstood by the latter, both references present the same model).

Avner (2002) and Hauptmann and Wagner (2007) among others used the evidence of relatively advanced technology as an argument against the early dating of the site, while Adams (1997) emphasizes the lack of any parallel Neolithic smelting from Faynan copper ore district, which has substantial settlements from the same period (Adams, 1997). The identification of the ceramic ware as Qatifian has also been disputed (Avner, 2002: f.n. 24). However, the site still may present a unique case in the very early "trial and error" attempts to produce metal, and more decisive evidence is needed. Hauptmann and Wagner (2007a:70-71) conducted a "simplified variant" (due to the small amount of material) of thermoluminescence (TL) measurements on one piece of slagged tuyère that produced a date of 1585-115 BCE (1σ) which suggests a younger age for the site. Following this attempt to independently date technological artifacts, and encouraged by the results of Ben-Yosef et al. (2008b) we conducted archaeointensity experiments on slag fragments from Site F2. Dating the slag material itself complements the study on the tuyère fragment, and stands against a possible claim that the tuyère may belong to the intrusive phase of occupation.

6.2.3.2 Archaeomagnetic dating of Site F2

As part of the current research (Ben-Yosef et al., 2010c) we have applied the archaeomagnetic dating technique to slag fragments from Site F2, obtained from the collection of the "Arabah Expedition" with the kind permission of Beno Rothenberg. The methodology is detailed in section 4.2.2 above, including discussion on its advantages and shortcomings. Here we focus on the results and their implications.

Using one slag fragment of shiny black color with visible green spots, ca. 3cm in diameter, (Sample IS27) we chipped 5 slivers, each a few mm in diameter (specimens IS27a1-5) and placed them in small glass tubes for further processing in the oven. It is worth noting that the specimens needed for archaeointensity experiments are usually very small in size for most burnt archaeological materials. We followed the "IZZI" experimental protocol described by Tauxe and Staudigel (2004) (see also Ben-Yosef et al., 2008a:Fig.11 for graphic illustration of the experiment) in which the first pair of heating steps are done with the zero-field step first and the second with the infield step first. In addition, all successful specimens were subjected to anisotropy of anhysteretic remanence (AARM) correction procedure (compensation for inherent possible bias derived from constraints of crystalline structure, see Tauxe 20010, chapter 10), as well as to non-linearity correction measurements (Selkin et al., 2007). Due to the fast cooling rate of slag material, there was no need for cooling rate corrections (see Ben-Yosef et al., 2008a). The experiments were conducted at the

paleomagnetic laboratory at Scripps Institution of Oceanography (University of California, San Diego).

We show the experimental data from all acceptable specimens in Fig.6.30 and those that were rejected in Fig.6.31. Arai plots are shown in Fig.6.30a,e,i and Fig.6..31a,b. These are generally linear from 200^{o}C to the maximum unblocking temperature of about 520-540^{o}C, although the plots in Fig.6.31 are less linear than those in Fig.6.30. The slope of the line between the two selected endpoints (diamonds) multiplied by the laboratory field gives an estimate of the ancient magnetic field (B_{raw}). These range from 58.4 to 68.7 μT.

The behavior of the remanence vector during cooling is depicted in the vector end-point diagrams (Fig.6.30c,g,k and insets to Fig.6.31a and b). Our acceptance criteria rule out multi-component behavior as displayed in Fig.6.31b; the diagrams in Fig.6.30 generally show simple decay to the origin.

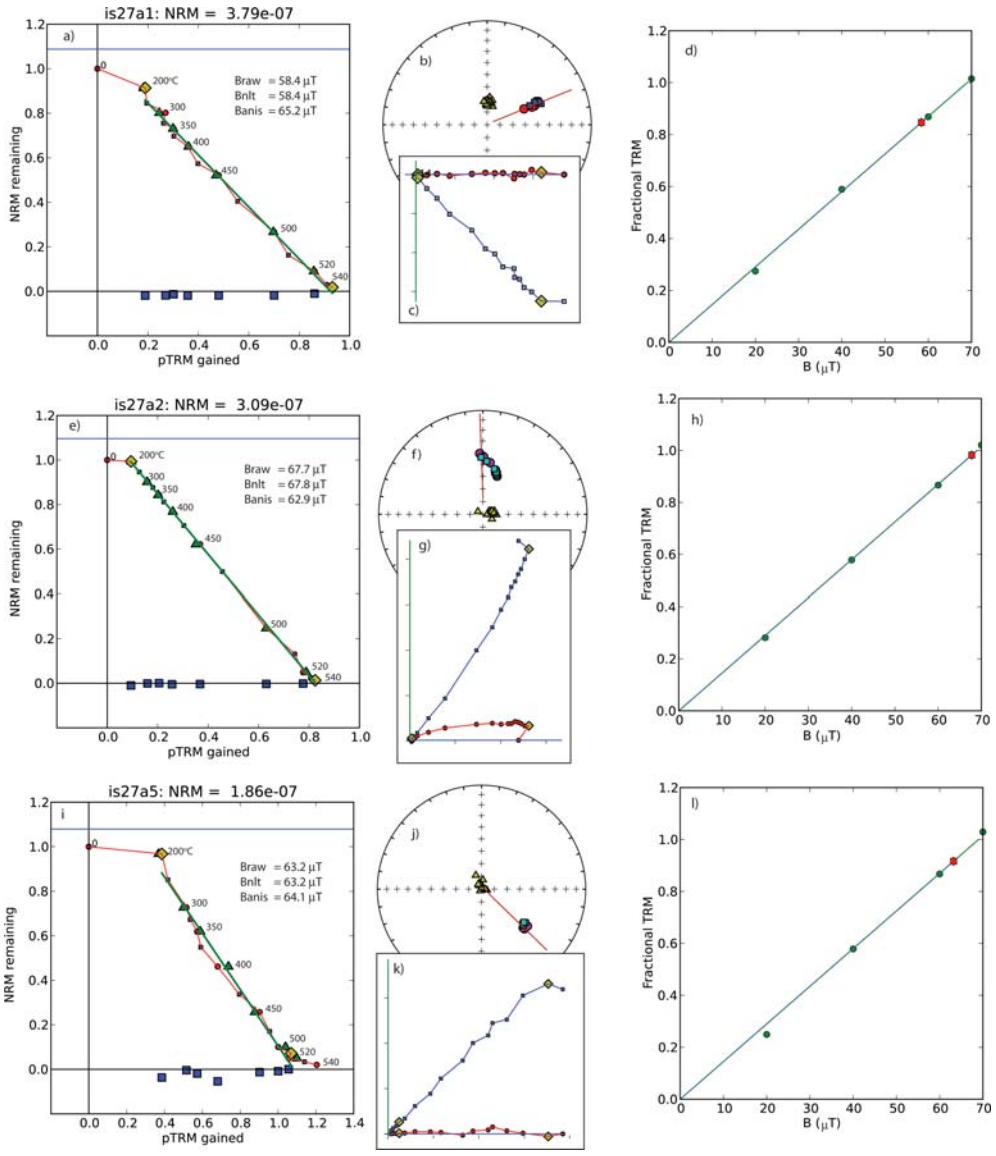


Fig.6.30: Archaeointensity experimental results from accepted specimens from Site F2. a,e,i) Arai plots are shown together with the calculated ancient field (B_{raw},) the slope of green line times laboratory field, B_{nlc}, corrected for non-linear TRM acquisition (see d,h,l), (B_{anc} corrected for remanence anisotropy). Open (closed) circles are the in field first (zero field first) steps. Triangles (squares) are the pTRM (tail) check steps. NRM intensities are in Am^2. b,f,j) Directional results plotted as equal area projections with vector end-point diagrams shown in c,g,k. The solid line from the center to the edge of the equal area projections is the direction of the NRM, which serves as the X axis direction in the vector end-point diagrams. The triangles in the equal area projections are upper hemisphere projections of the directions of the pTRM gained at in-field temperature step. The applied field was at the center of the diagram (in the up direction). Offset from the applied field direction implies significant anisotropy of remanence; requires anisotropy correction. Circles (squares) are zero field first (in field first) steps and closed (open) symbols are lower (upper) hemisphere projections. d,h,l) TRM acquisition experiments. Specimens are given a total TRM by heating to 600 °C and cooled in varying applied fields (dots). The data are fit with the best-fit hyperbolic tangent (solid line). B_{raw} (diamond) is found using the linear acquisition assumption. The actual field required to produce the same TRM (square) is B_{nlt}.

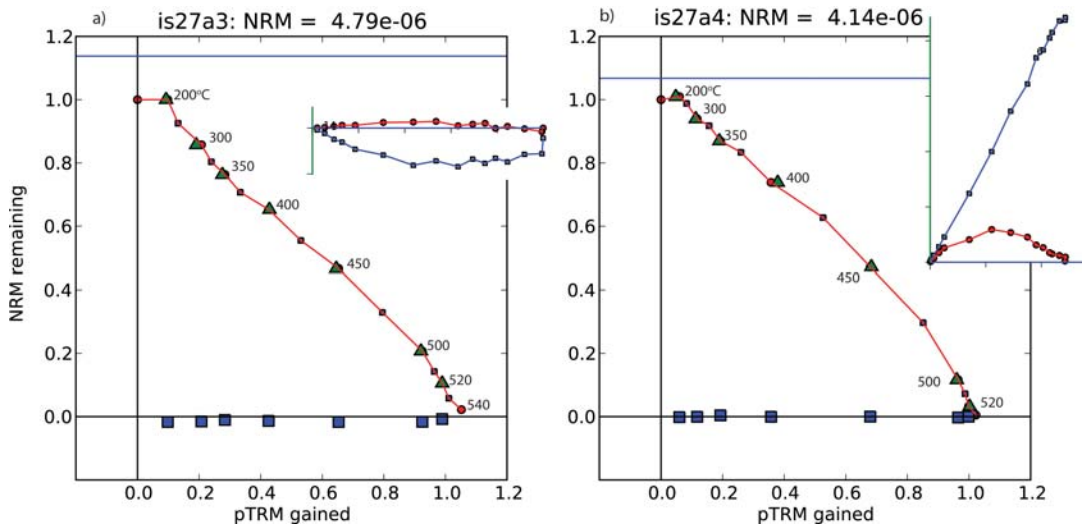


Fig.6.31: Examples of archaeointensity experiment results from rejected specimens. See caption to Fig. 6.30.

The directions of magnetic remanence during the heating experiments are also shown in the equal area projections in Fig.6.30b, f, and j. The remanence directions measured in the zero-field first steps are circles while the infield first steps are squares. The triangles are the directions of the remanence acquired during the infield cooling. Nominally, these should be parallel to the lab field directions (at the center of the diagram) and deviation from this direction (as in Fig.6.30b) indicates that the specimen's remanence acquisition is anisotropic.

In addition to the demagnetization and remagnetization experiments described in the preceding, we also have performed two additional experiments. The first is to check the primary assumption of the Thellier-Thellier technique of a linear relationship between the applied field and the remanence acquired. For this, we heat

the samples to above their Curie temperatures and cool them in laboratory fields ranging from 20 to 70μT. The resulting curves are shown in Fig.6.30d, h and l and demonstrate that the linearity assumption is excellent. The intensity estimates after correction for non-linear TRM acquisition B_{nlt} are identical to the original estimates B_{raw}. The second experiment relates to the anisotropy of remanence acquisition. Specimens are given an anhysteretic remanence (ARM) in nine different directions. From these data the remanence anisotropy tensor can be calculated and applied to the laboratory TRM, correcting for the anisotropy. The intensity estimates after this final correction, B_{anis}, range from 62.9 to 65.2 μT, in much better agreement with one another.

Three out of five specimens yielded excellent archaeointensity results and agree well with each other, giving an average value of 64.1±1.1 μT (VADM of 126±2.2 ZAm^2) (Fig.6.30). Although there is no consensus regarding cut-off values of control variables, the successful specimens pass the strictest standards of the commonly used criteria, among them a straight slope of the Arai plot, single component in the vector end-point diagram. The criteria applied here are the same as those used in our previous study Ben-Yosef et al. (2009c). The other two specimens (Fig.6.31) failed because the curved vector end-point diagrams suggested multi-component remanences.

When comparing the archaeointensity data from Site F2 with the Levantine curve of Ben-Yosef et al. (Ben-Yosef et al., 2009c) and with the global model of Korte and Constable (2005) (Fig.6.32) it is evident that the only time period with VADM values as high as 126 ZAm^2 is around the 2^{nd} – 1^{st} millennia BCE. The relatively high archaeointensity value recorded in the slag sample agrees well with the peak in intensity spanning the Late Bronze and Iron Ages (1400-700 BCE). Although the result from Site F2 matches more than one point on the Levantine curve (heavy line in Fig.6.32), it most probably indicates 13-11 c. BCE smelting activity, given the published ^{14}C date from the site, the similar values to other sites from similar period at Timna (compare with values from sites Timna 2, Timna 3 and Timna 30 published in Ben-Yosef et al., 2008a; Ben-Yosef et al., 2008b) and the history of metal production in the southern Arabah that show proliferation of metallurgical activities in this period.

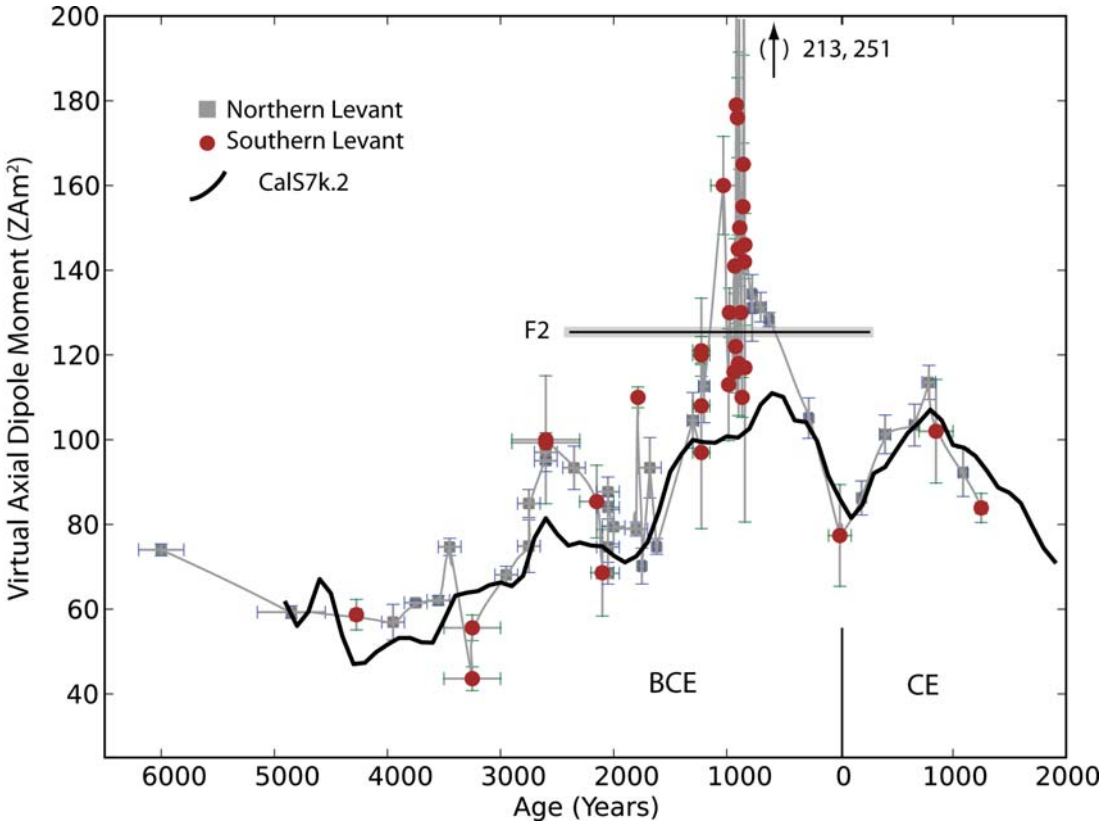


Fig.6.32: The Levantine curve compiled by Ben-Yosef et al. (2009c). Data from the Northern Levant (Syrian data from Genevey et al., 2003; Gallet et al., 2006) and from the Southern Levant(Israeli and Jordanian data from Ben-Yosef et al., 2008a; Ben-Yosef et al., 2009c) are shown as squares and circles respectively. The reference curve (thin black line) is from the CalS7k.2 model of Korte and Constable (2005). The data from F2 are shown as the solid black bar (grey margins represent σ of the average) and are consistent with a 13-11th c BCE age for this site.

6.2.3.3 Implications on modeling the Iron Age society in the southern Arabah

As mentioned above (section 4.1), the previous dating of Site F2 was based on the concept of a "technological horizon"- a common practice for dating archaeometallurgical remains in the work of the Arabah Expedition. Nonetheless, as shown in the new research presented here the archaeological reality has been found to be much more complex. Because we now have better tools for dating remains and

artifacts, our insights about the arrangement and development of the copper production in the Arabah are more detailed. The results from Site F2 demonstrate the complexity of technological practices and developments in the Timna copper ore district.

The archaeointensity age range for Site F2, together with the published ^{14}C and TL dates, confirms a young age of the smelting activities, most probably around the same period of intense copper production activities taken place in the region during the Late Bronze and Early Iron Ages. The so-called "primitive" characteristics of the technology is also well established by various studies of the slag, tuyères and ore fragments, especially in comparison to the advanced smelting technology documented for the Late Bronze and Iron Ages in the region (as mentioned above, the presence of tuyères makes it difficult to claim for "most primitive" technology). A very similar case is the site of Yotvata (site 44, Rothenberg et al., 2006) in which "primitive" technological remains, considered by the excavator to represent Chalcolithic or even Neolithic smelting activities, were dated by archaeointensity to the Late Bronze Age – Iron Age I (Ben-Yosef et al., 2008b:2876) (section 6.2.4 below).

The apparent mismatch of "primitive" technology practiced in a late period can be explained in at least two ways, given that production models are not confined to the "Standard View" of technology (section 4.1 above); both provide important insights on the society responsible for copper smelting in the research area. One interpretation

suggests simultaneous occupation of Site F2 (and other sites of "primitive" technology like Yotvata, see details in Ben-Yosef et al., 2008b, and section 6.2.4 below) with the major Late Bronze - Iron Age I smelting camps in Timna Valley. In this case, Site F2 stands as evidence for segregation within a given society or between different social groups. The know-how of advanced smelting and/or the required organization of production were limited to the social group that maintained the large scale smelting operation (this may explain the walls surrounding the large smelting camps of Timna 30 and 34), while others (the mining workers or different social group for instance), being aware of the potential of copper production from the abundant ore, practiced the simplest technology at hand. Another interpretation suggests that during hiatuses in the major smelting operations (even for a few years) marginal groups of nomads invaded the copper rich area and practiced small scale, “primitive” copper production. This may be a wider phenomenon than has been documented so far, as Site F2 was found in a “Model Survey” of only 4 km^2, and additional similar sites are being documented constantly, some with comparable dating problems (Ben-Yosef et al., 2008b). In the Faynan copper ore district, similar “primitive” Iron Age smelting installations have been found in association with ephemeral campsites that may be linked to this oscillating process of technological intensification and reduction (see Chapter 5). This phenomenon is discussed also in Chapters 9 and 10 below, as part of the general fabric of the Iron Age society and industry in the copper ore districts of the Arabah.

6.2.4 *Other possible Iron Age smelting sites in the southern Arabah valley (Yotvata, Hai Bar, Timna 39b, Timna 149 and Givat Yocheved)*

Four small sites in the southern Arabah yielded archaeomagnetic data indicating Late Bronze – Iron Age smelting activities (Ben-Yosef et al., 2008b). These sites were previously dated to much earlier periods mostly based on the relatively simple smelting technologies represented in their archaeometallurgical record. As we have demonstrated also for the case of Site F2 (section 6.2.3), technology alone cannot be a reliable chronological marker. Also in the case of these sites, the high archaeointensity values suggest that they were active in the same general periods when the relatively advanced Late Bronze – Iron Age technology was practiced, simultaneously with the major smelting sites or intermittently, maybe on a seasonal basis or, more probably, between the main 'smelting campaigns' to the region (given that the smelting activities were not perpetual but rather based on 'campaigns', see Chapter 9 below and section n 6.2.3.3 above).

The sites of Hai-Bar and Yotvata (EB) in the Timna region (Table 6.1) are considered to be early (Chalcolithic/Early Bronze Age) mostly according to the slag type and archaeometallurgical typology. Both were only cursorily studied, Hai-Bar was surveyed (archaeologically by A. Avner and A. Naor, and with a magnetometer, by S. Atkis; Avner, and Holtzer pers. comm. 2002, 2004, 2006. no publication available) and Yotvata was surveyed by the Arabah Expedition (Rothenberg,

1967b:292, there it is described as “a pile of slag with some Byzantine ceramic”), and excavated by A. Avner (not published). The latter has two type of slag associated with different ceramic: large plate of tap slag, dated to the Nabataean period (based on ceramics) and small fragments of simple tap and furnace slag considered to represent Early Bronze smelting based on the simple technology utilized in their production.

Ben-Yosef et al. (2008a; 2008b) and Ben-Yosef (2008a) present results of archaeointensity experiments on slag from Hai-Bar and Yotvata (their the latter site is called ‘Yotvata-EB’ to distinguish the simple technology slag from the Nabataean), and discuss the dating of the sites and the implications of the results. According to our archaeointensity results (Fig.6.33), both are dated to later periods (on the methodology, see section 4.2.2 above). Hai-Bar can most probably be dated to the Late Bronze Age – Iron Age I, the climax of copper production in the area of the southern Arabah. Nevertheless, other periods are also possible for this site, such as the Early Islamic. The results from Yotvata indicate probably Iron Age II smelting activities.

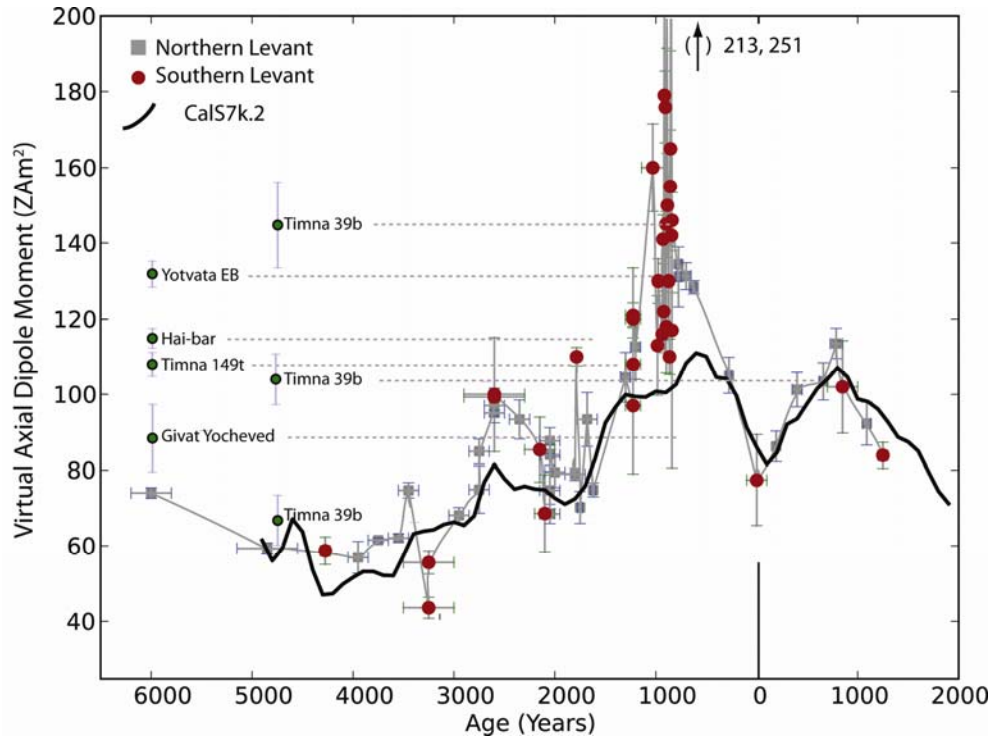


Fig.6.33: The Levantine curve compiled by Ben-Yosef et al. (2009c). Data from the Northern Levant (Syrian data from Genevey et al., 2003; Gallet et al., 2006) and from the Southern Levant(Israeli and Jordanian data from Ben-Yosef et al., 2008a; Ben-Yosef et al., 2009c) are shown as squares and circles respectively. The reference curve (thin black line) is from the CalS7k.2 model of Korte and Constable (2005). The archaeointensity values from sites 39b, Yotvata, Hai Bar and 149 are shown; they indicate a younger age for these sites than the previously purposed, probably the Late Bronze / Iron Age. For experimental procedure and selection criteria see Ben-Yosef (2008b).

Slag from two additional sites, 39b and 149, have yielded high values of geomagnetic intensity that represent late, most probably Late Bronze (149) and Iron Age (39b), smelting activities (Ben-Yosef et al., 2008b). The site of Timna 149 (Rothenberg and Shaw, 1990a, 1990b; Rothenberg and Glass, 1992:144; Rothenberg, 1999b:84-86) is located in the northeastern part of the Timna Valley, and considered by its excavator to be a key site for understanding the development of metallurgy in the Early Bronze Age IV (ca. 2200-2000 BCE). The site consists of two separate parts, one on top of a hill facing the Wadi Arabah and the other on a plain to the west of the

hill. The latter was excavated during 1984 and 1990, and dated by indicative ceramics from well defined context to the Early Bronze Age IV. The excavated area contains two shallow lines of walls, ground stones, slag fragments and clay rods, and was interpreted as a preparation camp for the smelting process which took place on the top of the hill. In addition, the excavation suggests slag processing and probably a secondary melting for the production of ingots (Rothenberg and Shaw, 1990a:7). The date of the finds from the hilltop is much less secure and based primarily on the supposed connection to the excavated site of the hillside. They include slag fragments and stones that were interpreted as part of sophisticated furnaces that replaced the earlier "pit in the ground" type. According to the excavator, they represent a progress in copper production attributed to this period (e.g. Rothenberg and Shaw, 1990b).

Our archaeointensity results (Fig.6.33) show clearly that there is no connection between the metallurgical activities of the hillside and the hilltop. While results from the former are indeed in agreement with data from previous studies and fit well in the Early Bronze Age IV, the results from the hilltop are distinct and represent a different period. This period is most probable the Late Bronze IIB (13^{th} century BCE), when the copper production activity in the area reached a climax under the Egyptian influence. Several other periods are also compatible with our results, including Early Islamic (638 – 1099 CE) and Early Bronze Age II-III (ca. 3000 – 2200 BCE) (Fig.6.33).

The alleged sophistication of the furnaces on the hilltop and the claims for industrial scale of copper production, with a breakthrough in technology (e.g. first appearance of tapping slag) are contentious, regardless of their date (e.g. Avner, 2002). The conclusion about metallurgical activities during the Early Bronze Age IV should be reassessed in light of the recently discovered large scale industry from this period in Faynan district (Levy et al., 2002b), as well as the interpretation of the finds from the excavated industry in the hillside. We suggest that the industry of the hillside included smelting in addition to preparation and processing activities. The clay rods, considered by the excavators to be components of crucible manufacturing (Rothenberg and Shaw, 1990a), might be part of the furnace wall smelting installation, as suggested for the same type of finds from Faynan district (Hauptmann, 1989:129-130; Hauptmann, 2000:149-155). In Faynan, however, the clay rods are part of the walls of wind-driven furnaces common in the Early Bronze II period there.

The site of Timna 39b is considered by its excavator, Beno Rothenberg, to be the most ancient copper smelting installation ever found anywhere (Rothenberg, 1990b and many other publications). Since its discovery (1960) and excavation (1965), there has been a ceaseless debate regarding its age (e.g. Craddock, 2001; Avner, 2002), which has not reached a satisfactory resolution so far.

The site is located in the southeastern part of Timna Valley, on top of a small hill facing the Wadi Arabah plain. It was excavated together with a domestic site

situated ca. 130 m to the southeast, on the lower slopes of the hill (Timna 39a). The final report (Rothenberg, 1978a) connects the two sites and concludes that both are dated to the early phase of the Chalcolithic. Site 39a, a household unit with scarce evidence of ore and metal processing, was first dated primarily by the lithic assemblage (Bercovici, 1978). The Chalcolithic age was confirmed later by radiocarbon measurement yielding the date of 5485±45 BP (4351±98 BCE 95.4% probability using OxCal 4.0) (Rothenberg and Merkel, 1998a). Site 39b is a "pit in the ground" smelting furnace, surrounded by many fragments of small furnace slag with homogeneous visual characteristics (Fig.6.34). It is 30-40 cm in diameter and ca. 40 cm in depth, although its partially stone lining suggest an upper structure of additional 40 cm (Rothenberg, 1978a). It was dated to the early phase of the Chalcolithic primarily by relying on the typology of the lithics uncovered in the small excavation around the furnace, the slag and furnace characteristics and the supposed connection to Site 39a (Rothenberg, 1978a, 1990b; Rothenberg and Merkel, 1998a).



Fig.6.34: The furnace at Site 39b: Chalcolithic or simple technology practiced in a later period? The research here shows that in this area copper smelting took place in several periods, including probably the Iron Age and the Chalcolithic. The installation itself probably dates to the later period, although no firm evidence is currently available.

Critical reservations regarding the early date of the furnace in Site 39b were raised, even before the publication of the final report, by J.D. Muhly (1973b; 1976a). He extended his criticism later on (Muhly, 1984b), and was followed by various of other scholars (e.g. Hanbury-Tenison, 1986:160; Weisgerber and Hauptmann, 1988:53; Adams, 1998; Craddock, 2001:156; Avner, 2002). In general, these objections for this early date are based on two aspects of the archaeometallurgical research of the site. The first is related to a comprehensive understanding of the metal production in the Chalcolithic (e.g. Shalev, 1994), which claims that copper smelting

was practiced within villages which could have been located far away from the ore. This is the case in Beersheva valley (e.g. Levy and Shalev, 1989b; Gilead et al., 1992), and in recently discovered industries near Aqaba (Hauptmann et al., 2004). The second aspect is related to the quality of the archaeological evidence (see updated summary and discussion in Avner, 2002).

The main arguments regarding the quality of the archaeological evidence include reassessment of the technology, reservations of the models employed by the investigators and a previously unpublished radiocarbon date from the furnace itself. The furnace structure and the characteristics of the slag were used by Rothenberg as evidence for a suggested technology that is even earlier than the Chalcolithic of Beersheva Valley (Rothenberg and Merkel, 1998a:3). However, revisiting of the evidence suggests an advanced, presumably late industry (e.g. Avner, 2002). The supposed connection between Site 39a and the furnace is not decisive, and the original publication of the lithic assemblage did not distinguish between the two sites (Bercovici, 1978) creating ambiguity in the interpretation. Most surprising is the radiocarbon date from the furnace, yielding the result of 1945±309 BP (Burleigh and Hewson, 1979) (761BCE – 645CE, 95.4% probability, using OxCal 4.0). Rothenberg, who characterizes this date as “Late Bronze Age” (Rothenberg, 1990b:11), explains the date as being derived from refill of the excavation pit that was brought from a different location. Others suggest the possibility of reusing the smelting location and/or installation in the course of more than one period (Avner, 2002).

Revisiting the site in 2004-5, we collected 10 samples of furnace slag from the furnace itself and its close vicinity. Four samples (based on 16 specimens) passed all of our rigorous selection criteria and yielded reliable archaeointensity results. They clearly show three distinct groups of ancient geomagnetic intensity (Fig.6.33), implying at least three periods of copper production in the site of Timna 39b. The group showing the lowest intensity (66±7 ZAm^2 VADM) might indeed represent copper smelting during the Chalcolithic. It is within a one standard deviation agreement with the archaeointensity results obtained for the Chalcolithic site of Shiqmim (58±4 ZAm^2 VADM) and is consistent with the general relatively low intensity throughout this period. Nevertheless, this group is compatible with copper smelting in other periods, mainly the Early Bronze Age I. The middle group, as well, might represent several different periods of copper production including Early Bronze Age II-III, Middle and Late Bronze Age, and Byzantine – Early Islamic periods. The latter corresponds to the radiocarbon measurement from the site. The group with the highest intensity (145±11 ZAm^2 VADM) fits best to the Iron Age I period, the latest phase of the intensive copper production in Timna region under the Egyptian influence (Rothenberg, 1999a).

The archaeointensity results from Site 39b provide additional support for Rothenberg's early Chalcolithic dating, although they do not decisively prove it. Moreover, there might be a difference between the dating of copper production in the

site and the dating of the installation found *in situ* today. While our results support the idea that smelting activities occurred in more than one period, the installation itself might represent only the latest one.

We do not find the evidence of copper production near the origin of the ore during the Chalcolithic to be unique. The evidence of metallurgical activities in the Chalcolithic site of Timna 39a (Rothenberg, 1978a), together with other small sites in the Timna region such as Yotvata hill (Rothenberg et al., 2004b) and 250b (Rothenberg and Shaw, 1990b) might suggest small scale domestic copper production in periods as early as the Chalcolithic, although this evidence is problematic (e.g. Avner, 2002; Hauptmann and Wagner, 2007b) and more research is needed. Moreover, in the light of other sites in the Wadi Arabah, the connection between sites 39a and 39b is a reasonable supposition. In many cases, the "cold industry" of crushing the ore and flux and processing slag was done at the foot of the hill, while the pyrotechnological industry, taking advantage of the wind, was done on the top of the hill (Site 189a: Avner and Naor, 1978; Rothenberg, 1990c; Site 201a: Rothenberg, 1999b; e.g. Avner, 2002). There is no doubt that the vast majority of data for Chalcolithic smelting in the southern Levant comes from the Beersheva region and supports the model of specialized industry far from the ore source. However, the new archaeointensity data points to more than one mode of production during the 5th millennium BCE.

The site of Givat Yocheved (also known as Nahal Amram and Timna 33) is located 15 km south of Timna Valley, near an intensive mining district. It consists of several structures and mounds of broken tapping slag. The Arava expedition dated the site to the New Kingdom (14^{th}-12^{th} centuries BCE) (Rothenberg, 1967c:41-50; 1990c:71 Footnote 23), a date that was confirmed with a radiocarbon measurement from the bottom of the slag mound (Rothenberg, 1990c:71 Footnote 21). However, based on the advanced metallurgical technology evidenced at the site, other scholars date the site to the Early Islamic period (Avner and Magness, 1998:42, 57) and point out another radiocarbon measurement from the same site, yielded a date from the 8^{th} – 9^{th} centuries CE (Burleigh and Hewson, 1979:350).

Our archaeointensity results (Fig.6.33) fit neither of the suggestions above, and indicate most probably copper smelting in the Early Roman period. A date from the Middle Bronze Age or earlier (Fig.6.33) is inconsistent with the advanced tapping technology, and the Early Roman period is compatible with the intensive mining of copper ore from this period in the close vicinity (Willies, 1990; Avner and Magness, 1998:40). However, the site very likely represents more than one period, including the New Kingdom, Iron Age and Early Islamic as well.

All of the sites discussed in this section (excluding Givat Yocheved) are relatively small and, probably together with other unknown small scale production sites, are less studied than the impressive smelting camps in the region. Such sites

should be taken into consideration when attempting to present a reconstruction of the organization of copper production in the area and the society responsible for it (Chapter 9).

6.3. Discussion

To understand the regional dynamics of the role of copper technology on social change in the southern Levant, this project carried out original field work and research not only in Jordan's copper ore Faynan district, but also in Israel's ancient mining district in Timna located ca.100 km to the south. In the southern Arabah there are only four 'large' smelting sites dated to the Late Bronze – Iron Age, all are located within the Timna Valley and in some distance from the mines themselves (Fig.6.1C, Sites 30, 34, 185 and 2, Table 6.1). The evidence of smelting in all of these sites together indicates a much smaller scale of production than the contemporaneous sites in Faynan. While slag in Timna are estimated to be in the range of a few thousands tons in total (Bachmann and Rothenberg, 1980), the total slag in the Iron Age sites of Faynan are estimated to be in the range of 100,000 tons and above (Hauptmann, 2007:147).

One of the main smelting sites of the southern Arabah, Timna 30, is now dated to the Iron Age only, with smelting activities spanning the 11^{th} – 9^{th} centuries BCE. The timeframe and technological developments of Timna 30 correlate with those

established recently for Faynan (Chapter 5). This correlation, together with striking similarities between the archaeometallurgical material culture of the two regions (Chapter 7), strongly suggest that the same social groups are responsible for the smelting operations along the entire Arabah *throughout* the Iron Age I-II (Chapter 10). The date of the other main smelting sites in the Timna Valley should be revisited in light of the new chronology of Timna 30. We believe that the other sites generally represent the same chronology, with possible limited Egyptian New Kingdom smelting taking place in Timna 2. Accordingly, the extensive mines (more than 9,000 blocked shafts, Conrad and Rothenberg, 1980), should probably be dated mostly to the Iron Age.

A few marginal sites represent an entirely different type of smelting activity, based on simple technologies. These sites, with their parallels in Faynan, suggest a complex and segregated organization of production, with smelting practiced simultaneously or intermittently with the practice of advanced Iron Age technologies in the main smelting sites (Chapters 9 and 10).

The copper mines in the Timna Valley (Table 6.1, Fig. 6.1C) represent extensive Late Bronze and Iron Age operation and demonstrate a rather sophisticated 'geological' knowledge. Because of geological differences between Faynan and Timna (Chapter 2) the *technological choice* regarding which of the copper bearing formations should be exploited was different in these two regions, and consequently

also the mining techniques and the mines' layout. In contrast to Faynan where the Mn-rich Burj formation was exploited *throughout* the Iron Age, in Timna the focus was on the sandstone formations whose copper ore is much more accessible than that of the Timna formation, the geologically-equivalent of the Faynan's Burj in the southern Arabah. Consequently, the flux used (deliberately or not) at Timna was iron oxide (common in the sandstone formations), except for a deliberate use of manganese ore in the smelting process evident only in Timna 30 Layer I (Chapter 9). Craddock's (1995:69) conclusion that the mines in Timna "were small, shallow and, although linked underground, display little evidence of any overall mining strategy, or of any knowledge of the possibilities of ventilation or drainage" is problematic. We believe that Craddock overlooked a number of the mine's attributes that indicate a well organized operation with advanced techniques (cf. Rothenberg, 2005). Similar to the Iron Age mines at Faynan (Chapter 5), the miners in Timna used the best method available to exhaust the ore resource that took into consideration the geological variables on the ground. Many of the shafts were part of a major reconnaissance project, intended to locate major ore veins in the underground sandstones, situated usually below alluvial terraces. The array of blocked shafts suggests attempts to achieve a full coverage of any potential ore deposit. The relatively shallow ore deposits in Timna (compared with Faynan) allowed relatively shallow shafts, and hence there are multiple and densely located shafts per mining complex. This situation also makes the 'double shaft' system recorded in Faynan less relevant in the region of the southern Arabah. The 'double shaft' was critical in Faynan because the number of

shafts per mine was limited and the shafts were much deeper, making it more efficient to work in double shafts for hoisting ore and people in one spot. The uncertainties mentioned above about the date of these mines is not crucial for the general discussion on Iron Age copper exploitation, as it is most probable that the early Iron Age (12th – 9th centuries BCE) copper mining techniques and strategies were the same as those applied by their Late Bronze Age predecessor miners. Neither in the southern Arabah nor in Faynan is there any indication of a significant technological change in mining methods *within* the Late Bronze and Iron Ages.

The Egyptian presence in Timna and their role in copper exploitation activities also await further clarification. The evidence from Site 200 in Timna ('the Egyptian sanctuary'), a few rock drawings, limited radiocarbon dates (only from Site 2, Table 6.2), and possibly some ceramic assemblages[74], indicate a (limited) presence of Egyptian New Kingdom officials in the region during the Late Bronze Age – very beginning of the Iron Age (13th – first half of the 12th centuries BCE; probably Seti I to Ramesses V). Various aspects of the archaeological record for this period demonstrate that the copper exploitation activities were practiced mostly by people from local societies, with some degree of Egyptian control / influence over the production system (in particular, the evidence from Site 200, see Rothenberg, 1988; and cf. Avner, 1999). Textual evidence from Egypt has been linked to Timna (e.g., Levene, 1998). If

[74] The reports on *Nilotic* ceramics in the Timna sites are still a matter of debate, especially in light of our new dates for Site 30. The lower chronology of the site suggests that the 'Egyptian' pottery assemblage was misidentified, either regarding its date ('New Kingdom') or its affiliation with Egypt in general. Because this project is not focused on ceramic, these issues await further research.

the identification of Timna is correct, this is another indication of strong Egyptian interest in the natural resources of the Arabah. We believe that the relation between Egypt and the copper production of the Arabah, including Faynan, is a key to understand technological and social developments in the region *throughout* the Late Bronze and Iron Ages. Although on the one hand the results of our new excavations at Timna 30 suggest much less Egyptian involvement in the production system than previously assumed, when examining the *long dureé*, from the 16th to the 6th century BCE, the role of the nearby empire in triggering social and technological processes has to be carefully considered. It appears that both the New Kingdom and the later Dynasties (including the 22nd Dynasty and Shishak's campaign) have been involved in the copper production system with varying degrees of intensities. Even in periods when there was no Egyptian presence in the mining and smelting sites themselves, Egypt most probably played a role in shaping the market and consequently processes in the Arabah. Egypt was a major consumer of imported copper, even during the Third Intermediate Period when Egypt was weak and with a fragmentary kingship (Ogden, 2000:150). These issues are discussed in greater detail in Chapter 10, including the implications of our new results both from Faynan and Timna.

7. The material culture of Iron Age copper production in the southern Levant

To model the dynamics of Iron Age copper technology and diachronic social change during this formative period in the ancient Near East, this chapter presents an in-depth analysis of the full range of archaeometallurgical material culture from new excavations primarily in Jordan (Faynan), and to a more limited degree in Israel (Timna). A comprehensive understanding of ancient metal production processes and adequate reconstructions of technologies and installations are based on multiple avenues of research, including field work, visual investigation and documentation of artifacts, ethnoarchaeological studies, experimental archaeology, analytical investigations, and more. Early on in the archaeological research of the Arabah it was realized that the investigation of ancient copper production's material culture required a different, multidisciplinary research approach (e.g., Glueck, 1936b). Intensive collaborative work in archaeometallurgy was pioneered (world-wide) by the research of the Arabah Expedition, headed by Beno Rothenberg and focused on the metallurgical remains in the (south-) western side of the Arabah Valley (section 3.2.1 above). Twenty five years of research (1959-1984) on the metallurgical remains of the Timna region has yielded a substantial amount of technological information based on field work (e.g., Rothenberg, 1999a; Rothenberg, 1999b), studies of artifact collections (e.g., Rothenberg, 1990a), analytic investigations (e.g., Bamberger et al., 1986; Leese et al., 1986; Gale et al., 1990; Tite et al., 1990) and experimental archaeology (e.g., Bamberger and Wincierz, 1990; Merkel, 1990).

The archaeometallurgical remains of Faynan were studied intensively by the German Mining Museum team, also as a multidisciplinary project (1982-1992, section 3.2.5 above). The German research had already recognized the similarity between the Iron Age archaeometallurgical record of Faynan and the Late Bronze / Iron Age copper production remains at Timna (e.g., Weisgerber, 2006). In the current research we were able to re-confirm this similarity and to further refine the correlation between the two copper production districts *throughout* the Iron Age (see below, and chapter 8). Moreover, the results of our new excavations in Timna Site 30 (section 6.2.1 above) challenge the accepted chronological framework of Timna, indicating that the general chronology of the main smelting sites is similar between the two sub- regions of the greater Arabah valley system (see discussion in section 6.2.1.4). This situation allows us to rely on previous conclusions, both of the Arabah Expedition in Timna and the GMM team in Faynan, in the interpretation of the archaeometallurgical record excavated as part of the current research. Our intensive excavations in Iron Age copper production sites have resulted in a substantial (and unprecedented) inventory of copper production-related artifacts presented for the first time here. These artifacts, together with tight control over their archaeological and chronological context, provide additional and more refined information concerning Iron Age smelting technology in the southern Levant.

7.1 Archaeometallurgical inventories from the Arabah

Previous to the research of the University of California, San Diego in Faynan (of which the current work is a part), Iron Age and Late Bronze Age archaeometallurgical artifacts from the Arabah were recorded and collected primarily as part of archaeological surveys. Only a few excavations of archaeometallurgical sites took place (Tables 5.1 and 6.1), including Sites 2 and 30 in Timna (the latter was re-excavated as part of the current research, section 6.2.1) and probes at Site 5, Khirbat en-Nahas and Barqa el-Hetiye in Faynan. The technological reconstructions of the Arabah Expedition were based primarily on the results of the excavations in Sites 2 and 30. In Faynan, technological reconstructions were based primarily on the archaeometallurgical finds from Site 5, where several furnace bases and other installations were uncovered (at Barqa al-Hetiye and Khirbat en-Nahas the excavations focused on architectural features without a targeted archaeometallurgical investigation). In addition, the Arabah Expedition surveyed and probed the typical 'Late Bronze Age' mines in the Timna Valley, and the German Mining team conducted several shallow probes in 'slag mounds' at Khirbat en-Nahas and Khirbat al-Jariya, as well as limited excavations of several mines in the area of Wadi Khalid – Wadi Dana.

Our research in Faynan and Timna has resulted in a new collection of archaeometallurgical artifacts from excavated and well documented contexts. This

collection, housed mostly at the UCSD Levantine Archaeology Laboratory, significantly substantiates the previous available inventories of Iron Age copper production technologies. Some of the artifacts uncovered in our research were previously sorted in the field and the bulk of slag fragments was discarded at the site after documentation as detailed in section 5.2.2 above. As most of the archaeometallurgical artifacts are not considered 'museum quality finds' and were found in vast quantities, we were able to ship them from Jordan to UC San Diego on permanent loan[75]. If weight and space consideration dictated otherwise, the artifacts were stored in the facilities of the Department of Antiquity of Jordan (DoAJ) in Amman. The archaeometallurgical artifacts from our excavations in Timna Site 30 are currently stored at the Institute of Earth Sciences of the Hebrew University of Jerusalem and intended for final storage at the facilities of the Israel Antiquity Authority (IAA) in Jerusalem.

A large part of the archaeometallurgical assemblage investigated in the current research came from the deep probe into the 'slag mound' at Khirbat en-Nahas, Area M. This mound is representative of the entire sequence of Iron Age copper production in Faynan as we currently understand it, from the late phase of the Late Bronze Age to the end of the 9th century BCE. The materials from this context, coupled with high resolution of radiocarbon dates and archaeomagnetic data (section 5.2.4.2 above),

[75] The UCSD Levantine Archaeology Laboratory is grateful to the Department of Antiquities of Jordan and especially its directors who have supported our research: Dr. Ghazi Bisheh, Dr. Fawwaz al-Khrayshah and Prof. Ziad Al-Saad.

provide an accurate diachronic reference for technological changes throughout the Iron Age.

The Iron Age archaeometallurgical inventories from the Arabah include a wide range of artifacts (and ecofacts) related to all aspects of ancient copper exploitation activities. In fact, most of the finds in the smelting and mining sites are related to different parts of the core actions constituting the *chaîne opératoire* of copper production (section 1.1.2 above and Chapter 9), and the rest are related to supporting 'gestures', mechanisms, and activities in the complex system of specialized, wide scale production (e.g., artifacts related to food supply, status maintenance, spatial organization of production, transportation, communication, etc.). As part of the *wider* definition of material culture, the principle artifacts and ecofacts of copper exploitation *technologies* consist of the following: (1) ore and flux, in the mining and smelting sites, together with related finds such as tailings (remains of the host rock [*gangue*] after ore dressing for beneficiation); (2) ground stones, of various types; (3) charcoal and wood; (4) furnaces and related installations (slag pits, working surfaces, etc.); (5) tuyères and bellows pipes; (6) slag; (7) raw metal and prills; (8) crucibles, molds and other related *technological ceramics*; (9) various related installations (retaining walls, storage pits for ore and charcoal, etc.); (10) sediment deposits related to copper production (ash layers, 'charcoal dust', fine crushed slag, clayey sediments of decomposed materials or as preparation for manufacturing of technological ceramics, etc.); (11) ingots and other final metal products (rare); (12)

archaeozoological remains (draft animals [means of transportation], food supply, supporting economic practices); and (13) mortuary remains (health and physical conditions, identity, gender and other attributes of the labor force). The artifacts from these categories are, not equally available in the archaeological record; different depositional mechanisms and/or formation processes of the archaeological record (e.g., Schiffer, 1987) exist and should be considered when analyzing excavated artifacts and when attempting to reconstruct the production system as a whole. For example, ore found in smelting sites may represent the low quality leftovers and not the original quality available in antiquity. Further considerations are emphasized in each relevant section below.

7.1.1 Faynan Iron Age Archaeometallurgy Assemblage: *Statistics from Khirbat en-Nahas and Khirbat al-Jariya*

The output of the archaeometallurgical recording system we applied as part of the field work of the current research provides important statistical information concerning basic technological artifacts uncovered during each excavation season. Here we summarize the result of the ELRAP's 2002 and 2006 field seasons at Khirbat en-Nahas and Khirbat al-Jariya. The 2009 excavations focused mostly on large-scale architectural features at Khirbat en-Nahas (Area R 'monumental building' and the Area W complex), and in this study, only some exceptional archaeometallurgical finds

are incorporated into the discussions below (section 7.2), together with some comments on the finds from Khirbat al-Ghuweiba and Timna Site 30.

The recording system for archaeometallurgical artifacts was somewhat different for the 2002 and the 2006 field seasons (for the latter, see details in section 5.2.2 above). The differences are mostly in categories of slag (more categories in 2006) and the attributes recorded for tuyères and bellows pipes (number of fragments and length in the 2006 season and number of fragments and weight in the 2002 season). Attributes recorded for furnace fragments were also slightly different between the two seasons (Table 7.1). The data in Table 7.1 are useful to characterize the excavated contexts (e.g., Layers MI, SII and AII of the 2002 are the richest in archaeometallurgical debris, representing a peak in metallurgical activity in each of the respective areas) and to evaluate the representative bulk volumes of metallurgical debris per typical context - and especially in a typical Iron Age 'slag mound' (see section 7.2.10 below). In addition, the following parameters help to indicate *technological* differences between excavated contexts: (1) the proportion of slag sizes represents advancement in technology as the relative amount of slab slag (and/or large slag) increases (section 7.2.6 below); (2) the average fragment weight (AFW) of furnaces has three distinct groups of values, probably indicating technological differences (Fig.7.1) (section 7.2.4 below); (3) a similar pattern is recognized in the average fragment length (AFL) of tuyères and the proportion between the number of tuyères and bellows pipes in each area (in Table 7.1 the tuyères of Area R represent

the largest AFL, and this correspond to other distinct technological patterns described below. Note that the 2006 Area M statistics include very little of Layer M1, as most of it was excavated during the 2002 field season).

Table 7.1 (next page): Quantitative summary of basic archaeometallurgical artifacts from ELRAP's 2002 and 2006 field seasons, presented by excavation Areas

* Total does not include sieved
** In these excavation areas we found a large quantity of well preserved ceramic bellows pipes (205 fragments in total length of 1005 cm in Area F and 214 fragments in total length of 872 cm in Area T). This type of artifact is unique to the pyrotechnological workshop of areas F and T; note also the relatively small AFW in these two areas in comparison to the rest of KEN.
*** Note that Area M 2006 statistics includes very little of Layer M1 as most of it was excavated during the 2002 excavation season.

Abbreviations: A/L=Area/Locus; AFL=Average Fragment Length; AFW=Average Fragment Weight; LF=Largest Fragment; NOB=Number of Baskets; NOF=Number of fragments; SF=Smallest Fragment; The average furnace fragment weight (AFW) and average tuyère fragment length (ATL) suggest that area R provided the most well preserved pyrotechnological artifacts

A/L.	Slag weight [kg]					Tuyères and bellows pipes				Furnace Fragments					
	Small	Large	Slabs	Sieved	Total*	NOF	Total Length [cm]	AFL [cm]	Weight [kg]	Total NOB	Weight [kg]	NOF	SF (cm)	LF (cm)	AFW (gr)
Khirbat en-Nahas, 2006 excavations															
A	465	387	187	2	1039	28	115	4.1		26	86	489	1	25	175.9
F**	637	584	207	26	1428	82	376	4.6		48	94	1077	1	25	87.3
T**	785	1827	662	11	3274	490	1911	3.9		73	230	2518	1	31	91.3
R	1068	1781	973	0	3822	447	2625	5.9		33	357	711	1	25	502.1
M***	3501	2321	981	55	6803	1070	4329	4		130	575	3536	1	30	162.6
Khirbat al-Jariya, 2006 excavations															
A	171	125	4	0	300	401	1486	3.7		18	85	579	1	20	147
Khirbat en-Nahas, 2002 excavations															
AI					70.3	0			0		0.64	1			
AIIa					507.6	179			7.6		8.2	178			
AIIb					1722.2	535			58.8		81.22	492			
AIII					172.1	64			6.4		11.4	51			
AIV					23.9	5			0.25		0.71	9			
A total					2496.1	783			73		102.18	731			
SI					3871.1	325			14.5		18.80	297			
SIIa					4308.35	846			56.8		133.6	1611			
SIIb					1077.7	280			18.2		70.5	726			
SIII					156.4	54			1.7		5.8	94			
SIV					3.7	0			0		0	0			
S total					9417.4	1505			91.2		228.8	2728			
MI					6625.4	6026			219.3		373.5	6869			
MIIa					NA	NA			NA		NA	NA			
MIIb					33.1	5			0.41		2.9	87			
MIII					89.4	5			0.23		1.1	127			
MIV					NA	NA			NA		NA	NA			
M total					6747.9	6036			220		377.5	7083			

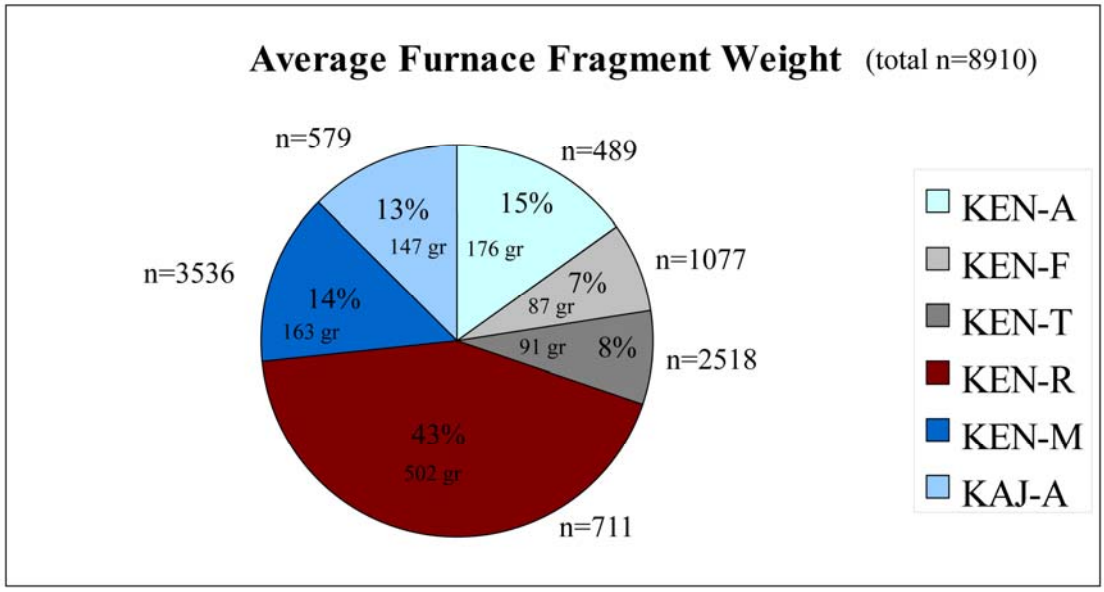


Fig.7.1: Average furnace fragment weight (AFL) by context, based on the recording system of the 2006 excavation season. Three distinct groups are visible (different shades of blue, grey, and red); these correspond to technological differences: KEN-T and KEN-F have evidence of refining/casting technologies, KEN-A, KAJ-A and KEN-M have evidence of smelting with smaller installations than those represented by KEN-R (note that KEN-M in this diagram contains little of the M1 assemblage, which was mainly excavated during the 2002 field season).

The data collected in the field are accompanied by detailed descriptions of the visual characteristics of each artifact (slag, furnace fragments, tuyères and bellows pipes), organized in a *Microsoft Access* format. These data are intended to become available online in the near future as part of the general ELRAP database.

7.1.2 *The Iron Age archaeometallurgical collection of ELRAP at UCSD*

Out of the thousands of archaeometallurgical artifacts collected during ELRAP's field seasons, we have selected 570 representative samples for further investigation in the laboratory (excluding slag) (Fig.7.2). As we wanted the collection

to represent both diachronic and synchronic technological differences we have focused on only a few contexts from the 2006 field season: (1) the deep sounding at the 'slag mound' in KEN-Area M (a high resolution sequence of metallurgical debris spanning the 13th – 9th centuries BCE); (2) KAJ-Area A (a high resolution sequence of metallurgical debris in a 'slag mound' representing the early Iron Age, 12th – first half of the 10th century BCE); and (3) KEN-Area F (10th [?] – 9th) centuries BCE specialized workshop). *All* of the excavated archaeometallurgical artifacts from these areas were re-investigated and sorted by us in the laboratory[76]. The collection was further complemented (although not with a systematic sorting method) by some artifacts from other excavation areas, including Area R (2006 and 2009 field season), Area T (2006 field season) and Area A (2006 field season).

The selected archaeometallurgical collection of ELRAP includes bellows pipes (n=31), copper ore (n=13), copper prills (n=12), metal objects (n=3), 'metal chunks' (n=92), tuyère fragments (n=159), technological ceramics (n=63), mold fragments (n=39), furnace walls (n=48), furnace stones (n=11), furnace smelting/melting residues (n=5), furnace rims (n=9), furnace fragments (n=77), furnace bases (n=5). Slag samples were sorted into a different collection and are discussed in Chapter 8 below (except from a few representative pieces, n=13, that are part of the general archaeometallurgical collection). All of these artifacts are now stored in special

[76] The work on the archaeometallurgical collection took place during the spring of 2010 with the much appreciated help of student and other volunteers. Many of the observations presented here have been achieved during fruitful discussions with Cindy Beck (ELRAP's ceramic-restoration expert) and Breanne Kebely.

containers according to the above categories; one container was designated for a 'representative metallurgical locus' and included all of the archaeometallurgical artifacts excavated from Locus 629 at Area M. The attempt to put together all the components of a metallurgical system (smelting) from one, well defined context was done to facilitate comprehensive technological reconstruction[77].

During the work on the archaeometallurgical collection it became evident that some of the particular definitions of artifacts were confused in the field and needed to be corrected. Most notably, bellows pipes were often recorded as tuyères (and sometimes vice-versa), and tuyère fragments were often recorded as furnace fragments; the 'S' shaped furnace fragments (see below) were often mistaken as large tuyères or other 'technological ceramics'; many of the molds were recorded simply as 'technological ceramic' and conversely, artifacts recorded as 'technological ceramics' were often found to be furnace fragments. The separation into furnace walls, fragments, rims and bottoms was not included in the field recording system as well as the separation between 'small' and 'large' tuyères (see below), which is often difficult even in the laboratory when only a small fragment of tuyère is available. In sum, the field-recorded database (GIS-based) regarding the archaeometallurgy remains should be treated with caution, especially when analyzing a small sample size. Analysis of contexts with a large sample size usually compensates for incorrect field recordings by rendering such mistakes negligible.

[77] It was beyond the scope of the current research to provide a restoration of such system; however, the collection is well organized and ready for future research.



Fig.7.2: Working on the archaeometallurgical collection at the UCSD Levantine Archaeology Laboratory. Out of thousands of artifacts (excluding slag) 570 were selected for careful investigation and special storage by category for future reference.

7.2 Artifacts and ecofacts related to Iron Age copper production in the southern Levant

7.2.1 *Ore and flux*

No special investigation of ore and flux[78] was conducted as part of the current research. However, a number of important observations can be made based on the

[78] Both ore and flux are context-defined terms (as well as the term 'gangue'); generally, ore is defined as an economically valuable mineral(s) (thus, ores defined by modern standards are very different than ores defined by ancient standards. This definition is in fact a derivative of *technology*). Flux is another mineral (such as iron or manganese oxides) added to the copper ore as an agent that reduces the copper

field work: (1) in the excavations of Timna Site 30 several installations designated for storage of ore, flux and probably charcoal were found, both during the Arabah Expedition's project and the new excavations at the site conducted as part of the current research (Locus 905 in Area S, see section 6.2.1.2 above). The recently excavated storage installation at Timna 30 was a circular stone-built feature containing fine crushed copper ore (a grain size of a few mm each). This grain size probably represents the original size used for preparation of the smelting mixture and is not a result of post-depositional decomposing processes. One of the installations uncovered by the Arabah Expedition in 1976 (Rothenberg, 1980a) contained manganese ore (pyrolusite) and was interpreted as a designated storage place for ore used as flux in smelting processes represented by Layer 1 (Mn-rich slag). This is an important observation, suggesting a *deliberate* fluxing in the latest phase of copper production at Timna 30. (2) At the Iron Age sites we excavated in Faynan no similar storage installations for ore and flux were found. However, Hauptmann (2007:102) reports several storage pits, possibly for charcoal and ore, from Faynan Site 5; (3) Many 'ore fragments' collected in Khirbat en-Nahas (and which are part of the ERLAP's archaeometallurgical collection) are possibly the result of decomposition of building stones of the DLS formation (Chapter 2), abundantly used at the site as a construction material. These stones often contain green nodules of copper minerals and probably do

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from the other components of the minerals, such as carbonates, sulfides and silicates. In essence, it facilitates the smelting process; also here the definition is relative, and flux is a context-specific term that depends on the raw ore smelted and the technology used (e.g., if the ore is silica-poor, quarts [sand] may be used as *flux*).

not represent the common type of mineral used for smelting, which came mostly from the shale unit (of the same formation that the building stones came from).

7.2.2 *Ground stones*

No special investigation of ground stones was conducted as part of the current research[79]. The various types of ground stones were an essential part of the copper extraction process, from ore dressing and crushing to the processing of slag material. Based on the general study of the ELRAP's inventory, the most common types of ground stones at Khirbat en-Nahas are summarized in Figs.7.3-7.5 (see also Levy et al., in press-a), and at Timna 30 (the new excavations) in Fig.7.6. In both sites a large assortment of ground stones exist, all made of the local rocks found in the nearby wadi beds. It is interesting to note that in both Faynan and Timna many of the flint flakes (if not all) found during the excavations are actually defragmented ground stones made of rounded chert nodules and used for crushing. Only a few of these were found intact; however, it seems that they were quite commonly in use during the Iron Age.

[79] Levy (in prep.), working with undergraduate student interns, carried out a detailed analysis of the ground stone artifacts from Khirbat en-Nahas



Fig.7.3: Common types of ground stone artifacts found at the smelting site of Khirbat en-Nahas: A) grinding slab (Area: T Locus: 1523 EDM: 40741_T); B) dimpled hammer stone (Area: R Locus: 1803 EDM: 30031_T); C) multiple use / sharpening stone (Area R: Locus: 1826 EDM: 30310_T); D) saddle quern (Area: T Locus: 1504 EDM: 40164_S); E) mortar (Area: T Locus: 1511 EDM: 40150_T); F) "ballistic" stone (Area: R Locus: 1827 EDM: 30479_T); G) grooved hammer stone (Area: T Locus: 1541 EDM: 40493_S); H) anvil (Area: A Locus: 160 EDM: 50126_T); I) hand stone (Area: M Locus: 693 EDM: 91503_T); j) hammer stone (Area: M Locus: 732 EDM: 91674_T); k) polishing stone (Area: M Locus: 707 EDM: 91577_T); L) pestle (Area: M Locus: 701 EDM: 91523_T).

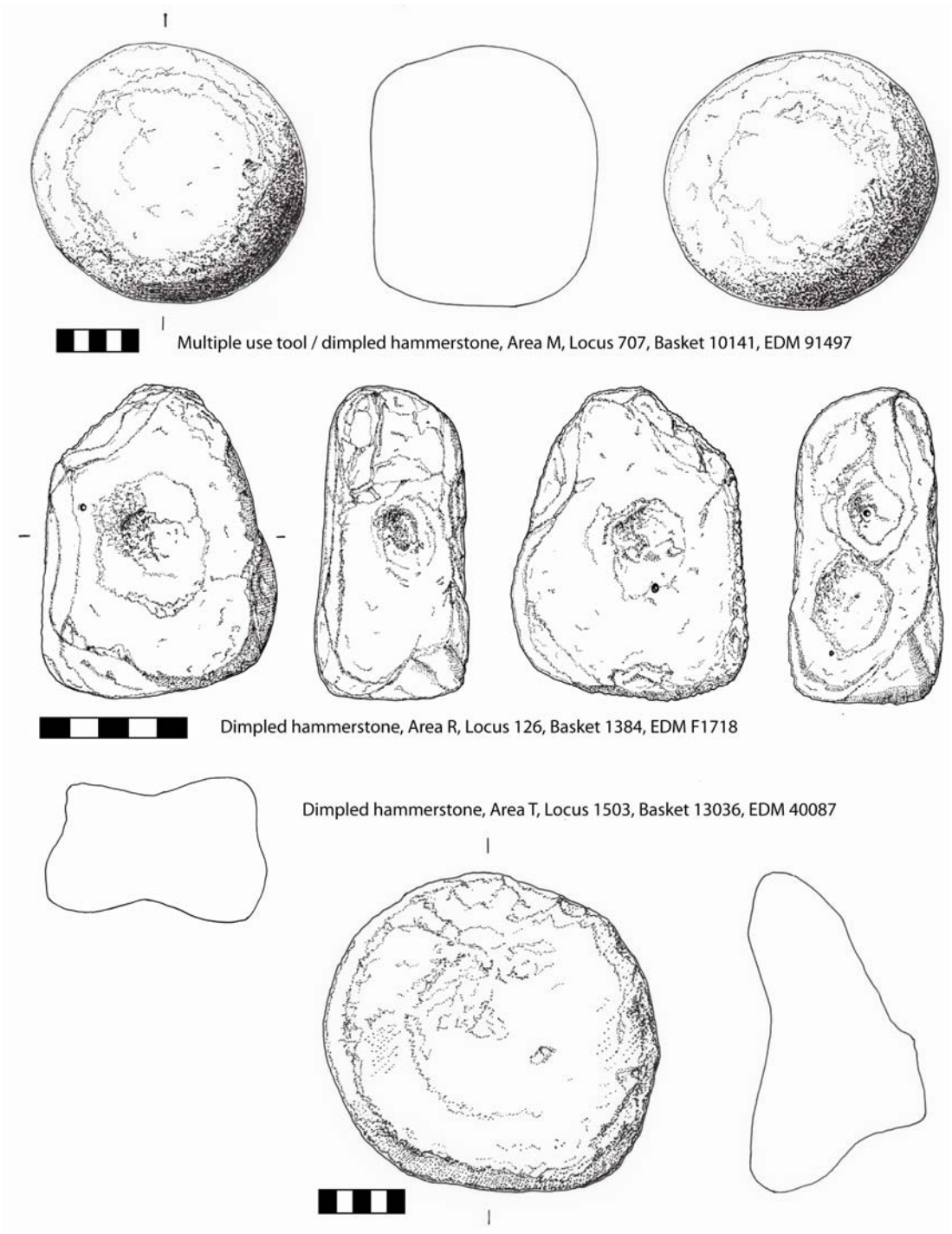


Fig.7.4: An illustration of some of the most common ground stones from Khirbat en-Nahas; many of the hammer stones have signs of use on more than one side (cf. dimpled hammer stone EDM F1718 above, signs of use on all 4 sides).



Fig.7.5: Dimpled hammer stones *in situ* (located in a defragmented stone basin) at Khirbat en-Nahas, Area T (EDM 40967).

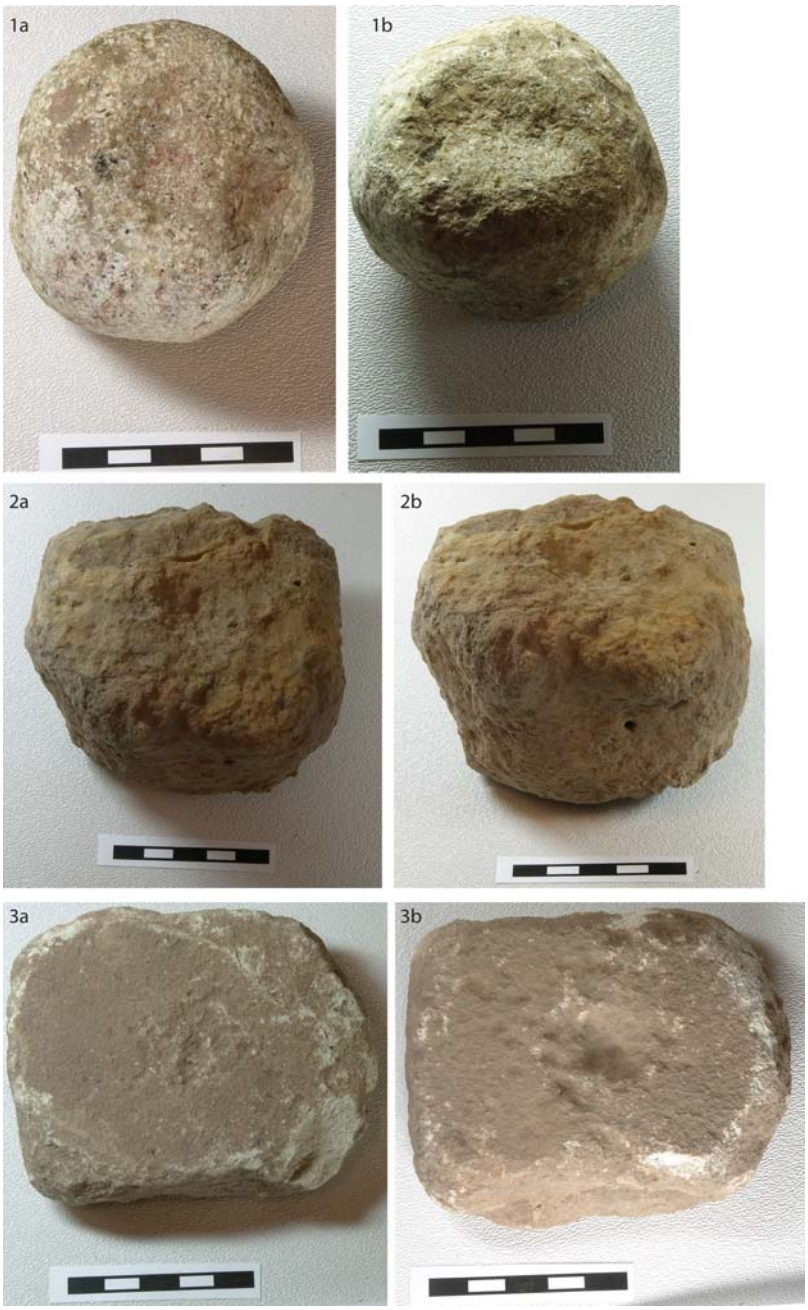


Fig.7.6: Various ground stones from the new excavations at Timna Site 30.

#	EDM #	Site	Area	Locus	Basket	Comments
1	160	T30	S	905	564	Two sides (a and b) of a rounded limestone pebble used as a hammer stone
2	271	T30	L	811	1511	Two sides (a and b) of a cylindrical brown limestone used as a hammer stone
3	34	T30	S	900	502	Two sides (a and b) of a flat, rectangular sandstone used as a hammer stone (one side with dimple) or an anvil

7.2.3 *Charcoal and wood*

As the basic fuel in ancient (s)melting processes, charcoal is usually abundant at smelting sites. However, charcoal in the archaeological record may also be simply the result of using wood as fuel for smelting. The assumption that deliberately made charcoal was used, and not wood, is based on ethnographic evidence (e.g., Bisson et al., 2000) and on the fact that charcoal is ideal fuel for smelting. However, recent experiments have shown that smelting in some ancient technologies could have been done with using wood only (see discussion in Chapter 9.1.1).

Currently, there is very limited archaeological evidence of charcoal production and only from some late sites in Europe, in location where locals preserve knowledge of older charcoal burning and archaeologists were able to identify special platforms or other designated areas used for the production of charcoal (e.g., Timperley, *nd*). The lack of archaeological evidence of charcoal burning is not surprising as charcoal production technologies do not require any substantial installations and leave little remains. To date, In Faynan and Timna there is no evidence of charcoal production for any period, and the use of charcoal as fuel is inferred mostly from technological consideration based on efficiency of the smelting process. Nevertheless, charcoal is abundant at smelting sites in both Faynan and Timna, in particular in Late Bronze Age and later ‘slag mounds’.

Regarding wood remains, it is important to point out the striking difference in the preservation quality of organic materials between Faynan and Timna. While the former has almost no uncharred organic remains, the latter has abundant, as is well exemplified by the results of our excavations in Site Timna 30 (section 6.2.1.2 above) (high preservation quality was reported also from other sites, including Timna 200, see e.g., Rothenberg, 1988). Consequently, we have found wood only in Timna 30, and quite frequently in relation to the small volume of excavated contexts. The wood pieces are uncharred, and can be identified visually as acacia (Fig.7.7). They were found both in Area S and Area L (15 pieces in total, 15cm the longest). Rothenberg (1980a) also reports abundant pieces of acacia and palm wood, mostly associated with Layer II.



Fig.7.7: Wood (acacia) remains found in the new excavations at Site Timna 30. The preservation of organic material in this site (and in Timna Valley in general) has no parallel in Faynan; A) Area L, Locus 808, Basket 169; B) Area L, Locus 801.

The evidence of wood, especially the small chopped fragments, raises the possibility that uncharred wood was also used as fuel. Although recent experimental

archaeology research has demonstrated that smelting with wood is also efficient and not substantially different from smelting with charcoal (Erica Hanning, pers. comm. 2010), this question must remain open in the current stage of research.

Charcoal was collected in large quantities in all of the excavations conducted as part of the current research. Besides sampling individual charcoal (or tight clusters) with precise recording for radiocarbon dates we collected large amounts of samples in general baskets for future analyses and in particular for species identification to complete a thorough investigation of the fuel sources (see section 5.2.2 above). Most of the samples from the Iron Age sites in Faynan are relatively thin branches and not thick parts of stems (Fig.7.8); this observation was not quantified in the current research.



Fig.7.8: The common type of charcoals in Iron Age Faynan is thin, distinct branches.

Relatively few charcoal samples have had their species identified as part of ELRAP's routine radiocarbon dating methodology. The identifications were done by Mark Robinson of the Oxford University Museum of Natural History and are summarized in Fig.7.9[80].

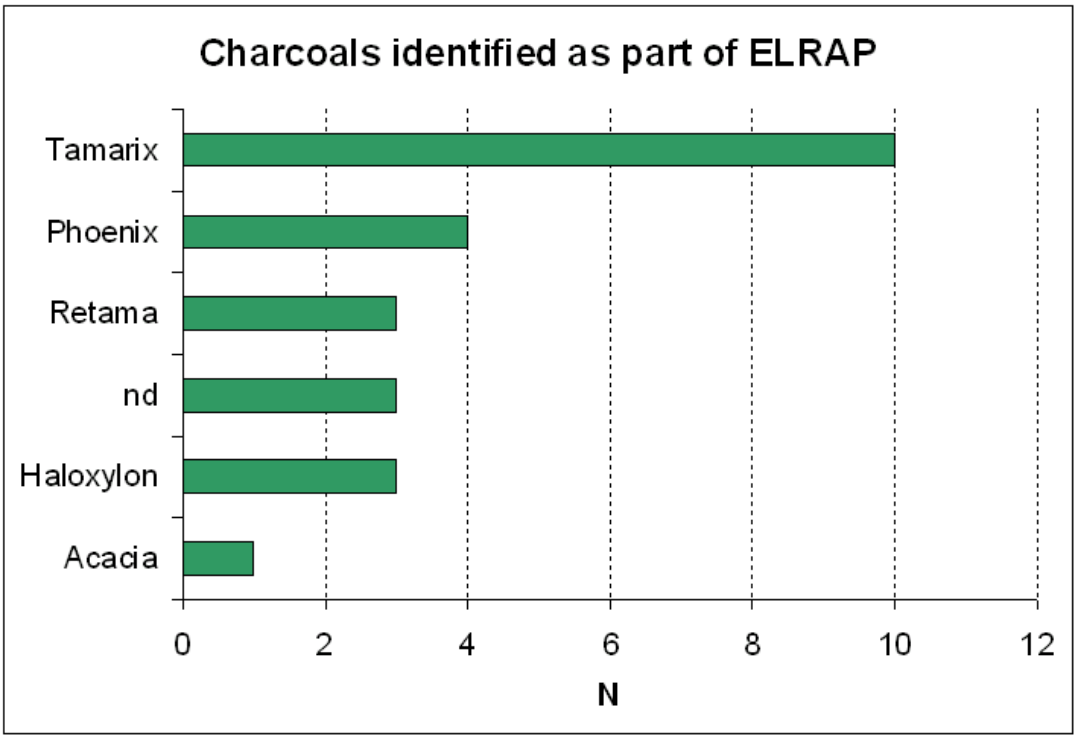


Fig.7.9: A histogram showing number (total n = 24) of identified charcoal samples per species (here technically represented by the genus; species are *Tamarix sp., Phoenix dactylifera, Retama raetam, Haloxylon persicum and Acacia sp.*) in ELRAP's investigations of Iron Age Faynan (note that these exclude seeds and other types of organic materials; nd = sent for identification but could not be identified; total n = 24; number of sample is too small to make any statistically meaningful analysis of precise contexts, i.e., species by Stratum of each site); Tamarix = tamarisk, salt cedar, Phoenix = palm, Retama = broom, Haloxylon = saxaul; based on Levy et al. (2008a:16463) and Ben-Yosef et al. (2010a:727, 733-734); other publications of radiocarbon from KEN (e.g., Levy et al., 2004c; Higham et al., 2005; Levy et al., 2005c) do not include charcoal identifications; more data are being prepared for publication in the near future (Levy et al., in press-d).

[80] Just before the final submission of this work we got some new species identifications of charcoal from ELRAP's 2009 fields season. Interestingly, it included two charcoal of *Juniper sp.*, the first to be reported from ELRAP excavations so far (cf. Fig.7.10 below for low quantities of juniper in KEN).

Although the sample size of the ELRAP charcoal species identifications is relatively small, it represents the same pattern reported by the German team based on thousands of samples from Khirbat en-Nahas, Khirbat al-Jariya and Faynan 5 (Baierle et al., 1989; Engel, 1992; Engel, 1993; Steinhof, 1994; Engel and Frey, 1996)[81]. A total of 2257 samples came from the upper part of one 'slag mound' at Khirbat en-Nahas. The 'slag mound' was partially excavated to a depth of 1.7 m and samples from 12 different contexts were analyzed. The statistical results, coupled with three radiocarbon dates spanning the second half of the 12th century to the first half of the 9th century BCE, brought Engel (1993:211) to conclude that:

> In the period of copper ore smelting represented by the slag heap examined here [i.e., early Iron Age], the species composition of the fuel did not change. Thus, no evidence was found for immediate influence on the vegetation by the collection of wood as fuel for metal extraction during more or less consecutive phases of copper ore smelting over two to three centuries […] Iron Age men seem to have kept the environment in a steady state by using mostly fast-growing shrub species. It can be concluded that even for one of the largest places of „industrial" Iron Age metal production the surrounding lowland vegetation of Khirbet en-Nahas was sufficient as fuel, and no transport of wood from further and higher localities was needed.

The 'steady state' of charcoal composition included all the species presented in Fig.7.9 in approximately the same percentage (Retama is the second in frequency after Tamarix in most contexts in Engel's research). Additional species that were identified by Engel in relatively small quantities were Chenopodiaeeae, Ephedra sp., Moringa peregrina, Olea europaea, Pistacia atlantica, Prosopis farcta, Rosaceae, Zilla spinosa, Ziziphus sp.; in the broad picture these are negligible. The statistics for *all* of the Iron Age charcoal identifications of the GMM and the Free University of Berlin tams,

[81] This intensive botanic research was conducted by the Institut fur Systematishce Botanik und Pflanzengeographie of the Free University of Berlin, in conjunction with the German Mining Museum Project.

including previously unpublished data, are provided in Hauptmann (2007:53) and is as follows: Tamarix 52.7 wt.-%, Retama 20 wt.-%, Phoenix 8.4 wt.-%.

The most common plants used for fuel in the Iron Age are shrubs that grow in open wadis and alluvial fans (Haloxylon and Retama) and hydrophilic plants (Tamarix and Phoenix) that grow in oases and areas with high water table. These plants, and Tamarix in particular, grow rather fast, and strategic pruning and pollarding probably kept the harvest yield constant. Robinson has found evidence of coppicing of Tamarix in the Iron Age samples from Khirbat en-Nahas (Levy et al., 2008a).

In contrast to Faynan, most of the charcoal from Timna, including the Late Bronze and Iron Age sites, were identified as acacia (e.g., Rothenberg, 1980a, there is no comprehensive discussion regarding fuel sources in any of the publications of the Arabah Expedition). Although detailed botanical research like that in Faynan was never conducted in Timna, acacia was probably indeed the main source of fuel in the latter because of the major difference in the biogeography of the two regions (section 2.3 above). In Timna, the shrubs discussed above and palm trees are much less abundant, and some (Tamarix and Phoenix) are rare in the immediate vicinity of the smelting sites.

7.2.3.1 Social implications of the Iron Age charcoal record of Faynan

The most notable feature in the charcoal assemblage of Iron Age Faynan is the almost complete absence of acacia – a common tree in this Saharo-Arabian desert zone (Danin, 1983). When compared to results of charcoal analyses from other periods in Faynan (Fig.7.10, after Baierle et al., 1989) this observation is even more striking as it is *unique* to the Iron Age smelting sites (with a possible exception at Khirbat al-Jariya, cf. Figs.7.10, 7.9 and Table 5.12). In the Early Bronze Age the most common source of fuel was the woodlands on the slopes of the Jordanian plateau (juniper trees, Fig.7.11C) and acacia was also exploited in the smelting process. In the next substantial phase of copper production, the Iron Age, shrubs were the primary source of fuel, with a strong dominance of Tamarix (again, excluding Khirbat al-Jariya whose report here is quite ambiguous, and the sample size is much smaller [out of the 9 samples obtained from KAJ at this research, no charcoal was identified as acacia, cf. Table 5.12]). In the Roman period the situation changes again and this time acacia is used as a fuel source, together with the local shrubs. The Ayyubid/Mamluk period has also its unique pattern; the woodlands of the slopes are exploited again but this time Quercus (oaks) are dominant and appear more frequently than junipers (this is an interesting pattern because oaks are more rare in this region and are found only in specific niches in the upper sandstones).

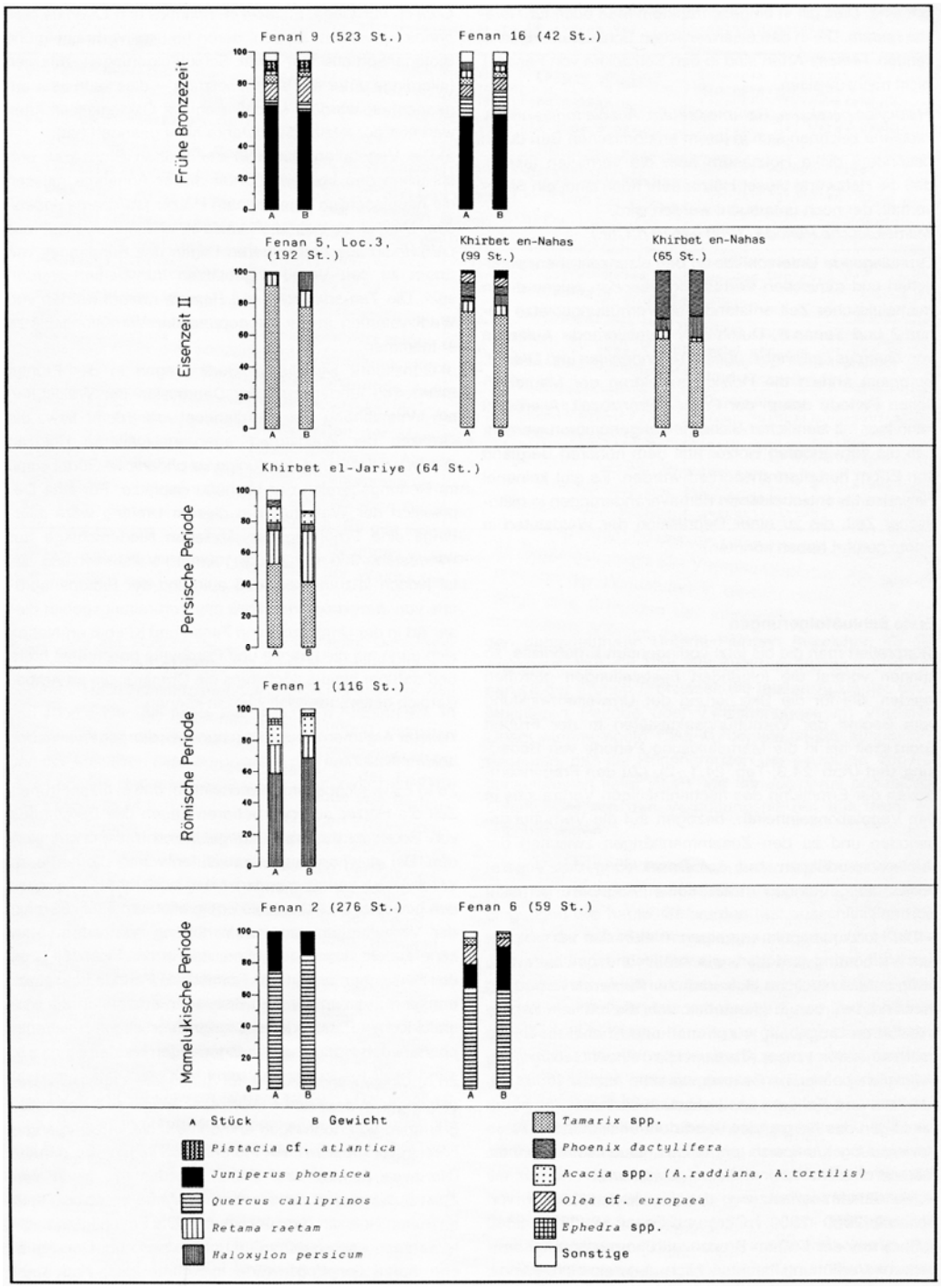


Fig.7.10: Frequency (by per cent the number of samples) of charcoal species used for smelting in Faynan (Baierle et al., 1989:219); there is a striking difference of fuel sources between the different periods. Note that Khirbet el-Jariya is mistakenly dated here to the Persian period (cf. section 5.2.5), and that the appearance of acacia at this site was not corroborated in the recent result of ELRAP (cf. Table 5.12).



Fig.7.11: Fuel sources in the Faynan area: A) several oases in the lowlands contain lush fast-growing vegetation, including Tamarix (the low bushes in front of the reeds), and Phoenix (palm trees), two of the most common fuel source in the Iron Age (in the picture: small oases in the sand dunes of Barqa al-Hetiye) B) the acacia tree (appears also in A) characterizes the desert landscape and is one of the most impressive perennial plants in the Arabah Valley and the lowlands of southern Jordan; C) the wooded land on the slopes of the Jordanian plateau (looking south from Busayra region towards Wadi Dana and Faynan); the open forest consists mostly of juniper trees.

In several publications the German team provides interpretations of the diachronic difference in fuel sources used for smelting in Faynan, and in particular the absence of acacia in the Iron Age record. Their approach is simplistic and based on deterministic principles that exclude the human factor. For example, Engel (1993:211) suggests that

> This [the absence of acacia in the Iron Age record of KEN] could either be due to a supposed change of climate causing a withdrawal of the more suitable fuel tree species to higher elevations of the highland of Edom, or to the extinction of these species in the immediate vicinity of the copper ore smelting places, so that lowland and wadi shrub species came into use as fuel.

Or Hauptmann (2007:52-53):

> But it has to be assumed that the tree population of the 3rd millennium BCE [Early Bronze Age] was also to be found at much lower altitudes than today, when the trees are limited to the Jordanian plateau. This would certainly have been the result of much more humid weather conditions then, and it eliminates the arguments summarized under the recent slogan of 'charcoal to the ore' concerning a longer transportation route. […] This [the absence of acacia in the Iron Age record] could be explained by the fact that the wadis still carried more water then.

The absence of acacia in the Iron Age archaeological record of Faynan cannot be satisfactorily explained by correlation to climate change or other deterministic interpretations for the following reasons: (1) the difference between the Iron Age and the current climate conditions (section 2.3.1 above) is not substantial enough to significantly affect the distribution of acacia and juniper trees in the landscape of Faynan; (2) the absence of acacia cannot be explained by differences in spatial distribution of sites between the different periods, as the Iron Age site of Faynan 5 is located in the immediate vicinity of Early Bronze, Roman and Mamluk sites, and its charcoal record presents the same pattern as the more isolated site of Khirbat en-Nahas; (3) the argument that junipers were exploited in the Early Bronze Age because the climate was more humid and the trees grew further down the slopes and closer to Faynan cannot be simply derived from the archaeological record. This is because in the Roman, and especially in the Mamluk periods, for which we have robust evidence that climate conditions were similar to the current ones, the archaeological record consists mostly of trees that grow up on the slopes of the plateau. In short, one has to take into account the human factor, and to apply considerations that derive from our

understandings of societies and their interactions with the environment. These interactions are usually more complex than the common assumption in research originating from the Natural Sciences, with the best representative case being the study of paleoclimates and their impact on ancient societies (cf., Rosen, 2007).

We suggest a different interpretation of the changing patterns of fuel sources through the *long dureé* of social change in Faynan, and in particular the unique absence of acacia in the Iron Age (Ben-Yosef, 2009b). This interpretation is based on ethnographic studies of Bedouin tribes in the Sinai Peninsula (Levy, 1980, 1983, 1987). These studies have demonstrated the unique place of the acacia tree in the folklore and tradition of pastoral nomads in arid zones, and in particular in the southern Levant. The tree is one of the most prominent perennial plants in the floral landscape of the deserts of modern Israel, Jordan and Egypt, and a substantial potential source of wood. It is has a substantial stem (Fig.7.11A-B) and a higher calorific value than the common shrubs of this region, thus it is most suitable as fuel for heating or as a strong building material. Nevertheless, among the tribal Bedouins societies of Sinai the acacia tree is considered sacred, and a strict system of laws and customs protects it from being cut down, pruned, or any other harm. Consequently, the main wood used by these desert societies originates in semi-shrubs and shrubs (e.g., *Ratama* and *Haloxylon*), and the rapidly regenerating hydrophytic vegetation (e.g., *Tamarix* and *Nerium*) when these are available (near high water table environments). Coupled with commonly accepted models for Iron Age societies in the southern Levant and in

particular those for Edom, these ethnographic observations of the semi-nomadic Bedouin society are very insightful. Based mostly on archaeological evidence, historical and biblical sources and some ethnographic studies, the common models for Iron Age Edomite societies suggest a '*tribal confederation*' or some other similar political structure that was founded and based on groups of semi-nomadic populations originating in the local desert area (e.g., LaBianca and Younker, 1995; Bienkowski and van der Steen, 2001; Levy, 2008b; Levy, 2009a, and see also section I.IV above and chapter 10 below). Thus, the lack of acacia in the Iron Age record of Faynan may be interpreted as representing the practice of similar costumes and values as those observed in modern Bedouin societies in the Sinai Peninsula; conversely, the same evidence strengthen the socio-political models for the Iron Age societies of Edom. These two ways of interpretation complement each other and emphasize different aspects of the correlation between models, archaeological data and ethnographic evidence. Assuming that the socio-political models for Iron Age societies in Edom are correct (and they are based on multiple factors), and given that the desert environment is the same, the correlation with practices of modern societies with similar socio-political organization, or at least similar original structure (of nomadic tribes), has a strong basis. On the other hand, leaving aside the socio-political models of Iron Age societies in Edom and assuming that the practices observed among modern Bedouin societies represents a common means for semi-nomadic tribal societies to cope with desert environments, the lack of acacia in the Iron Age record of Faynan can be used as an additional strong argument concerning the social structure of the people in

Faynan during this period, and may have implications on the origin of these societies (semi-nomadic desert tribes). The latter is based on a model suggested to explain the origin of the special regard for acacia in modern Bedouin societies (e.g., Levy, 1983). The model, which in itself is based on deterministic principles, basically argues that special care for preservation of acacia trees is an essential economic strategy for pastoral nomadic societies in the desert environment, as the perennial and enduring tree is the only reliable source of food for the livestock (mostly goats) in times of drought. Being dependent of the survival of livestock in an extremely varied annual pattern of precipitation (section 2.3 above), preserving the tree by embedding it into the society with a complex system of rules and values is in essence a long run economic and subsistence strategy. If this mechanism is valid, the evidence from Faynan may directly indicate the presence of a pastoral nomadic society and the survival of their social values even when the main subsistence source changed to the production of copper. The lack of acacia can also stand as evidence that *tribalism* was the fundamental mechanism of social interaction in Iron Age Faynan, where collective decisions were done by a coalition of chiefs (or in borrowed Arabic term for modern tribal societies, a confederation of 'sheikhs'). In comparison to ethnographic studies of tribal organization, the leaders of such tribes were very much dependent on the support of the people. Thus, the fact that more than one leader was involved in decision making, and that all of the leaders were dependent on the support of all (male) members of the community, explains the preservation of social values that may have originated from a more pastoral-based society, even when high calorific fuel was

very much needed and the long-run subsistence of the society was not dependent on the acacia tree anymore.

The conclusion that the field evidence from Faynan supports *tribalism* as the practiced mechanism in the local societies and a pastoral-nomadic origin (and practice, as pastoralism was probably one of the components of the economy, see Chapter 10) of the local tribes, is further substantiated even by only a cursory investigation of the charcoal patterns in the *long dureé* (Fig.7.10). The striking difference in fuel source patterns between the Iron Age and the preceding (Early Bronze Age) and following (Roman) periods represents well studied differences in social structures. In both Early Bronze Age and Roman periods (and in the Mamluk) the political and social organizations were related to a wider social context than the local semi-nomadic societies; this is most notable for the Roman period, when the region was controlled by political organization of a vast empire and its provinces. Given that the local governor and director of copper exploitation in Faynan was most probably part of the wider political system (see Friedman, 2008), this person would care less for preservation of acacia, or the values of the local population, and would be guided entirely by practical consideration and efficiency. Thus, in the charcoal record of the Roman period in Faynan we see *all* of the fuel sources, in more or less the same proportions as their availability.

Our tentative interpretation should serve as a model for further inquiries regarding exploitation of natural resources in Faynan. Such inquiries should focus on the social components of human-nature interactions in which the physical conditions are a background for a complex system of social mechanisms. For the question of fuel patterns in Faynan, further ethnographic comparisons and more field data are required for establishing firm conclusions.

7.2.4 *Furnaces*

7.2.4.1 *In situ* furnace-related installations

Intact copper smelting furnaces are extremely rare in the archaeological record. In fact, only one complete Iron Age furnace is known thus far from the Eastern Mediterranean, and even this furnace was reconstructed from over 60 individual fragments found in the site of Agia Varvara-Alymyras in Cyprus (Fasnacht et al., 2008, the furnace is dated to around 400 BCE). Furnaces had to be broken at the end of each smelting cycle to extract the metal chunks and copper-rich furnace slag for further processing. As a result, only the bases of furnaces and associated ground installations are found intact, and even these are not a common find. In the Arabah Valley, Rothenberg (1990a) reports several Late Bronze – Iron Age intact furnace bases from Timna and Hauptmann (2007:97-103) reports some similar remains from the Iron Age site of Faynan 5. As with the typology of tuyères (see below), there is a great similarity between furnace remains from Iron Age Faynan and Timna. In light of

the new dates from Timna Site 30 (section 6.2.1.3) we now know that there is also a significant chronological correlation, and that the metallurgical remains at Timna do not necessarily represent a Late Bronze Age precedent to the Iron Age technology of Faynan but rather a simultaneous operation. Thus, the finds from Timna and Faynan 5, and their interpretations are fundamental to our analyses of furnace-related finds from the new excavations (here mostly from Khirbat en-Nahas).

In our ELRAP investigations, only a few excavated contexts were interpreted as intact furnace bases or related installations. All of these are at Khirbat en-Nahas, except from an accidental find at Timna Site 30 (see below). The probes at KAJ, KAG, RHI, and KHI in Faynan did not yield any intact finds related to furnaces; therefore most of our understanding of the shape, size, and construction methods of Iron Age furnaces is based on meticulous analyses of furnace fragments (FF) that were recorded and collected by the thousands (section 7.1). In contrast to the relatively standardized construction of tuyères (below) it appears that smelting furnaces had a variety of shapes and sizes, yet all conform to some basic principles and are made of the same basic materials.

In Area M at Khirbat en-Nahas only one furnace base was found *in situ* (Fig.7.12). It was uncovered during the 2002 excavation season and dismantled during the 2006 excavations. The remains are of a semi-circular feature, located in 'Horizon 6' in the upper part of the probe into the 'slag mound' (see Fig.5.33 for location; this is

part of Layer M1 of the 2006 excavations, the latest phase of copper smelting at KEN). The feature was interpreted as a partially destroyed furnace, with its upper part completely missing. The interior diameter of the furnace was ca. 70 cm. The walls were relatively thick (ca. 15 cm) and were preserved to a height of 20-30 cm. The bottom of the furnace was not preserved. Inside the area defined by the furnace walls was an extremely high concentration of furnace fragments with almost no sediment. Under these was an ashy sediment with a very high concentration of charcoal. Large tap slags were found directly under the furnace.



Fig.7.12: Furnace base at KEN Area M, Locus 510. Semi circular in shape, interior diameter of ca. 70 cm; walls 15-20 cm thick preserved to a height of 20-30 cm. The furnace extended into the eastern balk of the probe, in order to try and define the rest of it the probe was extended ½ meter east into square HHH27 (L. 517). The furnace extended only a few centimeters into HHH27. Inside the furnace was an extremely high concentration of furnace fragments with almost no sediment. Under these was an ashy sediment with a very high concentration of charcoal. Some wood was also found and collected (EDM # 80337). The bottom of the furnace was not found probably because it was ripped out after the smelting in order to extract the copper. Large tap slags were found directly under the furnace. A tap slag fragment can be seen here in the center of the furnace.

Some features of the furnace base of KEN Area M are similar to another furnace base documented by us at the site of Timna 30. The latter was uncovered by accident as a result of unsupervised maintenance work during the 1990s, and apparently had never been properly documented (Fig.7.13)[82]. Like the furnace base at KEN-M, this base is also a semi-circular feature with a ca. 70 cm interior diameter and quite thick walls (ca. 20 cm). The material of the walls, rough clay with slag inclusions, is also similar to the KEN-M furnace. The preservation of only half of the original furnace base in both cases may be just coincidental, however, this may indicate that deliberate breaking of such furnaces took place from one side only, probably the one in which the tapping process took place. Unfortunately, it is hard to determine the exact stratigraphic context of the furnace at Site 30. It is likely that it represents the same period (9th c. BCE) of the furnace at KEN-Area M (described above), and thus belong to Layer 1 of Site 30.

[82] The workers used some of the material of the central 'slag mound' to pave trails and refill some excavated pits; the mound is clearly disturbed in its northern and northwestern sides and many of the Layer 1 tap slag there are not in situ (A. Avner, pers. comm. 2009).



Fig.7.13: Furnace base accidentally uncovered during maintenance work at Timna Site 30 and first documented in the current research (photograph courtesy of R. Shaar).

In the metallurgical complex of Khirbat en-Nahas, Area R (section 5.2.4.1) two areas were interpreted by us as remains of furnace bottoms (Loci 123 and 106, 2009 excavations, Fig.7.14). These remains were found directly adjacent to roughly built walls (one row of stones in width, several courses in height), which are part of a larger structural complex (Fig.7.14). Initially the walls and the enclosed spaces were interpreted as remains of buildings that preceded the metallurgical activity; however, in the current research we show that these walls were in fact *part* of the metallurgical activities, and had an important function for maintaining spatial divisions and organization of the intense labor at the smelting area (see section 5.2.4.1 above, and

section 7.2.9 below). One area, Locus 123, is a large concentration of furnace slag and furnace fragments (2 x 0.8 m), constituting a rather thick accumulation (0.4m) attached to wall Locus 106.The other, Locus 124, is a similar cluster of badly preserved furnace fragments and furnace slag measuring 1.5 by 1 m, and 0.5 m thick, attached to wall Locus 094. Based on the distinct layout of the furnace fragments (including base fragments), we interpret the cemented conglomerates of furnace slag, charcoal and clay fragments (some of the latter had finger imprints and may be intact) as the remains of furnace bottoms from the last phase of activity at this area. It is quite different from the regular dumps of metallurgical waste commonly found at KEN.

Near the 'furnace bottom' remains of Locus 123 one of the most well preserved tuyères (31 cm long, 15 cm wide) was found on top of a bed of charcoal (L.071). The tuyère is adjacent to wall Locus 106 and was presumably found *in situ*, or at least very close to its original position relative to the furnace. Oriented samples were taken from the slag adhering to the mouth of this tuyère in order to test whether it is indeed *in situ,* though no other intact furnace remains were observed.



Fig.7.14: Remains of furnace bottoms (?) in the metallurgical complex of Khirbat en-Nahas, Area R (photograph courtesy of ELRAP-LAL).

In the same metallurgical complex of Area R one of the best preserved furnace-related installations was uncovered (Locus 142, 2009 excavations). This furnace was already identified as a unique feature during the 2006 excavations, and was left untouched due to time constraints (Fig.7.15).



Fig.7.15: Khirbat en-Nahas, Area R, the metallurgical complex. The unexcavated patch in the front of the photograph and attached to wall Locus 104 is one of the best preserved furnace-related installations at the site (photograph courtesy of ELRAP-LAL).

The furnace-related installation is a saucer-like structure with a basin measuring 1.01 meter by 0.80 m across (Figs.7.16-7.19). The hard clay walls are five centimeters thick. It survives to 0.31 m high at the spot where it appears to begin to curve upward to allow an opening in the center of the dome. The base of the furnace is free of slag, though slag was found adhering to curved pieces of the installation, believed to be the neck of it near the opening.

The remaining top parts of the furnace-related installation's dome are adjacent to a rectangular installation composed of small stones and chunks of slag (R09L151, Fig.7.20). Two dimpled hammer stones were re-used in the construction of this

installation. This installation bridges a gap between wall Locus R09L104 and the furnace-related installation itself. The purpose of the installation remains unknown, however, we suggest it served either to support the furnace-related installations or as a foundation for metallurgical/smelting activities. The installations in this area were all covered by a thick layer of ash, slag, and baked clay furnace material (R09L135).



Fig.7.16: A dome-shaped furnace-related installation at Khirbat en-Nahas, Area R (Locus 145); also visible is the stone and slag installation Locus 151 between the dome-shaped installation and wall Locus 104 (Fig.7.20). The dome-shaped installation is probably a slag pit of the most advanced, 9th century BCE smelting technology (see text for details) (photograph courtesy of ELRAP-LAL).



Fig.7.17: A close up on the dome-shaped furnace-related installation at Khirbat en-Nahas, Area R (Locus 145) (photograph courtesy of ELRAP-LAL).

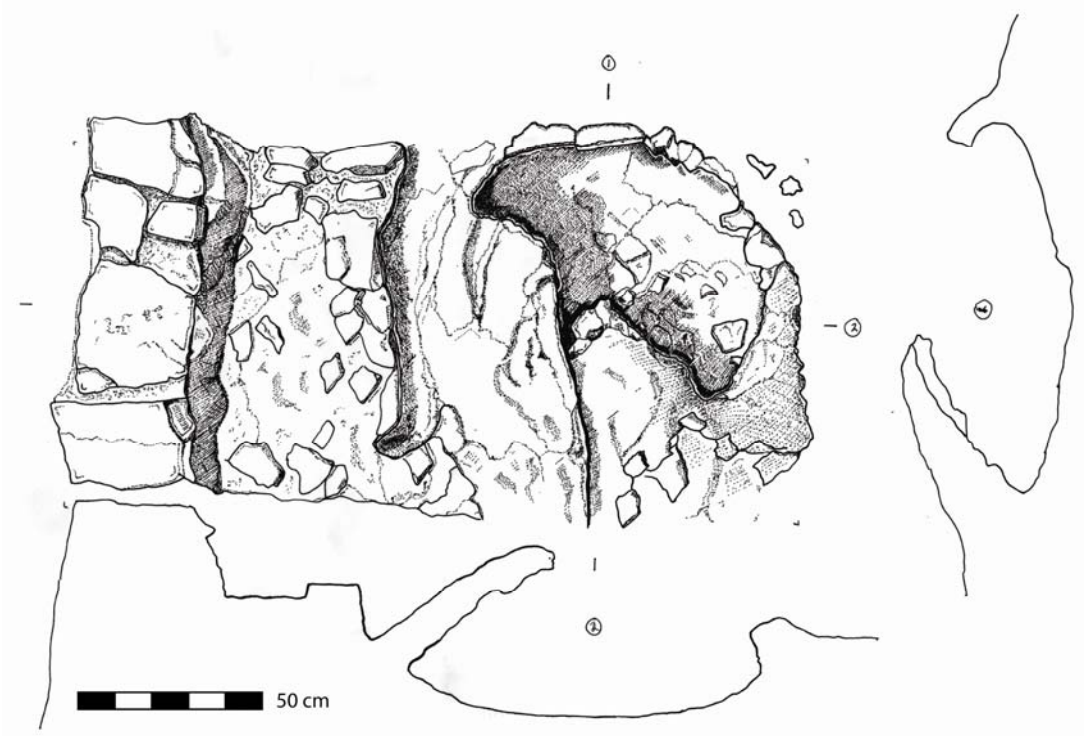


Fig.7.18: Drawing of the furnace-related installation Locus 145, stone and slag installation Locus 151, and wall Locus 104 at the metallurgical complex of Khirbat en-Nahas, Area R.

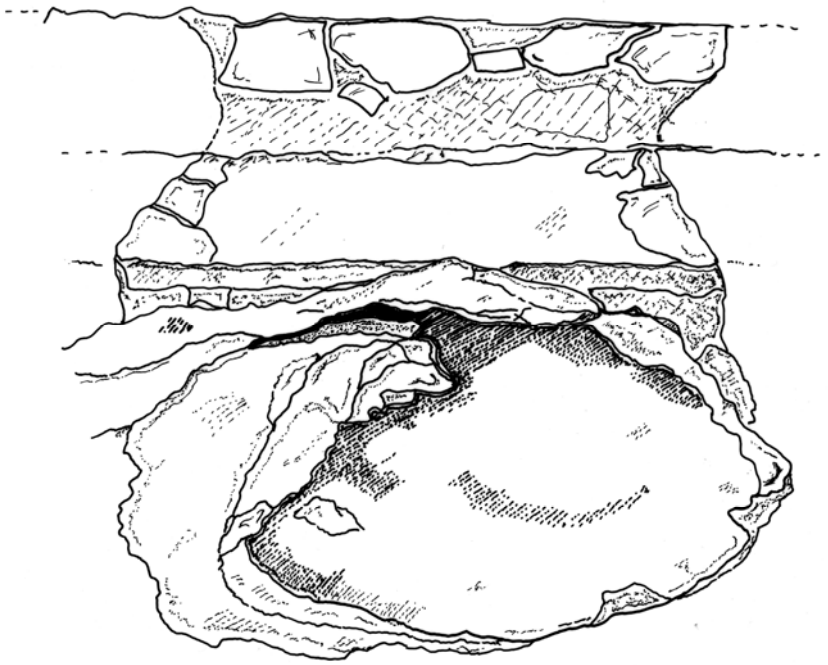


Fig.7.19: Another view of the unique installation at Khirbat en-Nahas, Area R: drawing of the furnace-related installation Locus 145, stone and slag installation Locus 151, and wall Locus 104.



Fig.7.20: The stone and slag installation Locus 151, KEN, Area R (photograph courtesy of ELRAP-LAL).

The furnace-related installation at KEN Area R is similar to two previously excavated installations. One is Locus 10, Layer 1 at Timna Site 30 (Rothenberg, 1980a:198-203, 1990a:46-48) (Fig.7.21) and the other is Locus 2 in Site 5 at Faynan (Hauptmann, 2007:101-103) (Fig.7.22). The installation at Timna is also a domed shaped structure with an inner diameter of ca. 90 cm (cf. 80 x 101 cm of the installation at KEN-R), interpreted as a "pyrotechnological installation" (Rothenberg, 1990a:47). Rothenberg (ibid.47-48) is careful with calling this installation a furnace:

> The large diameter of the underground structure makes it difficult to see this installation as a smelting furnace, although it is quite possible that originally Locus 10 had been a smelting furnace of smaller dimensions which became deformed and damaged beyond repair by continuous use and was subsequently in secondary use for storage. When found, Locus 10 contained a 10 cm thick deposit of tiny slag fragments (0.3-0.5 cm), and may well have been a store of tempering material… In any event, Locus 10 serves as good evidence for the construction methods of Iron Age II furnaces in Timna.

The dome-shaped structure at Timna 30 was also constructed in a short distance from a wall and also here a stone 'pavement' was found in between the installation and the wall (see Rothenberg, 1990a:Fig.70). At Faynan 5 one of the best preserved smelting-related installations was found in Locus 2, and it also has a dome-shaped part which is very similar to KEN-R (similar, not well preserved features have been found also in Loci 1 and 4). Hauptmann (2007:101-103) briefly describes the installation and suggests interpretation of the dome-shaped feature:

> The construction has a flat, circular depression in the middle, which is covered by a dome. A comparison with the Iron Age tap slags indicates that *the depression is the slag-tapping pit of a furnace*. The entire construction is made from slag-tempered clay and is only weakly fired. The inner diameter of the lentil-shaped pit is at most 1 m, the height in the middle up to 40 cm. The dome has in the middle an opening towards the top, where the impressions of vertically set slag or stone plates are very clearly recognizable… A second hole opens at the slope. The dome-covered tapping pit leads, via a small threshold, into a smaller hollow, which is almost completely vitrified and slagged due to intense heating… this hollow might possibly represent

> the last remains of the furnace combustion chamber, while the furnace upper walling is completely destroyed.

The interpretation of the domed installation as a slag pit located in front of a furnace is appealing, as it may explain a few of the field observations, in particular the size and shape of the depression and the lack of tuyère holes. However, it is not clear for what purpose the slag-pit should have been so carefully constructed, and why it should have had a dome with a central opening[83].

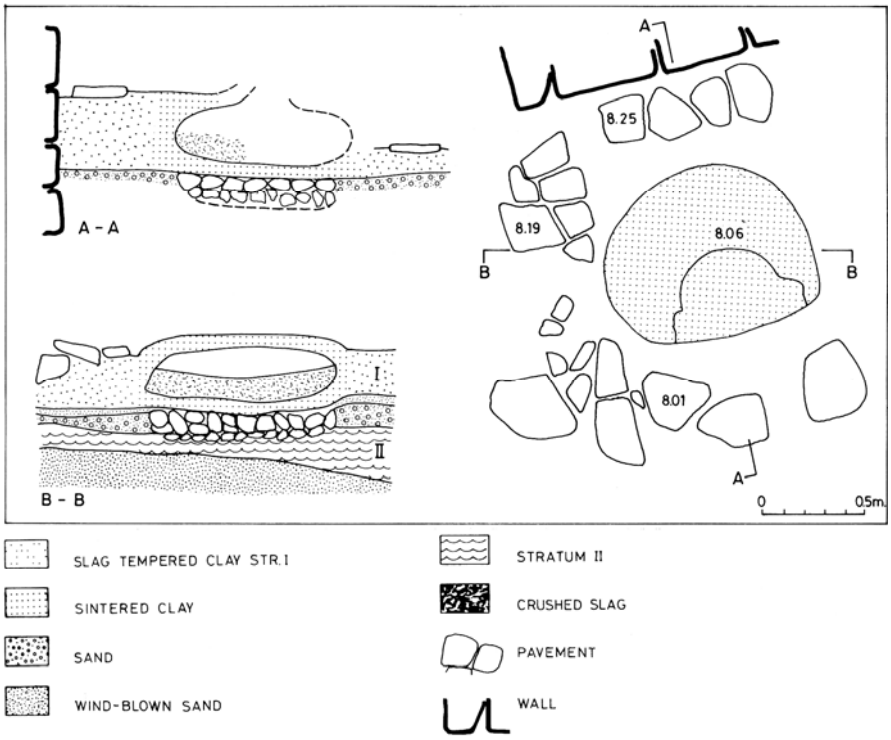


Fig.7.21: Site 30, Layer I, Locus 10 (Rothenberg, 1990a:47); the dome-shaped installation is similar to Locus 145 at KEN Area R; note that also the context is similar – near a stone 'pavement' separating the installation from a wall.

[83] Hauptmann does not provide an explanation for these features in any of his publications. As mentioned below, the basic limiting factor that excludes the interpretation of such installations as furnaces is their size. After considering additional evidence from Faynan 5 and KEN-R it became clear that the size of the depression is not a result of a secondary use for storage or a deformation of the original furnace (as suggested by Rothenberg for Timna 30), but rather the original size and shape of such installations.

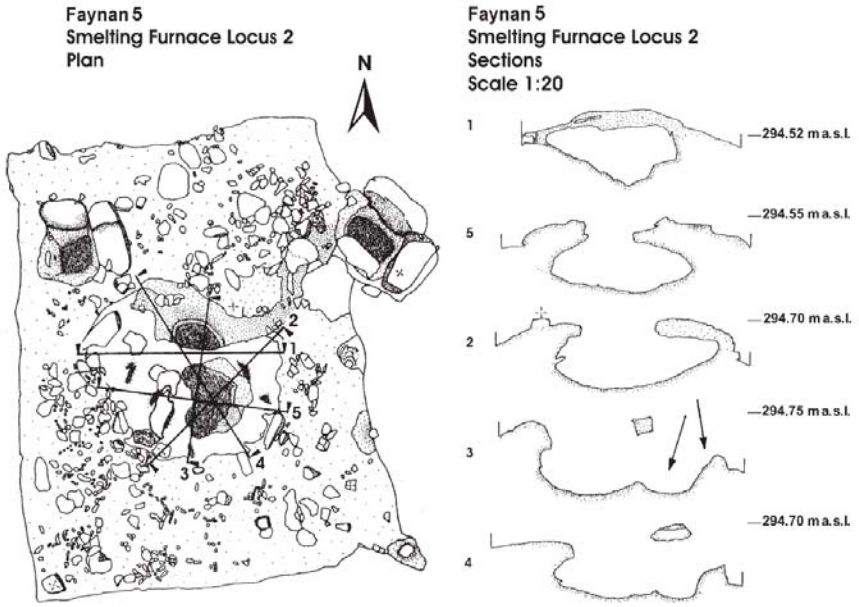


Fig.7.22: Faynan 5, Locus 2 (Hauptmann, 2007:102); a domed shaped installation similar to Locus 145 from KEN Area R. The installation was interpreted as a slag-pit, located in front of a furnace (which is represented by a heavily sintered base, indicated with arrows in the section on the right).

The new excavations at Timna 30 and the high precision radiocarbon dates obtained as part of the current research (section 6.2.1.3 above) indicate a 9th century date for Layer 1. A similar date, also based on radiocarbon analyses, was obtained for the Site of Faynan 5 (with one date associated with locus 2, 889-789 BCE 68.2% probability, see Table 5.2). These dates support the interpretation suggested in the current research that the archaeometallurgical complex at Area R represents the latest stage of copper metallurgy at Khirbat en-Nahas and dates to the 9th century BCE. This date has been supported (or at least not contradicted) recently by new radiocarbon measurements from this area (Levy et al., in press-b). The domed shaped installations and the semi-circular features described above (from KEN-M and Timna 30) represent the intact finds of the 9th century BCE copper production technology. From the earlier

phases of Iron Age copper production, only some ‘working surfaces’ and stone-built installations that are probably related to smelting activities were found *in situ*. Such features are most notable in the deep sounding into the ‘slag mound’ of Khirbat en-Nahas, Area M (Figs.7.23).



Fig.7.23: Stone installations at KEN Area M. These are probably related to smelting installations of the 12th-10th century BCE (supporting furnace bases and/or walls, see text for details). (1) EDM 91242, Locus 678; (2) EDM 90351, Locus 629; (3) EDM 91249 (photo), Locus ?.

7.2.4.2 Furnaces' upper structure

The evidence for the upper furnace structure is based entirely on fragments. Even in the (relatively) well preserved smelting installations of the 9th century BCE, it is only the dome-shaped slag pit (?) that was found intact, while the furnace itself is reconstructed according to the (supposed) nearby base. In Timna Sites 30, 185 and 2 several furnace bases have been excavated and interpreted as New Kingdom (Late Bronze Age) installations (Rothenberg, 1990a). According to the reports of the Arabah Expedition, there is a high variability in furnace shapes in the main phase of copper production in Timna. However, to carefully assess their conclusions, we must acknowledge the difficulties in Timna's chronological framework discussed in previous chapters (see especially Chapters 4 and 6). First, the finds from the 'New Kingdom phase' in Timna Site 30 (Layers 2 and 3) (Rothenberg, 1990a:8-12) should now be regarded as early Iron Age (late 12th – 10th century BCE), and probably the same revision should be applied to the furnace at Timna Site 185 and at least to some of the furnaces at Site 2. Second, some of the furnaces at Timna Site 2 may represent a much later (early Islamic) installations. This is very likely especially for furnaces 'Z' and 'I' that yielded late radiocarbon dates (Rothenberg, 1990a:71, all dates are mentioned and briefly discussed only in the endnotes) (FuZ: BM2242, 1400±100, [543-767 cal. CE, 68.2% probability, OxCal 4.1, IntCal09, © C.B. Ramsey 2010]; FuI: Grn 4381, 1350±50 [640-766 cal. CE, 68.2% probability, OxCal 4.1, IntCal09, © C.B. Ramsey 2010]). Only furnace IV in Site 2 yielded an early Iron Age date (H3625-

2782, 2940± 50 [1257-1056 cal BCE, 68.2% probability, OxCal 4.1, IntCal09, © C.B. Ramsey 2010]), but also the connection between the sample and this furnace installation is questionable. Regarding the complex evidence from Site 2, the present author agrees with the conclusion of Avner and Magness (1998:e.n.7) that the *ring slag* (but not all 'cake slag') represents only Nabataean or later smelting technology[84]. This is supported in addition to the late radiocarbon dates, by our observation that Timna 2 is the *only* archaeological context out of the entire "Late Bronze / Iron Age" smelting record in which such ring slag have been found (for definition of ring slag see section 7.2.6 below).

Although the furnace fragment collection from ELRAP is probably as comprehensive as the nature of the archaeological record allows (excluding possible future accidental discoveries), and although it provides important new data on furnace structures, it is still relevant to reiterate what Bachman and Rothenberg (1980), and later Hauptmann (2007:103), have stated:

> It has to be emphasized that neither in the Iron Age smelting sites of Faynan nor at those in Timna have there ever been any finds or contexts which would have allowed a realistic reconstruction of the smelting furnaces… It is therefore quite probable, also following comparisons with other smelting sites, that the smelting furnaces have systematically been destroyed after each smelting process.

Nevertheless, the large sample size we currently have from Iron Age smelting contexts allows us to reconstruct at least some basic components of such furnaces. Evidence

[84] Avner and Magness (1998) consider all of the 'cake slag' (i.e., the massive, solid slag slabs) to represent later smelting activities, and this is the reason that they include Timna Site 30 in their Islamic site distribution map (ibid.Fig.1). However, we have clearly shown here that this type of slag are typical to the 9th century BCE smelting technology both in Faynan and in Timna (see in particular Chapters 6, 8, and section 7.2.6 below).

from Timna (Rothenberg, 1990a), smelting experiments (in particular Merkel, 1990) and analytical investigations (in particular Tite et al., 1990; Al-Shorman, 2009) also support basic models of furnace reconstruction for this time period (Late Bronze – Iron Age).

Smelting furnaces *throughout* the Iron Age are primarily made of clay. Small stones, often found in 'slag mounds', may have been used in the construction of furnaces, as part of the foundations or for propping up the (usually heavy) clay upper structure (at KEN Area M we have recorded several dozens 'furnace stones'). They may have also been used for delineating slag pits (as was recorded in a few of the furnaces at Timna Site 2). Such stones usually show heat impact such as cracks, spalls and blackened faces; they are roughly trimmed, usually rectangular and flat, in the scale of 15-30 x 20-40 cm. Most of these stones were not found *in situ*; however, in some contexts (e.g., Fig.7.23:2) they probably represent their original layout as supporting a bottom of a furnace. The use of stones for supporting a furnace is evident in Timna, where stones were used to support the base (located beneath the furnace, cf. Rothenberg, 1990a:Fig.2), and/or as a support for the clay walls at the non-tapping sides of the furnaces (e.g., Furnace I, II, IV, VII, VIII, cf. Rothenberg, 1990a:Figs.32, 40, 42, 52).

According to our preliminary investigation of hundreds of well preserved furnace fragments, the same type of furnace clay was used *throughout* the Iron Age.

This local clay is very coarse, reddish – pink, and containing a large quantity (up to 30%vol.) of crushed slag, up to 5 mm in diameter (Figs.7.24, 7.26-7.31). However, both at Timna Sites 30, 2, and 185, and in Faynan Site 4, remains of clayey materials that do not contain crushed slag and that are tempered with quartz grains were reported as furnace fragments (or furnace linings) from the earlier stages of Iron Age copper production (or Late Bronze Age according to the commonly accepted date for Site 2 and 185). Rothenberg (1990a) describes this material as 'clay-like mortar' that was used as lining in bowl-shaped furnaces dug in the ground (Timna 30 and 185) or stone-built furnaces (Timna 2), and Tite et al. (1990:173) describe this clay in further detail (furnace walls containing 0.1-1mm diameter quartz grains, but deliberate tempering is questionable). Al-Shorman (2009:208-212) analyzed one fragment of furnace lining from Faynan 4, and reported it to be made of high CaO clay with quartz inclusions (and probably mixed with straw). This fragment also had no slag inclusions, and according to al-Shorman it represents a continuation of the 'Early Bronze tradition' in the area.

Technological remains from the latest phase of copper production at Khirbat en-Nahas contain the best preserved and most abundant furnace fragments. These fragments constitute a large portion of the collection because of the intensive excavations at the metallurgical complex of Area R which represents the 9th century BCE technology. As a consequence, our reconstructions are mostly based on the later remains, and extrapolations onto the previous technologies may be biased. However,

even in the earlier contexts we found furnace fragments that contain large amount of crushed slag (e.g., in KEN Area M Loci 636 and 660; WAG Area E, Locus 008, Fig.7.31 below). In the current stage of research we could not pinpoint a distinct technological transition based on furnace fragments alone; the major technological change evident in the record of tuyères (section 7.2.5) has to be correlated with a change in furnace structure, but for now this change has been assessed only qualitatively (below).

Based on petrographic and chemical analyses of two fragments of typical furnace lining from Khirbat en-Nahas, A.H. Al-Shorman (2009:208-212) has found that the coarse slag fragments constitute approximately 15-30 vol.% of the clay. The clay itself (illite and montmorillonite) is low or non-calcareous, with CaO content ranging between 4.8 and 7.7 wt.%, silica 55.3-60.8 wt.% and alumina 10.8-11.6 wt.%. Non-calcareous clays were used as furnace linings also in Timna Site 30 (both in Layers 1 and 2) (Tite et al., 1990). Given that the temperature range for smelting copper is 1100-1200°C (cf. 600-1050 degrees C for ceramics, Maniatis and Tite, 1981), furnaces should be designed to survive temperatures of 1150-1200° without total collapse or large scale bloating. The typical furnace clay (with slag inclusions) is *not* a refractory material; in fact, only the material constituting the front part of the tuyères was suitable for such temperatures (however, this material is less stable and needs special treatment, see below). The crushed slag probably did help with heat resistance to some degree; it was deliberately used as temper mostly to reduce

shrinkage and distortion, and to allow the escape of volatiles that evolved from the clay (Freestone, 1989)[85]. They also help to achieve the rigidity needed for the furnace walls to retain their shape prior to firing (Tite et al., 1990). By examining the slag inclusions from furnace clay from Timna 30 Layer I, Tite et al. (1990:170) argue that the crushed slag was reheated before being used as temper (based on petrographic evidence – no angular boundaries, oxidation zone at their outer boundaries, etc.)[86].

Instead of using refractory clay for furnace walls and lining, we believe that the solution to the heating and distortion problem was building relatively thick furnace walls consisting of multiple layers (Fig.7.24; these are the first to decompose by breaking apart along the seams between the clay layers, thus multilayered furnace walls are rarely found intact). The clay has low thermal conductivity, which would have resulted in only the thin surface layer of the ceramic reaching high temperatures: a temperature of 1100°C is typically reached at a depth of 5 mm after the surface of the ceramic has been exposed to 1150°C for about two hours (Tite et al., 1990). The furnace linings that were exposed to heat are sintered and in some cases slagged; they tend to flake off, and are often found as thin, relatively flat fragments in 'slag mounds'. The main body of the furnace was cylindrical and averages 30-50 cm in diameter. Some rare evidence for the use of cloth in the construction process was found on several furnace fragments (Fig.27:5). The cloth was probably used to

[85] However, slag is also a fluxing agent in clays (eases the melting process see Al-Shorman, 2009:212)
[86] Tite et al. (1990) also observed that the slag used as tempers for furnace clay in this context is manganese-rich (our "type A", see section 6.2.1.2 above), and not iron-rich; this may be a deliberate choice, but the sample size is too small.

stabilize the un-fired furnace structure, and was laid between different clay layers of the furnace wall. A more common find are furnace fragments with finger imprints, remains of hand fettling with the furnace clay (Figs.24-25). The same pattern was found in Timna (Rothenberg, 1990a:12, and also in the new excavations, see Fig.7.25:4).

An indicative type of furnace fragment is the 'double curve' or the 'S' shaped furnace wall (see in particular Figs.7.28-29). This represents the middle portion of a pear-shaped shaft furnace (Fig.7.32). In Timna this furnace shape has been considered as representing only the later, 9th century technology (Timna 30 Layer I) (Rothenberg, 1990a:46, and in particular Figs.67 and 68). However, in Faynan it seems that this shape had precedents in the earlier Iron Age (e.g., Figs.7.28:1,4, both are from deeper contexts of Layer M3; and more). The dimensions given by Rothenberg (ibid.) are similar to ours: an upper shaft of approximately 20 cm in diameter, and lower shaft of approximately 40 cm, with *rounded* corners at the bottom. The proposed location of the tuyères, right at the curve (Fig.7.32) is supported by the evidence from KEN. There is a distinct 'slag line' representing the level of the molten mixture and the active smelting area that had been located just in front of the tuyères (Figs.7.28:2-3). We found one fragment with a rim (Fig.7.29); this seems to be a unique find so far from the Arabah Valley. This fragment shows that the upper shaft was rather short, about 15-18 cm from the beginning of the curve. Another unique find is probably an 'imprint' of a furnace base (Fig.7.30). This fragment is a detached furnace bottom

composed of heavily sintered clay and some copper droplets. The fragment shows that the bottom of the furnace had rounded corners, and that the lowest most part of the furnace was approximately 15-20 cm in diameter (while the diameter of the lower shaft is about 40 cm).

In the current stage of research it is still difficult to suggest a satisfactory reconstruction of furnaces from the early part of the Iron Age (12^{th}-10^{th} centuries BCE), and our understanding of furnace construction in later phases (late 10^{th} – 9^{th} centuries BCE) is only somewhat better. The state of preservation of furnace fragments at KAJ, KAG and Layers 2-4 in the new excavations at Timna 30 is poor as are fragments found in the deeper layers of 'slag mound' of KEN Area M. The substantial difference in the state of preservation between the two technological phases is shown in the 'Average Fragment Weight' (AFW) values in Table 7.1 (see also Fig.7.1). While the recording methods applied during the ELRAP's 2006 field season at KEN were the same in all excavation areas, the metallurgical complex at Area R has an AFW three times more than the AFW of the sounding at Area M 'slag mound' (502 vs. 162 kg respectively). This is not accidental: the excavated contexts at Area R contain remains of the most advanced, 9^{th} century technology, while most of the 2006 sounding in Area M was done in earlier contexts (the 9^{th} century metallurgical debris was excavated during the 2002 field season). This difference stands as evidence of substantial change in furnace construction techniques and probably also furnace operation procedures between the two major technological phases evident in the Iron

Age archaeometallurgical record of the Arabah Valley (and defined in the current research, see Chapter 8 and section 7.2.5 below). Most of the "S" shaped fragments discussed above and other parts of the pear-shaped furnaces came from late contexts; however, as mentioned above, some are from earlier contexts and suggest *continuity* in the basic shape with a possible change only in dimensions. Based on the typical slag and tuyères of each of the two main technological phases of the Iron Age, it is also evident that the furnaces of the later phase were much larger (sections 7.2.5 and 7.2.6 below). Finally, it is also noted that there was more variety in smelting installation shapes in the early phase of the Iron Age technologies (12^{th} – 10^{th} centuries BCE), including, as mentioned above, the use of stones. While furnace fragments from the later contexts were easily typified in the ELRAP metallurgical collection (3-5 forms), the fragments from the earlier contexts presented a high variability of shapes and materials (more than 8 different forms and shapes). The large sample number in the selected collection at UCSD (several hundreds of fragments) makes this qualitative observation reliable. Further research is needed to pinpoint specific technological differences.



Fig.7.24a: Well preserved furnace fragments; inner lining with fettling marks (finger imprints) on the clay. Heat impact, is visible, including blackish residues (KEN Area R, late 10^{th} – 9^{th} century copper production, EDM r09f0978, Locus 079, Basket 0861) (cf.Fig.7.24).

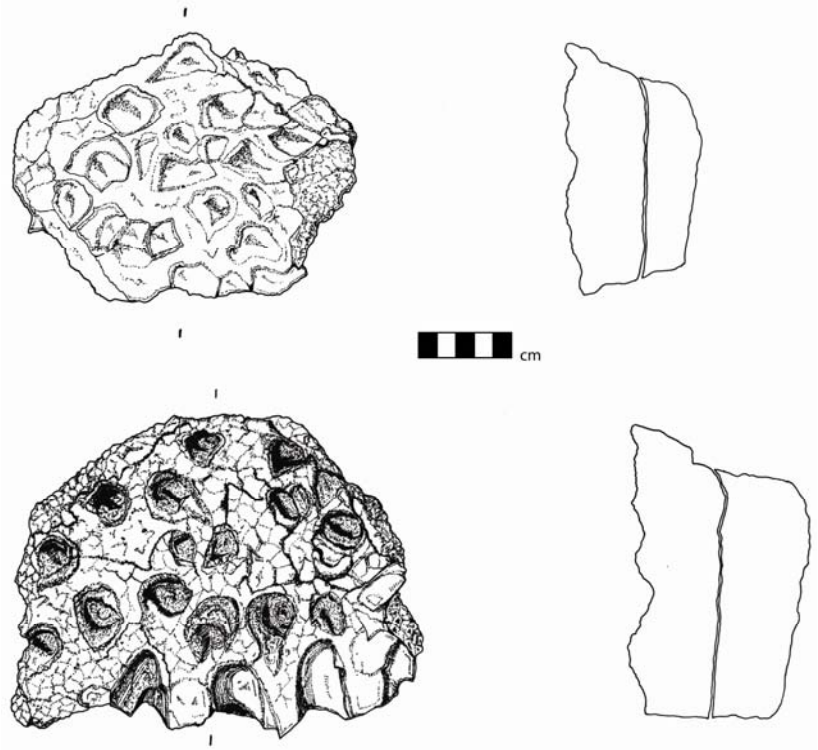


Fig.24b: Furnace fragments with finger imprints on the inner linings; note the distinct two layers of clay used in furnace construction. (EDM 0978, Locus 079, Basket 0861); see photo Fig. 7.24a.



Fig.7.25: Representative furnace fragments with finger imprints of the artisan who constructed the walls and linings.

#	EDM #	Site	Area	Locus	Basket	Comments
1	91285	KEN	M	682	9983	Reddish clay with slag inclusions and fingers imprints
2	90121	KEN	M	612	9048	Pinkish clay, finger imprints, a layer of lining without slag attached to slag-rich furnace wall
3	90788	KEN	M	647	9590	Finger imprints on a furnace fragment
4	NA	T30	S	900	NA	(from the section's collapse at the 'slag mound'), fingers imprints on a lining layer of a furnace fragment (cf.2)



Fig.7.26: Examples of furnace walls from KEN.

#	EDM #	Site	Area	Locus	Basket	Comments
1	90432	KEN	M	629	9280	Furnace wall, section, clay with slag inclustions
2	12043	KEN	M	629	9181	Furnace wall, smooth inner lining
3	90360	KEN	M	629	9213	Furnace wall, multiple layers of linings
4	R09f0979	KEN	R	073	0962	Furnace wall, heat impact



Fig.7.27: Various furnace fragments from ELRAP excavations.

#	EDM #	Site	Area	Locus	Basket	Comments
1	12047	KEN	M	629	9205	Rim fragment (?), typical reddish clay with slag inclusions
2	12130	KAJ	A	105	3196	Furnace fragment with marks of fettling fingers
3	90814	KEN	M	647	9610	Curved furnace fragment
4	90581	KEN	M	636	9417	Curved furnace fragment with a thinning edge
5	12060	KEN	M	660	9758	Furnace fragment with cloth marks on one face
6a	12176	KEN	M	732	10429	Furnace fragment; (a) back side, reddish clay, marks of fettling fingers (?), (b) front (inner) side, slag coating, bloating, heat impact
7a	10034	KEN	M	629	9270	Three vies (a, b, c) of a furnace fragment; note the curve, the clay layers, and the heat-impacted face



Fig.7.28: Various fragments of the ‘S’ shaped (double curved) part of furnaces from KEN-M.

#	EDM #	Site	Area	Locus	Basket	Comments
1	90657	KEN	M	636	9479	Two views (a and b) of the upper part of the ‘S’ section in a furnace wall
2	90313	KEN	M	629	9197	Bottom part of the ‘S’ section in a furnace wall; a side (a) and a front (b) vies; note the distinct ‘slag line’ indicating the level of the molten mixture in the furnace
3	91492	KEN	M	767	10136	Bottom part of the ‘S’ section in a furnace wall; note the distinct ‘slag line’ indicating the level of the molten mixture in the furnace
4	91015	KEN	M	665	9778	A front view and a section of furnace wall

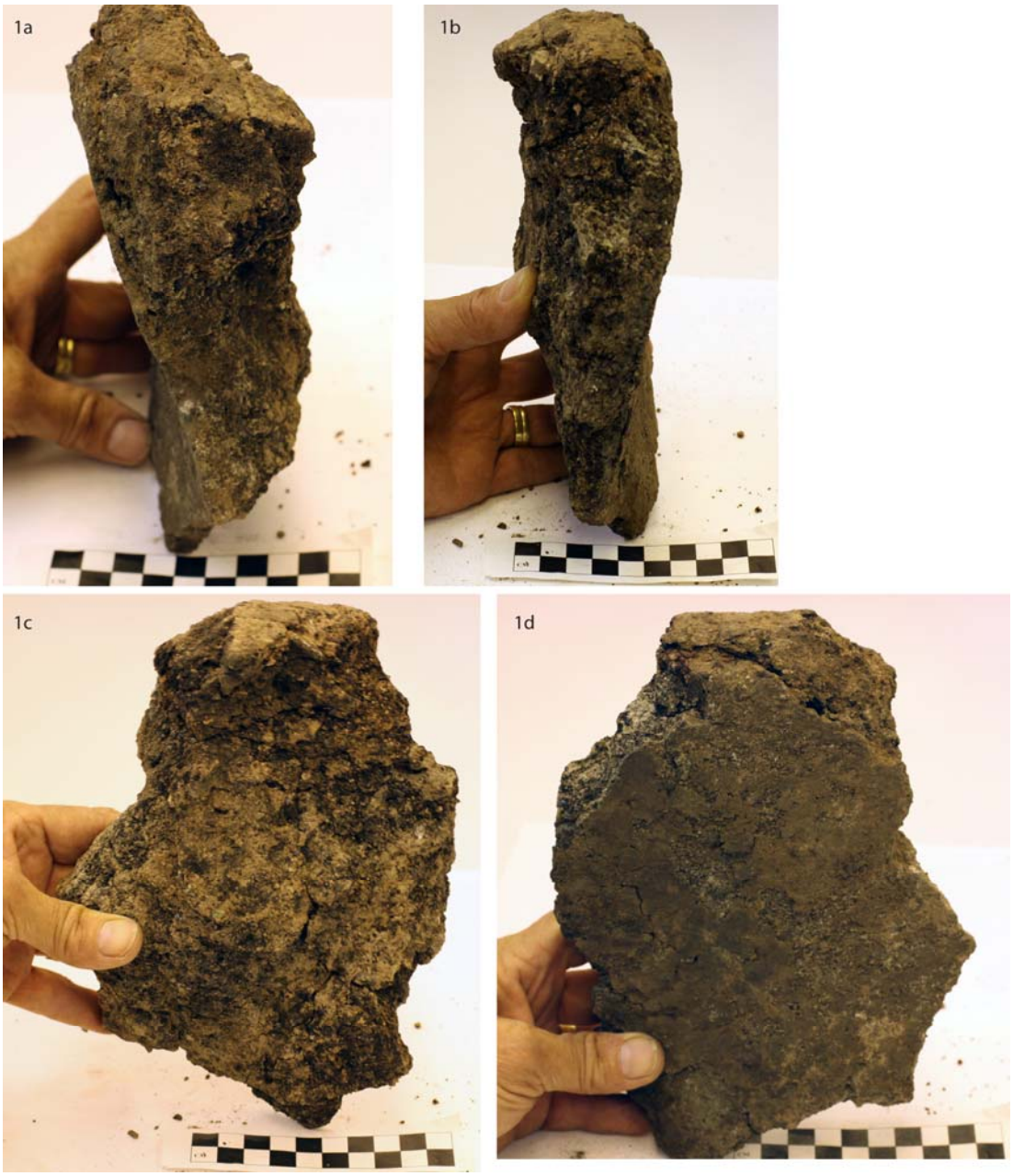


Fig.7.29: Well-preserved furnace fragment, including furnace rim, KEN-M.

#	EDM #	Site	Area	Locus	Basket	Comments
1	91795	KEN	M	745	10541	Four different views of a furnace fragment with a rim



Fig.7.30: An ‘imprint’ of a furnace bottom.

#	EDM #	Site	Area	Locus	Basket	Comments
1	90649	KEN	M	641	9471	Layer M2b, the sounding into the ‘slag mound’, an ‘imprint’ of a base of a furnace (a: up side down, b: up side up); heavily sintered clay that flaked off the furnace bottom



Fig.7.31: Furnace fragments from Khirbat al-Ghuweiba, Area E; the clay contains large amount of slag inclusions (EDM 0113, Locus 008, Basket 99).

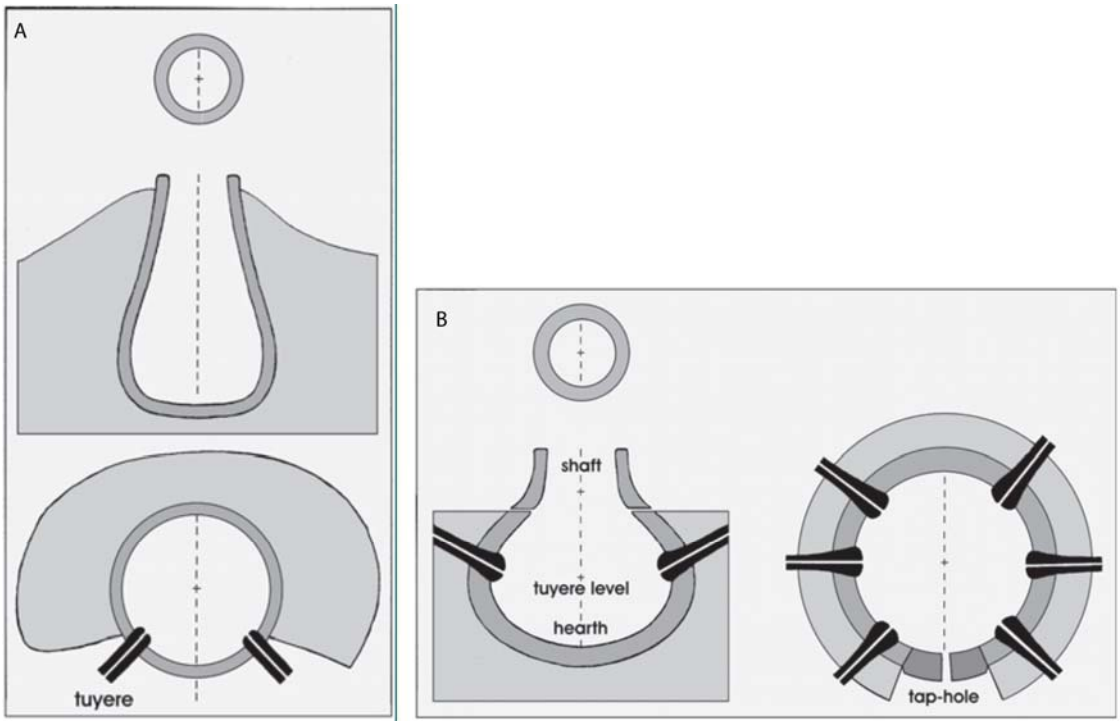


Fig.7.32: Basic reconstruction of smelting furnace in Timna 30 Layer II-III (A) and Layer I (B) according to Rothenberg (1990a) (from Hauptmann, 2007).

7.2.4.3 Miscellaneous technological ceramics

Many fragments of ceramics (including slag-less clay vessels) that seem to be related to pyrotechnical technologies but did not have the typical qualities of furnace fragments, molds or crucibles (and obviously domestic pottery), were labeled by us generally as 'technological ceramics' (Fig.7.33). Such clay fragments may be related to installations associated with the (s)melting furnaces, such as 'slag pits', the bellows system (of which we know very little), refining and melting installations, etc. As most of these have also not been fired, the record is usually too fragmentary to say much about their function in this stage of research. Many of the finds in Area F at Khirbat en-Nahas were labeled as 'technological ceramics'; together with the relative large quantities of copper metal chunks, mold fragments, bellows pipes, large stone basins and other architectural installations, As described earlier, Area F has been interpreted by us as a specialized workshop for refining, melting and casting of copper metal (e.g., Fig.33:2,4 and sections 7.2.5, 7.2.7, 7.2.8 and 7.2.9 below). Some similarities between the archaeometallurgical assemblages of Areas F and T suggest that the latter has also functioned as a specialized metallurgical workshop, although the metallurgical area there was only excavated to a limited degree and the archaeometallurgical assemblage has not been thoroughly studied yet (cf. Table 7.1 [see also notes to the table]).

A typical and ubiquitous find in all of the Iron Age smelting sites of Faynan are thin and flat clay fragments, smooth on one side and covered with a layer of

crushed slag on their opposite side (Fig.7.33:1). At the field recording stage we could not provide a satisfactory explanation for these fragments, and all were labeled as ‘technological ceramics’; however, after working on the archaeometallurgical collection, it appears that these are fragments of sintered furnace linings that flaked off the slag-rich furnace clay walls probably when the furnaces have been broken. A layer of crushed slag from the furnace walls adhered only to the back side of the lining and resulted in this characteristics appearance (nicknamed ‘cookies’ by us).

A unique find (Fig.7.33:3) possibly represents the location/position of a (large) tuyère within the furnace wall. The artifact was found in a context of smelting debris and is composed of furnace clay material. A reconstruction of the fragment based on its original shape suggests that it is a hole in a furnace wall; this hole has an inclination of about 10° from the horizon, supposedly pointing towards the bottom of a furnace. The dimensions of the hole can fit a tuyère. However, the smooth face of the hole and other features challenge such interpretation, and this artifact may be related to other technological activities. Many other unique fragments are still without proper interpretation and await future research.



Fig.7.33: A few artifacts labeled as ‘technological ceramic’ and a bellows pipe from Area F.

#	EDM #	Site	Area	Locus	Basket	Comments
1	40897	KEN	T	1563	13591	A common artifact labeled as ‘technological ceramic’ in Iron Age smelting sites excavated as part of the current project. They are now interpreted as the back (a) and front (b) of a sintered furnace lining.
2	?	KEN	F	?	?	A fragment of a ‘technological ceramic’ with unknown function; found in Area F and may be related to refining or casting procedures
3	91551	KEN	M	707	10184	A fragment of ‘technological ceramic’; may represent a tuyère hole in a furnace wall (see text)
4	12009	KEN	F	858	1173	A fragment of bellows pipe with a coating of oxidized copper in its inner tube

7.2.4.4 Furnaces, pottery, and '*technological style*'

In addition to inclusions in furnace clay, crushed slag was commonly used as a temper in domestic pottery vessels at KEN and KAJ, and probably also in other Iron Age copper production sites (Smith and Levy, 2008; Smith, 2009; Smith and Levy, in press; Smith et al., in press-b)[87]. Crushed slag was found in almost all the local vessel types, although in some cases, especially among very fine pottery, it was found on the microscopic level only (suggesting that pottery was produced on site and slag became part of the clay unintentionally). In Cooking pots, Pithoi, Hand Made ware, and some Kraters, it is evident that the slag was intentionally added; many inclusions of slag are present, mostly 1 mm in diameter, and it is unlikely that such amount of fine crushed slag was part of the original clay deposits. Slag as a temper may have had practical benefits in domestic ceramics, such as rendering the vessels more resistance to higher temperatures and breakage, and facilitating 'sweating' of vessels by rendering them more porous (this is sometime desirable, e.g., when cooling water in storage jars etc.). It was also a material that was abundant at the copper production sites. However, it is very likely that this phenomenon represents a specific *technological choice*, and more precisely a *technological style* of the society responsible for the copper production in

[87] At the site of Rujm Hamra Ifdan, located a few km from the main smelting sites (Table 6.1, Fig.6.1) most of the vessel types of the early Iron Age (ca. 1200-800 BCE) pottery contained slag inclusions. Interestingly, in the pottery assemblage of the late Iron Age (ca. 700-500 BCE) from this site *only* Pithoi contained slag inclusions (Smith, pers. comm. 2010). This may represent some continuation of pottery traditions of the local societies. The pottery assemblage from the late Iron Age fortresses of Ras al-Miyah (the only other late Iron Age ceramic assemblage from Faynan, section 5.2.6) was not thoroughly studied; presence of slag inclusions in vessels from this assemblage (as opposed to any vessel on the plateau at this period) will support local traditions of ceramic manufacturing practices, and some dichotomy between the plateau and the lowlands also in the late Iron Age activities.

Faynan throughout the Iron Age I-II (12^{th} – 9^{th} centuries BCE) (cf. Lechtman and Merrill, 1977; Lechtman, 1988, and see section 1.1.3 above). *Technological style* is expressed by a common attitude towards different materials, not unlike stylistic choice studies in other realms of material culture by anthropologists (Conkey and Hastorf, 1990; Dietler and Herbich, 1998). The choice of using slag inclusions in most of the pottery vessel types, even if in some cases this was a substitute for other commonly used non-plastic tempers such as calcite ($CaCO_3$) in cooking pots (Rye, 1976:116-117; Rice, 1987:229), is clearly a conscious choice, a technological practice that originated not only from functional reasoning. A number of ceramic studies (e.g., Rice, 1987:119, and references therein) have shown that potters added different inclusions into their pottery that served no functional purpose but rather is related to habitus, religion or superstition (e.g., if we do not put this in the clay, then the pottery will break or something worse will happen). Given the central place slag material must have had in many different aspects of the copper production system (including being a source of 'hidden' metal, a flux, and a proxy for the success of the smelting cycle, see section 7.2.6 below) and its origin directly from a s(melting) processes (often considered as a magical phenomenon in traditional societies, see Introduction to this work), it is highly likely that slag material had an extra value, a symbolic quality and a social function that we are unable to completely decipher today. The use of slag in manufacturing domestic pottery at the Iron Age smelting site may indeed represent embedded social meanings. This distinct feature in a very common material (that is often considered as representing ethnicity, but see Chapter 10 for further discussion),

may have also been used as an identifier of the social group working at the smelting sites.

7.2.5 *Tuyères and bellows pipes*

In previous research three main groups of ceramic objects related to the bellows system have been recognized in the Iron Age (and Late Bronze Age) archaeometallurgical record of the Arabah (cf. Rothenberg, 1990a; Hauptmann, 2007). These include ‘small tuyères’, ‘large tuyères’ and bellows pipes (or ‘tubes’). The results of the current research provide additional information on the nature of these objects and their manufacturing process. In addition, based on several thousand fragments from various sites, these objects have, for the first time, been precisely correlated with specific spatial and temporal contexts. In turn, as these objects are distinct and relatively easy to recognize (cf., e.g., furnace fragments above), they are excellent temporal and functional markers, as demonstrated below.

Two of these object groups are tuyères, distinguished from each other by their size and hence classified as ‘small tuyères’ and ‘large tuyères’ (following both Rothenberg, 1990a; Hauptmann, 2007). It has been recognized that the difference between these groups represent a technological development corresponding to time (e.g., Hauptmann, 2007:100, there the 'small tuyères' are suggested to represent a Late Bronze Age smelting technology, and cf. Hauptmann's discussion on the tuyères at

KAJ described in section 5.2.5.1 above). However, only now we can precisely pinpoint the timeframe of this technological change and suggest a correlation with culture-historical events in this region. The third group of objects consists of bellows pipes (or 'tubes'), and according to our research *does not* represent primary smelting activities. These objects have been found in specific contexts associated with secondary metallurgical activities, in particular refining, melting and casting of copper metal. In Faynan, bellows pipes were found only at the excavated site of Faynan 5 (Hauptmann, 2007:Fig.5.10.13) and at Khirbat en-Nahas (mostly Areas F and T). These are the only sites in Faynan that also include remains of the more advanced copper smelting technology (associated with the 'large tuyères' and other technological features), dating to the late 10^{th} – 9^{th} centuries BCE. This may imply that bellows tubes were only used in association with the more advanced smelting technology. However, the sample size from the earlier Iron Age contexts at Khirbat en-Nahas and other sites (mostly KAJ and KAG), is possibly too small for decisively excluding the practice of a similar technology in special workshops also in the earlier phase of the Iron Age. As reconstructed here, the use of bellows pipes for refining processes in the *later* phase of Iron Age smelting activities is in accordance with the abundance of iron-contaminated copper chunks in smelting contexts associated with advanced smelting technologies (see section 7.2.7 below). In Timna the situation regarding evidence of bellows pipes is more complex. From Timna Site 30 Layer 1, the only context where evidence of advanced Iron Age copper smelting technology in the southern Arabah has been identified, no bellows pipes are reported in the

publications of the Arabah Expedition, and none were found in our recent excavations at the site. This may be attributed to the relatively small size of excavated material representing this technological phase at the site (and as mentioned above, bellows pipes are less abundant and found in very different contexts than tuyères). In Timna Site 2, a few "tubular tuyères" were reported only *in situ* in several furnaces (Fu II, Fu IV and Fu Z, see Rothenberg, 1990a:35-36) and have been reconstructed as having a tapering nozzle (although they were attached to the furnace walls and apparently never separated). The tapering nozzle and the dimensions of these tuyères (10-12 cm in diameter of air holes, clay wall of ca. 1 cm thick, ca. 20 cm long) render this type of object distinct from any of the other bellows-related object groups documented by us for the Iron Age. Either this group of "tubular tuyères" represents an earlier, Late Bronze Age technological phase (not documented anywhere else), or, most likely, this distinct object type is additional evidence for the *late* date of these furnaces (Early Islamic, see discussion about slag typology and radiocarbon dates for this site in section 7.2.6 below, and general overview of the site in Table 6.1).

A great difficulty in the interpretation of furnace remains in the Arabah Valley concerns the reconstruction of the location and number of tuyères that were used in relation to each furnace type. Concerning the position of the tuyères', Rothenberg (1990a:35) suggests using the distinct border line between the slag-coated portion of the tuyère and the bare portion to reconstruct the angle of the tuyère in the furnace wall (see e.g., Fig.40:2c-2d). In addition, the solidified drops of slag material on the

tuyère's bottom (that look like a 'beard') are a good indication of the original angle of the tuyère in the furnace (e.g., Fig.42:2c). In general, based on the KEN assemblage, we agree with the main conclusions of Rothenberg regarding the position of both the small tuyère (1990a:37) and large tuyère (1990a:48-49; cf. Hauptmann, 2007:99). The small tuyères were located in two different positions in the furnace: a) inclined at 25-30° to the horizontal and located in a straight, upright segment of a furnace wall (indicated by a straight, diagonal border line); and (b) inclined up to 40-50° in a curved segment of the furnace wall (see above, section 7.2.4, and the description of the double curved furnaces) (indicated by a curved borderline and the steep angle of the pendent slag drops). The large tuyères were also found to be located in two different positions in the furnace: (a) inclined at 20-25° to the horizontal (cf. Fig.42:2c), and (b) inclined at ca. 60° (cf. 40-60° for large tuyères from Faynan 5, Hauptmann, 2007). Most of the large tuyères came from a curved segment of the furnace and very few from a straight segment. Their location was determined to be in the convex base of the upper shaft. We have found this conclusion to be supported by ample finds of s-shaped furnace fragments, as there was a distinct slag line in the inner part of the furnace, right at the curve, separating the slag-coated lower part of the interior and the bare clay lining on the upper part (cf. Figs.7.28:2-3). Regarding the number of tuyères per furnace, there is still not enough archaeological evidence to provide a decisive reconstruction. The general reconstruction of the furnaces, coupled with experimental archaeology (Merkel, 1990), suggests that there could not have

been more than three tuyères per furnace (and probably there was more than one tuyère; this applies to both types of tuyères discussed here).

7.2.5.1 Small tuyères

Both the small and large tuyères of the Iron Age Arabah are composite ceramic objects intended to protect those portions of a bellows system that were most exposed to heat during the smelting process (Figs.7.34-7.42)[88]. These objects protruded into the furnace walls and contained the tip of an air pipe that was connected to the bellows and was probably made of animal skin. Skin-made artifacts and other organic materials related to the bellows system (such as ropes) are rarely preserved in the archaeological record. It is possible that the skin fragments, ropes and textile excavated by us in the organic-rich layers of Timna 30 represent some parts of the bellows system (section 6.2.1.2 above). The bellows were probably composed of organic materials and not ceramic or stone. The commonly suggested reconstruction of a pot-bellows for the Late Bronze Age / Iron Age smelting sites in the Arabah (e.g., Bachmann and Rothenberg, 1980:230) is based on Egyptian tomb drawings and not on archaeological evidence. The excavations of the Arabah Expedition in the southern Arabah Valley and our recent research in Faynan yielded not a single artifact that can be interpreted as related to a pot-bellows system. The very few examples of identified

[88] The use of multi-layer refractories has also been reported from the bronze working Iron Age site of Kh Edh-Dharih where calcareous illitic red layer and non-calcareous sandy white layer were used in the melting crucible manufacture (Klein et al., 1997). This suggests that the production of multi-layer refractories was a local technological tradition (see Chapters 9 and 10 below).

pot bellows from the Ancient Near East (Davey, 1979) came only from workshops for secondary metallurgical processes within settlements (e.g., Tel Beit Mirsim, Meggido, Ras Shamra, Enkomi and more) (cf. Yahalom-Mack, 2010, for the use of bellows in Iron Age metallurgical workshops in settlements). Alternative reconstructions of bellows operation are discussed in Chapter 9 below.

The small tuyères are made of two separate parts that fit into each and together protected and facilitated the operation of the bellows system. The front part (referred to also as 'nozzle' or 'cap', Fig.7.34) is made of the most refractory material in the smelting system, in accordance with its exposure to the highest temperatures achieved during smelting operations. Smelting experiments have shown that while average temperatures in smelting furnaces are about 1000°C, there is a wide range of temperatures that correspond to the distance from the tuyère. Temperatures near the tuyère itself may get up to 1300°C (Tylecote and Boydell, 1978) or even 1500°C (Juleff, 1996), and consequently the most active slag-forming and copper extraction zone is also located around the tuyères. The material making up the front part of the small tuyères could have resisted distortion at temperatures over 1200°C (Tite et al., 1990, and cf. clay of furnaces and the rear parts of tuyères with distortion occurring at about 1150°C). The back part (referred to also as 'rear part' or the 'main body') of the small tuyères is made of reddish clay with slag tempers, similar to that used for furnace walls (Fig.7.35). As mentioned in the discussion on furnaces above, this is not a true refractory material, and it was probably easily replaceable.

The tuyère fragments from Khirbat al-Jariya, Area A, belong only to the small tuyère group (most probably similar to all other archaeological contexts from KAJ, see discussion about Area A 'slag mound' and dating in section 5.2.5 above), and thus their measurements may stand for the entire group. The average diameter of the small tuyère air holes is 3±0.7 cm (n=23; 5 fragments = 3 cm; 3 fragments = 2 cm; 6 fragments = 2.5 cm; 7 fragments = 3.5; 2 fragments = 4 cm). There is a relatively large variation in the dimensions of the air hole of these tuyères (in comparison to the 'large tuyères'), and in some cases also in the quality of materials used. The nozzles are made of white sandy clay and the rear part (main body) made of unfired reddish clay tempered with slag inclusions; in ELRAP's excavations and in the new excavations at Timna 30 there were few fragments found of the rear parts, as might be expected from a non-fired and much more fragile material. Another, more indicative measurement of tuyère dimensions is its thickness. As the common find is the tapered front part, we measured the thickness from the edge of the hole in the center of the back part of the socket to the external edge of the tuyère (assuming the socket is located in more or less the same position in relation to the tapering tuyère). There were fewer fragments from Khirbat al-Jariya that allowed such measurement as the front part of the tuyère was often found disintegrated. The results indicate an average thickness of 3.5 cm (n=7, 1 fragment = 2.5 cm; 2 fragments = 3 cm; 2 fragments = 3.5 cm; and 2 fragments = 4 cm). Fragments EDM#20200 and EDM#20181 had the longest slagged

portions, representing the minimum length of the portion of the tuyères that was inside the furnace. Both are approximately 9 cm in length.

Cloth marks are observable on the back parts of the tuyères, on the side that connects to the nozzle (front parts) (Fig.7.34:3a). Only a few of the nozzle sockets have observable cloth marks on them (Fig.7.34.4), but this is probably due to the difference in materials, as the sandy clay is less plastic and thus is less likely to preserve cloth marks. The external parts of the nozzles (front part) are usually covered with slag, but where there is no slag, usually the areas that were inside the furnace wall, cloth marks are often visible (the part of the nozzle that protruded into the furnace is easily recognized by slag cover, molten parts and other heat impacts. In some cases a distinct slag line represents the boundary between the protruding portion of the tuyère and the one that was embedded in the furnace's wall). The rear part of the small tuyère is often found with typical reed marks (Fig.7.35)[89]. The cloth and reed marks provide clues about the manufacturing process of the small tuyères. Based on our detailed observations, we have amended Rothenberg's (1990a:41) and Werker's (1990) suggestions regarding the manufacturing technique of such tuyères. Our tentative suggestion seems to be the most parsimonious reconstruction, based on the currently available archaeological evidence; however, slightly different alternatives

[89] Only one fragment from KAJ had the typical reed marks of the small tuyères (EDM #20227, Locus 118, Basket 3705), but this is the only fragment that represents the bulk of the body of the rear part of the tuyère in the entire archaeometallurgical assemblage from this site. This relatively well-preserved fragment represent a minimum external diameter of the rear parts of small tuyères, ca. 11 cm. This fragment also has ca. 40 parallel reed marks with representing differently cut reeds (i.e., the marks are not equal in width). Similar fragments were found in Area M at KEN.

are also relevant (including the use of designated molds, different firing stages of clays, etc.). According to our suggestion here, a shallow hole was dug into the earth that was lined with cloth before the sandy white clay was placed into it. A layer of cloth was then also placed upon the lump of clay before the socket was pressed into it by some hard round object (smooth rock or fired ceramic). A reed or piece of wood matching the average 3 cm diameter was used to create the air hole. This piece, representing the front, refractory part of the tuyère, was then fired in a kiln before the tuyère body (rear part) was fit into it (a kiln probably used for this purpose has been uncovered in Timna 30 Layer II, see Rothenberg, 1990a:Fig.21). The clay of the tuyère body, red clay tempered with slag, was then placed into the socket of the nozzle and a reed or wooden rod was inserted through the centers of both pieces. The cloth imprints from the socket of the nozzle would transfer onto the soft clay of the tuyère body. Then a small pliable reed mat (or 'net') was used to form the outer body of the tuyère into the tubular shape that was fitted into the furnace wall[90]. Often it included more than one layer of clay (usually two layers: clay, pliable reed mat, and clay, and sometime three layers; the external layer was clay, and the typical fragments with reed imprints such as those in Fig.7.34 are broken in a way that the reeds imprints are exposed). The two parts of the tuyère were easily separated after they were used in the furnace; the rear part was replaced, and when possible the refractory front part was re-used for a new tuyère. Re-use of the front nozzles is supported by observations reported by al-Shorman (2009:114).

[90] The way a Sushi roll is made is somewhat similar to the procedure we suggest here.

The small tuyères of the southern Arabah Valley and Sinai vary in size with outer diameters from 5-8 cm (measured on the rear parts), lengths of 4-9.2 cm and air hole diameters of about 2 cm (Rothenberg, 1990a:35-36). Overall, they represent the exact same technology as the one in contemporary Faynan. At Timna, the manufacturing technique of those tuyères was reconstructed by the Arabah Expedition as fitting clay around a wooden rod of ca. 2 cm. The clay was then wrapped in a net of reeds, and then with another layer of clay and sometimes another net of reeds, forming a tuyère body in a clay-reed-clay-reed pattern. Based on a single random find of an 'unused' tuyère fragment found at Timna Site 13, it has been assumed that the whole tuyère was fired in a kiln (Rothenberg, 1990a:36-37). In some fragments, charred reed remains have been found. These reeds have been identified as *Phragmites australis*, a common plant in the springs and marshes of the desert areas of the southern Levant (Werker, 1990).

7.2.5.2 Large tuyères

The best representative context of large tuyères from the recent excavations in Faynan is the metallurgical complex at Khirbat en-Nahas, Area R (Figs.7.36-7.42). In the metallurgical deposits excavated so far in this area, all of the tuyères belong to this group. This type of tuyère, like the small tuyères described above, is composed of two primary components, a front part (a 'nozzle' or a 'cap') made of refractory clay and a

rear (or ‘back’ or ‘main body’) part made of reddish clay rich in crushed slag inclusions. The most distinct difference between the two groups of tuyères is the circumference of the front part (the sandy white clay), and the depth of the socket made into it. The same features recorded for the small tuyères were recorded also for the large tuyères from Area R. The average air hole diameter was found to be ca. 2.5±0.4 cm (n=15, 6 fragments = 2 cm, 4 fragments = 2.5 cm, and 5 fragments = 3 cm), demonstrating less variability than the small tuyères. The average thickness (measured from the edge of the hole in the socket side to the external edge of the tuyère) was found to be ca. 6±0.9 cm (n=12, 3 fragments = 5 cm; 1 fragment = 5.5 cm; 3 fragments = 6 cm; 1 fragment = 6.5 cm; 3 fragments = 7 cm; 1 fragment = 7.5 cm), demonstrating more variability than the small tuyères. The large tuyères do not have cloth marks. Instead and in the same locations there are marks of organic material (grass, or weeds, with no defined pattern to the markings, Fig.7.40:3b)) (on the nozzles, beneath the slag, e.g., Locus 1853, EDM 30675, Basket 16530; on the sockets of the nozzles, e.g., Locus 071, Basket 0886 EDM F1007; on the tip of the inner parts, e.g., Locus 1833, Basket 16384, EDM 30506). In addition, the rear parts do not have the typical reed marks described above for the small tuyères. Large fragments and intact tuyères (Fig.7.41:3-4) preserved additional socket(s) related to the composite construction of the rear part (main body).

In the excavations at Area R a few large tuyères have been found *intact* (Figs.7.36-7.38), the first such artifacts from the smelting sites of the southern Levant.

The dimensions of the complete tuyères are approximately 32 cm long, 15 cm wide and 13 cm height (from the supposed original stance; the tuyère is thus not entirely rounded). The length of the complete tuyère is surprisingly large, suggesting a very thick furnace wall; it appears that, similar to the poor preservation of the main bodies of the tuyères,(rear parts) most of the furnace wall material was entirely decomposed, and the preserved parts represent only the inner layers that were hardened by heat. There are no intact furnace fragments in the entire collection that correspond to 30 cm+ wall thickness, and we believe this is a consequence of poor preservation of the unfired clay material that the furnace walls were made of.

Large tuyères in the southern Arabah have been reported only from Timna Site 30 Layer I. They have nozzle diameters measuring from 13.0-16.5 cm and air hole diameters ranging from 2.0-2.3 cm. No completely intact tuyère was found, and the greatest length measured was 12.3 cm. The tuyères were made from clay that was highly tempered with crushed slag, just like the material of the furnace walls (Rothenberg, 1990a:48). As for the construction of the "large" tuyères, Rothenberg (ibid.49) writes of superimposed layers of clay being used to construct the tapered body, then a quartz clay was applied to form the outer refractory casing (front part) of the tuyère. Similar to the small tuyères, Rothenberg argues that the whole tuyère was pre-fired in a kiln before it was inserted into the furnace. As indicated here, the new evidence supports that only the front part of the tuyères (small and large) were pre-fired and the body itself was not fired (and thus has easily decomposed; a few

fragments of body parts showed that one side of the body was flattened as the still soft clay have been set to rest on one of the stone walls that served as a support for the tuyere and as a side of the furnace).

Based on our observations we suggest the following reconstruction for the manufacturing technique of the large tuyères (both in Faynan and in Timna). Like the construction technique used with the small tuyères, a shallow hole was dug into the earth and then lined with organic material such as straw, grass, or reeds to allow for the easy removal of the part after it dried. After placing a lump of the white sandy clay in the hole, another layer of organic material would be laid on top, a socket was then pressed into it and a hole made before this piece was fired. After being fired, a mass of red clay would be placed into the nozzle socket. This red clay would then be pressed with a round object to create the second socket. Other layers may have been made on top of this in the same manner, resulting in a tuyère constructed in layers. In contrast to the small tuyères, the bodies of the large tuyères do not show evidence of the net reed markings. It seems that the large and heavy bodies of the large tuyères could not be constructed using net of reeds, and that the ‘multi-layers’ (and multi-sockets) construction technique was necessary for creating a stable tuyère.

7.2.5.3 Tuyère materials

Tuyères from Faynan 5 were investigated by Hauptmann (2007:99). At the site two different types of tuyères were found and were believed to represent different dates (following Rothenberg's publications, Late Bronze Age and Iron Age for the small and large tuyères respectively). The site itself (Table 5.1) is considered by its excavator to be the second largest Iron Age smelting site in Faynan (after KEN), containing about 30,000 tons of slag. Hauptmann's analytic results of the large tuyère indicate that the front part contains 70-80 wt.-% SiO2 and 10-20 wt.-% Al_2O_3, ,a composition that is heat-resistant up to over 1100°C, thus a highly refractive material. Hauptmann (2007:99) suggests that the clay of this ceramic is made of kaolinite or from a siliceous rock. The back part, made of reddish clay tempered with crushed slag, contains nearly 65wt.-% SiO2, has 7-9 wt.-% of Fe oxides, and is thus much less fire/heat- resistant.

Al-Shorman (2009) also provides analytical data on tuyère fragments from the GMM work at Faynan 5, Khirbat en-Nahas and Sinai. The back parts contain 'moderate amounts of non-plastic inclusions, 15-30 vol.-% quartz with two grain size population (*hiatal* texture), and the same amount of angular, very coarse crushed slag. It is made of calcareous clay[91]. The front parts can be considered, 'from a modern

[91] Al-Shorman (2009) reports that back parts of tuyères from Sinai are made of non-calcareous clay with no slag inclusions. The front parts of the tuyères in Sinai have more or less similar composition, with lower amount of quartz, coarser grains and higher feldspars (there are few reports on the quality of archaeometallurgical artifacts from Sinai).

point of view… as fireclay refractories' (Al-Shorman, 2009:223) and represent *the first time that true refractory vessels appear in the southern Levant* (in Faynan, Timna and southern Sinai simultaneously). They contain a mixture of clay and quartz, fine-medium sub-angular grains, exceeding 50 vol. -%; small amounts of feldspars. Mullite and cristobalite, high aluminum-silicate and silicate minerals, were present in the front parts, formed as a result of the heat. The main clay was non calcareous (kaolinite /illite for KEN) (values ranges CaO=2.1 to 0.44 wt.%; Si=79.9-81.9 wt.%). The quartz amount in the front part is ideal, as more than 60 vol. -% would be too crumbly, and less would be less refractory. Tylecote (1982) further emphasized the qualities of quart-rich materials as refractories. The quartz grains remained inert and did not react extensively with the matrix (throughout the 'short duration' of the smelting process). The formation of a network of mullite crystals formed a bonding phase that enhanced its refractoriness. Mullite has a low thermal expansion, high thermal shock resistance, high creep resistance, strength at high temperatures and an outstanding stability in aggressive chemical environments – solution for the strength of composite materials. The initial vitrification of the front part of the tuyère occurs at 900°C; at 1200°C, and even up to 1250°C, it still retains its shape without any signs of terminal distortion. Micro-textures of these nozzles indicate that the original firing temperature was greater than 1200°C, confirmed by the formation of mullite and cristobalite (mullite forms in non-calcareous illite and kaolinite clays between 1000-1200°C, cristobalite at 1200°C, but the existence of both indicates greater than 1200°C. Al Shorman (2009) also points to 1230°C as the temperature in the reaction area, around 80°C more than

the estimation of Title et al. (1990), but still lower than the finds of experimental archaeology (around 1300-1500°C, see above).

7.2.5.4 Dating technological change

The difference between the two primary types of tuyères represents a major technological change in the Iron Age archaeometallurgical record of the southern Levant. The front parts of the tuyères are usually well preserved in the archaeological record. Because they have unique and easily recognized characteristics corresponding to the tuyère type (as described above), these artifacts constitute an excellent chronological marker that is much better defined than any of the other archaeometallurgical materials, and in most cases even better than ceramic typology. Following the publications of the Arabah Expedition, it was accepted that the small tuyères represented a Late Bronze Age smelting activity, and the large tuyère represented Iron Age production. The new excavations, and in particular Area S in Timna 30 and Area M at Khirbat en-Nahas, provide a much better dating resolution, with significant revision of the previous accepted chronological – technological framework.

The small tuyères have been recorded at all New Kingdom-related sites in the southern Arabah and Sinai (Rothenberg, 1990a:29). It is likely that even when considering the new chronological framework suggested here for some of the principal

smelting sites in the Timna Valley (Chapter 6), this type of tuyère indeed represents a technological tradition that first appeared in the southern Levant during the 13th century BCE or even earlier (for the possible origin of this technological tradition, see Chapters 9 and 10). This is based on radiocarbon dates from KEN and Khirbat Faynan (which include the Late Bronze Age, Table 5.2), on the accepted date of the site of Bir Nasib in Sinai, and on a few radiocarbon dates from Timna Site 2 (Table 6.2). The appearance of the new (larger) type of tuyère occurred *within* the Iron Age, and its date now can be pinpointed in the section of Area S in Timna 30 and in the deep sounding in Area M at Khirbat en-Nahas. In Timna 30, only the upper most deposits, found in a very limited portion of the site, contain the large tuyères (Layer I). The transition between this layer and the deposits below occurred, according to the new radiocarbon dates and Bayesian analysis, between 912 – 836 (1σ modeled, calibrated age, BCE) / 970 – 808 (2σ modeled, calibrated age, BCE (Table 6.5, Fig.6.17). The stratigraphic layout at the site shows that a break in occupation of the site occurred just before the new technology arrived. This break, however, was probably rather short (cf. radiocarbon dates in Table 6.5).

The deep sounding in the 'slag mound' of Area M provides excellent chronological control over the contexts of archaeometallurgical debris. Working with the entire metallurgical assemblage (section 7.1.2 above), we were able to characterize each metallurgical locus by the type of its tuyères (small or large). Using the Harris Matrix, the sections' drawings (Figs.8.5-8.7) and the associated radiocarbon dates

(Fig.5.57 and Table 5.10), we could precisely pinpoint the technological transition that occurred at KEN. The loci containing small tuyères are as follows: 629 (representative 'model' locus with many tuyères in the collection), 657, 666, 707, 660, 612, 606, 653, 652, 631, 642, 659, 647, 659, 641, 624, 627. The loci containing large tuyères are: 663, 701, 608, 620, 648~, 616, 602, 620. Locus 701 contained all large tuyères but did include a piece of tuyère body that was reed marked (EDM: 91545, an outlier?). The stratigraphic context and the radiocarbon dates indicate the same time range for the technological change as the one from Timna 30. It is evident that this change occurred simultaneously in Timna and Faynan, and that it happened in the late 10th – early 9th century BCE, probably after a short break. The correlation of this date with historical events and the socio-cultural implications of it are discussed in Chapters 9 and 10 below.

7.2.5.5 Bellows pipes

Bellows pipes (Figs.7.43-7.45) are made of reddish clay, not tempered with slag or large quartz inclusions. They are much less abundant than tuyères, and are found in more specific archaeological contexts. According to our interpretation of the archaeological record, these vessels are not related to primary smelting but are a part of secondary, refining, melting and casting activities that took place in specialized, designated workshops. Such a workshop was discovered at Khirbat en-Nahas, Area F. From this area, *only* bellows pipes and not a single tuyère were unearthed (at least

from the occupation contexts of the workshop, Layer F2). On the other hand, in the Area R smelting complex at KEN, *only* tuyères (large) were found, and not a single bellows pipe. Interestingly, bellows pipes were not found at any of the other sites probed in the current research. This may be the result of the small sample size (because, as mentioned above, bellows pipes are more rare and located only in specific contexts) or the result of time/technology differences, if bellows pipes are correlated only with the later, more advanced smelting technology (which is not evident in any other sites excavated in the current research except Timna 30). The latter possibility is supported by the abundance of metal chunks of a copper-iron mixture found mostly in context of the later and more advanced smelting (e.g., Area R, see section 7.2.7 below). These metal chunks possibly represent the raw smelting product that *needed* to go through a specialized refining process before ingots could have been produced. This is also supported by the distribution of bellows pipes at Khirbat en-Nahas, Area M. In this area, all of the bellows pipes came from upper (younger) contexts that (mostly) correlate with the advanced, later technology. Tentatively, we correlate the bellows pipes and the Area F workshop only with the advanced technology (Chapter 9).

The results of our work on the archaeometallurgical collection of ELRAP include the following:

(1) Bellows pipes from Area M were found only in loci 619 – EDM 90213, 90131, 689 – EDM 91349, 619 – EDM 90134, 701 – EDM 91418, 628 – EDM 90261,

607 – EDM 90062, 699 – EDM 91939, 604 – EDM 90044, 613 – EDM 90116, 707 – EDM 91527.

(2) Fragments with well preserve edges (fronts) include at Area F: EDM 20714 L. 902; and EDM 20643 L. 888, and at Area M: EDM 90062, L. 607; EDM 90134, L. 619.

(3) Longest fragment of bellows pipe in the entire collection is 11 cm long (Area M, EDM 90134, L. 619), and has a diameter of ~6cm, and an air hole diameter of ~2cm (it has a front slagged complete edge). Eleven cm should be considered the *minimum* length of bellows pipes.

(4) Average diameters 5.5 – 6.5 cm, average air hole diameter 2 cm (n=14, see possible exception in Fig.7.44:2).

(5) Several unique finds provide additional technological information: EDM 20498 L. 855 and EDM 20701, L.900 have a flat side, indicating its position on the melting/refining installation; EDM 20213 L.858 (Fig.7.45:2) is a large fragment of a bellows pipe found probably *in situ* in the metallurgical workshop of Area F.

The exact function of the bellows pipe in the melting/refining system is still not clear. The general layout of the Area F workshop is described in section 5.2.4.1 above, and some other related installations and artifacts in the following sections. The identification of the workshop at Area F and the distinct use of the bellows pipes, which is clearly different from the contemporaneous tuyères, are one of the main

contributions of the current research to our understanding of Iron Age copper smelting technologies in the southern Levant.



Fig.7.34: Small tuyères

#	EDM #	Site	Area	Locus	Basket	Comments
1	20200	KAJ	A	106	3188	Small tuyere – front part
2	20181	KAJ	A	106	3169	Small tuyere – front part, refractory clay, slag coat, heat impact, copper remains
3	20210	KAJ	A	105	3196	Small tuyere – exterior (a) and interior (b) views of a rear part, textile marks on the exterior
4	90595	KEN	M	641	4430	Small tuyere – front part, textile (cloth) marks on the interior socket; tuyere is deformed as a result of heat impact
5	90808	KEN	M	642	9604	Small tuyere – front part view of section; note the textile (cloth) marks on the socket

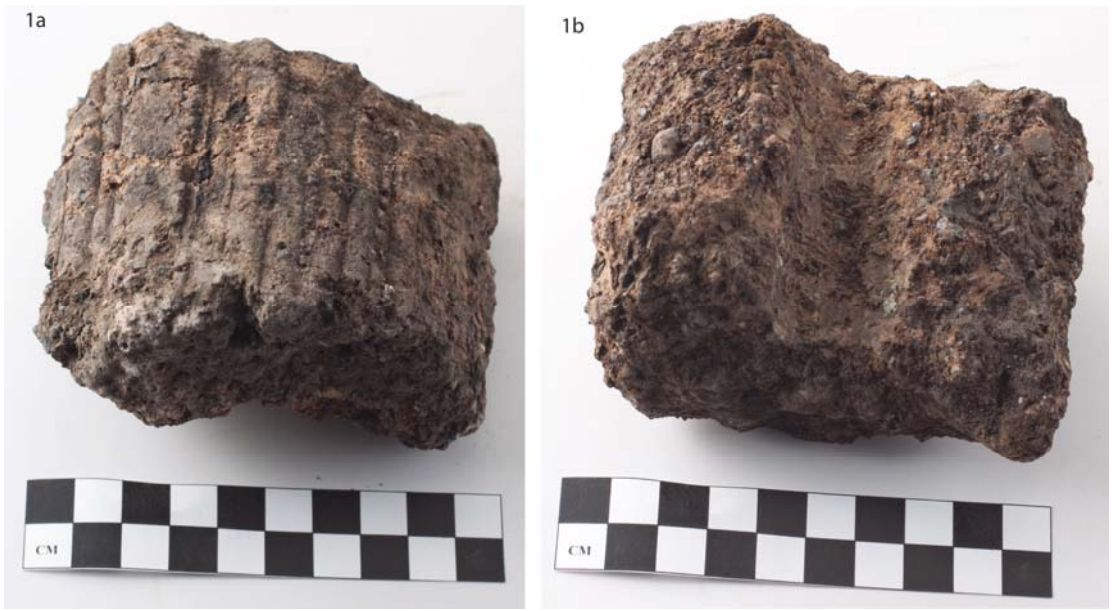


Fig.7.35: Small tuyère, rear part – cylinder with typical reed marks

#	EDM #	Site	Area	Locus	Basket	Comments
1	20227	KAJ	A	118	3705	Cylindrical rear part of small tuyere, reed marks on the exterior (a) and its air tube (b); rough reddish clay with inclusions of crushed slag



Fig.7.36: Intact large 9th c. BCE tuyère found in KEN Area R (EDM R09f1007). Its location near a probable furnace base suggests that it was found close to its original location.



Fig.7.37: Detail of intact large tuyère from KEN Area R.

#	EDM #	Site	Area	Locus	Basket	Comments
1	R09f1007	KEN	R	071	0886	Large tuyere with rear part still attached to the front (the rear part has been entirely decomposed in shipment); front view (a), back view (b) and side view (c)

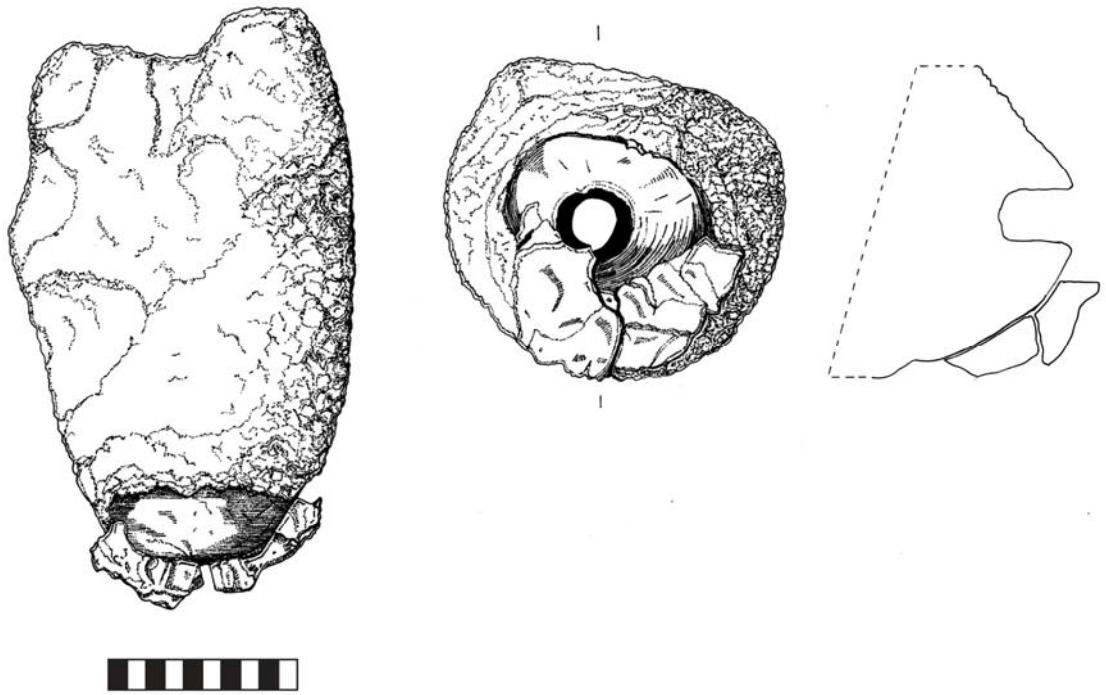


Fig.7.38: Drawing of a large tuyère from KEN Area R (EDM R09f10070).

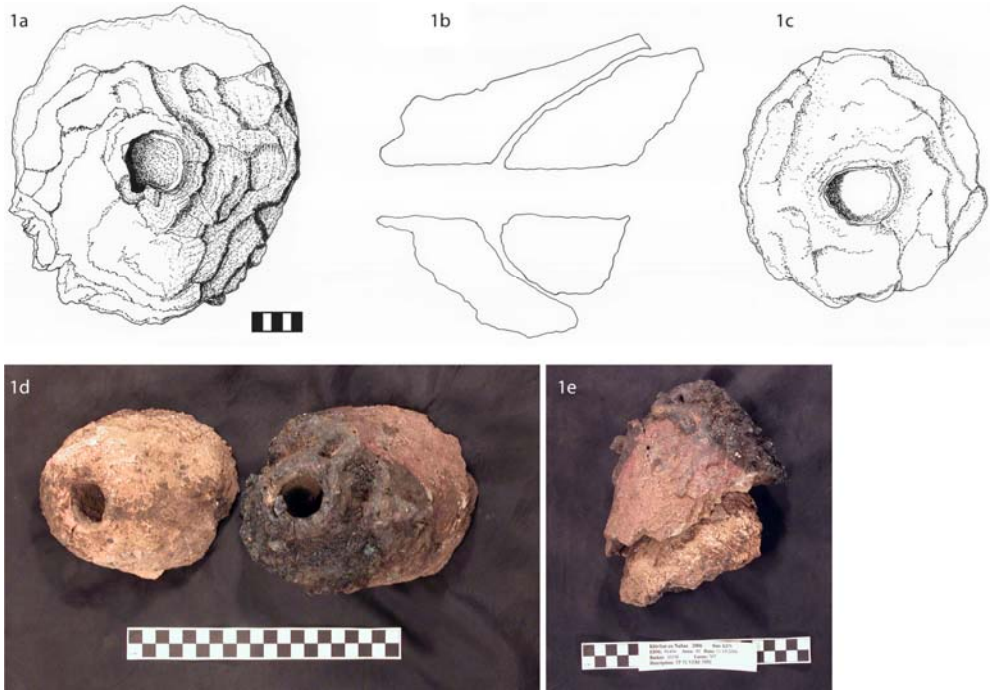


Fig.7.39: Two matching parts of a large tuyère, Area M; illustration (a-c) and photographs (d-e) (EDM 91494, Locus 707, Basket 10138).



Fig.7.40: Large tuyères, front pieces (usually well preserved in the archaeological record, in comparison to the back, unfired parts)

#	EDM #	Site	Area	Locus	Basket	Comments
1	NA	KEN	R	NA	NA	Front pieces of large tuyères in situ as found in the metallurgical disposal designated zone in Area R
2a	30433	KEN	R	1833	16317	Large tuyère, front part, back (a) front (b) and side (c, d) views; note the distinct socket, the copper prills on the tuyère front, and the sharp line of slag coating representing the original position of the tuyère in the furnace
3a	30603	KEN	R	1847	16464	Large tuyère –front part, covered with slag and copper prills (a), and reed/weed marks below (b)



Fig.7.41: Several views of typical large tuyère fragments from Iron Age KEN.

#	EDM #	Site	Area	Locus	Basket	Comments
1	91527	KEN	M	707	10169	Large tuyère – close-up on the refractory front part (quartz-rich clay)
2	R09f1466	KEN	R	R09l093	R09b1186	Large tuyère – rear part, front (a) and back (b) views; this part fitted into the socket of the front piece, reddish clay with crushed slag tempers
3	90215	KEN	M	612	9122	Large tuyère – rear part, front (a) and back (b) views; manufacturing method, using several layers of clay, is evident by the way the artifact is defragmented
4	30506	KEN	R	1833	16384	Large tuyère – rear part, additional socket in the back side of the rear part (usually not preserved)

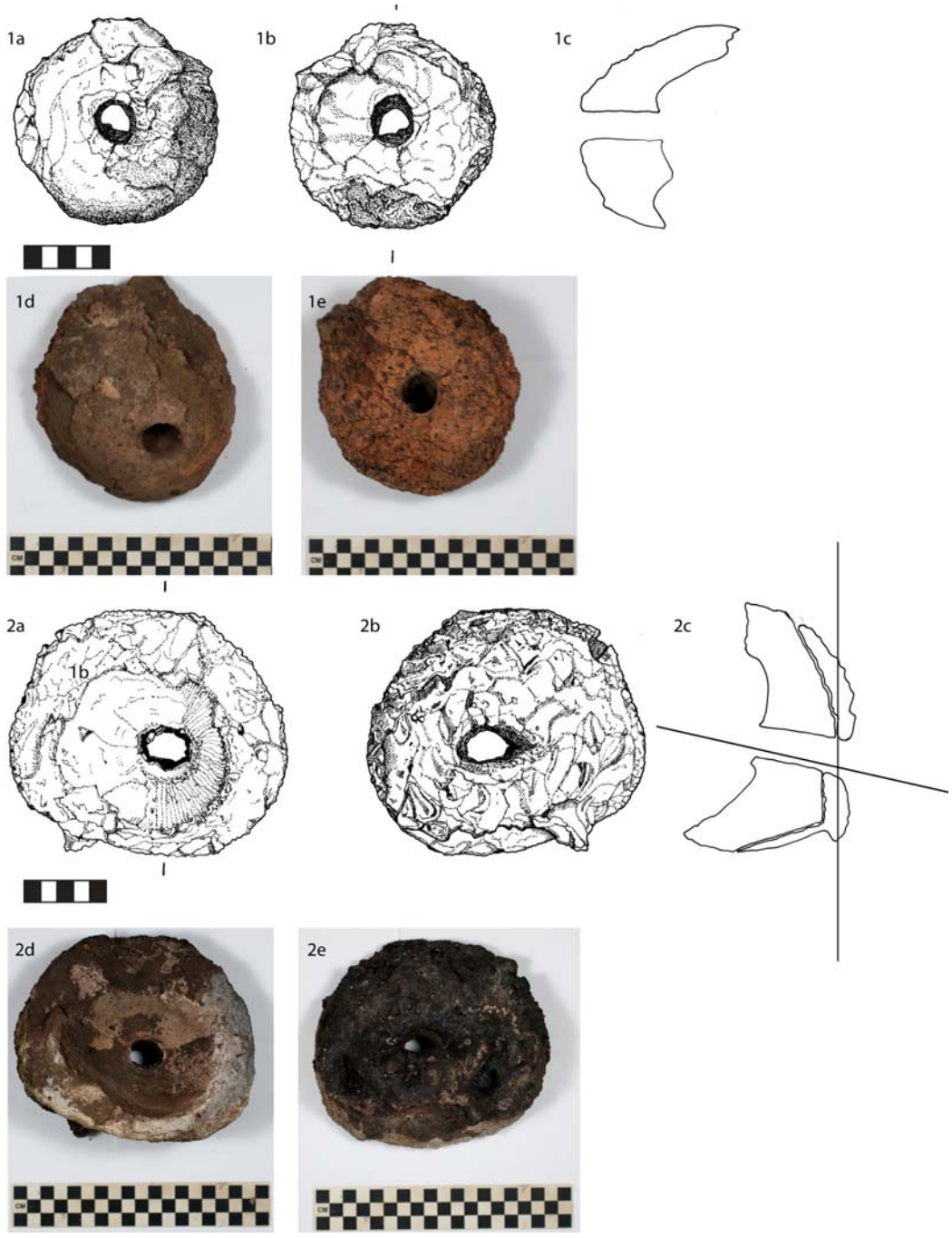


Fig.7.42: Large tuyères; two fronts and two back parts. Note the illustration of angle measurement (2c), KEN-R.

#	EDM #	Site	Area	Locus	Basket	Comments
1	R09f1466	KEN	R	093	R09b1186	Front (a, d), back (b, e) and side (c) views of a back part of a large tuyère (probably related to 2)
2	R09f1467	KEN	R	093	R09b1187	Back (a, d), front (b, e) and side (c) views of a front part of a large tuyère



Fig.7.43: A few typical fragment of bellows pipes from the special workshop in Area F, KEN.

#	EDM #	Site	Area	Locus	Basket	Comments
1	12011	KEN	F	819	1190	Two fragments of bellows pipe; vitrified exterior parts (a), interior reddish clay (b)
2	20394	KEN	F	819	1218	Bellows pipe – side view (a), top view, narrow air hole (b), and diagonal view (internal heat impact)
3	20298	KEN	F	833	1162	Vitrified fragments of bellows pipes
4	20215	KEN	F	836	1111	Vitrified exterior of bellows pipe; copper prills



Fig.7.44: Some representative fragments of bellows pipes, Area F, KEN.

#	EDM #	Site	Area	Locus	Basket	Comments
1	20643	KEN	F	888	1394	Bellows pipe – fragments, (a) exterior, vitrified area and copper prill indicate heat impact zone (furnace side) (b) top view
2	20703	KEN	F	860	20703	Bellows pipe – fragments, (a) exterior, vitrified, (b) interior, flakey red clay and possibly a wider air hole



Fig.7.45: Bellows pipes, with *in situ* fragments in one of the installations of Area F, a refining / casting workshop at Khirbat en-Nahas.

#	EDM #	Site	Area	Locus	Basket	Comments
1	20701	KEN	F	900	1447	Bellows pipe – fragments, vitrified and bloated area indicates heat impact; side (a) and top (b) views
2	20312	KEN	F	858	NA	Bellows pipe in situ, excavated in the metallurgical workshop of Area F

7.2.6 *Slag*

Slag is a mixture formed during smelting, originating from the molten gangue and fluxes. It mainly consists of silicates and metal oxides (FeO, MnO, CaO, etc.), and has a relative low density enabling it to solidify as a separate layer on top of the molten metal. Because of the fast cooling rate, slag is usually composed of high proportion of glassy, non-crystalline mass. In contrast to the modern definition of the material, slag in antiquity was usually not an immediate waste (Hauptmann, 2007:18). Due to limited control over smelting conditions, in many cases slag contained metal and metallic phases (e.g., copper sulphide, delafossite) that can be further extracted by re-(s)melting or by mechanic exploitation of copper prills. As we show in the current research, slag material was used as a flux in the Iron Age copper smelting process (Chapter 8).

As slag is present in (almost) all metal extraction sites, it is a key for studying the smelting technology (e.g., Bachmann, 1982b; Hauptmann, 2007). Its texture, shape, size, mineralogy and chemical composition help to determine the smelting method (e.g., tapping vs. non-tapping), conditions in the furnace (e.g., control over temperature, maximum temperatures achieved, redox conditions), and physical characteristics of the smelting installations (size of 'slag pit', orientation of tuyères in the furnace, etc.). Furthermore, assessment of *scale, intensity* and *efficiency* of production are commonly derived from slag studies. The amount of metal in slag is a

proxy of smelting efficiency, and estimations of slag quantities can in some cases (cautiously) be used to calculate amounts of metal produced in the investigated contexts (site, layer, etc.). For copper production slag in Faynan and Timna the calculation of quantities of copper is based on the assumption that we know the quality of the original copper ore (Cu wt.-%). This is somewhat speculative, as the ore found today probably represents 'leftovers', and the degree of ore beneficiation is not easy to estimate; the numbers used for ore quality in Faynan and Timna (10%-15%) should be taken as *minimum* values for any calculation based on this feature (see also section 2.2.2 above for description of the ore deposits in the Arabah and the basis for ore quality estimations).

The Iron Age slag deposits of the Arabah Valley were re-assessed as part of the current research. Based on field observations alone, these deposits can be divided into two main types, corresponding to their physical appearance. We had already defined two main types of slag, "A" and "B", in the early stages of the new research at Timna 30 (Shaar et al., 2010). These types are associated with the technological development evident in the tuyère record, and have distinct physical appearance. "Type A" slag is found only in Khirbat en-Nahas, Khirbat Faynan (represented by slag deposits of Faynan 5, excavated as part of the German Mining Museum project) and Timna 30 (possibly also in Timna 2, but this is not clear, see discussion below). The slag of this type is mostly represented by large slabs of solid black tap slag, up to 1 m in diameter (Figs.7.46 and 7.47:1,2,11). These slabs are often found intact, and the

broken pieces are not a result of deliberate crushing but rather a consequence of post-depositional weathering. The massive slabs were formed in a well-designed, clay-built 'slag pit', probably represented by the intact installations found at Faynan 5, KEN Area R and Timna 30 (discussed above, section 7.2.4.1) (Fig.7.46). They do have matching furnace slags that consolidated in the furnace itself; the furnace slags are also quite solid (less porous than the "Type B" slag). It is not entirely clear if the furnace slags of Type A were further processed by deliberately crushing or simply discarded together with the debris from the broken furnaces. The results of the laboratory analyses presented in Chapter 8 indicate that the smelting process associated with this type of slag was extremely efficient (about 0.4 wt.-% of Cu in average of wide range of slag samples from "Type A" contexts), thus further processing of slag for extracting copper prills was probably not necessary. However, in Timna Site 30 there is some evidence that these slags were crushed, at least to serve as a flux in the smelting process and to be used as tempers in furnace and tuyère clays. In Timna 30 "Type A" slag is different from "Type B" slag also in the main chemical and mineralogical composition, thus X-ray fluorescence and microscopic analyses can be used for distinguishing between the two types also in very small fragments. Tite et al. (1990) show that the slag used as temper in furnace and tuyère clays found in the Type A archaeological contexts has the same chemical and mineralogical compositions of Type A slag (Mn-rich in general, tephroite as the main mineralogical phase), a clear indication that Type A slag were further processed and crushed to

millimeter-size grains[92]. In Faynan, as both Type A and Type B slag has the same bulk chemical and mineralogical compositions, such distinction was not practical.

"Type A" slag also corresponds to stratigraphic context, i.e., to diachronic technological development. This type is found only in late 10^{th} – 9^{th} centuries BCE contexts (Khirbat en-Nahas Layer M1, and general Stratum I, Timna 30 Layer I), and represents the latest and most advanced phase of *successful* Iron Age copper smelting in the Arabah (see discussion of late Iron Age [probably failed] attempts of copper exploitation in Chapters 9 and 10 below, and Chapter 5 above). Both in Khirbat en-Nahas and Timna 30 there is evidence of use of the large slabs of tap slags as a *building material*. The most prominent evidence comes from KEN Area R, where such slabs were used as part of the retaining walls in the archaeometallurgical complex (see section 7.2.9 below), and in Timna 30, where such slabs were used for building the wall of installation Locus 809 (section 6.2.1.2 and Fig.6.14 above). Using slag slabs as a building material in walls probably started only with the advancement in technology such as that seen in the Arabah region, which entailed production of huge, relatively flat, black stones useful for building. Such use of slag for construction of massive walls is known from various places, including the field mosque from the Early Islamic period of Beer Ora (e.g., Sharon et al., 1996), (Fig.7.48A-B) and the

[92] Because the extraction of metal in the smelting technology associated with Type A slag was much more efficient than in the smelting technology associated with Type B (see Chapter 9), it is not clear if further processing of furnace slag was part of the *chaîne opératoire* of this technological phase. The evidence from Timna 30 indicates that Type A slag was crushed, at least to be used as a temper, but probably also for further extraction of prills (from the furnace slag), because Type B slag was abundant and could have been used as a source of temper in the later technological phase.

Roman smelting site of Skoriotisa in Cyprus (Fig.7.48B). Previous to the appearance of the large slag slabs of the late 10^{th} – 9^{th} century, slag, and in particular crushed slag, were used for construction only as a foundation material (see below).

The distinct physical appearance of Type A slag, especially when compared to the immediately predecessor Type B slag, has caused some confusion in the research of the Timna region. In their review of the Islamic activities in the southern Arabah, Avner and Magness (1998:e.n.7) argue that *all* of the large tap slag from the Arabah represents only Nabataean or later smelting processes, including Timna 30 Layer I and the upper layers of Timna 2. The new excavations at Faynan and in particular our new excavations and high precision radiocarbon results from Timna 30 have clearly demonstrated that the solid slabs of tap slag first appeared in the Iron Age (IIA/B). Nevertheless, we agree with Avner and Magness that all the *ring slag* (large slabs of tap slag with a distinct hole in the middle, Fig.7.48:16) indeed appeared not earlier than the Nabataean period. Such slag are present in Timna 2, and there they are associated with early Islamic radiocarbon dates and other chronological problems (Chapter 6, Table 6.1).

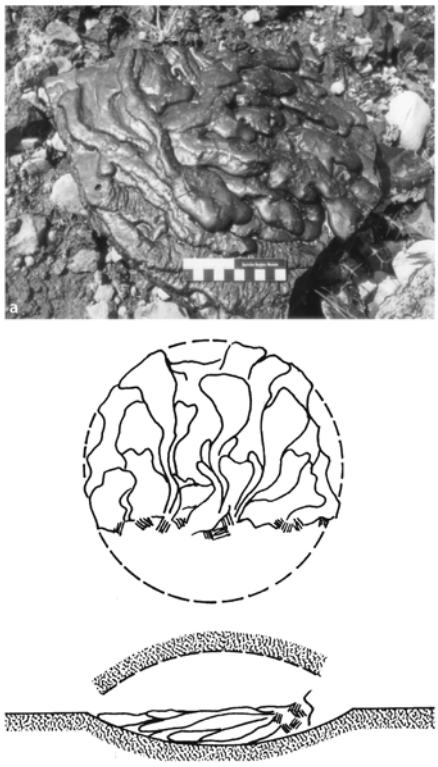


Fig.7.46: Type 'A' slag. A complete slag slab (or 'cake') from Faynan 5 and a reconstruction of the 'slag pit' (from Hauptmann, 2007:98); note the flow texture, the multilayer layout and the transition between tap slag and furnace slag in the edge closest to the furnace (cf. Rothenberg, 1990a:Fig.80).

"Type B" slag includes all the slag fragments formed earlier than the technological transition of the late 10th early 9th century BCE discussed above (Fig.7.48:10,12-15). In fact, it is impossible to *visually* distinguish between slags of the Late Bronze Age, Iron Age I, and those of most of the 10th century BCE (but see Chapter 8 for analytic methods and fine changes found *within* this period). These slags are also a result of *tapping technology* (in the Arabah region, from the Early Bronze Age smelting technologies can be considered to be *tapping* to some degree; the technology of the Late Bronze Age is based on advanced tapping procedures). However, it appears that all of the slags were further processed to some degree, and

that there was no *standard* 'slag pit' (and final slag shapes). Also here there is a difference between tap and furnace slag; furnace slag often contains embedded charcoals (Fig.7.48:15), copper prills, and sometimes incompletely smelted ore fragments or gangue (Chapter 8, Fig.8.36:D). The furnace slags are very heterogeneous, both in distribution of mineralogical phases per sample and distribution of grain sizes per sample. Often these slags are found in 'slag mounds', discarded with mixed furnace materials (Fig.7.48:10). Tap slags of "Type B" have less inclusions (of charcoals, prills, etc.) and are found broken to a roughly 5 – 20 cm (in diameter, although the shapes are irregular). It is reasonable to assume that both furnace and tap slag of Type B slag were further processes by crushing (maybe with a preference to furnace slag, that probably contained more copper). Storage places with crushed slag have been reported from sites in Timna (e.g., Rothenberg, 1990a:47-48) and Faynan (Hauptmann, 2007:102-103), and the extensive thick layers of crushed slag distributed all over the slopes surrounding Khirbat en-Nahas are the result of well organized crushing activities and piling up of such material for further use (see detailed description of these layers in section 5.2.4.4 above). The extensive crushed slag layers at KEN are unique and not well dated. It is important to try and achieve a reliable date for these deposits in the future in order to accurately correlate them with the technological phases at KEN. The results of the current research substantiate previous observations and indicate that crushed slag was used for the following: (1) preparing 'technological clays' for furnace walls, rear parts of tuyères, and other pyrotechnological installations (section 7.2.5 above), (2) preparing clays for certain

domestic ceramic vessels (section 7.2.4.3 above), (3) facilitating the smelting process by adding crushed slag to the smelting mixture as a flux (section 8.5.2 below), and (4) construction of buildings, by using layers of crushed slag as foundation material. This has been observed in many of the probes beneath the architectural features at Khirbat en-Nahas (Areas R Rooms 1 and 5, Areas T, A, and M, see section 5.2.4 above). In all of those areas the first material encountered just below the foundations was a distinct layer of fine crushed slag). In summary, further processing of slag was an essential part of the Iron Age copper exploitation process, and slag material was definitely not considered as purely waste by the Iron Age smelters.

Type B slag characterizes the present day surface of several Iron Age smelting sites, including Khirbat al-Jariya and Khirbat al-Ghuweiba in Faynan. This is in agreement with the chronological time frame of these sites, established as part of the current research, which shows that copper production there ceased during the second half of the 10th century BCE. The same correlation between slag type and chronology may be used as a tool for initial dating of Iron Age 'slag mounds'. For example, the excavations of the 'slag mound' at Khirbat Hamra Ifdan (section 5.2.8) showed two distinct layers composed of different types of slag; the upper (younger) layer has slag that is similar to Type A and the lower (older) has slag that is similar to Type B. The mound was dated roughly to the Iron Age by archaeomagnetic techniques and one loosely associated radiocarbon date (section 5.2.8.2). The slag typology may indicate that the upper layer is 9th century BCE and the lower layer is 10th century or older.



Fig.7.47: Examples of slag fragments for the Arabah Valley. 1-2) A *large* tap slag slab representing the technology of the late 10th – 9th century BCE at KEN Area M, top (1) with clear layered flow texture and bottom (2) with typical rugged appearance; 3) Intact tap slag from the Iron Age 'slag mound' at Khirbat Hamra Ifdan; 4-8) glassy fragments and 'droplets' of slag from Khirbat en-Nahas; 9) a unique pattern of holes on a tap slag – bubbles in slag, or deliberately made with a stick (KEN, F, EDM 20209, L.837, B.1107); 10) A mix of furnace slag and tuyère fragments, remains of a broken furnace; 11) a large slab of tap slag of the later technology (KEN, Area W, L.20); 12) broken furnace slag with oxidized copper / ore residues and embedded charcoals (KEN, Area M, EDM 90493, L.629, B.9333); 13) typical broken tap slag of the main technological phase at Khirbat en-Nahas (Area W, L.111); 14) broken tap slag with 'slag droplets' (cf.#6-7) (KAJ, surface find); 15) furnace slag with embedded charcoals; 16) typical *ring slag* from the Early Islamic site of Beer Ora in the southern Arabah. Similar ring slags from Timna 2 probably belong to the same period and *not* to the Late Bronze / Iron Age (see text).

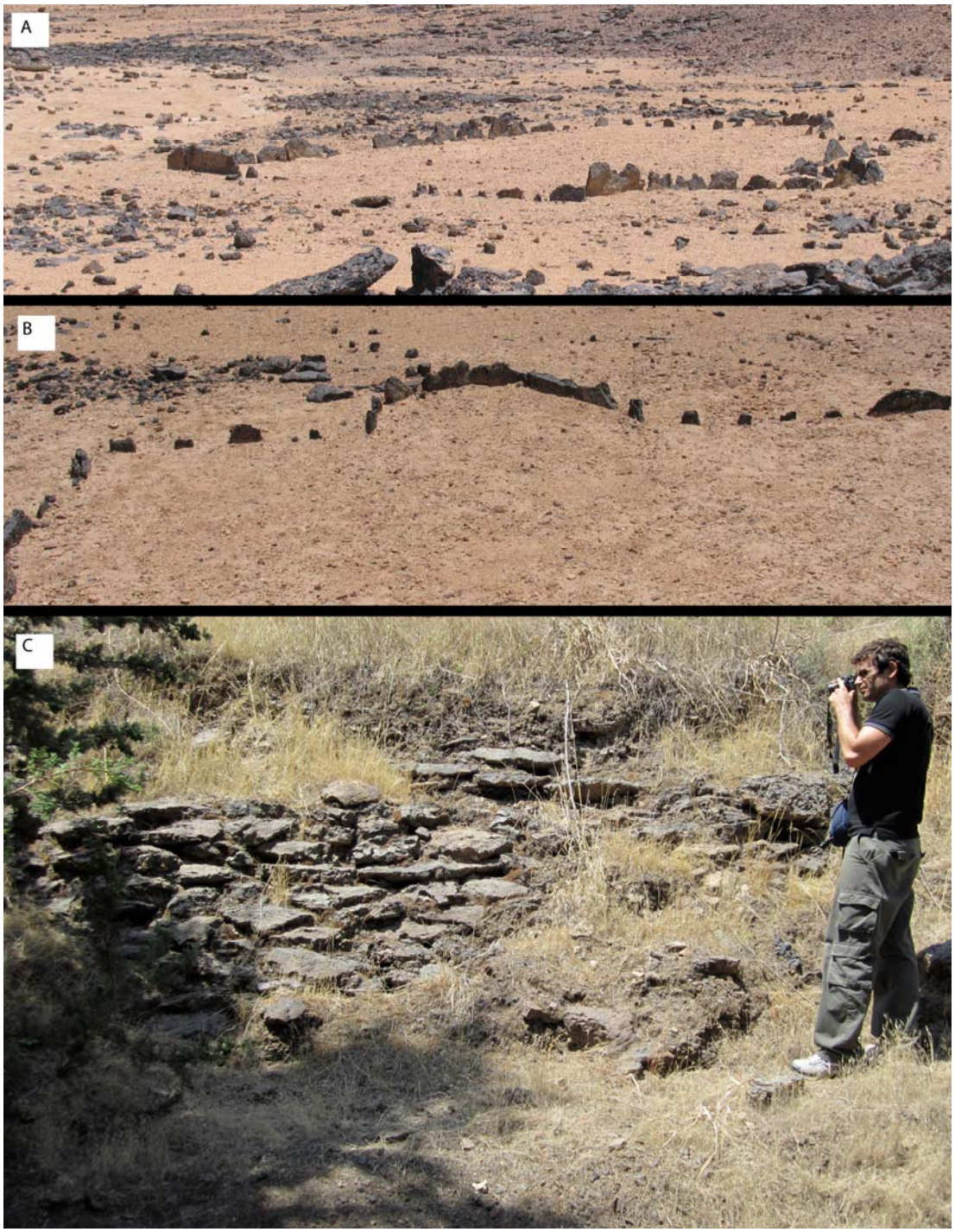


Fig.7.48: Examples of buildings made of slabs of tap slag. A) – B) 'Open mosque' in Beer Ora, southern Arabah (Early Islamic), Israel; C) terraces at the Roman site of Skoriotisa, Cyprus. The first constructions with tap slag in the southern Levant havebeen observed in the Iron Age, with tap slag of the later technology at the metallurgical complex at KEN, Area R and installations at Timna 30 (late 10^{th} – 9^{th} centuries BCE).

7.2.7 *Raw metal and prills*

Copper prills are an important raw product of the smelting process (Fig.7.49). These are rounded metallic droplets extracted from the molten phase during the smelting, but usually staying trapped within the slag material. In excavations they are found embedded in slag as individual artifacts (probably a result of weathering of slag material) or on the slag coating the tuyères (Fig.7.40:3a this is common occurrence as the tuyère was located in the most active smelting zone in the furnace). Their size ranges from microscopic dimensions (e.g., Figs.8.39-8.40) up to a centimeter or two, but usually they are in the range of several millimeters. Copper prills must have been collected for further processing that included re-melting and casting. It is possible that prills, like metal chunks (below), contained a large amount of iron that had to be removed in a refining process. Prills were not chemically analyzed in the current research but some have observable residues of iron (Fig.7.49:3-4). We have collected several hundreds of prills during the different ELRAP excavations.

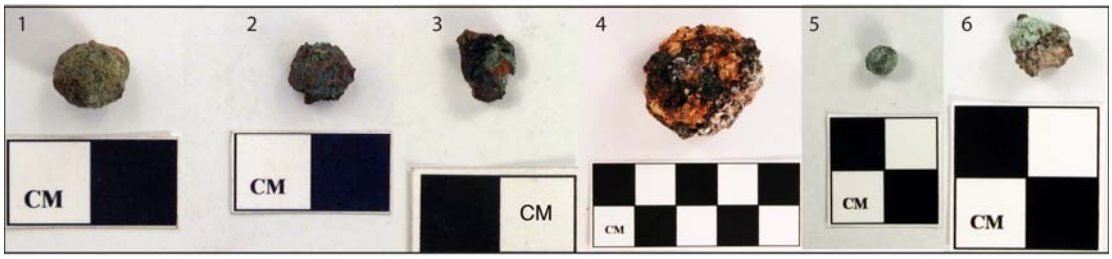


Fig.7.49: Copper prill samples; note that some (3, 4, 2?) have indication of iron contamination

#	EDM #	Site	Area	Locus	Basket	Comments
1	91280	KEN	M	680	9978	Copper prill
2	90868	KEN	M	618	9651	Copper prill
3	90871	KEN	M	649	9654	Copper (-iron?) prill
4	90176	KEN	M	621	9085	Copper-iron prill
5	20146	KEN	F	819	1078	Copper prill
6	50046	KEN	A	0	4019	Copper prill

It has long been recognized that the model predicting a nicely rounded ('bun-shaped') pure copper ingot in the bottom of the furnace at the end of each smelting cycle (e.g., Rothenberg, 1972a:236) is too idealistic (e.g., Merkel, 1990). Instead, the results of our excavations suggest that the raw smelting process produced 'metal chunks', small (2 – 12 cm in diameter, irregular shapes, Fig.7.50) metallic concentrations that accumulated in the furnace bottom and should have been separated from the attached furnace slag above. Generally speaking, these can be considered as large scale prills that were heavy enough to sink to the bottom of the furnace. These 'metallic chunks' must have been further processed, or at least melted and cast into 'commercial' ingots.

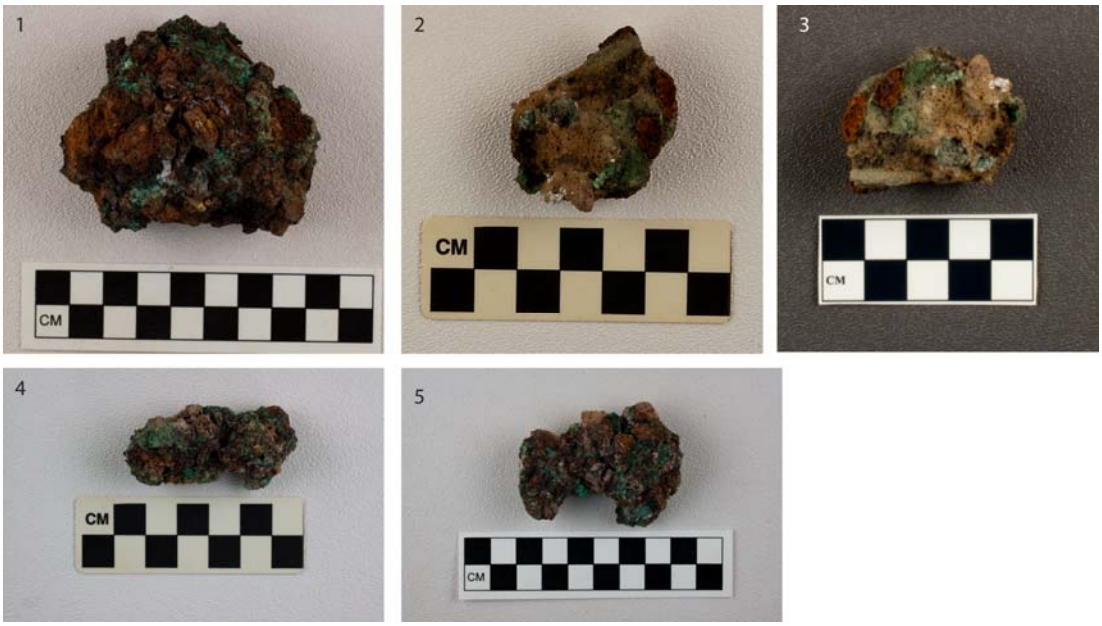


Fig.7.50: A few examples of iron contaminated copper chunks from Khirbat en-Nahas, Area R (1: EDM r09f1990, Locus 143, Basket 1524; 2-3: EDM R09f0029, Locus 003, Basket 0023; 4: EDM r09f0461, Locus 043, Basket 0369, 5: EDM r09f0560, Locus 055, Basket 0458)

Preliminary analyses of such metal chunks indicate that they are present in all smelting contexts and are much more abundant in contexts of the late, $10^{th} – 9^{th}$ centuries BCE technologies. In addition, most of these chunks appear to be contaminated with iron, a pattern that is much more prominent in metallic chunks of the later technology (represented mostly by the metallurgical complex at KEN Area R). A few x-ray fluorescence analyses on such chunks indicate high concentration of iron (Fig.8.34 below). The question whether the excavated metal chunks are the remains of 'failed' smelting attempts or rather the remains of representative raw products is discussed in section 8.5.1. We believe that these represent the raw product, and that further processing must have taken place in specialized workshops. Moreover, we see the iron contamination mostly as a problem of the advanced smelting process,

in which iron was reduced to metal much more easily. As discussed earlier, a specialized workshop for refining metal chunks was discovered at KEN Area F (section 5.2.4.1 above). The archaeometallurgical assemblage from this excavation area is unique (with some similarities to Area T only, see above), both in pyrotechnological installations and metallurgical-related artifacts. In the workshop of Area F, iron-contaminated copper chunks similar to those found in the smelting complex of Area R were recorded. However, in addition to recording this chunk type, relatively abundant pure copper metal 'droplets' and chunks have been found (Fig.7.51, cf. almost none at Area R and only a few in Area M). These finds support our interpretation of Area F as a refining and casting workshop, transforming the raw smelting products into commercially valid commodities.

Further analyses are needed to achieve a conclusive answer regarding the quality of raw copper smelting products and the procedures of further refining in the Iron Age smelting sites of the Arabah (for example, careful examination of the residues on molds [and crucibles] from Area F, to track iron remains from the secondary processing stage). This should be done in consideration of the two distinct technological traditions discussed in the current research.



Fig.7.51: Metal chunks from Area F, KEN.

#	EDM #	Site	Area	Locus	Basket	Comments
1	12171	KEN	F	861	1181	Fe-rich metal chunk
2	20595	KEN	F	888	1357	Fe + Cu metal chunk
3	20083	KEN	F	804	1043	Fe-rich copper prills
4	20285	KEN	F	819	1155	Copper metal droplets (amorphous pure Cu metallic fragment, probably a spill from refining/casting activities; note the not oxidized pure copper in several places)
5	20327	KEN	F	803	1178	Oxidized copper metal chunks
6	20359	KEN	F	819	1199	Oxidized copper metal droplet
7	20362	KEN	F	815	1201	Oxidized copper metal droplet

7.2.8 *Molds, Crucibles and ingots*

Clay molds are extremely rare in the archaeological record, and very few are reported from Iron Age contexts in the southern Levant. This is because such molds were not fired, were deliberately broken to extract the copper products and are often difficult to recognize in the archaeological record. For example, it took some years for the Arabah Expedition to identify ceramic fragments from Timna 30 as molds (Rothenberg, 1990a:54). Being aware of this situation, we paid careful attention to such material and tried to identify molds and other pyrotechnological clay vessels (like crucibles) in the field. However, most of the clay molds from the ELRAP expeditions were identified only later, during the meticulous work on the metallurgical collection at UCSD. In the field, most of these artifacts were labeled as 'furnace fragments' and some as 'technological ceramic'. In the sample collection of selected artifacts described above, about 30 fragments were identified as molds. They are mostly from Area F (Fig.7.52). It is possible that some of these objects are very shallow or fragmentary crucibles, but in the current stage of research we could not confidently identify *any* crucible in the archaeological record. The issue of the use of crucibles should be investigated in the future, together with other technological aspects of the specialized workshop at Area F. The refining/melting and casting process is far from being clear, and given the novelty of this recent discovery, a considerable (analytic and other) effort should be focused on this intriguing feature of copper exploitation at the Iron Age Arabah Valley.

Mold fragments have been found also in Area M (Fig.7.53), mostly from upper (younger) loci. This is in accordance with finds of bellows pipes at these contexts (section 7.2.5.5 above). These finds probably indicate the existence of a specialized workshop similar to the one uncovered in Area F somewhere nearby (with its debris disposed of in Area M).

Only a handful of copper ingots were found in the Arabah Valley (Rothenberg, 1990a:63-66), some of which were associated with the Late Bronze Age copper production in Timna, including small 'ingots' from the workshop at Site 2 (although those pieces are probably the results of primary smelting, as other 'copper lumps' [in this work those are called 'chunks'] and amorphous 'ingots' from Site 3). Three plano-convex pieces of copper, two from Bir Nasib in Sinai and one from Ain Yahav in the northern Arabah, may represent Late Bronze Age – Iron Age ingots, although they also were found to be very impure and the result of primary smelting (ibid.65-66). The 'ingots' from Bir Nasib are ca. 10 cm in diameter, 3 cm thick and weigh ca. 680 gr. The dimensions of the 'ingot' from Ain Yahav, considered to originate from Faynan, are 19 x 14.5 cm and 5 cm thick. In sum, the best evidence we have thus far for the shape of the traded copper ingots is the fragments of clay molds found in the smelting sites of the Arabah.

Very limited evidence from Khirbat en-Nahas indicates the casting of final products (not commercially valuable ingots) at the site. This includes a copper pin found intact inside a small clay mold at Area M (Fig.7.53:3) and a casting mold for a female figurine (see Levy, 2008b). Rothenberg (e.g., 1990a:65) describes the casting workshop (copper smithy) identified in Timna (e.g., Timna 2 Area K) also as the production center of jewelry and many other final products.

Fig.7.52 (next page): Example of mold fragments from KEN Area F, a specialized metallurgical workshop for refining and casting (see text).

#	EDM #	Site	Area	Locus	Basket	Comments
1	12107	KEN	F	910	1515	Mold fragment, edge, (a) sintered black top side, (b) bottom side
2	20420	KEN	F	819	1240	Mold fragment, edge, sintered black upper side
3	12123	KEN	F	860	1412	Mold fragment, edge, clay with slag inclusions (similar to furnace walls' material); top (a) and bottom (b) sides
4	20733	KEN	F	902	1475	Mold fragment, edge, sintered, black upper side
5	20641	KEN	F	860	1392	Mold fragment, heavily sintered black upper part
6	20641	KEN	F	860	1392	5 resotrable fragments of a mold; although same recording details as (5), the fragments probably belong to a different mold
7	12122	KEN	F	900	1503	Mold fragment, (a) top sintered black part, (b) bottom side, reddish clay
8	20420	KEN	F	819	1240	Mold fragment, (a) top sintered black part, (b) bottom side
9	20597	KEN	F	895	1359	Mold fragment, (a) bottom side, reddish clay, (b) top side, sintered blackish copper residues


1a
1b
2
3a
3b
4
5
6
7a
7b
8a
8b
9a
9b



Fig.7.53: Clay mold fragments from Area M, KEN; two probably for ingots (1, 2) and one for a final product (copper pin, 3)

#	EDM #	Site	Area	Locus	Basket	Comments
1	90190	KEN	M	619	9098	Mold fragment, upper side, edge, clay with slag fragments
2	91283	KEN	M	681	9981	Mold fragment (section), edge, clay with slag fragments
3	90079	KEN	M	607	9025	Small mold with copper pin intact; evidence of final product casting at KEN

7.2.8.1 A unique mold from Timna Site 30

As part of the current research in Timna Site 30 (section 6.2.1 above), a small copper ingot mold was unearthed that probably dates to the 11th century BCE (EDM 23, Locus 900, Basket 501, Layer II?). The mold has general features of the oxhide ingot type (Buchholtz's type 2 and sub type 3) and may link the southern Levant with the Mediterranean world at the end of the second millennium BCE; this is currently a speculative interpretation, and it is presented here as a reference for further discussions. Even more important is the physical evidence of casting molds for ingots. The presence of a casting mold in a major primary smelting site, its extremely fragile texture and growing evidence of similar finds in other parts of the southern Levant (and especially from KEN-Area F, see above) gives some insight into the materials used for casting ingots in antiquity.

While clearing the old section in the central 'slag mound' at Timna Site 30 (Area S) and preparing it for sampling, we uncovered a fragment of a casting mold with intact parts of three edges (Figs.7.54and 7.55). The fragment is *c.* 20 x 17cm in size and has a well defined narrow curve where probably the narrower end of the original elongated mold was. This curve is clearly the meeting point of two broken 'handles'. The other edges of the originally long side are slightly curved inwards towards the centre of the original mold (concave) and it seems that the complete mold was more or less symmetrical. The edges are about 2cm wide and they rise up to 3cm

above the surface of the mold. The thickness of the bottom ranges between 2 and 3cm. Our reconstruction of the complete mold appears in Fig.7.56 and indicates a mold for a ca. 50 cm long and 20 cm wide ingot, with four 17 cm tapering ‘handles’. The ingot could be up to 3 cm thick. This suggestion is based on the assumption of symmetry and the necessity to reconstruct a closed shape that could maintain the liquid copper. The lack of any other known ingot shapes or tools that fit this mold fragment (as far as we are currently aware) supports our suggestion. Furthermore, the primary smelting sites of the southern Levant show no evidence of bronze production (all the reported final products were usually small copper pins, figurines and other ‘trinkets’, e.g., Gale et al., 1990), and since utilitarian tools in the early Iron Age southern Levant were usually made of bronze (and increasingly iron) we strongly believe that the mold fragment represents an ingot and not a final metal product; this is in accordance with the interpretation of a few other small fragments found at Timna by the Arabah Expedition (see below).

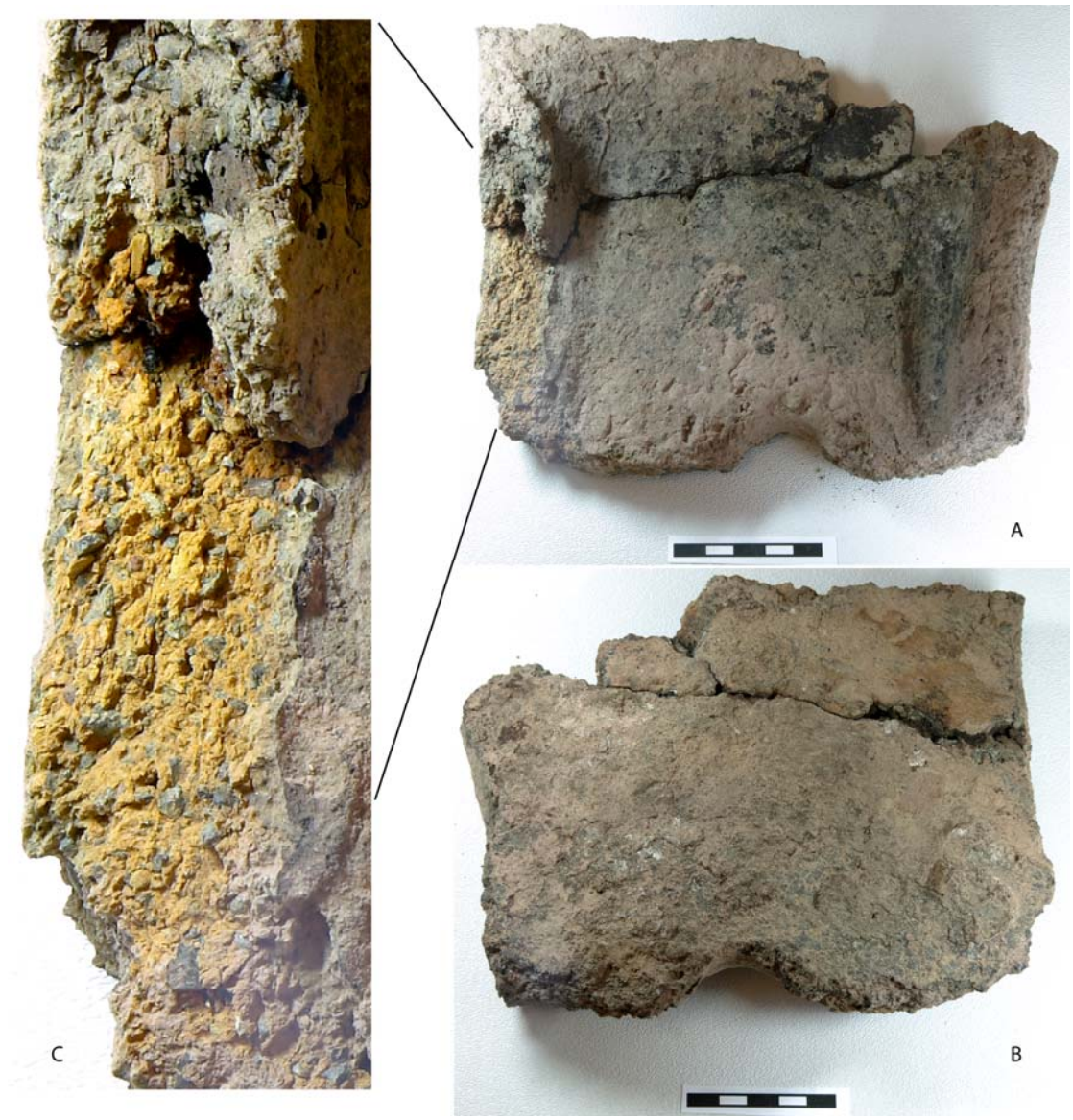


Fig.7.54: Front (A) and back (B) of a clay casting mold for copper ingot from our recent excavations at Timna Site 30. The mold is made of unfired clay with quartz and slag tempers (C), red tint biased to emphasize texture).

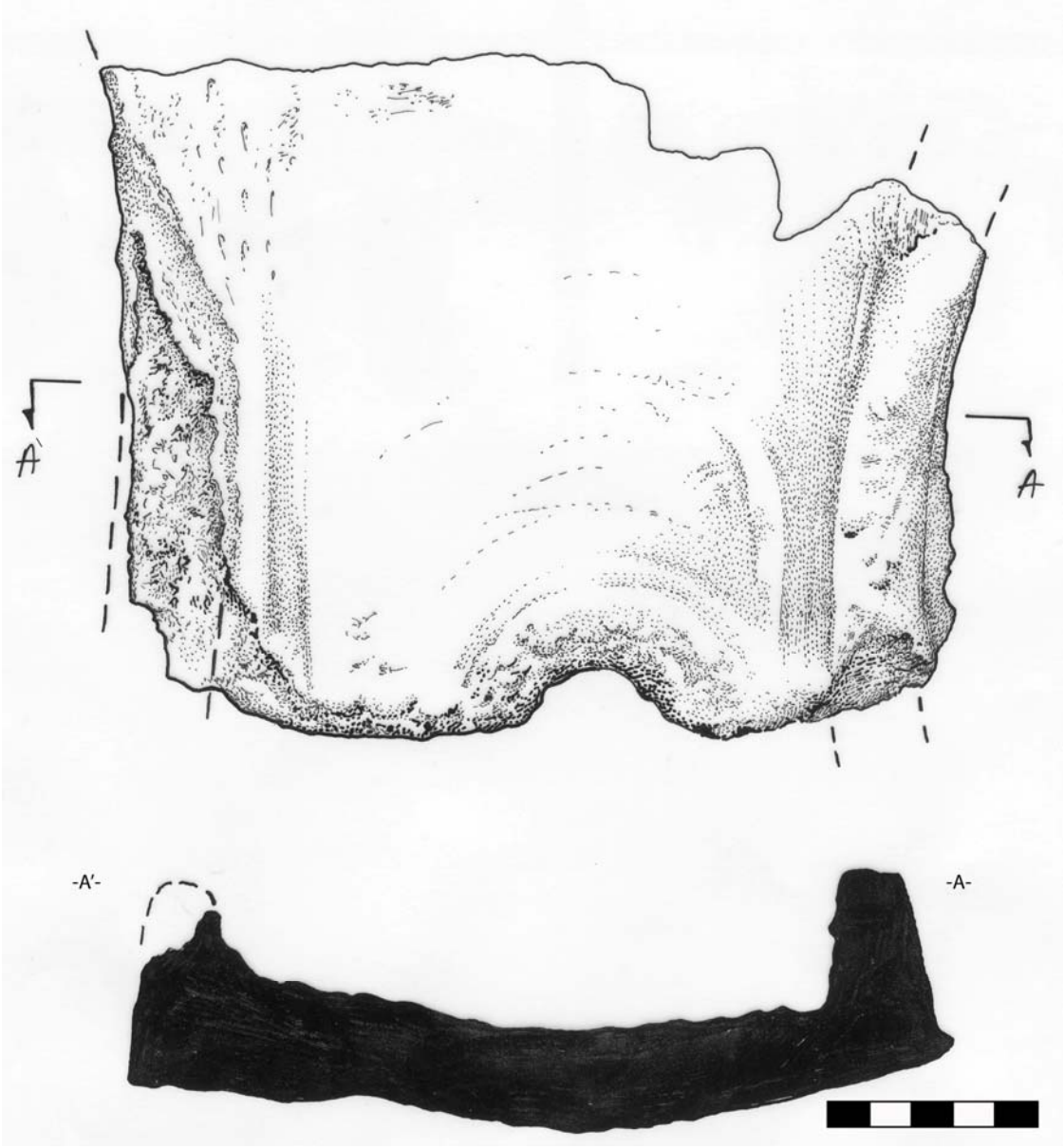


Fig.7.55: A clay casting mold from Timna Site 30, front and section (cf. Fig.4)

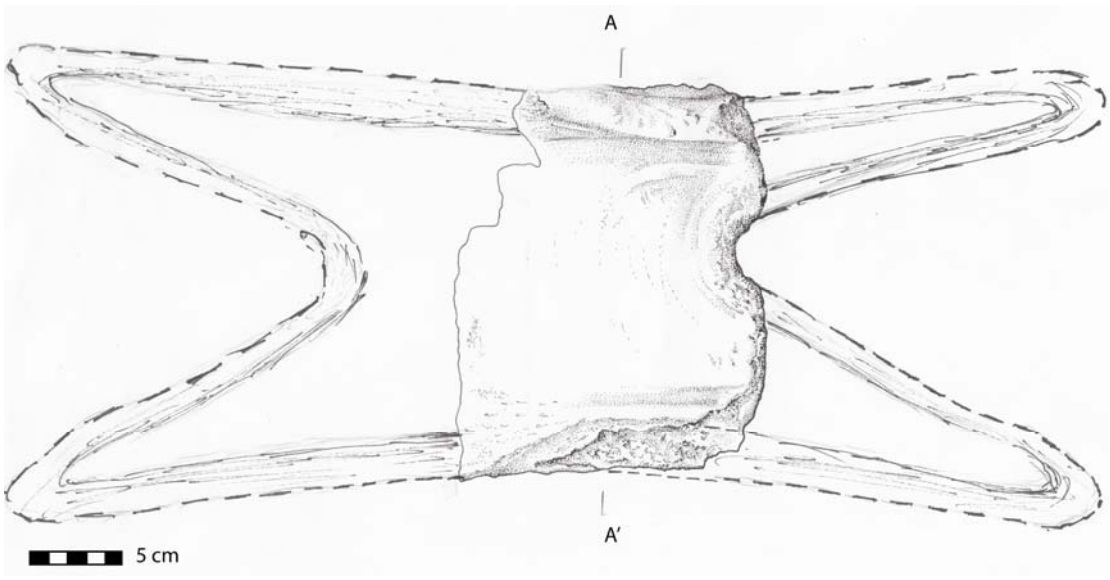


Fig.7.56: Suggested reconstruction of the complete mould from Timna Site 30. The suggested symmetry is speculative as it is a hand-made roughly made ceramic vessel, but seems to be the simplest shape for an elongated ingot.

The mold is handmade and consists of unfired reddish clay with 1-2 mm fragments of slag (Fig.7.54C); it has signs of use with some evidence of heat impact and gray and black residues on the casting surface (Fig.7.54A). The mold fragment is extremely fragile and was broken when we attempted to lift if in the field (Fig.7.54). A small part from the edge was completely decomposed when it broke; the other was glued in the conservation laboratory at the Hebrew University of Jerusalem.

Unfortunately, the mold was not found directly in the cleaned section of the 'slag mound'. Its exact context (locus 900, basket 501) was in the lower part of the collapse material from the original section excavated in the 1970s. The entire section of the 'slag mound' from which the mold was retrieved now dates between the 11th and 9th centuries BCE (no earlier than 1130 BCE, modeled calibrated 2-sigma age

boundary, see Shaar et al., in press, and section 6.2.1.3 above). Based on its relative elevation, context, and the new AMS dates, it is reasonable to assume that the mold dates to the 11th century BCE.

The basic features of the Timna 30 mold recall the oxhide type of ingots found in various locations around the Mediterranean (e.g., Yalcin et al., 2005; Lo Schiavo et al., 2009). Although oxhide ingots show a wide variety of forms, sometimes even in a single context (e.g., Bass, 1967), the common type has relatively large dimensions and weighs up to about 40 kg; for example, the oxhide ingots from the Cape Gelidonya (where more than 34 ingots were found, most of them complete or nearly complete pieces) are about 4 cm thick and averaging 60 x 45 cm in length and width. Estimations of weight for complete ingots range between 16 and 25 kg (Bass, 1967). Three of the largest copper ingots, said to originate from Enkomi, measure up to 72 x 42 cm, have a thickness of 3.75-5.5 cm and weigh up to 39.18 kg (Kassianidou, 2009:43) (Fig.7.57). The oxhide ingots have been studied for more than a century and were the focus of various investigations concerning their provenance (e.g., Gale, 1991), typology and chronology (e.g., Buchholz, 1959; Bass, 1967), iconographic representation and symbolic meanings (e.g., Papasavvas, 2009), role in trade and international connections (e.g., Knapp and Cherry, 1994; Kassianidou and Knapp, 2005) and more. Hundreds of fragments of such ingots have been found (see distribution map in Maddin, 2009:497), while the main assemblages of such complete ingots come from the two well studied shipwrecks found along the coast of Turkey,

near Uluburun (ca. 1300 BCE, Yalcin et al., 2005) and near Cape Gelidonya (ca. 1200 BCE, Bass, 1967).

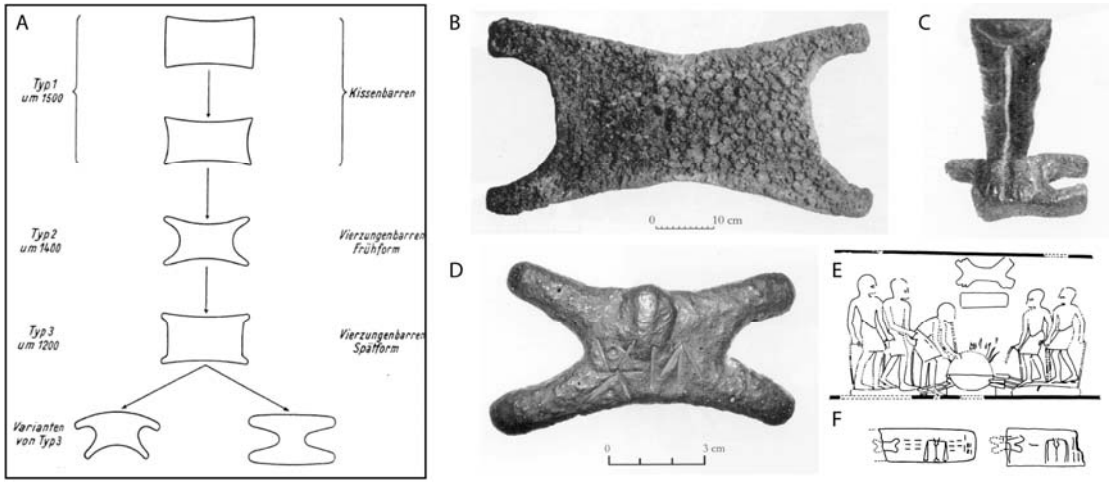


Fig.7.57: Oxhide ingots: A) the original schematic typology of Buchholz (1959:7); B) a large oxhide ingot, said to come from Enkomi (Kassianidou, 2009:77); C) a detail of the Bomford figurine from the Ashmolean Museum (Papasavvas, 2009:123); D) bronze miniature ingot, probably from Enkomi and now in the Cyprus Museum (Papasavvas, 2009:125); E) scene of Egyptian metal workers with copper ingot and another, rectangular ingot below, from the Tomb of Nebamun and Ipuky at Thebes (Bass, 1967:65); F) oxhide ingots depicted on Linear B tablets from Knosos (Bass, 1967:68).

Although the mold found at Timna 30 represents an ingot that is quite different in size and dimensions from the common oxhide type, it does resemble what Buchholtz (1959:7) labeled as "type 2" (the outward curvature of the elongated sides) and "sub-type 3" (the narrow angle between the two handles on each narrow side) (Figs.7.56 and 7.57A). "Type 3", according to Buchholtz and Catling (1964:281), is the latest type, common around 1200 BCE and later. However, the chronology of the different types is debated (e.g., Bass 1967); probably there is no direct connection between typology and age, and the ingot inventory for each period was varied in shape and size. General parallels to the shape of the Timna 30 mold can be also found in the

iconography of the oxhide ingots (see in particular Buchholz, 1959; Bass, 1967; Papasavvas, 2009). Some of these parallels are presented in Fig.7.57 and include the Knossos tablets, the Bomford figurine, miniature bronze ingots from Cyprus (probably from Enkomi) and a painting from an Egyptian tomb. All these depictions have a narrow curve connecting the handles at each end, and a slight inward curvature of the long edges. Interestingly, some of the tin ingots from the Uluburun shipwreck have similar shapes to the Timna 30 mold (Pulak, 1998:Fig.13, 2000:Fig.21-22).

Except from the shipwreck assemblages mentioned above, there are relatively few complete ingots recovered from the archaeological record around the Mediterranean. Most of the finds consist of fragments, some of which are rather small, and some may represent smaller ingots with a narrower connection of the handles similar to the shape of the Timna 30 mold (e.g., Lo Schiavo, 1998:Fig.9:1? 12:12?), although it is often hard to reconstruct the entire shape of the artifact. The majority of the finds from land sites are from the three Mediterranean islands of Cyprus, Crete and Sardinia, with lead isotope studies showing that most of the ingots, even those found in Sardinia, originate in the Cypriote copper mine fields (Gale, 1999; Hauptmann, 2009). The oxhide ingots are therefore commonly interpreted as representing an 'island oriented' trade network, and as having unique economic as well as symbolic significance for the metal workers and traders of those islands in particular (e.g., Papasavvas, 2009). The use of ingots of the oxhide shape lasted for a few centuries, at least into the 11th century BCE, with little known about the intensity and means of

metal trade in the successive period of the Iron Age. Although copper was gradually replaced with iron, it was still a major player in the economy of the Mediterranean at least in the early part of this period.

The destination of the copper products from Timna during the heyday of Mediterranean metal trade in the later part of the Late Bronze Age has not been thoroughly assessed. It was generally assumed that it ended up in Egypt and was considered a rather local southern Levantine - Egyptian exploitation (e.g., Ogden, 2000). As mentioned above, we now know that the extensive smelting operation at Site 30 took place a bit later, and the mold probably represents the shape of an 11th century BCE ingot. There are two ways to interpret the typology of this artifact; it can be related to the Mediterranean world of oxhide ingots (homologous) or it may be the result of local development, and the similarity is simply because of the utility of the shape (analogous). There are strong reasons to believe that the metalsmiths of Timna during the 11th century BCE were aware of the common metal trade customs of the Mediterranean world including the preferred shapes of ingots. They may have adjusted the prototype a bit to suite their needs or to identify themselves among the other production centers, but the typological influence came from the west, and the smaller mining district adopted the dominant fashion. We should also mention here the intriguing albeit controversial suggestion of Rothenberg (1998) to consider the copper workers at Timna (the ‘Midianites’) as one of the Sea Peoples immigrating to this region at the end of the Late Bronze Age. Rothenberg based his arguments on

characteristics of the local pottery and a few local rock drawings that depict the metal smiths with costumes similar to those of the Sea Peoples in Egyptian art. The Timna 30 mold with its oxhide features fits such a reconstruction well, which may explain the origin of its typology. There is not enough field (or other) evidence to support Rothenberg's suggestion; nevertheless, extensive immigration of 'Sea Peoples' did take place around this time in the Eastern Mediterranean and Egypt, and it is possible that some of those immigrants were specialists in metal work and influenced the local industry, if only by spreading new ideas of technology and style.

Interestingly, in Egypt, the probable destination of the Timna copper, there is a depiction of several ingots that are similar to the Timna 30 mold. They are drawn on the walls of the Ramses III (1192 – 1160 BC) temple at Medinet Habu, not far from the drawings of the Egyptian battles against the Sea People (Fig. 7.58). The ingots are depicted in two different sizes, both have a very narrow curve at their narrow ends, and slight inward curvature on their long edges, and slight outward curvature on their long edges. These may represent ingots from the southern Arabah, possibly shipped by boats through the Gulf of Aqaba and the Red Sea. Buchholz notes on his ingot distribution map (1959:14) a 'type 3' ingot at 'Ezion-Geber', the Biblical port of King Solomon. The actual site is Tall el-Kheleifeh, located at the head of the Gulf of Aqaba and excavated by Nelson Glueck in the late 1930s (Glueck, 1939). Reassessment of the excavation results dated the major occupation levels to no earlier than the 8th century BCE (Pratico, 1993b) (thus the identification of Ezion-Geber is not valid

anymore). In any case, a ‘type 3’ oxhide ingot on a port site may further connect the inventory of the Arabah to Egypt and the Mediterranean. Unfortunately, we could not track down the publication of this artifact.

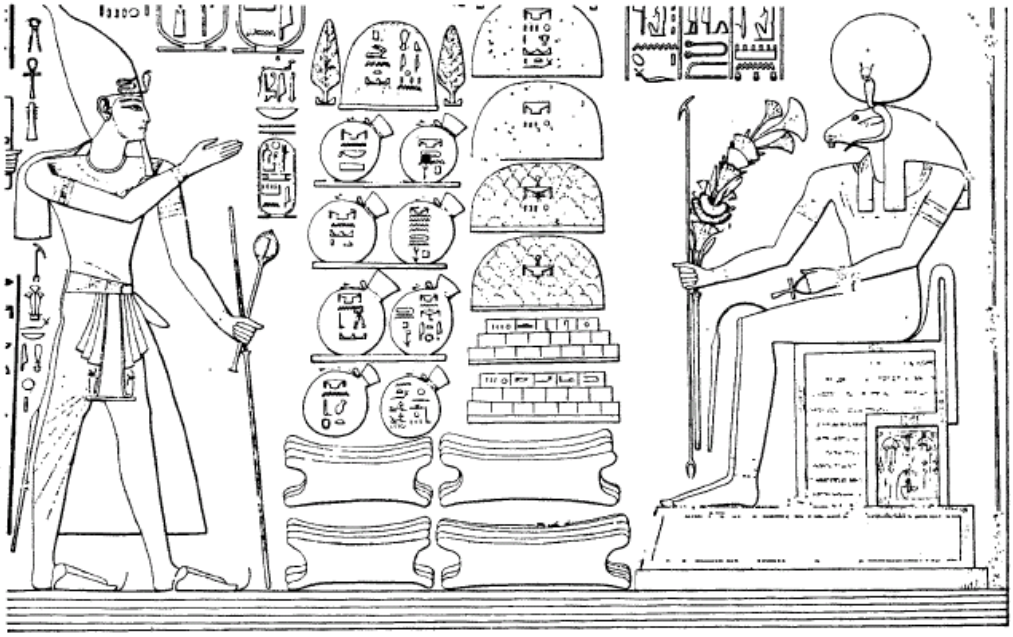


Fig.7.58: Oxhide ingots depicted on the walls of Ramesses III temple at Medinet Habu. The scene was probably copied from the 13th century BCE Ramesseum (from Bass, 1967:67)

Another possible interpretation of the typology of the mold from the southern Arabah is not connected to the Mediterranean world of the Late Bronze Age. Buchholz (1959:23) brings two examples of ingots similar in shape to the Timna 30 mold (Fig.7.59). One is a gold ingot from Zimbabwe and the other is tin ingot from south England. The fact that those ingots are made of different materials and originate from remote locations suggests that the shape developed separately, solely due to its functionality and utility. As can be seen in many artistic depictions from Egypt and the

Aegean (e.g., Bass, 1967), the oxhide shape and in particular the ‘handles’ renders the ingot portable; it is easier to carry a heavy piece of metal that has ‘handles’ and the depictions show more than one way of doing so.

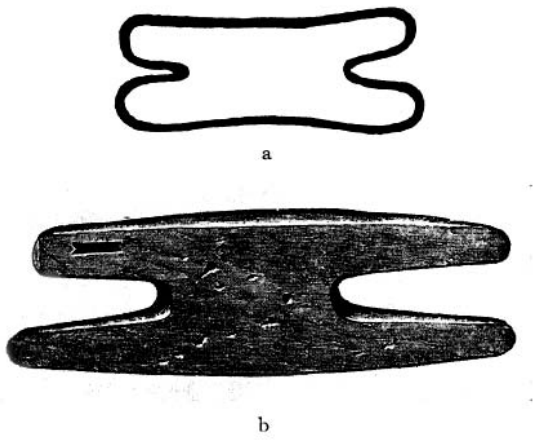


Fig.7.59: Gold ingot from Zimbabwe (top) and tin ingot from south England (bottom) with ‘oxhide features’ (handles) (Buchholz, 1959:23).

Notwithstanding the hundreds of fragments of oxhide ingots found all over the Mediterranean, only one casting mold made of stone has been found so far, at Ras Ibn Hani near Ugarit (Lagarce et al., 1983). Although the current lack of molds in the archaeological record was explained by the practice of casting in sand (Hauptmann, 2009:505), a casting technique that is apparently supported by experiments (Merkel, 1986; Nibbi, 1998; Lokeren, 2000) and ethnographic observations (Levy et al., 2008b), we believe that the situation mainly reflects the poor preservation of clay casting molds and the difficulty of identifying such artifacts in excavations. The casting mold from Timna 30, made of unfired clay, was preserved by mere chance and

started to crumble when collected in the field. Such molds were probably made for a single use. They are easily constructed from local clay, and they were broken after casting to extract the ingot. The debris was thrown into the waste pile, probably together with the other metallurgical waste. Indeed, it is now clear that 'slag mounds' such as the one excavated in Timna 30 and in other locations in Faynan (Ben-Yosef et al., 2010a, and section 7.2.10 below) are usually made of less than 40% slag material and the rest is mostly decomposed clay artifacts derived from broken furnace fragments, tuyères and most probably would include molds. The bulk of discarded mold material would be no more than wads of clay embedded in the deposits of metallurgical debris.

Although Timna 30 was excavated for two long seasons in 1974 and in 1976, it was not until the material was re-examined carefully in the laboratory that the researchers of the Arabah Expedition identified 21 clay fragments as pieces of casting molds (Rothenberg, 1990a). The main reasoning for this identification was that the clay pieces did not match any of the reconstructed furnace types; Rothenberg (1990a:54) concludes: "We would like to suggest that similar crude mould fragments also exist at other sites of copper production, but have not been identified as such because they are very similar to furnace fragments." Mold fragments can easily be mistaken for crude pottery, especially if the casting workshops were part of a settlement with various domestic ceramic types. The fragments of molds from Khirbat en-Nahas Area F discussed above, interpreted here as remains of ingot casting molds,

are associated with a designated refining and casting area in which raw metal products were processed and finally made into ingots. The growing evidence of molds from the Arabah supports the assumption that ingots, and especially the carefully shaped oxhide ingots, were cast in clay molds and not just in sand. The probable symbolic value of such an iconic shape and the need for standardization in commercial interactions also support casting in clay molds that could be more controlled. A recent study concerned with the reconstruction of mold materials used for casting the Uluburun ingots concluded, based on evidence in the ingots' metal texture and the results of experiments, that clay was the most suitable material for the molds, and definitely not sand (Larson, 2009). The fragmentary quality of the archaeological record is misleading; nevertheless, excavating with careful attention to such elusive artifacts will reveal more information in the future.

7.2.9 *Other installations*

The Iron Age archaeometallurgical record in the Arabah contains other various installations related to the copper exploitation process, such as architectural features, rock basins, and more, including many that we do not recognize as related to the production system or that we do not understand. For example, in the mining areas in Faynan carved holes for a winch have been reported in a few shafts (but many of the shafts do not have any, see section 5.2.6.2 and Fig.5.84). We have reported for the first time the feature of holes carved into a rock face in both Ras al-Miyah West and East,

and was probably also related to the mining system (Ben-Yosef et al., 2009a, and section 5.2.6.2 above). Small stone-built installations like the ones exposed in the deepest parts of the sounding at KEN-Area M, and a 'standing stone' in KEN-Area F might be related to the copper production system, maybe to the religious/cultic aspects of it, but these are usually not associated with further indicative finds (e.g., Fig.5.50).

We interpret the wall complex at KEN-Area R as a deliberate construction of designated disposal spaces and retaining facilities, done as part of careful organization of the *smelting* working area (section 5.2.4.1). The well organized dumping is illustrated in Fig.7.60. The walls themselves are loosely built of local stones and tap slags; they include some features that we could not explain (such as deliberate 'windows' or holes). Retaining walls and designated dumps have also been recorded at Timna Site 30 (Rothenberg, 1990a). It seems that this carful organization and tight arrangement of working and disposal spaces (including digging subterranean installations) mostly characterizes the advanced phase of copper production (late 9^{th} – 10^{th} centuries BCE). This is probably part of deliberate efforts to increase efficiency in production, a trend that is evident in many other aspects of the production system (Chapter 9). It is possibly also related to the fact that the later technological phase was practiced on previous deposits and in areas with dense remains and constructions, which required better control over space for keeping a smoothly working production system.



Fig.5.60: The metallurgical complex at KEN Area R; walls constructed for organizing working and disposal spaces.

Another set of installations is associated with the specialized metallurgical workshop at KEN Area F and includes large rock basins (Fig.7.61) and various architectural features. These have to do with the refining/melting and casting operation at the site, but their exact function is still not clear.



Fig.7.61: A large stone basin at KEN Area F (Scale = 20 cm).

7.2.10 *Copper production related sediments and the composition of a 'slag mound'*

The bulk of the sediment in copper production sites is directly related to technological waste. Detailed description of various sediments and their quality is provided as part of the discussion on the deep sounding at KEN-Area M (section 5.2.4.2). The main conclusion of our observations is that less than 40 vol.-% of the deposits of a 'slag mound' are actually slag material (at KEN-M it has been found to be around 38 vol.-%; at KAJ-A it was found to be much less [no precise value available], see section 5.2.4.2). The rest of the sediment in a typical 'slag mound' includes large amounts of clayey deposits, ash, charcoal, organic materials (in the case

of Timna 30), and domestic waste (a large component of the ‘slag mound’ at KAJ-A). The clayey sediments are derived from furnace walls and tuyères, probably in considerable quantities as the un-fired clay component of these vessels and installations have been found in the current research to be substantial (see discussion on ‘large tuyère’ above). They may also simply represent deposition of clay brought to the site as part of the manufacturing process of relevant installations and vessels (e.g., red clay deposits at Timna 30 Area L). Charcoal, ‘charcoal dust’ and ash are also a prominent composition of deposits in a ‘slag mound’. Those are mostly the refuse of furnaces (and other pyrotechnical installations), but probably include charcoal being prepared for use in smelting and remains of charcoal processing before their use in the furnace. Before the final use of charcoal as fuel (see section 7.2.3 above) it was important to get rid of all the fine charcoal fragments, as those would choke the fire. Thus, in many ethnographic examples, charcoal was sieved as part of its final preparation. The fine fragments were disposed, and those are probably part of the ‘slag mound’ debris (cf. layer 62 in the Corto Lago section at Rio Tinto, Rothenberg and Blanco, 1981:105). If wood was used as fuel (section 7.2.3 above), ash would have accumulated in large quantities (which is the case in many contexts, however, this is typically related to domestic activities [oven] or kilns).

The relative low amount of slag in a typical ‘slag mound’ found in the current research is corroborated by the results of recent excavations of ‘slag mounds’ associated with iron production in England (Gill Juleff, pers. comm. 2008, and see the

Exmore Iron Project website: http://www.ndas.org.uk/exiron.htm). The quantities of slag material in 'slag mounds' have important implications on estimating quantities of metal produced at a site. The quantities of metal are derived from the estimated quantities of slag, which are based on surface observation and estimation of volumes of 'slag mounds'. Therefore it appears that previous investigations overestimated quantities of metal produced in ancient sites (see Chapter 9 for relevant discussion regarding the Iron Age sites of the Arabah).

7.3 Summary

Technology-related remains constitute the bulk of Iron Age material culture in the smelting sites of the Arabah Valley. These artifacts reflect social and cultural meanings that can, to some degree, be deciphered by careful investigation of the material culture of technology. This chapter has provided an overview of the most common artifacts in the Iron Age copper smelting sites of the Arabah Valley and introduced substantial new datasets and new insights based on our recent excavations at various sites in Faynan and Timna. In addition to refining specific technological reconstructions (furnace height, tuyères length, etc.), the main conclusions of this preliminary investigation are:

(1) Two *main* copper smelting technological traditions exist in the Iron Age southern Levant. The first, a continuation of Late Bronze Age smelting technologies, was in practice until the late 10th beginning of the 9th century

BCE and is represented in all of the Iron Age sites investigated in the current research. The second technological tradition appears *abruptly* and replaces previous technological practices. This happens shortly after the first tradition ceased to be in use[93] sometime during the late 10th early 9th centuries BCE. The introduction of the new and more effective technology was accompanied by a major re-organization of production: copper smelting was practiced in fewer sites (only in Khirbat en-Nahas, Timna 30, and Khirbat Faynan), and some sites were abandoned as part of this general change (Khirbat al-Jariya, Khirbat al-Ghuweiba).

(2) A third copper smelting technological tradition was probably practiced simultaneously with the large-scale Iron Age technologies. This was a marginal, small scale production using simple ('primitive') smelting technology outside the main smelting centers of the Iron Age southern Levant. Currently the evidence for this technology comes from a few sites in the southern Arabah and Faynan (Chapters 5 and 6, and see especially sections 6.2.3 and 6.2.4 for discussions).

(3) Each of the copper smelting technological traditions of the Iron Age southern Levant presents a distinct assemblage of material culture remains; these assemblages can be characterized by visual investigation of the artifacts (for

[93] A short break between the practice of the two technological traditions, rather than a continuous practice of smelting activities (with only a re-organization of production), is supported by the stratigraphic layout of the archaeometallurgical deposits (in particular Timna 30 Area S, where a distinct 'abandonment' horizon has been exposed in the 'slag mound') and by a change on a regional scale where abandonment of sites and a major re-organization of production excludes any possibility of organic, internal developments.

analytic characterization see Chapter 8 below). The most notable differences between the technological traditions are evident in *slag* and *tuyères*. Slag of the later (late 10^{th} – 9^{th} century BCE) tradition are significantly larger and the tap slags were not crushed. They were produced in a standardized 'slag pit', demonstrate flow marks and are often layered, probably a result of more than one smelting cycle. The tuyères of the later technology are also significantly larger, more effective, and manufactured in a slightly different way than the tuyères of the previous, early Iron Age – Later Bronze Age tradition (for more details, and for differences in *furnaces*, *metal*, and artifacts, see text above). The simple copper smelting technological tradition can also be characterized by visual investigation of slag and tuyères (when available), these resemble remains of typical Early Bronze Age or earlier smelting technologies.

(4) Slag material in the Iron Age copper production system *was not* purely a waste product. After production, slag was crushed to extract copper prills, to be used as tempers in technological ceramics (mostly furnaces and tuyères) and in domestic ceramics, as a flux in the smelting process and as foundation layers for building construction.

(5) The ubiquity of slag within the material culture of Iron Age smelting sites, even in non-technological artifacts, indicates a specific *technological style* of the Iron Age craftspersons in the Arabah Valley. The use of crushed slag in ceramic production was a tradition, an idiosyncratic quality of the societies

engaged in copper exploitation that may have become a symbolic feature or emblematic cultural tradition, rather than only functional.

(6) Based on patterns of archaeometallurgical remains at Khirbat en-Nahas, a basic technology-related spatial model is suggested: The 'slag mound' of area M (one of over 20 visible at the site) was mostly a designated dump area for metallurgical waste with occasional activity surfaces that are represented by *in situ* installations; Layer M1 represents the late 10^{th} – 9^{th} century BCE most advanced and efficient smelting technology. This layer was partially deposited on top of Room 1 (and maybe on some other parts of Building 1), after it went out of use, probably because of the heat and weight (pressure) impact of the adjacent production area and the accumulation of copper production debris against the walls. Most of the site surface of Khirbat en-Nahas is covered with large slabs of tap slag representing wide spread smelting activities in the late 10^{th} – 9^{th} centuries BCE. The metallurgical complex in Area R also presents the most advanced technology at the site; this implies that most of it was dug into the courtyard of the early to mid-10^{th} century BCE monumental structure. The loose walls in this area are *not* the remains of a previous occupation layer, but rather represent installations contemporaneous to the smelting activities and were used mostly as retaining walls for holding back metallurgical debris and as dividers between designated spaces for different technological activities (and as support for some installations). Area F (and parts of Area T, although the relevant materials from this area are less exposed and were studied less in

the current research) represents a specialized workshop for refining and/or melting and casting ingots.

(7) Charcoal was used as a fuel, and possibly also wood in some cases. The pattern of charcoal species used at Iron Age smelting sites (in particular the absence of acacia in the archaeological record of Faynan) possibly reflects the social values of semi-nomadic societies in a desert environment and supports the model of *tribal kingdom* (confederacy/chiefdom) for Iron Age southern Jordan. This is based on comparison to ethnographic and ethnobotanical studies of modern Bedouin societies in the Sinai Peninsula.

(8) Growing evidence suggests the casting of copper ingots in clay molds (rather than in depressions dug in sand / wadi sediments). A relatively large amount of mold fragments has been uncovered in KEN Area F, supporting our interpretation of this area as a workshop for refining and/or casting.

(9) Limited evidence from Khirbat en-Nahas indicates the casting of final products (a copper pin found intact in a clay mold and a clay mold of a female figurine).

(10) The composition of a typical 'slag mound' is a mix of many metallurgical related debris; in fact, the slag content is less than 40% (by volume) and most of the deposits are clayey sediments, derived from decomposed furnaces, tuyères (cf. the full length of original large tuyère body, exceeding 30 cm), molds, etc.

As comprehensive as the archaeometallurgical assemblage might be (there are over 6 tons of this material stored at UCSD), many aspects of the technological practice are missing, such as associated ritual, magic, and other spiritual factors that leave very little, if any, physical evidence in the archaeological record. Nevertheless, some indications of associated cultic activities do exist in the Iron Age copper production sites, such as the figurine site of FBRS 27 near the copper mine complex of Ras al-Miyah East in Faynan, Area W in Khirbat en-Nahas, the kneeling bronze figure found in the Area A fortress gatehouse at KEN and some sites in the Timna Valley (mostly dated to the Late Bronze Age, but see reservations about this date in Chapter 6 above). The descriptions of these sites and their finds are incorporated in Chapters 5 and 6 above.

The vast archaeometallurgical collections of ELRAP and the preliminary work presented here constitute a firm basis for future research. Many technology-related questions are still open and further investigations of the various artifacts are a key to better understanding the Iron Age smelting technologies and the society(/ies) responsible for them. Some problems identified in the current stage of research, such as the presence of iron in the raw copper smelting product, the reconstruction of refining and melting installations (with their particular bellows pipes), the quality of the end products (ingots), and the use of clay molds, call for further collaborative research on the materials available in the archaeometallurgical collection at UCSD.

8. New analytical data and technological insights on Iron Age copper production

To objectively study the nature of ancient technological systems and monitor their changes through time, it is useful to harness a wide range of laboratory analyses to achieve robust insights into a given part of a cultural system. This is of course also true for studies of ancient metallurgical technologies. However, in the research field of archaeometallurgy it is often the case that intensive laboratory analyses are conducted, but the social and cultural implications of the data are overlooked. Here we intend to use analytical methods as a means to understand better the Iron Age societies responsible for the copper production activities in the Arabah.

8.1 Background: analytic approaches in archaeometallurgy

Laboratory analyses of technology-related artifacts have become an essential part of technological studies, and in particular in the field of archaeometallurgy (e.g., Craddock, 1989; Tylecote, 1992:chapter 11). They complement field observations and visual studies of artifacts by providing further insights into the physical properties of various aspects of the technology. Analytical methods used in archaeometallurgical studies are the basis for accurate identification of raw materials, including ore (its mineralogy, ‘quality’ [concentration of Cu in bulk fragment], distribution in the host rock), fuel (identification of plant species), and materials used for constructing vessels

and installations (types of clay, tempers, stones, etc.). They are the basis for assessing the efficiency of metal extraction processes, the level of technological complexity, the degree of standardization, and other physical properties that are directly related to the quality and characteristics of the technological practice itself (e.g., how hot was the furnace and how insulating were its walls? How fast did the slag flow out of the furnace? How long did the smelting process take?) (for definition of 'efficiency', 'technological complexity', and 'standardization' see section 1.2.1 above). Finally, for anthropological archaeology studies, the data produced by these analytical methods are useful for testing socio-economic models that examine cultural change through the lens of technology (Chapters 9 and 10).

The suite of analytical methods most common to archaeometallurgical investigations, and in particular those applied to materials related to smelting (and typically found in 'slag mounds'), is summarized in Table 8.1. This table also includes dating techniques and the common method used in provenance studies (lead isotope analysis [LIA], see section 2.2.3 above).

Table 8.1: Basic materials found in a 'slag mound' and relevant analytical methods (after Craddock, 1995; and Hauptmann, 2007:16); in **bold** are methods applied as part of the current research (botanical studies and most of the ^{14}C analyses were done as part of the general ELRAP studies)

Material	Information	Technique*	Comments
Ore: Fluxing agents; Clay	Composition of the charged ore; Type of metal; Provenance of clay Provenance of ore	Chemical and mineralogical analysis (AAS, ICP-OES, XRD, microscopy etc.); Petrography LIA	Ores in ancient smelting sites are often waste ('leftovers'). Sampling in ancient mines is more promising.
Fuel	Dating; Fuel supply; Paleoclimates; Material input for slag formation	**14C**; **Botanical studies (SEM)**; Chemical analysis of ashes	Charcoal usually available at all smelting sites
"Refractory" materials (technolo-gical ceramic)	Temperatures and duration of process; Composition of refractory materials (manufacturing process); Metal composition; Reconstruction of technological installations	SEM-studies on vitrification; Petrography; AAS, XRF, SEM/EDS **Stitching fragments (restoration)**	As precise as possible spatial localization of samples is needed. Mixing up with slag is possible
Slag	Temperatures; redox conditions; Viscosity, different steps in metal production; type of metal; Efficiency of smelting; Provenance of components of charge Dating, magnetic mineralogy Dating	**Chemical and mineralogical analysis** (AAS, ICP-OES, **XRD**, **XRF**, **microscopy/petrography** etc.); LIA **Archaeomagnetic techniques** TL	Ever present and important material at old smelting sites and workshops
Metal	Efficiency of smelting process; Parameters of (s)melting installations; Differentiation of raw material-alloy; Provenance of metal Trade/exchange	Analyses of trace elements (AAS, ICP-OES, NAA); metallography; LIA	Exist as inclusions in slag. Larger pieces of metal could be waste

* *AAS*: Atomic Absorption Spectrometry; *^{14}C*: radiocarbon dating; *EDS*: Energy Dispersive Spectrometry (spot analysis); *ICP-OES*: Inductively Coupled Plasma with Optical Emission Spectrometry; *NAA*: Neutron Activation Analysis; *SEM*: Scanning Electron Microscopy; *XRD*: X-ray Diffractometry; *XRF*: X-ray Fluorescence Spectrometry; *LIA*: Lead Isotope Analysis

Base-line archaeometallurgical data for the Faynan region is provided by Hauptmann (2007, esp. chapter 5 and appendix, with more reference therein). This includes substantial analytical data related to Iron Age copper production, such as numerous analyses of slag and metal, mostly from survey collections (section 3.2.5 above). These data cover a broad range of periods and copper exploitation techniques (amounting to more than 8,000 years) and constitute a good reference for studying the *longue dureé* processes and changes in this region. Similarly, analytical data are available for sites investigated by the Arabah Expedition in the southern Arabah and Timna (e.g., Bachmann, 1978a; Bachmann and Rothenberg, 1980; Leese et al., 1986; Rothenberg, 1990a:69-70; Tite et al., 1990). To provide a context for the analyses of the current research, Table 8.2 presents representative published data of slag chemistry and mineralogy from various periods and sites in the Arabah and the northern Negev.

Our investigation focused mostly on Iron Age slag samples from a very high resolution context of time and space. In addition to better characterizing the chemistry and mineralogy of copper slag material from Iron Age Faynan (and Timna) as a whole with a substantial quantity of new analyses, we aimed at using the slag as a proxy for identifying fine technological changes *within* the Iron Age. Besides slag material we analyzed the chemical composition of a few samples of metal ‘chunks' considered according to their context to represent raw smelting products (or a failed smelting attempt, see below).

Table 8.2: A representative set of published mineralogical and chemical composition of slag from sites in the Arabah Valley and the northern Negev. Published data from Iron Age Faynan are emphasized in shaded red

[1] Abbreviations for mineralogical phases: Bust = Bustamite, $(Mn,Ca)_3Si_3O_9$, Cup = Cuprite, Cu_2O, Del = Delafossite, $CuFeO_2$, Fay = Fayalite, Fe_2SiO_4, Hed = Hedenbergite, $CaFeSi_2O_6$ (Pyroxene), Kneb = Knebelite, Fe_2SiO_4, Mag = Magnetite, Fe_3O_4, P = Pyroxene, Q = Quartz, Sp = Spinel, Teph = Tephroite, Mn_2SiO_4.
[2] References and methods: [1] Lupu (1970). [2] Segal et al. (2004). [3] Hauptmann and Weisberger (1987), [4] Rothenberg (1990d), [5] Lupu and Rothenberg (1980), [6] Hauptmann (2007), bulk chemical analyses made using AAS.

Comments:

Bulk chemical analysis of slag is a common procedure in archaeometallurgical research and is done by various methods (unfortunately in many publications the methodology used is not described. See also Table 8.1). The main observations provided by the table below are: (1) slag samples are extremely heterogeneous (note that this might be affected by the methodology used, in particular when, AAS and XRF are applied on original not-pulverized samples); (2) copper content in slag is a general proxy of technological efficiency: as the content is lower, the smelting cycle was more probably more efficient (note that also here there is an inherent difference between furnace and tap slag); (3) the content of manganese and iron indicate differences between Faynan and Timna in flux and/or ore sources.

Mineralogical and chemical composition of slag samples provides important information regarding the smelting technology (e.g., maximum temperature of furnaces, slag viscosity and its cooling rates, etc.)

Locality	ID#	Chemical composition (by % weight)																	Phase[1] (XRD)	Ref[2].
		SiO_2	$Ti O_2$	Al_2O_2	FeO	MnO	MgO	CaO	BaO	K_2O	Na_2O	P_2O_5	S	Ni	Cu	Zn	Pb	Total		
Chalcolithic (ca. 4600-3500 BCE)																				
Timna 39B	58a	34.2			21.69										15.12				NA	1
Timna 39B	50	30.7			49.51	2									1.3				Del, Fay, Q, Sp	1
Early Bronze Age I (ca. 3500-2950 BCE)																				
Wadi Fidan 4	JD-8/10a	35.8	na	4.40	4.51	0.02	0.07	4.80	na	0.22	0.20	na	na	na	34.6	0.03	0.02	84.66		6
Wadi Fidan 4	JD-8/10b	39.5	na	1.10	1.90	0.02	0.60	5.50	na	0.35	0.17	na	na	na	32.6	0.01	0.01	81.75		6
Ashkelon-Afr.	284-2235-2	38.8			12.1	0.02									21.5				Q, Del	2
Ashkelon-Afr.	284-2262	10.2			45.1	0.01									9.4				Fay, Mag, Cup	2
Early Bronze Age II/III (ca. 2950-2200 BCE)																				
Ras en-Naqeb	JD-5/1a	32.3	0.22	4.55	2.65	23.4	4.96	13.0	1.93	1.01	0.38	2.12	<0.01	0.07	3.67	0.14	0.93	91.24		6
Faynan 9	JD-23/1a	23.1	0.21	4.56	2.05	40.3	0.54	3.84	3.48	1.39	<0.14	0.81	1.22	0.08	8.07	0.14	1.54	91.33		6
Middle Bronze Age (ca. 1950-1550 BCE)																				
Wadi Dana	JD-13/10a	35.5	0.19	2.31	6.69	45.4	0.81	4.55	0.78	1.59	<0.14	0.21	0.60	0.07	0.85	0.05	0.04	99.91		6
Wadi Dana	JD-13/10b	33.0	0.18	2.15	6.16	47.4	0.95	3.45	0.55	1.04	<0.14	0.16	0.94	0.07	1.68	0.05	0.03	97.80		6

Table 8.2 continued

Locality	ID#	Chemical composition (by % weight)																	Phase[1] (XRD)	Ref[2].
		SiO_2	$Ti O_2$	Al_2O_2	FeO	MnO	MgO	CaO	BaO	K_2O	Na_2O	P_2O_5	S	Ni	Cu	Zn	Pb	Total		
Late Bronze Age-Early Iron Age (ca. 1300-1150 BCE)																				
Timna 2	LR5	35.7			32.9	2.7									2.3					5
Iron Age I-II (ca. 1100-800 BCE)																				
Faynan 5	JD-1/40	26.4	0.25	5.01	2.17	37.4	1.37	15.3	1.28	3.06	<0.14	3.47	2.33	0.07	0.54	0.03	0.12	98.72		6
Kh. en-Nahas	JD-2/2a	29.8	0.23	5.05	3.32	41.0	1.38	7.55	0.56	2.75	0.50	3.40	0.76	0.07	0.36	0.04	0.02	96.80		6
Kh. en-Nahas	JD-2/2b	32.1	0.20	4.60	3.61	37.5	1.28	9.18	0.48	2.19	1.03	2.48	1.80	0.08	0.40	0.02	0.02	97.03		6
Kh. en-Nahas	JD-2/2c	34.3	0.22	4.93	3.34	39.5	1.11	5.76	0.72	1.78	0.44	1.45	0.83	0.09	0.31	0.02	0.02	94.83		6
Kh. en-Nahas	JD-2/3	51.3	0.24	5.30	2.49	20.5	1.09	4.28	0.56	2.67	0.59	1.82	0.45	0.06	1.37	0.03	0.16	92.85		6
Kh. en-Nahas	JD-2/5a	32.7	0.20	4.27	3.90	40.7	1.60	7.63	0.36	2.45	0.55	2.58	0.56	0.07	0.37	0.03	0.03	98.04	Teph, Glass	6,3
Kh. en-Nahas	JD-2/5b	30.4	0.21	3.78	3.34	43.7	1.40	7.63	0.21	2.30	0.55	2.04	1.07	0.07	0.35	0.03	0.01	97.13	Teph, Glass	6,3
Kh. en-Nahas	JD-2/6	33.5	0.26	5.53	3.73	36.8	1.47	7.48	0.43	2.95	0.85	2.17	0.98	0.07	0.59	0.03	0.09	96.97		6
Kh. en-Nahas	JD-2/20b	30.4	0.20	4.40	5.35	40.2	0.77	7.29	0.95	2.22	<0.14	3.45	0.53	0.07	0.56	0.06	0.08	96.76		6
Kh. en-Nahas	JD-2/20c	28.3	0.22	4.47	2.69	40.8	1.36	9.19	1.24	2.50	0.82	3.36	1.05	0.07	0.43	0.06	0.07	96.60		6
Ras en-Naqab	JD-5/3	33.3	0.25	5.59	3.38	28.6	3.00	13.4	1.64	1.97	0.42	2.01	<0.01	0.06	0.70	0.08	0.36	94.89		6
Ras en-Naqab	JD-5/3a	37.8	0.28	5.11	4.35	25.0	3.14	13.9	1.56	1.73	<0.14	2.33	0.03	0.07	0.83	0.08	0.39	96.65		6
Ras en-Naqab	JD-5/3b	33.7	0.25	5.01	3.53	24.4	2.75	12.4	1.63	1.65	<0.14	1.79	0.02	0.07	1.48	0.09	0.60	89.31		6

Table 8.2 continued

Locality	ID#	Chemical composition (by % weight)																	Phase[1] (XRD)	Ref[2].
		SiO_2	$Ti O_2$	Al_2O_2	FeO	MnO	MgO	CaO	BaO	K_2O	Na_2O	P_2O_5	S	Ni	Cu	Zn	Pb	Total		
Ras en-Naqab	JD-5/3c	31.8	0.25	4.96	2.82	35.0	2.45	12.0	1.90	1.90	<0.14	1.74	0.10	0.07	0.38	0.06	0.39	95.82		6
Wadi Fidan 4	JD-8/1	25.3	0.32	6.43	2.10	34.0	1.46	16.0	0.68	3.59	<0.14	6.76	1.19	0.06	0.48	0.06	0.19	98.61		6
Kh. al-Jariya	JD-11/2	33.6	0.21	4.66	6.99	35.3	0.98	7.97	0.52	3.69	<0.14	3.46	0.61	0.07	0.61	0.05	0.04	98.73		6
Wadi Dana 1/6	JD-13/1b	29.9	0.16	2.43	4.35	49.2	0.92	5.26	0.39	0.61	0.61	0.28	0.58	0.08	1.47	0.07	0.02	96.31		6
Early Roman (ca. 100 BCE-200 CE)																				
Fenan 1	JD-1/23a	42.6	0.30	4.86	5.49	33.9	0.49	2.29	0.65	1.32	0.42	0.16	0.16	0.07	0.49	0.01	0.01	93.16	Bust, Teph, Glass	6,3
Wadi Ratiye	JD-12/3a	25.2	0.21	2.21	32.1	5.0	4.53	17.2	0.10	0.85	0.31	0.98	0.05	0.07	4.39	0.01	0.02	93.28		6
Early Islamic (ca. 650-900 CE)																				
Timna 28	127B	38.6			27.9	1.74									0.99					4
Timna 28	134	24.7			37.83	2.03									1.28					4
Mamluk (ca. 1200-1350 CE)																				
El-Furn	JD-6/2A	34.0	2.20	5.16	37.7	15.4	0.47	2.48	0.61	1.01	0.28	0.44	0.19	0.07	0.94	0.05	0.05	101	Kneb, Px, Glass	6,3
Faynan 6	JD-1/2a	35.5	0.32	6.52	20.0	17.9	1.44	10.6	2.79	1.79	0.55	2.72	0.31	0.08	0.33	0.04	0.03	100.9		6,3

New analyses of other important components of the Iron Age copper production technology such as analyses of clay artifacts and metals were beyond the scope of the current research. Nevertheless, relevant data from previous researches in Faynan are incorporated in the descriptions of raw materials, artifacts and ecofacts in Chapter 7. These include charcoal species identifications (e.g., Engel and Frey, 1996) and composition of materials of Iron Age technological ceramics (Al-Shorman, 2009). Radiocarbon dates of the current project and ELRAP are incorporated in Chapters 5 and 6, together with new data of archaeomagnetic dating. A few new charcoal identifications of ELRAP are discussed in Chapter 7. There is always room for further analyses, also by different methodologies, to strengthen the foundations of archaeological and anthropological interpretations of the fragmented archaeological record.

It is often the case that techniques from the Natural Sciences are applied to archaeological materials without properly defining research questions that have archaeological, anthropological or historical merit (e.g., Van der Leeuw, 1974; Pollard, 2004; Ben-Yosef, 2010). Although the accumulation of any scientific data regarding archaeological materials may prove useful for future inquiries even when the immediate archaeological implications are not apparent, it is misleading to publish such data in the archaeological literature without the additional ‘human aspect’ of the numbers, formulas and tables. Only an integrative approach would make analytical data beneficial to archaeological and anthropological research; multidisciplinary

collaboration with different laboratories, research institutions and experts is often required. The data presented here are the result of collaboration with several different laboratories, including the German Mining Museum (with A. Hauptmann), Bochum, Scripps Institution of Oceanography, San Diego (L. Tauxe), and the Institute of Earth Sciences at the Hebrew University of Jerusalem (H. Ron and R. Shaar).

8.1.1 *The Investigation of slag material*

The analytic investigation of slag material from archaeological contexts was pioneered by researches like those of Morton and Wingrove (1969; 1972) on Roman and Medieval material, and Milton et al. (1976), and Lupu and Rothenberg (1970) on slag from Timna. The publications of Bachmann (1978b; 1980; 1982b) are some of the basic methodological guides for investigations of ancient slag with modern analytical techniques. Interested in the reconstruction of ancient smelting technologies, and focused mostly on slag from advanced technologies (Late Bronze – Iron Age samples from Timna), Bachmann suggested investigating basicity, viscosity, and smelting temperature, all can be derived from the chemical and mineralogical compositions of the samples (software was provided with the publications). In turn, these parameters are used to assess the efficiency of the smelting process and the level of control over the smelting conditions. Building on Bachmann's work, Hauptmann (e.g., 2007:20-21) summarized the principal parameters that defined the conditions of ancient smelting processes: (1) composition of the charge, (2) firing temperature, (3)

gas composition and redox conditions during smelting, and (4) the duration of the smelting process as represented by reaction kinetic between components of the charged material. All of these parameters have their impact on the final slag material, and can, to a certain degree, be estimated from investigation of the chemical and mineralogical compositions of slag. However, Hauptmann (2007:20-21) includes an important reservation:

> Until the recent past, it was traditionally assumed that the tight clustering of ancient iron-rich silica slag compositions… reflect[s] exclusively the [high] technical skill of ancient metallurgists who, having found a suitable charge composition to produce a useful product on one occasion, were then able to reproduce that charge again to produce a similar result. In view of the limited control that ancient metallurgists could have had over the essential components of the raw materials as well as the smelting processes and *the lack of significant differences among most of the slag found throughout wide geographical areas and produced over centuries,* this appears to be a highly unlikely assumption. (emphasis mine)

This important observation is demonstrated in the data presented in Table 8.2 and Fig.8.1. The tight cluster of the elements of the quaternary system CaO – FeO(+MnO) – SiO_2 – Al_2O_3 (represented in Fig.8.1 as the one side [ternary diagram with alumina] of the tetrahedron) is the result of the very limited ways in which all the ancient slag, which were melted in relatively low temperatures, could have been produced. Most of the slag samples that have been studied, from all periods, have compositions that are close to cotectic troughs or eutectics, i.e. represented in the low melting parts of the quaternary system; thus the tight cluster represents the basic constraints over all ancient smelting technologies, and not necessarily the homogeneity practiced by smelters that have found the correct mixture of ore and flux. Nevertheless, the concentration of the different components of this quaternary system enables a rough, but useful estimation of the firing temperature a given charge of ore was exposed to in

a furnace. Or, with other words, it indicates the temperature range under which a slag was liquefied.

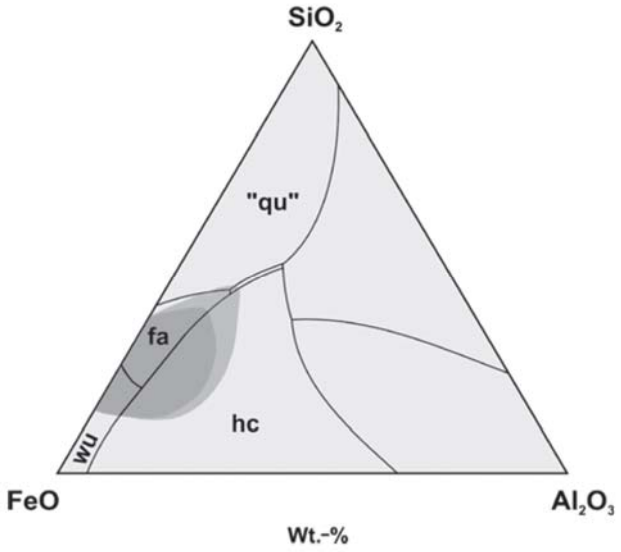


Fig.8.1: Average composition of copper smelting slag (medium shaded area) and (for comparison) iron smelting slag (dark shaded area) (from Hauptmann, 2007:21). This represents a large sample size covering different locations and periods. The compositions match mainly the eutectic area of the FeO – SiO_2 – Al_2O_3 system. Wu = Wüstite, hc = hercynite; Fa: olivine; Qu = quartz.

Variability in ancient smelting technologies can be detected by investigating several features of the slag material, including its shape and macro and micro texture, bulk chemistry and phase content (mineralogical studies). The technological information that can be inferred from these features is, for example (Hauptmann, 2007:21-27, 180-186):

(1) Estimation of reduction – oxidation conditions (air supply technologies, furnace structure, etc.): according to the principle known as *Bowen –Fenner – Trend* in petrology, that predicts that under high Po_2 magnetite and a silica-rich compound crystallize first (and Fe is mainly bound as an oxide), and in low

Po_2 no magnetite will be formed, but an iron rich silicate (fayalite), and in cases metallic iron precipitates.

(2) Estimation of smelting temperature: the ratio of the main elements of the system CaO - FeO(/MnO) – SiO_2 – Al_2O_3 can indicate temperature constraints when plotted on phase diagrams.

(3) Estimation of smelting duration: studying the different mineralogical phases, their parageneses (order of formation) and grain size, and identification of un-decomposed remains of ore charge.

(4) Information about the origin and nature of ore: by studying the chemistry and mineralogy (see discussion below about Iron-rich vs. Mn-rich slag from the Arabah), and un-decomposed components of ore and flux in the slag (observable microscopically or macroscopically).

The above proxies to reconstruct technological conditions are based on theoretical concepts of physical chemistry, which are based on ideal conditions of equilibrium. In reality, equilibrium never happens, but research thus far has shown that these principles are still valid, in particular when the slag was solidified from homogenous liquids. In the following we present the results of our analyses and their preliminary evaluation, with focus on technological / organizational inferences. The data can be used later for in depth investigations that are more concerned with the study of chemical and physical properties of slag materials (here, mostly Mn-rich) *per se*.

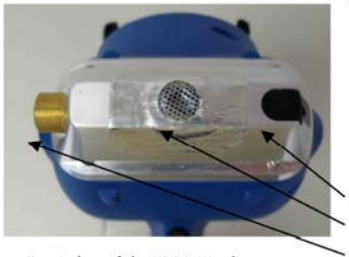
8.2 Introduction to analytical methods used in the current research

8.2.1 *X-ray Fluorescence (XRF)*

X-Ray Fluorescence Spectrometry (XRF) is a method for determining the chemical composition (elements) of materials. In the current research we used the TRACeR handheld unit by Bruker AXS (Fig.8.2) that can detect elements as low as Na(11) (practically Mg is the lowest element detected) and up to U(92). Oxygen cannot be identified by common XRF machines; its quantity in oxidic materials is calculated by estimation of the different phases in the material and their chemical formulas (e.g., SiO_2, MnO, etc.). The spectral analysis is done with the PXRF software and provides both qualitative and quantitative results; the latter depends on calibrating the instrument readings for the specific type of material measured (e.g., metals, glasses, rock by types, etc.). When calibrated properly, the TRACeR handheld unit can accurately detect elements down to several hundreds of parts per million (ppm). The spatial resolution of the instrument is about 30μm (0.03 mm).

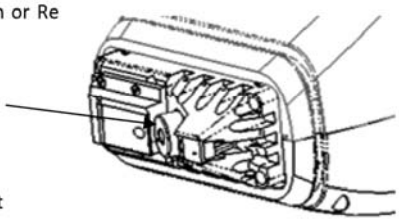
TRACeR

The TRACeR is a handheld ED-XRF unit used for instant nondestructive elemental analysis anywhere, anytime. It can be used in a wide range of applications including elemental analysis in material research, archeological digs, museum artifact analysis, conservation and restoration, electric utility industry, engine assembly, airframe assembly, scrap industry, metal producers, foundries, and maintenance assessment, and many other applications.



Front view of the TRACeR unit

- X-ray tube (typically Ag, Rh or Re Target)
- Up to 45kV X-rays
- 170eV Si PIN or 145eV SDD
- 13µ Be Detector Window
- IR Safety Sensor
- Vacuum window
- User selectable filter/target
- Up to 200 kcps (SDD)



Sketch of TRACeR module



Si PIN Diode/SDD Detector Parameters

CHARACTERISTIC	Si (Silicon)
Atomic Number, Z	14
[1]Specific Density, [g/cm^3]	2.33
[2]Band Gap, [eV]	1.12
[3]Melting Point, [°C]	1412
[4]Hardness, [Brinell]	1150
[5]Energy/Pair, [eV]	3.62
[6]Resistivity	10^4
[7]Mobility, [cm2/(Vsec)]	
electrons:	1400
holes:	480

Si PIN/SDD characteristics
(see Appendix B for explanations)

X-ray Tube	Ag, Rh, or Re
Filter	Selectable (See Appendix A)
Voltage Selection	Variable, 0-45 kV
Current Selection	Variable, 0-60 µA
Scan Length	Selectable
Optimal Pulse Density	15,000 max cps (PIN), 150,000 (max cps (SDD)
Environment	Air or Vacuum
Detector Channels	1023 PIN/2048 SDD

TRACeR operating parameters

Fig.8.2: Technical information on the Bruker TRACeR handheld XRF instrument used in the research presented here (Kaiser, 2010:8).

Most of the XRF analyses presented here were conducted in the Levantine Archaeology Laboratory at UCSD and some in the ELRAP's 2009 field season in Faynan. One of the advantages of using a handheld unit is the possibility of conducting measurements during a field season, in the field laboratory or in the site itself, 'on the fly' and in real time of excavation / survey (Levy et al., in press-c). Portable high precision XRF instruments have become common in archaeological field research (e.g., Potts and West, 2008), and in particular in archaeometallurgy (e.g., Yekutieli et al., 2005; Grattan et al., 2007; Vardi et al., 2008, these few examples are all related to ancient metallurgy associated with Faynan), as the prices of such devices have come down in recent years.

The basic principle behind XRF analyses relates to the unique atomic structure of each element. When inner shell electrons are removed from an atom, electrons from shells with less binding energy take the place of the missing electron and may release x-ray radiation in this transition ('fluorescence'). This radiation is characteristic to the element (±2eV) and equivalent to the difference in energy between the original shell and the new one into which the electron moved. By bombarding an atom with x-ray radiation that exceeds the binding energy of its electrons, excitation and ejection of inner shell electrons occur. By measuring the energy of resultant x-rays emitted from the atom, it is possible to detect its chemistry. In a sample, measuring the energy levels and number of resultant x-rays enables to determine the composition and proportional concentrations of those elements (Kaiser, 2010).

Two common methods of x-ray spectroscopy are available: Wavelength Dispersive XRF (WD-XRF) and Energy Dispersive XRF (ED-XRF). The main difference between the two methods is related to the method of measuring the emitted x-rays. In WD-XRF an analyzing crystal is used to diffract the different x-ray wavelengths and the detectors are located in various angles around the sample to measure the number of x-ray diffracted at each of those angles. As the energy is emitted from the crystal in different angles, if a single energy detector is used it has to move and cover all angles. Energy Dispersive X-Ray Fluorescence uses a detector that collects x-rays of all energies. Detecting each x-ray energy level is done by measuring the amount of electrons each x-ray (emitted from the sample) knocks free in the detector lattice itself, typically silicon. The number of electrons knocked free depends on the in coming x ray energy and the particular interaction that that x-ray has with the material of the detector's lattice. All electrons that have been knocked free from each event that occurs in the detector must be collected and converted to represent the x-ray energy as a digital signal. Consequently the detector measures one x-ray at a time (for comprehensive overview of the physics see e.g., Beckhoff et al., 2006).

The Bruker TRACeR handheld unit is an ED-XRF instrument. The results of each measurement, i.e., the 'dispersed' energies detected, are plotted as a spectrum, where intensity is set against energy (using the PXRF software, see e.g., Fig.8.17). The resulting peaks shown in the spectrum indicate the elements present in the sample

(their location corresponds to their characteristic emitted energy) and its concentration in the sample (the height of the peak). Note that in not calibrated measurements a qualitative analysis can be done within a sample level only between elements that have close values of characteristic emitted energy (i.e., they are also close in their atomic number; e.g., Mn – Fe – Ti, K – Ca, etc.) by comparing the relative height of their peaks (or the areas below them). Two main conditions should apply when comparing relative amount of elements between two samples (or more): the matrix (the bulk composition) of the samples have to be the same (e.g., metal oxides in silica matrix, metal alloys with limited range of compositions, etc.), and the *real time* (i.e., the time of measurement) should be the same or normalize to represent the same time (counts of x-rays emitted from a sample depend directly on the measurement time; however counting achieves 'saturation' after a while). It is also necessary that the instruments used for measurements are of the exact same brand and type (and preferably the same instrument if possible) and that the technical setting of the instrument(s), such as filter/polarizer used (see below) are the same. This is a fundamental principle of XRF analyses, especially when using the same instrument for various types of materials without calibrations, which is a common practice in field research. In the current research the Bruker TRACeR instrument had calibration data for metals only, and we had to calibrate it for analyses of slag material as well.

For better detecting and quantifying elements, the Bruker TRACeR instrument has the option to work with *filters* (Kaiser, 2010:7) (Table 8.3). A filter can be

placed between the tube and the sample to remove undesirable background radiation below a certain voltage, thus each filter is suitable for detecting a different range of elements. The level of radiation filtered out is dependent on the filter element composition and its thickness.

Table 8.3: Filters available for the Bruker TRACeR instrument; for slag analysis we have used both the green (copper) and blue (cellulose) filters for increasing the accuracy of quantitative measurements of a wide range of elements

Filter	**Thickness**	**kV range**	**Elements**
No filter	N/A	4-50	All, Na-Ca
Cellulose	Single sheet	5-10	Si-Ti
Thin aluminum	25-75 μm	8-12	S-V
Thick aluminum	75-200 μm	10-20	Ca-Cu
Thin anode element	25-75 μm	25-40	Ca-Mo
Thick anode element	100-150 μm	40-50	Cu-Mo
Copper	200-500 μm	50	>Fe

In addition to choosing the adequate filter (or no filter at all), the Bruker TRACeR instrument enables control of additional technical components. One is the use of a vacuum between the sample and detector, which is necessary when measuring light elements (especially for qualitative analyses). Another technical feature is the ability to control the voltage and current of the x-ray tube. Adjusting these parameters helps to isolate spectral phenomena that obscure desired information in a given spectrum, such as Compton and Rayleigh scatters and sample matrix effects. We applied several different settings according to the type of material and the sort of information we were looking for (quantitative vs. qualitative, only main pattern vs. all elements etc.), with special attention to slag.

8.2.2 *X-Ray Diffraction (XRD)*

X-Ray diffraction is a semi-qualitative method used to determine mineral phases and their abundance based on their crystalline structures (e.g., Cullity, 1978). This method is commonly used in archaeometallurgy to complement microscopic investigation of thin sections, for identifying invisible minerals (opaque) and for getting better estimation of the mineralogical composition of the sample as a bulk (in contrast to thin sections which represent a fragment of heterogeneous material). In slag and ore the analysis is usually performed on small quantities (a few grams) of pulverized samples spread out over a glass stage. The stage is inserted into a diffractometer and the sample is irradiated by X-Rays.

For a few hours the X-Ray tube rotates around the sample on a circular path spanning 180 degrees. The diffracted X-Ray intensities are recorded and plotted against the angle of diffraction (or reflected angle) multiplied by two. The plotted pattern of intensity peaks is comparable to the distances between diffraction planes of atoms within the crystal, i.e., each mineral phase has its own pattern. This correlation is based on Bragg's Law ($n \lambda = 2d \sin \theta$, Fig.8.3) that defines the reflected angle (θ) (which equals the angle of the incident beam) by the fix (and characteristic) distance between atomic planes of a crystal's lattice (d), the number of wavelengths in the path length (n) and the wavelength (λ). In other words, only when the conditions defined by Bragg's law exist the beam will be reflected. The practical implication of the physics

is that each type of crystal (= different minerals) has a unique pattern of X-Ray diffraction that can be identified when compared to standards.

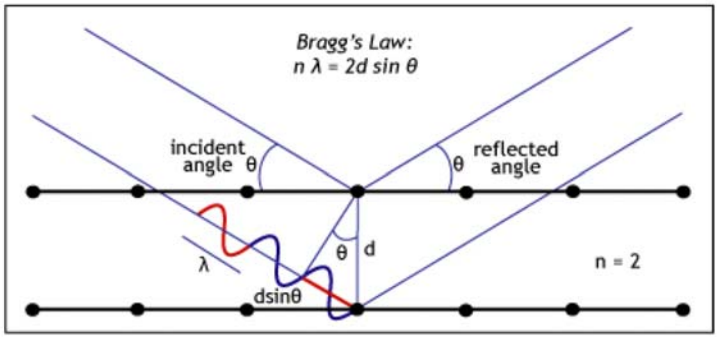


Fig.8.3: The principles of Bragg's Law, in case where n=2 (from: http://www.matter.org.uk/glossary/).

Each plotted peak corresponds to a known atom-distance pattern. In case there are many mineral phases, the presence of multiple peaks can make the matching process quite cumbersome. Most modern instruments, including the one used in the current research at the German Mining Museum in Bochum, have software attached that facilitate the matching process and the identification of minerals by providing a searchable database and suggestions for correlations. Estimations of concentrations of mineral phases are done by the intensity of the peaks, and are usually only semi-quantitively. Visual comparisons of peak patterns with reference samples of known concentrations and experience are part of the process. In this study the estimations were done by Dirk Kirchner of the German Mining Museum, Bochum.

8.2.3 *Petrography (optical microscopy)*

In the context of the current research optical microscopy is used for investigating the content, and in particular the texture and different mineral phases of slag material. The optical microscope is based on magnified observation of light (as opposed for example to the electron microscope) as it is projected through a thin section of a sample (a 30 μm-thick slice of the material investigated mounted with epoxy onto a 27 × 46 mm glass slide). This method, together with the use of polarized light, is the most basic procedure used to identify non-opaque minerals in rocks (hence petrographic microscope), and to investigate other features such textures and patterns that can reveal important details regarding the formation processes and 'life history' of the material. Analyses of thin sections are limited as a procedure to identify and quantify mineralogical phases in heterogeneous samples, which are the common case in rock (and slag); a thin section represents only a fragment of the bulk sample, and even if multiple sections are studied, there still is a chance that some minerals would not be indentified. Thus, for mineralogical studies, it is best to complement optical microscopy with XRD analyses that provide a bulk mineralogical composition including identifications of opaque minerals and (rough) estimation of quantities (see above). The advantages of thin section studies are the possibility to identify rare phases that might be obscured by the matrix material and thus cannot be detected by the XRD analysis (e.g., Fig.8.40E, thin section showing Covellite that was not detected in the XRD analyses of the same sample; and see section 8.5 for discussion),

and above all the ability to reconstruct formation history and other processes represented by the texture and other visual elements of the material.

Ancient slag materials experienced rapid cooling, thus they usually consist of a very fine grained mixture of different phases (Hauptmann, 2007:19; Shaar et al., 2010). In optical microscopy of slag usually only the main components are detected (e.g., olivine, spinel and pyroxene). In some cases the matrix is a true glassy state with only cryptocrystalline or hyalocrystalline phases that even XRD analysis cannot detect, and the use of scanning electron microscopy (SEM) or electron probe microanalysis (EPMA) is needed. The purpose of conducting optical analyses of slag in the current research was to gain additional insights on Iron Age smelting technology by complementing the XRF and XRD data with visual investigation of the slag texture. A detailed description of the petrography of slag and its application in the study of ancient smelting technologies (with emphasis on copper) is available in Hauptmann (2007:186-199).

Table 8.4 (continued on page 791): Common mineral phases of copper production slag from the Arabah Valley and their chemical formula (from Hauptmann, 2007:165)

Mineral phase	Chemical formula
Cu-phases in all slag	
Cuprite	Cu_2O
Chalcocite	$Cu_{2-x}S$
Covellite	CuS
Copper	Cu
Mn-free slag of the 4th millennium BCE Faynan	
Akermanite	$Ca_2MgSi_2O_7$
Alite	Ca_3SiO_5
Calcite	Ca_2CO_3
Celsian	$Ba[Al_2Si_2O_8]$
Dlafosite	$Cu^{+}Fe^{3+}O_2$
Diopside	$CaMgSi_2O_6$
Fe-rich diopside ('salite')	$Ca(Fe,Mg)Si_2O_6$
Glass	Fe-Al-Ca silicate
Magnetite	Fe_3O_4
Merwinite	$Ca_3MgSi_2O_8$
Periclas	MgO
Quartz/tridymite/cristobalite	SiO_2
Schreibersite	Fe_3P
Mn-bearing slag of later periods	
Baryite	$BaSO_4$
Bixbyite	$(Mn,Fe)_2O_3$
Lead-silicate (glass)	$Pb\text{-}SiO_2$
Braunite	$Mn^{2+}Mn_6^{3+}[O_8/SiO_4]$
Celsian	$Ba[Al_2Si_2O_8]$
Crednerite	$CuMn_2O_4$
Fe-phosphate	$Fe_2P_2O_8(?)$
Glass	Mn-Ca-Al silicate
Hausmannite	Mn_3O_4
Hilgenstockite (?)	$Ca_4P_2O_9$
Jakobsite	$(Mn,Fe)_3O_4$
Johannsenite	$(Mn,Fe,Ca)[SiO_3]$
Knebelite	$(Mn,Fe)_2SiO_4$
Partridgeite	Mn_2O_3
Pyrolusite	MnO_2
Pyroxenoids (busmtamite, pyroxmangite, rhodonite)	$(Mn,Fe,Ca)[SiO_3]$
Schreibersite	Fe_3P
Tephroite	Mn_2SiO_4

8.2.4 *Scanning Electron Microscope – Energy Dispersive Spectrometry (SEM-EDS)*

The scanning electron microscope is a type of electron microscope that creates images of the sample surface (thin sections of the studied material see 8.2.3 above) by scanning it with a beam of high-energy electrons (Leng, 2009:121-145) (Fig.8.4). The interaction of the electrons with the atoms of the sample produces different signals. These contain information about various features of the sample, such as topography of the surface (visual investigation), chemical composition (by causing the sample to emit characteristic x-rays), and electrical conductivity. The high magnification of the SEM (up to 500,000 times, about 250 times the magnification limit of the best light microscopes) is very useful for examining the mineralogy, phases and texture of slag materials as those contain a substantial amount of hayalo- and crypto- crystals (in addition to glass) that are not visible with light microscope and cannot be detected with XRD analyses. Thus, an SEM analysis can help detect mineralogical phases that exist as very fine grains, micro-textures and other visual parameters.

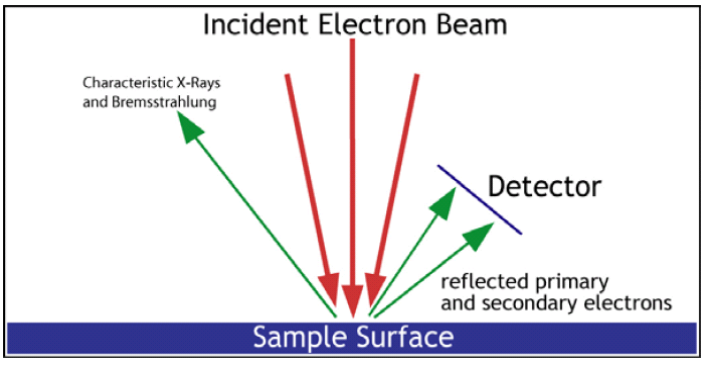


Fig.8.4: Basic principles of SEM operation (from Veldhuijzen, 2005:120).

In addition to the visual examination of the image produced by the SEM, the instrument can detect the characteristic x-rays that the atoms in the sample emits, and thus to provide a chemical analyses (elements) of the specific spot the electron beam hit. The detectors for x-rays can be one of two types of spectrometers: *Energy Dispersive Spectrometry* (EDS) or *Wavelength Dispersive Spectrometry* (WDS). A relative accuracy of -1% can be achieved using WD spectrometer, and slightly lower precision and accuracy (1-10%) with using ED. The chemical composition helps to identify the mineralogical phases and the composition of the glass. As part of the examination of the magnetic characteristics of different types of slag from Timna and Faynan we conducted SEM-EDS analyses on several samples (Ben-Yosef et al., 2008a:Fig.9; Shaar et al., 2010, here with specific focus on Iron Age material). The ultra-fine grains of the glassy parts of slag (usually the fast-cooling parts such as small droplets or the crest of large pieces) have a single-domain type of magnetization which is ideal for archaeointensity research (see section 4.2.2 above). The main goal of the SEM analyses was to identify and characterize the magnetized phase. However, a significant difference between slag of the Iron Age was found (and discussed below), and this bears important information regarding the smelting technology.

8.2.5 *Archaeomagnetic investigations of slag material*

One consequence of the intensive recent research on the magnetic characteristics of slag and its behavior in archaeointensity experiments (Ben-Yosef et

al., 2008a; Ben-Yosef et al., 2008b; Ben-Yosef et al., 2009c; Ben-Yosef et al., 2010c; Shaar et al., 2010; Shaar and Ben-Yosef, in press; Shaar et al., in press, and see section 4.2.2 above) is a preliminary development of a paleomagnetic technique to differentiate between different slag types of the southern Levant (namely, the Mn-rich vs. the Fe-rich slag). Essentially in its current stage of development this technique can replace an XRF analysis in case it is not available (both are rather fast). Technical details about the methodology are presented in section 4.2.2 above and a lengthy discussion concerning the principles behind the methodology is provided by Tauxe (2010).

8.3 Sample selection

Investigations of Iron Age slag samples from Faynan were part of the intensive research of the German Mining Museum team (Hauptmann, 2007, and references within), as well as the pioneering research of the Arabah Expedition (see e.g., Lupu and Rothenberg, 1970 for a study of 'Iron Age' slag [before those were dated to the Late Bronze Age]). Building on these important studies, we focused on detailed analyses of Iron Age slag (only) from many different archaeological contexts. The ERLAP slag collection (section 7.1.2 above) was sampled from deep sections into ‘slag mounds’ carefully excavated as part of the current research as well as numerous well-defined metallurgical loci from several different sites (Chapters 5 and 6 above). This constitutes an invaluable resource for the study of ancient technology by the

analytical methods presented above. Here we present only preliminary results; the vast collection, including the selected samples for the current analyses, is stored at UCSD Levantine Archaeology Laboratory (directed by T.E. Levy). All the samples came from well recorded archaeological contexts (see sections 5.2.1, 5.2.2, and 7.1.2 above).

For the analyses conducted in the current research we chose slag samples according to the following parameters: (1) samples should represent different *spatial* locations, i.e., different metallurgical sites in Faynan as well as some comparison with slag from Timna; here we chose Khirbat en-Nahas, Khirbat al-Jariya, Timna 30 and F2 (Chapters 5 and 6); (2) samples should represent different archaeological contexts within a site; here we focused on the extensively excavated site of Khirbat en-Nahas, including samples from Areas M, F and A; (3) samples should represent a deep time dimension *within* the Iron Age; here we focused on (a) the deep pit in Khirbat en-Nahas Area M (section 5.2.4.2), with samples collected directly from the southern wall ('South Section') and eastern wall ('East Section'), and from some of the excavated loci, (b) the probe at Khirbat al-Jariya Area A (section 5.2.9), with samples collected directly from the western wall ('West Section') and the northern wall ('North Section), and (c) the re-excavated 'slag mound' at Timna 30 Area S and the associated excavation square (Area L) (section 6.2.1.2). All of the investigated contexts are associated with high resolution AMS radiocarbon dates subjected to Bayesian analyses which provide excellent temporal information; together with

archaeomagnetic data from all of these sites, correlation between different contexts is feasible (and presented in Chapter 9).

Out of the tens of thousands of slag fragments collected and processes as part of the ELRAP and our new excavations at Timna, we selected more than one thousand samples for further analyses according to the principles described above. Each of these samples was described in detail, including size, color, texture (prorosity, flow texture, etc,), and visible inclusions (charcoal, unsmelted ore, metal prills etc.). Several hundred of the selected samples were subjected to archaeomagnetic (mostly archaeointensity) experiments. These required special preparation (breaking 5-15 small chips of a few mm each from each slag sample and inserting them into small glass tubes); however, it is beyond the scope of the current research to elaborate on this issue and only aspects that are directly relevant to the archaeometallurgy of Iron Age copper production are discussed briefly in section 4.2.2 above and section 8.4.4 below (with references within).

The descriptions (with reference to context, e.g., Locus, Layer, Strata etc.) of all samples that were subjected to XRF, XRD and/or petrography analyses are summarized in Table 8.5. The locations of these samples, together with some of the 'successful samples' (i.e., those that yielded reliable results) of the archaeomagnetic experiments, are depicted in Figs.8.5-8.12. For further information about the context *cf*. relevant descriptions in Chapters 5 and 6 above.

8.4 Sample preparation

XRD analysis is preformed on powders and petrography and SEM analyses on thin sections. XRF analysis can be done on the original sample; however, the area analyzed by the instrument is relatively small (in the scale of a few mm in diameter and in depth, depending on the specific structure of the device, its settings and the type of material analyzed). This should be taken into account in the case of heterogeneous, corroded or patinated samples, and such metadata regarding sample characteristics must complement the XRF data especially when the analysis is preformed on intact samples.

Slag is an extremely heterogeneous material (sections 8 .4.1 and 8.4.2 below), thus, even though XRF analysis is not a destructive technique (a great advantage when examining more homogeneous archaeological artifacts), for an accurate measurement of the bulk chemical composition of slag, a representative portion of a sample should be pulverized. Half-fist size portions of 97 slag samples from different contexts were crushed in the petrographic laboratory at Scripps Institution of Oceanography[94] into a powder of very fine grains (several tens of microns) (Fig.8.13). The rest of the slag sample was stored and labeled as "control" (c = control on Figs.8.5-8.12, in contrast to p = powder). In case the original sample was small, it may have been completely

[94] The crushing procedure at the petrographic laboratory of Scripps Institution of Oceanography was done during the summer of 2009 with the kind permission of Castillo Paterno.

pulverized (thus only 'p' samples exist) or, when the sample was even too small for the crushing procedure, we left it intact (thus only 'c' samples exist). The powders were stored in zip-lock bags; a few grams of each sample were inserted into special 'sample holder' suitable for analyses with the Bruker TRACeR handheld XRF machine we have used (Fig.8.14), and 31 pulverized samples (from representative contexts) were sent to the German Mining Museum (GMM) for XRD analysis, including preparation (small portion of the sample were mounted onto small standard metallic discs)[95]. 30 'control' slag samples (from representative contexts) were sent to the GMM for thin section preparation[96]; the pulverized portions of some of these samples were also subjected to XRD analyses.

Table 8.5: Visual observations on slag samples and their archaeological context; c = 'control', indicating that there is a not-pulverized portion of the sample available for comparison with the bulk analyses of the powders and further investigations (y=yes, available, n=no, not available); A = Area, S = Section (when applicable), L = Layer, St. = Strata (cf. Chapters 5 and 6 and Figs.8.5-8.12)

Sample Name	Site	A	S	Description of control
3261	KAJ	A	W	blue/black, shiny, dirty
3262	KAJ	A	W	black, shiny, dirty, charcoal, brittle, bluish, rough
3263	KAJ	A	N	black, some green, rough, holes, somewhat dirty, hard
3266	KAJ	A	W	shiny, black, some orange, smooth, dirty, bluish color
3267	KAJ	A	W	black, dirty, porous, little orange, some shiny spots, wet
3269	KAJ	A	W	dirty, black with orange, mostly smooth
3271	KAJ	A	W	entire sample used to make powder, brownish-black, small pieces, a little shiny
3272	KAJ	A	W	small pieces, gray, some shine, rough, wet
3274	KAJ	A	W	entire sample used to make powder, black, copper, rough, brown minerals, some shine
3275	KAJ	A	N	filthy, black, shiny, rough, mineraly, lots of copper, tough
3276	KAJ	A	N	black, some white & orange, rough, little dirty
3277	KAJ	A	N	shiny, black, dirty, rough on one side, smooth on the other side, tough

[95] The XRD sample preparation and analysis procedures were conducted by Dirk Kirchner of the GMM.
[96] A Standard thin section is a 30 µm-thick slice of rock, concrete, etc., mounted with epoxy onto a 27 × 46 mm glass slide. Using a grinding process involving flat, horizontal wheels (called lapping).

Table 8.5 continued

Sample Name	Site	A	S	Description of control
3278	KAJ	A	N	shiny, bluish-black, dirty, minerals, rough, wet, tough
3279	KAJ	A	N	grey,/orange, blue tint, pretty clean, smooth
3280	KAJ	A	N	bluish-black, shiny, brown minerals, dirty, green mineral, charcoal, damp
3281	KAJ	A	N	shiny, dirty, black
3282	KAJ	A	N	shiny, dense, evidence of chracoal, minerals (red, green, brown)
3283	KAJ	A	N	shiny, dirty, bluish-black minerals, shiny brown minerals, charcoal
3287	KAJ	A	N	shiny, blush-black, dirty, minerals, rough, wet, tough
10250	KEN	M	S	bluish-gray, shiny (very shiny in some places), mostly smooth, dry
10256	KEN	M	S	bluish sheen, dirty, rough, some copper deposits, dry
10259	KEN	M	S	shiny spots, some orange, bluish/gray, little dirty, faily smooth
10260	KEN	M	S	flat, smooth, dense, black/greenish, dry
10262	KEN	M	S	rough, copper residue(green minerals), dirty, shiny
10267	KEN	M	S	black, rough, dirty, shiny, minerals present, tough, damp
10270	KEN	M	S	dirty, black, shiny, porous (somewhat), damp
10277	KEN	M	S	dirty, bluish black, gray, rough
10280	KEN	M	S	black, rough, dirty, charcoal, copper, shiny minerals
10282	KEN	M	S	very dirty, black, lots of minerals, rough, sandy exterior, some shiny parts, copper, charcoal
10283	KEN	M	S	tiny pieces, glassy, brown minerals (glassy), blue-gray
10460	KEN	M	E	black, rough, dirty, copper residue, porous
10461	KEN	M	E	black, large holes, crystals, hard, chracoal
10462	KEN	M	E	black, blue, charcoal, copper inclusions, crumbly but tough, wet
10463	KEN	M	E	red/orange, very grainy & porous, already crushed
10464	KEN	M	E	very small sample, used entire sample for powder, copper, black, wet
10465	KEN	M	E	black, porous, dirty, somewhat smooth
10466	KEN	M	E	black, dirty, small pieces, rough, brown minerals on surface, porous, red & green minerals, very wet
10467	KEN	M	E	black,/blue, green spots, dirty
10468	KEN	M	E	rough, black, minerals, brittle, moist, sandy
10471	KEN	M	E	black, dirty, porous, slightly shiny on inside, very hard, damp
10474	KEN	M	E	black, dirty, dull, minerals, slightly porous, charcoal, glassy, damp
10475	KEN	M	E	bluish-black; extremely rough, shiny, porous, dirty, minerals
10476	KEN	M	E	blue/gray/brown, porous, dirty, dense inside, light brown/gray green
10477	KEN	M	E	black/gray, smooth, muddy, large interior bubbles
10478	KEN	M	E	black, green, dirty, somewhat smooth
10479	KEN	M	E	black, dirty, slightly shiny
10480	KEN	M	E	black/blue, course & very porous, dirty, a lot of charcoal
10481	KEN	M	E	bluish/gray, black, dirty, gray, rough
10482	KEN	M	E	large, black/gray, porous, tough to grind, dull, dirty,
10483	KEN	M	E	black with orange, globular, sharp

Table 8.5 continued

Sample Name	Site	A	S	Description of control
10484	KEN	M	E	blue, shiny, smooth, brown shiny stuff, glasslike texture, tough, sharp sherds
10485	KEN	M	E	blue/black, shiny, mostly smooth with small bumps, dirty, bits of orange
10486	KEN	M	E	blue/gray/a little black, slightly smooth, dull w/ shiny specks
10487	KEN	M	E	blue/gray, shiny specks, porous, orange bits of color, dirty
10488	KEN	M	E	tan/gray, slightly porous inside, smooth outside, sharp
10489	KEN	M	E	gray, smooth with large interior bubbles (porous)
10490	KEN	M	E	black, dirty, charcoal, brown minerals
10492	KEN	M	E	shiny, dirty, grey/black, dense, smooth, debris stuck to the outside, damp
10493	KEN	M	E	rough, black, some shine, dirty, brown minerals on surface, green minerals, moist
F-2 A	F2	F	-	sparkly, black, mineral inclusions, copper specks on outside; inside dull gray, porous
F-2 B	F2	F	-	brown, smooth, porous
F-2 C	F2	F	-	dull, smooth, black, slightly porous
F-2 D	F2	F	-	dull, smooth, black, slightly porous
F-2 E	F2	F	-	dull, smooth, black, slightly porous
L.170 B.4160	KEN	A	-	black/brown, dirty, muddy, wet, porous, very soft, like black sand, red, green and blue inclusions
L.174 B.4190	KEN	A	-	dirty brown, sparkly, large pieces of cylinder charcoal, crumbly
L.180 B.4273	KEN	A	-	black and dirty
L.180 cooked	KEN	A	-	cooked; dark gray and charcoal?
L.192 B.4376	KEN	A	-	black, muddy, dense, non porous, hard, greenish
L.193	KEN	A	-	blue/black, first and shiny, smooth
L.602 B.9013	KEN	M	-	black/gray, globular with large bubbles
L.606	KEN	M	-	dirty, black, some bluish shine, rough
L.615 B.9037	KEN	M	-	surface is shiny, bluish-black, minerals
L.620	KEN	M	S	black/tan dense and globular, sharp
L.620(2)	KEN	M	-	black/tan dense and globular, sharp
L.622	KEN	M	-	bluish-black, pink minerals, shiny, rough, porous, charcoal
L.629	KEN	M	-	black/gray, med green bubbles, tan marbling
L.647	KEN	M	-	black, rough, dirty, brown minerals, some bluish tint in some parts
L.659	KEN	M	-	rough, dirty, copper, some shiny parts, lots of minerals, shiny on the inside, hard
L.660	KEN	M	-	dirty, black, red mineral deposit, rough
L.666	KEN	M	-	
L.667	KEN	M	-	
L.670	KEN	M	-	bluish-black, pink minerals, shiny, rough, porous, charcoal
L.670 B.9481	KEN	M	-	black, charcoal, dirty, rough, sand on the surface, little shine
L.671	KEN	M	S	black, gray, tan with small red inclusions, lots of large holes
L.674	KEN	M	-	black, brown, muddy, dirty, very wet
L.808 B.1200	T30	L	-	dirty, brown deposits/dust, porous, rough, copper (green minerals)
L.809 B.1800	T30	L	-	shiny, bluish-black, minerals

Table 8.5 continued

Sample Name	Site	A	S	Description of control
L.813 B.1400(2)	T30	L	-	dirty, brown, porous
L.813 B.1400(3)	T30	L	-	dirty, brown, porous
L.816 B.1059	KEN	F	-	black/brown muffy, green inside
L.842	KEN	F	-	black, muddy, smooth large charcoal inclusions
L.859	KEN	F	-	black, muddy, dirty, large, charcoal inclusions
L.860 B.1412	KEN	F	-	black, muddy, wet
L.860 B.1412 cooked	KEN	F	-	black, muddy, wet
L.903 B. 561	T30	L	-	brown, rough, dirty, porous, copper? Charcoal, some shiny areas
S1 L.902 B.557	T30	S	-	rough, dirty, copper, charcoal, iron?, hard
S1 L.907 B.505	T30	S	-	dirty, charcoal, porous, brown minerals
S2-51	T30	S	-	bluish-black, shiny parts, dirty, brown minerals, very hard
S2-510	T30	S	-	rough, large amt. of charcoal, black, brown dust on surface, dirty, shiny sections, hard
S2-52	T30	S	-	black, brown dust on surface, charcoal, blue sheen, hard
section4 SMAR0904	KEN	M	S	black, rough, dirty, bluish-shine

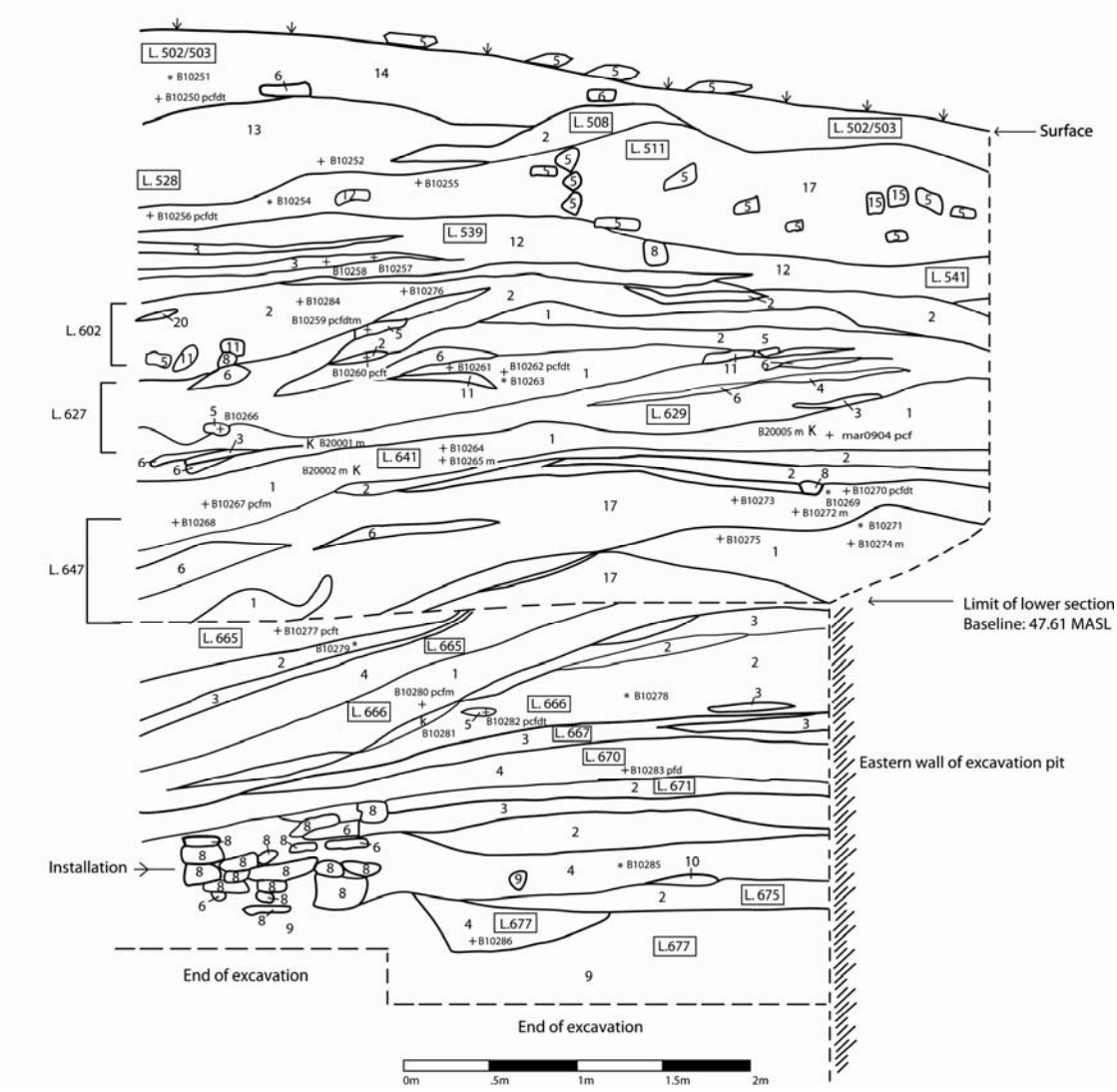


Fig.8.5: Khirbat en-Nahas, Area M, South Section: location of samples that were subjected to analytic analyses as part of the current research. c = control sample available; d = XRD; f = XRF; m = archaeomagnetic; P = pulverized sample available; T = thin section / petrography (see text).

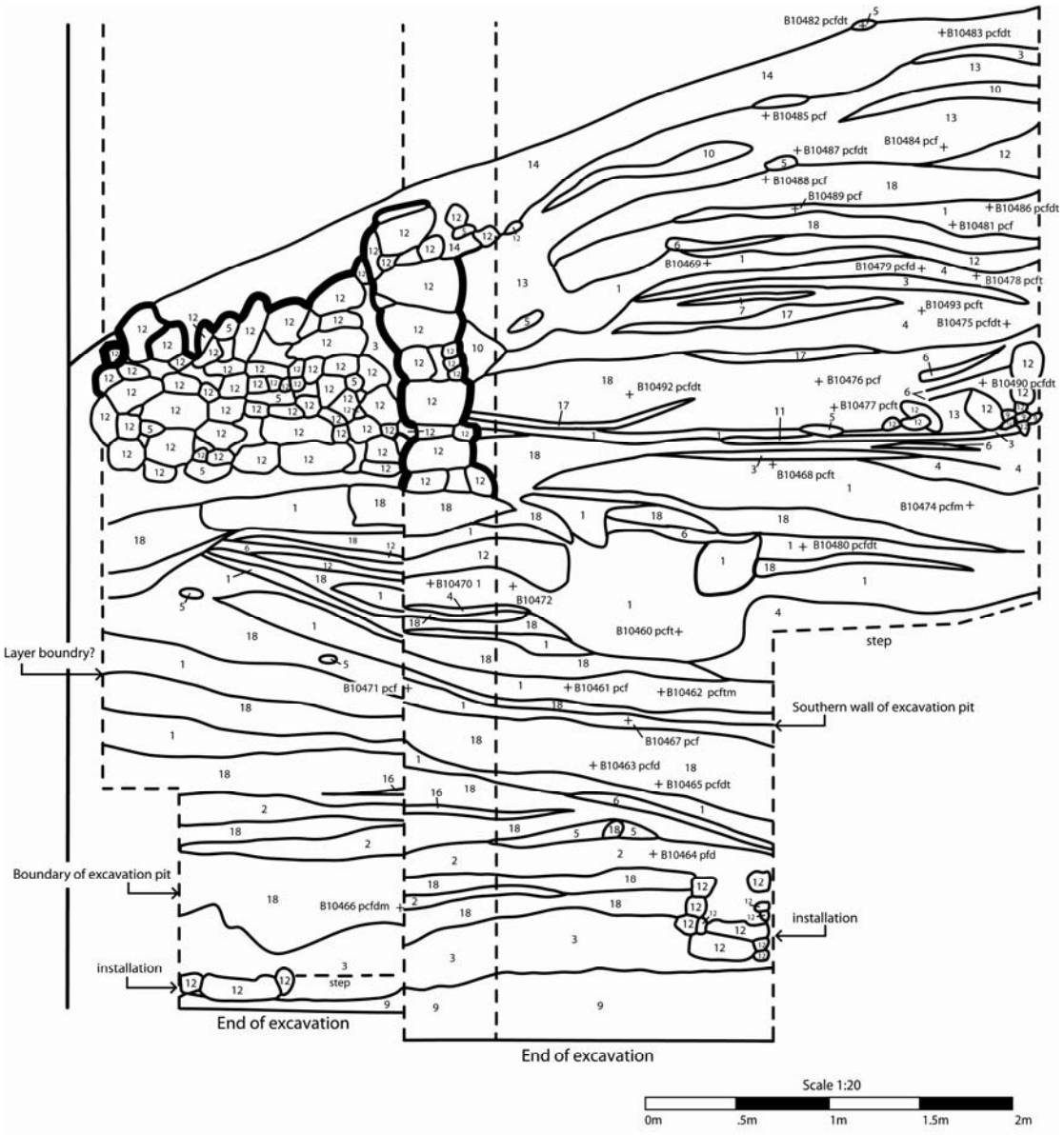


Fig.8.6: Khirbat en-Nahas, Area M, East Section: location of samples that were subjected to analytic analyses as part of the current research. c = control sample available; d = XRD; f = XRF; m = archaeomagnetic; P = pulverized sample available; T = thin section / petrography (see text).

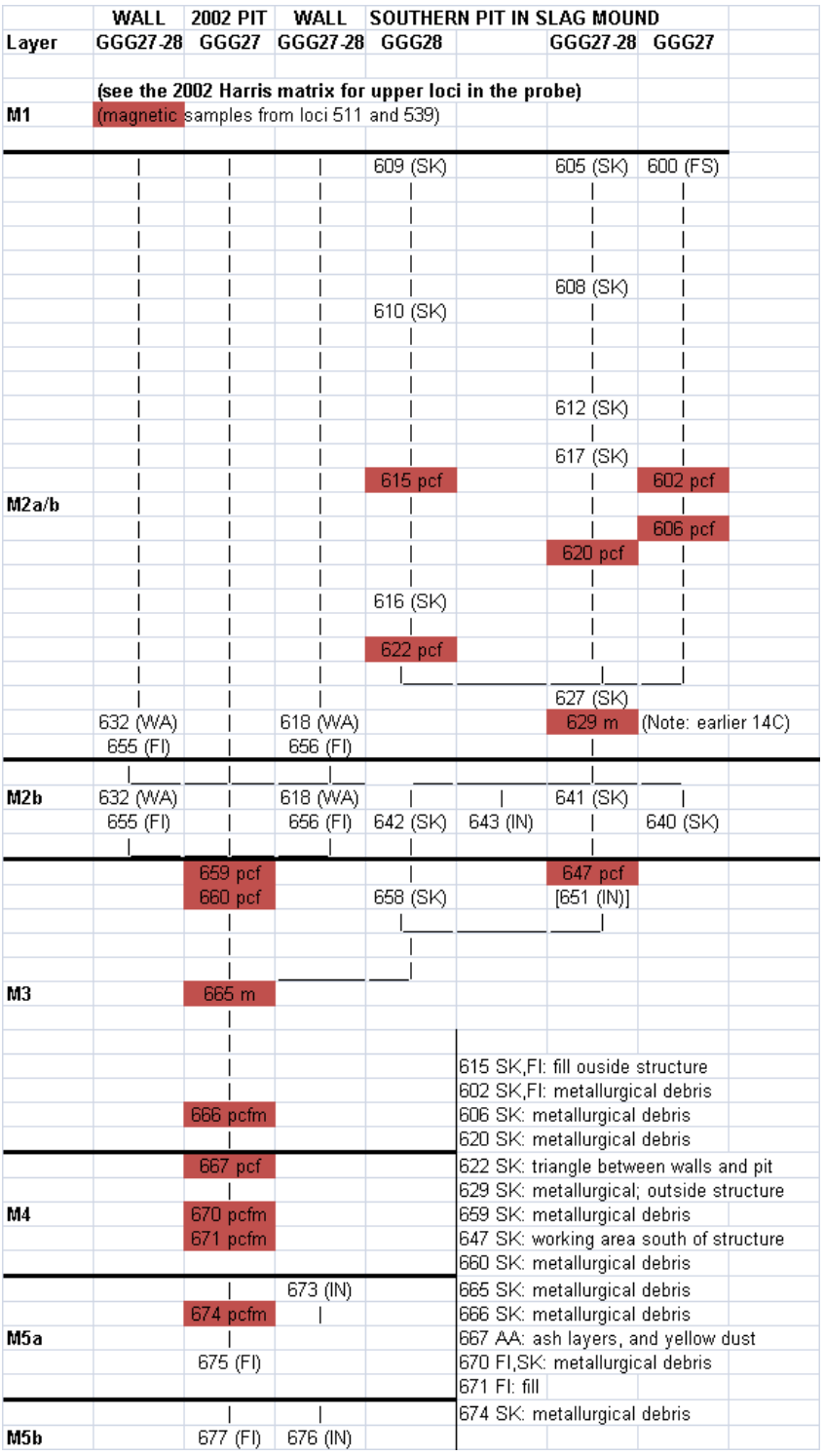


Fig.8.7: Khirbat en-Nahas, Area M, Harris Matrix of locus distribution. Location of samples that were subjected to analytic analyses as part of the current research is indicated in red.. c = control sample available; d = XRD; f = XRF; m = archaeomagnetic; P = pulverized sample available; T = thin section / petrography (see text).

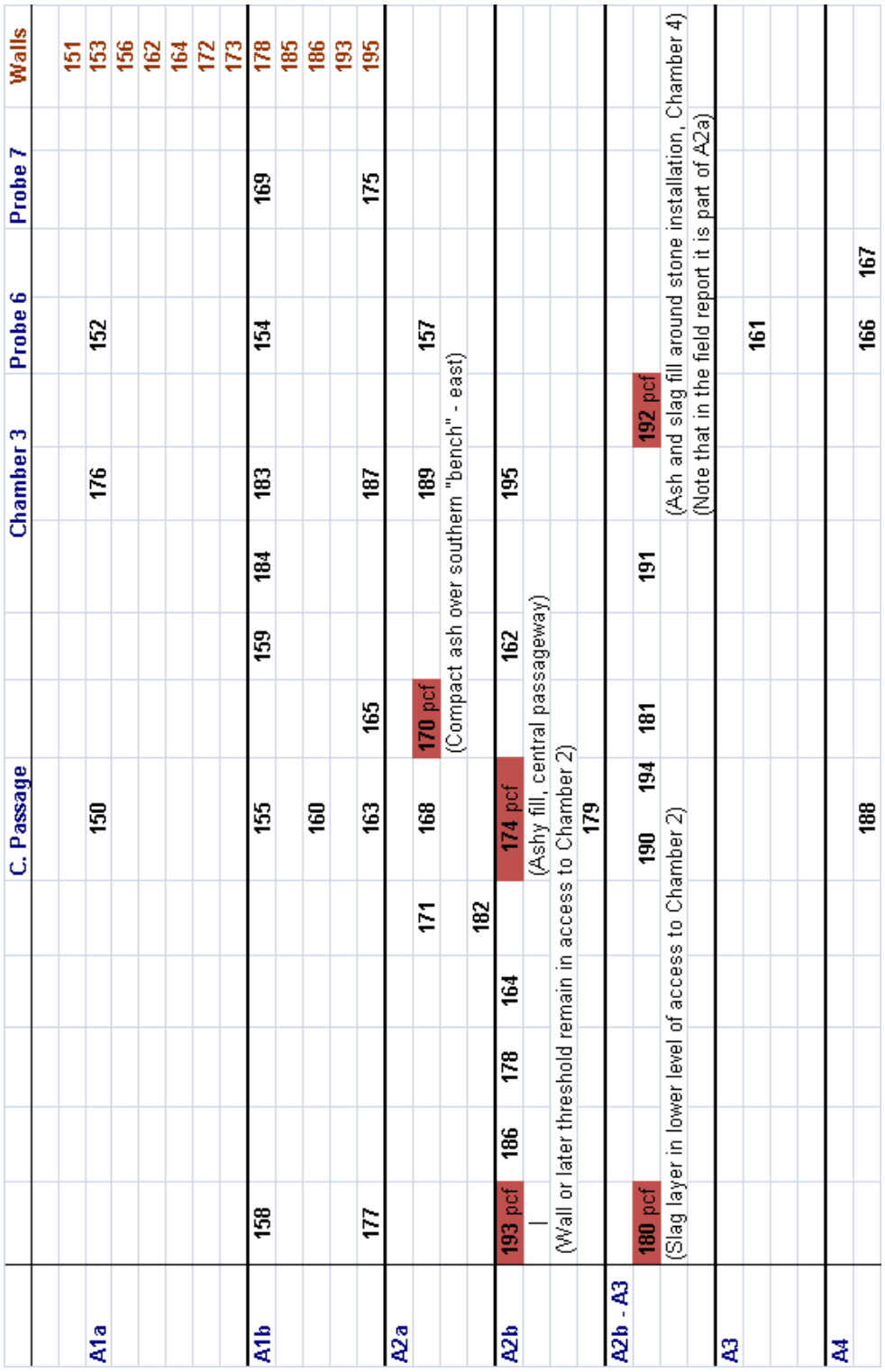


Fig.8.8: Khirbat en-Nahas, Area A, Harris Matrix of locus distribution. Location of samples that were subjected to analytic analyses as part of the current research is indicated in red; relevant description of the loci is also provided. c = control sample available; d = XRD; f = XRF; m = archaeomagnetic; P = pulverized sample available; T = thin section / petrography (see text).

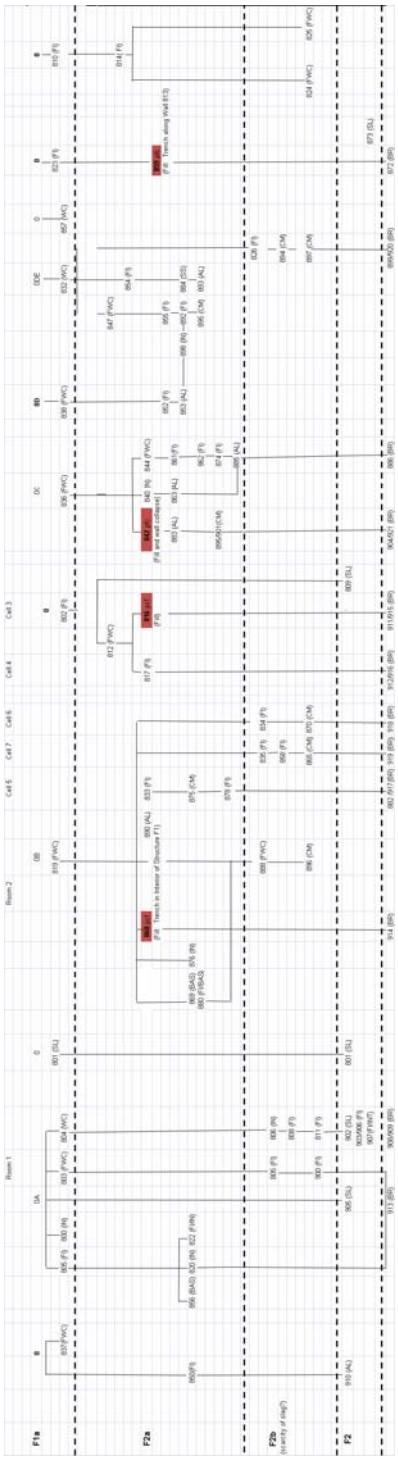


Fig.8.9: Khirbat en-Nahas, Area F, Harris Matrix of locus distribution. Location of samples that were subjected to analytic analyses as part of the current research is indicated in red; relevant description of the loci is also provided. c = control sample available; d = XRD; f = XRF; m = archaeomagnetic; P = pulverized sample available; T = thin section / petrography (see text).

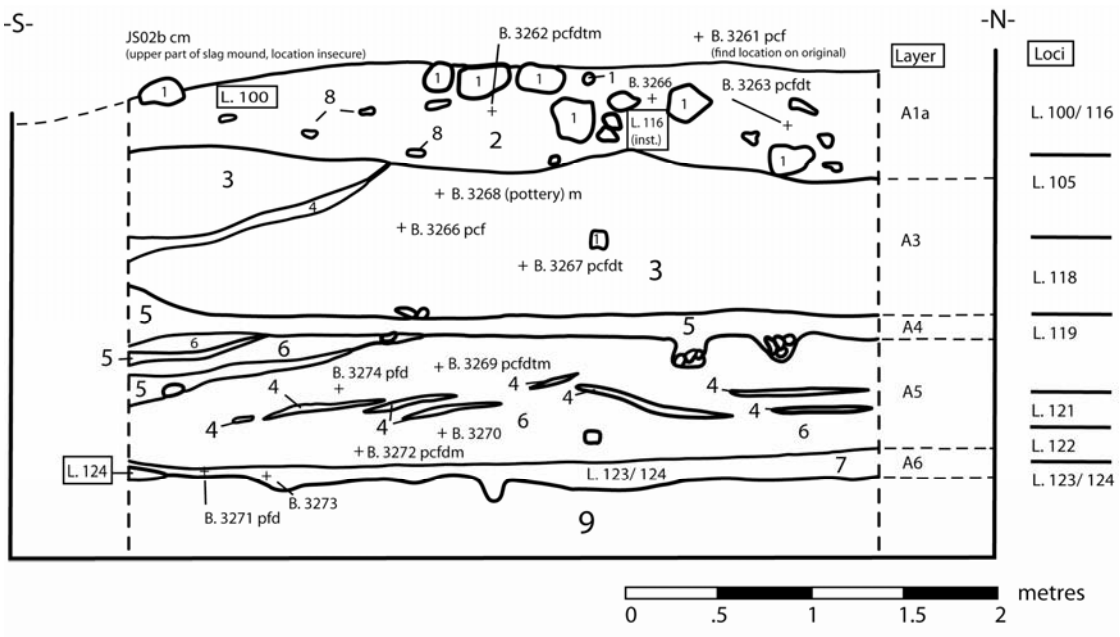


Fig.8.10: Khirbat al-Jariya, Area A, West Section: location of samples that were subjected to analytic analyses as part of the current research. c = control sample available; d = XRD; f = XRF; m = archaeomagnetic; P = pulverized sample available; T = thin section / petrography (see text).

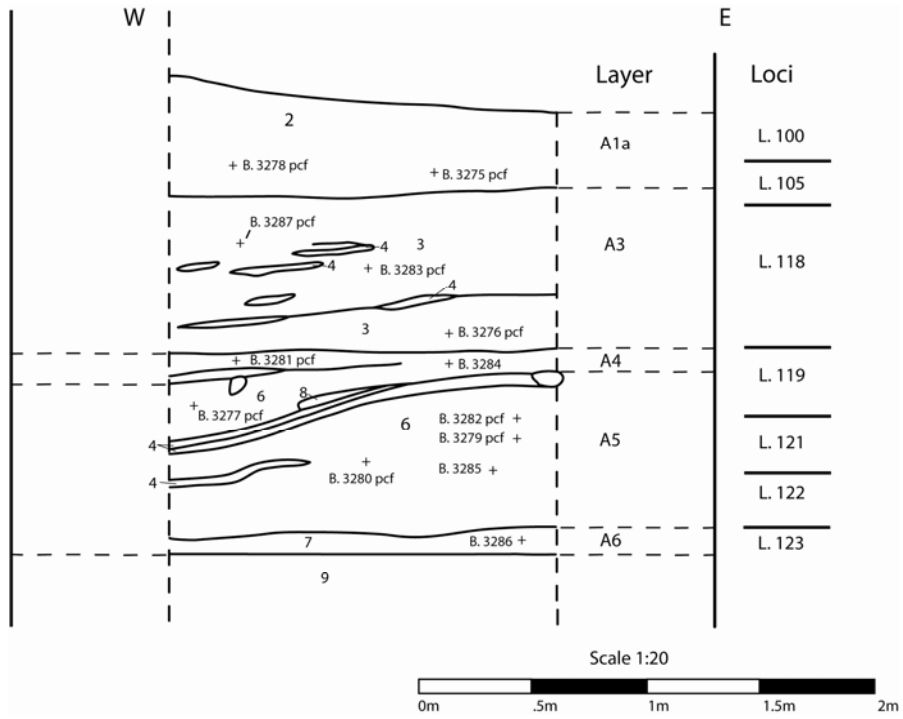


Fig.8.11: Khirbat al-Jariya, Area A, North Section: location of samples that were subjected to analytic analyses as part of the current research. c = control sample available; d = XRD; f = XRF; m = archaeomagnetic; P = pulverized sample available; T = thin section / petrography (see text).

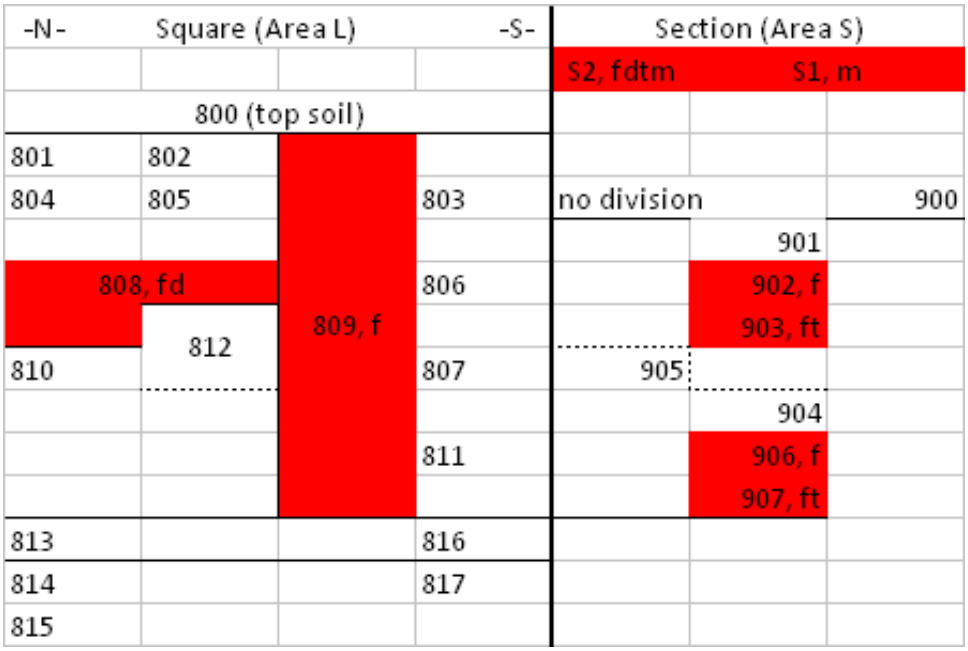


Fig.8.12: Timna Site 30, Harris Matrix of Areas L and S (for correlation see discussion in section 6.2.1.3): location of samples that were subjected to analytic analyses as part of the current research is indicated in red. c = control sample available; d = XRD; f = XRF; m = archaeomagnetic; P = pulverized sample available; T = thin section / petrography (see text).



Fig.8.13: Crushing slag in the petrographic laboratory at Scripps Institution of Oceanography, UCSD (summer of 2009). A) starting with hand crushing (hammer); B) further crushing into small chunks with the splitter machine; C) final crushing into fine grained powder with the rock grinding machine (the container is the metallic cylindrical device on the table in A).



Fig.8.14: Preparing samples for XRF and XRD analyses. The original slag samples are represented by powder ('p', in the zip-lock bags) and control ('c', also in zip-lock bags), or only by one of those; the sample holder in the inset is pulverized slag prepared to be analyzed with XRF.

8.5 Analytic procedures and results

8.5.1 *XRF and XRD analyses*

We used several technical settings of the Bruker TRACeR instrument for different types of measurements. In the field, when only rapid examination of bulk compositions was desired (i.e., a quick check of the list of elements present in the material and some qualitative estimations), we usually used the 'lab rat' mode (40Kv, 5μA, no vacuum for 300 seconds) on all types of artifacts (Fig.8.15). When analyzing slag material we used two different settings, one for measuring the light elements, from Fe and below (15Kv, 15μA, vacuum, blue filter, 300 / 500 seconds), and one for measuring the heavier elements, from Cu and above (40Kv, 15μA, no vacuum, green filter, 300 / 500 seconds). Examples of the standard plots of XRF reading for one slag sample from Khirbat al-Jariya is presented in Figs.8.16 and 8.16. The plotted information (X-rays counts / energy levels) is contained in our system as a *PDZ* file that can be manipulated for calculating peaks areas (for qualitative analyses) and absolute quantities of elements if calibration for the specific material is available (see below). The *PDZ* file name contains the settings information together with all principle other parameters of the sample, for example, the file names of two different measurements of the sample presented in Figs.8.17 and 8.18 below are:

KAJ_A_W_3271_slag_P_15_15_blue_v_300_light powder.pdz

KAJ_A_W_3271_slag_P_40_15_green_nv_300_light powder.pdz

Standing for: KAJ = Khirbat al-Jariya, W = West Section, 3271 = sample number (EDM, Locus or Basket, this is the most important parameter for sample identification), slag = material type, P (/C) = powder (/control, not pulverized), voltage (15 or 40 KeV in this example), current (15 and 15μA in this example), blue/green = filter type, v/nv = vacuum / no vacuum, 300 = measurement length (in seconds), light powder = short description of the sample.

During the ELRAP's 2009 field season at Khirbat en-Nahas, our team integrated data from routine XRF measurements with the master GIS-based database of the excavation. The XRF reading of each artifact (a *PDZ* file) is linked to its EDM number (see above, section 5.2.1), and by it to its spatial coordinates, context (locus, basket), digital photography and other information included in the relevant *Access* database. This structure facilitated further research of the artifact after the end of the field season and in turn also the study of the context (one can easily access and analyze the entire artifact information by spatial categories of locus, stratum, area, etc.).

More than 600 artifacts were measured with the XRF instrument, including many that could not be shipped out of the country (Fig.8.15) (and see also in Levy et al., in press-c). From the archaeometallurgical perspective, these measurements helped to confirm the absence of bronze artifacts and provide some basic information on 'metal chunks' discussed below (and in section 7.2.7 above), to securely identify iron

objects (arrow heads, handle of a sword embedded in copper sheath etc.) and to correlate between groundstones and copper production (crushing/grinding of ore) activities. These preliminary results will be discussed elsewhere, and the data (*PDZ* files and plots) are intended to be made available in the near future as part of the online database of ELRAP (http://daahl.ucsd.edu/DAAHL).

The Bruker TRACeR instrument came only with calibration data for metals. To gain quantitative results of slag analysis we calibrated the instrument with 10 samples of slag that had known values, kindly provided by A. Hauptmann of the GMM. All of the samples were Mn-rich slag, and although Fe-rich slag has quite similar matrix, our few iron-rich samples from Timna 30 were a bit out of calibration range, thus we have to treat those numbers with caution (indicated in Table 8.7 in red). In addition to calibrating the instrument, we measured various samples in different ways to estimate the accuracy and precision of the analyses, and the general quality of slag material. Table 8.6A presents results of heating experiments on two samples of slag. In some previous archaeometallurgical researches slag samples were heated in an oven, supposedly to avoid possible impact of moisture on the XRF analyses (e.g., Veldhuijzen, 2005). Here we found that heating the samples (50°C for 12 hours) results in a significant change in XRF readings that is probably related to changes in the chemistry of the slag (most notably concentrations of Pb) rather than the absence of moisture. We did not include heating in our standard procedure of treating samples.

Tables 8.6B and 8.6C demonstrate the extreme heterogeneity of slag and the consequential necessity of analyzing pulverized samples for estimations of bulk chemical compositions. The average standard deviation (%) of repeated measurements on an original, intact sample of slag is about 37.5% while the average of repeated measurements on pulverized sample is about 5% (for averages per element consult tables). The estimation of precision of XRF analyses performed on pulverized samples and presented in Tables 8.6B-8.6C is based on substantial number of measurements (13 samples with 2-5 measurements each), and is the basis for estimating the measurements' error ranges of the calibrated data which are based only on one XRF measurement per sample (Table 8.6). In some cases the original samples were too small to be pulverized and the XRF measurements have been performed only on the control (original) sample. Such is the case for slag from Site F2 at Timna (section 6.2.3) and some samples from Site Timna 30. The uncalibrated results of their measurements are presented in Tables 8.6B and 8.6C as a general reference. The large number of measurements enables identification of some statistical pattern even on uncalibrated unpulverized ("control") samples. For example, the average standard deviation (%) of slag samples from Site F2 (only "controls" = ±32.5%) is significantly larger than the average standard deviation (%) of slag samples from Khirbat en Nahas (only "controls" = ±22%), suggesting that slags from Site F2 are more heterogeneous in composition.

The main chemical elements of 96 pulverized slag samples were analyzed with the Bruker TRACeR instrument for 300 seconds for each one of the two settings described above. The calibrated (w.-%) values are presented in Table 8.7. The main mineralogical phases of 31 pulverized samples were analyzed with the XRD machine at the German Mining Museum. Example plots of both XRF and XRD analyses, together with their interpretations, are presented in Figs.8.17-8.20; the results of the XRD analyses are incorporated in Table 8.8. All of the original XRF and XRD plots, together with the *PDZ* original files of the XRF analyses, will be available through the ELRAP's online database (check for updates at: http://www.anthro.ucsd.edu/~tlevy/Archaeology_in_the_Levant/Home.html).

The large sample number (n=96) of slag samples subjected to XRF measurements in the current research enables recognizing statistically valid patterns related to the Iron Age smelting technology as a whole, and *through time*, based on the exact stratigraphic context of the samples as presented in Figs.8.5-8.12 and detailed in Chapters 5 and 6. Some of the patterns indicated by the current data are tentative, and should be substantialized with further measurements. The charts figures (located after the tables below) emphasize some of the chemical characteristics of Iron Age slag based on the data in Table 8.7.

The ternary diagram of the system $CaO – SiO_2 (+Al_2O_3) – FeO(+MnO)$ (Fig.8.21) presents as a whole higher silica values than the 'typical' range identified

by Hauptmann (2007:Fig.6.18) for the Iron Age, although this may be the result of having alumina added to the silica in this diagram. There is also a trend of less calcium in slag from the most advanced technology of Iron Age copper production period (cf. M1, L-1 and their contexts, Figs.8.5, 8.6 and 8.12 vs. all other contexts, except KEN-F that also presents constantly low values of calcium).

One of the best indicators of efficiency in copper smelting technologies is the content of copper in slag. The more efficient the technology, the more copper will be extracted from the ore in a single smelting cycle. This is most evident in the general development of the smelting technologies since the Chalcolithic (Table 8.2), with a substantial change in copper content of slag occurring between the Early Bronze (3rd millennia BCE) and the Late Bronze – Iron Ages. The change in technologies and its implications on copper contents in slag throughout major archaeological periods has been identified and discussed by many scholars (e.g., Conrad and Rothenberg, 1980; Rothenberg, 1990e; Hauptmann, 2007). Here we were able to recognize and contextualize improvement in technology within the Iron Age; the correlation between Cu contents in slag and stratigraphic contexts is striking. This trend is most evident in the deep sounding excavated in the 'slag mound' of Khirbat en-Nahas, Area M (Fig.8.22 and Figs.8.5-8.7 for locations, section 5.2.4.2 for details and dates). The average copper content in slag decreases *monotonically* according to stratigraphy, where the oldest Layers (M5-M4) present the highest concentration (average= 1.49±0.5 wt.-%), and the youngest Layer (M1) presents the lowest concentration

(average= 0.47±0.2 wt.-%). There is also a correlation between stratigraphy and the tightness of distribution of Cu contents, represented by the standard deviations of the measurements, presenting a better control on the smelting technology through time. This is definitely the case in the transition between the technologies represented by M4-5, M3 and M2 (standard deviations 0.5, 0.6 and 0.4 respectively) and the concentrations of slag in Layer M1 (standard deviation 0.2). The only other contexts that are similar to Layer M1 in Cu concentrations and tightness of distribution are Timna 30, Layer 1 (0.40±1.5 wt.-%, Fig.8.24), and, surprisingly, Khirbat en-Nahas, Area F, Layer F2 (0.38±0.1 wt.-% [n=5], main activity phase in the refining/casting workshop, see section 5.2.4.1). The correlation between KEN M-1 and T30 L-1 represents a similar technological change that took place in Timna and Faynan simultaneously, approximately at the end of the 10th or beginning of the 9th century BCE (see further discussions below). This change is supported by many other characteristics of the archaeometallurgical remains (Chapter 7). On the other hand, the current date we have for KEN-F2 (section 5.2.4.1 above) corresponds to the earlier technologies, before the major technological change occurred. Thus, the slag from this context may represent a different activity, i.e., not smelting but refining of the original product (although no distinct visual difference was indicated). There was no evidence in Area F for the advanced technology of the 9th century, and the metallurgical installations were significantly different from the ones in the smelting areas. The possibility that these slags represent waste discarded in Area F after the 10th century

workshop ceased to operate is still open and investigation of these slags (exact context, descriptions etc.) and other features in Area F is needed.

The low contents of Cu in slag from Timna 30 Layer I and Khirbat en-Nahas M1 may explain the characteristic of their depositional process. Only in these two Iron Age sites the surface is scattered with distinct large slabs of tap slag (most of the surface in KEN, and only a small portion in Timna 30). These slabs, which can measure over 60 cm in length, are present only in a rather thin layer on the site surface and represent the last phase of metal production before these sites were abandoned. They are larger than any of the other excavated slag samples and they were not deliberately broken or crushed. The low Cu contents in these slags explain why they were not part of the crushing process (note that most of these represent the tapped slag and the furnace slag may have been further processed and crushed).

At Khirbat al-Jariya, slag of the lowest Cu concentrations are entirely absent, in accordance with the earlier dating of this site (section 5.2.5.4). Nevertheless, stratigraphic differences were observed (Fig.8.23), representing a gradual improvement in smelting technologies. The lowest Layers (A5-6) represent the highest Cu concentration in the entire investigated contexts in the current research (average 1.83±1.1 wt.-%), in agreement with radiocarbon ages from the earliest part of the Iron Age. The above Layers A3-4 and A1 demonstrate a decrease in Cu contents and

tightening of the distribution of concentrations (average 1.58±0.9 wt.-% and 0.91±0.5 wt.-% respectively).

When copper content averages in slag samples are plotted by context (Site/Area/Layer, Fig. 8.25), distinct clusters can be distinguished. The large sample number enables further, statistical conclusions: (1) the low Cu-content group discussed above (T30-L1, KEN-M1, KEN-F2) are not only tight at the context level, but also in the inter-context level (average of all samples from low Cu-content contexts is 0.42±0.18 wt.-%); this means that in addition to having more control over smelting processes in the level of each individual workshop, there was a standard, and well established technology across sites (especially regarding T30-L1 and KEN-M1). (2) KEN-M2-3, KEN-A2-3 and KAJ-A1, represent a cluster, with average contents of Cu in slag of 0.97±0.66 wt.-%; also here there is an excellent agreement with stratigraphic location and date, as all of these contexts represent (early?) a10th century smelting operation (Table 5.3). (3) KAJ-A3-4, KAJ-A5-6, T30-L2 and KEN M4-5 represent a cluster of the highest copper containing slag, and the highest distribution (1.62±0.83 wt.-%); these are all from the deepest excavated layers, at these sites and date mostly to the Iron Age I (1200-1000 BCE).

A similar trend can be detected in concentrations of other components, although here mostly as the tightening of their distribution range from old to young strata (while the average concentrations stay more or less the same, or not present a

distinct change). This indicates the improvement in control over the smelting process through time. For example, averages of CaO concentrations at KEN Area M do not present a distinct pattern of change (Fig.8.27), however, the standard deviations by Layer do get smaller as the Layer is younger (all values are in wt.-%: M4-5 = 7.02±3.61, M3 = 6.47±3.01, M2 = 8.93±1.98, M1 = 7.37±1.71). However, the situation with CaO concentration in Khirbat al-Jariya is less clear (all values are in wt.-%: A5-6 = 9.65±2.78 [n=8], A3-4 = 8.39±4.15 [n=6], A1 = 8.95±1.5 [n= 5]). There is slight variation in averages of CaO contents between sites (Fig.8.26) that may derive from changes in the local clay sources, but this is not a significant enough difference to draw any firm conclusions.

Figs.28-29 present concentrations of alumina and potassium in slag samples according to their stratigraphic location in Khirbat en-Nahas and Khirbat al-Jariya (respectively). Especially in the alumina concentrations there is a distinct trend of tightening through time, in both sites (all values are in wt.-%: KEN M4-5 = 4.63±0.46, M3 = 4.45±40, M2 = 4.41±0.22, M1=4.34±0.32; KAJ A5-6 = 4.62±0.58, KAJ A3-4 = 4.67±0.46, KAJ A1 = 4.87±0.24).

In general the proportions of MnO / FeO in slag from Faynan are more or less even distributed across contexts (Figs.8.31 and 8.34) with no distinct patterns, except maybe KEN M1 and T30-L1 located in the upper part of MnO concentrations (Fig.8.31). A well known difference between Faynan and Timna is demonstrated in

Figs.8.32 and 8.33, where Layer 1 in Timna 30 has high concentrations of iron oxides and low concentrations of manganese oxides, just the reverse of the common slag concentration in Faynan, in all sites from the Early Bronze Age and later (when MBS was the only source of mining in early periods, i.e., Chalcolithic, the slag was Fe-rich also in Faynan). In fact, the exception in Site Timna 30 is Layer 1, which is the only context in the entire southern Arabah were Iron Age Mn-rich slag are present. This will be discussed extensively with regard to Chaînes opératoires (Chapter 9).

In addition to slag material we present here preliminary results of XRF analysis of one metal chunk (Fig.8.34), representing the general composition of many other similar artifacts that were measured during the ELRAP's 2009 field season. This kind of artifact (section 7.2.7) came from clear contexts of smelting activities at Khirbat en-Nahas; it is much more abundant in the later (9th century BCE) contexts (Area M layer M1, and Area R – 'the metallurgical complex' [see discussion on this area in section 5.2.4.1 above]). The preliminary, qualitative results, although measured on the outer portion of the chunks (and not on sections or cleaned areas), were able to clearly demonstrate the presence of a large quantity (up to 70%) of iron in this type of material. The presence of iron-copper mixture in smelting contexts suggests that these are representative raw smelting products, especially associated with the advanced smelting technologies. These impure metals were further refined to pure copper in special workshops at the site (e.g., Area F). Our preliminary interpretation is based, in addition to the context of the finds, on Merkel's (1990) experiments concerning Late

Bronze (/ Iron Age) copper smelting technologies at Timna (and especially the ones represented by the archaeometallurgical remains of Timna Site 30). A frequent result in his experiments was impure, iron-rich copper (Merkel, 1990). This problem of undesired metal as the raw smelting product appeared in the southern Levant mainly with the introduction of mass production (and controllable) technologies during the late 2nd millennium BCE (there are some indications of earlier cases, see Strathmore and Cooke, 1975), and is probably a consequence of the very high temperatures achieved during the smelting process. If such iron-copper mixtures were indeed the raw products of the first smelting cycle, they had to go through further processing to achieve pure, commercially viable copper. The consequential engagement with metallic iron during the primary smelting and especially during the refining process was the background to the suggestion of Gale et al. (1990) that the metallurgy of iron has its origin in copper smelting processes, exactly in this time when advanced copper smelting started to be widely practiced. Nevertheless, this model was criticized by Merkel and Barrett (2000) based on metallographic evidence, and this question is still open.

There is another way to explain the presence of copper-iron mixtures associated with smelting activities. Rather than representing evidence of the raw smelting product, these may be the result of a *failed* smelting cycle. This may explain their relative abundance in the archaeological record, as they may have been discarded instead of further processed to pure copper metal. The extraction of copper from

copper-iron mixture with 'further processing' is not well studied and seems to be a very difficult task (e.g., Strathmore and Cooke, 1975). In the current stage of research we prefer the first interpretation mostly because it seems unlikely that so many failed cycles were part of the most advanced technology of the Iron Age in the Arabah Valley. As demonstrated in this chapter, this advanced technology presents a high level of ability to tightly control the entire aspects of smelting conditions. The discovery of the (until now) unique workshop at Khirbat en-Nahas, Area F, further supports a sophisticated refining and casting activities, as regular part of Iron Age smelting technologies (both the earlier and later ones; the workshop is dated to the 10th century).

Iron is found also in Iron Age copper and bronze artifacts (Strathmore and Cooke, 1975; Craddock and Meeks, 1987). This phenomenon might be explained in light of the data from the raw smelting processes presented here, as the result of reduction of iron in the advanced smelting technologies of the late 2nd – beginning of the first millennia BCE. This is in accordance with Strathmore and Cooke's (ibid.251) proposal that "the iron was introduced as a result of simultaneous reduction of iron oxides in the furnace burden to solid metallic iron during the copper smelting operation." This also supports their assessment that "this phenomenon [iron in copper and bronze objects] may have been more widespread than is realized."(ibid.). Similar conclusions were presented by Craddock and Meeks (1987:202): "…thus, the rise of copper content of the resulting copper [from the smelting process] in any area may be

taken as indicative of the adoption of the more sophisticated process". Our new research from Iron Age KEN provides additional evidence rooted in the technological remains of the smelting sites themselves.

The XRD data (Table 8.8) complement the microscopic observations on thin sections of slag presented below; the slag has typical mineralogical phases of Mn-rich (tephroite) slag in Iron Age Faynan (except one from Layer 2 in Timna 30 which is fayalitic slag); for further details on the basic mineralogy of such slag see Hauptmann (2007). The importance of using changes in smelting technology measured here as a proxy for socio-economic change in Iron Age Edom is discussed in the final chapter of this thesis.

8.5.2 *Microscopic and magnetic analyses*

Preliminary petrographic analyses of Iron Age slag thin sections were conducted in the German Mining Museum by the present author with the kind guidance of A. Hauptmann (see Table 8.8 for full sample list and contexts). Selected thin sections are presented here as scans (regular digital scanning, Fig.8.36) and as photographs as seen through a light microscope (Figs.8.37-8.41). A few representative scanning electron microscope images are presented in Figs.8.42-8.43. These images were taken at the Unit for Nanoscopic characterization, the Hebrew University of Jerusalem by R. Shaar as part of our investigation of magnetic characteristics of slag

material (see Shaar et al., 2010), and they demonstrate the utility of using SEM for identifying crypto-crystalline and hyalo-crystalline phases in slag (in this case we were aiming for identifying the magnetic carrier phases). Representative archaeomagnetic results of Iron Age slag are presented in Fig.8.44. For details and interpretation of each figure, see captions. Here we emphasize some of the *copper technology-related* finds gleaned from the microscopic and magnetic analyses presented here.

Out of the total sample, a few thin sections have clear indications of re-(s)melted slag. Fine fragments of slag inclusions are part of the general matrix of slag S2-S2 from Timna 30 Layer I (Fig.8.36D) and of slag 3263 from KAJ Layer A1. This observation probably indicates the deliberate addition of crushed slag as part of the smelting charge. This helps the mixture to reach the eutectic composition and thus facilitates the smelting process. A few cases of ethnographic evidence for the use of crushed slag as part of the smelting mixture exist, those are discussed in section 9.1.3 below.

Mn-rich slag sample from Timna 30 Layer I has an inclusion of a sandstone fragment (Fig.8.36D). This may be evidence for the use of ore from the sandstone formations and not from the dolomite-shale copper bearing units of the Timna formation. If this is indeed the case, the Mn-rich slag of Site 30 Layer 1 indicates a deliberate use of flux, as the sandstone ores do not contain manganese. Further support for deliberate use of manganese ore as flux was found in the excavations of the Arabah

Expedition (storage pits with manganese ore, interpreted as flux prepared for smelting)(Rothenberg, 1980a). The issue of deliberate fluxing and the sophisticated technology of Timna 30 Layer I are further discussed in sections 7.2.1 and 9.1.1.

Another interesting, although limited, evidence of technological practice is the slag sample 3269 from Khirbat al-Jariya Layer A5 (Figs.8.36A, 8.39 and 8.40A-C). This distinct type of slag is rich in copper prills that were oxidized into cuprite during the smelting process. Hauptmann's (2007:171-174) intensive analyses on slag material from Faynan suggest that the crystallization of Cu oxides in slag is particularly typical of the early stages of extractive metallurgy, especially from the Early Bronze Age I (Wadi Fidan 4) and the Early Bronze in general. Similar slag was described from the site of Wadi Fidan 4 (Hauptmann, 2007:171), and other Early Bronze Age sites in Faynan. The evidence of such slag in KAJ may stand for a secondary smelting of Early Bronze Age slag during the Iron Age. Similar practice was described for the Iron Age smelting site of Ras al-Naqb (Table 5.1) where a nearby scatter of Early Bronze Age II-III slag was re-used in the Iron Age for further extracting copper from the Cu-rich slag (Hauptmann, 2007:123-126). If the evidence from Khirbat al-Jariya does represent typical Early Bronze Age slag in an Iron Age context, it means that the reddish slag brought to the site from a considerable distance (the closest remains of Early Bronze Age smelting is probably located ca.5 km to the south, but cf. Table 5.14 FBRS Site 23). This indicates the exhaustive exploitation of any copper source available, and the special care for recycling that is very common in ancient

technologies, with supportive evidence in ethnographic research (e.g., Levy et al., 2008b). However, in the current stage of research we cannot exclude the possibility that this type of slag was a (by-) product of Iron Age smelting technologies as well.

Magnetic investigations of slag material from the Arabah are another avenue to establish slag typologies (Figs.8.42-8.44) that can inform us about different technologies and/or source materials used in the smelting process. As part of our study of magnetic properties of slag (e.g., Ben-Yosef et al., 2008a; Shaar et al., in press) it became apparent that slag from the Arabah can be divided into three distinct groups based on their behavior in archaeomagnetic experiments (Fig.8.44). The basic difference is the *blocking temperature* indicated for the magnetic carriers in slag (the blocking temperature has impact on several other magnetic qualities of the sample, and can be identified in several experimental procedures, see Fig.8.44 and Tauxe, 2010 for further details). In general, there is a group of low blocking temperatures (300°C-350°C), high blocking temperatures (450°C-550°C) and samples that fall somewhere in between. The low blocking temperature slag corresponds to the Mn-rich slag from Timna 30 Layer I and most of the Iron Age slag from Faynan, while the high blocking temperature slag corresponds to Fe-rich slag from Iron / Late Bronze Age in Timna (Fig.8.44). SEM investigation of the slag textures (Figs.8.42-8.43) has demonstrated that the magnetic carrier of the low blocking temperature slag is mostly jacobsite, and that the magnetic carrier of the high blocking temperature slag is mostly

magnetite (further magnetic characterization of slag and discussion can be found in Shaar et al., 2010).

8.6 Summary of analytical results cal results – An integrated approach to archaeometallurgical research in the southern Levant

As part of the current research we conducted the following analyses on Iron Age slag material from Faynan and Timna: XRF, XRD, petrography (optical microscopy), SEM and magnetic characterizations. In addition, several metallic 'chunks' from Khirbat en-Nahas were analyzed preliminary by XRF (for context and other macro-characteristics of these materials [slag and metal chunks] see Chapter 7 above). All of the slag samples from Faynan are Mn-rich and a few from Timna are Fe-rich. It is important to note that Mn-rich slag in ancient copper (and other metals) production sites is rare, and the most common slag is Fe-rich (see discussion in Hauptmann, 2007:180-199); thus Faynan represents an exceptional case in the study of ancient slag.

The following summarizes the most important technological insights derived from our analytic results (above). Some of these confirm previous observations regarding Iron Age copper smelting technologies in the Arabah, and many are new:

(1) As far as can be deduced from the chemical composition of slag, Timna and Faynan present the same smelting technologies and the same technological

development throughout the Iron Age sequence. One notable exception is the use of iron ore or iron-rich copper ore as the main source of fluxing in the early Iron Age Timna (12^{th}-10^{th} centuries BCE) in contrast to Mn ore or Mn-rich copper ore in Faynan; this difference, however, does not stand as evidence for different smelting technologies per se.

(2) The slag from Timna Site 30 Layer 1 is an exception in the entire Iron Age (and Late Bronze Age) copper smelting sites in the southern Arabah. It is the only context with typical large slabs of Mn-rich tap slag. They are deposited on top of earlier production debris, which are composed of relatively small fragments of Fe-rich slag (and represent the typical Iron Age / Late Bronze Age production debris in the southern Arabah).

(3) There is a distinct pattern of gradual improvement throughout the early Iron Age (12^{th} – 10^{th} centuries BCE) and an abrupt technological improvement in the late 10^{th} / early 9^{th} century BCE (further discussion and a tentative proposal of a narrower date appears in section 9.1). These are indicated by several factors (a) the contents of copper in slag, which demonstrate a striking correlation to stratigraphic context. The average copper contents decreases gradually with time in the early Iron Age, and sharply declines in the transition mentioned above (to very low values, averaging around 0.4 wt.-%). (lower contents of copper in slag indicates increase in efficiency of each smelting cycles); (b) there is a tightness in the distribution of copper contents in slag (standard deviation). Although this factor also becomes tighter with

time throughout the Iron Age, the most notable change is between the early Iron Age (12^{th} – 10^{th} centuries BCE) and the abrupt technological improvement in the late 10^{th} / early 9^{th} century. The copper contents not only become much tighter in a site level (KEN M1 and T30-L1), but also present inter-site tight values, indicating a well established and highly standardized technological practice; (c) tighter distribution with time throughout the Iron Age of other components, such as calcium oxides and alumina, indicating better control over the smelting process.

(4) Part of the smelting procedure included using crushed slag in the smelting charge. Slag was crushed not only for extracting copper prills but also as a (major?) resource for facilitating the smelting. This is indicated by inclusions of small slag fragments in the matrix of slag in thin sections.

(5) There is a limited indication for possible re-(s)melting of Cu-rich Early Bronze Age slag as part of the Iron Age smelting procedures. This is indicated by a Cu-rich slag from Khirbat al-Jariya, which is typical Early Bronze Age slag (see discussion above). If true, this may indicate an exhaustive use of all available resources during the Iron Age, the practice of recycling (in this case of ancient slag), and an advanced knowledge on slag qualities; it will further support the recycling of Early Bronze Age slag reported from the Iron Age site of Ras en-Naqb in Faynan (Hauptmann, 2007).

(6) There is a limited indication that the ore used for smelting in Timna Site 30 Layer 1 came from the sandstone formations (Amir/Evrona). This is indicated

by a sandstone fragment in slag thin section. If true, this observation indicates a *deliberate* use of manganese ore as flux in the (most advanced) Iron Age technology represented by this context. For further discussion on the question of deliberate fluxing in the Iron Age see section 9.1.1.

(7) The extensive XRF analyses of slag from Site F2 in Timna performed in the current research support the simplicity of technological practice at this site (suggested by others, see section 6.2.3 above). This is indicated by the wide distribution of results in a sample level (only not-pulverized samples were analyzed), which is significantly wider than the average distribution of compositions in Iron Age (complete) slag samples from Khirbat en-Nahas.

(8) The content of many metal 'chunks' found in smelting contexts is shown here to be a mixture of iron and copper, with up to 70% iron in some cases. These are only preliminary results, as the analyses have been preformed in the field laboratory and only on the exterior of the metal chunks (without slicing / cleaning them). However, it seems that this was the typical raw product of the primary smelting cycle, most likely associated only with the most advanced technology (late 10^{th} / 9^{th} centuries), and that it had to be further refined in a special workshop for producing final products of pure copper ingots. Another possibility is that these chunks represent failed smelting cycles (see discussion and references above).

(9) We have demonstrated the applicability of some archaeomagnetic techniques to distinguish between the two common slag types of the Arabah (Fe- and Mn-rich slag).

The extensive dataset presented here is open to further manipulations and interpretations. Careful investigations of the analytic results in light of their specific and well defined contexts (provided in section 8.3 and Chapters 5 and 6 above) may uncover further technological insights not discussed in the current research. How these new data relate to the organization of production are discussed in relation to the chaîne opératoire models presented in Chapter 9 and their socio-economic implications in Chapter 10.

Table 8.6A (next page): Following other studies that included pre-heating of slag samples before chemical analyses (e.g., Veldhuijzen, 2005) we conducted a limited experiment to check the possible influence of moisture in slag from Khirbat en-Nahas and Timna Site 30 on the results of their XRF analyses. Two samples (L860-1 and L180-1) were divided into two pieces each, one of which was "cooked" in an oven (heated in 50°C for 12 hours); both were pulverized and were measured with the exact same settings by the XRF instrument. The calibrated results of the pulverized slag samples (C = cooked) are presented below. The average standard deviation (%) is higher by approximately a factor of two from the average standard deviation (%) of multiple measurements performed on the same pulverized sample (±5, Tables 8.6B and 8.6C), demonstrating a substantial chemical change; however, this does not seem to be the result of changes in moisture but rather a change in chemistry of the samples, most notably the evaporation of lead (emphasized in red). The conclusion was that heating the slag samples is not necessary, and might even be harmful.

Sample	Context	Al_2O_3	SiO_2	K_2O	CaO	BaO	TiO_2	MnO	FeO	Ni	Cu	Zn	Pb	
L860-1	F2a	4.94	34.95	1.02	3.02	1.45	0.25	39.75	1.86	0.07	0.40	0.03	0.24	Sum=87.98
L860-1-C	F2a	4.93	33.82	0.85	3.50	1.39	0.25	40.53	1.81	0.08	0.33	0.02	0.09	Sum=87.61
Average		4.94	34.39	0.94	3.26	1.42	0.25	40.14	1.84	0.08	0.37	0.03	0.17	
Standard deviation (%)		0.20	2.33	12.83	10.43	2.82	0.00	1.37	2.18	13.33	13.70	40.00	66.67	Av. Stdev.(%)= 13.82
Standard deviation		0.01	0.80	0.12	0.34	0.04	0.00	0.55	0.04	0.01	0.05	0.01	0.11	Av. Stdev.= 0.18
L180-1	A2b-A3	4.79	29.97	2.37	8.68	1.81	0.26	37.47	2.52	0.07	0.77	0.03	0.18	Sum=88.92
L180-1-C	A2b-A3	4.74	29.15	2.49	6.72	1.94	0.31	42.63	3.10	0.07	0.66	0.03	0.12	Sum= 91.97
Average		7.70	1.88	0.29	40.05	2.81	0.07	0.72	0.03	0.15	7.70	1.88	0.29	
Standard deviation (%)		18.05	4.80	14.04	9.11	14.59	0.00	11.19	0.00	26.67	18.05	4.80	14.04	Av. Stdev.(%)= 8.71
Standard deviation		0.04	0.58	0.08	1.39	0.09	0.04	3.65	0.41	0.00	0.08	0.00	0.04	Av. Stdev.= 0.53

Table 8.6B: Results of different experiments testing the accuracy and precision of XRF measurements on slag samples using the XRF TRACeR instrument; calculations are based on uncalibrated results (numbers represent the area below each element's peak), showing differences in measurements on the same sample with the same settings (here all samples analyzed with a green filter) (see text).

sample name	voltage	current	filter	time	Mn	Fe	Ni	Cu	Zn	Pb	Avg
F-2-A-C-1	40	15	green	300 sec	174	243	106	13667	295	71	
F-2-A-C-2	40	15	green	300 sec	57	14926	94	7813	218	705	
F-2-A-C-3	40	15	green	300 sec	74	28939	130	54536	844	593	
F-2-A-C-stdev(%)					62	98	17	100	75	74	71
F-2-A-C-stdev					63	14349	18	25454	341	338	6761
F-2-A-C-average					102	14703	110	25339	452	456	
F-2-B-C-1	40	15	green	300 sec	1681	144588	50	559	770	333	
F-2-B-C-2	40	15	green	300 sec	983	109662	61	744	854	268	
F-2-B-C-3	40	15	green	300 sec	1133	111418	70	437	585	305	
F-2-B-C-stdev(%)					29	16	17	27	19	11	20
F-2-B-C-stdev					367	19677	10	155	138	33	3397
F-2-B-C-average					1266	121889	60	580	736	302	
F-2-C-C-1	40	15	green	300 sec	316	57425	32	78040	1191	562	
F-2-C-C-2	40	15	green	300 sec	437	83302	67	6958	675	473	
F-2-C-C-3	40	15	green	300 sec	178	69814	92	2081	560	422	
F-2-C-C-stdev(%)					42	18	47	146	42	15	52
F-2-C-C-stdev					130	12942	30	42517	336	71	9338
F-2-C-C-average					310	70180	64	29026	809	486	
F-2-D-C-1	40	15	green	300 sec	118	61180	78	3061	1138	366	
F-2-D-C-2	40	15	green	300 sec	193	64907	39	11217	570	201	
F-2-D-C-3	40	15	green	300 sec	83	45648	53	5574	728	253	
F-2-D-C-stdev(%)					43	18	35	63	36	31	38
F-2-D-C-stdev					56	10215	20	4177	293	84	2474
F-2-D-C-average					131	57245	57	6617	812	273	
F-2-E-C-1	40	15	green	300 sec	158	51774	171	26142	1696	1559	
F-2-E-C-2	40	15	green	300 sec	124	27345	127	35568	1387	1430	
F-2-E-C-3	40	15	green	300 sec	80	13015	185	90062	1306	916	
F-2-E-C-stdev(%)					32	64	19	68	14	26	37
F-2-E-C-stdev					39	19598	30	34507	206	340	9120

Table 8.6B continued

sample name	voltage	current	filter	time	Mn	Fe	Ni	Cu	Zn	Pb	Avg
F-2-E-C-average					121	30711	161	50591	1463	1302	
KAJ_A_N_3275-p-1	40	15	green	500 sec	58947	7485	341	7106	343	750	
KAJ_A_N_3275-p-2	40	15	green	500 sec	59173	7514	319	6609	379	718	
KAJ_A_N_3275-p-stdev(%)					0	0	5	5	7	3	3
KAJ_A_N_3275-p-stdev					160	21	16	351	25	23	99
KAJ_A_N_3275-p-average					59060	7500	330	6858	361	734	
KAJ_A_W_3267-p-1	40	15	green	500 sec	61290	6543	345	3536	357	486	
KAJ_A_W_3267-p-2	40	15	green	500 sec	62207	6462	320	3898	356	554	
KAJ_A_W_3267-p-stdev(%)					1	1	5	7	0	9	4
KAJ_A_W_3267-p-stdev					648	57	18	256	1	48	171
KAJ_A_W_3267-p-average					61749	6503	333	3717	357	520	
KEN_F_1412a-cooked-p-1	40	15	green	500 sec	101336	7758	414	1782	264	1394	
KEN_F_1412a-cooked-p-2	40	15	green	500 sec	101117	7709	361	1850	291	1357	
KEN_F_1412a-cooked-p-3	40	15	green	500 sec	99995	7705	381	1877	267	1322	
KEN_F_1412a-cooked-p-stdev(%)					1	0	7	3	5	3	3
KEN_F_1412a-cooked-p-stdev					719	30	27	49	15	36	146
KEN_F_1412a-cooked-p-average					100816	7724	385	1836	274	1358	
KEN_M_E_10481a-C-1	40	15	green	300 sec	71678	9231	231	2851	637	388	
KEN_M_E_10481a-C-2	40	15	green	300 sec	68119	8756	206	1768	620	361	
KEN_M_E_10481a-C-3	40	15	green	300 sec	51117	18742	148	3143	521	2964	
KEN_M_E_10481a-C-4	40	15	green	300 sec	64114	8939	205	1980	600	383	
KEN_M_E_10481a-C-stdev(%)					14	43	18	27	9	126	39
KEN_M_E_10481a-C-stdev					8975	4887	35	665	51	1293	2651
KEN_M_E_10481a-C-average					63757	11417	198	2436	595	1024	
KEN_M_E_10481a-p-1	40	15	green	500 sec	109424	15392	390	5140	863	861	
KEN_M_E_10481a-p-2	40	15	green	500 sec	110800	15143	351	5112	928	892	
KEN_M_E_10481a-p-3	40	15	green	500 sec	110901	15430	343	5243	885	861	
KEN_M_E_10481a-p-stdev(%)					1	1	7	1	4	2	3

Table 8.6B continued

sample name	voltage	current	filter	time	Mn	Fe	Ni	Cu	Zn	Pb	Avg
KEN_M_E_10481a-p-stdev					825	156	25	69	33	18	188
KEN_M_E_10481a-p-average					110375	15322	361	5165	892	871	
KEN_M_E_10485a-C-1	40	15	green	300 sec	48531	16996	159	1277	121	273	
KEN_M_E_10485a-C-2	40	15	green	300 sec	50406	15000	174	1206	75	126	
KEN_M_E_10485a-C-stdev(%)					3	9	6	4	33	52	18
KEN_M_E_10485a-C-stdev					1326	1411	11	50	33	104	489
KEN_M_E_10485a-C-average					49469	15998	167	1242	98	200	
KEN_M_E_10485a-p-1	40	15	green	500 sec	94464	27806	303	2052	165	366	
KEN_M_E_10485a-p-2	40	15	green	500 sec	94798	28266	327	1535	235	389	
KEN_M_E_10485a-p-3	40	15	green	500 sec	94341	27890	328	1604	152	367	
KEN_M_E_10485a-p-4	40	15	green	500 sec	87924	25878	329	1222	206	371	
KEN_M_E_10485a-p-stdev(%)					4	4	4	21	20	3	9
KEN_M_E_10485a-p-stdev					3311	1073	13	342	38	11	798
KEN_M_E_10485a-p-average					92882	27460	322	1603	190	373	
KEN_M_S_10260a-C-1	40	15	green	300 sec	41444	7570	247	2545	515	5062	
KEN_M_S_10260a-C-2	40	15	green	300 sec	39290	7509	183	2028	356	2415	
KEN_M_S_10260a-C-3	40	15	green	300 sec	41252	7639	147	3533	470	4242	
KEN_M_S_10260a-C-4	40	15	green	300 sec	33324	5385	182	3145	553	3955	
KEN_M_S_10260a-C-stdev(%)					10	16	22	24	18	28	20
KEN_M_S_10260a-C-stdev					3796	1095	42	662	85	1107	1131
KEN_M_S_10260a-C-average					38828	7026	190	2813	474	3919	
KEN_M_S_10260a-p-1	40	15	green	500 sec	69917	11450	374	4013	536	3698	
KEN_M_S_10260a-p-2	40	15	green	500 sec	69480	11307	296	3774	448	3763	
KEN_M_S_10260a-p-3	40	15	green	500 sec	69654	11300	423	3993	506	3730	
KEN_M_S_10260a-p-stdev(%)					0	1	18	3	9	1	5
KEN_M_S_10260a-p-stdev					220	85	64	133	45	33	96
KEN_M_S_10260a-p-average					69684	11352	364	3927	497	3730	
T30-S1-541-C-1	40	15	green	300 sec	16625	101543	38	2029	527	974	

Table 8.6B continued

sample name	voltage	current	filter	time	Mn	Fe	Ni	Cu	Zn	Pb	Avg
T30-S1-541-C-2	40	15	green	300 sec	6762	60594	36	6091	193	167	
T30-S1-541-C-3	40	15	green	300 sec	12537	87259	51	6947	327	210	
T30-S1-541-C-stdev(%)					41	25	20	52	48	101	48
T30-S1-541-C-stdev					4955	20784	8	2627	168	454	4833
T30-S1-541-C-average					11975	83132	42	5022	349	450	
Timna_L808_b1200-p-1	40	15	green	500 sec	28380	186777	157	5520	590	485	
Timna_L808_b1200-p-2	40	15	green	500 sec	28516	186079	109	5379	579	477	
Timna_L808_b1200-p-3	40	15	green	500 sec	28269	182850	100	5473	510	499	
Timna_L808_b1200-p-stdev					0	1	25	1	8	2	6
Timna_L808_b1200-p-stdev					124	2095	31	72	43	11	396
Timna_L808_b1200-p-average					28388	185235	122	5457	560	487	
Timna_L809_b1800-p-1	40	15	green	500 sec	91740	15126	315	1922	146	897	
Timna_L809_b1800-p-2	40	15	green	500 sec	92869	15532	292	1894	132	869	
Timna_L809_b1800-p-3	40	15	green	500 sec	92048	15900	339	1889	136	932	
Timna_L809_b1800-p-stdev(%)					1	2	7	1	5	4	3
Timna_L809_b1800-p-stdev					584	387	24	18	7	32	175
Timna_L809_b1800-p-average					92219	15519	315	1902	138	899	
Timna_S1_b505-p-1	40	15	green	500 sec	25836	159275	132	7655	371	901	
Timna_S1_b505-p-2	40	15	green	500 sec	25739	155869	191	7662	426	919	
Timna_S1_b505-p-3	40	15	green	500 sec	26465	160044	112	8698	465	934	
Timna_S1_b505-p-stdev(%)					2	1	28	7	11	2	9
Timna_S1_b505-p-stdev					394	2222	41	600	47	17	554
Timna_S1_b505-p-average					26013	158396	145	8005	421	918	
Timna_S1_b557-p-1	40	15	green	500 sec	14106	177374	99	4568	899	268	
Timna_S1_b557-p-2	40	15	green	500 sec	13499	172369	135	4758	956	228	
Timna_S1_b557-p-3	40	15	green	500 sec	13867	175835	125	4647	889	252	
Timna_S1_b557-p-stdev(%)					2	1	16	2	4	8	6
Timna_S1_b557-p-stdev					306	2564	19	95	36	20	507

Table 8.6B continued

sample name	voltage	current	filter	time	Mn	Fe	Ni	Cu	Zn	Pb	Avg
Timna_S1_b557-p-average					13824	175193	120	4658	915	249	
Timna_S2_S10a-p-1	40	15	green	500 sec	87275	22332	316	4253	306	2474	
Timna_S2_S10a-p-2	40	15	green	500 sec	86015	22024	365	4015	192	2527	
Timna_S2_S10a-p-3	40	15	green	500 sec	87222	22198	430	3665	244	2540	
Timna_S2_S10a-p-stdev					1	1	15	7	23	1	8
Timna_S2_S10a-p-stdev					713	154	57	296	57	35	219
Timna_S2_S10a-p-average					86837	22185	370	3978	247	2514	
Av. stdev. (%) of controls (not pulverized samples) (N=10)					28	31	20	51	29	46	34
Av. stdev (%) of powders (N=11)					1	1	12	5	9	3	5

Table 8.6C: Results of different experiments testing the accuracy and precision of XRF measurements on slag samples using the XRF TRACeR instrument; calculations are based on uncalibrated results (numbers represent the area below each element's peak), showing differences in measurements of same sample with same settings (here all samples analyzed with a blue filter) (see text).

sample name	voltage	current	filter	time	Si	K	Ca	Average
F-2_A-c-1	15	15	blue	300 sec	1034	1661	12661	
F-2_A-c-2	15	15	blue	300 sec	1968	2760	5331	
F-2_A-c-stdev(%)					44	35	58	46
F-2_A-c-stdev					660	777	5183	2207
F-2_A-c-average					1501	2211	8996	
F-2_B-c-1	15	15	blue	300 sec	176	99	1566	
F-2_B-c-2	15	15	blue	300 sec	185	67	6496	
F-2_B-c-3	15	15	blue	300 sec	226	110	1147	
F-2_B-c-stdev(%)					14	24	97	45
F-2_B-c-stdev					27	22	2975	1008
F-2_B-c-average					196	92	3070	
F-2_C-c-1	15	15	blue	300 sec	549	1202	8184	
F-2_C-c-2	15	15	blue	300 sec	603	935	7435	
F-2_C-c-3	15	15	blue	300 sec	715	1121	8296	
F-2_C-c-stdev(%)					14	13	6	11
F-2_C-c-stdev					85	137	468	230
F-2_C-c-average					622	1086	7972	
F-2_D-c-1	15	15	blue	300 sec	511	380	7347	
F-2_D-c-2	15	15	blue	300 sec	1053	855	16078	
F-2_D-c-3	15	15	blue	300 sec	802	496	16708	
F-2_D-c-stdev(%)					34	43	39	39
F-2_D-c-stdev					271	248	5232	1917
F-2_D-c-average					789	577	13378	
F-2_E-c-1	15	15	blue	300 sec	1611	1255	7197	
F-2_E-c-2	15	15	blue	300 sec	1137	1323	10312	
F-2_E-C-3	15	15	blue	300 sec	900	650	5361	
F-2_E-C-stdev(%)					30	34	33	32
F-2_E-C-stdev					362	370	2503	1078

Table 8.6C continued

sample name	voltage	current	filter	time	Si	K	Ca	Average
F-2_E-C-average					1216	1076	7623	
KAJ_A_N_3276-p-1	15	15	blue	500 sec	1176	4118	14114	
KAJ_A_N_3276-p-2	15	15	blue	500 sec	1184	4088	13994	
KAJ_A_N_3276-p-3	15	15	blue	500 sec	1266	4072	14242	
KAJ_A_N_3276-p-stdev(%)					4	1	1	2
KAJ_A_N_3276-p-stdev					50	23	124	66
KAJ_A_N_3276-p-average					1209	4093	14117	
KAJ_A_W_3262-p-1	15	15	blue	500 sec	1033	4667	20615	
KAJ_A_W_3262-p-2	15	15	blue	500 sec	1092	4931	21193	
KAJ_A_W_3262-p-3	15	15	blue	500 sec	1089	4888	21674	
KAJ_A_W_3262-p-stdev(%)					3	3	3	3
KAJ_A_W_3262-p-stdev					33	142	530	235
KAJ_A_W_3262-p-average					1071	4829	21161	
KAJ_A_W_3267-p-1	15	15	blue	500 sec	815	5702	30020	
KAJ_A_W_3267-p-2	15	15	blue	500 sec	704	5110	28439	
KAJ_A_W_3267-p-stdev(%)					10	8	4	7
KAJ_A_W_3267-p-stdev					78	419	1118	538
KAJ_A_W_3267-p-average					760	5406	29230	
KAJ_A_W_3274-p-1	15	15	blue	500 sec	1230	5019	38234	
KAJ_A_W_3274-p-2	15	15	blue	500 sec	1128	4705	36741	
KAJ_A_W_3274-p-3	15	15	blue	500 sec	982	4681	35248	
KAJ_A_W_3274-p-stdev(%)					11	4	4	6
KAJ_A_W_3274-p-stdev					125	189	1493	602
KAJ_A_W_3274-p-average					1113	4802	36741	
Ken_M_E_10477a-c-1	15	15	blue	300 sec	589	3200	17769	
Ken_M_E_10477a-c-2	15	15	blue	300 sec	62	940	6903	
Ken_M_E_10477a-c-3	15	15	blue	300 sec	114	3005	7170	
Ken_M_E_10477a-c-4	15	15	blue	300 sec	196	2301	13246	

Table 8.6C continued

sample name	voltage	current	filter	time	Si	K	Ca	Average
Ken_M_E_10477a-c-5	15	15	blue	300 sec	549	3435	17000	
Ken_M_E_10477a-c-6	15	15	blue	300 sec	313	2515	10632	
Ken_M_E_10477a-c-stdev(%)					73	35	39	49
Ken_M_E_10477a-c-stdev					223	902	4710	1945
Ken_M_E_10477a-c-average					304	2566	12120	
Ken_M_E_10477a-p-1	15	15	blue	500 sec	969	5961	27342	
Ken_M_E_10477a-p-2	15	15	blue	500 sec	826	5844	27088	
Ken_M_E_10477a-p-3	15	15	blue	500 sec	964	5964	27124	
Ken_M_E_10477a-p-stdev(%)					9	1	1	3
Ken_M_E_10477a-p-stdev					81	68	137	96
Ken_M_E_10477a-p-average					920	5923	27185	
KEN_M_E_10481a-p-1	40	15	blue	500 sec	927	3336	17969	
KEN_M_E_10481a-p-2	40	15	blue	500 sec	806	3172	17585	
KEN_M_E_10481a-p-3	40	15	blue	500 sec	880	3226	18362	
KEN_M_E_10481a-p-stdev(%)					7	3	2	4
KEN_M_E_10481a-p-stdev					61	84	389	178
KEN_M_E_10481a-p-average					871	3245	17972	
KEN_M_E_10485a-p-1	40	15	blue	500 sec	1153	4223	15814	
KEN_M_E_10485a-p-2	40	15	blue	500 sec	1145	4042	14941	
KEN_M_E_10485a-p-3	40	15	blue	500 sec	1098	3877	14256	
KEN_M_E_10485a-p-stdev(%)					3	4	5	4
KEN_M_E_10485a-p-stdev					30	173	781	328
KEN_M_E_10485a-p-average					1132	4047	15004	
Ken_M_E_10488b-c-1	15	15	blue	300 sec	757	1654	13737	
Ken_M_E_10488b-c-2	15	15	blue	300 sec	879	1772	19837	
Ken_M_E_10488b-c-3	15	15	blue	300 sec	908	2352	13753	
Ken_M_E_10488b-c-4	15	15	blue	300 sec	279	2486	8569	
Ken_M_E_10488b-c-5	15	15	blue	300 sec	779	1904	14094	
Ken_M_E_10488b-c-6	15	15	blue	300 sec	865	1768	12845	

Table 8.6C continued

sample name	voltage	current	filter	time	Si	K	Ca	Average
Ken_M_E_10488b-c-stdev(%)					32	17	26	25
Ken_M_E_10488b-c-stdev					236	345	3600	1394
Ken_M_E_10488b-c-average					745	1989	13806	
T30_S1-541-c-1	15	15	blue	300 sec	760	734	7334	
T30_S1-541-c-2	15	15	blue	300 sec	283	720	4251	
T30_S1-541-c-3	15	15	blue	300 sec	200	296	3374	
T30_S1-541-c-stdev(%)					73	43	42	52
T30_S1-541-c-stdev					302	249	2080	877
T30_S1-541-c-average					414	583	4986	
Timna_F-2a-c-1	15	15	blue	300 sec	1288	1565	9265	
Timna_F-2a-c-2	15	15	blue	300 sec	978	242	3486	
Timna_F-2a-c-3	15	15	blue	300 sec	1637	2512	7645	
Timna_F-2a-c-stdev(%)					25	79	44	49
Timna_F-2a-c-stdev					330	1140	2981	1484
Timna_F-2a-c-average					1301	1440	6799	
Timna_F-2b-c-1	15	15	blue	300 sec	137	55	1615	
Timna_F-2b-c-2	15	15	blue	300 sec	127	2	1084	
Timna_F-2b-c-3	15	15	blue	300 sec	112	22	1283	
Timna_F-2b-c-stdev(%)					10	102	20	44
Timna_F-2b-c-stdev					13	27	268	103
Timna_F-2b-c-average					125	26	1327	
Timna_F-2c-c-1	15	15	blue	300 sec	701	1302	8933	
Timna_F-2c-c-2	15	15	blue	300 sec	341	510	3883	
Timna_F-2c-c-3	15	15	blue	300 sec	524	688	6041	
Timna_F-2c-c-stdev(%)					34	50	40	42
Timna_F-2c-c-stdev					180	416	2534	1043
Timna_F-2c-c-average					522	833	6286	
Timna_F-2d-c-1	15	15	blue	300 sec	799	819	10485	

Table 8.6C continued

sample name	voltage	current	filter	time	Si	K	Ca	Average
Timna_F-2d-c-2	15	15	blue	300 sec	1028	668	12828	
Timna_F-2d-c-3	15	15	blue	300 sec	1124	911	15601	
Timna_F-2d-c-stdev(%)					17	15	20	17
Timna_F-2d-c-stdev					167	123	2561	950
Timna_F-2d-c-average					984	799	12971	
Timna_F-2e-c-1	15	15	blue	300 sec	932	838	4975	
Timna_F-2e-c-2	15	15	blue	300 sec	644	711	9323	
Timna_F-2e-c-3	15	15	blue	300 sec	282	58	630	
Timna_F-2e-c-stdev(%)					53	78	87	73
Timna_F-2e-c-stdev					326	419	4347	1697
Timna_F-2e-c-average					619	536	4976	
Timna_L808_b1200-p-1	15	15	blue	500 sec	1185	343	12447	
Timna_L808_b1200-p-2	15	15	blue	500 sec	1098	413	12126	
Timna_L808_b1200-p-3	15	15	blue	500 sec	1149	409	12025	
Timna_L808_b1200-p-stdev(%)					4	10	2	5
Timna_L808_b1200-p-stdev					44	39	220	101
Timna_L808_b1200-p-average					1144	388	12199	
Timna_L809_b1800-c-1	15	15	blue	300 sec	930	754	8237	
Timna_L809_b1800-c-2	15	15	blue	300 sec	839	2436	7345	
Timna_L809_b1800-c-3	15	15	blue	300 sec	583	690	6817	
Timna_L809_b1800-c-4	15	15	blue	300 sec	482	828	8225	
Timna_L809_b1800-c-5	15	15	blue	300 sec	320	212	3803	
Timna_L809_b1800-c-6	15	15	blue	300 sec	731	1299	8268	
Timna_L809_b1800-c-stdev(%)					35	74	24	45
Timna_L809_b1800-c-stdev					229	768	1728	908
Timna_L809_b1800-c-average					648	1037	7116	
Timna_L809_b1800-p-1	15	15	blue	500 sec	1317	1054	14184	
Timna_L809_b1800-p-2	15	15	blue	500 sec	1671	1068	14266	
Timna_L809_b1800-p-3	15	15	blue	500 sec	1655	1006	14013	

Table 8.6C continued

sample name	voltage	current	filter	time	Si	K	Ca	Average
Timna_L809_b1800-p-4	15	15	blue	500 sec	1527	1006	13615	
Timna_L809_b1800-p-stdev(%)					11	3	2	5
Timna_L809_b1800-p-stdev					164	32	290	162
Timna_L809_b1800-p-average					1543	1034	14020	
Timna_L903_b561-p-1	15	15	blue	500 sec	1102	532	8848	
Timna_L903_b561-p-2	15	15	blue	500 sec	1054	545	8494	
Timna_L903_b561-p-3	15	15	blue	500 sec	1230	467	8853	
Timna_L903_b561-p-stdev(%)					8	8	2	6
Timna_L903_b561-p-stdev					91	42	206	113
Timna_L903_b561-p-average					1129	515	8732	
Timna_S1_b505-p-1	15	15	blue	500 sec	1371	1232	14151	
Timna_S1_b505-p-2	15	15	blue	500 sec	1470	1172	14362	
Timna_S1_b505-p-3	15	15	blue	500 sec	1310	1051	13352	
Timna_S1_b505-p-stdev(%)					6	8	4	6
Timna_S1_b505-p-stdev					81	92	533	235
Timna_S1_b505-p-average					1384	1152	13955	
Timna_S1_b557b-c-1	15	15	blue	300 sec	248	1429	7871	
Timna_S1_b557b-c-2	15	15	blue	300 sec	650	641	4175	
Timna_S1_b557b-c-3	15	15	blue	300 sec	617	1542	8291	
Timna_S1_b557b-C-4	15	15	blue	300 sec	34	35	1716	
Timna_S1_b557b-C-5	15	15	blue	300 sec	1	51	401	
Timna_S1_b557b-C-6	15	15	blue	300 sec	968	1049	5849	
Timna_S1_b557b-C-stdev(%)					92	83	68	81
Timna_S1_b557b-C-stdev					386	660	3223	1423
Timna_S1_b557b-C-average					420	791	4717	
Timna_S1_b557-p-1	15	15	blue	500 sec	1228	620	25157	
Timna_S1_b557-p-2	15	15	blue	500 sec	1182	528	23871	
Timna_S1_b557-p-3	15	15	blue	500 sec	1191	623	24912	
Timna_S1_b557-p-stdev(%)					2	9	3	5

Table 8.6C continued

sample name	voltage	current	filter	time	Si	K	Ca	Average
Timna_S1_b557-p-stdev					24	54	683	254
Timna_S1_b557-p-average					1200	590	24647	
Timna_S2_S10a-p-1	15	15	blue	500 sec	1553	2132	13820	
Timna_S2_S10a-p-2	15	15	blue	500 sec	1523	2119	13252	
Timna_S2_S10a-p-3	15	15	blue	500 sec	1657	2161	13674	
Timna_S2_S10a-p-stdev(%)					4	1	2	3
Timna_S2_S10a-p-stdev					70	22	295	129
Timna_S2_S10a-p-average					1578	2137	13582	
Av. stdev. (%) of controls (not pulverized samples) (N=16)					36	45	40	41
Av, stdev.(%) of powders (N=13)					6	5	3	5

Table 8.7: Bulk chemical compositions (in wt.-%) of pulverized slag samples from Khirbat al-Jariya Area A (KAJA contexts in the table), Khirbat en-Nahas Areas A (A), M (M) and F (F) and Timna Site 30 (L). Blue (green) indicates measurements with blue (green) filter. In red are values that were out of the calibration range and should be treated with caution (these are Fe-rich slag from Timna, in contrast to the bulk Mn-rich slag studied here). Note that the totals are below 100 wt. -%. This is because Cu exists also in its oxidic state but was calculated as $Cu^{\pm 0}$, and the Fe concentrations were calculated as FeO although several different Fe oxides are present. In addition, slag may contain sulphur in the form of Cu sulphide, which was not analyzed. Compare with Figs.8.5-8.12, and Tables 8.5 and 8.8; the standard deviations (%) are taken from the averages of repeated measurements presented in Tables 8.6A and 8.6B above (the average standard deviation of all elements is about 5%).

Sample	Context	Al_2O_3±?	SiO_2±6%	K_2O±5%	CaO±3%	BaO±?	TiO_2±?	MnO±1%	FeO±1%	Ni±12%	Cu±5%	Zn±9%	Pb±3%	total
3275	KAJA1a	4.99	34.89	2.90	10.86	0.03	0.19	28.81	2.00	0.08	1.02	0.04	0.04	85.85
3276	KAJA3	4.20	33.37	2.08	4.01	0.54	0.19	33.37	2.47	0.07	2.65	0.08	0.11	83.14
3277	KAJA5	4.09	33.17	4.44	8.46	0.91	0.20	38.99	2.13	0.09	0.87	0.04	0.05	93.45
3278	KAJA1a	4.48	34.45	2.14	8.59	0.49	0.19	21.23	2.12	0.08	1.74	0.06	0.06	75.63
3279	KAJA5	3.96	29.36	3.80	11.05	0.06	0.19	37.13	2.12	0.07	1.90	0.08	0.06	89.76
3280	KAJA5	4.83	32.52	3.93	10.51	0.33	0.19	32.99	1.44	0.07	1.56	0.05	0.03	88.45
3281	KAJA4	4.99	36.08	3.33	8.18	0.15	0.19	31.35	1.49	0.07	1.11	0.04	0.04	87.04
3282	KAJA5	4.68	35.40	3.71	9.08	0.32	0.19	29.19	2.22	0.08	1.54	0.07	0.08	86.56
3283	KAJA3	5.44	35.67	3.18	11.01	0.26	0.19	30.05	2.08	0.08	2.59	0.07	0.09	90.71
3287	KAJA3	4.60	31.97	3.58	11.60	0.31	0.19	21.06	2.20	0.07	1.85	0.06	0.06	77.53
3261	KAJA1	5.03	33.77	2.78	7.54	0.58	0.19	34.06	3.28	0.07	0.56	0.05	0.03	87.93
3262	KAJA1a	4.81	32.57	3.85	7.62	0.86	0.20	38.76	3.68	0.08	0.60	0.04	0.03	93.09
3263	KAJA1a	5.06	32.90	3.02	10.16	0.41	0.19	39.63	2.15	0.08	0.63	0.04	0.03	94.30
3266	KAJA3	4.39	29.44	3.66	11.63	0.79	0.19	29.38	4.31	0.07	0.58	0.04	0.02	84.51
3267	KAJA3	4.42	31.04	2.88	3.71	1.87	0.24	31.62	1.80	0.07	0.66	0.04	0.03	78.38
3269	KAJA5	4.10	34.67	3.31	3.85	1.50	0.23	35.12	4.32	0.06	4.25	0.12	0.24	91.77
3271	KAJA6	5.71	31.53	2.52	11.74	1.33	0.21	39.52	5.36	0.06	2.06	0.10	0.22	100.37
3272	KAJA5 (bottom)	4.89	33.90	3.19	13.05	0.37	0.19	28.91	1.46	0.08	0.56	0.03	0.07	86.70
3274	KAJA5	4.87	39.27	2.97	9.46	0.46	0.19	23.07	2.09	0.08	1.93	0.07	0.09	84.53
L170-1	A2a	5.14	34.83	1.81	5.29	0.02	0.19	27.11	2.66	0.07	4.11	0.10	0.73	82.05
L174-1	A2b	4.68	33.63	1.81	3.26	1.37	0.23	37.96	3.72	0.07	0.75	0.07	0.54	88.09
L180-1	A2b-A3	4.79	29.97	2.37	8.68	1.81	0.26	37.47	2.52	0.07	0.77	0.03	0.18	88.92

Table 8.7 continued

Sample	Context	Al_2O_3±?	SiO_2±6%	K_2O±5%	CaO±3%	BaO±?	TiO_2±?	MnO±1%	FeO±1%	Ni±12%	Cu±5%	Zn±9%	Pb±3%	total
L192-1	A2a-A2b-A3?	4.45	30.78	3.82	7.66	0.27	0.19	42.42	2.34	0.07	0.35	0.01	0.04	92.40
L193-1	A2b	4.61	35.11	2.53	10.64	-0.08	0.19	31.02	3.94	0.08	0.42	0.02	0.04	88.51
L816-1	F2a	4.31	34.02	2.81	6.54	0.49	0.19	42.07	2.09	0.08	0.27	0.02	0.03	92.90
L842-1	F2a	3.99	28.80	4.24	8.30	0.26	0.19	43.04	3.27	0.07	0.35	0.02	0.02	92.56
L859-1	F2a	4.28	30.06	1.20	7.35	0.55	0.19	36.26	2.82	0.07	0.54	0.04	0.12	83.49
L860-1	F2a	4.94	34.95	1.02	3.02	1.45	0.25	39.75	1.86	0.07	0.40	0.03	0.24	87.98
L893-1	F2a	4.47	36.19	2.57	10.91	0.13	0.19	0.19	31.19	nd	nd	nd	nd	85.84
10460	M3	4.02	32.25	3.76	7.72	0.83	0.20	37.95	2.54	0.07	1.07	0.06	0.12	90.58
10461	M3	4.44	31.69	3.91	6.33	0.60	0.19	39.62	2.02	0.08	0.85	0.04	0.12	89.90
10462	M3	4.34	32.81	2.38	7.61	0.67	0.19	38.03	4.67	0.07	1.29	0.07	0.07	92.19
10463	M3 (lower)	5.49	44.80	4.84	Error	Error	0.23	error	2.05	0.10	0.32	0.01	0.05	50.03
10464	M4	5.45	34.79	2.82	13.03	-0.02	0.19	26.82	2.56	0.07	1.62	0.06	0.13	87.53
10465	M3 (lower)	4.86	34.63	2.30	3.64	0.83	0.19	40.49	2.18	0.08	0.58	0.05	0.27	90.11
10466	M4 (lower)	4.92	43.00	3.12	5.48	-0.15	0.19	24.39	3.02	0.07	1.77	0.05	0.07	85.93
10467	M3 (lower)	4.50	36.88	3.56	3.33	0.30	0.19	43.17	1.96	0.07	1.43	0.07	0.33	95.79
10468	M3 (upper)	3.90	29.11	3.43	10.71	0.91	0.21	40.20	1.55	0.07	0.45	0.02	0.15	90.72
10471	M3 (lower)	4.15	29.39	4.58	6.05	0.69	0.20	42.14	2.61	0.07	1.23	0.06	0.15	91.34
10474	M3 (upper)	4.57	36.37	3.59	9.75	0.15	0.19	33.40	3.26	0.08	0.32	0.03	0.05	91.75
10475	M2	4.57	34.47	4.46	9.53	0.01	0.19	35.16	4.67	0.08	0.65	0.07	0.14	94.01
10476	M2	4.21	30.73	3.58	9.56	0.55	0.19	36.90	3.80	0.07	1.13	0.07	0.36	91.14

Table 8.7 continued

Sample	Context	Al_2O_3±?	SiO_2±6%	K_2O±5%	CaO±3%	BaO±?	TiO_2±?	MnO±1%	FeO±1%	Ni±12%	Cu±5%	Zn±9%	Pb±3%	total
10477	M2	4.66	31.83	3.73	9.57	0.09	0.19	37.02	3.87	0.07	0.59	0.06	0.31	91.99
10478	M2 (upper)	4.64	33.92	2.18	7.30	0.34	0.19	30.07	7.37	0.06	1.64	0.06	0.19	87.96
10479	M2 (upper)	4.60	33.85	2.63	4.90	-0.01	0.19	34.76	3.72	0.09	0.90	0.08	0.23	85.95
10480	M3	4.14	29.04	3.06	9.74	0.59	0.19	38.40	4.88	0.06	1.49	0.06	0.10	91.76
10481	M2 (upper)	4.33	30.48	1.90	6.61	0.58	0.20	43.90	3.57	0.06	0.84	0.09	0.06	92.62
10482	M1	4.18	31.19	2.34	7.98	0.39	0.19	43.19	4.08	0.06	0.46	0.03	0.03	94.12
10483	M1	4.75	30.02	1.53	10.00	0.77	0.21	40.80	4.79	0.07	0.65	0.07	0.18	93.83
10484	M1-M2	4.31	35.65	2.42	5.37	0.00	0.19	37.01	6.82	0.08	0.25	0.01	0.02	92.14
10485	M1-M2	3.99	39.20	2.75	5.66	-0.06	0.19	36.68	6.18	0.08	0.27	0.01	0.02	94.96
10486	M2 (upper)	4.50	32.13	2.47	8.22	0.60	0.19	44.04	2.40	0.09	1.05	0.02	0.01	95.73
10487	M1-M2	4.09	32.41	2.72	8.00	0.22	0.19	41.72	3.30	0.07	0.87	0.06	0.06	93.71
10488	M2 (upper)	4.57	32.52	1.66	7.41	0.48	0.19	39.85	1.90	0.07	0.80	0.05	0.01	89.50
10489	M2 (upper)	4.30	29.94	3.29	11.74	0.09	0.19	37.71	2.58	0.08	0.46	0.04	0.02	90.41
10490	M2	4.26	30.88	3.58	7.23	0.13	0.19	42.84	4.43	0.06	0.79	0.09	0.31	94.82
10492	M2	4.15	32.17	2.71	8.53	0.62	0.19	40.39	3.27	0.07	0.82	0.09	0.12	93.13
10493	M2	4.35	35.01	2.77	11.70	-0.08	0.19	30.24	5.13	0.07	2.14	0.12	0.16	91.80
L602-1	M2	4.53	35.64	4.27	6.69	0.14	0.19	42.40	2.41	0.07	0.39	0.03	0.02	96.77
L606-1	M2	4.66	35.58	4.01	8.03	0.39	0.19	34.20	3.51	0.08	0.72	0.06	0.41	91.83
L615-1	M2	4.20	34.81	2.03	8.69	-0.23	0.19	40.76	3.26	0.07	0.42	0.03	0.02	94.25
L620-2	M2	4.37	31.37	3.19	10.85	0.81	0.19	39.63	4.09	0.06	0.50	0.05	0.03	95.15
L620-1	M2	4.35	35.02	3.36	8.50	0.27	0.19	40.01	3.33	0.06	0.43	0.04	0.13	95.69

Table 8.7 continued

Sample	Context	Al_2O_3±?	SiO_2±6%	K_2O±5%	CaO±3%	BaO±?	TiO_2±?	MnO±1%	FeO±1%	Ni±12%	Cu±5%	Zn±9%	Pb±3%	total
L622-1	M2	4.28	37.46	3.01	9.38	-0.09	0.19	33.28	7.17	0.06	0.80	0.06	0.10	95.69
L629-1	M2?*	3.97	31.73	2.92	4.85	1.38	0.23	38.89	4.68	0.05	1.71	0.08	0.45	90.94
L647-1	M3	3.90	32.54	2.68	7.15	0.95	0.22	38.76	3.65	0.06	2.19	0.08	0.35	92.50
L659-1	M3	4.75	32.49	2.97	10.63	0.42	0.19	33.63	4.62	0.08	1.00	0.11	0.24	91.14
L660-1	M3	4.68	34.51	3.97	9.48	0.39	0.19	35.40	1.92	0.09	0.65	0.03	0.05	91.36
L666-2	M3 (lower)	4.73	35.73	2.87	3.65	0.75	0.21	41.99	3.59	0.06	1.96	0.12	0.65	96.31
L666-1	M3 (lower)	4.59	37.17	2.99	3.70	0.69	0.21	41.19	3.44	0.06	1.78	0.11	0.56	96.48
L667-1	M4	3.94	36.02	2.83	2.65	0.56	0.20	43.27	4.41	0.06	1.37	0.09	0.31	95.72
L670-1	M4	4.67	32.82	2.03	6.27	0.06	0.19	35.74	2.79	0.06	1.77	0.07	0.08	86.54
L670-2	M4	4.65	31.37	3.32	4.94	0.49	0.19	39.41	1.90	0.08	1.46	0.05	0.29	88.16
L671-1	M4	4.07	31.02	4.42	8.65	0.46	0.19	36.67	3.67	0.07	0.95	0.06	0.08	90.30
L674-1	M5	4.39	30.14	3.89	11.69	0.64	0.19	31.03	2.46	0.07	0.73	0.04	0.02	85.28
10250	M1	4.72	41.22	3.29	7.24	-0.13	0.19	30.73	6.89	0.09	0.33	0.02	0.03	94.61
10256	M2 (upper)	4.57	34.20	3.60	11.58	0.43	0.19	34.59	1.77	0.07	0.53	0.03	0.10	91.67
10259	M2	4.29	34.12	3.84	10.36	0.05	0.19	34.74	2.61	0.07	0.80	0.05	0.24	91.35
10260	M2	4.28	34.41	3.70	11.00	0.05	0.19	30.27	2.79	0.08	0.67	0.05	0.22	87.69
10262	M2	4.44	33.63	3.01	10.60	0.26	0.19	37.68	4.62	0.07	1.06	0.09	0.67	96.31
10267	M2-M3 (M3 upper)	4.22	30.55	4.73	10.93	0.11	0.19	37.18	1.73	0.07	0.35	0.02	0.07	90.14
10270	M3 (upper)	4.63	38.33	3.06	6.23	0.39	0.19	32.98	4.88	0.07	1.27	0.08	0.21	92.32
10277	M3 (lower)	4.35	35.49	2.54	7.11	0.79	0.20	40.65	5.33	0.09	0.43	0.04	0.03	97.05

Table 8.7 continued

Sample	Context	Al_2O_3±?	SiO_2±6%	K_2O±5%	CaO±3%	BaO±?	TiO_2±?	MnO±1%	FeO±1%	Ni±12%	Cu±5%	Zn±9%	Pb±3%	total
10280	M3 (lower)	4.03	31.45	2.19	3.57	0.28	0.19	40.48	2.52	0.08	1.63	0.06	0.41	86.89
10282	M4?	4.65	34.55	1.80	2.88	0.24	0.19	41.39	2.16	0.09	2.43	0.08	0.48	90.95
10283	M4	4.95	35.71	3.08	7.57	0.55	0.19	36.25	1.91	0.07	1.33	0.07	0.57	92.23
MAR0904	M2 (lower)	4.98	30.83	4.04	9.49	0.28	0.19	36.82	2.16	0.06	0.54	0.06	0.25	89.69
L809-1	L-1	5.08	38.53	0.55	5.03	1.70	0.26	39.94	4.06	0.07	0.37	0.02	0.06	95.67
S2-510	L-1	4.78	35.63	0.89	9.84	1.38	0.24	36.91	4.25	0.09	0.24	0.02	0.09	94.35
S2-51	L-1	4.82	43.92	1.22	4.43	0.81	0.19	35.32	5.04	0.08	0.61	0.03	0.14	96.62
S2-52	L-1	4.35	38.64	1.11	6.41	1.14	0.22	39.03	4.02	0.08	0.38	0.01	0.13	95.52
L808-1**	L-2	4.08	38.28	0.13	4.34	0.56	0.20	0.01	40.04	0.01	1.05	0.07	0.04	88.80
L902-1**	L-2	4.85	35.93	0.37	8.65	0.27	0.19	2.16	23.43	-0.02	0.87	0.10	0.01	76.85
L903-1**	L-2	3.92	36.29	0.32	2.43	0.01	0.19	1.63	48.27	0.00	2.91	0.13	0.07	96.16
L907-1**	L-2	4.09	42.91	0.56	4.51	0.16	0.19	2.30??	12.76??	0.01	1.38	0.05	0.07	68.99
Average of Mn-rich slag only		**4.54**	**33.82**	**2.95**	**7.80**	**0.50**	**0.20**	**35.94**	**3.28**	**0.07**	**1.05**	**0.05**	**0.16**	**90.26**

* Context insecure (^{14}C indicates earlier date)

** Out of calibration range (in red)

Table 8.8: Mineralogical phases in slag samples as determined by XRD analyses and light microscope petrography; for visual description of slag and contexts see Table 8.5, bulk chemistry Table 8.6, chemical formulas of the minerals Table 8.4 and images of thin section in Figs.8.37-8.43 below

Sample Name	Lab number	TS	XRD	Phases detected by XRD (main)	Phases detected by XRD (additional)	Comments
10493	4512-10	+	-			
10492	4511-10	+	+	Tephroite = 85	Analcime = 10, Leucite < 5	
10490	4510-10	+	+	Tephroite = 75	Cristobalite = 10, Fluorapatite = 5, Gypsum < 5, Others = 5	
10487	4509-10	+	+	Tephroite = 85	Leucite < 5, Fluorapatite = 5, Gypsum < 5	
10486	4508-10	+	+	Tephroite = 85	Feldspar = 10, Fluorapatite = 5	
10483	4507-10	+	+	Tephroite = 80	Cristobalite = 10, Wollastonite = 5, Fluorapatite = 5	
10480	4506-10	+	+	Tephroite = 85	Qz < 5, Fluorapatite = 5, Gypsum = 5	Apatite is Hydroxyapatite
10480	4505-10	+	+	Tephroite = 75	Leucite = 10, Fluorapatite = 10, Gypsum = 5	
10479	4504-10	-	+	Tephroite = 75	Analcime = 15, Leucite = 5, Gypsum = 5	
10478	4503-10	+	-			
10477	4502-10	+	-			
10475	4501-10	+	+	Tephroite = 85	Fluorapatite = 10, Others = 5	Others probably is Covelline
10468	4500-10	+	-			
10466	4499-10	-	+	Tephroite = 60	Analcime = 5, Leucite = 5, Qz = 30	
10465	4498-10	+	+	Tephroite = 70	Analcime = 15, Leucite = 5, Qz = 5,Gypsum = 5	
10464	4497-10	-	+	Tephroite = 45-50	Qz = 30, Fluorapatite = 5, Gypsum = 5, Calcite = 10-15	Apatite is Hydroxyapatite
10463	4496-10	-	+	Qz = 40	Analcime = 5, Others = 45 (Orthoclase (40) and Microcline (5), mostly composed of glass (!) ; however this sample and measurements is an outlier	
10462	4495-10	+	-			
10460	4494-10	+	-			
10283	4493-10	-	+	Tephroite = 95	Qz = 5	Extremely glassy slag
10282	4492-10	+	+	Tephroite = 75	Analcime = 20, Fluorapatite = 5	
10277	4491-10	+	-			
10210	4490-10	+	+	Tephroite = 85-90	Analcime = 15	

Table 8.8 continued

Sample Name	Lab number	TS	XRD	Phases detected by XRD (main)	Phases detected by XRD (additional)	Comments
10262	4489-10	+	+	Tephroite = 85	Fluorapatite = 10, Others = 5	
10260	4488-10	+	-			
10259	4487-10	+	+	Tephroite = 80	Leucite = 10, Fluorapatite = 10, Gypsum = 5	
10256	4486-10	+	+	Tephroite = 95	Fluorapatite = 5	Apatite is Hydroxyapatite
10250	4485-10	+	+	Tephroite = 95	Covellite < 5	
3274	4484-10	-	+	Tephroite = 70	Leucite = 10, Qz = 5, Fluorapatite = 15	
3272	4483-10	-	+	Tephroite = 95	Qz = 5	
3271	4482-10	-	+	Tephroite = 100		
3269	4481-10	+	+	Tephroite = 75	Analcime = 10, Leucite = 10, Qz = 5	
3267	4480-10	+	+	Tephroite = 80	Fluorapatite = 10, Gypsum = 5, Others = 5	
3263	4479-10	+	+	Tephroite = 85	Leucite = 10, Gypsum = 5	
3260	4478-10	+	+	Tephroite = 85	Analcime = 5, Leucite = 5, Fluorapatite = 5	Apatite is Hydroxylapatite
S2-S2	4477-10	+	+	Tephroite = 45, Qz = 45, Bustamite = 45	Feldspar = 10	Feldspar is Anorthite
S2-S1	4476-10	+	+	Tephroite = 85	Bustamite = 5, Gehlenite = 5, Feldapar = 5	Feldspar is Sanidine
907	4475-10	+	-			
903	4474-10	+	-			
902	4473-10	+	+	Fayalite = 55, Bustamite < 40	Akermanite = 5	
808	4472-10	-	+	Tephroite = 95	Qz < 5	



Fig.8.15: Analyzing artifacts with a handheld XRF instrument in the ELRAP's field laboratory, Qurayquira, Faynan, Jordan during the 2009 field season.



Fig.8.16: The XRF instrument at the German Mining Museum facilities in Bochum, Germany (left – the measurement machine, right – sample holder discs).

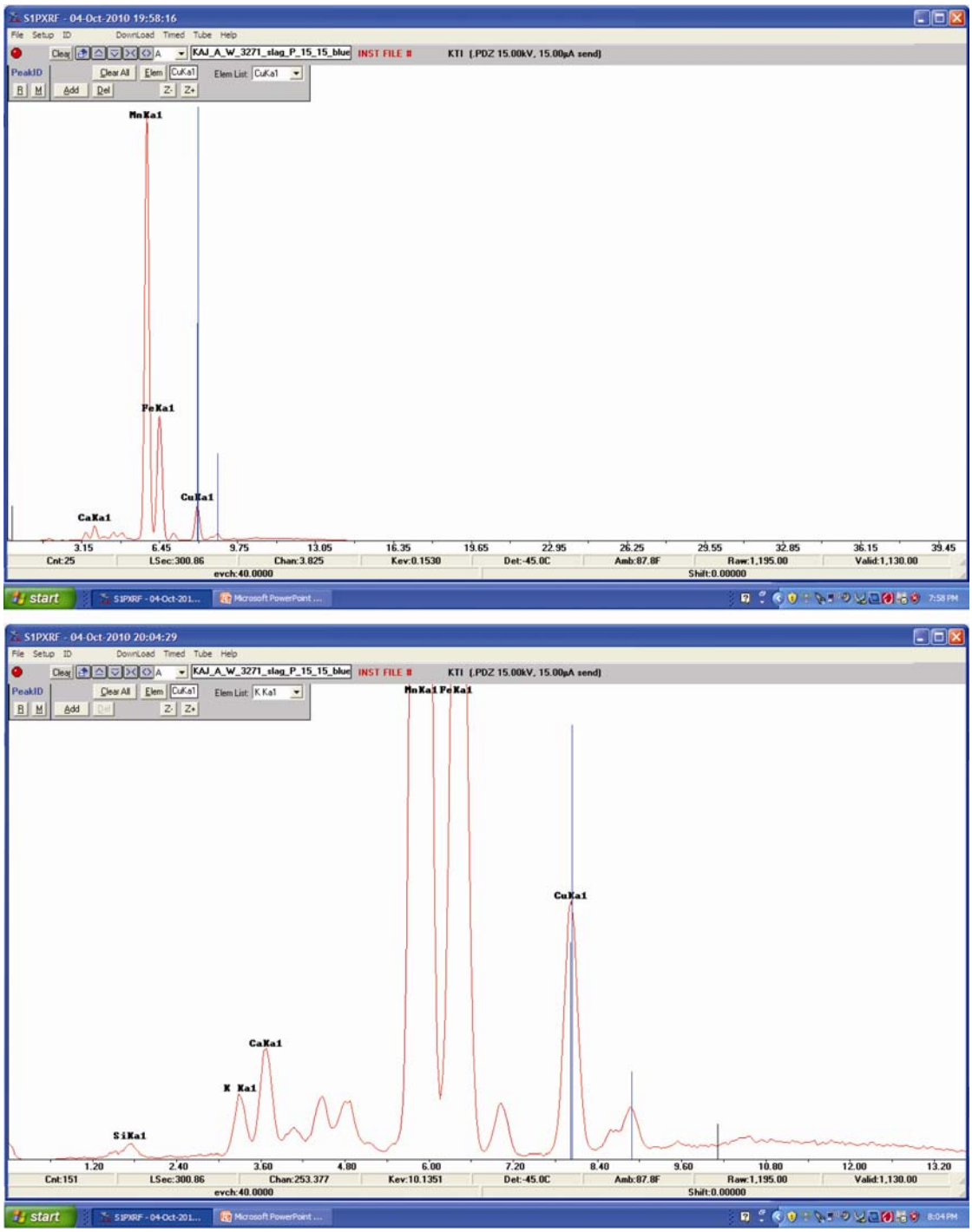


Fig.8.17: Plots of counts vs. energy level of XRF analysis on sample KAJ_A_W_3271_slag_P_15_15_blue_ v_light powder.pdz (pulverized slag from Khirbat al-Jariya West Section, measured using blue filter and vacuum, enabling better detection of the light elements). Upper figure shows the entire energy range and lower figure is a close up on the peaks of the less abundant elements (cf.Fig.8.17, green filter).

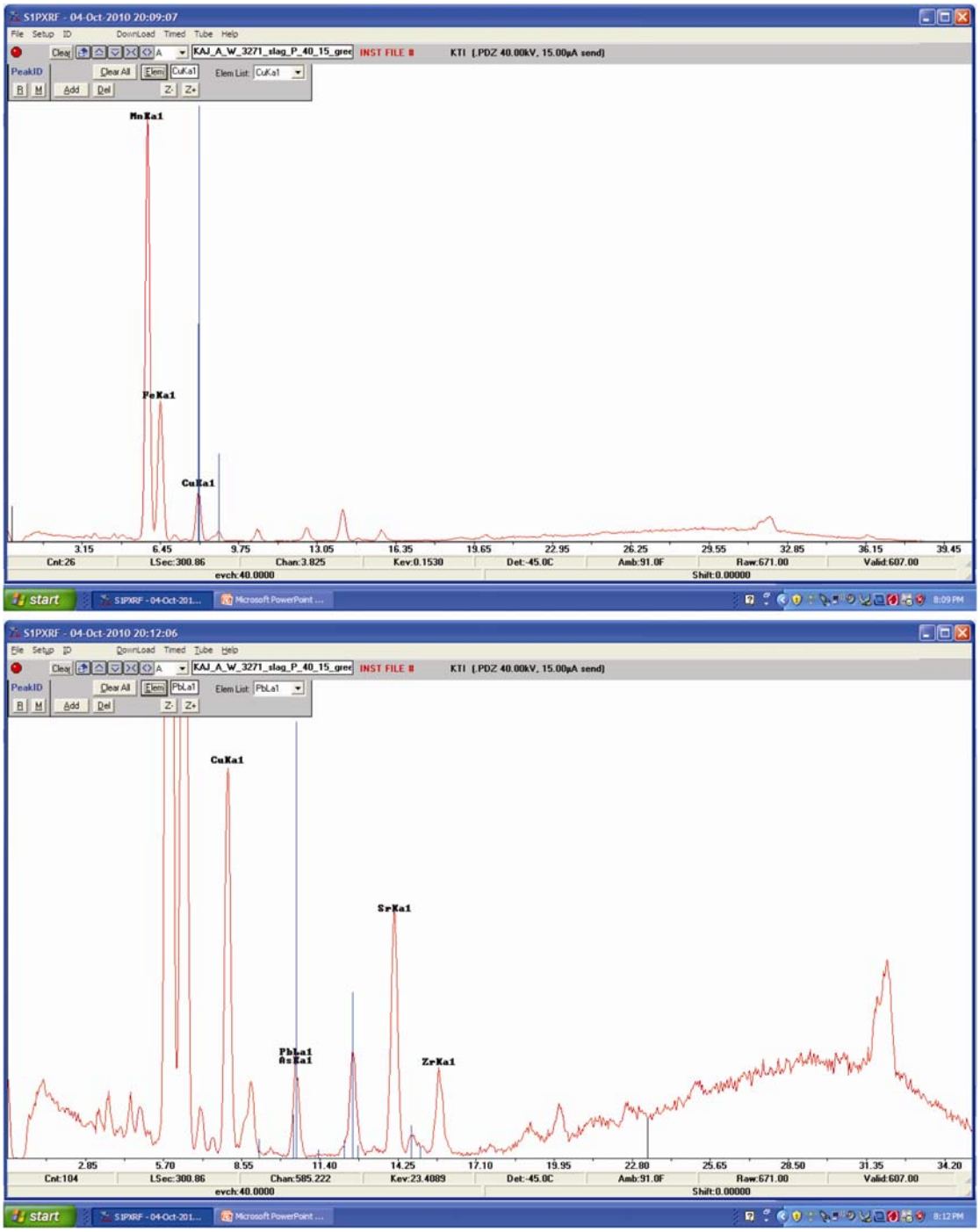
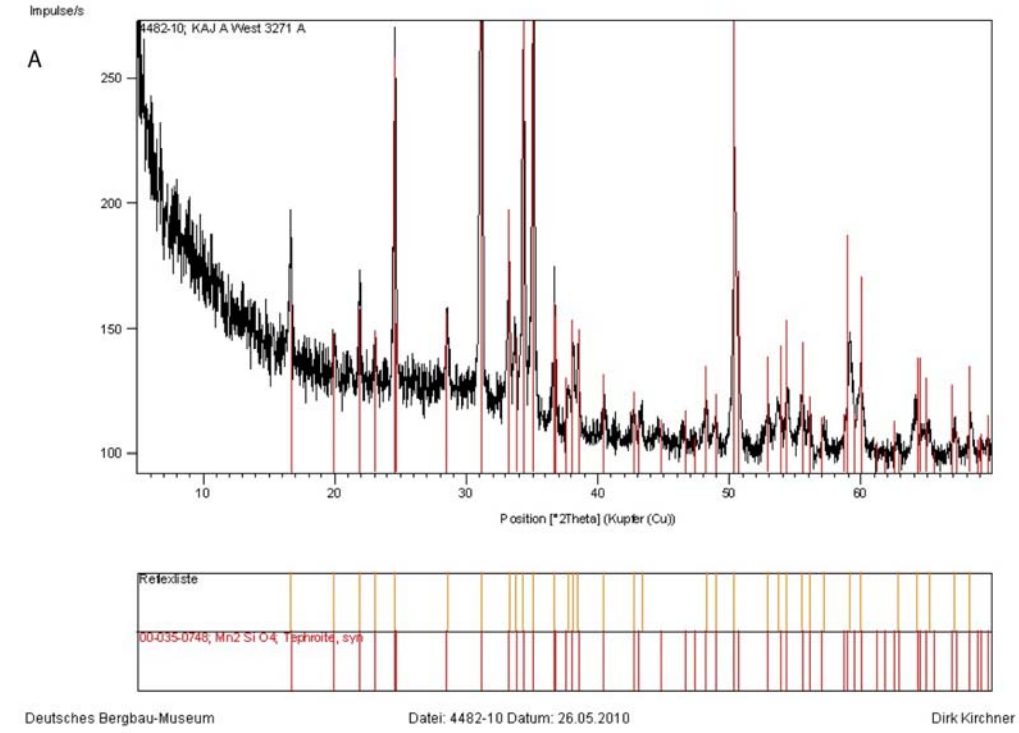


Fig.8.18: Plots of counts vs. energy level of XRF analysis on sample KAJ_A_W_3271_slag_P_45_15_green _nv_light powder.pdz (pulverized slag from Khirbat al-Jariya West Section, measured using green filter that enables better detection of the heavy elements). Upper figure shows the entire energy range and lower figure is a close up on the peaks of the less abundant elements (cf.Fig.8.16, blue filter).



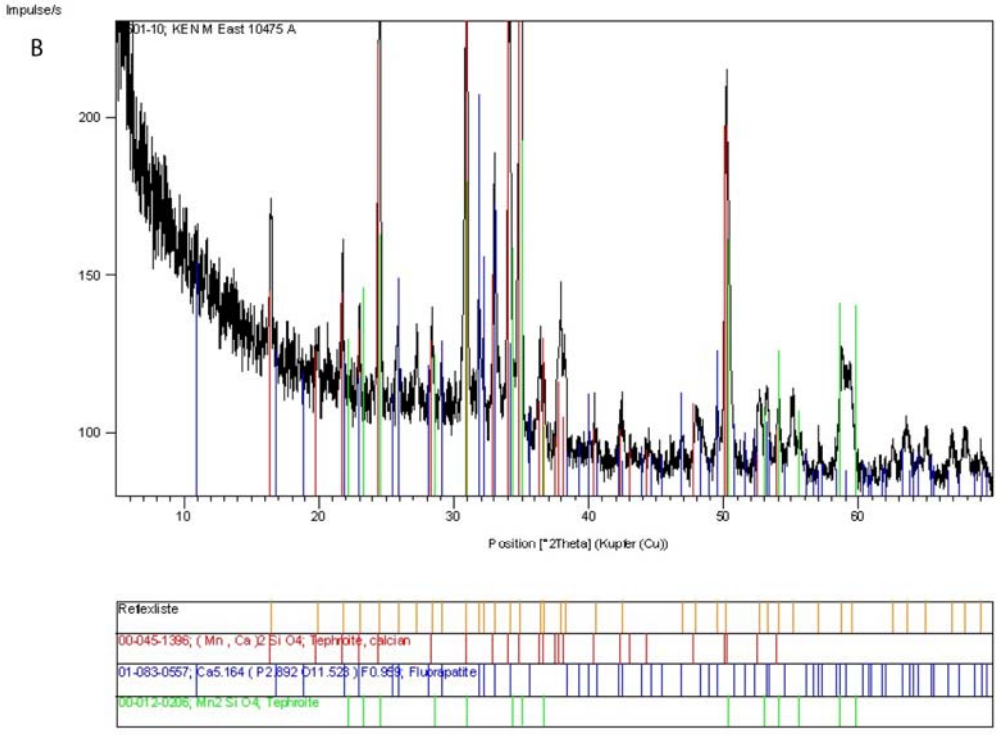


Fig.8.19: Example of standard XRD plot and mineralogical phases detection;

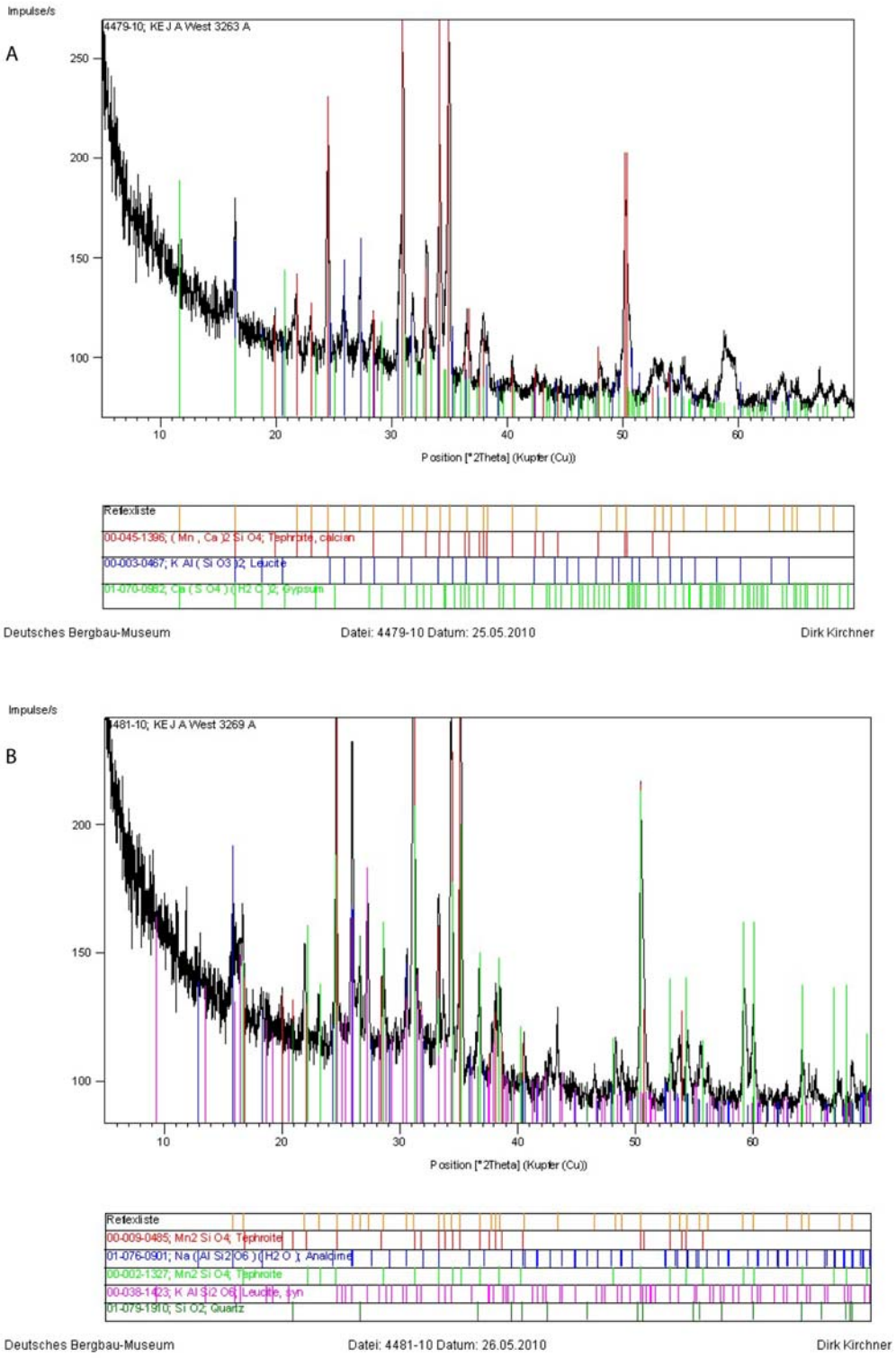


Fig.8.20: Example of standard XRD plot and mineralogical phases detection

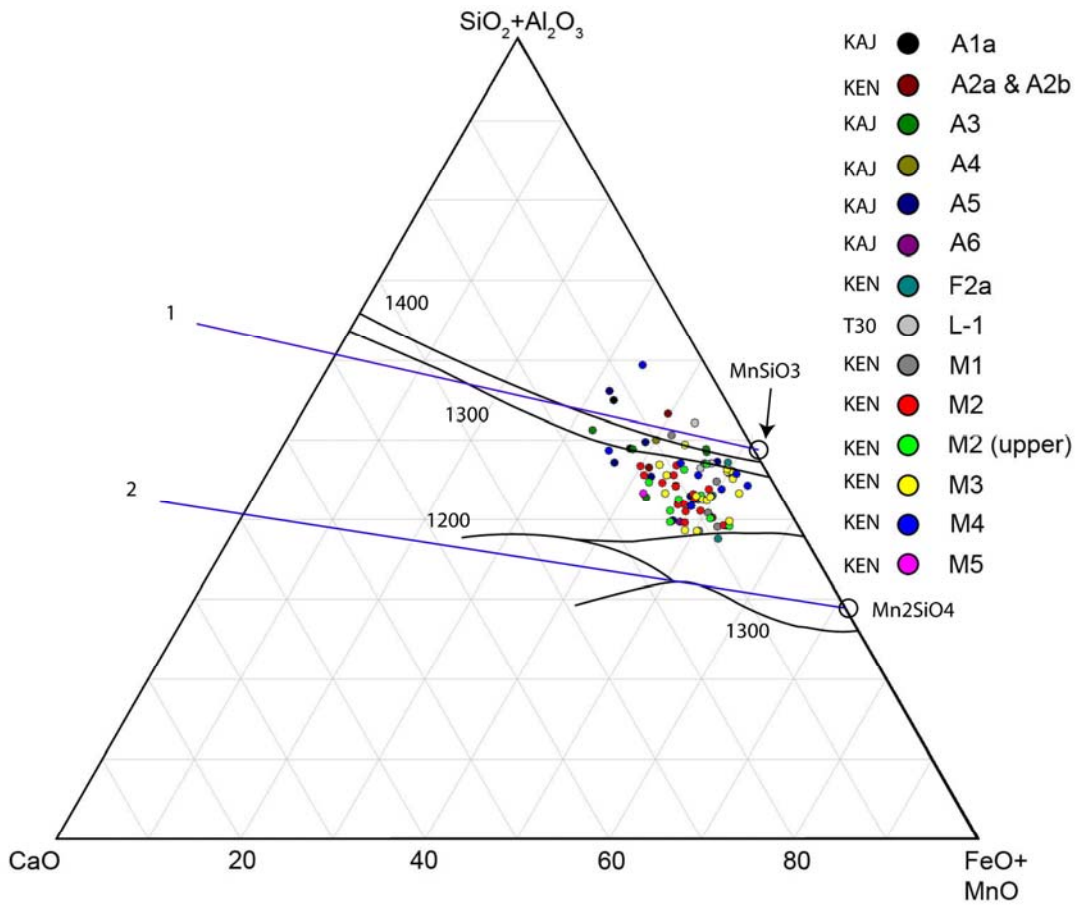


Fig.8.21: A Plot of XRF data on the ternary diagram of the system CaO – SiO_2 (+Al_2O_3) – FeO(+MnO); the plot contains all (Mn-rich) slag samples with calibrated XRF data (Timna 30 L-2, was out of calibration range [iron-rich slag]); 1: line of metasilicates, 2: line of orthosilicates. Cf. Hauptmann (2007:Fig.6.16). The samples as a whole shows more silica then the 'typical' range identified for the Iron Age by Hauptmann (including the 'typical' range for Roman slag). Most of the slag samples plotted here match the low melting area between $MnSiO_3$ and Mn_2SiO_4 on the right corner of the triangle. Few data which plot into the "forbidden" quartz – rich liquidous field probably contain inclusions of unreacted quartz. The samples are in good agreement with those of Hauptmann (2007, in various places); drawn are a few isotherms of the system which roughly indicate the low melting area in contrast to the high temperature field of quartz.

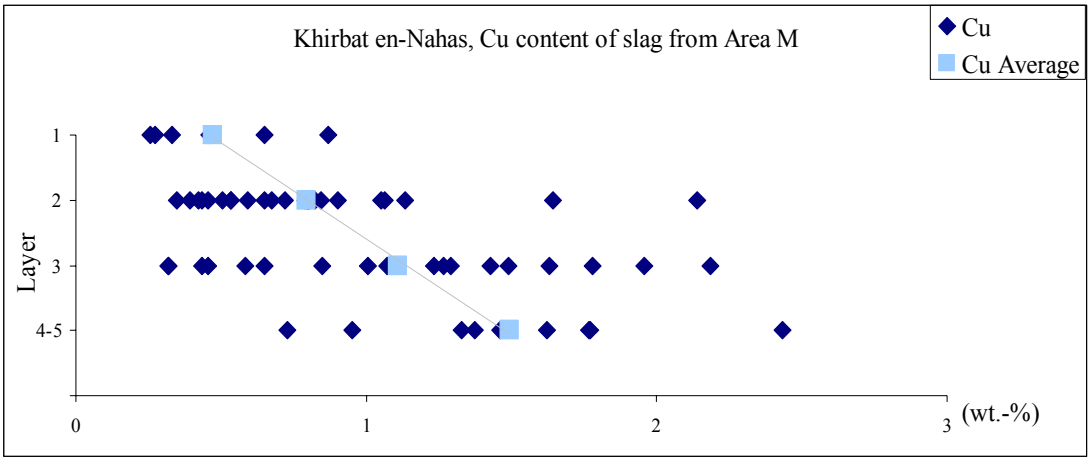


Fig.8.22: Khirbat en-Nahas, Area M, content of copper in slag samples plotted by stratigraphy. There is a linear correlation between stratum (time) and copper content indicating gradual improvement of the smelting technology (higher efficiency in extracting metal from ore). The slag samples from layer 1 presents, in addition to the lowest concentrations of copper, the tightest cluster, indicating better control over the technology and probably more standardization of the product (including final product).

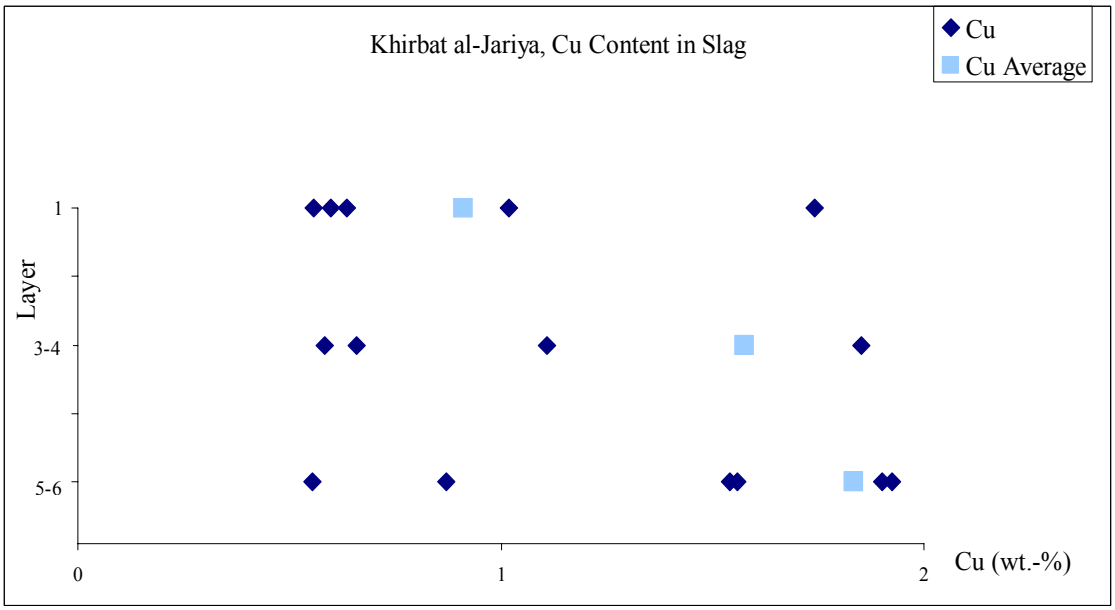


Fig.8.23: Khirbat al-Jariya, Area A, content of copper in slag samples plotted by stratigraphy. Although statistically not significant, a trend in copper content is observable (notice averages) and indicate the possibility of gradually improving the efficiency of the process through time. This tentative conclusion should be further examined with a larger sample size.

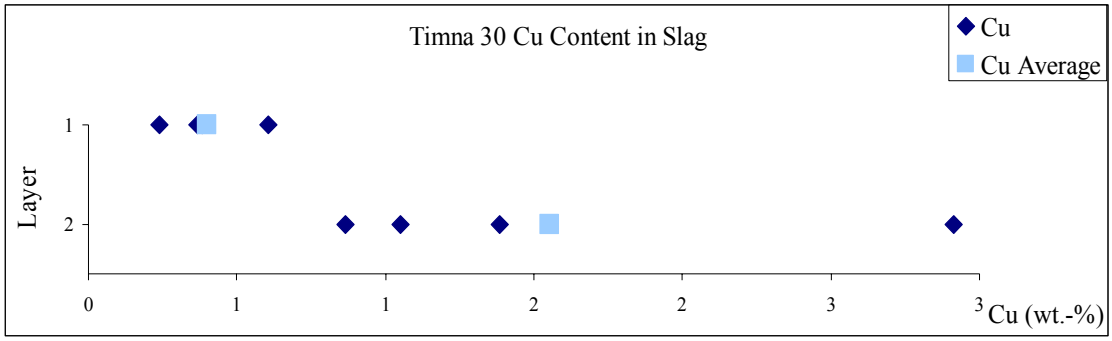


Fig.8.24: Timna Site 30: content of copper in slag samples plotted by stratigraphy. Slag samples from Layer 1 present lower concentrations of copper as well as a much tighter cluster, indicating a more efficient and better controlled smelting technology (and probably also more standardization of the production and products).

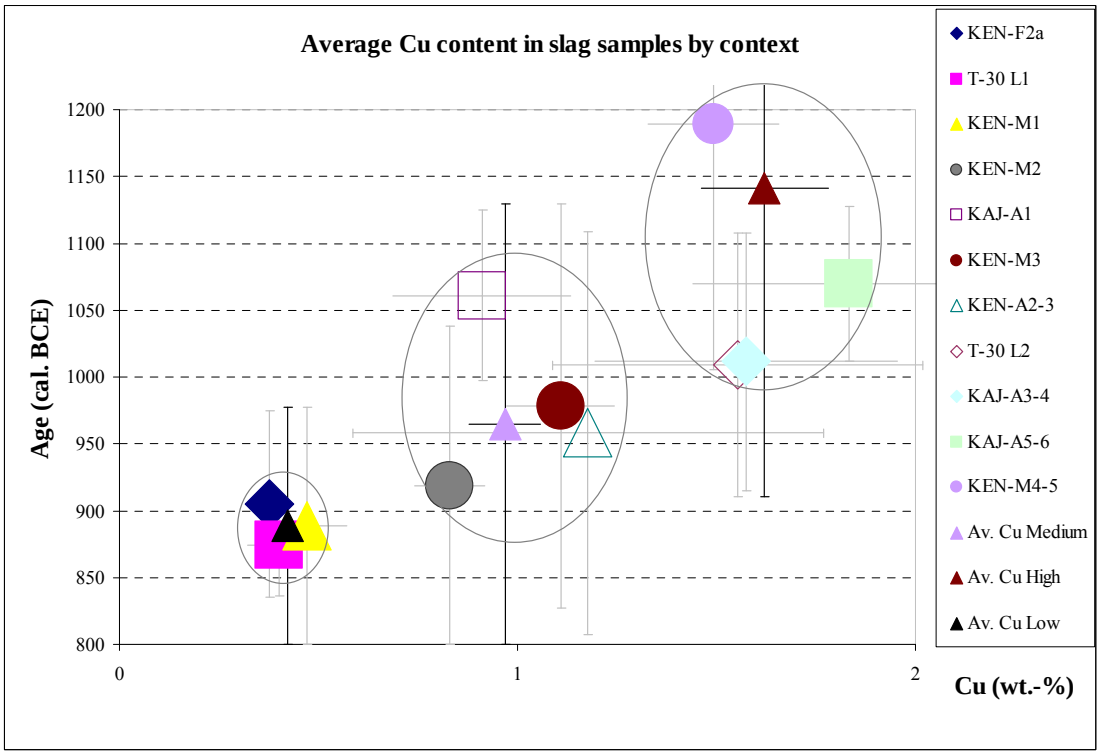


Fig.8.25: Average Cu content in slag samples by context (error bar of the x-axis represent standard error); there are three distinct groups of copper content that correspond to stratigraphic context and time periods *within* the Iron Age (see text for discussion). Ages are based on radiocarbon dates (all data within the 68.2% probability range; see Chapter 5 and 6 for details). Averages are calculated for all samples in the group range (and not average of the context averages); the lowest copper-containing slags also represent the tightest group (n=15, values in wt.-%: average =0.42±0.18, median=0.37, max=0.87, min=0.24); the medium copper-containing group (n=54, values in wt.-%: average=0.97±0.66, median=0.79, max=4.11, min=0.32) and the high copper-containing group (n=27, values in wt.-%: average=1.62±0.83, max=4.25, min=0.56) has wider ranges (also in other chemical components, see charts below) and represent less controlled (and standardized) operation. Sample

number by context: KEN-F2a=5; T-30 L1=4; KEN-M1=6; KEN-M2=24; KAJ-A1=5; KEN-M3=18; KEN-A2-3=6; KEN-M4-5=9; T-30 L2=4; KAJ-A3-4=6; KAJ-A5-6=8.

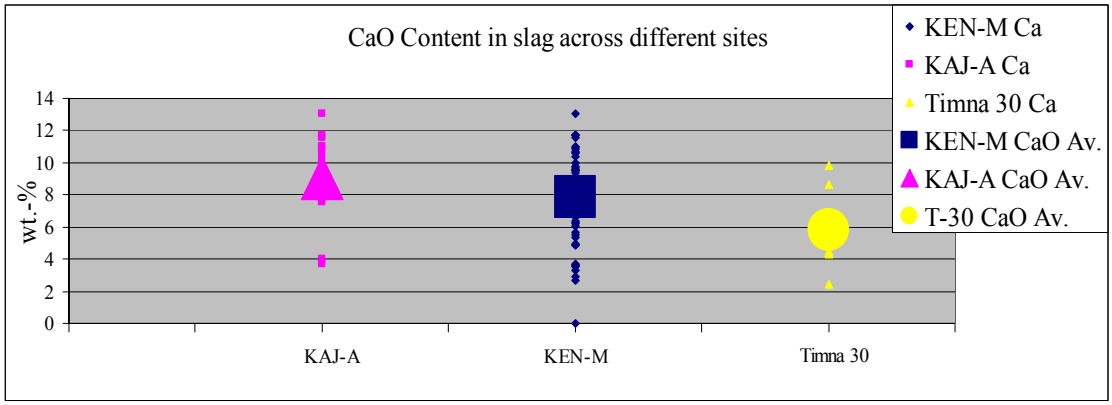


Fig.8.26: Calcium oxide content in slag samples from three different sites in Faynan and Timna.

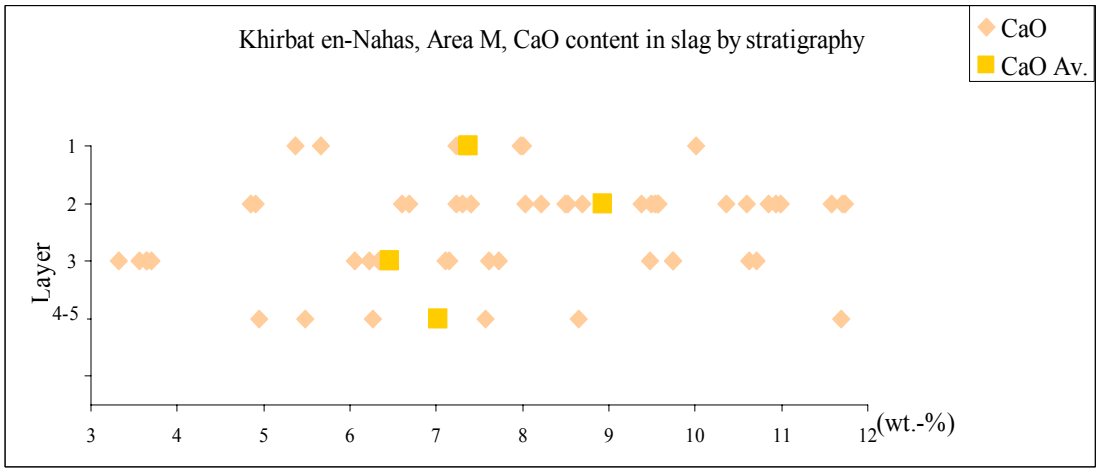


Fig.8.27: Khirbat en-Nahas, Area M, content of calcium in slag samples plotted by stratigraphy.

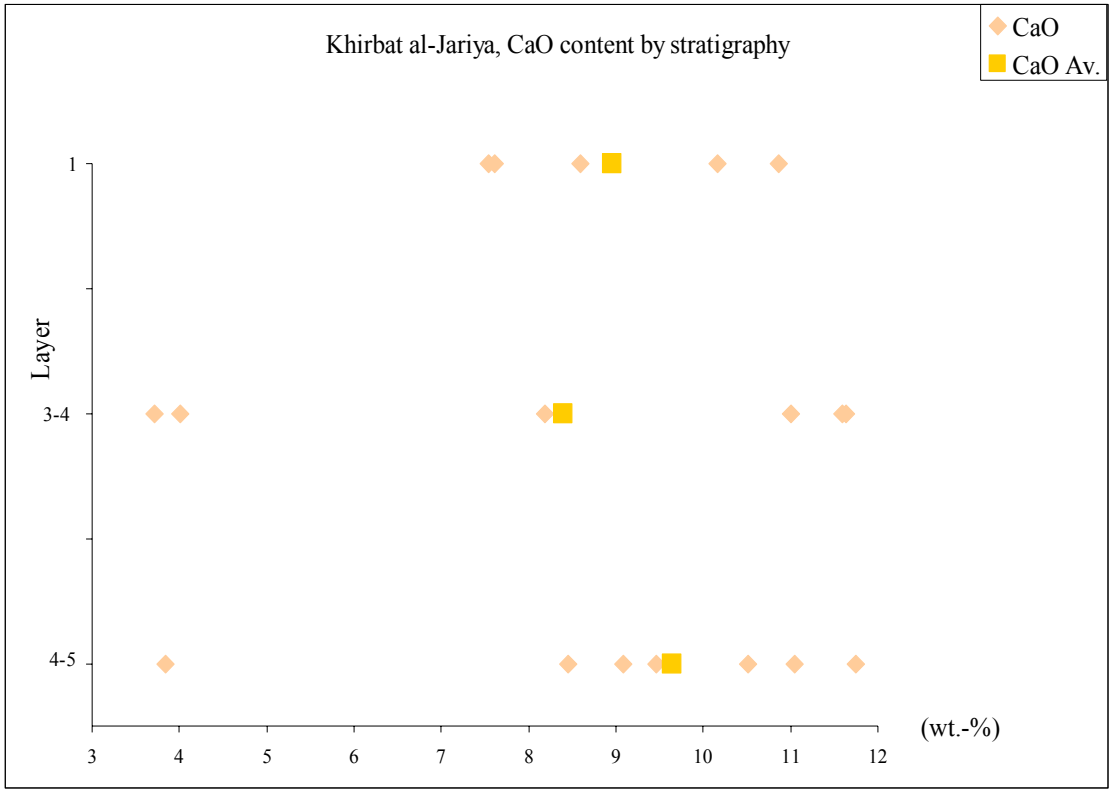


Fig.8.28: Khirbat al-Jariya, Area A, content of calcium in slag samples plotted by stratigraphy. Calcium is one of the most variable elements in the slag from this context.

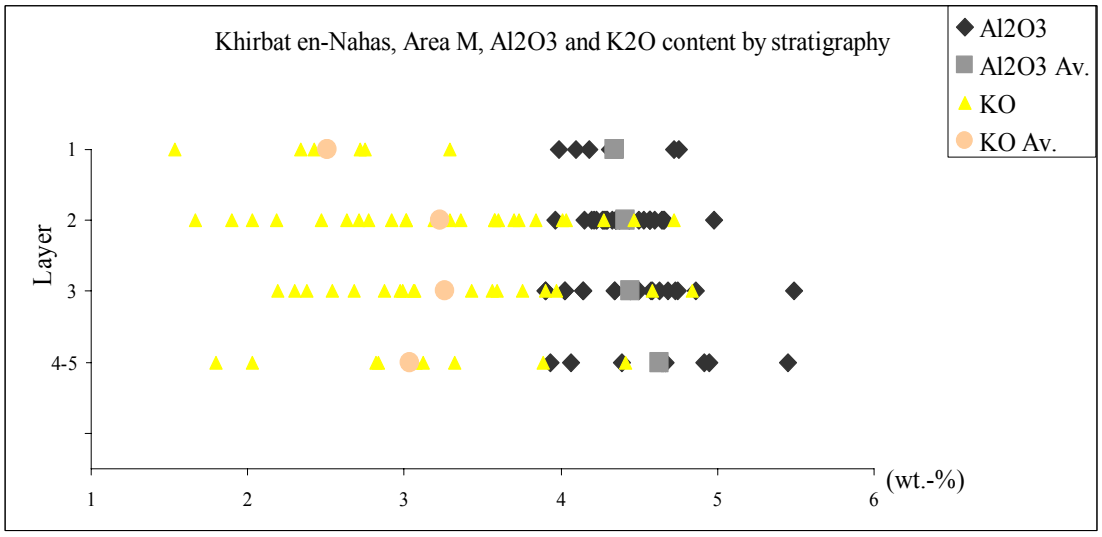


Fig.8.29: Khirbat en-Nahas, Area M, content of alumina and potassium in slag samples plotted by stratigraphy.

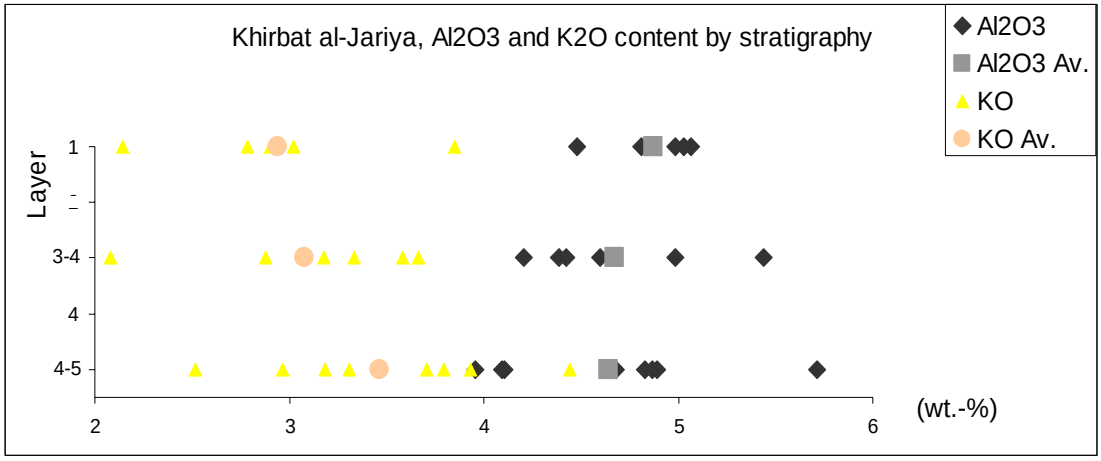


Fig.8.30: Khirbat al-Jariya, Area A, content of alumina and potassium in slag samples plotted by stratigraphy. There is a clear pattern of tighter cluster of alumina through time that indicates better control over the smelting technology (cf.Fig.8.25 for copper).

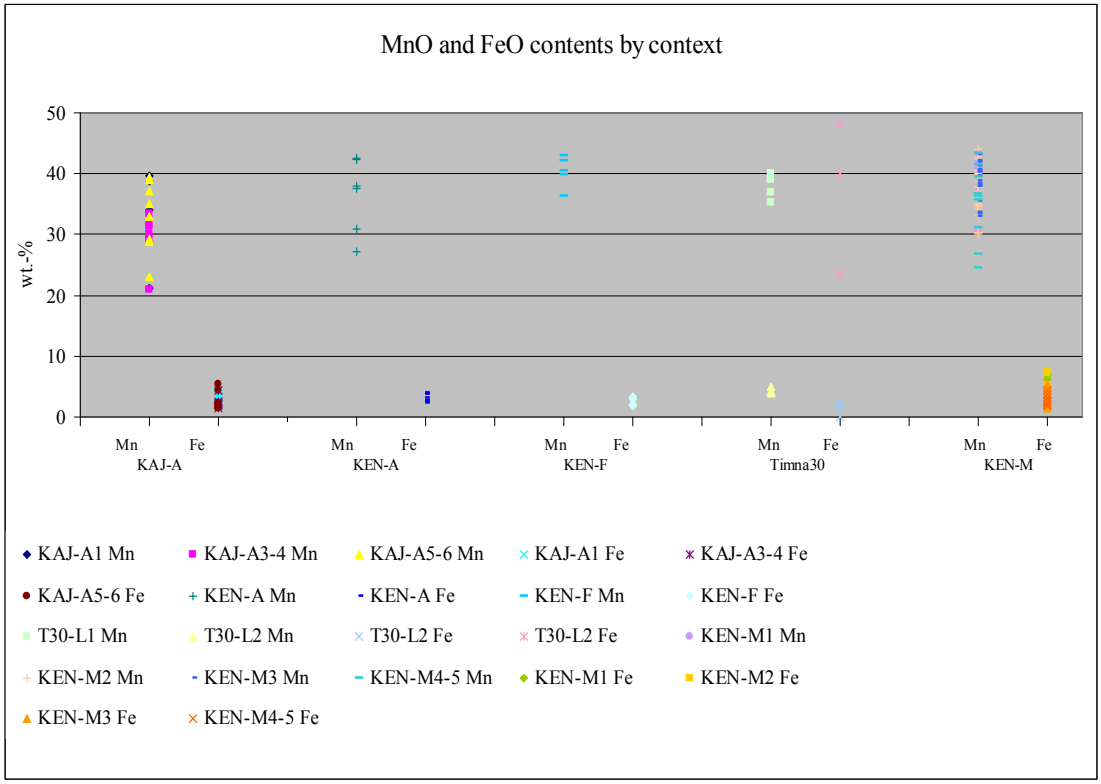


Fig.8.31: MnO and FeO contents in slag by context; the bulk proportions of all samples is similar, except from Timna 30 Layer II where the abundance of each element is reversed.

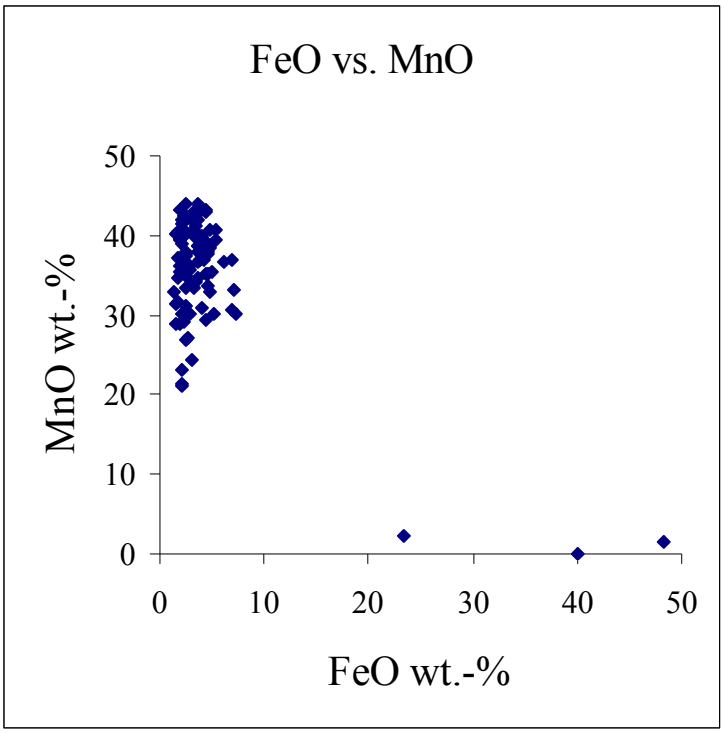


Fig.8.32: MnO vs. FeO contents in slag samples from Faynan and Timna. The Mn-rich slag of Faynan and Timna 30 L-1 has relative tight distribution. The three Fe-rich samples are from Timna 30 L-2.

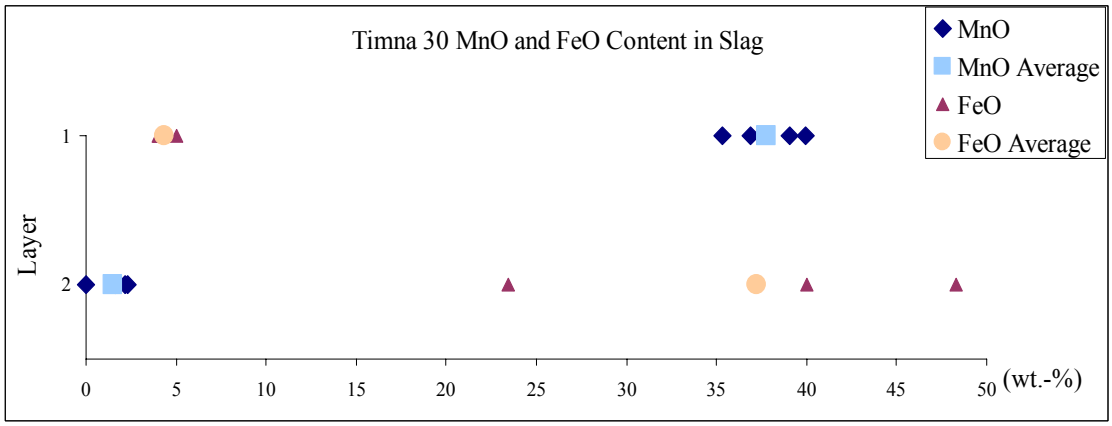


Fig.8.33: Timna Site 30: content of manganese and iron in slag samples plotted by stratigraphy. Slag samples from Layer 1 present low iron and high manganese concentration while samples from Layer 2 present high iron and low manganese concentrations. These significant differences (that was noticed in previous research, e.g., Bachmann and Rothenberg, 1980) represent an abrupt change in technology and organization of production that was recognized in the current research also in Faynan. In addition, our results demonstrate more unified compositions of slag samples from Layer 1 (i.e., tighter clusters of all elements, cf. Fig.8.19), which indicates a better controlled smelting technique and probably more standardization of the products (including the final ones).

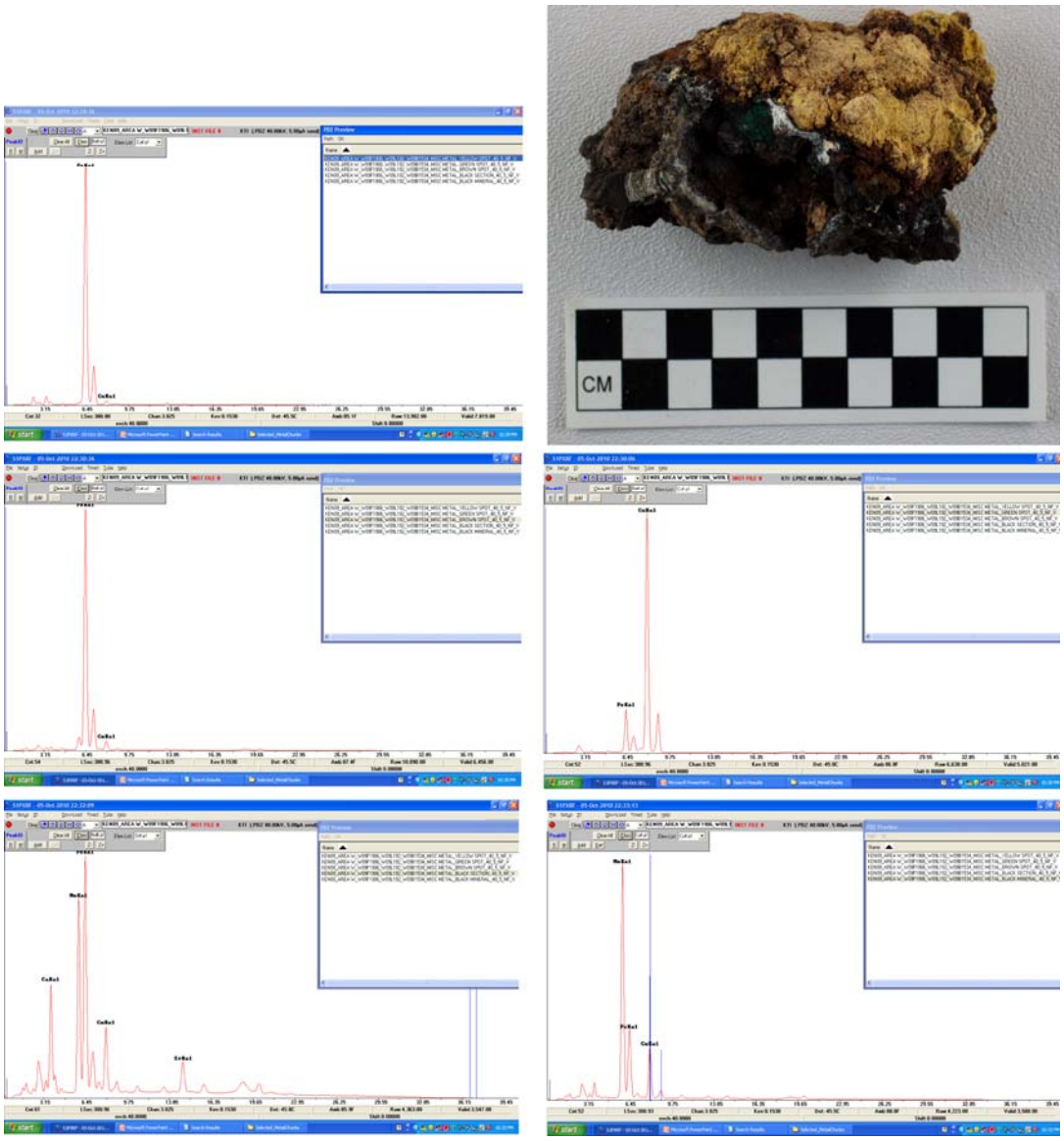


Fig.8.34: Example of XRF plots for ‘metal chunks’, an abundant find especially in the late (9th century BCE) layers at KEN (Area W, EDM w09f1906, Basket w09b1534, Locus w09l192). These metal chunks, found in smelting related contexts, present a mixture of iron and copper (they are the dominant components in all plot, with different proportions). These preliminary analyses imply that iron was part of the raw (primary) smelting product. Is it the result of a failed smelting operation or is it the typical raw product that was further refined (e.g., in the workshop found in KEN Area F), is still not clear (see text).



Fig. 8.35: Petrographic microscope at the German Mining Museum used to analyze slag thin sections in the current research.



Fig.8.36: Scans of selected thin section of slag samples (regular digital scanning); A) SM 4481 (KAJ-3269), reddish slag, containing high concentration of cuprite and microscopic copper prills (cf. Figs.8.39, 8.40A-C); B) SM 4507 (KEN-10483), four different layers in slag fragment representing different cooling fronts – the original vertical position can be inferred (in this image the top was the original top of the slag while cooling); C) SM 4480 (KAJ-3267), slag layer (right) attached to a fragment of sandstone (left), the crust on the sandstone margins is secondary gypsum; D) SM 4477 (T30-S2-S2), a piece of re-(s)melted slag (bright rectangle on the right) and a fragment of sandstone from Timna Site 30 Layer 1, ; E) SM 4479 (KAJ-3263) slag inclusion in slag from Khirbat al-Jariya, indicating the use of crush slag as part of the smelting process; F) SM 4492 (KEN-10282), quartz grains attached to a piece of slag (?).

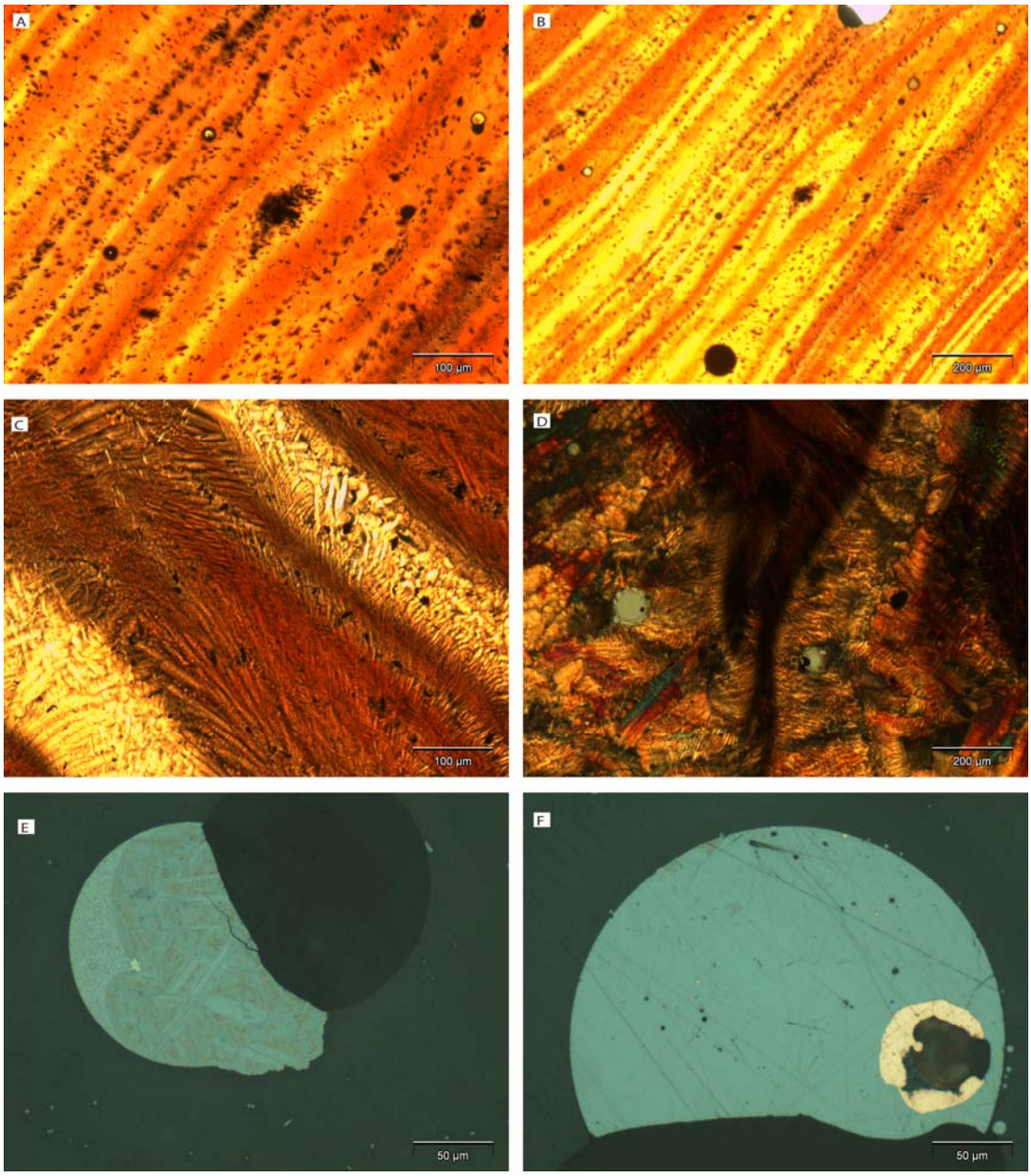


Fig.8.37: Photographs of selected thin section of Iron Age slag (Sample Number [SN] 4488, KEN-10260) as seen with different magnifications through a light (petrographic) microscope (some with polarized light). A)-B) Streaks in a 'glassy' slag with micro-scale inclusions of cuprite and copper (large inclusion in B is copper prill); C)-D) typical insipient stage of crystallization of olivine (in this case probably tephroite) from a glassy slag; E) inclusion of chalcocite; F) Cu-sulphide with metallic copper (bright), gas bubble and corrosion (black part).

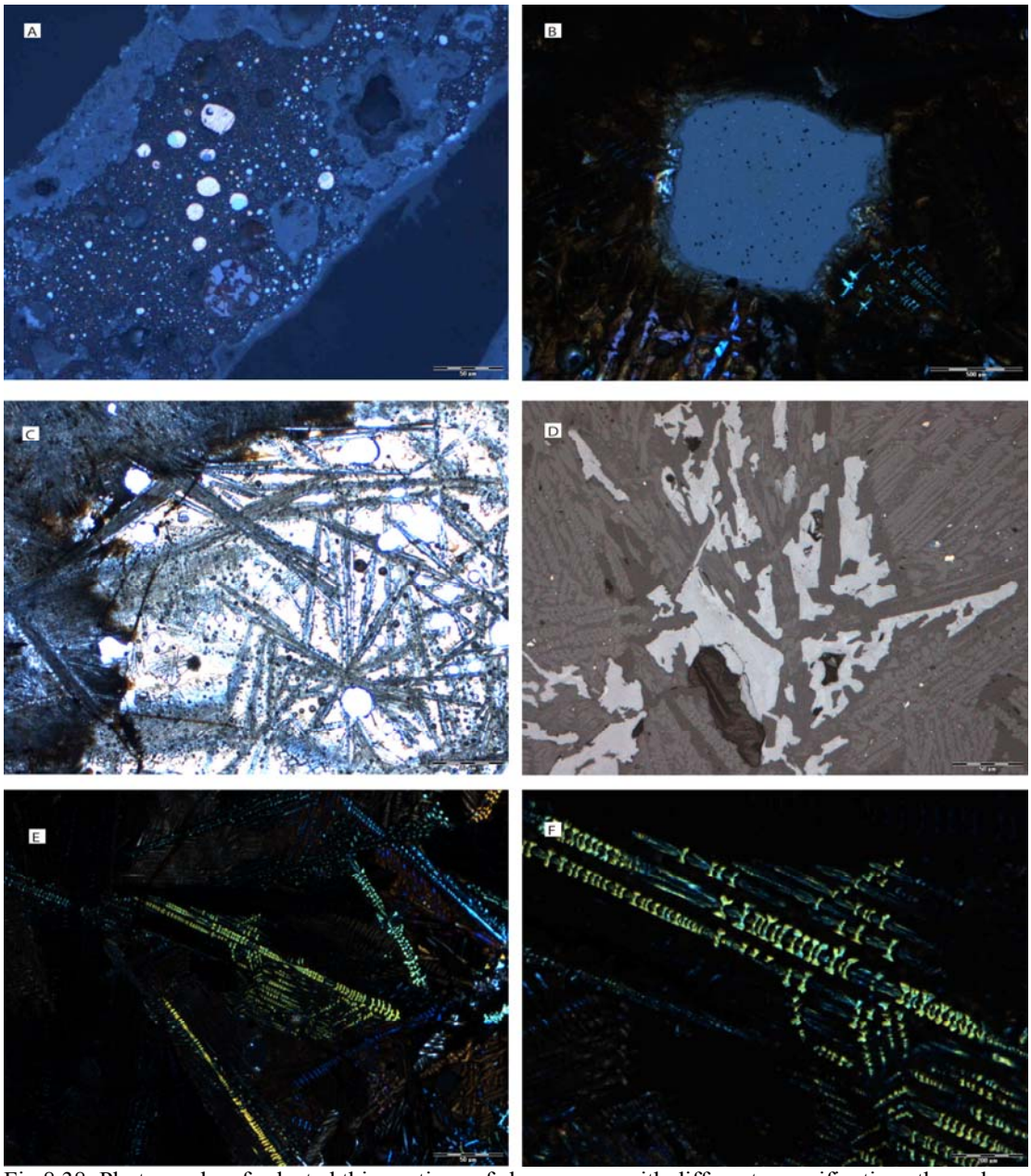


Fig.8.38: Photographs of selected thin sections of slag as seen with different magnifications through a light (petrographic) microscope (some with polarized light): A) SN 4477 (T30-S2-S2); (B) SN 4476 (T30-S2-S1); C) SN 4477 (T30-S2-S2), slag inc; D) SN 4501 (KEN-10475), Mn ore remains; E) SN 4479 (KAJ-3263); F) SN 4479 (KAJ-3263).

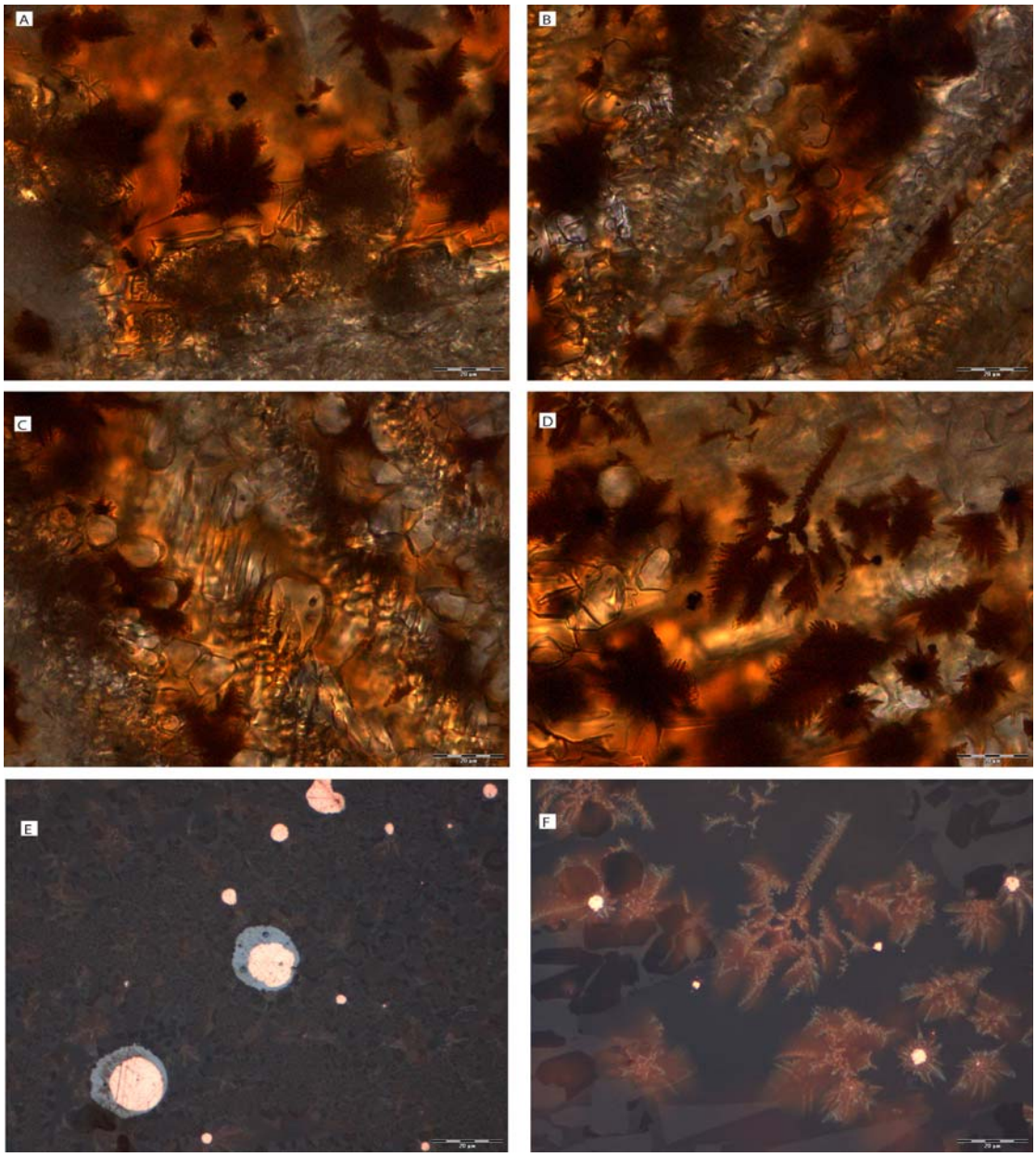


Fig.8.39: Photographs of selected thin section of slag (SN 4481, KAJ-3269) as seen with different magnifications through a light (petrographic) microscope (some with polarized light) (cf. Fig.8.36A): copper prills and cuprite.

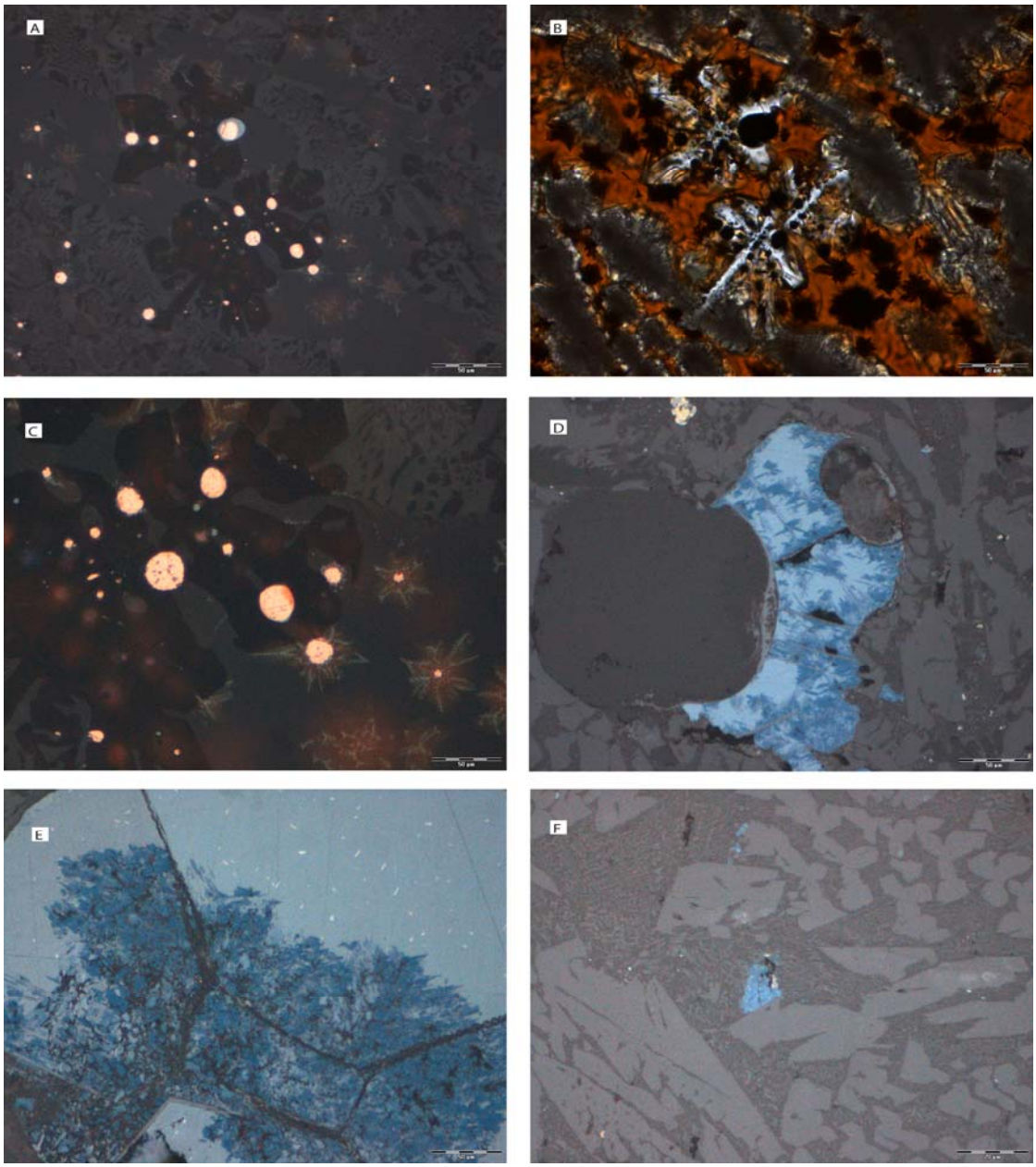


Fig.8.40: Photographs of selected thin sections of slag as seen with different magnifications through a light (petrographic) microscope (some with polarized light): A) SN 4481 (KAJ-3269) Cu prills, lucite; B) same as A) with polarized light; C) SN 4481 (KAJ-3269), Cu prills, cuprite; D) SN 4501 (KEN-10475), covelite around Cu prills; E) SN 4501 (KEN-10475), covelite; F) SN 4501 (KEN-10475), covelite and Cu.

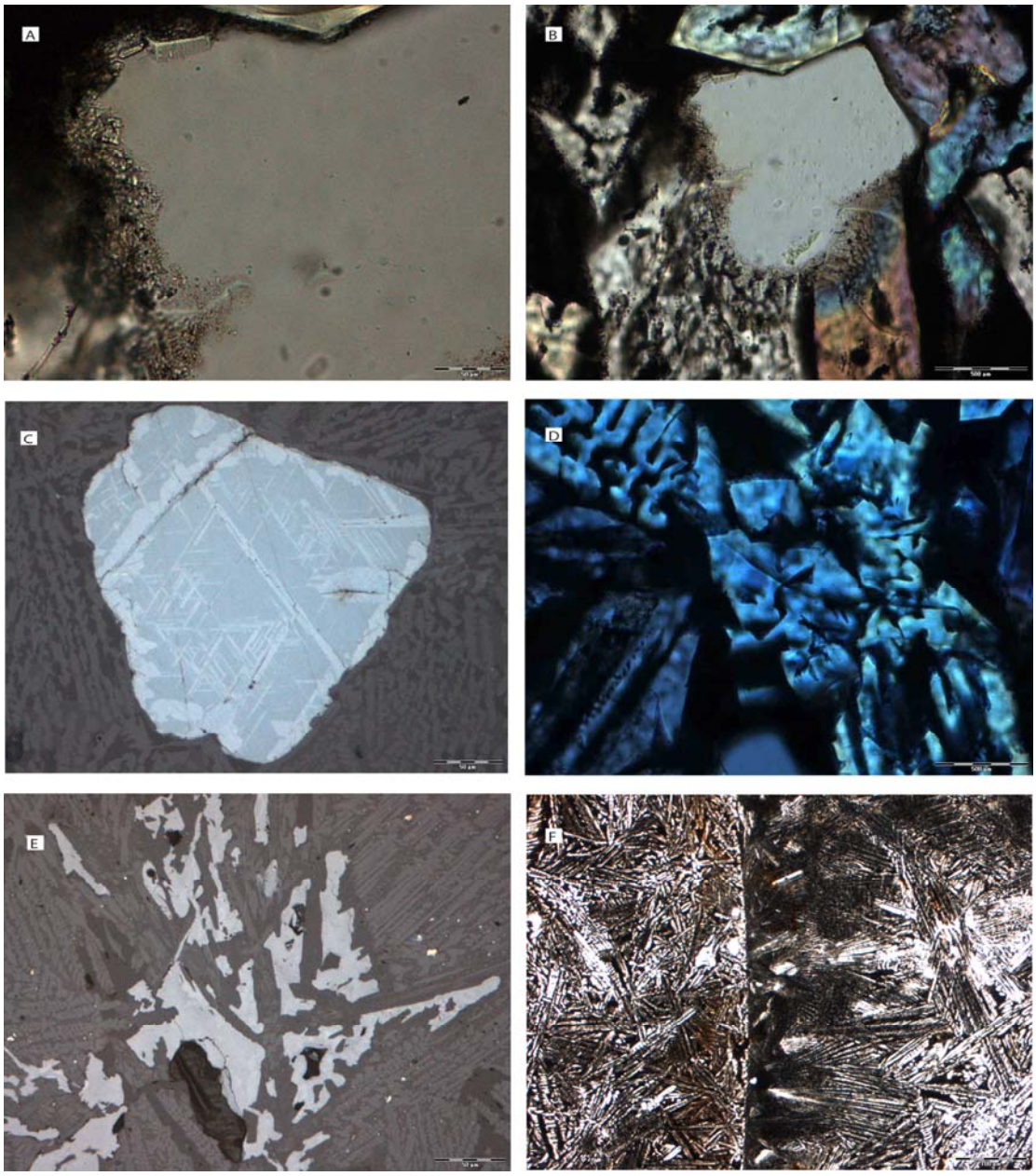


Fig.8.41: Photographs of selected thin sections of slag as seen with different magnifications through a light (petrographic) microscope (some with polarized light): A) SN 4507 (KEN-10483), cristobalite; B) SN 4507 (KEN-10483), cristobalite (same as A with a smaller magnification); C) SM 4494 (KEN-10460), chalcocite; D) SN 4510 (KEN-10490), tephroatie?; E) SN 4501 (KEN-10475), covelite; F) SN 4507 (KEN-10483), layers representing cooling fronts in slag.

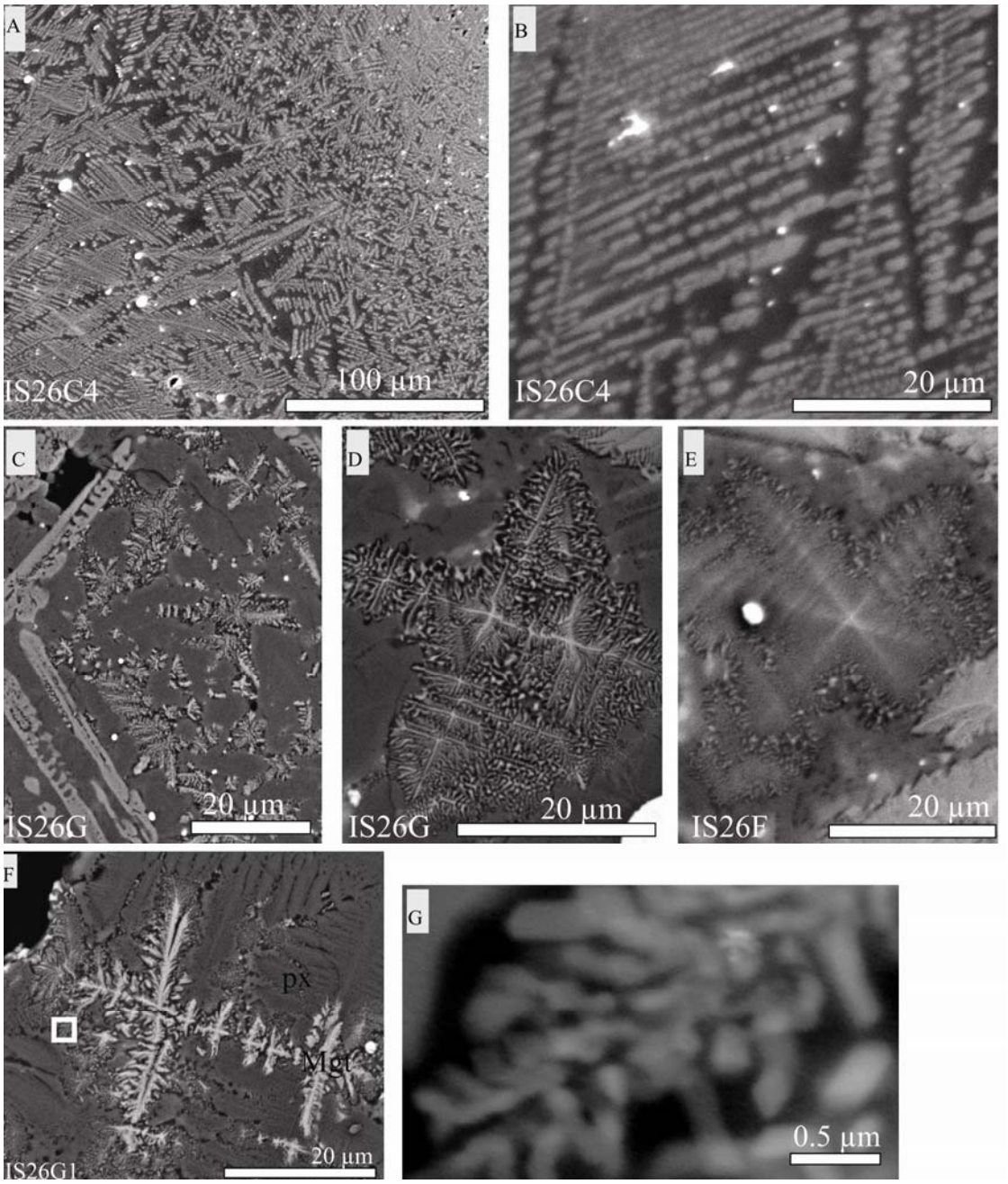


Fig.8.42: Representative scanning electron images of Iron Age slag samples from Timna Site 30 (photographs courtesy of Ron Shaar, see Shaar et al., 2010): A) and B) are textures of 'group A slag' (Mn-rich slag from Layer 1, see section 6.2.1.2 above), the slag contains thre phases: Mn–Fe oxides arranged in a dendritic texture (light gray), pure copper droplets (bright white), and a silicate matrix (dark gray). C)–G) textures of 'group B slag' (Fe-rich slag from Layer 2, see section 6.2.1.2 above), the slag contains large needle-shaped silicate phenocrysts, copper droplets (bright white), Fe oxides arranged in a dendritic texture (light gray), and a silicate matrix (dark gray).

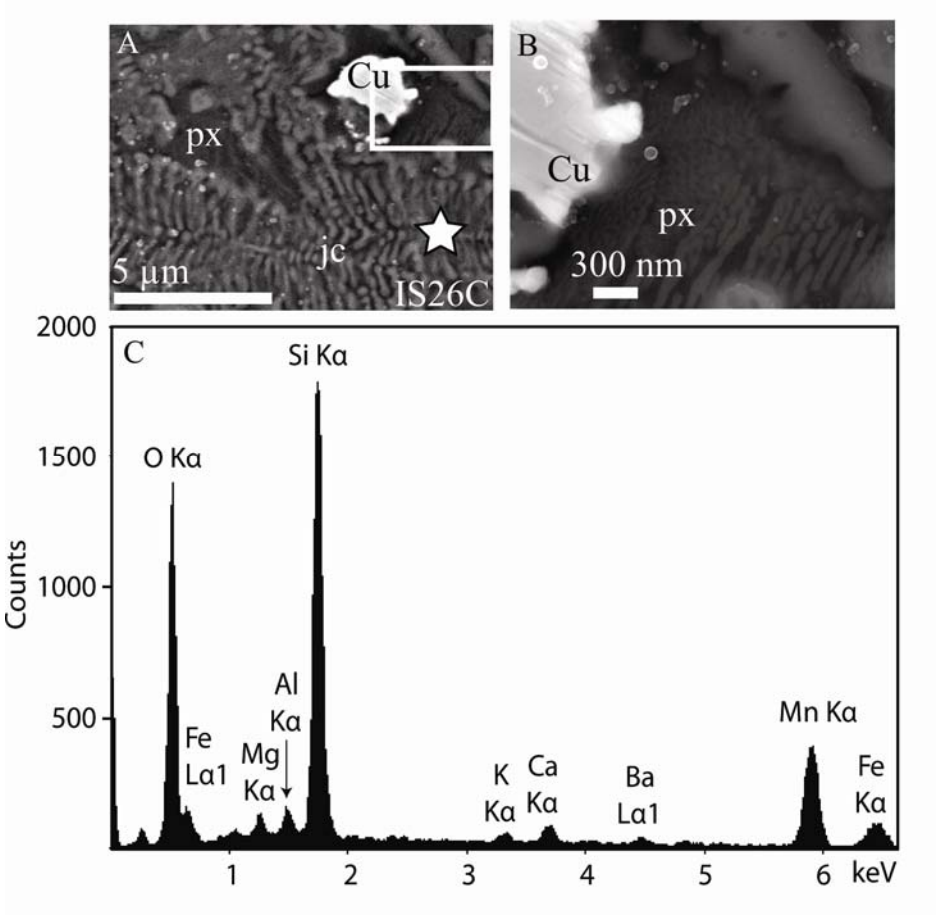


Fig.8.43: Electron microscope analysis of Iron Age slag from Timna Site 30 (Group 'A', Mn-rich slag from Layer 1) (figures courtesy of Ron Shaar, see Shaar et al., 2010): A) Backscattered electron image of Group A slag showing copper droplets (Cu), dendrites of strongly magnetic, isometric, Mn-rich oxide (jc), and intergrowths of enstatite and wollastonite (px). B) A magnified view of the intergrowths of enstatite and wollastonite adjacent to the copper droplet. C) EDS compositional measurement of the Mn-rich oxide. The star in (A) indicates the location of the measurement.

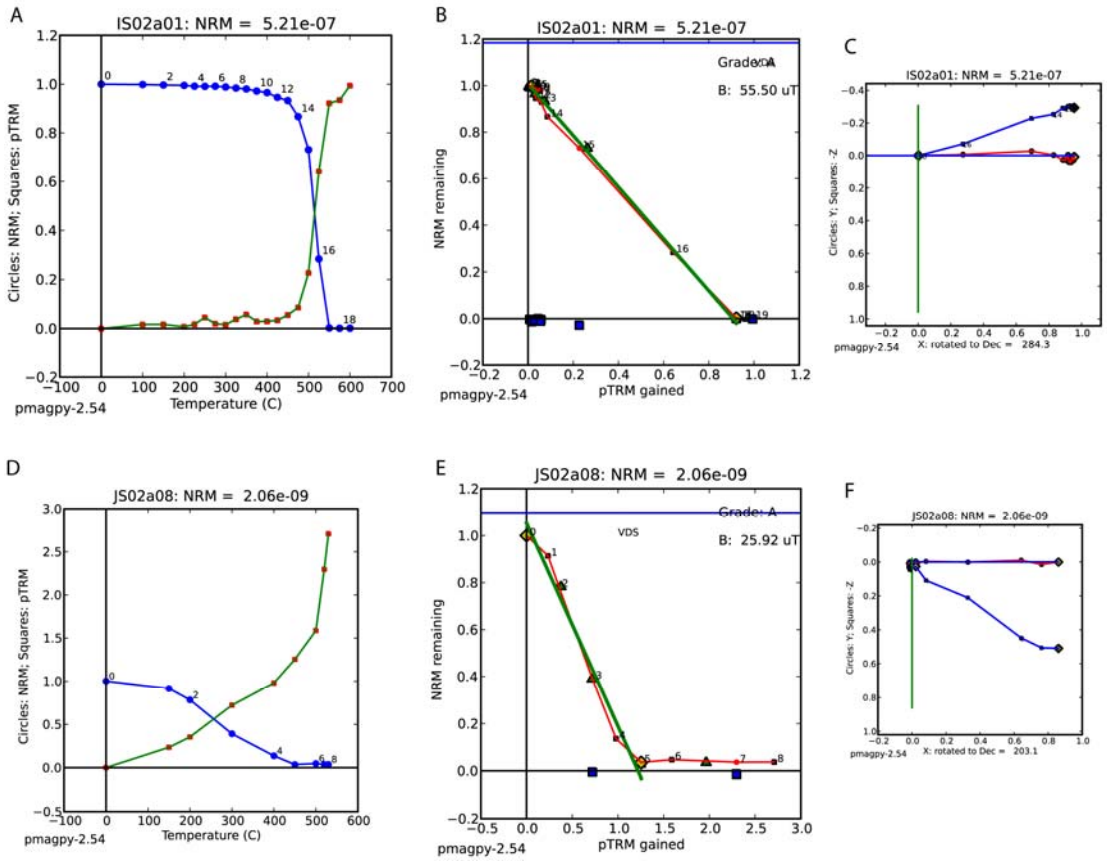


Fig.8.44: Examples of magnetic behavior of common two types of Iron Age slag (Mn- and Fe-rich): A)-C) Sample IS02a01 from Site 149 in Timna (section 6.2.4) represents typical behavior of Fe-rich slag during archaeomagnetic experiments; D)-F Sample JS02a08 from Khirbat al-Jariya represents typical behavior of Mn-rich slag. The main difference between the two types is the *blocking temperature* of magnetization (Tauxe, 2010). The Mn-rich slag has much lower blocking temperature (magnetic carrier is mostly jacobsite, see Shaar et al., 2010) than the Fe-rich slag (magnetic carrier is mostly magnetite). For explanation of the method see section 4.2.2; for detailed explanation and key to the diagram see Fig.6.30 above, and Tauxe (2010)

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PART III

SYNTHESIS

9. Chaînes opératoires

This chapter attempts to synthesize the currently available data regarding Iron Age copper production in the southern Levant and to reconstruct various aspects of production systems *throughout* this period, with emphasis on the interrelations between technology and society. The data, both environmental and archaeological, are presented in detail in previous chapters and include substantial amounts of new information gathered as part of the research presented here. The analytic method (*chaîne opératoire*) and the theoretical concepts (mostly derived from technology and production studies) used to organize and interpret the data are introduced in Chapter 1 above. To contextualize observations of ancient material culture, it is essential to consider culture-historical processes to help explain *change* in combination with social mechanisms. This is especially important when a case study covers a substantial interval of time (here, ca. seven centuries) in a region with a history of dynamic geopolitical developments. Thus, culture history developments that are relevant for the interpretation of the technological record are also discussed here.

Basic *chaînes opératoires* related to copper production technologies in the Arabah Valley have been introduced previously by several scholars. Hauptmann

(2007:7) provides general scheme for copper production in Faynan in general, with components applicable to any period (Fig.9.1). Refining this approach, Levy et al (2002a:431) applied the method to Early Bronze III metal production in Faynan. Merkel (1990:78) and Craddock (1995:157) provide detailed schemes regarding Late Bronze – Iron Ages *smelting* and *ore beneficiation*[97] technologies (respectively) in Timna (Figs.9.2 and 9.3). As we have demonstrated throughout this work, the technological reconstructions for Timna are relevant to Iron Age Faynan because of technological and temporal parallels. In fact, for the discussion presented here we considered both records to represent production systems and technologies of the same social groups (see Chapter 10), because our analyses presented here (Chapters 6, 7 and 8, as well as the corresponding chaînes opératoires presented in this chapter) demonstrate that the Iron Age archaeometallurgical records are indistinguishable from each other, with the exception of some components dictated by environmental differences. Levy et al. (in press-a) present the only scheme so far that includes social components of the Iron Age (10^{th} century BCE) copper production system in Faynan (Fig.9.4). However, this scheme also provides a very basic skeleton, with few interpretive components and without a demonstration of the dynamic and contextual aspects of the Iron Age production systems. The following provides a more holistic view of Iron Age primary copper production systems, integrating technology, organization of production and social contexts.

[97] In mining, beneficiation is the process of separation of the ore minerals from the host rock (or gangue) to increase the concentration of the desired material.

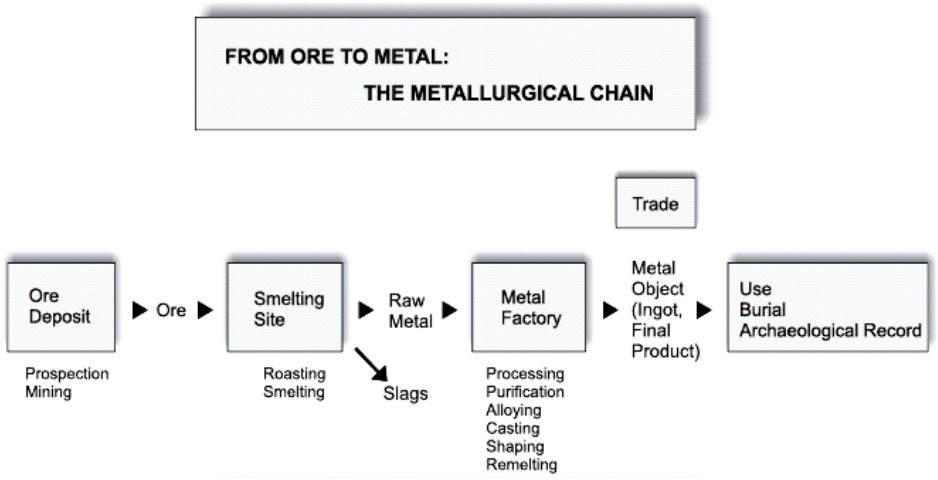


Fig.9.1: Basic chain of copper production components in Faynan, Jordan (from Hauptmann, 2007:7). The scheme is relevant to all periods of copper exploitation in this region.

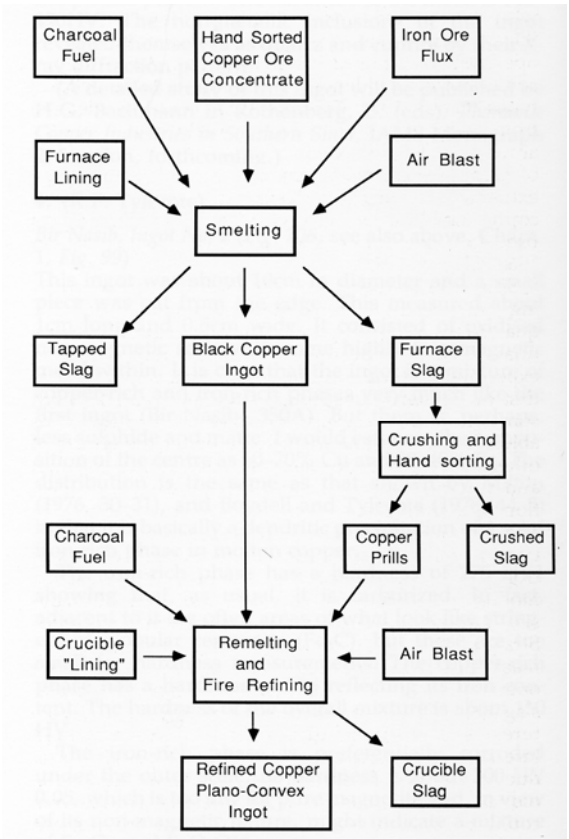


Fig.9.2: Basic chain of copper smelting in Late Bronze – Iron Age Timna (from Merkel, 1990:78).

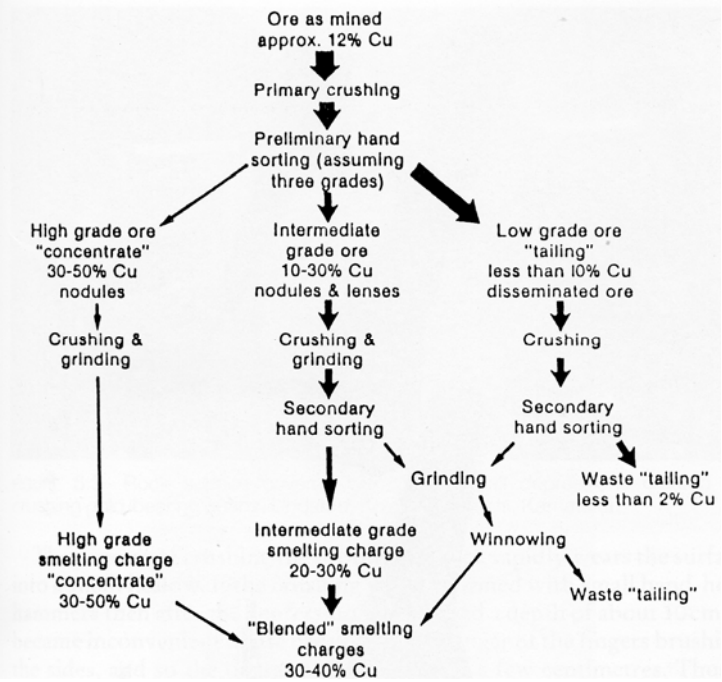


Fig.9.3: Basic chain of copper ore beneficiation in Late Bronze – Iron Age Timna (from Craddock, 1995:157).

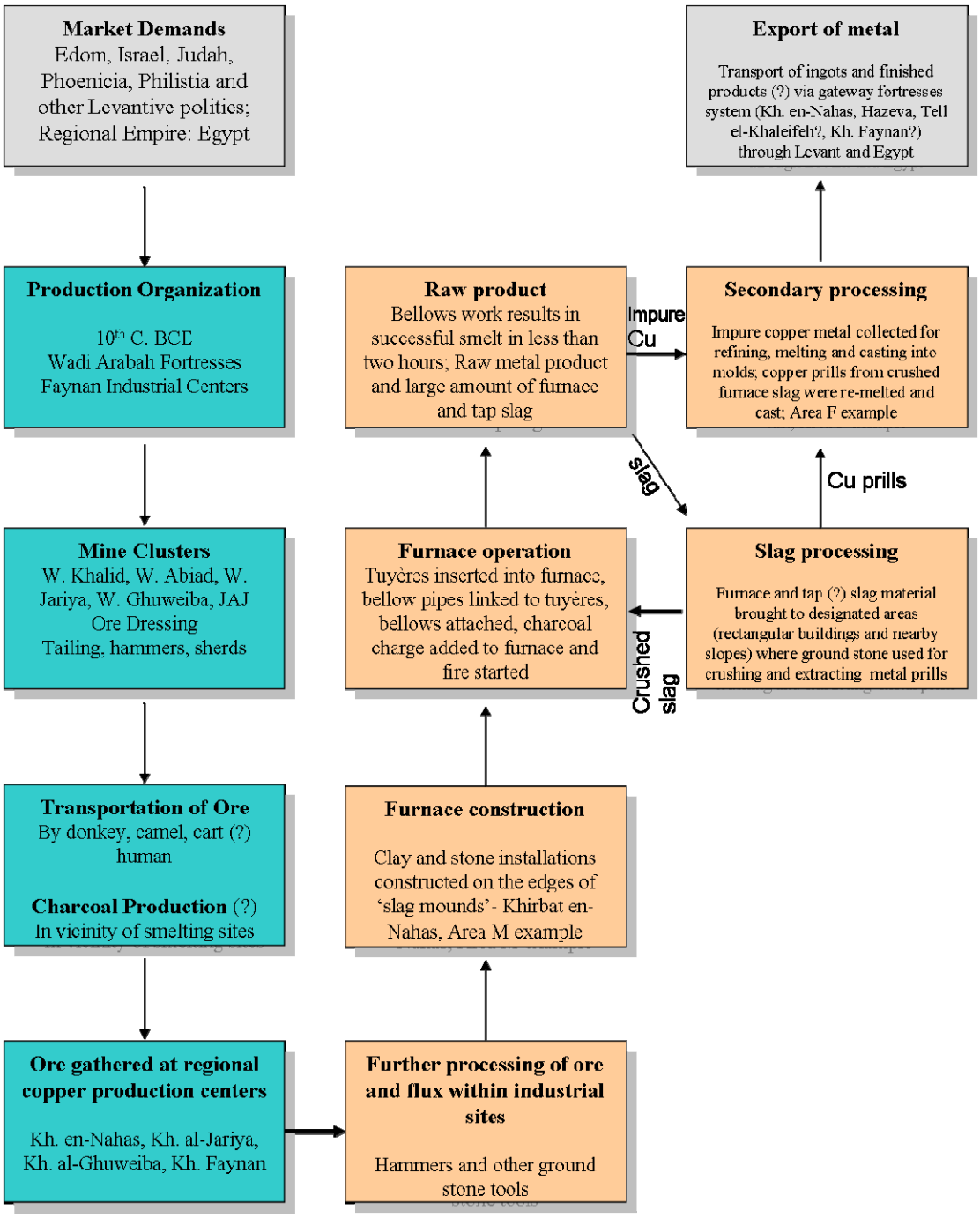


Fig.9.4: Flow chart delineating the main components of the *chaîne opératoire* for the 10th century BCE copper production in Faynan, Jordan (from Levy et al., in press-a).

9.1 Chaînes and meanings: detailed reconstruction of Iron Age copper production technologies in their social context

Detailed analyses of the archaeological datasets obtained in this work, including field and laboratory evidence concerning the Iron Age archaeometallurgical record of the Arabah Valley, coupled with new suites of radiocarbon dates and relevant published materials of previous research, indicate that at least five distinguishable copper production systems operated in the southern Levant throughout the Iron Age (ca. 1200 – 586 BCE; Figs.9.5 and 9.6). Four of these systems (1-3 and 5, cf. Fig.9.5) can be divided into two regional subsystems each, occurring simultaneously in Faynan and Timna (during the Iron Age I – IIB), and one system (4, cf. Fig.9.5) is evident only in Faynan, and today includes the only secure evidence of mining (Iron Age IIC). The analyses also indicate change in production and periods with no production at all (Figs.9.5 and 9.6), and hints for a sixth production system located at Khirbat Faynan during the late Iron Age.

In the tradition of Mauss (Mauss, 1935) and the methodology developed by Leroi-Gourhan (1943; 1957) and Lemonnier (1992) (see Chapter 1), we present here the detailed technological *chaîne opératoire* for each production system (Figs.9.6 and 9.7). The core components of the different Iron Age copper production technologies defined here are similar to all of the production systems; however, the differences are a key to socio-historical-related interpretations, as they "often designate different

social realities" (Lemonnier, 1986:155), and often represent social choices (identified by detecting 'strategic moments', see Lemonnier, 1989a:156, and Chapter 1). The main advantage of delineating the technological components of the copper production systems by applying the *chaîne opératoire* method (section 1.1.2) is the objective ground it provides for interpretive attempts from the entire range of theoretical approaches in the study of technology (Chapter 1), i.e., the *chaînes* constitute the 'hard data' and should be the same regardless the theoretical medium of the interpretation (processual vs. post-processual, practical vs. cultural reason, agency vs. practical reasons etc.). The following delineates the basic components of the principal *chaîne*, with comments about differences through time (now based on radiocarbon dating and archaeomagnetic correlations) and space (Faynan – Timna [- Sinai]) (cf. Figs.9.6 and 9.7).

Fig.9.5A: Five copper production systems identified for the Iron Age southern Levant. Four systems (1-3, 5) consisted of two local sub-systems (Faynan and Timna [and probably Sinai for System 1]) that were evidently part of regional super-systems. Cf. Fig.9.6 and see text for details.

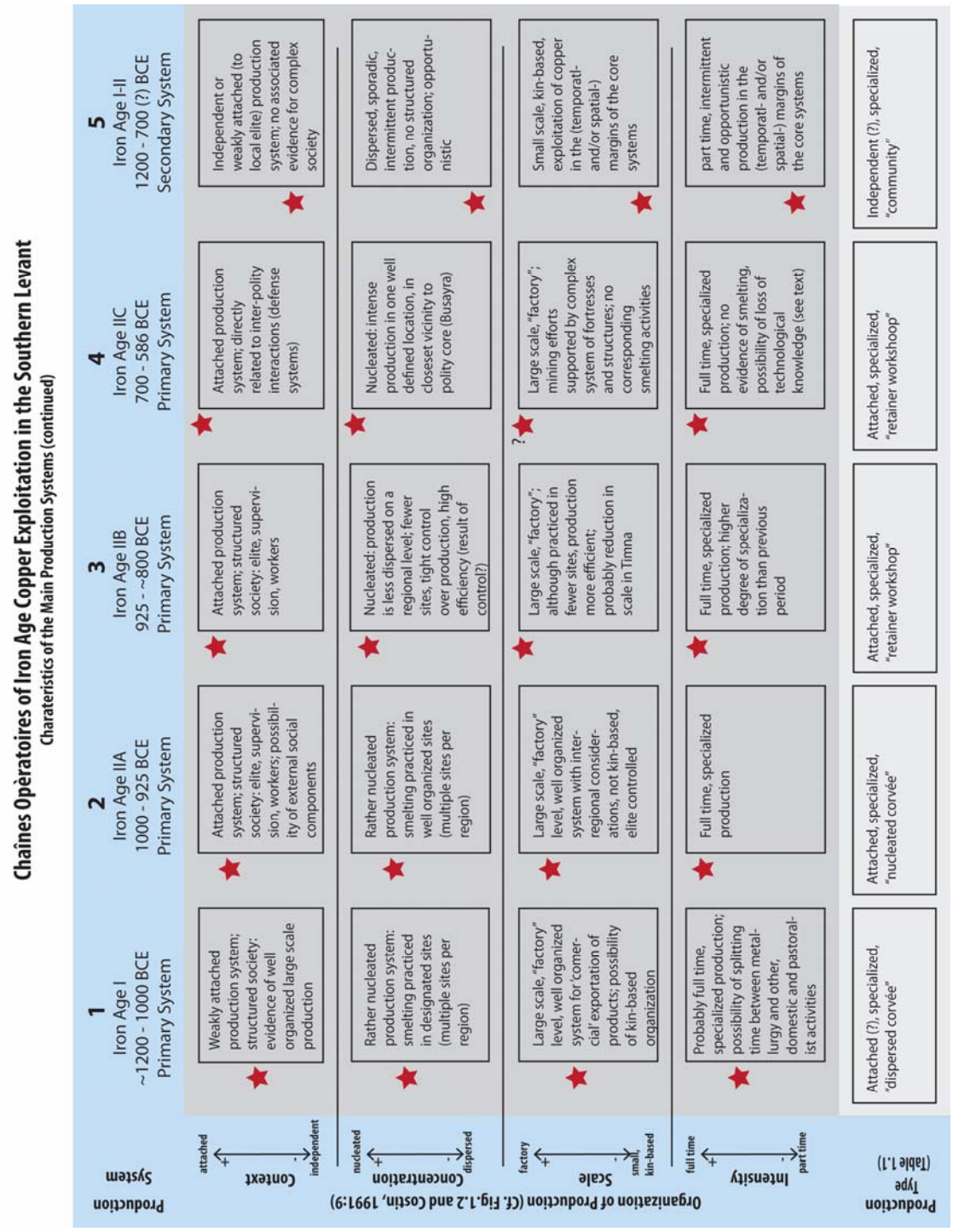


Fig.9.5B: Five copper production systems identified for the Iron Age southern Levant. Characterization of each system according to four fundamental parameters of organization of (specialized) production defined by Costin (1991). The red stars (*) indicate the *relative* degree of each parameter per each production system; they correspond to the 'y-axis' to the left (cf. Fig.1.2, Table 1.1, section 1.2; and in this chapter Figs.9.5A and 9.6).

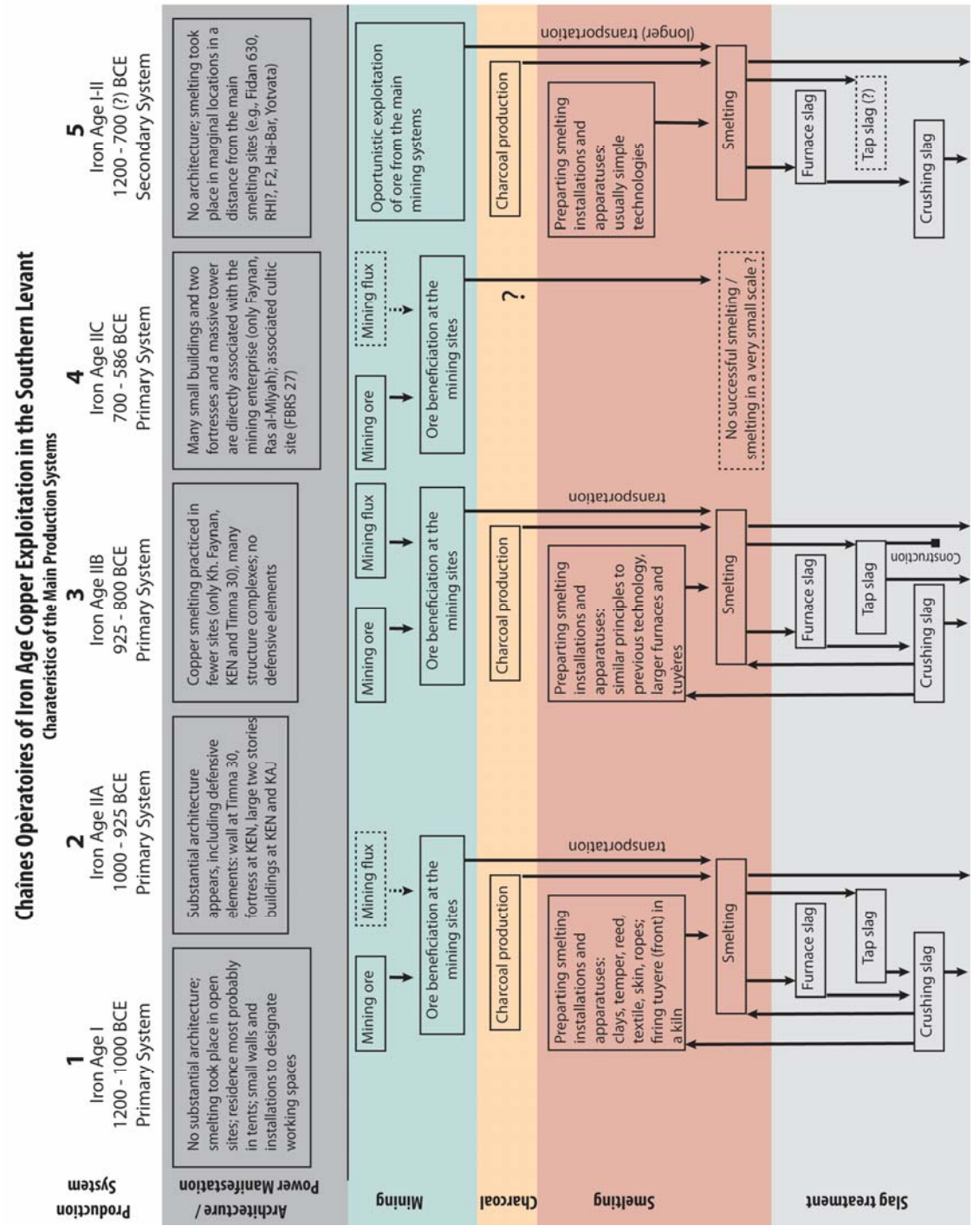


Fig.9.6A: Basic *chaînes opératoires* of Iron Age copper production in the southern Levant organized according to *production systems* (cf. Fig.9.5); part I (see Fig.9.6B for part II): mining, smelting and slag treatment. Dashed arrows and boxes indicate optional components with no or weak evidence (see text). For more details see Fig.9.7.

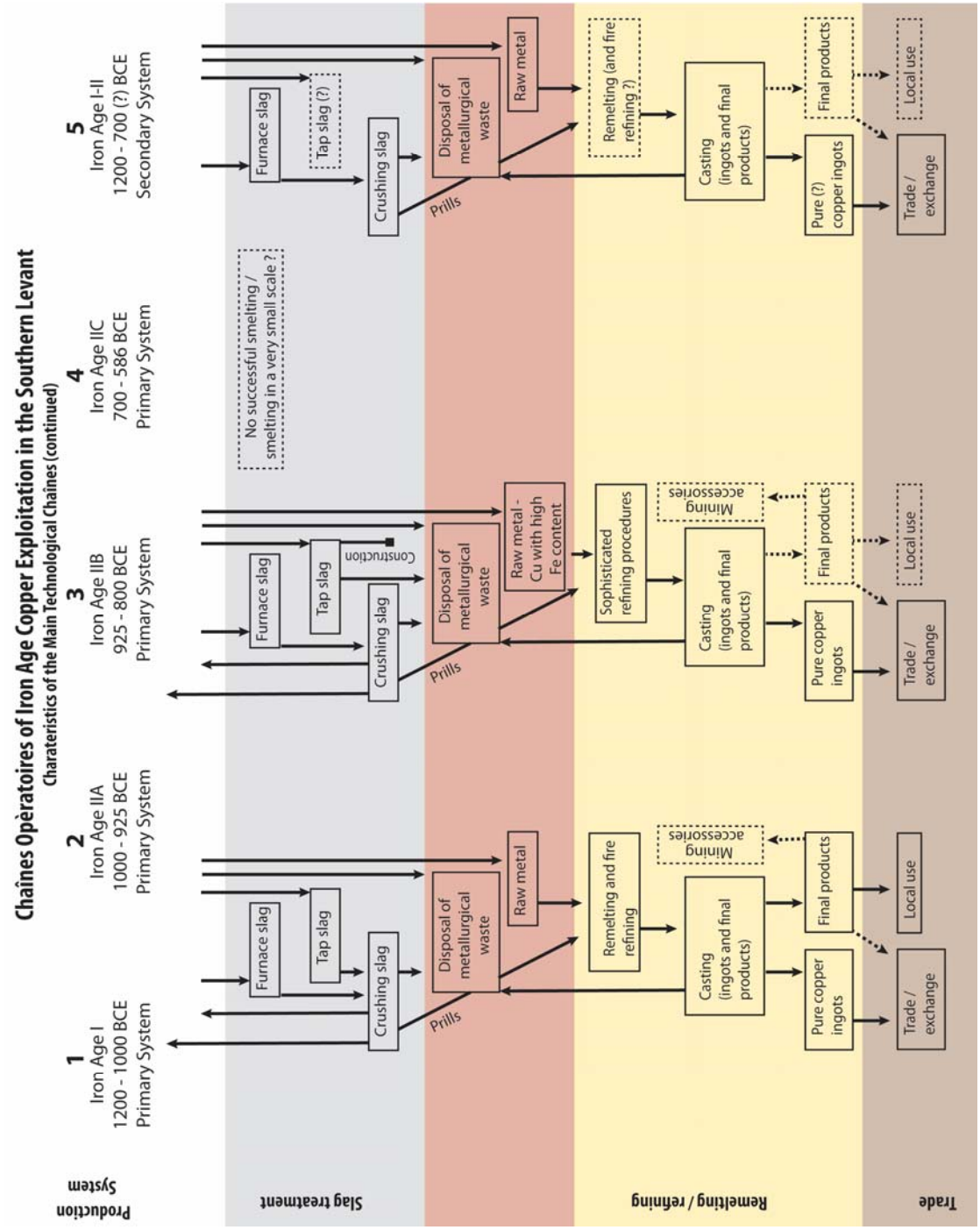


Fig.9.6B: Basic *chaînes opératoires* of Iron Age copper production in the southern Levant organized according to *production systems* (cf. Fig.9.5); part II (see Fig.9.6A for part I): slag treatment, refining, casting and exchange. Dashed arrows and boxes indicate optional components with no or weak evidence (see text). For more details see Fig.9.7.

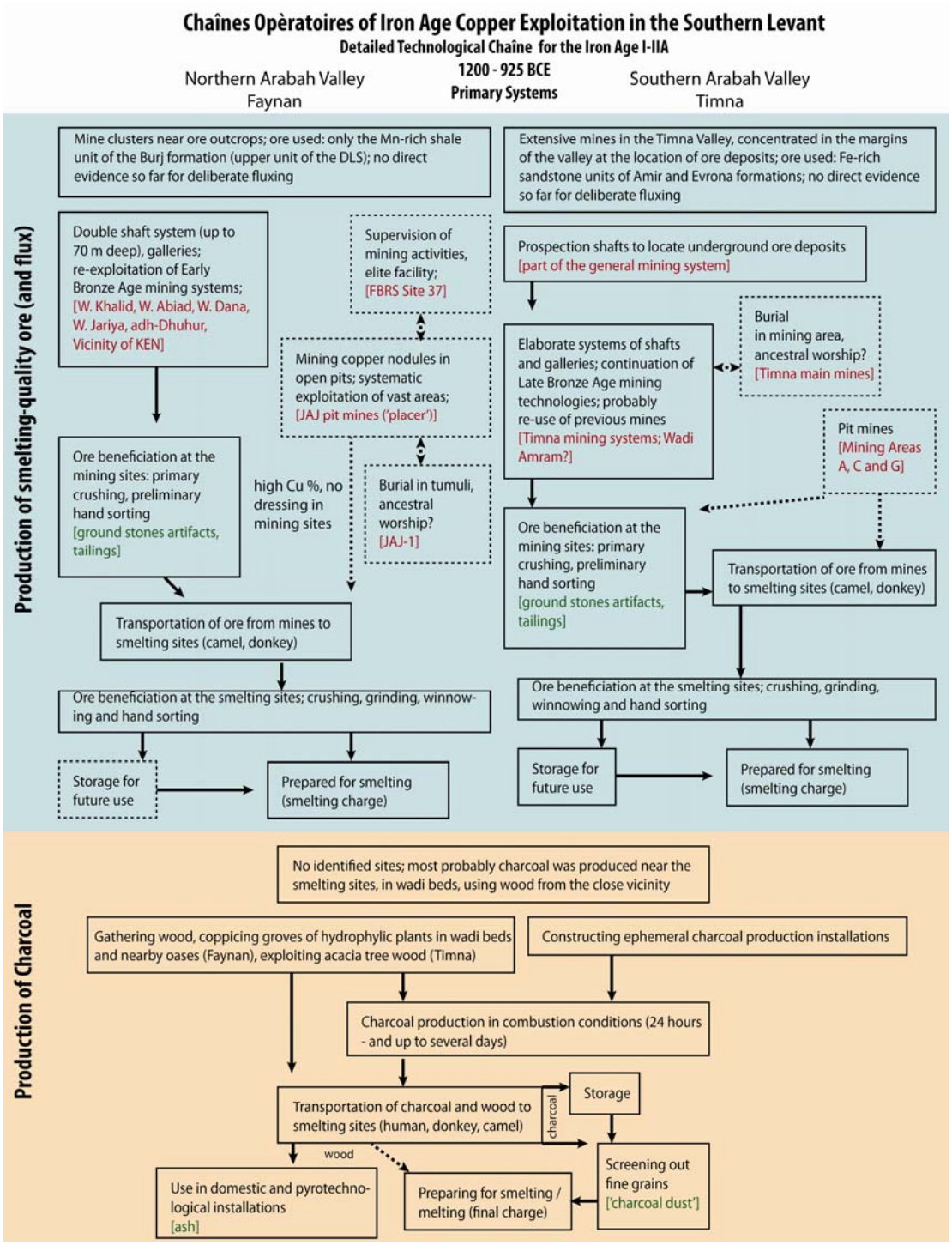


Fig.9.7A: Detailed *chaîne opératoire* of Iron Age copper production in the southern Levant (Production Systems 1 and 2). Most of these components are relevant to *all* of the Iron Age production systems (cf. Fig.9.5); part I (see Fig.9.7B for part II): mining and charcoal production. Dashed arrows and boxes indicate optional components with no or weak evidence (see text).

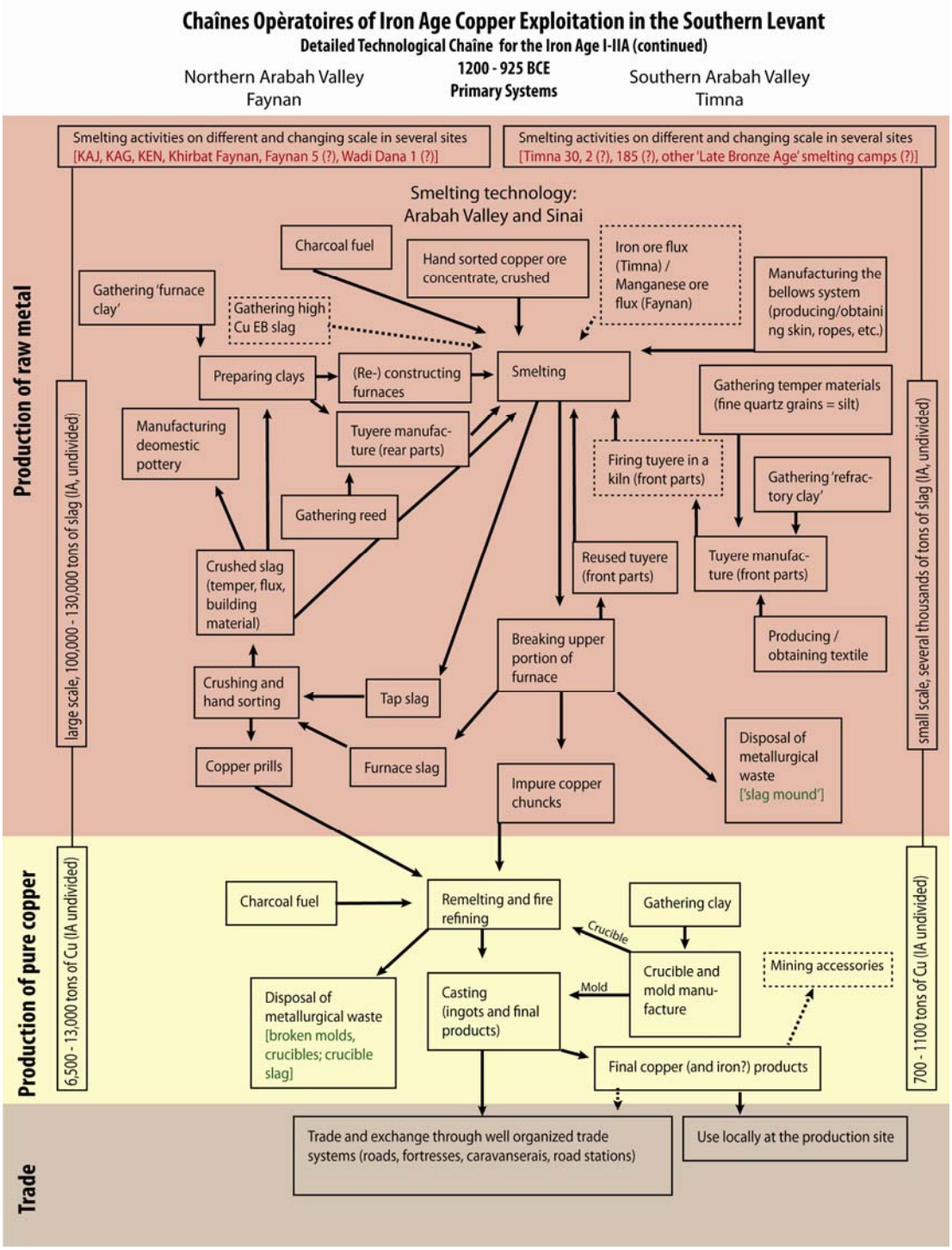


Fig.9.7B: Detailed c*haîne opératoire* of Iron Age copper production in the southern Levant (Production Systems 1 and 2). Most of these components are relevant to *all* of the Iron Age production systems (cf. Fig.9.5); part II (see Fig.9.7A for part I): smelting refining, casting and exchange. Dashed arrows and boxes indicate optional components with no or weak evidence (see text).

9.1.1 *Copper production activities outside of the smelting sites*

Mining

The extraction of ore is a fundamental activity in any metal production system. It involves prospection activities, the organization of labor, food and water supplies for the workforce, mining technologies, and the transport of the ore to primary smelting sites. Due to the scarcity of datable finds, dating resolution of mines and mining-related activities (e.g., piles of tailings produced by ore dressing) is usually low. Accordingly, the Iron Age mines in Faynan and Timna are dated generally to the Iron Age without fine division into sub-periods; thus tracking technological change or different mining strategies *throughout* the Iron Age is impossible at the current stage of research, except from the unique case of Ras al-Miyah in Faynan (section 5.2.6) where evidence of Iron Age IIC mining activities was found (Ben-Yosef et al., 2009b). Both in Faynan and Timna there is a possibility that *placer*[98] was mined in open pits in addition to the main 'hard rock' mining activities in shafts and galleries (section 5.2.9). However, the Iron Age date of these mines is currently speculative. Our OSL dates from the pit mines in Faynan (JAJ-1, section 5.2.9.4) weakly support Iron Age activity and are far from being decisive. As open pit mining requires much simpler technologies than shafts and galleries, there is indeed the possibility that those fields were depleted prior to the Iron Age because the ore nodules would have been more

[98] *Placer* is an alluvial (or colluvial) deposit (or glacial) of sand or gravel containing eroded particles of valuable minerals; the best known examples are gold and tin mines in the Indus Valley and western USA.

easily accessible. The same logic suggests that if these fields were first exploited in the Iron Age, they were the first to be exhausted during the early part of the period. However, the argument that these mines should be dated to earlier periods because they demonstrate simple technologies (e.g., Rothenberg, 2005, and also implicitly in other publications) does not hold (Chapter 4), as there is no reason to exclude the possibility of the simultaneous practice of simple and advanced technologies, especially if there was no advantage in utilizing "advanced" technologies in the case of *placer* mining. Both pit mine fields in Timna (fields A, C and G) and Faynan (JAJ 1, 2 and 3) demonstrate a calculated attempt to exhaust every possible occurrence of ore, with pits dug in a dense array covering the entire potential alluvial/colluvial deposits.

The principal Iron Age mining methods in both Timna and Faynan were based on shafts and galleries, and technological variations between the two regions appear to be primarily a consequence of local environmental differences. In Faynan, the ore-bearing unit of the Burj (DLS) formation was exploited by digging shafts (usually single or double shafts) into the lower portion of the Umm Ishrin sandstone formation, and then galleries into the Burj ore bearing unit (Fig.9.8). On many occasions the Iron Age miners re-exploited the Early Bronze Age mines, using longer galleries supported with shafts for ventilation and transportation of ore and people (Hauptmann, 2007:146). The ore was not confined to veins, thus the galleries were restricted only by the thickness of the ore bearing unit. Sockets for poles of a winch were found in

several shafts (cf. Fig.5.84, Weisgerber, 2006:16). The mining systems of the late Iron Age (7th – 6th centuries BCE) at Ras al-Miyah documented for this study demonstrate similar technological principles to those of the earlier Iron Age mining systems. However, the operation there was the *only* Iron Age mining activity that was associated with a massive defense system (two fortresses and a massive tower), and dense scatter of architectural features. In addition, the cultic site of FBRS 27 (section 5.2.6.5) is also directly associated with the mining activities, and is the only clear evidence thus far of cultic practice in the mining areas themselves (because of the scarcity of indicative finds for cultic / ritual activities, the absence of evidence in other mining sites definitely does not imply the lack of such practice there. On the contrary, the rare and accidental find at Ras al-Miyah may testify for the practice of associated rituals in other Iron Age mining systems).

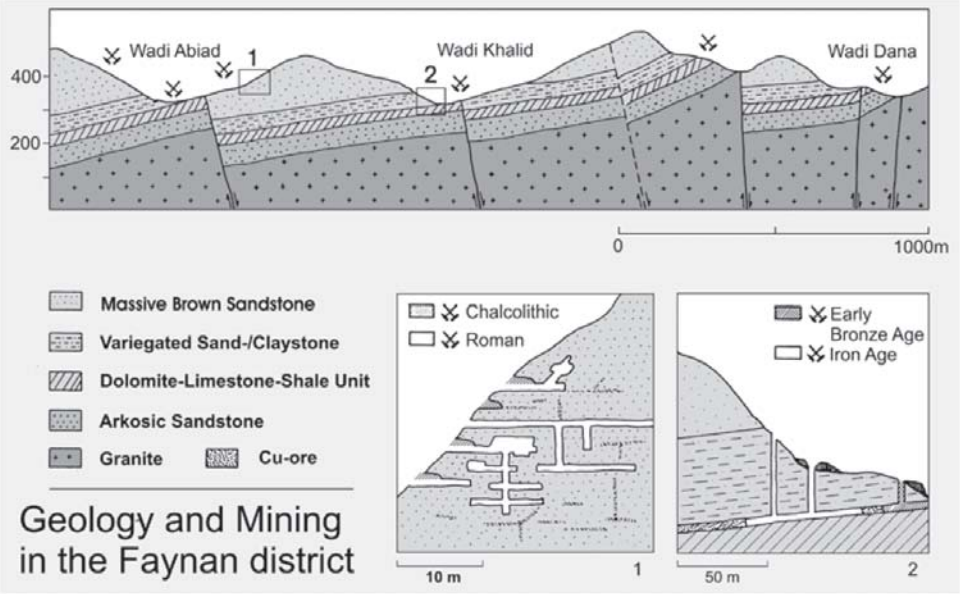


Fig.9.8: 'Shaft and galleries' mining technologies in Faynan. Note in particular the typical mining systems of the Iron Age (cf. Fig.5.77, from Hauptmann, 2007:146).

At Timna, ‘double shafts’ and sockets for winch installations similar to Faynan were found in several places (cf. Weisgerber, 2006:Figs.22 and 26). Although the Timna mines are considered to represent mostly Late Bronze Age activities (cf. Rothenberg, 1980c), as shown here (section 6.3), many of those southern Arabah valley mine systems should now be dated to the Iron Age. In any case, it seems that both Late Bronze and Iron Age mines demonstrate the same mining technology (Fig.9.9), including prospection shafts, shallow mining shafts and galleries that follow the copper mineralization veins in the sandstone formations (Conrad et al., 1980). As discussed in section 6.3, we believe the mining system in Timna Valley represents a well-planned operation demonstrated in a dense array of prospecting and mining shafts for ‘geological’ reconnaissance, ventilation and transportation of ore and people (contra Craddock, 1995:69). This is demonstrated also by comparison to other mining systems, contemporary or even later (see below). Copper pick heads, such as the one found in Timna (Fig.9.10), were probably in use in all of the Iron Age shaft-and-gallery mining systems, although it is possible that those were replaced by iron tools in the later part of the period (no metal mining tools have been reported from Faynan so far). The fact that this artifact is made of copper and not of the harder and more suitable bronze may indicate that it was locally produced and easily repaired, instead of importing bronze metal from the workshops located in the settlements far from the ore sources. The source of such copper heads was probably the smelting sites themselves, where they may have been replaced and repaired. Ground stones for ore dressing and mining activities, wood for hammer-handles, support of the galleries and

for construction of winches or similar installations (cf. the holes installations at Ras al-Miyah, Fig.5.82C-D) and a large array of organic-based artifacts were necessarily part of the mining activities, including ropes and bags (textile [cloth], skin, wicker bags) (cf. Ordentlich and Rothenberg, 1980:179). Light in the mines was based on oil lamps, as demonstrated by several fragments found in the mining area (cf. Fig.5.94:7).

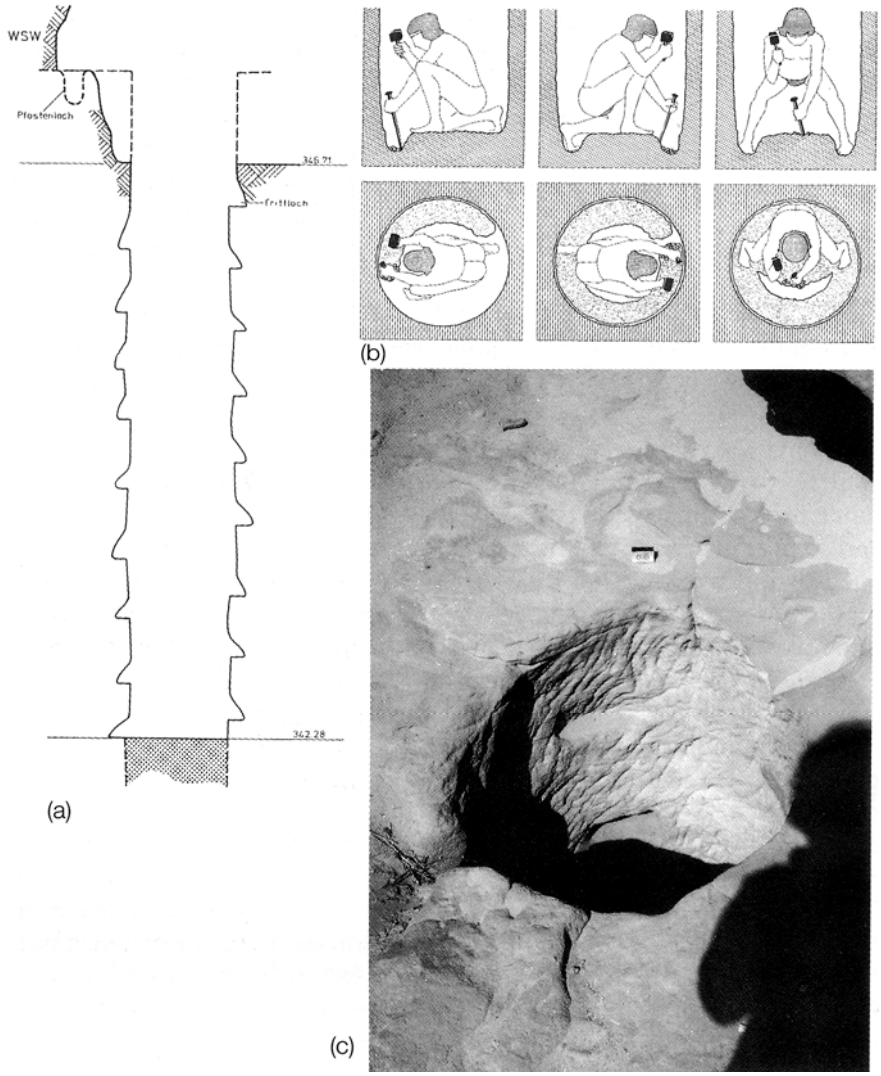


Fig.9.9: Typical Late Bronze and Iron Age mine shaft in Timna Valley (from Craddock, 1995:68)

It is difficult to estimate the quality of the ore used in the Iron Age. Based on the differences (temporal and spatial) in geological sources, the primary ore must have been of varying initial quality and had to go through beneficiation process of varying degrees. The beneficiation process started at the mines themselves, near the shafts, where ore was dressed to get rid of the gangue material. This is evident in particular in Faynan, where black tailings of shales are spilled on the bright sandstone slopes (cf. e.g., Fig.5.5). Following Craddock (1995:157, and see Fig.9.3 above), Hauptmann (2007:68-79) and Bartura et al. (1980), it is reasonable to assume original ore quality (as mined) of 8 – 15 wt.-% Cu, and beneficiation process (crushing, grinding and hand sorting) that resulted in up to 40-50 wt.-% Cu in the ore used for smelting. The last part of the beneficiation process probably took place at the smelting sites themselves.



Fig.9.10: A copper pick head found at Timna mines (from Craddock, 1995:64). The fact that this is made of copper and not of bronze may indicate that it was locally produced (see text).

Flux (section 7.2.1) is another raw material that was possibly deliberately used in the Iron Age copper production systems. The addition of flux to the smelting mixture facilitates the extraction of metal by reducing the temperature needed for smelting, principally by making the initial smelting mixture closer to the eutectic composition (section 8.1). In addition, this material helps render a slag easy-flowing (e.g., Tylecote, 1992:182) and facilitates the physical separation of slag and metal. The most suitable candidates of flux material in the Iron Age are manganese ore in Faynan and iron ore in Timna, in addition to crushed slag. There is a methodological difficulty to prove *deliberate* fluxing in the Iron Age (or in any other period), as the copper ore sources contained initial quantities of manganese and iron ores in the respective geological formation of Faynan and Timna. Thus, the smelting process could have been based on 'self-fluxing' copper ores, and no deliberate mining of flux was needed. The beginning of deliberate use of flux in copper smelting processes is debated. It has been assumed that intentional use of flux agents was fundamental for smelting processes from the earliest stages of metallurgy (Wertime, 1980; Avner, 2002), and others (e.g., Tylecote, 1992) suggest that deliberate use of flux should be associated with the first appearance of large 'slag mounds.' (Without indicating an exact date, in the Arabah Valley this may correspond to the production systems of the Late Bronze and Iron Ages in the late 2nd millennium BCE). For Timna, it has been suggested that deliberate use of iron ore for fluxing started already in the Late Neolithic (Rothenberg and Merkel, 1995; Merkel and Rothenberg, 1999)[99], together with the deliberate

[99] In Bachmann (1980) and Bachmann and Rothenberg (1980) the interpretations are more careful and

addition of other materials in later periods (such as dolomite, Lupu and Rothenberg, 1970; salt, Zwicker et al., 1975; and lime, Bachmann, 1980). However, we accept Hauptmann's (2007:251) assertion that *deliberate* fluxing in the smelting sites of the Arabah Valley is not evident before the Iron Age. In fact, the results of the current research indicate that deliberate fluxing probably started only in the late $10^{th} – 9^{th}$ century BCE, with the introduction of the Production System 3 described above (Figs.9.5-9.6). The evidence for this comes from Timna Site 30 Layer I. This layer contains Mn-rich slag (Type A slag, see section 7.2.6 above), with (limited) evidence for the use of ore from the Mn-free sandstone formations (section 8.5.2). Thus, a deliberate fluxing is implied (rather than mining self fluxing ore from Timna formation). This is further supported with the Arabah Expedition find of two storage pits containing manganese ore and associated with this layer (Bachmann and Rothenberg, 1980).

The unique case of Timna Site 30, located in a region where the common and most accessible ore is in the sandstone formations that do not contain rich manganese ore (but do contain iron ore) has important implications on our understanding of the copper production systems during the Iron Age. Deliberate fluxing with manganese ore appears abruptly together with the new smelting technology represented in Timna 30 Layer I. The contemporary record in Faynan cannot provide similar evidence because throughout the Iron Age the main copper ore source was the Burj formation

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the possibility of self-fluxing ore is also suggested.

that contains manganese ore closely associated with the copper minerals, thus it is difficult to recognize deliberate use of manganese ore as flux, even if such practice did exist. The evidence from Timna indicates that the knowledge regarding the advantages of deliberate fluxing, and even more, the knowledge that manganese ore is more efficient than iron ore as a flux in smelting processes (e.g., Bachmann and Rothenberg, 1980), was available to the societies engaged in copper production along the Arabah Valley at least in this period (late 10^{th} – 9^{th} centuries BCE, Production System 3). It may be the case that some knowledge of fluxing was available to the smelters in the earlier phases of the Iron Age (and in the Late Bronze Age; Production Systems 1 and 2), however it is difficult to provide firm evidence for this, and in any case if such knowledge was available it was much less sophisticated than that applied in Production System 3.

The deliberate use of manganese ore in Production System 3 entails special mining efforts in the corresponding formations. As discussed in sections 8.5.2 and 8.6, it is probable that in Timna the copper ore was mined from the more accessible sandstone formations and that manganese ore was mined in a *different* formation (Timna formation, see section 2.2.2), although it is also possible that there was a shift in copper ore source and that also the copper minerals came from the manganese rich formation (cf. section 8.5.2 for limited evidence supporting the former option). Engaging in mining of two different ore sources, one of which is dedicated to the exploitation of flux in a more remote location (probably in Nahal Mangan where

mining evidence was found, cf. Rothenberg and Shaw, 1990a)[100], entails more complex organization of production. The evidence from Timna 30 indicates that the corresponding copper production system in Faynan (Production System 3) also included deliberate mining of manganese flux, or at least the knowledge to mine copper ore with suitable manganese content for efficient smelting process. The use of crushed slag as a fluxing agent was probably practiced earlier (Production System 2? see below, under 'smelting').

Preparation of fuel - Charcoal

The provisioning of fuel for smelting the ore extracted from mines was another key variable to facilitate large scale copper production. Charcoal was the most common fuel for ancient smelting processes (Percy, 1861:107-142, including many ethnographic example related to metallurgy). Even though preparation of charcoal is scarcely visible in the archaeological record, it is treated as an integral part of metal extraction procedures (e.g., Tylecote, 1992). Charcoal is an ideal fuel for smelting from various reasons (Craddock, 1995), including: (1) its ability to maintain very high temperatures in a small volume due to its high calorific value; (2) its function as a reduction agent, facilitating the reduction of oxidic ores to metals (carbon, the main

[100] These small mines (located in Giv'at Sassgon near Nahal Mangan; Mangan = Hebrew for manganese) are the only evidence so far for mining activities in the Mn-rich Timna formation. They have been associated with Early Bronze Age IV smelting activities in Site 149 located nearby. However, both their interpretation as mines (instead of natural caves) and their date have been questioned (Avner, 2002:47, and section 6.2.4 above). Additional outcrops of the Mn-rich Timna formation were located in the area of the modern copper mines in Timna, and the source of the manganese flux used in Timna 30 might have been located there.

constituent of charcoal, has a strong affinity for oxygen); (3) it has very small amounts of injurious elements such as sulphur and phosphorus (it does contain magnesium, calcium and sometimes zinc, the latter might be the source of zinc observed on clay smelting installations). The main disadvantage of charcoal (compared to wood) is its strength. It cannot endure long distance transportation as it would easily become a useless powder. Furthermore, under a heavy load of charge charcoal would be crushed and the fire extinguished. However, during the Iron Age (and in fact, until the introduction of water-powered bellows in Middle Ages Europe) furnaces were small enough that this did not present a problem.

Charcoal production technologies are designed to separate the volatile hydrocarbons from the involatile carbon. The latter is the main component of the resulting charcoal. The process of producing charcoal leaves very little 'archaeological' remains; there are usually no durable structures or distinctive artifacts associated with the technology and there is hardly any reported archaeological evidence of the process. Avitsur (1988) provides a detailed description of the common charcoal production technology used in Palestine throughout the last centuries, which may represent charcoal production in this region, including Faynan and Timna, in antiquity. Another detailed description of charcoal production is provided by Craddock (1995:191-195), including examples mainly from Europe.

A common assumption in archaeometallurgical research is that charcoal was an essential part of the smelting process since the earliest stages of metallurgy (Craddock, 1995:190; Avner, 2002). However, this is *not* based on archaeological evidence, since as mentioned above the charcoal production technologies leave (almost) no enduring remains. Basically, there is no reason to doubt this assumption, as it is based on considerations of efficiency and availability of a rather simple technology. This is especially valid for the Iron Age in Faynan where smelting centers such as Khirbat en-Nahas and Khirbat al-Jariya have yielded large quantities of charcoal. However, new experimental archaeology research indicates that wood was efficient enough in some basic and advanced smelting technologies (Erica Hanning, pers. comm. 2010). In addition, the abundant wood unearthed in Site Timna 30 (see section 7.2.3 above) may also indicate the use of wood, in addition to charcoal, in the smelting process. This is further supported by the fact that Timna 30 demonstrates unique conditions for excellent preservation of organic materials (section 6.2.1.2 above) and the reasonable assumption that charcoal production would have taken place outside of the smelting sites.

In the following we assume that charcoal preparation did take place near the smelting centers as part of the Iron Age copper production in Faynan and Timna. The acquisition of wood material for pyrotechnological technologies or for domestic activities (hearths, cooking, etc.) required the same first procedures used for charcoal production (i.e., maintaining constant supply of wood). There is no indication thus far

for diachronic changes in the charcoal inventories *within* the Iron Age (section 7.2.3). However, important spatial difference does exist between Faynan and Timna regarding the plant species used as fuel during the Iron Age (section 7.2.3).

The technology of charcoal preparation usually involves cutting hard, heavy wood that has high calorific value (e.g., acacia, oak, etc.) into small pieces and burning it under partial combustion conditions in a limited air supply (de Jesus, 1980:37-39; Craddock, 1995:189-195). The process can take up to several days. At Iron Age Timna the most common fuel source was the local acacia trees, while in Faynan it was primarily tamarisk and other fast-growing shrubs (section 7.2.3). Interestingly there is evidence from the Roman period in Europe for the preference of fast-growing shrubs over old heart wood (Cleere, 1976). Furthermore, in this case charcoal came from coppiced shrubs grown specifically for fuel production. The coppiced shrubs were regularly pollarded; the preferred wood was poles of about 10 – 15 cm in diameter, representing about 10 – 15 years' growth since the bole was last pollarded. ELRAP Paleobotanist Mark Robinson has demonstrated that coppicing was indeed carried out on the Tamarisk samples recovered from the copper production contexts at Khirbat en-Nahas (Levy et al., 2008a).

It is likely that the fast-growing shrubs used for charcoal production in Faynan were specifically treated to control and encourage their growth. Haloxylon and retama are available in a short walking distance from all of the Iron Age smelting sites, and

today the hydrophilic species tamarisk and Phoenix are available in a distance of maximum ca. two hours walk (in the case of KAJ). It is also possible that the climate conditions were slightly better, especially during the Iron Age I (ca. 1200 – 1000 BCE, see section 2.3.1 above), and that tamarisk and Phoenix were more abundant than the present day situation and perhaps even closer to the production sites like KEN.

The preparation of charcoal probably took place on flat areas, perhaps on the gravel of the wadi beds, outside of the smelting sites[101]. The wood was cut into small pieces and then left to dry for some times before combustion (up to several months, although the dry climate of the Arabah would have facilitated this process). The most common combustion technologies involve the use of pits or free-standing stacks covered with earth to limit the air supply (Avitsur, 1988; Craddock, 1995:191-192). The combustion process usually took several days and in the end the stack (or the pit) was opened and the charcoals transported to the nearby smelting site, simply by the workers or with help of draft animals.

The size of the charcoal was of special importance in the smelting process, as it directly influenced the circulation of gases through the furnace charge. Thus, the charcoal dust (known as *fines*) was screened by sieving, probably after the (short) transportation of the prepared charcoal to the smelting site. Charcoal dust was

[101] During an excursion to the wadis near the village of Rahma in the eastern margins of the southern Arabah, we observed intensive remains of modern charcoal production (by the local Bedouins) in the wadi bed of Wadi Sha'alan. This example is a possible reference to reconstructing Iron Age charcoal production, and to the characteristics of the remains of such activity.

identified in ‘slag mounds’ investigated as part of the current research (section 7.2.10); it may have originated from such activity of screening the load of charcoal near the smelting area, right before it was used to prepare the furnace charge.

Charcoal had to be stored at the smelting sites for establishing a continuous fuel supply. However, such designated storage places have been rarely recognized in the archaeological record (a pile of charcoals buried in a building in Site 47C at Rio Tinto may represent a storage facility, see Rothenberg and Blanco, 1981). Most of the charcoal samples found in smelting sites are those that survived the smelting processes and were dumped in together with the other metallurgical waste. That said, there are over 90 unexcavated buildings visible on the surface of KEN (ref. map that shows surface architecture), and a few dozens at KAJ, and some of those may have functioned as storage facilities for charcoal, ore and other materials. For rough estimations of quantities of charcoal produced, and the possibility that charcoal was a limiting factor in the smelting activities at Timna, see under ‘smelting’ below.

Transportation

The organization of transportation was an important part of the Iron Age copper production systems and included insuring the constant flow of materials and people in and out of the production sites. Raw materials such as ore, clay and wood were transported into the smelting and charcoal production sites; final products,

probably copper ingots, were transported to the consumer and became part of a physical market, with activities that demanded transportation of goods and people to locations of exchange; basic supplies of water and food were transported into the production sites and had to be constantly maintained[102]; many auxiliary items were constantly transported into the production sites to support technological activities (textile, skin, ropes, bellows?, etc.); transportation of people and written materials were the only means of communication between production centers and practically anywhere else; et cetera.

The camel was domesticated during the last centuries of the 2nd millennium BCE and appears in the southern Levant during the Iron Age I or somewhat earlier (Jasmin, 2006, and references therein). Because the domesticated camel is the most suitable draft animal in the arid zones of the southern Levant (Bulliet, 1975) it is reasonable to assume that it was the primary means of transportation during the Iron Age. This is supported to some degree by camel bones identified in the excavations of the Arabah Expedition at Timna 30 (Girgson, C. pers. Comm. 2008, and cf. Jasmin, 2006). At KEN, only 7 bones were identified as camel (<1% of the total), but this is expected as these animals were probably not eaten for food and died old (Muniz and Levy, in press).

[102] Cf. the earlier Egyptian descriptions of expeditions to the turquoise (and probably copper) mines in Sinai: during each mining campaign (occurring annually in the spring) a train of 500 donkeys conducted by 43 preasants was used to maintain a constant flow of supplies of all kinds, including food and water, to the various mining camps (Glueck, 1940c:64).

Organizing and administrating transportation included maintenance of roads, especially if camel was used as a draft animal in mountainous regions (loaded camels require well built roads in order to pass through steep areas, in comparison donkeys are much more 'flexible'). The FBRS project reported several substantial road constructions along the main route from Faynan (Ras al-Miyah) to Busayra that are probably dated to the Iron Age (Ben-Yosef, 2008b; Ben-Yosef et al., in press) and represent deliberate and well organized efforts to maintain transportation routes between the highlands and lowlands of southern Jordan.

It is probable that donkeys and people were also used as a means of transportation during the Iron Age (the latter is relevant in particular if the labor force at the mines consisted of slaves and/or war prisoners). Auxiliary items such as carts, skin or textile bags, were also part of the transportation system. However, the archaeological record of transportation is scarce, and little of the above is supported by 'hard' evidence. Finally, it is important to consider the transportation part of the production *chaînes* as a possible 'contact zone' between different social groups. This contact, including exchange of goods and knowledge, took place at the destination locations of the final product, at 'commercial' centers designated for exchange, and/or at the production sites themselves (e.g., exchange could have taken place at the fortress of KEN).

9.1.2 *The metal production landscape: spatial distribution of smelting sites*

To understand the organization of metal production, it is important to examine the spatial location of the primary smelting centers in relation to copper ore sources and evidence of mining. Most smelting sites are located near the main copper ore deposits of the Arabah Valley (Fig.5.1 and 6.1), and a few are in southwestern Sinai, also in close proximity to the copper mines there. To date, unlike earlier periods such as the Chalcolithic when smelting took place mostly inside settlements (Levy, 1995) there is no evidence of primary copper smelting (extraction of copper metal from ore) at any of the Iron Age settlements in the populated areas of the southern Levant, although dozens of metallurgical workshops have been reported mainly for bronze production (Ilan, 1999; Yahalom-Mack, 2010)[103]. The farthest smelting from the mines in the Iron Age is evident in Barqa al-Hetiye in Faynan, ca. 9 km from the nearest possible ore source, and Tell el-Kheleifeh in the southern Arabah, ca. 15 km from the closest mines (if those were located in Nahal Amram). However, those are exceptions, and smelting commonly took place in the proximity of the mines and up to 3 km away.

The smelting activities of the Iron Age Production Systems 1 – 3 (spanning the Iron Age I – IIB, 1200 – 800 BCE) took place at *the same* sites, with changes in intra-

[103] Contra to Finkelstein's (e.g., Finkelstein and Piasetzky, 2008) emphasis on the connection of the metallurgical workshop at Tell Masos to the primary copper production near the mines (of Faynan), the remains from this site (Fritz, 1989) was a standard workshop for secondary processing of metal (bronzes?) similar to the abundant ones described by Yahalom-Mack (2010) for this period in the southern Levant (and see below).

site organization and the abandonment of some sites in the transitions from one system to another. Production System 1 (Iron Age I, ca. 1200 – 1000 BCE) is evident in all of the Iron Age smelting sites. There is a possibility that some sites were abandoned in the (organic) transition into Production System 2 (Iron Age IIA, ca. 1000 – 925 BCE), especially in Timna (Sites 2, 3, 15 ?), however, further dating is needed to better characterize this transition. In the (abrupt) transition between Production System 2 and 3 many sites were abandoned and only a few *central* sites has evidence of *rekindled* smelting related to Production System 3 (Iron Age IIB, ca. 910 [?] – 800 [?] BCE). The new smelting installations and associated facilities of Production System 3 were established at exactly the *same* sites of the previous systems, indicating some sort of continuity. The locations of later Roman and Late Islamic smelting activities, which are usually different from the Iron Age sites (although sometimes very close by, cf. Faynan 1 and 5, KEN and Khirbat Nuqeib es-Samar, etc.), indicates that the choice of constructing the new facilities of the Production System 3 on the previous Iron Age remains was not dictated by some sort of technological or other advantage, but rather by some other, possibly social-related aspects.

The distribution of the smelting sites associated with Production System 3 indicate a deliberate re-use of the most central sites in *each* of the two main ore deposits districts: in the northern Arabah, the sites are Khirbat en-Nahas and Khirbat Faynan (represented by Faynan 5), the two most central sites in the entire Arabah

Valley, and in the southern Arabah Valley *only* at Timna 30 (so far), the central smelting site in the Timna Valley.

Production System 4 is currently evident only with the (extensive) mining complexes of Ras al-Miyah (section 5.2.6). This is the latest system, dated to the Iron Age IIC (ca. late 8th early 6th centuries BCE). There might have been older Iron Age mines in the same location related to the early Iron Age smelting activities at the nearby Khirbat al-Ghuweiba (section 5.2.7), however, the majority of the mines and associated architectural features are from the later phase only. It is not accidental that these mines are located in the closest ore outcrops to Busayra (Ben-Yosef, 2008b), the main administrative center of the local polity at this time, and in one of the most remote locations in Faynan to those coming from the west. As discussed below, the fortresses and other elements emphasize the unique conditions of this production systems and the existence of a real threat, most probably from the west.

The smelting sites associated with Production System 5 are located on the margins of the primary production systems of the Iron Age I-IIB. They are found both on the geographic margins far from the mines and main smelting sites (Yotvata, Hai-Bar, Barqa el-Hetiye [?], KHI [?], WF 630) and on the margins of large production enterprises, in tow of the main activities of mining (F2 and other sites in the mining areas of Timna, RHI [?], FBRS 23 [?] in Faynan).

Although metal smelting during the Iron Age was conducted in central, confined and well organized sites (cf. the sporadic distribution of Early Bronze Age smelting sites, e.g., Hauptmann, 2007:85-147, and Fig.3.9 above), the intensive production and vast quantities of waste materials had a substantial impact on the environment, far beyond the immediate vicinity of the sites themselves (e.g., Pyatt et al., 1999; Grattan et al., 2007). Although the exact scale and of the industrial impact on the environment and its implication to the human population living in the region of the mines is debated (REF-Marc), there is no doubt that the large scale production of the Iron Age generated waste that can be traced in the entire region.

9.1.3 *Intra-site copper production and related activities at primary smelting sites*

Defensive elements

Defensive architectural elements in the Iron Age smelting sites of the Arabah Valley are securely identified only in Khirbat en-Nahas, including a large fortress (73 x 73 m), and massive structures (towers?) (Areas R and T and other unexcavated buildings, section 5.2.4.1). In a few other smelting sites probable defensive elements were found, including large structures (towers?) at Khirbat al-Jariya (section 5.2.7), the peripheral wall at Timna 30 and the location (on a mesa surrounded by cliffs) and low wall at Timna 34. With caution, we suggest that all of these relate to Production System 2 of the Iron Age IIA (1000 – 925 BCE). The fortress and massive buildings at KEN are securely dated to this period. Given the new chronological framework of

Timna 30 presented above (section 6.2.1.3) and the previous conclusions of the Arabah Expedition regarding the stratigraphic location of the wall, it is very probable that this (probably) defensive element is dated to the 10th century BCE as well. The dates of the massive buildings at KAJ are insecure, although Ben-Yosef et al. (2010a) suggest a 10th century date based on one probe at the site and the associated suite of high precision radiocarbon dates (see also section 5.2.7 above). The date of smelting activities within the Iron Age at Timna 34 is unknown at this stage of research.

According to the tentative model suggested here (Figs.9.5-9.6), defensive elements at smelting sites appears *only* during the operation of Production System 1. These elements are *not* accompanied by any parallels at the mining sites themselves (cf. the fortresses at the mining complexes of Production System 4, section 5.2.6). A system of towers and fortresses on a regional level (not in the smelting sites), may be related to the primary production system of the 10th century BCE as well, although the date of most of these elements are insecure and debated (below).

Other important architectural elements

Some of the 'defensive elements' mentioned in the previous section in the context of Production System 2 were not necessarily *purely* defensive, and may have had a different, or *additional* purposes. For example, Glueck (1935:28, and section 3.1) suggested that the fortress at KEN and the walls at Timna 30 and 34 were used to

keep prisoners or servile labor force in the smelting sites, rather than as part of a defensive system against external enemies. If Glueck is correct and these architectural elements were necessary to control a servile labor force, we should expect similar structures in the mining areas, as it is there that such a source of labor was the most suitable and not in the sites of the much more specialized craft of copper smelting, refining and casting. As noted above, there are no corresponding defensive elements in the mining areas, and thus Glueck's suggestion seems less likely. Another non-defensive interpretation of these elements, especially the low walls of the sites in Timna 30 and 34, is that they were more symbolic, or rather were used to delineate and confine special working zones, in which the most sophisticated technological procedure of smelting took place. Smelting refining and casting are *not* technologies that could have been conducted by simple employment of slaves. These technologies were conducted, or at least closely supervised, by highly specialized craftspersons (see 'smelting' below). The technological knowledge was definitely an asset that was probably confined only to certain people. The 'know-how' (*savoir faire*) of specific key techniques, even if the general technology was widely known (e.g., that smelting took place in 'shaft furnaces' with bellows system, etc.), was enough to control the entire process and determine its failure or success[104]. Therefore it is possible that the purpose of the walls in Timna, and even the fortress at KEN, was to confine highly specialized working areas from the 'public', in this case the majority of the labor force, living in tents outside the smelting sites themselves (see below). The fortress at

[104] Rothenberg (e.g., 1990a) ascribed a high degree of specialization and tight control over 'know-how' to the craftspeople at Timna 2. In his view, contemporary technological variations at the same site represent different groups of craftspersons that correspond to ethnicity (Table 6.1).

KEN is a square building that was in fact an extensive wide courtyard with very little associated architectural features (e.g., Fig.5.17). The walls of the fortress confined the most specialized workshop at the site, located in the northwestern side of the courtyard (Area F, section 5.2.4.1). The walls still provided segregation even after the fortress was decommissioned at the late 10th century BCE.

The fortress at KEN is related mostly to Production System 2, although the massive structure had several different functions during the operation of Production System 3, including various activities at the decommissioned gatehouse (section 5.2.4.1) and confining the specialized workshop of Area F that probably operated during Production System 3. The extensive courtyard and a few associated small structures protected by the walls of the fortress were possibly the storage place of final products (copper ingots) and a center for exchange with caravans of traders coming to unload goods and load ingots.

To date, it appears that substantial architectural elements (defensive and non-defensive) in the Iron Age smelting sites were first introduced in association with Production System 2 (Iron Age IIA, 10th century BCE). The Late Bronze Age date of several architectural complexes in Timna (e.g., Site 35, 13, the structures at Site 2 and more, Table 6.1) is currently insecure and they may also be part of the Production System 2 (section 6.2.1.4). These stone-built structures included during Production System 2 mostly defensive elements (above), although the large building at KEN and

KAJ could have served as elite residences and/or as supervision facilities to control the work at the smelting sites, rather than for defense against external enemies. Only a few other structures and small architectural features belong to this Production system (e.g., Structure 276 at KAJ, section 5.2.5.2, storage and working facilities at Timna 30, section 6.2.1.1). In the time of Production System 3, defensive elements seem to be decommissioned and instead, at least in Faynan, more domestic-oriented, none industrial and non-defensive architectural complexes were built (KEN Areas M, and the building excavated by V. Fritz; probably also Areas S and W), as well as some specialized workshops (e.g., KEN Area F, and possibly Area S: the nature of this building included domestic and copper production-related elements, section 5.2.4.1) and maybe ritual-related buildings (KEN Area W, and possibly buildings at Timna Site 2). The evidence of Production System 3 in Timna has no substantial architectural features associated with it (section 6.2.1.1).

Construction of furnaces, smelting and refining/melting accessories

As noted earlier, there is a paucity of evidence for complete furnaces in the archaeometallurgical record due to the need to break these facilities during the smelting process. In spite of these difficulties, it is possible to make generalizations about construction methods concerning these Iron Age pyro-technology facilities. The raw materials and the construction procedures of furnaces, tuyères and other smelting accessories were similar throughout the Iron Age. The technologies of the Iron Age I-

IIA were basically the same as the Late Bronze Age (evident in Timna and Sinai). Even after the major technological change was introduced together with Production System 3 (Iron Age IIB, Fig.9.5) the basic preparation of all smelting related materials remained similar to that of the previous systems, including the types of clay and other fundamental components of the installations. The principal differences between the installations of Production System 3 and its predecessors were size and shape of furnaces and tuyères, and probably the introduction for the first time of bellows pipes and more variety of technological ceramics (crucibles and molds) related to the refining/melting procedures.

The basic components of the construction of furnaces, tuyères and bellows pipes are detailed in Chapter 7 (sections 7.2.4 and 7.2.5). In general, all are made of local clay, mixed with crushed slag or high quantities of fine-grain quartz as temper. The furnaces and tuyères had a composite, multi-layer structure, made with careful attention to consideration of heat-resistance vs. structural stability vs. labor investment, and all represent a high level of craftsmanship. The different clays had to be gathered at the vicinity of the smelting sites, in addition to sand/silt and relevant organic materials (reed and weed). Crushed slag was collected at the site to be used as temper in furnaces, tuyères and in some cases molds. The interesting observation of Tite et al. (1990) that the crushed slag present in parallel materials from Timna was re-heated before it was added to the clay as temper was not corroborated in other investigations (cf., e.g., Al-Shorman, 2009).

The preparation of tuyères required a special workshop/activity area and the use of kilns (for firing the front parts) and the construction of furnaces at the designated smelting areas required constant maintenance of the furnace walls and re-building the broken furnaces after each smelting cycle. The preparation of the smelting mixture, including charcoal, crushed ore and crushed flux (the use of the latter is currently evident only in Production System 3, see section 9.1.1) probably took place in (open?) workshops adjacent to the smelting areas, and thousands of ground stones found at the smelting sites are the most prominent remains of these activities. There is limited evidence of storage facilities that were probably used for ore and flux in a 'ready to use' state (in Timna 30 remains of crushed ore and manganese flux were found in stone-built storage installations). The maintenance of constant supply of 'smelting mixture' would have required storage, to buffer the balance between the production of read-to-use smelting mixtures and the smelting operation itself.

The furnace charge was crucial to the success of the smelting process (e.g., Merkel, 1990). The knowledge of the correct proportions of ore-flux-charcoal and the precise size of their fragments was probably a key to the success and efficiency of the smelting processes. The gradual improvement in the efficiency of the smelting process during the operation of Production Systems 1 and 2 may have been the result of a better control over variable such as the exact composition of the furnace charge rather

than a change in the smelting installations themselves, which was not distinguishable in the archaeological record.

The ostensibly simple task of preparing materials and installations for smelting (cf. the succinct outline in Figs.9.1 and 9.2) required complex administration and substantial amounts of labor. This is demonstrated by the intricate and well-coordinated procedures detailed above. A shortage in ready-to-be smelted raw materials or in the availability of skilled craftspersons (of many different expertise, including constructing and re-constructing furnaces, operation of kilns, constructing tuyères, etc.) the entire production system would fail. The efforts these procedures entailed, the abundance of variables that dictated quality of results and the potential loss of a failed smelting cycle (in materials and labor) are also demonstrated by detailing *chaînes*: technological components and their interconnections. In turn, the meaning of such processes to the society engaged in the production system is further elucidated and (often archaeologically invisible) components such as associated rituals and the possible existence of ranking among craftspersons become more relevant in the analysis of the interrelations between ancient technology and society.

Smelting

The Iron Age (and Late Bronze Age) copper smelting technologies of the southern Levant have been intensively studied in previous research (cf. Hauptmann,

2007:242-254), based on field work (Bachmann and Rothenberg, 1980; Rothenberg, 1990a), material analyses (Bachmann, 1980), experimental archaeology (Tylecote and Merkel, 1985; Merkel, 1990), and laboratory simulations (Merkel, 1983; Bamberger et al., 1986, 1988; Bamberger and Wincierz, 1990). Here we briefly outline the basic principles (including estimates of time and labor) and emphasize some contributions of the current research to our understandings of the process. The material culture related to furnaces is discussed in detail in section 7.2.4.

The Iron Age I-IIA smelting installations and accessories are a direct continuation of the Late Bronze Age technologies, represented by a very similar inventory in the archaeological record. Although substantial, the changes introduced in the Iron Age IIB (Production System 3) are still based on the same technological traditions. This is indicated by several observations, including the use of identical raw materials, the construction of multilayer composite tuyères, and the probable use of similar bellows (in both the Faynan and Timna assemblages ‘pot bellows’ are absent). The basic differences were the size of the tuyères and furnaces (much bigger in Production System 3), the shape of the furnace (more standardize and with the prominent S shape portion in Production System 3) and the shape and construction method of the ‘slag pit’, including probably a different tapping procedure (larger, well constructed pits in Production System 3).

The furnace operation included several basic steps, and all are crucial for the success of the smelting process. Based on Merkel's (1990) experiments, still considered the most accurate reconstruction of smelting technology of the type evident in Timna and Faynan, the smelting cycles (furnace operation from construction to destruction) included the following:

(1) During all stages of furnace operation, bellows were used to force air through tuyères into the (lower part) of the furnace. The optimal number of tuyères often mentioned in the literature is three, although there is a possibility of less (3 is the maximum). The common reconstruction for the Late Bronze – Iron Age smelting in the Arabah Valley suggests the use of pot bellows, based on Egyptian tomb paintings depicting metallurgical activities with two pairs of such device (Fig.9.11). However, according to the recent large scale excavations described in this study, we believe that the bellows were made of organic material probably similar to the bag bellow made of goat skin in Fig.9.12.

(2) Preheating. This could be done by operating the furnace with small (~1 kg) charges of charcoal that were repeatedly loaded into the furnace; alternative options described in Agricola (1556) included preheating with slag from previous smelting (to transfer heat from the combustion zone to the furnace bottom and to seal and protect the furnace walls and bottom from slagging), or preheating with iron ore flux (to flux the ash from the preheating charcoal).

The first method (charcoal alone) seems the most probable, although preheating with slag is quite effective.

(3) Before loading the ore (and flux) charge, the entire furnace shaft was filled with charcoal (~12 kg), preferably with an overlying smaller size rage of charcoal to support the smelting charges and prevent the ore and flux from falling unreacted into the furnace bottom.

(4) The charge of ore and flux was loaded in the center of the furnace. Merkel (1990) found that the ideal ratio of copper ore to iron ore flux is 1:4 (suggesting a starting ratio of 1:3 and increasing flux according to the progress of the smelting). Bamberger et al. (1988:9) suggested minimum ratio of 1:1.5 based on physical-chemical-mathematical models. However, the flux might have been part of the ore itself (see discussion regarding the deliberate use of flux in the Iron Age under 'mining' in section 9.1.1 above). Only small charge weights were used to prevent compacting of the charcoal under the ore and flux (Merkel (1990) used 'handful' of charge each time, out of the total 4 kg of charge).

(5) When the first charge was loaded, the furnace was already heated to its maximum temperatures (with three tuyères and airflow of approximately 1050 liters per minute, Merkel (ibid.) reported temperatures of 1400°C near the tuyères, and rarely over 1100°C at the bottom and 600°C-800°C at the top). Smelting and slagging occurred within minutes.

(6) The successive charging of ore-plus-flux and fuel was probably monitored by the colors of the burning exhaust gases at the top of the furnace (blue flame roughly indicates excess of fuel, yellow represents oxidizing atmosphere in the furnace etc.)

(7) Charging of charcoal and ore-plus-flux in layers was continued until the tuyères started to block with slag, or until the smelter estimated that slag level was close to the tuyère line and initiate the tapping. Such estimation could have been done based on monitoring the quantities of charge and would have saved the tuyères from slagging[105].

(8) After the level of slagging was identified as sufficient, the lower front wall of the furnace was punctured (with a wooden stick?), and the molten slag immediately poured into the slag pit. Merkel (ibid.:112) reconstruct a single tapping cycle per furnace operation with resulting slag rings of up to 25.9 kg. Hauptmann (Hauptmann, 2007:254) suggest several tapping event based on the multilayer texture of typical slag. This observation was corroborated in the current research by microscopic and macroscopic observations on slag (Chapter 8; the layering is most prominent in Type A slag of Production System 3). If the furnace operation was based on several successive tapping cycles, the tapping hole would have been blocked, probably by a wad of clay, immediately after tapping was done. Such operation would result in a larger amount of copper per each cycle of furnace operation.

[105] Calculations of slag volumes vs. furnace volumes indicate production with small quantities of slag, possibly representing a deliberate effort to protect the tuyères (Merkel, 1990:112).

(9) Post-heating stage was possibly conducted to further separate the furnace slag from the copper, or to refine the copper *in situ*, although it seems that such operation entails undesired complications and was probably avoided.

(10) After cooling the furnace was broken, and copper chunks were recovered, together with furnace slag rich with copper prills. The entire operation took between 3 and 6 hours and the amount of copper is estimated between 2-3 kg per smelting cycle.



Fig.9.11: Egyptian wall painting depicting metallurgical workshop of melting and casting. The use of pot bellows to operate the furnace was the source of the common reconstruction of bellows in the Late Bronze Age and Iron Age smelting furnaces in the Arabah. No pot bellows were found so far, and we believe the bellows were made only from organic materials (cf. Fig.9.12). (Tomb of Rekhmire, ca. 1440 BCE; Wall 14 Tomb 100, Thebes, Egypt; New Kingdom Dynasty 18 reign of Tuthmosis III to Amenhotep II; Photographer: Arielle Kozloff Brodkey; Date of photograph: 1979, source: ArtStore) (cf., Davies, 1943).



Fig.9.12: Bag bellows made of sawn goat skin (the ‘head’ is connected to the tuyère) used in experimental archaeology reconstructing the Bronze Age eastern Alpine copper smelting process (this experiments are part of the PhD research of Erica Hanning, Deutsches Bergbau-Museum; photos courtesy of Erica Hanning).

The above demonstrates the many variables that control a single smelting cycle and emphasizes the high skill required for conducting a successful smelting. The gradual improvement in smelting efficiency during Production Systems 1 and 2, found in this research only by XRF analyses of large sample of slag (Chapter 8, and in particular Fig.8.25), was probably due to improvement of control over the smelting process and techniques, without the introduction of substantial technological innovations (such were not identified in the archaeometallurgical material culture, cf. Chapter 7). This is different from the technological shift represented by Production System 3. The smelting process of the new technology was not only much more efficient, it was much better controlled and standardized (cf. section 8.6).

After the smelting process ended, the slag and copper were taken to designated locations for further processing and the furnace was rebuilt, the tuyères re-used (their front parts) and the waste disposed in the dumping zone.

Slag processing

Hauptmann (2007:245) correctly notes that "the role of mechanically reworked/processed slag has not been sufficiently considered in the reconstruction of metallurgical processes". Further processing of slag was an important component and an integral part of all of the Iron Age copper production systems in the Arabah Valley (except, probably, of Production System 4 that currently has only mining evidence),

and required proper organization to coordinate between the origin of the raw slag material (slag should have been constantly removed from the smelting area), its processing, and the distribution of the processing products. Slag in the Iron Age was not considered an immediate 'waste material' (section 7.2.6). After it had been solidified in and outside the furnace, the slag was taken to designated areas for crushing. This activity resulted in the extraction of copper prills and a mass of fine crushed slag. The mechanical beneficiation of metal rich slag, i.e., further extraction of metal residues in slag, was "a characteristic and recurring step in metal production" (Bachmann and Hauptmann, 1984), at most periods and not only regarding copper. The prills were further processed in the refining/casting workshops and the crushed slag was used as a foundation material in building construction, for temper in smelting installations and domestic pottery and as a flux (sections 7.2.6 and 8.5.2).

Percy (1861) provides many ethnographic examples for the processing and use of slag in metallurgy. These include the use of slag as a flux in copper melting (ibid.:319, 321) and smelting processes (in Swansea and elsewhere, ibid.:323-324), and the use of fine crushed slag as a foundation for kilns in Upper Silesia "that proper drainage might be secured" (ibid.:152).

During the operation of Production System 4 (Fig.9.5) the tap slag was not crushed and thus the surface of the respective smelting sites is covered with large slabs of slag. Evidence from Timna 30 indicates that the furnace slag in this production

system was crushed (section 7.2.6), but it is not clear if copper prills were extracted as the smelting process was more efficient than any of the previous smelting technologies, and the content of copper in slag was very low (section 8.5.1, see also e.g., Figs.8.22 [KEN-M], 8.24 [T30], and 8.25). The unique depositions of crushed slag on the hill slopes of the outskirts of Khirbat en-Nahas (section 5.2.4.4) have no parallels in other Iron Age smelting sites. At this stage of research, these deposits are not precisely dated within the Iron Age, thus it is impossible to relate them to any of the three production systems represented at the site. The suggestion of Hauptmann (e.g., 2007:129) that the texture of these 1.5 m thick deposits of crushed slag is the result of water used during the crushing process (to separate copper prills ?) is difficult to prove, and the scarcity of water (even if the climate was somewhat better, section 2.3.1) together with the lack of parallels from any period in the Arabah Valley, render this suggestion speculative at this stage of research.

Refining and casting

The technologies of refining and/or melting of the copper chunks produced in the smelting process and the casting of copper into molds and perhaps other ephemeral installations have very fragmentary evidence in the archaeological record. Regarding the Iron Age archaeometallurgical record of the Arabah Valley the results of the current research provide significant new insights on this hitherto enigmatic part of the production system.

There is a substantial difference in the refining/remelting procedures between Production Systems 1-2 and Production System 3. While there is very little evidence of these technologies for the former systems, the discovery of the unique metallurgical workshop at KEN Area F provides new data regarding the latter. This includes various installations (section 7.2.9) and abundant bellows pipe (section 7.2.5). Such bellows pipes were found in previous research, however, here we demonstrate their direct connection to refining and casting activities, and show their disconnection to the smelting operation. The appearance of the bellows pipes correspond to increase in metal chunks that are heavily contaminated with iron (section 7.2.7). This probably indicates that Area F represents a *refining* workshop and not only re-melting of copper and casting. The origin of this technology is suggested here to be Egypt (section 10.1) based on similarity to bellows pipes from a metal foundry in Tebes (Fig.9.13) among other considerations. The separation of iron from copper is difficult and the exact process is not entirely clear. Although evidence of iron contamination was found in Timna and experimental archaeology, and reconstruction of a refining process was suggested (cf., Merkel, 1990), the actual feasibility of such process is still debated (Andreas Hauptmann, pers. comm. 2010). We believe that the evidence at KEN from Production System 3 can provide solution to this issue in future research.

Refining, remelting and casting took place in special workshop with specialized craftspersons. The casting of ingots, probably in clay molds (section 7.2.8)

but possibly also in simple ephemeral installations (cf. Fig.9.14), as well as the casting of limited amounts of final products such as copper pins and small figurines (section 7.2.8) were the last part of the production process before the end products entered into the trade system. There are virtually no ingots in the archaeological record (section 7.2.8) and the shape of these products as well as the level of standardization is unknown at this stage of research.

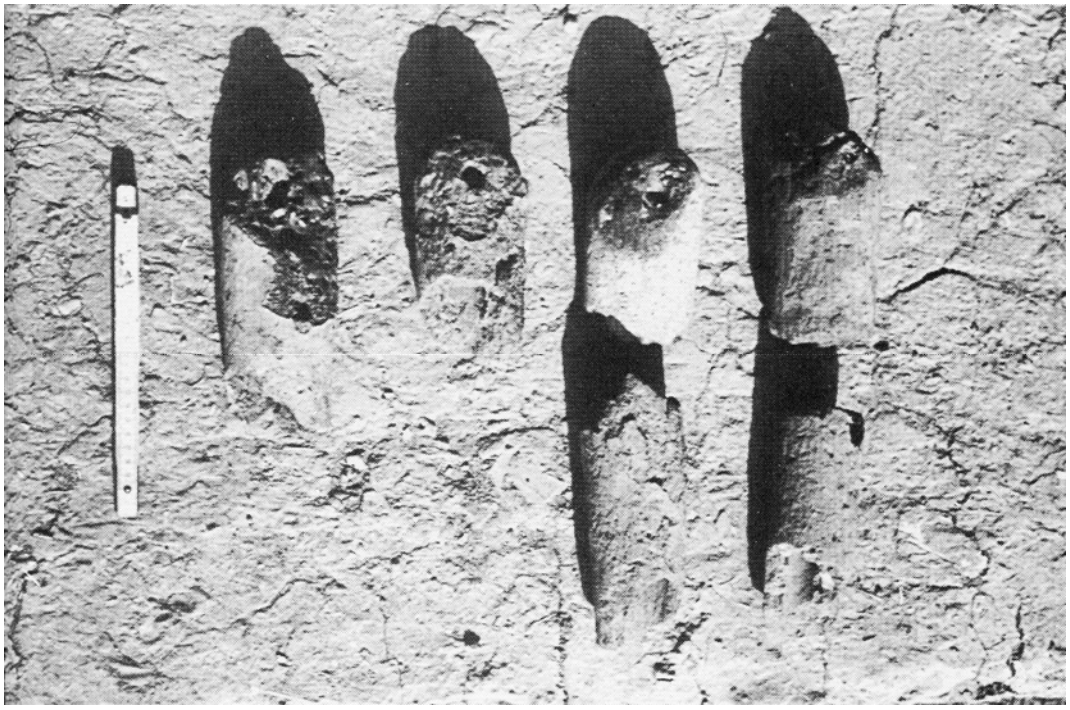


Fig.9.13: Bellows pipes from the Ptolemaic metallurgical workshop at the funerary temple of Seti I in Egypt (from Scheel, 1989:28). These objects show similarity to the bellows pipes of the refining/casting workshops associated with Production System 3 of the Iron Age Arabah Valley (cf. Figs.7.43-7.45).



Fig.9.14: Casting metal ingots in sand; hereditary bronze workshop, Swamimalai, India (Levy et al., 2008b, photograph courtesy of T.E. Levy).

Estimates of quantities: raw materials and final products

Estimates of quantities of raw materials and final (export quality) products are difficult to accurately produce, but important for evaluating the scale of production and the role an ancient production system may have had in any given corresponding market. Serious methodological difficulties exist, especially in the case under discussion. The basic estimates relevant for Iron Age copper production in the Arabah Valley are based on the following:

(1) Evaluation of the volume of slag deposits (‘mounds’) (by visual observation or direct measurements with survey devices)

(2) Assumed portion of slag material in a slag deposit ('mound')

(3) Assumed quality of copper ore *after* beneficiation

(4) Assumed Cu-minerals and the general specific gravity of ore

(5) Assumed quantity of deliberate additions of other (non-slag) material as a fluxing agent

(6) Evaluation of the efficiency of the smelting process (i.e., how much copper went into slag material)

(7) Assumed ratio of ore to charcoal in the smelting process

(8) Assumed ratio of charcoal to wood.

It is impossible to provide separate estimates of quantities for each of the three primary production systems (1-3, the systems with evidence of substantial smelting, Iron Age I-IIB, 1200 – 800 BCE) because separate estimates of slag quantities is difficult at this stage of research. Coupled with other insecure variables (use of deliberate ore, degree of ore beneficiation, possible changes in ore sources etc.) any attempt to provide separate estimates would be too speculative, and even the total estimates for these three production systems are quite rough.

For the Iron Age copper production systems in the Arabah we make the following assumptions:

(1) the portion of slag material in a slag mound is ca. 40% (section 7.2.10)

(2) copper ore after beneficiation contained ca. 40 wt.-% Cu (cf. discussion above, Fig.9.3 and Craddock, 1995:157)

(3) for the general calculations below, it is assumed that the smelted mineral was only malachite, which has a specific gravity of ca. 3800 kg/m^3 (the differences of specific gravity of other copper minerals are negligible in the rough calculation here)
(4) for the general estimates, we assume *no* deliberate fluxing (see discussion under 'mining' above, the evident deliberate fluxing of Production System 3 in Timna is negligible)
(5) for the general estimates we assume an efficiency of 100%, i.e., all of the copper was extracted from the slag material (Cu residues are negligible)
(6) the assumed ratio of ore to charcoal in the smelting process is 1:1 by weight, based on Merkel's (1990) experiments
(7) the assumed ratio of charcoal to wood in the region of Faynan is 1:4 (cf. Percy, 1861:130, values ranges 15-28% charcoal weight compared to the original wood).

For this study, we will use the estimates of the GMM team of 100,000 – 130,000 tons of slag in Faynan, and several thousand in the southern Arabah that were based on volume estimates and the assumption that slag mounds consist of approximately 100% slag material'[106]. However, as will be shown below, based on our excavation of the slag mound in Area M at KEN, there are problems with the GMM estimation that our work helps to resolve. Using a round number for the entire Arabah Valley of 125,000 – 135,000 and correcting it according to our investigation of the Area M slag mound (number 1 in the assumption list above), slag quantities for the

[106] This is only implicit in the publications of the GMM; as far as we know there is no detailed explanation on the estimation methodologies.

Iron Age Arabah Valley is in the range of 50,000 – 54,000 tons. Consequently these quantities represent:

(1) 33,000 – 36,000 tons of copper

(2) 90,000 tons of ore (= 23,600 cubic meter; the actual volume of mined material, including the host rock, was at least four times larger given initial ore quality of ca. 10% wt.-% and the need to mine shafts and galleries in non ore-bearing rocks)

(3) 90,000 tons of charcoal

(4) 360,000 tons of wood

These are the materials consumed and produced over a period of ca. 400 years, with notable oscillations in production intensities. It is interesting to compare these numbers to the values provided by the GMM team: according to Hauptmann (e.g., 2007:53, 147), 100,000 – 130,000 tons of slag represent 800,000 tons of wood and 6,500 – 13,000 tons of copper. The reason that we suggest larger amounts of copper even though we estimate smaller amounts of slag is probably the result of the different assumptions of ore quality after beneficiation[107] (see estimates also in Hauptmann and Weisgerber, 1987:422; Hauptmann, 1990:58; Hauptmann et al., 1992:7; Weisgerber, 2006:16-17; Hauptmann, 2007:242).

[107] Hauptmann (2007:253) probably uses the estimate of 10 wt.-% Cu in ore for copper yield calculations. If the grade of copper ore after beneficiation would have been around 10 wt.-% Cu, the amount of copper produced would have been around 6,000 tons. This does not seem to be the case, as ore-as-mined is often consists of more than 10 wt.-% Cu (however, cf. Merkel's 1990:112 estimation of 2kg of copper to 30 kg of slag based on experimental archaeology. Also Merkel considered the copper ore quliaty to be the key for such calculations).

The new estimate presented above represents a larger scale copper of production for the Iron Age than was previously assumed. Not only are the estimates of exported copper some three times higher than the previous suggestion, we now know that these amounts represent production systems that operated only in the early part of the Iron Age (ca. 1200 – 900 BCE), during ca. 400 years, and *not* a continuous production throughout the Iron Age (ca. 700 years, cf. e.g., Hauptmann, 2007). Although oscillations in intensity and scale of production did occur during these 400 years, it is very difficult to quantify these changes because the evidence comes from multiple sites and layers. It is possible, for example, that early production was practiced on a smaller scale on site level, but because it occurred simultaneously in more sites the amounts of final products will be similar to the later production. The excavations of the 'slag mound' at Khirbat al-Jariya (section 5.2.5.1) provides some evidence for change in intensity on the site level by *comparison* of the bulk material excavated there to younger layers excavated at the 'slag mound' of KEN Area M. The presence of much more domestic debris intermixed with the metallurgical waste suggest a smaller scale of metallurgy and simultaneous practice of domestic activities in very close locations (see discussion in section 5.2.5.1). In any case, Finkelstein and Piasetzky's (2008) attempt to estimate changes in intensity of production at KEN by ignoring stratigraphic consideration and averaging the number of radiocarbon dates per 50 years intervals is misleading if only for the simple reason that much fewer early contexts were exposed in our excavations, and that radiocarbon dating at the site was

done with careful consideration of stratigraphic context (see also Levy et al., 2010b, 2010a).

Regarding the impact of charcoal production on the environment, the results of the botanic investigations in Faynan done by the GMM and FU teams indicate that charcoal production did not have a significant impact on the natural vegetation in the vicinity of Faynan and that during the Iron Age the wood source was managed (harvested) such that the fuel supply would be constant (e.g., Engel, 1993, and sections 7.2.3 and 9.1.1). In Timna, on the other hand, the fuel source was the old wood of the acacia trees; according to the principles detailed above, during the Iron Age at least 30,000 tons of wood were used. This supports the possibility that fuel source was a *limiting factor* for the copper production at the southern Arabah Valley, and this may explain the significant differences in smelting intensities between Faynan and Timna (in two orders of magnitude). Ore does not seem to be a limiting factor in either Faynan or Timna during the Iron Age (see discussion in section 10.1).

The Iron Age copper production record of the Arabah Valley presents the largest quantities of yield in comparison to *any* other ancient period (e.g., estimates of slag from the Early Bronze Age II-IV in Faynan = 5,000 tons, Roman = 40,000 – 70,000 and Early Islamic = 1500). The quantities of Iron Age copper produced in the Arabah Valley are substantial also in comparison to other central copper production in the Old World, including Early Bronze Age Oman (3rd – 2nd millennia BCE,

between 2000 - 4000 tons of copper, Hauptmann, 1985:115; Weeks, 2004:34) and Late Islamic Oman (3,000 - 3,700 tons of copper, Hauptmann, 1985:115). For mega-centers of copper production in the Ancient Near East estimates of quantities of copper produced range from ca. 50,000 tons in Early Islamic Oman (Hauptmann, 1985:115) to 200,000 tons in 3,500 years of copper production in Cyprus (Constantinou, 1992:63; via Muhly, 2005:141)[108].

9.1.4 *Trade and exchange*

Regional organization of production and exchange: fortresses, caravanserai and trade routes

In the vicinity of the copper ore districts of the Arabah Valley there is archaeological evidence for satellite administrative systems that supported the primary copper production operations during the Iron Age. The evidence is currently limited, and the date of the main features is insecure. Nevertheless, it seems that substantial elements were introduced already in the 10th century BCE, in association with Production System 2 (Fig.9.5), and maybe even earlier (Table 9.1).

[108] The estimates of copper quantities for Cyprus are not undivided by periods, as most of the slag mounds are not dated (cf., Stos-Gale et al., 1998).

Table 9.1: Sites related to the administrative systems supporting the primary Iron Age copper production systems in the Arabah Valley

Production System	Site	Dating status	Function
1 Iron Age I	Barqa el-Hetiye (Table 5.1)	Insecure	Large '4-room' building: a road station? Caravanserai?
	Yotvata fortress (Table 6.1)	Insecure	Control over the oasis of 'Ain Ghadian; control over northeastern access to the Timna Valley;
2 Iron Age IIA	KEN fortress (section 5.2.4.1)	^{14}C, well dated	Center for exchange? Main storage of goods and final metal products?
	RHI (Table 5.1)	^{14}C, well dated	A tower at the main western entrance to the copper ore district, located on a strategic knoll on a principal junction and near the oasis of 'Ain Fidan; control over trade and access to the region
	'Ain Hazeva Fortress / structures (Cohen and Yisrael, 1995)	Insecure, debated	A central road station, caravanserai, fortress; located in a strategic point near a local oasis and on a main road junction (connecting roads from Faynan, Busayra (via Wadi Dahal), and the Negev (cf. Figs.2.4-2.5); control over trade, exchange, and possibly territorial boundaries
	Yotvata fortress (Meshel, 1990, 1993) (Table 6.1)	Insecure	Control over the oasis of 'Ain Ghadian; control over northeastern access to the Timna Valley;
	Jazirat Far'un (e.g., Rothenberg, 1967a)	Insecure	A port and possibly a fortress on a small island close to the coast at the head of the Gulf of Aqaba; was suggested to represent Solomonic activity (instead of Tell el-Kheleifeh); strategic location for controlling ancient seafaring and caravans heading to or from southern Sinai
3 Iron Age IIB	KEN fortress (decommissioned) (section 5.2.4.1)	^{14}C, well dated	The decommissioned building was still a prominent central location at KEN; still a center for exchange?
	RHI (Table 5.1)	^{14}C, well dated	A tower at the main western entrance to the copper ore district, located on a strategic knoll on a principal junction and near the oasis of 'Ain Fidan; control over trade and access to the region
	'Ain Hazeva Fortress / structures (Cohen and Yisrael, 1995)	Insecure, debated	A central road station, caravanserai, fortress; located in a strategic point near a local oasis and on a main road junction (connecting roads from Faynan, Busayra (via Wadi Dahal), and the Negev (cf. Figs.2.4-2.5); control over trade, exchange, and possibly territorial boundaries
	Yotvata fortress (Meshel, 1990, 1993) (Table 6.1)	Insecure	Control over the oasis of 'Ain Ghadian; control over northeastern access to the Timna Valley;

Table 9.1 continued

Production System	Site	Dating status	Function
4 Iron Age IIC	RHI (Table 5.1)	^{14}C, well dated	A tower at the main western entrance to the copper ore district, located on a strategic knoll on a principal junction and near the oasis of ‘Ain Fidan; control over trade and access to the region
	Ras al-Miyah fortresses and tower (section 5.2.6)	Ceramics, well dated	In addition to their main function to protect and support the mining operations in this area, the fortresses protect the northeastern entrance to Faynan copper ore district; conversely (and not less probable) the fortresses protect one of the access routes to Busayra and the Edomite highlands
	‘Ain Hazeva Fortress / structures (Cohen and Yisrael, 1995)	Ceramics, well debated	A central road station, caravanserai, fortress and central shrine; located in a strategic point near a local oasis and on a main road junction (connecting roads from Faynan, Busayra (via Wadi Dahal), and the Negev (cf. Figs.2.4-2.5); control over trade, exchange, and possibly territorial boundaries
	Tell el-Kheleifeh (section 6.2.2)	Ceramics, well dated; there is still possibility of earlier elements at the site	Major site with two successive fortresses (both are currently dated to the Iron Age IIC) on the head of the Gulf of Aqaba; major trade station, ancient port, control of seafaring and trade; In the current stage of research there is no evidence of successful simultaneous copper production

The Iron Age trade routes are discussed in section 2.1.2 above (see in particular Figs.2.4 and 2.5). These routes had to be maintained and protected to sustain viable ‘commercial’ activity that supported the production systems. The administration of trade had a direct influence on the ‘value’ of the products and the economic benefits of the society (-ies) engaged in the copper production systems. Keeping tight control over transactions was a basis for securing a monopoly over the market (with attempts to break it possibly evident in Production System 5, Fig.9.5). Further investigation of the principal sites (Table 9.1), characterization studies of

traded Iron Age objects, and especially more precise dating of relevant sites, are the basis for more in depth insights on the trade-related activities.

The Iron Age copper production systems interacted to some degree with the Arabian trade that started to become a significant component of the local economy in the early stages of the Iron Age and probably already in the Late Bronze Age (Finkelstein, 1988; Jasmin, 2006). The trade with goods from the southern region of the Arabian Peninsula had an enormous influence on socio-political developments in the southern Levant (in particular the Negev and southern Jordan, e.g., ibid and Singer-Avitz, 1999; Magee, 2004; Tebes, 2006; Tebes, 2007b). The main "Incense Road" may had several outlets including in the northern Jordan Valley (e.g., Artzy, 1994), but it seems that its main destination was the southern coastal plain in the north-western Negev through the region of Tel Masos and Tel Beersheva. One of the preferable routes must have been the easy descent from Busayra and the King's Highway to the Arabah through Naqb ad-Dahal and from 'Ain Haseva to the Beersheva valley through the Aqrabim Ascent (Figs.2.4 and 2.5). Bearing in mind the problems of Biblical source criticism (e.g., Friedman, 1988; Halpern, 1988) it is interesting to examine the description of a flourishing trade in this region in Ezekiel, probably representing a (late) Iron Age reality:

> Edom did business with you because of your abundant goods; they exchanged for your wares turquoise, purple, embroidered work, fine linen, coral, and rubies… Arabia and all the princes of Kedar were your favored dealers in lambs, rams, and goats; in these they did business with your. The merchants of Sheba and Raamah

> traded with you; they exchanged for your wares the best of all kinds of spices, and all precious stones, and gold. (Ezekiel 27:17, 21-22)

Given that this description probably represent the later part of the Iron Age, and in light of the results of the current research, it is not surprising that copper is not mentioned in regard to trade with Edom (cf. Fig.9.5). However, in the early part of the Iron Age (I-IIA) copper was the major good exported from Faynan and Timna through the routes noted above, and this thriving trade was an additional important component to the development of social complexity in this region, on top of the organization of production and the highly specialized technological practices emphasized in the current research (see discussion in Ben-Yosef et al., in press).

Destination of final products (copper ingots)

The reconstruction of metal trade and markets is difficult when it is based solely on the archaeological record. The problems with Lead Isotope Analysis (LIA), the basic analytic method available to study provenance of metals, is discussed in some detail in section 2.2.3 above, together with the status of research concerning Iron Age metal provenance in the southern Levant. The typology of copper ingots is another means of tracking trade connections (e.g., Adams, 2006, for Early Bronze Age copper trade in Faynan; Hauptmann et al., 2009, for Chalcolithic - Early Bronze Age I trade in the southern Arabah). However, ingots are extremely rare in the Iron Age archaeological record (none were reported from Iron Age settlements and only a handful of fragments were found in the Arabah Valley, mostly out of context, cf.

Rothenberg, 1990a:63-66), and their shape is currently cannot be well-defined, even on the basis of the mold fragments identified in this study and previous research (section 7.2.8).

The archaeological record does provide some indications for probable destinations of the products from the Arabah Valley. A limited number of LIA data were published recently for tin bronzes objects from the Late Bronze Age IIB and Iron Age I Beth Shean (Yahalom-Mack and Segal, 2009, n=19), and for metal objects of the 11th century from Tel Jatt (Stos-Gale, 2006, n=12, 2 are pure copper). Both the data from Beth Sean and Tel Jatt indicate that most of the copper during the Iron Age IB (11th century BCE) originate from the ore deposits of the Arabah Valley. The attempt to distinguish between Timna and Faynan in both cases is problematic (section 2.2.3) and seems to be less relevant in light of the results of the current research that demonstrate a unified production system during the Iron Age IB (Production System 1, Fig.9.5) in the Arabah Valley. In Bet Shean, the metal objects from the Iron Age I show different LIA signature from the metal objects of the Late Bronze Age IIB. The latter indicate diverse origin of the copper (Greece, Anatolia, 2 objects from Timna and an unknown source), probably the result of the highly developed Late Bronze Age trade network. Although the sample size is extremely small (both number of sites and number of objects), the evidence from Beth Shean and Tel Jatt is important for delineating possible markets for the copper production systems in the Arabah. The earliest evidence for Production System 1 in Timna (Timna 30, Layers 3-4 of the new

excavations, section 6.2.1.3) is dated to shortly after the reign of Ramesses V, the last Pharaoh to be associated with Timna. It seems that the new production system started to operate in the entire Arabah Valley during this time (cf. dates from KAJ, section 5.2.5.3), shortly after the Egyptians left the region, and that this system had a different market from that of the Late Bronze Age. Production System 1 provided copper for bronze workshops (the objects from both Beth Shean and Tel Jatt are tin bronzes) in the neighboring lands and replaced the much more varied sources (dominated by Cyprus) of the previous periods, as a result of the collapse of the previous trade network (Chapter 10).

Bronze workshops are common in Iron Age I settlements in the populated lands of the southern Levant (Ilan, 1999; Yahalom-Mack, 2010). Although recycling of scrap metal was probably common in these workshops, raw copper was probably also part of the circulation of metal in this system of production. In the copper ore districts of the Arabah Valley there is no evidence for the production of bronzes during the Iron Age (or any other period), and the final products were (probably ingots) of pure copper. These ingots, according to the evidence from Beth Shean and Tel Jatt, were destined, probably among other destinations (Chapter 10), to the small bronze workshops inside the settlements of the populated regions of southern Levant. As far as we can tell there is currently no LIA evidence that provide relevant information regarding the market of Production Systems 2 and 3. The analytical research on metal artifacts from Iron Age settlements is in its infancy (most of the

effort in the last decades was concentrated on the Late Bronze Age elaborated trade system), and much awaits future research.

Two metallurgical facilities similar to the common Iron Age I bronze workshops noted above are in particular interesting and worth further discussion. One is the metallurgical workshop at Tel Masos, located in the eastern Beer-Sheba Valley on the main trade route from the Arabah to the Mediterranean coast to the west (Fritz and Kempinski, 1983; Lupu, 1983). This metal workshop has been a central argument of Finkelstein and others (Finkelstein, 2005b; Fantalkin and Finkelstein, 2006; Finkelstein and Piasetzky, 2008; Finkelstein and Singer-Avitz, 2009; Finkelstein, 2010) for connecting Faynan to the Iron Age I-IIA settlement system of the Beer-Sheba Valley and the suggestion that Tel Masos was the administrative center of this system for the entire southern Levant. It is implied from the geographic distribution of sites that the copper production system in Iron Age Faynan was indeed connected to the settlements of the Beer-Sheba Valley by the trade network. However, guided by questions derived from the debate on the historicity of the Hebrew Bible, Finkelstein argues for a social unity between the two regions (and thus rejects the existence of an independent complex society in the east, which might be identified with Biblical Edom). To prove affinity between the societies of the two regions, Finkelstein and other rely on the metallurgical workshop at Tel Masos, which in their view represent sophisticated copper production in the tradition of Faynan. However, it is clear from reading the field reports and analyses, that the metallurgical evidence from Tel Masos

is weak, and represents at most a small bronze workshop similar to many others in the Iron Age southern Levant. The same conclusion was introduced recently by Yahalom-Mack (2010:272-273) as part of her general examination of bronze workshops in the early Iron Age:

> Fritz and Kempinksi excavated the site of Tel Masos, no doubt the largest and most complex site of the first wave of settlement in the Iron Age Negev (Masos I, Tebes, 2003). They identified two localities of metalworking in Stratum II, one in Building 96 and the other in Building 314. Copper metallurgical remains, indicating probably the remelting of copper and bronze (rather than smelting) were indeed found in one of the rooms in Building 96, However in Building 314 not a single metallurgical remain had been found; Fritz (1989) based his reconstruction of metalworking on a stone anvil and other stone objects found in the room. Bronze or copper were certainly not processed in Building 314, and it thus appears that the possible ritual function of Building 314 is unrelated to metallurgy, nor are the Midianite sherds found in the building. The role of Masos in distributing copper from Faynan as suggested by Fritz (1994a:136-150) and later by Finkelstein (2005b; Fantalkin and Finkelstein, 2006), cannot be based hitherto, as demonstrated above, on evidence of metalworking.

Another bronze workshop that was connected to Faynan is the only one reported thus far from southern Jordan during the Iron Age. It was found in the French excavations at Khirbat edh-Dharih near Tafila on the Jordanian plateau, ca. 40 km northeast of Faynan (Klein et al., 1997; Klein and Hauptmann, 1999), and dated by the excavator to the Iron Age II[109]. Hauptmann and Klein (1999) suggest Faynan as the source of copper (although their basic argument is geography, no LIA of artifacts has been carried out so far), and al-Shorman (2009) suggests a connection between Faynan and edh-Dharih based on similar technological traditions (Chapter 10.1).

[109] The workshop was dated by pottery sherds; it was found below a Nabataean occupation layer and was not completely exposed (Francois Villeneuve, pers. comm. 2010).

Other possible destinations can only be speculated on at this stage of research, based on geographical and historical considerations (e.g., the role that Egypt played in the Iron Age metal trade even as a weak power during the late dynasties; see Chapter 10 for further discussion). If the Biblical accounts regarding the 10th century BCE do preserve kernels of historical reality, the descriptions of the flourishing Red Sea trade of King Solomon (1 Kings 9:26-28; 1 Kings 10:22) may represent possible (and rather exotic) destination of the metal produced in the Arabah Valley during this time (Production System 2, Fig.9.5)[110].

9.1.5 *The invisible components of the chaînes opératoires: metallurgy as a human experience*[111]

Cult, magic and other invisible components of sociotechnical systems

Watson's (1991:265) equation of the substantive difference between processual and post-processual archaeology to the difference between a "soulless

[110] The accounts of the Solomonic Red Sea trade (1 Kings 9:26-28) do not mention explicitly copper as one of the traded goods. In fact, there is no direct reference to the copper mines of the Arabah Valley in the Hebrew Bible (a few verses were identified with mining activities, but these identification is insecure). The Red Sea trade was carried out from the port at Ezion-geber with the support of Hiram of Tyre (1 Kings 9:27). The Biblical description of this activity alone was sufficient for early scholar to stand for copper exploitation at the Arabah Valley. For example, Dame Kathleen Kenyon (Kenyon, 1960:256-257) stated: "it would have been not unreasonable to suggest that the most flourishing period for this exploitation was that of the reign of Solomon…" and also "The mineral wealth of the district is no doubt one reason for the prolonged struggles between Israel and Edom, for its control was clearly of great economic importance." Earnest Wright (1961:61) noted that: "one would think it very strange if material from that date [Solomon's period] were not found [in the Arabah mines]." The Biblical accounts also refer to Solomon *metal* trade in the Mediterranean with the Tarshish metal trading ships (cf., Albright, 1941:21-22; Rothenberg and Blanco, 1981).

[111] Title taken from Smith (1977).

method" (the former) and a "methodless soul" (the latter) seems to be adequate in the methodological discussion regarding the study of ancient technologies. Ethnographic and historic evidence, folklore, myths and epics of contemporary and ancient societies (Amzallag, 2008, in particular the references therein) and the nature of the technological practice itself, in particular the highly specialized metallurgical craftsmanship related to fire and the creation of metal from rock (cf. the place of alchemy in Medieval European societies, e.g., Eliade, 1978), all testify for the importance that rituals, magic and alike probably had in ancient copper production systems. However, there is a real methodological difficulty to understand these spiritual components in ancient societies based on the archaeological evidence. In most cases, the evidence simply does not exist, or hard to interpret. Resorting to arguments based on ethnographic parallels will be highly speculative and can easily wander into the realm of over-abstractness. In the case of copper smelting practices, the contemporary ethnographic evidence is limited to one case of traditional society in Nepal (see Introduction) that is not adequate for drawing relevant insights to the large scale operations in the southern Levant.

Nevertheless, others have recently tried to face this challenge in the field of archaeometallurgy with various degrees of success (e.g., Budd and Taylor, 1995; Pryce et al., 2007). Here, adopting practical (and more 'secure') approach, we consider the *recognition* of the probable existence of such components in ancient technological systems to be the key to balance the physical (and visible) evidence with the invisible

one. The entire array of ‘spiritual’ activities (rituals, magic, ceremonies, etc.) that are directly related to the technological practice is left as an ‘unknown’ (x); this unknown can be elucidated with implied insights, and unique finds.

Some unique finds related to worship do exist in association with the Iron Age archaeometallurgical record of the Arabah Valley. In Timna, Site 200 or and some structures in Site 2 (Table 6.1) were interpreted as a temple (“the Miners Temple”) and (Semitic) shrines (respectively). These were dated to the Late Bronze Age / Egyptian New Kingdom by the Arabah Expedition, except from Stratum II of Site 200 that was interpreted as a “Semitic tented desert shrine” (Rothenberg, 1988:277) that was active during the Iron Age I, right after the Egyptians left the region (although it was only “a short-lived, makeshift establishment,” ibid.). In light of the new chronological framework suggested here for Timna (section 6.2.1.4), it is likely that the small shrines in Timna 2 represent Iron Age activities, and were part of the copper production systems of this period. Another cultic site (Timna 198, Table 6.1), may also be part of the Iron Age activities in the valley.

In Faynan, except from small finds from Khirbat en-Nahas, such as figurines, amulets, and other artifacts that may have had some cultic meanings, only the architectural complex of Area W was interpret as possibly a temple or shrine (section 5.2.4.1). This area has some indications of activities that were symbolic and ritual-related, possibly associated with Production System 3 (radiocarbon samples are

currently being processed). Some finds in the unique metallurgical workshop in Area F (section 5.2.4.1), including a 'standing stone' and a fragment of decorated pottery similar to that discovered in the 'Edomite Shrine' at 'Ain Hazeva (below)[112], may indicate cultic activities that were conducted as part of the highly specialized refining/casting activities at this workshop (Production System 3).

A unique cultic site near the mining complex of Ras al-Miyah (FBRS 27, section 5.2.6.5) was related to the mining activity of Production System 4. From this period (Iron Age IIC) we have archaeological and textual evidence regarding the Edomite religion (in addition to the Hebrew Bible). Archaeological excavations of Edomite sites in both sides of the Arabah Valley have yielded material from cultic places that contribute greatly to the reconstruction of the Edomite religious practices. The unique cultic inventories from sites such as 'Ain Hazeva and Hurvat Qitmit of the eastern Negev suggest an idiosyncratic and rich Edomite rituals in the 7th and 6th centuries BCE (e.g., Beit-Arieh, 1991; Beit-Arieh, 1995a; Beit-Arieh, 1995b)[113]. From theophoric names of two Edomite kings mentioned in Neo-Assyrians texts (Qos-malaku and Qos-gabr) we learn about an Edomite deity named Qos/Qaus (Bartlett, 1989b:122-145; Millard, 1992). The same divine name appears also in "Edomite" script on a few seals and seal impression from archaeological sites of the late 8th-6th

[112] Interestingly, this unique pottery from KEN Area F, dated to the 9th century BCE and possibly earlier, is a couple of centuries older than the similar (Edomite) finds at 'Ain Hazeva, currently dated to the 7th-6th centuries BCE. This also supports the 'Edomite' ethnicity of the early Iron Age smelters at Faynan (Chapter 10).

[113] For a recent discussion and critics about the "Edomite" characteristics of the finds from the eastern Negev see Dearman (1995:121-123).

centuries BCE in southern Jordan and eastern Negev (Bartlett, 1989b:204-205; Beit-Arieh, 1995b; Vanderhooft, 1995). In addition, the name Qos is known from Nabataean texts, pre-Islamic Arabian sources and a few widely scattered references preserved in Greek inscriptions (Healey, 1989; Bartlett, 1990; Graf, 1990).

Was FRBR 27 a worship place for Qos? Was the worship of Qos involved in the metallurgical activities, was this deity born in a society engaged in copper production? Although the literature on Edomite religion is substantial, except from the knowledge that the Edomites worshiped a deity named Qos, other inferences are speculative. These include the debated primacy of Qos in Edomite society, the time of its appearance and its connection to the royal line (e.g., Bartlett, 1978). The study of Edomite religion becomes even much more complex when considering the Hebrew Bible, in particular if one cares for historical realities. Although the relation of the Edomite religion to the new archaeological evidence of Iron Age copper production in Faynan is intriguing, this is not the place to elaborate on these speculative issues. However, it is worth noting a recent non-conventional and controversial publication by Nissim Amzallag (2009, Yahweh, the Canaanite God of Metallurgy?) that attempts to connect the copper metallurgy of the Arabah Valley to the emergence of both the Edomite and the Israelite main deities. The main argument is far from being firmly supported by evidence (archaeological or textual), but the introduction and the references therein are a good background to this topic.

9.2 Summary

By parsing out the various components of the *chaînes opératoires* of Iron Age copper production technologies as reflected in the archaeological record of the Arabah Valley, we have identified five distinct production systems *throughout* the Iron Age and were able to characterize the basic components of the associated organization of production (Fig.9.5). In addition, we were able to recognize and describe *technological change*, *technological innovation*, *socio-technical boundaries,* patterns of developments and other elements of the technological record that represent social meanings (further discussed in Chapter 10).

All of the production systems described here were based on highly specialized craftsmanship, and four of them, including that of the early Iron Age (Production System 1, ca. 1140 – 1000 BCE) were large-scale, full-time[114] and *attached*. These four included the employment of a large labor force ('corvée' or 'retainer' in the terminology of Costin [Fig.9.5])[115] that was subordinate to *local* elite by varying mechanisms and degrees of control. The archaeological record of the Iron Age copper production in the Arabah Valley represents the most extensive copper production in this region in history, eclipsing production during periods of documented state-level control over the organization and administration of the enterprise (e.g., the Roman-Byzantine period). The technology, in particular the sophisticated smelting represented

[114] If smelting campaigns were seasonal, 'full-time' refers to occupation during the production season, see section 10.1.
[115] These terms are useful to typify the Iron Age production system on the comparative basis used here, even that their common connotation is with Feudalism.

in Production System 3, was among the most advanced known in antiquity, including the technologies of later periods in the Arabah Valley and elsewhere (cf. Rothenberg, 1990a; Hauptmann, 2007:243).

The *chaînes* detailed in this chapter also demonstrate the complexity of the production system and its numerous variables, which had a direct influence over the process of copper extraction from the ore source to the exchange market. This complexity implies on social realities that are further discussed in the next, and concluding chapter of this dissertation.

10. Conclusion: modeling ancient societies through technology - the Iron Age of the southern Levant and copper production

Extracting social meanings out of the fragmented and silent archaeological record is a difficult task. Accordingly, the conclusions outlined in this summary chapter often consist of more than one interpretation of the evidence. The basis of the following discussions are the robust identifications and reconstructions of the Iron Age *chaînes opératoires* and *production systems* for copper exploitation in the Arabah Valley presented in the previous chapter. Where relevant, the limitations of the currently available data are stated.

10.1 Main social and culture history insights

Social unity of Faynan and Timna

The similarities between the archaeometallurgical records of Faynan in the northern Arabah valley and Timna in the south were first noted by Hauptmann (1989) and further detailed by Weisgerber (2006), as part of the GMM research in Faynan (contra the original publications of the Arabah Expedition, e.g., Rothenberg, 1988:17). Hauptmann (2007:103) notes that:

> the repertoire of finds from the Late Bronze Age/Iron Age smelting locations repeats itself not only in the sites in the Faynan region… Fragments of the furnace walls, clay tubes, slag and the furnace installations are practically identical to corresponding material from Timna 30, Stratum I… This provides evidence of clear

> parallels in the metal technology between Timna and Faynan, contrary to Rothenberg's opinion…

and this has been corroborated in the current research. Moreover, the parallels in time and archaeometallurgy material culture have been refined here, and it is now evident that both records demonstrate the same diachronic developments and indistinguishable inventories, to the level of minute details in installation construction and facilities operations. The only technological differences between the two records (e.g., fuel source and mining techniques; Chapter 9) are directly derived from environmental constraints imposed by each region (Chapter 2).

We suggest interpreting the technological similarities between the two sub-regions of the Arabah valley as evidence for social unity, i.e., the same social groups inhabited both regions, and operated the copper extraction systems simultaneously and under the same general production system and organization management. The following arguments support this interpretation of viewing the entire Arabah valley as a large extractive metallurgy zone: (1) in ethnography of technology, it is rarely (if at all) the case that the *exact* same technological traditions cut across different societies (for examples concerning metallurgy, see e.g., Knapp et al., 1998; Bisson et al., 2000); (2) beyond elements of the technology *per se*, the similarities include components of organization of production. For example, the spatial organization of production, the establishment of designated working spaces for different activities and the tightly organized disposal areas at the site level demonstrate similar patterns. Furthermore, the organization of production appears to have similar attributes on a

regional level: the Iron Age I (12th – 11th centuries BCE) smelting activities seem to have operated in open sites in both regions (the date of the 'defensive' elements in Timna 30 and 34 is questionable), the Iron Age IIA (10th century BCE) smelting activities included defensive elements in both regions (KEN fortress and 'towers', Yotvata fortress, the walls at Timna 30 and Timna 34; but see reservations below), and the Iron Age IIB (late 10th – 9th century BCE) smelting activities were more concentrated (fewer sites) in both regions; (3) the similarities between the two technological records of Faynan and Timna include attributes that are not purely functional, i.e., there are elements of *technological style* that are considered culturally idiosyncratic and stand for social unity. These mostly include the additional use of slag as temper in domestic pottery that characterizes the Iron Age societies and seems to be beyond the functional (section 7.2.4.4), and possibly the inventory of 'trinkets' produced locally for local use (copper pins and some iron objects); (4) the two records of Faynan and Timna are in fact also indistinguishable in other aspects of the material culture. Although, as detailed above (Chapter 4), the pottery and other elements of the material culture that are not directly related to the copper production are rather poor in the archaeological records of the northern and southern Arabah, the assemblages are quite similar. Both include (in corresponding periods) "Negebite" pottery, QPW (section 6.2.4.1) and local wheel made pottery that demonstrate similar forms[116].

[116] The comparison between the local wheel made (and non-Negebite handmade) ceramics of Timna and Faynan is limited and should be regarded as tentative because of lack of sufficient research. Glueck (1935) was the first to note the ceramics parallels, and his views should be taken into account again, in light of the results of the current research. The ceramics identified in Timna as Nilotic – Egyptian (New

Identifying ancient technological records with specific social groups or using technological records to delineate social boundaries have problems similar to the well known issue in archaeological research often labeled as "pots and people" (e.g., David and Kramer, 2001:148-149, and cf. 173ff). This analogy – archaeometallurgical record : people :: ceramics record : people ('people' refers to society / ethnicity / culture) also was briefly touched upon by the Arabah Expedition in their discussions on Late Bronze Age furnaces and ceramics in the Timna Valley (see section 7.2.4). The study of ceramics (pottery) is in fact an instance of technological record investigations. Relatively to other technologies, ceramic assemblages are often considered to be embedded with rich aspects of social meanings and identities, thus they can provide clues for social boundaries and interactions (see below). Although records of ancient metallurgical traditions can represent diffusion of similar technological ideas to different societies and/or the presence of craftspersons of a different social affiliation in the center of (small) production workshops (e.g., wanderer metalsmiths), this does not seem to be the case in the Arabah Valley for the reasons outlined above. In conclusion, the same social groups were responsible for the (large scale) metallurgical activities in the entire Arabah Valley during the Iron Age I – IIB (1200 – 800 BCE) – a period that corresponds to three specific technological traditions identified in the *chaîne opératoire* analyses presented in Chapter 9.

Kingdom), require further investigation and re-examination in light of the new chronological framework for Timna 30 provided here. We believe that this type of ceramics was misidentified in most cases (section 6.2.4.1).

Similarities between the smelting technologies of Iron Age Faynan and the melting technologies found at the bronze workshop at Khirbat edh-Dharih (Klein et al., 1997; Klein and Hauptmann, 1999) may also indicate that the same social groups were responsible for both production systems. Khirbat edh-Dharih is located on the Jordanian plateau, ca. 40 km northeast of Faynan (near the modern village of Tafila), and the metallurgical remains there are dated generally to the Iron Age II. The refractory ceramics (mostly related to manufacturing of crucibles) have the same double (or multi-) layer structure made of two distinct types of clay: the calcareous illitic red clay and the non-calcareous sandy white and highly refractory clay (cf. section 7.2.5 and 9.1.3). This principal pyrotechnological component is not paralleled in Iron Age I (and probably later) bronze workshops in Cisjordan (cf. Yahalom-Mack, 2010), and as al-Shorman (2009:223) puts it "this suggests that the production of multi-layer refractories was a local regional technological tradition." Examples from iron workings in Africa demonstrate that technological specialization might indeed be based on ethnicity (de Barros, 2000:184, and references therein).

The centrality of Faynan

Notwithstanding the social unity of Faynan and Timna, the archaeological records demonstrate a substantial difference in the *scale of production* between the northern and southern ends of the Araba valley. Throughout the Iron Age I – IIB

sequence, copper production in Faynan was at least two orders of magnitude more intense than the corresponding systems in Timna (Chapters 5, 6, and 9). The limiting factor could not have been the availability of ore, as intensive copper exploitation took place in the southern Arabah in later periods (Roman-Nabataean and Early Islamic) using similar ore sources as those of the Iron Age. It is possible that fuel and proximity to agricultural land were a limiting factor that prevented the Timna sub-region from eclipsing that of Faynan. The archaeological record of the southern Arabah indicates that acacia wood was the main source of charcoal for smelting in this region (section 7.2.3), probably reflecting environmental constraints. This source is quite scarce in the desert landscape and very slow to rejuvenate (in contrast to the rapidly growing hydrophilic plants used in Faynan), thus the possibility of depleting the fuel source should be taken into account (Fig.10.1:Model 1). The other major 'advantage' of Faynan over Timna is the availability of water resources for agriculture in the lowlands of the Faynan region where perennial streams have enabled agriculture to be carried out in the valley bottom of the Wadi Faynan and many of its tributaries for millennia (Barker et al., 2007b), possibly including in the Iron Age (Mattingly et al., 2007b). In addition, the highland plateau immediately above lowland Faynan is rich in agricultural land where crops could be grown and exchanged. This situation does not have a parallel in the southern Arabah.

On the other hand, rapidly growing plants were available to the smelters in the southern Arabah if a longer transportation distance would have been considered as

part of the production systems (for example, tamarisk could have been cropped at the oasis of ‘Ain Ghadian, located northeast of Timna Valley and just near the Iron Age fortress of Yotvata, Table 5.1). This raises the possibility that Faynan was more central not because of limiting factors in the production of copper in the southern Arabah, but rather because of fundamental components in the geographic distribution of the society(-ies) engaged in copper exploitation that transcend the mere functionality of copper production (Fig.10.1:Model 3) and/or that the centrality of Faynan stemmed from the destinations of products and the attempt to reduce costs of transportation (Fig.10.1:Model 2). Given the reservations presented above regarding fuel as a limiting factor to the production of copper, field evidence that Egypt was a probable destination for copper products (below) and the reasonable assumption that trade routes existed between the southern Arabah and Egypt during the Iron Age (via land or sea), the intrinsic affinity of the social groups in the Arabah to the Faynan region seems to have more weight in the interpretation of the difference between the two records.

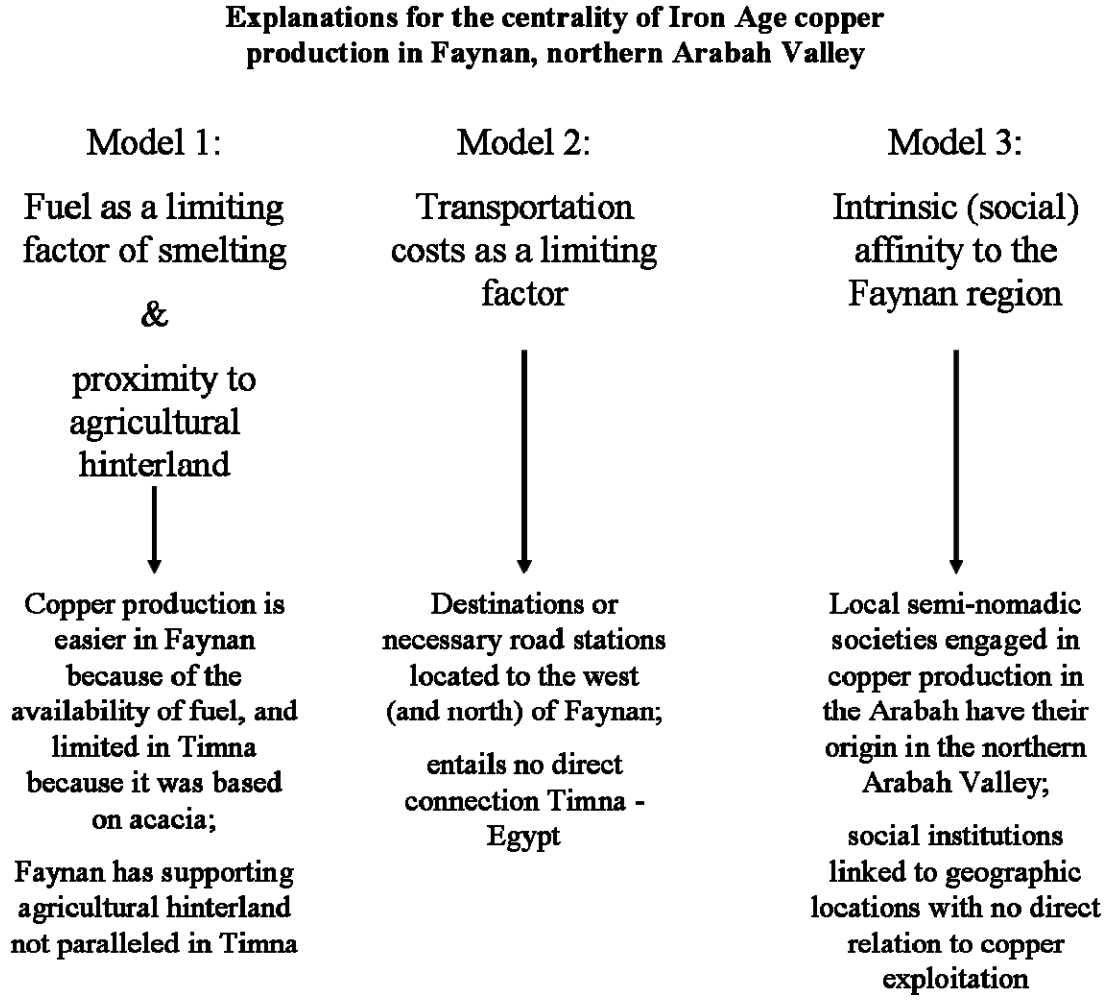


Fig.10.1: Three models of possible reasons for the centrality of Faynan Iron Age copper production system (in comparison to Timna), assuming that availability of copper ore was not a limiting factor. A combination of more than one model probably reflects production realities, however, examination of the archaeological evidence and historical considerations give more weight to Model 3.

Basic socio-economic components of the Iron Age societies of Faynan and the Arabah Valley

"…there can be no general rules concerning the tempo of social development. If the conditions are right, states and even empires can be built within a single lifetime." (James et al., 1991:315)

Based on the archaeological data analyzed for this project, two main assumptions underlie the interpretations suggested in this chapter: social complexity can evolve rather fast, and nomadism (i.e. lack of architectural remains) is not a proxy for social complexity.

The evidence of mining and smelting in the Arabah throughout the Iron Age lacks architectural remains that could have provided habitation for the corresponding working force. Only during Production System 1 and 2 were there several building complexes that could have been used for the residences of the elite (notably the massive structures at KEN and KAJ), but even those are insufficient for accommodating even a small portion of the workers. Thus, we could conclude that the society responsible for the copper production consisted basically of tent dwellers. This is in accord with other models suggesting that the society of southern Jordan, at least during the first part of the Iron Age (Iron Age I-IIB) consisted of fundamental semi-nomadic components, and was structured in a sort of tribal chiefdom (or kingdom)

(e.g., LaBianca and Younker, 1995; Bienkowski and Steen, 2001). Further evidence from Faynan supports social models based on semi-nomadic society(ies), including the results from the excavations at the cemetery of Wadi Fidan 40 (Table 5.1) (see discussion in Levy, 2009b) and possibly, as suggested here (section 7.2.3.1) the pattern of charcoal species used as a fuel source during the Iron Age.

The nomadic and 'tent dwelling' components of the Iron Age societies *are not* a proxy for the complexity of social organization or for the socio-political structure of these societies (e.g., Khazanov, 1994, and see in particular chapter 5 there)[117]. The technological record of copper production reflects a complex social organization throughout the Iron Age. The first secure evidence of complex social organization that is not *directly* attached to Egypt appears in the technological record in the last phase of the 12th century BCE (as evident in KAJ-A, KEN-M, and Timna-30, see in particular sections 5.2.4.5, 5.2.5.3, 6.2.1.3 and 6.2.1.4 above). It is probably not a coincidence that this date is somewhat after the last clear evidence of an Egyptian presence in Timna (Ramesses V, reigned until 1149 BCE, see Table 10.1).

A fundamental question remains: did copper production in the Arabah stimulate social processes and the development of local polity(ies), or does the evidence of these production systems only reflect a complex society that resided (in

[117] Among many other examples, the well-known case of the Mongol Empire (ca. 13th century CE) demonstrates the disconnection between nomadism and political power (Fitzhugh et al., 2009).

tents) in the area of the copper ore[118]. The solution probably lies between these two options – the ancient technological record testifies for the complexity of the society, and the engagement in these production systems, including the derived economic incentive, stimulated the development of more complex social organization. It should be noted, however, that the first evidence of copper smelting during the second half of the 12th century BCE already reflect high degree of social complexity. As 'high degree of complexity' is a *relative* measure, it should be regarded in light of parallels (diachronic and synchronic) (e.g., Iron Age Cyprus, Early Bronze Age or Roman Faynan, all currently do not present larger production scale than Iron Age Faynan) and the absence of evidence for small scale 'trial and error' smelting practices. The Iron Age I evidence for smelting technology and at Timna 30, KAJ and KEN and KAG is substantial from its early phases.

The semi-nomadic nature of the Iron Age societies engaged in copper production supports the possibility that the smelting operations were conducted on a *seasonal* basis. Because the bulk of the labor force dwelt in tents, the movement

[118] It is intriguing to consider the latter of these two options with regard to the debate about the political power and social organizations of the United Monarchy during the 10th century BCE. If it is indeed the case that the evidence of sophisticated smelting operations in the Arabah Valley is just a visible testimony for a complex society that resided in a copper ore district and dwelt in tents, it implies that other semi-nomadic societies in neighboring regions at the same time had a complex structure (maybe of a *statehood*) but because they were mostly tent dwellers, and because their main economic activities were related to agriculture, they are much less visible in the archaeological record than their parallel in southern Jordan. In sum, it is possible that the complexity evident in the copper production of Faynan has implications for our understandings of other polities in the southern Levant during this time, including the United Monarchy, and that in this case highly 'archaeologically visible' technological practices replace what many other scholars are looking to find in architectural remain, which are simply not an adequate means for deducing social complexity (and see discussion regarding tents in ancient Israel in Homan, 2002).

between the lowlands and the highlands was rather easy and may have been similar to patterns observed in modern Bedouin societies (e.g., Palmer et al., 2007). In this case, the smelting and mining took place during the winter, when it is cooler and water is more available in the lowlands of Faynan and Timna. During the summer, the workers of Faynan and those of Timna moved to the highlands of southern Jordan, where subsistence based on pastoralism and small scale agriculture could have taken place during the hot and dry summer. The model of seasonal production is supported by comparison to the Egyptian turquoise and copper exploitation in Sinai that has textual evidence for annual and seasonal expeditions (see footnote 92 above) and fits well to the 'social unity' and culture history interpretations suggested here. The highlands of Faynan were the closest and most suitable agricultural and pastoral hinterlands of the copper production center *both* of Faynan and Timna (the latter corresponds to the more southern parts of the Jordanian plateau). Thus, it is reasonable to assume both social unity of the two regions, and a strong connection of the copper working populations to the *east* (i.e., Edom at least in the later part of the period), rather than to the west. Although this model (suggested to some degree already by Glueck, e.g., 1940c) seems to be most suitable, especially in light of the research presented here, the possibility of year-long operations cannot be excluded at this stage of research. An answer to this question can possibly be provided by a through archaeozoological research in the future (e.g., Rocek and Bar- Yosef, 1998).

Ethnicity: Edomites, Israelites, and others

The question of ethnicity is one of the greatest challenges in archaeological research (cf. Jones, 1997). The study of technology presented here contributes only a little to the identification of the ethnicity of the people engaged in Iron Age copper production in the southern Levant. This question is also discussed in some detail in sections 2.1.1, 6.2.1.4, and 7.2.8.1 above. This issue is even more complex when considering the probable option that the production systems incorporated more than one ethnic group. This may be the case if the labor force consisted of slaves or war prisoners, and/or if small groups of highly specialized craftspersons provided special services in a production system managed mostly by a different society. The scarcity of material culture that is not related to copper production technology (Chapter 4) also makes this discussion difficult and highly speculative.

Production System 4 (ca. 700 – 586 BCE) has abundant ceramic finds that are similar to the ones found in Busayra considered to be 'Edomites' (section 5.2.6.4). It is commonly accepted in the scholarly research to regard the population of southern Jordan as 'Edomite' at this period (Iron Age IIC) (e.g., Bartlett, 1989b). During the 6th century BCE the Edomite polity functioned under the influence of Assyria, and it is possible that some Assyrian presence is also reflected in the archaeological record.

In the early Iron Age, Production Systems 1-3 (1200 – 800 BCE), the situation is more complex. From the perspective of ceramics analyses the issue of ethnicity and social boundary is discussed in the recent work of Smith (2009) mostly in regard to Faynan. In essence, the bulk of the ceramic finds are *locally produced* and considered to be predecessors of 'classic' Edomite types (of the Iron Age IIC) and do not correspond to the main typological scheme of Cisjordan at that time (e.g., Smith and Levy, 2008; Smith and Levy, in press; Smith et al., in press-b). These results have been criticized by Finkelstein and Singer-Avitz (2009), and the debate is still ongoing.

From the perspective of copper production technology, the case of Khirbat edh-Dharih noted above (cf. section 9.1.9.4) supports a cultural affinity between the Arabah copper production centers and the east, i.e., the heartland of Edom. In addition, the 'natural' and closest hinterland, supporting the copper operations with basic supplies etc., is the fertile lands of the Jordanian plateau, located only a few km to the east. However, documenting these links is admittedly rather weak at this stage of research.

Evidence for three additional ethnic groups may be reflected in the archaeological record of the early Iron Age, however, the material culture appearance of these groups is always minor (if present at all) and may reflect trade or exchange rather than a physical presence. These include the Egyptians (sections 5.2.4 and

6.2.1.4), 'Midianites' (section 6.2.1.4)[119] and early 'Israelites' or other social groups from the Negev or southern Judah. The presence of ethnic elements from the west is currently supported only by architectural parallels between Khirbat en-Nahas (Production System 2, Iron Age IIA) and some sites in the Negev, especially the so called "Israelite fortresses" (e.g., the 10th century building at KEN-Area R [Fig.5.30] and the fortress at Atar Haro'a (Cohen and Cohen-Amin, 2004; Shahack-Gross and Finkelstein, 2008))[120]. However, this link is rather weak, and no further conclusions regarding "western" elements (including speculative attempts to affirm Biblical accounts regarding this period) can be made at this stage of research.

Small Egyptians artifacts, including scarabs (cf. section 5.2.4.2) but not pottery, were found at KEN in the context of Production Systems 2 (Iron Age IIBA), 3 (Iron Age IIB) and possibly 1 (Iron Age I). The interpretation of these finds is not clear, but it is currently assumed that they do not represent an Egyptian presence at the site in any of these Production Systems (cf. Levy et al., 2008a; Ben-Yosef et al., 2010a). The situation in Timna is more complex and discussed in detail in section 6.2.1.4 above. In essence, Egyptians were present in Timna and in Sinai during the Late Bronze Age (and in Sinai perhaps even earlier), and were engaged in the copper production systems in both regions. It should be noted that at Timna, according to the common interpretation, the Egyptians were the elite controlling the production and *not*

[119] For a highly speculative suggestion of a connection between the 'Midianite' and the Sea Peoples see section 7.2.8.1 above.
[120] If these parallels do represent a "western" ethnic component, they might reflect the Biblical accounts describing Israelite (Davidic) control over Edom in this period (2 Samuel 8:14).

the labor force itself, which was made of *local* nomadic tribes (cf., e.g., Conrad and Rothenberg, 1980).

The case of the so called 'Midianite' pottery tradition is also discussed in some detail in section 6.2.1.4 above because it bears also on chronological issues. The identification of this 'ethnicity' is based on unique pottery often found in association with late 2nd – 1st millennia BCE copper production sites in the southern Levant (but also in a few settlements), and considered to originate (the pottery and the people it supposedly represents) from the Arabian Peninsula. According to the new dates obtained in the current research, the pottery appears in the archaeological record of the copper production sites (mostly in the smelting sites, but also in the 'Egyptian sanctuary' at Timna and in Barqa el-Hetiye in Faynan) in association with the Late Bronze Age Egyptian activities in Timna, and with Production Systems 1 and 2. The observation of Rothenberg that Timna 30 Layer I contains no 'Midianite' pottery, i.e., that Production System 3 is not associated with this ceramic group, was corroborated in the new excavations at Timna conducted as part of the current research. Also in Faynan, the excavations of the late 10th – 9th century contexts at KEN (Production System 3) yielded no 'Midianite' pottery so far (at least not from secured contexts, Smith, pers. comm. 2010). This may have implications on culture history interpretations of the archaeological record, as we now know that the change between Production System 2 and 2 was abrupt, and relatively short, and most probably related

to external interference. Thus, the absence of 'Midianite' pottery from the later record might be the result of a conflict, rather than an organic development.

In the research of the Arabah Valley it has been suggested that the people represented by the 'Midianite' ceramics were skilled metallurgical craftspersons, incorporated into the production systems to control and direct the highly sophisticated operation of the smelting technologies (e.g., Rothenberg, 1998, and references therein). However, this cannot be supported by corresponding archaeological evidence, except by the fact that in the southern Levant this pottery is mostly associated with smelting sites (but not exclusively), and that at these sites it always consists of a very small portion of the entire ceramic assemblage (contra the situation in the Arabian sites, e.g., Sawyer and Clines, 1983).

The role of Egypt: origin of technologies, destination of products?

The following model attempts to explain the role of Egypt in the development and maintenance of the Iron Age copper production systems in the southern Levant. It is based on the archaeological record of copper smelting technologies in the southern Levant as we currently understand it, the complimentary Egyptian evidence from Timna and the Sinai Peninsula (Chapter 6), and the preliminary analyses of the Egyptian-related artifacts from the recent excavations at Iron Age Faynan. In addition, this model takes into consideration the possibility that *a major* part of the Egyptian

copper metallurgical tradition, including primary smelting of copper ore, is awaiting discovery in the Eastern Desert. This is very likely to be the case, as extensive copper ore deposits are known is this region along almost the entire length of the desert into Nubia, and very little field research was done there (Ogden, 2000:150). In addition, the proximity of this region to the heartland of Egypt, the rich metallurgical tradition evident in wall paintings and some archaeological workshops (Scheel, 1989), and the evidence of large scale consumption of copper throughout the history of the Egyptian Empire, also support the assumption that the Eastern Desert was a major source of copper (notwithstanding the textual evidence of exportation of copper from the north, probably Cyprus, first appearing during the New Kingdom)[121].

The extensive remains of the copper production center at Bir Nasib in Sinai (Table 6.1) constitute fundamental evidence for the connection between Egypt and the technological traditions of the Iron Age southern Levant. Although this site was only probed by Rothenberg (1987), there is clear evidence for intensive smelting during the Late Bronze Age and probably also in the Middle Bronze Age. These smelting activities are connected to Egypt by various Egyptian finds, including stelae and inscriptions on the rocks nearby. The key here is that the copper smelting technological remains are similar to the later tradition of Production System 1 of the Iron Age I in the Arabah Valley (ibid., and cf. Rothenberg, 1990a). This suggests that

[121] Another 'terra incognita' with protential for future archaeometallurgical discoveries is the north western mountainous region of the Arabian Peninsula, where copper ore deposits exist. Orings of metallurgical traditions from this region are in accord with the presence of QPW pottery in smelting sites of the southern Levant (see section 6.2.1.4 and above, under 'Ethnicity.'

Egyptian smelting technology, practiced in Sinai and probably also in the Eastern Desert, was the source of the basic Iron Age smelting technologies, *adopted* by the local societies through the Egyptian expeditions to the region. The Iron Age (and Late Bronze Age) archaeological record in Timna and Faynan does not include any stages of 'trial and error' or slow technological developments that might indicate local innovations. On the contrary, although gradual improvement did occur during Production Systems 1 and 2 (cf. section 8.6), the smelting technologies appeared in the Arabah Valley in a fully developed state.

The interactions between Egyptian craftspersons and local laborers during the Late Bronze Age were probably a mechanism for the diffusion of technological knowledge. It is interesting to note that evidence of an Egyptian presence in the copper production centers decreases exponentially the greater the distance from Egypt it is[122]. In Sinai, large temples and numerous inscriptions and stelae testify for Egyptian presence during the Middle and Late Bronze Ages (and earlier), while in Timna the core evidence comes from a small shrine and a few petroglyphs, and in Faynan only from sporadic small finds (none of which were found in a secure Late Bronze Age context). Egyptian presence in Timna during the New Kingdom is probably also supported by textual evidence, in particular Papyrus Harris that includes a description

[122] This reflects Gil Stein's (1999) concept of the 'tyranny of distance', which argues against many of the assumptions in ancient World Systems theory for the dominance of core civilizations over their peripheries (see also Levy et al., 1997; Levy and van den Brink, 2002, for the Early Bronze Age situation, ca. 3600 – 3000 BCE).

of an Egyptian expedition to a place called ‘Atika’, commonly identified as Timna Valley (e.g., Levene, 1998).

The Egyptian interest in the copper industry of the Arabah Valley probably did not cease after the withdrawal of Egypt from Timna during the days of Ramesses V (1149 – 1145 BCE), the last pharaoh that is represented in finds from the ‘Egyptian sanctuary’ in the center of the valley (Rothenberg, 1988). The current research have shown that, *contrary* to previous assumptions in the research of the southern Arabah, copper production activities were rekindled to a relatively high intensity shortly after the Egyptians left the region (section 6.2.1.4). This is paralleled in Faynan (both in the time frame and material culture evidence) and together the entire renewed production efforts in the Arabah Valley are considered here to be part of the same production system, and to represent the same social groups (Production System 1, cf. Fig.9.5). As discussed above, this production system is based on local society(-ies). However, it is probable that the market still included Egypt, but since the balance of power changed production was now managed by the local societies only. A model connecting the rekindled production system and its successors (Production Systems 1, 2 and 3) to the Egyptian market will provide a solution to Ogden’s (2000:150) ‘missing link’: “Strangely, there is no evidence so far for any exploitation of the Timna mines in the Late Period – the period when the production of copper statuettes and the like in Egypt increased exponentially.” The sporadic Egyptian finds at KEN (a few scarabs, an

amulet, etc.) probably represent this type of connection between the weak late Egyptian dynasties and the production centers of the Arabah, which were economic-based interactions of trade and exchange. The Egyptian finds possibly indicate that caravans of traders from Egypt came to the Arabah Valley to exchange goods for copper (but not necessarily, local traders could have obtained such artifacts in Egypt carry them back to the Arabah sites).

The abrupt end of Production System 2 at the second half of the 10th century BCE simultaneously in Faynan and Timna, including re-organization of production sites and abandonment of others, coincides with the date of the military campaign of Pharaoh Shoshenq I (Biblical Shishak) to the southern Levant, described on the walls at the temple of Karnak at Tebes (Kitchen, 1986; Kitchen, 2003). Our suggestion to identify evidence of disruption and re-organization of production at Khirbat en-Nahas and the abandonment of Khirbat al-Jariya with this military campaign (Levy et al., 2008a; Ben-Yosef et al., 2010a, respectively) was discussed elsewhere. The current research provides the technological and organization of production perspectives for the processes of this time period: the change observed in the archaeological record not only included abandonment and disruption but also represents a shift between production systems in the entire Arabah Valley and the introduction of *new and more advanced copper production technology* (in particular section 7.2.5.4).

Given the data at hand, it is highly unlikely that the new technology of Production System 3 is the result of local developments. It appears in a fully developed stage abruptly with the initiation of the new production system sometime in the late 10th or early 9th century BCE. One of the main technological innovations concerns the introduction of a new type of bellows pipe (section 7.2.5.5) that has parallels in the metalworking site (bronze foundry) at the funerary temple of Seti I at Thebes (Fig.9.12). Although this workshop is probably dated to a later period (Ptolemaic Egypt, late 4th century BCE), it preserves Egyptian metallurgical traditions (Davies, 1943; Ogden, 2000:150). Even without this parallel, the most suitable source for the new technology would be Egypt, as their interest in the economy of the southern Levant and in particular the metal production in the Arabah Valley is evident in the campaign of Pharaoh Shoshenq I. Moreover, although the new technology is has substantial differences, it still represented the same technological tradition (see section 9.1.3 for details). The question of exactly how the introduction of the new technology occurred remains open. However, it is intriguing to consider Finkelstein's and others (e.g., Finkelstein and Piasetzky, 2008) recent suggestion that the campaign of Shoshenq I stimulated the copper production in the region. In the view of Finkelstein and others, this campaign *did not* disrupt an earlier production system, but rather 'gave a push' to a small scale production system that existed previously in the region. Although we do not accept the benevolent interpretation of the military campaign, it is a possibility that after disrupting the existing production system (Production System 2 – that was not small scale production as suggested by Finkelstein), it was the *Egyptian*

themselves who initiated the new production system (Production System 3) that was based on Egyptian technological knowledge and a local labor force, at least for some time at the beginning of the renewed technological operations. The problem with this interpretation lies in the absence of decisive archaeological evidence for an Egyptian *presence* or occupation in the Arabah Valley during this production system phase. The claim of Rothenberg (e.g., 1980b) that in Timna 30 Layer I (Production System 3) there are indicative ceramic sherds of the 22nd Dynasty, and that this production is directly related to Shoshenq's campaign, was not corroborated in the current research, and does not have (thus far) parallels in Faynan where much more extensive excavations have taken place. However, closer attention to the question of an Egyptian presence in the archaeological record will probably provide more insights in the future[123].

Even when supported with Bayesian modeling (section 4.2.1), the abundant radiocarbon dates of ELRAP still have a margin of error that prevent us from definitely identifying Braudel's (1976) *événement* or 'episode' linked to this rapid change indicated by high precision radiocarbon dating[124] (i.e., the exact socio-cultural and historical background for the shift). That said, the documentation of technological

[123] The entire ceramic assemblage of Timna should be revisited now in light of the new dates obtained in the current research. In particular, all the 'Nilotic' New Kingdom ceramics (section 6.2.1.4).
[124] Even the exact date of the most suitable historical event to explain the change in the technological record of the Arabah at the late 10th – early 9th centuries BCE, namely the campaign of Pharaoh Shoshenq I to Canaan, is not confirmed (cf. Shortland, 2005), neither is its exact geographic course in the south (cf. Fantalkin and Finkelstein, 2006).

change presented here is rather detailed, and not common in the archaeometallurgical literature.

"Ancient efficiency"

The critique and reservations of Costin (e.g., 2001:289) concerning the use of the concept of *efficiency* when analyzing ancient production systems (section 1.2.1) was not a major concern in the current research because efficiency of a production system was consistently measured here relative to adjacent (in time or space) production systems, and always referred to a specific technological aspect (the efficiency of *smelting* technology, rather than the efficiency of the entire production system). Costin's critique is demonstrated in the case of Iron Age copper production in Faynan, where the archaeological record reflects a much more complex array of considerations included in production systems than the simplistic (and, in Costin's definition, Western) principle of least-cost and other optimizing models of production. It is most evident in the record of charcoal at the Iron Age copper smelting sites. This record demonstrates that other considerations, probably inherent social values that are beyond the least cost principle, were involved in the basis of the production systems (see section 7.2.3.1 for details).

Hegemony, and control over technological knowledge

Notwithstanding the extensive archaeological research in the Arabah Valley, the archaeological evidence of Production System 5 (ca. 1200 – 800 [?] BCE) was first identified only in the current research because of two main reasons. First, the sites are small, thus they were less attractive for in depth research (only a few were excavated). And second, the evidence of a simple technological practice was in many cases incorrectly interpreted as representing earlier activities. A critique of this simplistic dating approach to ancient technological records is presented in section 4.1 and further discussed in section 6.2.3.3.

Production System 5 could have operated simultaneously with the primary Iron Age production systems or intermittently and interchangeably with the primary systems in periods when the primary systems did not operate (whether on a seasonal basis or on a more prolonged cycles of time intervals). In any event, this was a marginal system, excluded from the activities of the more dominant social components. The associated material culture at these sites is too scarce to draw any firm conclusions regarding the nature of the society responsible for the archaeological record of Production System 5. This technological system can represent a different social group from the one engaged in the primary system or a marginalized component of the same social group responsible for the main technological record. The evidence suggests that in both cases there was a strong element of segregation and implies that

access to technological knowledge and/or sufficient resources (labor, means of control and organization) were necessary for conducting smelting operations at the advanced level evident in the primary Iron Age production systems in the Arabah (see more details in section 6.2.3.3).

Culture history events as reflected in the technological record

In addition to constituting a source for insights regarding ancient social processes and realities, the copper production technological record of the Arabah Valley is a proxy for identifying external influences and some 'global' events. Table 10.1 summarizes possible correlations between the archaeological record of copper technology and historical events in the southern Levant in light of the research presented here.

Table 10.1: Suggested correlation between copper production systems in the southern Levant, social processes and culture history events

Period date BCE	Culture history framework / Historical events	Primary Production System (cf. Fig.9.5)	Production records (technology)	Social processes	Correlation with culture history events
Middle Bronze Age (MB) (?) 2000-1550 Late Bronze Age (LB) 1550-1140	MB: Egyptian expeditions to Sinai, turquoise and probably copper smelting at Bir Nasib (Table 6.1) LB: The southern Levant is under Egyptian New Kingdom control	The predecessor and the technological origin of Production System 1	Archaeological records of smelting technologies in Sinai (mostly Bir Nasib) are similar to those used during Production System 1 and may be dated as early as the Middle Bronze Age. Late Bronze Age smelting is evident in Sinai, and in a limited scale in Timna (Table 6.1) and even more limited in Faynan (Table 5.1). Intensity of production during the LB corresponded directly to the geographic distance from Egypt	Local, tribal, semi-nomadic desert societies were the main source of labor at least in Timna. Attached production system under Egyptian control and elite personnel. Complex relation between different social groups (local tribes, Egyptian, "Midianites" (section 10.1)	
The reign of Ramesses V 20th Dynasty 1149-1145	The last pharaoh to control Timna (Rothenberg, 1988)	*Change*	To date, there is no decisive evidence for continuity or break in production after the Egyptians left the southern Arabah. Evidence from Timna 30 indicates that Production System 1 started shortly after this period	Local societies in the Arabah were freed from the yoke of the Egyptians shortly after or during the reign of Ramesses V	The Egyptian withdrawal from Timna is part of a global collapse of central powers in the Ancient Near East and their withdrawal from the entire southern Levant
Iron Age I 1140–1000	Debated. Possibly first emergence of local polities with substantial political power, including Edom and the Israel of the Period of the Judges	Production System 1	Smelting and mining technologies similar to the previous period; production started to flourish shortly after the Egyptians left the region, both in Faynan and in Timna. Gradual improvement of smelting processes, probably related to better administration and skills rather than technological innovations	Complex organization of production under one system over the entire Arabah Valley; gradual improvement in administration and control (?);	First appearance of local complex social organization, probably with substantial regional impact based on control over economic resources, may reflect the first appearance of the 'historical' independent polity of Edom

Table 10.1 continued

Period date BCE	Culture history framework / Historical events	Primary Production System (cf. Fig.9.5)	Production records (technology)	Social processes	Correlation with culture history events
Iron Age IIA 1000-925	Debated. United Monarchy, the supposed reign of David and Solomon; Edom described in the Hebrew Bible as a strong rival of the United Monarchy, was subjugated to David's kingdom (1 Chronicles 18:13)	Production System 2	Same basic components of Production System 1 with improvement in efficiency, related to better administration and skills rather than technological innovations (or innovation on a small scale); First secure appearance of defensive systems, both on a regional and site levels; First appearance of substantial administrative buildings inside smelting sites	More complexity in the organization of production; consolidation of social institutions responsible for administration of a large scale of production, including intensive trade, exchange, and protection of geographic (and social) boundaries	Evidence of conflicts with neighboring polities is present in the defensive system associated with the copper production, and may reflect some historical kernels in the accounts of the Hebrew Bible
Pharaoh Sheshonq (Shishak) I, who reigned ca. 945–924 BCE	Military campaign of Egypt to the southern Levant (cf. Kitchen, 1986)	*Change*	In the late 10th or early 9th century BCE major production sites are abandoned, and others are disrupted; a new production system is introduced (shortly) after the abrupt end, and is associated with a different organization of production and a new and more advanced technology new organization of production	The abandonment of some smelting sites and disruption of production in others most probably represent an external event (military campaign) and not internal development	We currently attribute the disruption and abandonment of sites in the end of Production System 2 to the military campaign of Shoshenq I to the southern Levant

Table 10.1 continued

Period date BCE	Culture history framework / Historical events	Primary Production System (cf. Fig.9.5)	Production records (technology)	Social processes	Correlation with culture history events
Iron Age IIB 925-800	The Divided Monarchy (Israel and Judah); independent Moab (Mesha stele, ca. 853-852 BCE); Edom, probably a vassal kingdom of Judah in parts of this period	Production System 3	Advanced, well organized, centralized and efficient smelting operations both in Faynan (extensive evidence) and Timna (limited, probably short-lived production); started shortly after the previous system was disrupted (see above) and ceased in the late 9th century BCE	Although technological innovations introduced in this period seem to be external, the new system was operated by the local society of the Arabah Valley; no defense system might be in accord with Edom being a vassal of Judah in part of this time	The most suitable source of the new technology is Egypt. The initiation of this production system might be related to the military campaign of Shoshenq I and economic interest of Egypt in the copper resources; however, the production systems were operated mostly, if not only, by the local society
Hazael's conquests in the southern Levant Late 9th century	Military campaign(s) of Aram to Transjordan; in ca. 798 BCE Hazael conducted military campaign that destroyed Gath in the southern coastal plain	*Change*	Production System 3 ceased to operate simultaneously in Faynan and Timna; no clear evidence of destruction		Hazael's military campaigns might have reached the northern Arabah Valley and be responsible for the end of Iron Age copper production in the southern Levant
Judah's military campaign to Edom Early 8th century	Judah establishes its hegemony over Edom by a military campaign (2 Kings 14:7)	*Change*	See above	See above	Judah's military campaigns might have been the reason for the end of Iron Age copper production in the southern Levant

Table 10.1 continued

Period date BCE	Culture history framework / Historical events	Primary Production System (cf. Fig.9.5)	Production records (technology)	Social processes	Correlation with culture history events
Iron Age IIC 700-586	Assyrian domination (from the military campaign of Tiglath-pileser III to the region, 732 BCE); Local conflicts and rivalry between Edom and Judah	Production System 4	Substantial attempt to produce copper is evident in Faynan, accompanied with massive defense system; this attempt probably failed (no substantial smelting sites from this period)	The production system reflects a well organized society with advanced institutions related to defense and control; ceramic finds indicate Edomite presence; the failure to smelt copper is probably the result of the area being a 'conflict zone' (see to the right), but there is some possibility that the technological knowledge of the advanced, early Iron Age technologies was no longer available (at least 100 years break), and that some small scale smelting was conducted with simple technologies	The failure of copper production, the massive defense system (two fortresses and a tower), and other regional archaeological evidence (in particular the phenomenon of the 'Edomite stronghold') suggest that the area was a conflict zone and that copper production could not take place because of a power balance and a regional status quo; this model is applicable also for the previous century (8th century BCE); additional component in the power balance was Assyria that controlled the region and probably had economic interests of her own that might prevent the rejuvenation of the copper industry in the Arabah Valley

The most notable change in the technological record (except from the abrupt stop of production at the end of the 9th century BCE when the main production centers of KEN, Khirbat Faynan and Timna 30 were finally abandoned) is the introduction of a new smelting technology in the late 10th early 9th century BCE. This was accompanied by a major change in the organization of production. Although technological change is usually accompanied by organizational change, it is not always the case (e.g., Ehrenreich, 1995; White and Pigott, 1996) and the presence of *both* technological and organizational change, together with the abrupt appearance of a fully developed technology, supports external interference. This was most probably related to Egypt, as discussed above.

Another technological assemblage that reflects external interference is that of Production System 4 (Iron Age, ca. IIC, 700 – 586 BCE, Fig.9.5). This attempt to produce copper failed, albeit the enormous and centralized efforts to mine ore in the closest outcrops to Busayra (section 5.2.6). The existence of two fortresses and a massive tower directly associated with the mining complex, the evidence for interruption in the midst of the construction process of the fortress of Ras al-Miyah East (section 5.2.6.3), and the fact that the production failed indicate that the area was a *conflict zone*, with a 'status quo' that did not allow any of the involved sides to exploit copper in Faynan at this time. Suggestions to tie this evidence with specific historical events appear in Table 10.1. This interpretation is supported by the well documented phenomenon of the 'Edomite strongholds' known for this period in

southern Jordan (Lindner and Farajat, 1987; Lindner et al., 1988; Lindner, 1992; Lindner et al., 1996; Lindner and Knauf, 1997; Lindner et al., 1997; Ben-David, 2001), including some sites in the regions neighboring Faynan (Glueck, 1939:38-41; Hubner, 2004). These 'stronghold' sites are located on difficult-access mountain peaks and may represent some sort of refuge locations that are indicative of a time of intense (and oscillating) conflict. This particular geographical reality is reflected in the Biblical accounts (cf. Jeremiah 49:16, Obadiah 1:3, 2 Kings 14:7). Together with many other Biblical accounts describing military (and spiritual) conflicts between Judah and Edom, it seems that the other component in this 'tension' evident in the archaeological record is the neighboring polity to the west, namely Judah.

Finally, another note regarding the question of Edom and the Iron Age copper production in Faynan. In a recent article, Finkelstein (2010:15-16) summarizes his opinion regarding our recent finds at Khirbat en-Nahas under the section entitled "Traditional Biblical Archaeology Strikes Back":

> Levy et al. have recently suggested affiliating the copper production site of Khirbet en-Nahas in the Araba Valley south of the Dead Sea with biblical Edom and dating the large square fortress there to the 10th century BCE.54 Accordingly, they argued that Edom emerged to statehood as early as the 10th century BCE, thereby seeing the verses in Gen. 36:31 and 2 Sam. 8:14 as historical. They also hinted that the copper production at Khirbet en-Nahas may be linked to the biblically described King Solomon's mines. This is not so, because:
>
> • Khirbet en-Nahas is not located in Edom. Production at Nahas is radiocarbon-dated between the late 12th and late 9th centuries BCE, that is, in the Iron I and Iron IIA. In the Iron IIA – the peak period of production – there was not a single settlement on the Edomite plateau. All sites there date later, from the late 8th and 7th centuries BCE.57 The Khirbet en-Nahas phenomenon connects to the settlement history of the Beer-sheba Valley to its west – along the roads that carried the copper to the Mediterranean ports, international roads of the coastal plain, and Egypt. The most significant site in the Beer-sheba Valley that may be mentioned in relation to the

> copper production at Khirbet en-Nahas is Iron I and IIA Tel Masos, which yielded evidence for copper production and trade. Based on comparison to the forts of En Hatzeva on the western side of the Araba and Tell el-Kheleifeh at the head of the Gulf of Aqaba, the fort at Khirbet en-Nahas seems to date to the late 8th or 7th century BCE. […] Therefore, Khirbet en-Nahas is not connected to the biblically narrated United Monarchy of ancient Israel.

Besides imposing his preconceived agenda on the field evidence ("Based on comparison… the fort at Khirbet en-Nahas seems to date to the late 8th or 7th century BCE") and dismissing ELRAP data achieved by meticulous field work, Finkelstein is incorrect in three basic things: First, his interpretation of the boundaries of Edom is incorrect (it is not well-delineated in the Biblical accounts, see section 2.1.1). Second, his interpretation of the metallurgical remains at Tel Masos as a unique primary copper production workshop directly related to the copper production of Faynan is incorrect, and although trade connections probably did exist between Faynan and the Beer-Shaba Valley, there are currently no firm indications that they belong to the same production-social system (see section 9.1.4, the archaeological evidence indicate no more than a small bronze workshop common in settlements of this time period). And third, Finkelstein's approach manifests what might be termed as an "architectural bias" – relaying solely on architectural remains (and their quality) for defining ancient statehood or other fundamental social institutions (for other models based on nomadic societies, see discussions above). In sum, based on the evidence from the Iron Age archaeometallurgical sites, there is no reason to exclude the possibility of early statehood in Edom already in the early stages of the Iron Age.

10.2 Main technological and related insights from the current research

The substantial new set of archaeological and archaeometallurgical data obtained in excavations and surveys carried out for the current research, coupled with a comprehensive synthesis of published material, has also resulted in various finds regarding specific technological and social aspects of the Iron Age copper production systems in the Iron Age southern Levant. These finds and related insights are discussed in detail in each of the relevant chapters. Some of them include, for example:

(1) Early Iron Age smelting technology in the Arabah Valley is a direct continuation of Late Bronze Age technological traditions recorded both in Timna and Sinai (sections 6.1 and 6.2.1).

(2) The most suitable candidate for technological influence *throughout* the Iron Age is Egypt, with evidence of similar technological traditions in the Sinai Peninsula from the preceding Late Bronze and probably Middle Bronze Ages, and a long history of metallurgical tradition in the heartland of Egypt (sections 6.1 and 10.1).

(3) The excavations at Timna 30 have resulted in a substantial revision in the chronological framework of the site, and probably of the other main smelting sites in the Timna Valley; a substantial suite of radiocarbon dates show that the occupation of the site is not earlier than the end of the 12th century and lasted until the end of the 9th century BCE (sections 6.2.1.3 and 6.2.1.4).

(4) Slag was a significant resource in itself, used as flux, temper (in domestic and technological ceramics) and building material; the use of this material may reflect *technological style* rather than being solely a pragmatic choice (sections 7.2.6, 8.5.2 and 9.1.3)

(5) Based on finds at Timna, we raised the possibility that wood was also used as fuel, in addition to charcoal, in some of the production installations (with parallels from recent experimental archaeology) (sections 6.2.1.2 and 9.1.3).

(6) No bellows pots were used in the smelting technologies of the Iron Age, indicating that bellows were made of organic material, probably 'bag bellows' made of animal skin (sections 7.2.5 and 9.1.3).

(7) Iron contamination in copper prills and metal chunks from smelting areas, especially of the advanced late 10^{th} – 9^{th} century technology, suggests that additional refining stage took place for removing the iron (KEN Area F?). This technology-related problem still awaits further research, and analyses of crucible and mold fragments collected from the refining / casting workshop may provide more insights in the future (sections 5.2.4.1, 7.2.7, 8.5.1 and 9.1.3).

(8) Growing evidence of clay mold fragments from the Iron Age smelting sites of the Arabah Valley (previously unidentified in Faynan) suggests that final casting of copper ingots was done using such objects, in addition to or without the need for the use of dug depressions in sand, ash lined pits etc.; This issue also awaits further clarification (sections 7.2.8 and 9.1.3).

(9) The discovery of the extensive JAJ pit mine fields that most likely date to the Iron Age. Although the OSL date is insecure, these mines may have played a significant role in the Iron Age copper production systems in Faynan (section 5.2.9).

(10) We have demonstrated the applicability of the OSL dating method to open mine pits; the dating of JAJ mines, and open mine pits in Timna, await further research before a secure date can be obtained (sections 5.2.9.3 and 5.2.9.4).

(11) We have demonstrated the applicability of archaeomagnetic techniques for dating and correlating archaeometallurgical sites (sections 4.2.2, 5.2.5.4, 5.2.8.2, 6.2.1.5, 6.2.3.2, and 6.2.4).

(12) The results of this research indicates that typical 'slag mounds' in the Iron Age Arabah Valley consists of less then 40% slag material and the rest is usually a variety of metallurgical waste and domestic debris, especially clay derived from furnaces and tuyères (sections 5.2.4.2, 7.2.10 and 9.1.3).

(13) This research provides evidence for the practice of simple smelting technologies alongside and in parallel with the primary production systems, questioning the 'unilinear technological development' principle commonly applied in previous research at the Arabah Valley (in particular sections 6.2.3.3, 6.2.4).

(14) The results of this research support the general models of tribal, semi-nomadic societies in the early Iron Age (12 – 9th century BCE) that has some affinity to the eastern regions (highlands of southern Jordan) rather than the western areas (the Negev highlands) (sections 7.2.3,1 and 10.1).

(15) With high resolution radiocarbon dating and archaeomagnetic correlations this research shows that ‘slag mounds’ comply to the principle of superposition, and consist of identifiable layers (contra e.g., Finkelstein and Piasetzky, 2008); moreover, this research demonstrate the applicability of such tools for evaluation of accumulation rates of slag deposits (sections 5.2.4.2, 5.2.5.1, 6.2.1).

(16) The identification of jacobsite as part of this research (in collaboration with Ron Shaar and others) as the magnetic carrier of slag from Faynan (and Timna 30 Type A) is a contribution to the study of slag mineralogy and the field of archaeomagnetism (section 8.5.2).

(17) Notwithstanding the lower estimates of slag quantities (see #12 above), this research estimates higher quantities of copper produced in the Arabah Valley during the Iron Age than previous estimates (30,000 tons vs. ca. 10,000).

Other insights and technological interpretations are discussed throughout the dissertation in relation to each particular new datum gleaned during this research. Some of the new data constitute a firm basis for future research and others, such as those concerned with technology-related questions (e.g., the problem of iron in copper, section 7.2.7, the use of clay molds, section 7.2.8, technological origin and innovation, section 10.1) and society-related questions (identities, boundaries, destinations and market structure) are only preliminary, and should be further investigated to support or reject interpretations and models suggested here.

10.3 Concluding remarks

For want of a nail the shoe is lost,
for want of a shoe the horse is lost,
for want of a horse the rider is lost,
for want of a rider the kingdom is lost.
------ George Herbert, *Jacula Prudentum*, 1651:line 499 (quoted by Benjamin Franklin in *Poor Richard's Almanac*, 1758)

The exploitation of the copper ore deposits of the southern Levant and in particular the richest outcrops located in Jordan's Faynan district played a major role in social and political processes during the Iron Age (12^{th} – 6^{th} centuries BCE). In turn, the archaeological record of sequences of metallurgical assemblages of copper production technologies reflects important aspects of these social realities. By applying the anthropological method of *chaîne opératoire* to a large set of new and published archaeological data, this study has analyzed the interrelations between technology and society and between production systems and power balances in a marginal region rich in natural resources. The results demonstrate the tight interconnection between the gradual elaboration of copper production systems and the development of early Iron Age (12^{th} – 10^{th} century BCE) polities, in particular Edom, known from the Hebrew Bible and ancient Egyptian and Assyrian texts.

The Iron Age copper exploitation technologies and organization of production demonstrate sophisticated and well planned production systems in comparison to previous (Early Bronze Age), later (Roman, Byzantine, and Islamic), or even contemporary Iron Age (Cyprus, Oman) copper exploitation enterprises. The

reciprocal technological – social mechanisms evident in the archaeological record represent complex, structured society(-ies), engaged in specialized, attached production, already in the early stages of the Iron Age (Iron Age I). Intensification of production during the 10th century BCE is attributed to local social processes and to the consolidation of a political body with evidence that cannot exclude the possibility of early state-level societies in both Edom and Israel/Judah.

In addition, field work and analyses presented here show striking similarities between the records of copper technology-related material culture of Faynan (Jordan) in the northern Arabah valley and Timna (Israel) in the southern Arabah from the 12th to the end of the 9th centuries BCE. These similarities indicate regional social unity, thus extending the geographical boundaries previously assumed for the Faynan society(-ies) to include the entire Arabah Valley, or at least the other primary center of copper production close to the head of the Gulf of Aqaba. A major and abrupt technological shift has been identified at sites sampled in this research, dated to between the late 10th – early 9th centuries BCE, and considered to be a result of rapid external influence rather than an internal socio-technological process. The same mechanism is responsible for the abrupt end of copper exploitation at the end of the 9th century BCE (in both Faynan and Timna), probably a military campaign of a neighboring power. A delicate power balance between local peer-polities and later also regional empires prevented the resumption of copper exploitation in the later

phase of the Iron Age, except for a short-lived failed attempt during the late 8th – 6th centuries BCE in Faynan.

Consequently, the current research defines and characterizes five *distinct* copper production systems for the Iron Age southern Levant: (1) Iron Age I (1200 – 1000 BCE), a direct continuation of Late Bronze Age technological traditions (evident in Sinai, Timna and probably in Faynan), (2) Iron Age IIA (1000 – 925 BCE), similar technological traditions associated with different organization of production; (3) Iron Age IIB (late 10th century – 800 BCE), different and more advanced technological tradition, new organization of production; (4) Iron Age IIC (ca. 700 – 586 BCE), concentrated mining efforts in Faynan, different organization of production, no smelting (?); and (5) a secondary system, simple smelting technology on the margins of the primary systems (Iron Age I-IIB ?). Copper production during these phases was not monolithic but reflects oscillations in socio-economic and historical change. Thus, we consider the identification of these production systems to be one of the most important contributions of the present work, providing an objective foundation for any future research of the Iron Age copper production in the southern Levant.

The conclusions of this work shed new light on Iron Age desert societies on the southern Levantine marginal zone during a contentious period in which biblical, textual and archaeological records do not always agree. The analytical methods (for dating and material analyses) and anthropological oriented approaches have resulted in

substantial new and objective data, which appears to strengthen the conventional understanding of societies and historical processes in the southern Levant during the late 2nd – early 1st millennia BCE, contrary to recent reductionist attempts to refute evidence of social complexity in this region during this period, in particular the 10th century BCE.

The case study presented here is an instance in the long history of natural resource exploitation by humankind. The investigated medium is ancient technological practices as reflected in the archaeological record. The results, we believe, emphasize the role of technology in shaping human societies and, in turn, demonstrate how social realities are reflected in ancient technological records.

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