Title

Reconstructing the Metallurgical Narrative of an Iron Age Smelting Site : New Excavations and Archaeometallurgical Investigations at Khirbat al-Jariya, Southern Jordan

Permalink

https://escholarship.org/uc/item/5m44j7cx

Author

Liss, Brady James

Publication Date

2015

Peer reviewed|Thesis/dissertation

UNIVERSITY OF CALIFORNIA, SAN DIEGO

Reconstructing the Metallurgical Narrative of an Iron Age Smelting Site: New Excavations and Archaeometallurgical Investigations at Khirbat al-Jariya, Southern Jordan

A Thesis submitted in partial satisfaction of the requirements for the degree of Master of Arts

in

Anthropology

by

Brady James Liss

Committee in charge:

Professor Thomas E. Levy, Chair
Professor Paul Goldstein
Professor Guillermo Algaze

2015

The Thesis of Brady James Liss is approved and it is acceptable in quality and form for publication on microfilm and electronically:

Chair

University of California, San Diego

2015

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF GRAPHS

ACKNOWLEDGEMENTS

I would like to thank my adviser and chair of my thesis committee Prof. Thomas E. Levy for his support and guidance with this project. I would also like to thank the other members of my committee, Prof. Paul Goldstein and Prof. Guillermo Algaze. Further thanks go to the UCSD Levantine and Cyber-Archaeology Lab including Aaron Gidding, Ian Jones, Kathleen Bennallack, and Matthew D. Howland as well as Dr. Kyle Knabb.

I would also like to thank all of those involved in the 2014 excavation season at Khirbat al-Jariya including Prof. Thomas E. Levy (Principal Investigator), Dr. Mohammad Najjar (Co-Director of ELRAP), Dr. Neil G. Smith, Matthew D. Howland, Craig Smitheram, Rosemary Y. Hoshino, Marc Wallace, and the locals of Qirayqira and Faynan. I would like to thank Thomas E. Levy’s Norma Kershaw Chair and the NSF IGERT Award “Training, Research and Education in Engineering for Cultural Heritage Diagnostics” for its financial support in this research. Also, thanks to ACOR and Dr. M. Jamhawi of the Department of Antiquities of Jordan.

Lastly, I would like to thank my family and friends for their constant support.

ABSTRACT OF THE THESIS

Reconstructing the Metallurgical Narrative of an Iron Age Smelting Site: New Excavations and Archaeometallurgical Investigations at Khirbat al-Jariya, Southern Jordan

by

Brady James Liss

Master of Arts in Anthropology

University of California, San Diego, 2015

Professor Thomas E. Levy, Chair

Technologies do not exist in a vacuum but rather are embedded within a greater social-historical-economic setting, forming a reciprocal and influential relationship with the society/people that harness technology to produce their material world (Lemonnier 1986, 1992). Renewed archaeological excavations at Khirbat al-Jariya (KAJ), an Iron Age copper smelting center in the Faynan region of Southern Jordan, explored this relationship by supplementing archaeological excavation with X-Ray Fluorescence (XRF) spectroscopy to investigate the copper smelting *chaîne opératoire*. In order to refine a possible static interpretation of KAJ as a copper smelting site simply exploiting local resources, an investigatory probe was excavated to bedrock in one of the large slag (metallurgical waste) heaps that populate the site’s surface to reveal its entire metallurgical history. By collecting slag samples for XRF analysis from secure stratigraphic contexts in conjunction with archaeology’s deep-time perspective, it was possible to detect temporal changes in the slag composition, and in turn, technological developments over the site’s history. In addition, site wide survey (from balloon-aerial photography) and sampling of metallurgical features provided synchronic details of the copper production system. Finally, additional excavations explored the site’s largest structure in an attempt to elucidate the social dynamics of copper smelting. This paper combines the excavation and post-excavation results to recreate the site’s metallurgical narrative and to reconstruct the intimate and interactive relationship between the metal workers and their craft during KAJ’s occupation.

1. Introduction

Technology inherently exists enmeshed within an interactive system that simultaneously encompasses the greater cultural, political, and economic milieu of a social group (Lemonnier 1986, 1992). In other words, the technologies employed by a given society to create its material world are shaped by its sociopolitical structures and choices (Lemonnier 1992: 17). As such, the study of ancient technologies provides a solid foundation to deduce these social, political, and historical contexts in which the technologies function. The *chaîne opératoire* analytical approach as developed within anthropological archaeology provides a means to this end, as will be discussed further below. By contributing to our understanding of the specific *chaîne* employed at an Iron Age copper smelting center in Southern Jordan, this study subsequently fosters the identification of its sociopolitical intricacies.

The Iron Age (ca. 1200-586 BCE) in the southern Levant (Israel, Palestine, and Jordan) is a contentious and vehemently debated period characterized by radical transitions and transformations in the political, social, and economic conditions of the region (see Mazar 2005; Finkelstein 2005a, 2010; Levy and Higham 2005). Out of the political void created by the collapse of the Late Bronze Age and its powerful empires emerged new complex polities. Associated with this political breakdown was a major disruption in the extensive trade networks that interconnected the Mediterranean world during the Bronze Age. The resulting disturbance to Cypriot copper trade, the previous primary supplier for the Levant, opened new economic opportunities to fulfill the sustained demand for the metal (Ben-Yosef et al. 2010; Yahalom-Mack et al. 2014). Following the chronological shift in Edomite origins facilitated by the results of the

Edom Lowlands Regional Archaeology Project (ELRAP) (discussed below), the development of the biblical kingdom of Edom and the associated industrial scale copper smelting is now situated within these unique historical circumstances of the Early Iron Age (Levy et al. 2014a: 3). However, Edom's historically attested semi-nomadic inhabitants caused debate concerning both their trajectory towards sociopolitical complexity and their relationship to the intensive copper production (Levy et al. 2014a: 66-68; Finkelstein 2005b, 2010: 15-16). The connection between tribalism and the emergence of a complex Edomite polity was approached in the scholarly discourse (e.g. LaBianca and Younker 1995), but the possible role of copper production received little attention (Ben-Yosef 2010: 16-17). Continued research in Faynan, the abundant copper ore resource zone within the Edomite territory, is critical to informing the debates surrounding the relationship between social complexity and craft production in the Iron Age (e.g. Ben-Yosef 2010). Khirbat al-Jariya (KAJ), an Early Iron Age copper smelting center in Faynan, provides a field laboratory to investigate this link through the site's metallurgical development.

For this purpose, a small team under Prof. Thomas E. Levy (Principal Investigator) and Dr. Mohammad Najjar renewed excavations at KAJ in the summer of 2014 (Figure 1). As part of the team, the present author supervised excavations at the site, having the opportunity to collect the samples analyzed for this thesis. In order to fully investigate the diachronic narrative of copper smelting at KAJ, excavations probed one of the large slag mounds on the site's surface (Area C). By revealing uncontaminated sandstone at its bottom, the sondage provided a complete history of copper production over the site's occupation. Slag samples collected from stratigraphically secure contexts within the sounding were subsequently analyzed with X-Ray Fluorescence spectroscopy. Using this method of analysis, it was possible to evaluate the elemental contents of slag to discern otherwise invisible details and temporal changes in the slag composition, and in turn, the sophistication/developments of the smelting technology. In addition, a site wide survey and sampling of KAJ's metallurgical features (based on balloon-aerial photography) provided synchronic details of the copper smelting *chaîne opératoire*. Finally, to situate KAJ's metal production within a sociopolitical framework, the largest structure visible on the surface was also excavated (Area B). Together, these lines of evidence (with foundational perspectives from the 2006 excavation season in Area A) provided the necessary horizontal and vertical breadth for a synchronic and diachronic examination of the metallurgical narrative. This renewed research contributes to the copper smelting operational sequence at KAJ with new evidence for intensive secondary processing of slags linked to unique bedrock mortars, a possible cultic component associated with the site's largest structure, and elemental evidence for a diachronic improvement in smelting technology.

2. An Anthropological Approach to Technology – The *Chaîne Opératoire*

In investigating the relationship between technology and the sociopolitical development of Edom, the ELRAP employs anthropological archaeology to extrapolate beyond the archaeological record into grander social, political, and economic understandings (Levy et al. 2014a: 1). To evaluate the technical systems involved in copper production and to deduce the social intricacies that influence these processes, the ELRAP engages with the *chaîne opératoire* analytical method (Levy et al. 2014a: 29-31; Ben-Yosef 2010: 881-954). The *chaîne opératoire* is essentially the sequence of physical actions and gestures utilized by ancient peoples to create their material world, and in turn, the archaeological record (Lemonnier 1992: 26; Levy et al. 2014a: 29). *Chaîne opératoire* developed out of the work of sociologist and ethnologist Marcel Mauss (1979[1950]) and anthropologist/archaeologist André Leroi-Gourhan (1993[1964]) (the first to apply the approach in archaeological settings), but it gained its footing in the realm of anthropology and archaeology largely through the work of Pierre Lemonnier (1989, 1992). Mauss (1983 cited in Lemonnier 1989: 156) documented the embodiment of social phenomena within the creation of the material world, and in following, Lemonnier (1989: 156) developed the anthropology of technology to study the relationships and reciprocal influences between social and technological systems.

For Lemonnier (1989: 156-157, 1992:5-6), a *technological system* includes five elements used in consort during technological activity (any action involving a physical intervention resulting in the transformation of matter): matter, energy, objects, gestures, and specific knowledge. In ‘gestures’, Lemonnier (1989: 156) included the physical actions and movements that move the ‘objects’ (tools or means of work) in a technological action. These gestures are organized into what Lemonnier (1992: 5) called “operational sequences” i.e. *chaîne opératoires*. Once a technical system and its *chaîne opératoire*, are elucidated, they can be integrated into larger systems or societies (Lemonnier 1992: 9). The particular *chaîne opératoire* used in a specific technological system is the result of choices, some voluntarily and others unintentional i.e. while there may be several means to same end, a society will often come to rely on one *chaîne* (Lemonnier 1992: 17). These choices drive the “strategic moments” (essential operations for the desired result) and “variants” within the operational sequence which are specific to “social realities” (Lemonnier 1986: 154-155). As such, the *chaîne opératoires* function as the hard data that can then be subjected to theoretical interpretations and geographic/temporal comparisons to recreate the “social realities” and technological choices associated with each *chaîne*, “to bridge the gap between technical phenomena and social phenomena” (Lemonnier 1986: 154-155; Ben-Yosef 2010: 887; Levy et al. 2014a: 31). Thus, parsing out the *chaîne opératoire* for copper production at KAJ is an invaluable endeavor to foster anthropological understandings of its inhabitants.

3. A History of Research in Faynan, Jordan - A Copper Resource Zone in the Eastern Mediterranean

The Wadi Arabah, stretching from the Dead Sea to the Gulf of Aqaba, is home to the two largest, natural copper deposits in the Southern Levant (Hauptmann 2007: 1). Originally a cohesive unit, the copper mineralizations were subsequently disconnected by tectonic activities along the Dead Sea Rift Valley (Hauptmann 2007: 64). Despite the geographic dissonance (approximately 105 kilometers apart), both resource rich zones, Faynan (Jordan) and Timna (Israel), witnessed intensive exploitation in antiquity (Hauptmann 2007: 64) (See Rothenberg 1972 for an overview of archaeological field work in Timna). Copper's significant role in the habitation and development of these environmentally harsh regions remains apparent on their surfaces in the form of significant architectural features associated with massive slag mounds. As such, this extensive metallurgical material culture received the attention of explorers and archaeologists leading expeditions into the region. Khirbat al-Jariya's location within Faynan warrants a brief review of the scholarly research concerning copper production in the region.

In 1883, Major Horatio H. Kitchener (1884) directed an early surveying trip into Faynan during his explorations from the Dead Sea to 'Aqaba, providing the first report of a major smelting site in the area (Ben-Yosef and Levy 2014a: 179). The Czech orientalist and explorer Alois Musil (1908) subsequently surveyed Faynan (fifteen years after Kitchener) recording other smelting sites in the region including the first sketch of the famous Khirbat en-Nahas (Levy et al. 2014c: 90). Kitchener and Musil provided the foundations for the paramount explorations of famed American, biblical archaeologist

Nelson Glueck (1934, 1935). In the Golden Age of biblical archaeology following World War I, Glueck (1934, 1940) systematically surveyed the greater Edomite territory and Faynan; the first scholar to correctly attribute the region's copper mines to the Iron Age based on ceramic typology. Along with this chronological assignment, Glueck (1940: 50-88; 1935: 50) identified King Solomon as the paramount controller of copper exports from the industrial scale production, "the first great copper king", a point of scholarly intrigue and contention (e.g. Muhly 1987). With his biblical assertions, Glueck secured Faynan's place in the scholarly discourse, providing the impetus for future generations of archaeologists to further examine the region.

Major modern investigations in Faynan began in the 1980's (MacDonald 1992; Hauptmann 2007). At this time, the western margin of Faynan was the subject of surveys by Burton MacDonald (1992). However, in 1983 Andreas Hauptmann (2007) initiated a long term archaeometallurgical investigation of the entire Faynan region. Under the auspices of the German Mining Museum, Hauptmann (2007) lead intensive geological and metallurgical surveys of Faynan between 1983 and 1993, contributing immensely to its archaeometallurgical narrative (discussed further below). In 1985, Burton MacDonald (1992) explored the northeastern Arabah Valley and the area around Faynan as part of the Southern Ghors and Northeast 'Arabah Archaeological Survey. In 1996, Wadi Faynan and the environs surrounding Khirbat Faynan (a massive Byzantine and Roman smelting center) were thoroughly surveyed by Graeme Barker et al. (2007) during the Wadi Faynan Landscape Survey. MacDonald (2004) returned to Faynan between 1999 and 2001 for three additional survey seasons – The Tafila-Busayra Archaeological Survey. This project focused on the highlands of Faynan, particularly the environs of the biblical capital of Edom, Busayra (MacDonald 2004: 3). Together, these modern projects surveyed much of the Faynan landscape and emphasized the metallurgical nature of the archaeological record, but they lacked the deep time perspective of stratigraphic excavation.

In 1997, the Thomas E. Levy of the University of California, San Diego (UCSD) and Mohammad Najjar of the Department of Antiquities of Jordan initiated an archaeological investigation into Faynan utilizing systematic survey and stratigraphic excavations - The Jabal Hamrat Fidan Project (Levy et al. 1999). The main incentive for the project was examining the procurement of naturally occurring copper ore throughout Faynan and its sociopolitical implications (Levy et al. 2001: 442). Initially focused on the Pre-Pottery Neolithic and Early Bronze Age, the project transitioned towards an emphasis on the Iron Age and the associated population inhabiting this region, the biblical Edomites (Levy et al. 2014a: 1). Now titled the ELRAP, anthropological archaeology and cyber-archaeological approaches are applied to discern the nuances between technology and social evolution. Ongoing archaeological expeditions have investigated predominant Iron Age copper producing sites throughout Faynan including Khirbat en-Nahas, Khirbat al-Jariya, and Khirbat al-Ghuwayba (See Ben-Yosef et al. 2014 for a complete review). In doing so, the ELRAP fostered the most complete understanding of the profound relationship between copper production and social transformations in Faynan.

From the Neolithic through the Islamic period, the abundant copper ores of the Faynan region played a major part in its inhabitants’ sociopolitical development (Levy et al. 2012: 197; Levy et al. 2014b). The period of peak production was previously attributed to the Late Iron Age (seventh to sixth centuries BCE) with the conventional

Edomite origins; however, the ELRAP shifted this paradigm by chronologically anchoring this production phase to the Early Iron Age (twelfth to ninth centuries BCE) through radiocarbon dating at its principal site, Khirbat en-Nahas (KEN) (Levy et al. 2008; Levy et al. 2004). KEN is the largest Iron Age copper smelting site in the southern Levant characterized by an enormous fortress, over 100 structures, and immense slag mounds (Levy et al. 2014c). A sounding stratigraphically excavated six meters into one of the slag heaps provided a complete chronological sequence for the site's occupation and metallurgical activities with twenty-two radiocarbon dates (Levy et al. 2014c: 150-151). This original suite of dates has since been supplemented by 115 measurements from stratified excavations by the ELRAP team, firmly securing the new chronological framework (Levy et al. 2012: 210). Excavations at KEN and KAJ along with a sounding at Khirbat el-Ghuwayba discerned two major phases of copper production in Faynan: the twelfth-eleventh centuries and the tenth-ninth centuries BCE (Levy et al. 2004: 876). The copper industry was disrupted at the end of the tenth century BCE, possibly by the historical Egyptian invasions of Pharaoh Shoshenq I, and it ceased in eight century (Levy et al. 2012: 210-212; Levy et al. 2014d). However, this roughly four hundred year period of opportunistic copper smelting was the foundations for historically attested, local nomadic tribes (the *Shasu*) to develop into the kingdom of Edom (Levy et al. 2004: 877). The ELRAP continues to explore the role of copper smelting in the region's social development by investigating the centers of production, most recently, through renewed excavations at KAJ.

4. Geology and its Implications on Iron Age Copper Smelting

The unforgiving climate and rugged terrain of Faynan deter from its desirability for habitation. As such, an ulterior motive most likely functioned as an impetus for occupation in this region – copper (Levy et al. 2014a: 66). The locally available copper ores in Faynan were the results of geological formations and mineralizations over millions of years. The genesis of copper ores in this region (as well as Timna) has been simplified to a three stage process: (1) The formation of primary copper-iron sulphide mineralization in Late Precambrian volcanic rocks roughly 500 million years ago; (2) The erosion of these volcanic rocks in the Lower Cambrian period resulting in copper rich dolostones in marine environments. This stage was also associated with the migration and redeposition of copper as chlorides and the mineralization of manganese ores; (3) Finally, the formation of the Rift Valley, its erosion/weathering, and faulting/fracturing created a karstic landscape (a barren area characterized by irregularities like caves and sinkholes) resulting in secondary copper and manganese ores in the Dolomite-Limestone-Shale (DLS) unit of Faynan (Hauptmann 2007: 67-68). The Cambrian sediments of the DLS, also known as the “Burj Limestone”, provided the principal ore source for Faynan copper production in antiquity (Ben-Yosef 2010: 98-99). While the thickness of this geological formation ranges from twenty to forty meters, the most substantial copper and manganese mineralization are found in the upper shale formations that are roughly one to one and a half meters thick (Hauptmann 2007: 65-66). These dark mineralization layers are easily recognizable throughout Faynan in the form of cliffs, terraces, and plateaus (Hauptman 2007: 65). The copper ore containing DLS units are imperatively located in outcrops near KAJ, KEN, and Khirbat el-Ghuwayba (Figure 2) (Hauptmann 2007: 64;

Rabba’ 1991). Thus, the DLS copper ores supplied the raw materials for the three main, known constituents of the Iron Age copper industry in Faynan.

The inter-growth of substantial manganese among the copper ores of the DLS, as described above, (an average manganese content of 41-43%) has direct implications on copper smelting and therefore, the archaeological record (Hauptmann 2007: 70, 71; Ben-Yosef 2010: 100). Concerning the smelting process, manganese can function as a fluxing agent - an additive that assists in purifying the metal and liquefying slag, resulting in smelts with purer metallic yields (Hauptmann 2007: 234; Tylecote 1992: 189). Fluxes were commonly a secondary additive to a smelt and required an additional procedure in the copper production operational sequence (Tylecote 1992: 189). Other fluxes used in copper smelting include iron minerals, as is seen in Timna, but manganese is more efficient in purifying the copper (Ben-Yosef 2010: 100). Manganese rich ores consequently afford a twofold advantage: they function as self-fluxing eliminating the need and procurement of secondary additives, and the manganese is a superior flux in comparison to other minerals such as iron.

Hauptmann’s (2000, 2007) extensive archaeometallurgical surveys of Faynan recognized developmental stages in ore procurement through antiquity. By analyzing the elemental composition of chronologically controlled slag samples, Hauptmann (2007: 184) discovered a dichotomy between the Early Bronze Age and Iron Age. In the Early Bronze Age, slags contained a broad range of compositions, whereas the Iron Age slags showed less variation in content and a prominent tendency for being rich in manganese (Hauptmann 2007: 184). In addition, there was no evidence for fluxing agents utilized in copper smelting before the Iron Age (Hauptmann 2007: 251). This indicates an advanced technical awareness during this period. Hauptmann (2007: 184, 251) further recognized this as possible evidence for deliberate and careful selection of manganese-rich ores by the Iron Age smelters for their self-fluxing properties, and moreover, as an indication of technological progress. This development is particularly relevant for the ability to recognize it in the archaeological record, as will be seen. These region wide phenomena are integral to understanding the development of copper production in Faynan; however, technological processes occurring over the occupation period of individual sites, like KAJ, required further investigation.

5. The Khirbat al-Jariya Case Study – A History of Research

KAJ is a roughly seven hectare site located in the eastern Wadi Arabah, three kilometers northeast of KEN (Glueck 1935: 23-26; Ben-Yosef et al. 2010: 726, 731). The site stretches across both banks of the Wadi al-Jariya subjecting its central portion to significant erosion by the deepening and changing course of the wadi over time (Figure 3). Its archaeologically significant remains include architectural features and slag heaps visible on the surface indicating its function as a large-scale copper production center. KAJ's location secluded among the rugged Faynan terrain has benefitted its preservation; it was mostly undisturbed since its Iron Age abandonment with the exception of a few Bedouin graves and robber's trenches (Ben-Yosef et al. 2010: 731). Therefore, the archaeological record was largely intact aside from natural formation processes when it became the focus of archaeological inquiries.

5.1 Discovery and Surveys

Recently, KAJ's discovery has been attributed to Kitchener during his above described surveys of Faynan (1884) (Ben-Yosef and Levy 2014a). In the report chronicling his expedition into the Arabah Valley, Kitchener (1884: 213-214) describes a day of exploration after pitching camp in the Wadi al-Ghuwayba. Roughly ten kilometers from the camp, Armstrong, one of Kitchener's associates, found "the ruins of a small town in a valley" with "ruined walls" and "some black heaps resembling slag heaps" (Kitchener 1884: 214). By comparing this description with the maps created by the expedition, Erez Ben-Yosef and Levy (2014a: 180, 183) successfully identified this small town as KAJ – roughly thirty six years before Nelson Glueck (1935) who was previously credited with its discovery. Thus, Major Kitchener's report was the first mention of the site in the scholarly literature.

Following Kitchener, in 1934, Glueck (1934: 23-26) described what he believed to be the original discovery of KAJ (Ben-Yosef and Levy 2014a: 179). The survey report characterized KAJ as a "copper mining and smelting center" based on the presence of slag mounds, copper ore, and alleged smelting furnaces (this interpretation of these unique structures has since been countered; See Ben-Yosef et al. 2014: 799) (Glueck 1935: 23-25). Glueck (1935: 23-26) highlighted the site's hidden location in the hills around the wadi and mentioned a strong wall enclosing KAJ; there is, however, no current evidence of such a construction (Ben-Yosef et al. 2014: 799). Based on the ceramic typology of sherds found across KAJ's surface, the site was attributed to the Early Iron Age (Glueck 1935: 25). Though Glueck was not the first to discover KAJ, his extensive reports disseminated knowledge of the site.

Subsequent investigations at KAJ were produced by Hauptmann (2000, 2007) as part of the survey of the greater Faynan region. This project's goal was to investigate ancient mining and metal extraction techniques utilized by the ancient populations (Hauptmann 2007: 4). Moreover, it hoped to elucidate the development from domestic to industrial copper production under the assumption that it would be possible to demonstrate the stages of progression (Hauptmann 2007: 4). As such, Hauptmann (2007: 6) led archaeological and geological surveys throughout Faynan to create a detailed archaeometallurgical examination. These surveys were not chronologically controlled, but the extensive metallurgical record from the Iron Age functioned as a catalyst for essential analysis of this period (Hauptmann 2007: 4-6). As part of this project, KAJ and its surrounding environs were systematically surveyed (Hauptmann 2007: 131-132). This was the first investigation focused on the site's archaeometallurgical relevance.

While preliminary, the survey results recognized a general layout to KAJ; slag mounds were distributed throughout the site, circumscribing a centrally located habitation area (Hauptmann 2007: 131). The occupation space contained circa twenty-four structures identifiable on the surface (Hauptmann 2007: 131). The survey also estimated the slag heaps at KAJ to contain between 15,000 – 20,000 tons of slag (including 100 tons of crushed slag), reiterating its industrial scale (as a point of comparison, 50,000 – 60,000 tons of slag were estimated for KEN) (Hauptmann 2007: 127, 131). In addition, three radiocarbon samples were collected and dated from one of the slag heaps (Hauptmann 2007: 89). These measurements indicated a date range between 1150 – 925 BCE, placing KAJ primarily within the Early Iron Age and corroborating Glueck's chronological assessment (Hauptmann 2007: 89). Hauptmann (2007: Figure 5.10, 131) also used the tuyères (ceramic nozzles used to deliver air into the furnace typically from bellows) found on slag mounds as an additional chronological marker. The small tuyères found at KAJ are part of a technological assemblage that is often associated with the Late Bronze Age and Early Iron Age (Hauptmann 2007: Figure 5.10). Moreover, the areas surrounding KAJ to the east and south contained evidence for ancient mines, including Iron Age exploitation of the local DLS ores (Hauptmann 2007: 132). Overall, the survey's preliminary investigation situated KAJ as a principal component of Faynan's Iron Age copper industry.

In the fall of 2002, the Jabal Hamrat Fidan Project under Levy and Najjar conducted surveys of the Wadi al-Ghuwayb and Wadi al-Jariya (Levy et al. 2003). The primary motivation for this survey was to explore the archaeological and settlement landscape associated with KEN, the anchor site for copper production in the Iron Age (Levy et al. 2003: 247). The survey of the Wadi al-Jariya recorded fifty-four sites populating its length; twenty-seven of these sites were identified as Iron Age making this the period of greatest occupation (Levy et al. 2003: 270). The two largest Iron Age sites were a cemetery designated WAJ 520 and KAJ (Levy et al. 2003: 270). The largest group of sites in the survey area, however, was associated with mining to the southeast of KAJ (Levy et al. 2003: 270). These mines were revealed by their tailing remains that followed the DLS unit in the area (Levy et al. 2003: 270). In total, twelve mines were recorded, and the project postulated KAJ's inhabitants as the possible miners (Levy et al. 2003: 270). Moreover, Levy et al. (2003: 259, 273) created the first topographic and architectural map for the site (Figure 4). Together, all of these studies furnished a foundational understanding of KAJ and its role as a smelting center in the Iron Age landscape; however, these interpretations inherently required confirmation through archaeological excavation.

5.2 Stratigraphic Excavation

In 2006, the ELRAP initiated the first systematic excavations at KAJ (Ben-Yosef et al. 2010). With Ben-Yosef acting as the field supervisor, excavations included a stratigraphic probe into a slag mound and an associated rectangular structure (Structure 276) on the eastern bank of the Wadi al-Jariya (Ben-Yosef et al. 2010: 731-732). A grid of four excavation squares (five by five meters each) were arranged over the edge of the slag mound and the entire structure; this excavation area was designated Area A (Ben-

Yosef et al. 2010: 731-732). Excavations were supplemented by a suite of radiocarbon dates with high spatial precision and a geomagnetic archaeointensity investigation (Ben-Yosef et al. 2010: 740). The goals for the excavation were twofold: to enhance the chronological resolution of KAJ and to consider the development of its copper industry, especially in relation to KEN (Ben-Yosef et al. 2014: 801). Since building on these results was an impetus for ELRAP's return to KAJ in 2014, a detailed review of the outcomes from this initial season are essential.

Structure 276 was apparent on the surface of KAJ, and it was selected for excavation based on its probable relationship with the large slag mound (Ben-Yosef et al. 2010: 732). The small rectangular structure was 6.5 meters long and 3.2 meters wide (Ben-Yosef et al. 2010: 738). The walls were constructed from one course of large boulders; some roughly cut, founded on a pile of metallurgical debris (Ben-Yosef et al. 2010: 738, 740). At its opening, the structure was filled with large irregular stones that were more indicative of an intentional filling than wall collapse (Ben-Yosef et al. 2010: 740). Following the removal of the fill, Structure 276 was excavated to an ephemeral floor surface of hardened earth representing its main occupation phase (Ben-Yosef et al. 2010: 740). Material culture associated with this floor was marginal, consisting of some pottery sherds, grinding stones, and charcoal (Ben-Yosef et al. 2010: 740). A small patch of pavement constructed from large tap slags (slags drained from a furnace while still in a liquid state) and a line of stones running perpendicular to the southeastern wall with indeterminable functions were also discovered. Against the south wall was a stone and plaster construction, possibly a bench, with a flat, floor-level stone in front of it with a similarly unclear purpose (Ben-Yosef et al. 2010: 740). Unfortunately, the limited artifacts and ambiguous features within the structure make interpreting its function difficult (Ben-Yosef et al. 2014: 810). Thus, the relationship between Structure 276 and the slag mound remains enigmatic.

Along with Structure 276, a sounding into its neighboring slag mound was excavated for a temporal investigation into KAJ copper production. At a depth of 2.4 meters, red bedrock sandstone was discovered at the bottom of the excavation probe (Ben-Yosef et al. 2010: 735). Directly above the virgin sediments, an initial occupation phase with some evidence for metallurgical activities was discovered (Ben-Yosef et al. 2010: 735-736). Thin layers of finely crushed slag, pits dug into the bedrock, ash, and copper ore fragments suggest an early metallurgical focus at KAJ (Ben-Yosef et al. 2010: 736). Roughly seventy centimeters of primarily domestic refuse were excavated above the original occupation horizon (Ben-Yosef 2010: 736). The material culture consisted of ceramics, bones, and ash with minimal remnants from metallurgy (Ben-Yosef et al 2010: 736). Accordingly, this layer is attributed to waste deposition from domestic activities. The area was subsequently used for habitation based on the excavation of pottery, stone installations, stone pavement patches, and possible tent-stake holes (Ben-Yosef et al. 2010: 737-738; 2014b: 803). Above this habitation layer was a thick accumulation of metallurgical debris comprised of tap and furnace slags, charcoal, furnace fragments, tuyère pipes, and copper metal embedded in ashy sediment (Ben-Yosef et al. 2010: 738). The final and uppermost layer of the slag mound was similarly a horizon of metallurgical debris; however, the slags were generally larger in diameter (Ben-Yosef et al. 2014: 810). This represents the final industrial phase and is probably contemporaneous with the occupation of Structure 276 (Ben-Yosef et al. 2014: 810). From bedrock to the site's surface, this slag sounding provides a complete picture of copper production at KAJ.

Despite only a small volume of the 'slag' mound actually being slag or related to copper manufacture, the collected material culture still matched the expected Early Iron Age metallurgy repertoire (Ben-Yosef et al. 2010: 732; Ben-Yosef and Levy 2014b). Tuyère sizes and slag morphologies transition with technological developments, thus making them valuable chronological markers (Ben-Yosef and Levy 2014b: 923-929, 940-942). As noted above, Hauptmann's (2007: 99) investigations in Faynan discovered a dichotomy in tuyère size between the Late Bronze Age/Early Iron Age ("small tuyères") and the tenth to eight centuries BCE ("large tuyères"). This technological transition has since been temporally secured to the tenth and ninth centuries BCE as a result of rigorous radiocarbon dating at Timna and KEN (Ben-Yosef and Levy 2014b: 928-929). Tuyère fragments collected from the slag sounding at KAJ belonged solely to the small tuyère group according to the circumference of their nozzles (Ben-Yosef and Levy 2014b: 925). The tuyères indicate metallurgical practices were active at KAJ prior to the innovation of large tuyères, put otherwise, in the Early Iron Age.

Slags are also divided into two main types correlating to their physical appearance and production system (Shaar et al. 2010: 202; Ben-Yosef and Levy 2014b: 940). Group A slags consists of large, flat slabs up to one meter in diameter; slags of this type have only been found at KEN, Khirbat Faynan, and Timna accompanied by large tuyères (Ben-Yosef and Levy 2014b: 940). Group B slags, produced by the pre-tenth century BCE technology with small tuyères, are typically irregular in shape and only five to fifteen centimeters in diameter (Shaar et al. 2010: 202). This slag group consists of broken tap slags and furnace slags – furnace slags are typically heterogeneous with inclusions of prills, ores, and charcoal and often found in mounds with technical ceramics (Ben-Yosef and Levy 2014b: 940). The KAJ slag mound produced slags fitting the Group B typology; broken tap slags and furnace slags with embedded charcoal characterized the mound (Ben-Yosef and Levy 2014b: 942). As such, the technological assemblage at KAJ corresponds to the Early Iron Age, and the radiocarbon dates (discussed below) lend support to using technological developments for chronological assessments.

Based on the excavations in the slag mound and Structure 276, a stratigraphic sequence of six strata was defined, A1 – A6 (the following paragraph is a summary of Ben-Yosef et al. 2010: Table 2 unless otherwise noted) (See Table 1 in the Appendix for a complete overview of the stratigraphy from both excavation seasons and their correlation). Stratum A1 was divided into 'a' and 'b' based on the location; Alb represents the post abandonment collapse and fill within Structure 276, and Ala is the top sediments and metallurgical debris on the slag mound. Stratum A2 is the occupation phase in Structure 276 as defined by the elusive floor and associated artifacts. Stratum A3 – A6 are only identifiable in the slag mound. Stratum A3 is the rich accumulation of copper production debris within the slag mound, roughly a half meter thick at its greatest (Ben-Yosef et al. 2014: Figure 12.20). Stratum A4 represents the disruption in metallurgical remains by a habitation phase in the area. The layer of domestic materials with some industrial debris discovered beneath the occupation horizon is designated Stratum A5. Finally, the occupation phase directly above bedrock with pyrotechnological remains is Stratum A6. This stratigraphic sequence is imperative in creating a correlation with the results of the slag mound probe from 2014.

To refine the chronology of KAJ, two advanced dating techniques were used in collaboration with standard ceramic typologies: radiocarbon dating and geomagnetic archaeointensity (Ben-Yosef et al. 2010: 740). Nine charcoal samples from various stratigraphic contexts were selected for dating (Ben-Yosef et al. 2010: 740). The laboratory dates were further honed through the application of Bayesian statistics (Ben-Yosef et al. 2010: 740; Buck et al. 1996). The Bayesian approach interprets data conditionally on the other information available i.e. a radiocarbon date will be considered along with its stratigraphic position and relation to other artifacts (Buck et al. 1996: 1). The study found that, with 68.2% probability, occupation in Area A began between 1092 – 1017 BCE and ended between 1002 – 933 BCE, once again placing KAJ within the Early Iron Age (Ben-Yosef et al. 2010: 704). These results affirmed with a high amount of certainty the previous attributions of KAJ to this period.

Moreover, a geomagnetic archaeointensity investigation was performed to complement the collection of radiocarbon dates. Geomagnetic archaeointensity is the study of the geomagnetic field as recorded in archaeological artifacts (Ben-Yosef et al. 2008: 2863). When artifacts containing iron oxides are fired, they acquire a thermal remanent magnetization during cooling that preserves the earth’s magnetic field at that moment (Ben-Yosef et al. 2008: 2864). This stored magnetic field can be measured and compared to a regional record of archaeointensity or to similar studies at different sites (Ben-Yosef et al. 2008: Figure 1; Ben-Yosef et al. 2010: 740). For this study, the archaeointensity for slag samples from Strata A5 and A3 was calculated (Ben-Yosef et al. 2010: 740). The results indicated a correlation in archaeointensity from Strata A1a – A3 with samples from KEN Stratum M3 in the large slag mound (Ben-Yosef et al. 2010:

740; Ben-Yosef et al. 2009: Figure 4). A connection was also recognized between KAJ Strata A5 – A6 with KEN Stratum M4 (Ben-Yosef et al. 2010: 740). These parallels in archaeointensity between the strata at KAJ and KEN are indicative of contemporaneity (Ben-Yosef et al. 2010: 740). The KEN slag mound stratigraphy was analogously dated through radiocarbon samples and Bayesian statistics (Levy et al. 2008). Stratum M4, attributed to the Early Iron Age, matches the Stratum A5 – A6 record at KAJ (Ben-Yosef et al. 2010: 742). As a result, by connecting the archaeointensity record between samples and KAJ and KEN, the chronology and archaeological record at both sites can be refined and connected.

The ceramic assemblage collected from KAJ during the 2006 season was analyzed by Neil G. Smith (Ben-Yosef et al. 2014: 810). The results of the initial investigation indicated that ceramics at KAJ were most likely fabricated by local potters (only one sherd had provenance elsewhere based on petrographic investigation) (Ben-Yosef et al. 2014: 810, 812). Interestingly, the handmade ceramic sherds contained slag inclusions (this will be further discussed below) (Ben-Yosef et al. 2014: 812). The majority of diagnostic sherds was wheel-made and found in forms consistent with the Edom lowlands assemblage for the Early Iron Age; the closest ceramic parallels were excavated from KEN Area M (Ben-Yosef et al. 2014: 810-812). Ceramic forms including cooking pots and serving vessels were excavated from contexts that included metallurgical remains, suggesting that domestic and metallurgical activities were adjacently taking place (Ben-Yosef et al. 2014: 811). In sum, while the ceramic sample from KAJ was small, and investigations preliminary, the results fit the general narrative and chronology for the site.

Overall, the stratigraphic excavations at KAJ contributed immensely to the site's historical and metallurgical narrative. The slag mound probe and its chronological assessment through absolute dating techniques secured the site's Early Iron Age genesis for the exploitation of local copper resources. Based on this understanding, it seems that KAJ was established to capitalize on the economic opportunities created by the Late Bronze Age collapse and the reduced availability of Cypriot copper (Ben-Yosef et al. 2014: 813-814). For the duration of KAJ's occupation, copper manufacture gradually developed from small/opportunistic to industrial scale; however, it would never reach the intensity of KEN before its abandonment (Ben-Yosef et al. 2014: 810, 813-814). The late tenth century BCE desertion of the site possibly relates to the Egyptian campaign in the region by Pharaoh Sheshonq I as corroborated by a coeval disruption at KEN (Ben-Yosef et al. 2014: 815; Levy et al. 2014d). However, this study examined the copper production record at KAJ through the modest window; the 2014 season and its archaeometallurgical investigation afford additional vision.

6. The Research Design for New Excavations at KAJ

While excavations in Area A were invaluable in providing a preliminary understanding of KAJ and its abundant copper production, the localized nature of these excavations in the southern aspect of the site warranted renewed investigations to increase the breadth of our understanding. The new excavations at KAJ in 2014 aimed to produce a more representative examination of the site and its metallurgy. It was hypothesized that a complete remapping and identification of metallurgical activity areas would facilitate a more informed reconstruction of the copper smelting *chaîne opératoire*; thus, all potential metallurgical features were mapped and ground truthed. In addition, the sociopolitical dynamics surrounding copper production remained elusive from the small structure excavated in 2006, so renewed excavations included nonindustrial settings to explore this aspect. The Area A slag mound revealed an intricate history of copper smelting (described above); however, these results were founded on only one of the many slag mounds that populate KAJ's surface. In order to further investigate the site's metallurgical narrative (and to develop and/or corroborate the results from Area A), an additional large slag mound was probed. Excavations expected to discover bedrock beneath the slag mound to expose the entire history of copper smelting over the site's occupation. This would facilitate an examination of the *chaîne opératoire* and its diachronic developments. The project was supplemented with systematic sampling of slags both within the probe and from other metallurgical features throughout the site. These samples could then be subjected to post-excavation analyses to examine temporal intricacies otherwise missed by macroscopic investigations. In sum, the 2014 excavations at KAJ aimed to foster a more representative understanding of the site which in turn would enable a reconstruction of the copper production *chaîne opératoire*.

7. The 2014 Excavation Season at KAJ

Two new areas were opened for systematic excavation during the 2014 season. Area B, seemingly the largest structure visible on the site's surface, was excavated in hopes of elucidating the social dynamics of copper production at KAJ, and Area C, a one by one meter test probe into a slag mound located on KAJ's southern extent explored the temporal developments of said production. Employing the cyber-archaeology methodology, excavations were accompanied by systematic mapping (balloon-aerial photography) and sampling of metallurgical deposits throughout the site to refine synchronic details of copper production. This section provides an overview of the methods and results from the 2014 excavation season (See Figure 5 for a topographic map of KAJ with the excavation areas labeled).

7.1 Excavation Methodology

In 1998, the ELRAP committed to a fully digital recording system for its archaeological expeditions (Levy et al. 2014a: 31-63; Levy et al. 2010). Since the genesis of the On-Site Digital Archaeology (OSDA) methodology, ever-advancing technology and recording techniques has facilitated the development of the most advanced archaeological approach used by the ELRAP team, OSDA 3.0 (Levy et al. 2010: 135). OSDA 3.0 combines off-the-shelf technologies with custom computer programs and hardware to approach archaeological and culture heritage problems in a sophisticated manner (Levy et al. 2014a: 32-33). The OSDA 3.0 has since been incorporated into Cyber-Archaeology - a complete integration of the latest advancements in computer science, engineering, science, and archaeology to facilitate and develop data acquisition, curation, analysis, and dissemination (Levy 2013: 28-30). For archaeologists, recording contextual data with high precision is critical for turning the material record into anthropological understandings (Levy et al. 2014a: 33). With this fundamental characteristic in mind, cyber-archaeology and OSDA 3.0 improved recording archaeological finds and their respective contexts by joining methods within survey and digital photography (Levy et al. 2014a: 33). This combination supplements spatial recording limited to x, y, and z coordinates with a visual element.

To maximize the spatial resolution for archaeological data in three dimensions, the ELRAP couples a Leica TS02 total station with the custom software package now known as *Archfield* (Smith and Levy 2012; Levy and Smith 2007). *Archfield* allows for real-time data review of geospatial data and creates metadata descriptions for all points and polygons recorded by the total station; thus, it generates a complete and descriptive spatial record of the excavation in the field. This provides exact x, y, and z coordinates within the international UTM (Universal Transverse Mercator) system, placing the recorded artifacts and contexts in their exact location in the world. Following their collection, the management of artifacts and their associated spatial/contextual metadata was also improved with additional custom software called *ArchaeoSTOR* (Gidding et al. 2013). *ArchaeoSTOR* links each artifact with its provenience in a digital database, allowing for spatial visualization and statistical applications. OSDA 3.0 also uses advanced imaging techniques to enhance and visualize the spatial record. While terrestrial photography is a commonality on archaeological excavations, OSDA 3.0 supplements this with balloon-based aerial photography (Levy et al. 2014a: 40). Balloon photography allows large-scale contexts to be photographed at a high resolution. Site-wide photos can be georeferenced to create a digital map (to scale) for an aerial survey of the site. The 2014 ELRAP season employed OSDA 3.0 and adopted a rigorous Structure from Motion recording campaign to create photorealistic three dimensional models of the excavation. Collectively, these methodologies created an expansive spatial and visual record of excavations at KAJ.

Excavation of the slag mound probe utilized a simplified variation of another ELRAP developed protocol for excavating such contexts (Ben-Yosef et al. 2014: 791-792). The abundance and unwieldly quantity of slag excavated at smelting sites makes field processing an essential aspect of the excavation method (Ben-Yosef et al. 2014: 791). In Area C, slags were sorted by size into designated rubber buckets as they were collected. Slag bits smaller than ten centimeters, roughly ten to fifteen centimeters and above fifteen centimeters were separated. All slags in the less than five centimeter and ten to fifteen cenimter ranges were weighed in the field using an electronic hanging scale and discarded. The largest slag fragments were also weighed in the field; however, these were brought back to the "dirty" lab for precise weighing on a table top scale and photography (Levy et al. 2014a: 35). Special slags, such as those with charcoal embedded in its matrix, if recognized in the field, were recorded with the total station for its exact spatial location and collected. Additional collecting of slag samples for post-excavation analysis is described below.

7.2 Area B – Building 2

Area B seemed on the surface to be the largest and centrally located structure at KAJ. As such, excavations focused on this structure, designated Building 2, to potentially investigate the control of copper production. The building was excavated using a single-context recording strategy allowing a complete exposure. The entire perimeter of Building 2 was delineated, and seven possible interior rooms were uncovered (Rooms 1-7) (Figure 6). The perimeter dimensions were 8.12 meters by 7.50 meters leaving an architectural footprint of 60.9 square meters. The walls were constructed of roughly cut, undressed stones with two possible entranceways into the building at its southern end. This edge of Building 2 is also demarcated by a passage way separating it from another, and possibly related, structure to the south. With the building's perimeter exposed, excavations focused on the interior rooms.

The western wall, along with Rooms 1-3, was excavated down to bedrock, the structure's foundation. In Rooms 1-3, excavations revealed material culture directly on top of the bedrock which functioned as an occupational surface. An artifact assemblage of principally grinding slabs and hammerstones along with some pottery were resting *in situ* on the bedrock floor in Room 1. The artifacts were primarily in the center of the room and at the eastern end was a semicircular feature abutting the north and east walls of the room, possibly a storage bin. Artifacts on the floor of Room 2 were principally stone tools including hammerstones, grinding slabs, and weights. In Room 3, a compact patch of a crushed slag surface was discovered in its northwest corner. Associated with this surface were two features related to production: a large, finely-manufactured grinding slab with its accompanying grinder and a bedrock basin, similar to those found with crushed slag mounds (discussed below). The two installations were adjacent and separated by a vertical stone slab. Other collected artifacts in Room 3 were also predominantly stone implements including hammer stones and grinding slabs. The artifact and feature assemblage on the bedrock floors from these three rooms suggest that Building 2 was dedicated to manufacturing or material processing during this occupational phase.

After the initial construction and use of Building 2, it was architecturally altered during a second habitation phase. The doorways previously connecting some of the interior rooms were intentionally blocked (Figure 7). The blockades were constructed down to the bedrock foundation of the building. The results divided the building into two separate activity areas while also completely blocking off Rooms 4, 6(?), and 7(?), perhaps signifying a unique disposition for this area. Rooms 1 and 3 became an isolated space only accessible through a possible building entrance in the southeast corner of the building. Rooms 2 and 5 were likewise isolated and also appear to be accessible through the building entrance south of Room 5. The door between Rooms 3 and 5 possibly remained open but the stone rubble within the doorframe could be collapse from an obstruction. While this architectural transformation certainly demonstrates a second occupation in Building 2, it is unclear whether or not it the bedrock surface was reused. It is also possible that the building was partially filled following the blockades in the doorways, and that the artifacts associated with this occupation were above the bedrock as will be seen.

Rooms 4-7 were only partially excavated due to the short field season and modest team size. Rooms 6(?) and 7(?) are questionably identified as rooms since their exact delineations were indeterminable; it is possible that they, along with Room 4, actually compose one larger space. Despite the limited excavations, Room 4 yielded the intriguing find of a possible standing stone (Figure 8). The large worked stone was roughly 1.5

meters long and rounded on one end. It had fallen from its original position and left *in situ* with the end of the excavation season. This discovery possibly indicates a cultic function for the room, and perhaps even the entire building. Other materials from around the standing stone included worked stones and charcoal. Directly north of Room 4, Room 6(?) produced significant material culture including pottery, noteworthy amounts of bone, and charcoal (including charred date seeds), perhaps from cultic practices related to the standing stone. Room 7(?) is a very small room south of Room 4 with questionable function and minimal artifacts. The function of Room 5, in the southwest corner of Building 2, is also unclear since no recognizable floor was found. The room has an entryway from the exterior of the building and doorways into Rooms 2 and 3. The limited excavation in these rooms left them at a higher elevation than those excavated to bedrock; thus, these finds are stratigraphically assigned to a separate occupation horizon.

Excavations in Room 1-3 similarly discovered evidence for this elevated stratigraphic phase. In the fill of Room 2, substantial amounts of ceramic were excavated including a possibly reconstructable vessel. Several grinding slabs and hammerstones were also found at the same level as the pottery. These finds were not associated with a discernible floor or surface but their concentration is indicative of an occupation. Rooms 1 and 3 yielded similar evidence at a level above bedrock including pottery, grinding slabs, hammerstones, worked stone, and charcoal. A mining hammer, copper pin, copper ore, and slag were also excavated from these rooms possibly suggesting Building 2’s relationship with copper production. Across all the rooms, there is evidence for two or three occupation horizons depending on the potential reuse of the bedrock floors in Rooms 1-3.

Following the abandonment of Building 2, its interior was filled with mainly wall collapse. Directly above the evidence for ancient occupation was a stratum of stone collapse embedded within a fine, Aeolian loess. A separate layer of collapse was recognizable by its lack of sediment fill consisting solely of large stones both within the building and along its exterior. Finally, there was evidence for some modern recycling of the stones on top of Building 2. The stones were repurposed in a circular construction most likely by the local Bedouin that populate the region; similar stone circles are found throughout the site and are possibly used to pen animals.

The ancient habitation of Building 2 appears to be related to production and possibly cultic practices. The centrally located grinding installation and bedrock basin in Room 2 were perhaps related to some form of ritual activity. The possible standing stone in Room 4 (which is directly in line with the grinding installation area in Room 3) and associated material culture, bones, pottery, and charcoal, in Room 5 possibly reiterate the potential cultic importance of Building 2. The subsequent blocking of the doorways into the ritual space perhaps supports its significance, representing a symbolic/tangible break with this area. The artifacts collected throughout the structure were predominantly stone tools emphasizing its relation to manufacture. Despite the original intentions to excavate a nonindustrial context associated with the control of copper production, the material culture of Building 2 suggests it was also dedicated towards KAJ’s industrial purpose.

7.3 Area C – Slag Mound 529

In the southeastern portion of KAJ, large scatters of broken slags and five possible slag mounds indicated significant metallurgical activities in the area (Figure 5). This area, designated Area C, is principally comprised of these metallurgical features as there are limited architectural elements on the surface. A substantial part of Area C was subjected to massive erosion since the site's abandonment with devastating effects on the archaeological record (Figure 9). Moreover, the modern mining roads through KAJ damaged two of the potential slag mounds in this area. However, while this recent intrusion altered the view of the past, it also provided a unique opportunity to examine the section of the slag mound before committing to stratigraphic excavation. Slag Mound 529, one of the larger slag mounds visible only by scattered fragments of tap slag on the surface, was cut on its northeast and southwest edges by the mining roads (Figure 10). Following the cleaning of the section created by the road, the slag on the surface was identified as not simply scatter but the top of a large mound. Once determined as such, a one by one meter probe was stratigraphically excavated to further investigate its contents with the goal of revealing the entire metallurgical history of the site. This, in turn, would provide an invaluable opportunity to evaluate diachronic changes and developments in copper production at KAJ.

The bottom of the excavation probe successfully reached the red bedrock sandstone at a depth of roughly 1.75 meters (Figure 11). Above the bedrock sediments was a substantial accumulation of crushed slags about seventy-five centimeters thick. Superimposed deposits of cemented crushed slag were separated by only thin layers of what appeared to be natural weathering. Almost no material culture was collected from the accumulation aside from a few pottery sherds near its bottom and some bits of charcoal indicating this horizons function as a metallurgical dump. Following the final deposit of crushed slags, a layer of ashy sediment with significant domestic refuse was excavated from a probable occupation period. This phase included a drastic increase in material culture including ceramics, bones, a ground stone artifact, and copious charcoal. Charcoal consisted of small bits of twigs and branches as well as a concentration of charred date seeds. A stone installation, four or five large stones in a line, was also excavated but its purpose was indeterminable. This stratum was superimposed by a thin layer of tan sediment, possibly decomposed technical ceramics. Artifacts included bits of slag, some pottery sherds, weathered technical ceramic pieces, and a broken copper object (possibly a ring). Above this fine accumulation was the main industrial phase of copper production in the slag mound during which this area again functioned as a waste depository. Roughly fifty centimeters of tap and furnace slag fragments embedded in a dark brown and ashy matrix was excavated directly below the surface of the mound. The slags ranged in size from small bits less than five centimeters in diameter to large cakes greater than twenty centimeters; about 450 kilograms of slag were excavated based on field measurements. Other artifacts were limited but included charcoal, some pottery, weathered technical ceramics and a hammer stone. This industrial stratum was the final use of this area, and possibly the final metallurgical phase at KAJ.

Based on the excavations in Area B and the slag mound probe in Area C, a stratigraphic sequence of ten strata was determined (Table 1). This stratigraphy is shared between the two areas but the connections are speculative and require further examination. The first stratum assigned, Stratum III, represents the sterile bedrock discovered at the bottom of the slag mound. Stratum IIe is the accumulation of crushed slags probably indicating the first phases of copper production at KAJ. The next stratum, IId, is the repurposing of the slag mound area for an occupational function based on the volume and types of material culture. Stratum IIc is the thin tan sediments between the domestic debris and the final metallurgical phase. The large industrial layer in the slag mound is Stratum IIb which is hypothetically connected to the first occupation phase in Building 2 (its initial construction) assigned to the same stratum. Stratum IIab consists of loci that were indeterminably associated with the one of the occupation phases in Building 2; this includes the crushed slag mounds (see below) in Areas B and C and some of the fill loci above bedrock in Building 2. Stratum IIa – Ia are only present in Area B. The second occupation in Building 2 associated with the blocked doorways is Stratum IIa. The wall collapse filled with Aeolian loess and the loose stone collapse on top of Building 2 are Strata Ic and Ib respectively. Finally, Stratum Ia is the modern repurposing of stones found in Area B.

7.4 Correlating the Area A and Area C Slag Mounds

By probing slag mounds in both the 2006 and 2014 excavation season, there is an opportunity to correlate the stratigraphic sequences (Table 1). The Area A sounding produced five stratigraphic layers from virgin bedrock to the surface of the mound. Excluding bedrock at the bottom of the Area C excavation, the slag mound was divided into four strata. The top two layers of Area A, Strata A1a and A3, included the surface sediments and main accumulation of copper production debris at the top of the slag mound. These strata representing the final industrial phase in Area A correspond to Stratum IIb in Area C – the main industrial phase denoted by roughly fifty centimeters similarly containing tap slags, furnace slags, and charcoal. The thick accumulation of metallurgical debris in Area A was preceded by two layers: a fill of domestic debris and an occupation period, Stratum A5 and A4 respectively. These strata match the composition of Stratum IId (and possibly also IIc) in Area C, an occupation horizon characterized by domestic refuse and a stone installation. Finally, above the red sandstone bedrock found at the bottom of both probes was a layer associated with finely crushed slags. In Area A, the crushed slags are accompanied by bedrock basins and ash signifying a metallurgical purpose. The Area C crushed slag is a dense accumulation suggesting this area's function as a disposal. However, because both layers are signified by their relationship with crushed slag directly above bedrock, Strata A6 and IIe also correspond.

Along with the stratigraphy, the composition of the two slag mounds is analogous (Table 1). Excavations at KEN and KAJ have since dispelled the understanding that slag mounds are composed purely of the metallurgical byproduct (Ben-Yosef et al. 2010: 732). At KAJ Area A, only "a very small volume" of the excavated material from the sounding was slag with much of the mound yielding domestic debris and refuse (Ben-Yosef et al. 2010: 732). The excavation results in Area C were not as extreme; however, a large portion of the slag mound was also composed of domestic and habitation remains. Despite the limited volume, slag excavated from both mounds matched the expected Early Iron Age morphology or Group B slags. Fitting this designation, the prevailing industrial layers in Area A and C were principally tap slags broken to five to twenty centimeters with irregular shapes. Furnace slags with heterogeneous compositions and inclusions of charcoal were interspersed among fragmented tap slags. Moreover, Group B slags are typically processed further by crushing for prill extraction; the deposits of crushed slag at the bottom of each sounding parallel this understanding (Ben-Yosef and

Levy 2014b: 941). In sum, the Area A and Area C “slag mounds” are consistent in both their stratigraphic and archaeological records.

7.5 Aerial Survey – Identifying Site Wide Metallurgical Features

By employing the ELRAP balloon aerial photography system, the 2014 excavation season was able to create photorealistic and georeferenced maps of KAJ. These maps were a valuable asset in determining the locations of metallurgical elements throughout the site. Using the ArcGIS geographic information system software, a georeferenced orthophoto (an aerial photo geometrically corrected to have a uniform scale, essentially turning a photograph into a map) was examined for possible deposits of metallurgical debris. Locations of dark accumulations were digitized using ArcGIS to create a map of possible archaeological features (Figure 5). Following this map, the locations were ground truthed; most of the deposits were correctly identified and included slag scatters (broken bits and chunks of tap slags strewn across the surface of the site), tap slag mounds, and crushed slag mounds. In total, twenty-four metallurgical accumulations were identified at KAJ covering much of its surface. This map presented a more complete picture of slag features across KAJ including the identification of previously unmapped accumulations (Compare Figures 4 and 5).

Among the unmapped features were at least five mounds of crushed slag – thick heaps of fine-grained slag (Figure 13); two mounds were discovered to the northeast of Building 2 on the outskirts of the central habitation area (Figure 5, 12), and three additional mounds were discovered in the eroded basin of Area C. These mounds in Area C were subjected to harsh weathering leaving behind only small inselbergs. The crushed slag was originally discovered by Hauptmann (2007: 131), but they were not mapped, and in following, recieved little attention. Similar depositions were discovered on the hill slopes on the periphery of KEN, and they were believed to be a unique phenomna to that site without parallels at other Iron Age copper smelting sites (Ben-Yosef 2010: 930; Ben-Yosef and Levy 2014b: 942). Slags were crushed to extract extraneous bits and prills of metallic copper trapped in its matrix during smelting. This practice has been identified as a standard step in the metal production process and not limited to only copper (Bachmann and Hauptmann 1984 cited in Ben-Yosef 2010: 929). The crushed slag deposits at KEN were difficult to date more precisely within the Iron Age or to associated with a specific production system (Ben-Yosef 2010: 930). Thus, the discovery of these heaps at KAJ helps refine the chronological attributions for these features, the site's habitation being limited to the eleventh and tenth centuries.

Circular basins cut directly into bedrock were found adjacent to three of the crushed slag heaps: the two northeast of Area B (Figure 14) and one in Area C. These basins functioned as mortars for grinding the slags; one basin was found still full of finely crushed slag corroborating this understanding. These areas of mounds and basins probably functioned as slag processing complexes. Once the copper was obtained, the crushed slag, however, was not an immediate waste product and served several functions in the Iron Age. These slags were repurposed as fluxes for subsequent smelts, as foundations for architectural features, and as temper for domestic and technical ceramics (as seen in the handmade wares from the 2006 season) (Ben-Yosef and Levy 2014b: 942; Martin and Finkelstein 2013). Moreover, the slag tempering practice in Faynan has been temporally confined to the Iron Age (Al-Shorman 2009: 256-258). Based on the many heaps across the site, the significant accumulation in Slag Mound 529, and the central bedrock basin in Building 2, secondary slag processing was a major operation at KAJ.

7.6 Slag Sampling

An additional aspect of the ELRAP excavation methodology is the use of analytical tools for determining the chemical compositions of materials (Levy et al. 2014a: 46-49). While the development of portable technologies now allows researchers to bring the laboratory to the field, the 2014 season utilized localized sampling for post-excavation investigations of materials upon their return to the UCSD Levantine and Cyber-Archaeology Lab (Levy et al. 2014a: 46). The sampling focused on metallurgical features at KAJ; samples were collected from the probe into Slag Mound 529 and other slag deposits throughout Area C and B. From Slag Mound 529, two representative samples of tap slag from the main industrial layer and a small amount of crushed slag from the accumulation above bedrock were collected. The three crushed slag mounds in the eroded basin of Area C were systematically sampled. Each mound was sectioned and examined for stratigraphic variation through its width (Figure 15). All of the mounds appeared to be homogeneous so samples were arbitrarily collected at equal distances through the created section. To maintain the spatial integrity of the samples, each location was recorded using the total station. Moreover, one sample was collected from the full bedrock basin north of Area B as an additional reference. Ten samples were collected from across the site and within the probe, and a small portion of these was returned to UCSD for chemical analysis by X-Ray Fluorescence to foster broad synchronic and diachronic conclusions.

8. Chemical Analyses of KAJ Metal Production: X-Ray Fluorescence Spectroscopy

As part of the post-excavation analyses, slag samples were analyzed using X-Ray Fluorescence (XRF) spectroscopy (Figure 16). XRF is a technique for analyzing the elemental composition of materials based on atomic properties. The atoms of specific elements are characterized by a unique electron structure (Kaiser 2010: 4). These electrons orbit the nucleus in levels known as shells that are associated with a specific energy binding the electrons to the nucleus of the atom. The innermost electron shells must remain full in order for an atom to be stable. Should an electron be removed from an inner shell, the atom becomes unstable, and it will fill the vacancy with an electron from an outer shell (Kaiser 2010: 4). When an electron moves from an outer shell to one closer to the nucleus, less binding energy is required to maintain the electron’s orbit; the excess energy from the shell transition is released as x-rays. This process is known as fluorescence. The amount of energy emitted is equivalent to the energy differential between the two shells the electron moved between, and this energy is unique to each element (Kaiser 2010: 4). Because the energy lost is elementally determined, the XRF measures this energy to identify the element from which it emanated.

In the UCSD Levantine and Cyber-Archaeology Lab, a Bruker TRACeR III-V+ hand-held XRF analyzer was used for investigating slag samples excavated during the 2006 and 2014 seasons. The method by which this instrument measures elemental contents can be simplified to two steps; displacing the inner electrons and detecting the fluorescing energies of the outer electrons. For the first stage, the TRACeR is equipped with an x-ray tube capable of generating enough energy (up to 45 kV) to penetrate the inner electron shells of elements between magnesium and uranium on the Periodic Table. The tube barrages the selected sample located at the nose of the instrument with a three by four millimeter beam of radiation greater than the binding energies of the inner electrons (Kaiser 2010: 4, 6). The amount of energy emitted by the x-ray tube, and thus which elements are excited/analyzed, can be controlled through the Bruker software and with interchangeable filters (the filters are discussed further below). In addition, an optional vacuum system can be attached to the instrument for increased sensitivity to lighter elements. By exceeding the electron binding energies, the XRF instrument successfully displaces the inner electrons of elements within the designated energy range.

Second, as the vacancies are filled by higher orbiting electrons and fluorescing energies disperse from atoms, the instrument's detector registers these energies. In the case of this Buker TRACeR, the detector collects all of the x-rays released by the sample and subsequently sorts them based on the number of electrons knocked free from the detector material, this is known as Energy Dispersive X-Ray Fluorescence (ED-XRF) (Kaiser 2010: 4). As the detector collects the incoming x-rays, it converts their energy into analog pulses (Kaiser 2010: 7). The processing system within the instrument translates these pulses into a digital signal that can be read by a computer and displayed as a spectrum (Figure 17) (Kaiser 2010: 7). The spectra are plotted on a coordinate plane with the energy along the x-axis and pulses along the y-axis. The spectra represent the presence and relative amounts of elements within the analyzed sample based on the location and heights of peaks, respectively. In other words, by interpreting the spectra, the elemental composition of the sample is revealed.

9. Sample Preparation and XRF Methodology

As described above, the handheld XRF instrument examines samples with a three by four millimeter beam. This beam size restricts XRF analyses to a small spot on the target sample. With homogeneous samples, this small beam can produce representative results of entire samples; however, this is obstructive when considering heterogeneous samples such as metallurgical slags. When the sample is heterogeneous, the location of analysis will have direct implications on the XRF results i.e. different locations on the sample will yield drastically different compositional outcomes. To provide an elucidating example, if the beam from the XRF instrument happens to encompass a copper prill embedded in the slag, the results will be an unrepresentative elemental composition of slag with disproportionate copper content compared to the rest of its matrix. With this issue in mind, it is best to homogenize samples to produce a more accurate representation of its elements. The best method for homogenization is to grind a portion of the sample into a fine powder thereby negating the restrictions of the beam size and avoiding a biased reading.

A routine methodology was followed for grinding all the slag samples selected for XRF analyses. The slags were ground by hand using an agate mortar and pestle. For larger tap slags, the cakes were initially broken down to a manageable size using a small sledge hammer (Figure 18). Grinding in the mortar followed a six step process. The mortar and pestle were initially abraded using sand to prepare for the sample. Once abraded, the sand was thrown out and the mortar and pestle were washed with water. After drying, a small proportion of the desired sample was ground to a fairly fine powder. This subsample was also discarded and the mortar was subsequently washed with water and dried. Finally, the sample selected for XRF was ground to powder with particle sizes in the range of microns in diameter. The ground sample was collected and the mortar and pestle were once again washed with water and dried. The entire process, from sand abrasion to final grinding and collection, was then repeated for each sample. The final samples were deposited into plastic cups specialized for XRF. These cups use a transparent thin-film (four microns thick) as a base. The thin-film does not inhibit the analysis and allows powdered samples to sit essentially flush against the instrument. Cups were filled with roughly one centimeter of material in order to guarantee no x-rays passing through the sample.

In order to maximize the value of comparative inquiries, the XRF settings were replicated as best as possible from Ben-Yosef's (2010) dissertation research which included XRF results from slags excavated from KAJ in 2006. These samples were analyzed on the same XRF instrument used in the current investigation. Ben-Yosef (2010: 812) used two different filters depending on the elements being analyzed. For heavier elements including iron/copper and above on the Periodic Table, Ben-Yosef (2010: 836-855) used a green filter and set the instrument at 40 kV/ 15µA for 300 seconds with no vacuum. The green filter restricts X-rays emitted by the instrument to energies between 17 and 40 kV. This is ideal for measuring elements from iron to molybdenum. To analyze lighter elements, specifically aluminum to iron, the instrument was run with the blue filter, at 15 kV/15 µA, and under vacuum for 300 seconds (Ben-Yosef 2010: 836-855). The blue filter is best for elements ranging between and including magnesium to iron by limiting X-rays to 3 to 12 kV. By using these two separate filters, detecting and measuring of all desired elements was maximized. These settings were matched as close as possible to analyze samples for the 2014 season at KAJ; the only difference was in the μA – the green and blue filters were operated at 13 and 35 μA respectively (these were the closest available presets on the instrument). At the current stage of research, comparisons between Area C and Area A XRF results are restricted to patterns in the data rather than specific amounts; thus, these differences in instrument settings are inconsequential.

Following the collection of XRF spectra, the results were quantitatively analyzed for a relative representation of the sample's elemental contents. From the Bruker software, photon counts were generated for the elements represented in the spectra. These counts are generated by considering the heights of the peaks within the spectra. Photon counts are equivalent to the number of atoms of a given element within the sample per duration of analysis. For example, sample KAJ2014_AreaC_L529_B10338_1 in Table 2 yielded 3111 copper photons indicating 3111 copper atoms within the analyzed region of the sample for the allotted time of 300 seconds. Thus, the photon counts were calculated for the desired elements in every sample analyzed. The results are transferred directly into a Microsoft Excel spreadsheet for further manipulation. In this stage, the data can be examined for patterns and/or inconsistencies to foster a greater understanding of copper production at KAJ.

10. XRF Results and Interpretation

Each of the ten slag samples (two tap slags and eight crushed slags) were analyzed (the tap slag samples were analyzed twice); the results concerning the elements of interest are presented in Table 2. For accurate interpretations, results should not be compared across filters as the instrument is at very different settings depending on the filter, and this directly influences the photon counts. From Table 2, two elements stand out as particularly interesting: manganese and copper. Manganese shows extremely high values when analyzing the light elements in the slag; this is more clearly visible when the values are displayed in a scatter plot (Graph 1). Moreover, three samples also have elevated manganese content in comparison to the other samples (B10338_1, B10338_2, and B10314_2). Copper content is also interesting for its drastic variation between samples. When the copper values are plotted in a bar graph, four samples have drastically lower copper than the others (Again, samples from B10338 and B10314) (Graph 2). From this assessment, slag samples B10338 and B10314 yielded greater manganese contents and lower copper values than all other samples analyzed. Due to small sample, these differences cannot be tested for statistical significance, but there confluence within the same samples warrants interpretation. These samples are further differentiated by their form and provenance; B10338 and B10314 were the two tap slag samples collected from the main industrial layer (Stratum IIb) in the slag mound probe.

The elemental vision from XRF allows certain conclusions otherwise unattainable by macroscopic examinations. As noted in the geology section above, the manganese in slags provides insight as to the origins of the copper ore used in the smelt that produced the slags, the timeframe of production, and the sophistication of the technology. The DLS ores in the Faynan region are interspersed with manganese mineralizations resulting in ores, and slags, with high manganese contents. By recognizing this pattern between ore and byproduct, Hauptmann (2007: 184) associated the DLS ores with primarily Iron Age smelting. In addition, the consistent use of these ores during this period indicates advancement in technology from the Early Bronze Age; the ores were probably intentionally selected for their self-fluxing capabilities. Thus, the manganese-rich slag samples suggest that the smelters at KAJ were intentionally exploiting locally available DLS ores for their self-fluxing nature. While KAJ has already been firmly dated to the Early Iron Age, the slags' high manganese contents support this understanding by their predominance in the Iron Age. The manganese content affords additional insight to technological development within KAJ's occupation period when stratigraphically examined from the slag mound probe. The manganese content in the crushed slag sample above bedrock is considerably lower than the two tap slag samples from the later production phase. This suggests the smelts associated with these slags successfully extracted more manganese impurities from the ores, resulting in more pure metallic yields. Since these samples represent the assumed first and last industrial periods at KAJ, it appears, the increased manganese content in the slags suggests smelting technology improved over the site's occupancy period.

The analyzed copper contents from the slags illustrate a similar understanding. The XRF results showed a clear distinction in copper content between tap slag and crushed slag samples. The crushed slags at the bottom of the probe and from the various slag mounds in Area C had much greater copper in their elemental composition than the tap slags. The amount of copper in a slag is symptomatic of technological sophistication

(Ben-Yosef 2010: 817-818). Copper in slags is metal lost during the smelt, thus it is representative of the efficiency of the smelting technology used. The higher copper content in the crushed slags associated with the initial phase of metallurgy at KAJ suggests a less developed technological methodology. The ensuing tap slags, with their decreased copper content, represent a progression in technology from KAJ's original occupation into the final production phase. Both the manganese and copper amounts in slags suggest that copper technology diachronically improved at KAJ.

It is also intriguing that the crushed slags obtained from the activity areas associated with bedrock basins/mortars show high manganese contents. Both the dating and contents of the crushed slag mounds has been questioned (Ben-Yosef 2010: 930; Hauptmann 2007: 245). Hauptmann (2007: 245) suggested that heaps like these found in the vicinity of KEN and KAJ dated to the Early Iron Age, but they were composed of Early Bronze Age slags post-processed by Iron Age populations. Following the chronological framework that the consistently manganese rich slags are byproducts of smelting DLS ores during the Early Iron Age and the XRF results of this study, it is possible to suggest the crushed slag mounds are comprised of slags produced in the Iron Age. All samples of crushed slag collected from the mounds and in the probe yielded high manganese contents. Moreover, the nearest known remains of Early Bronze Age copper smelting are five kilometers from KAJ at Ras en-Naqab, a great distance to transport heavy slag (Ben-Yosef 2010: 827). It also seems unlikely that the slags would be transported to KAJ rather than crushing at their original location to reduce the carrying load. While this dating schema is impaired by very small sample sizes, it demonstrates a provisional attribution of crushed slag mounds to the Early Iron Age, as well as the need for an extensive investigation of these features.

These XRF results mostly conform to the data patterns in Ben-Yosef's (2010: Table 8.7) study on slags excavated during the 2006 season (Table 3). From Table 3, the significant manganese content is immediately apparent making up as much as 39% by weight of the slag composition. The manganese in the slags is variable through the section of the slag mound from which they were excavated, and it does not seem to follow a temporal pattern as was suggested by the 2014 slag probe. However, the copper content in the slags does conform to a stratigraphic pattern, as recognized by Ben-Yosef (2010: 819). In Graph 3, the lowest copper amounts came from slags excavated from Strata A1a and A3 (Ben-Yosef 2010: 819-820, Figure 8.23). These strata make up the top two layers of the slag mound, the later phase of copper production at KAJ. As with the 2014 study, the stratigraphic reduction in copper towards the surface of the slag mound is indicative of technological development over KAJ's occupation (Ben-Yosef 2010: Figure 8.23). From the results of the XRF analyses, the two slag mound probes indicate the exploitation of DLS ores with ever-advancing copper smelting technology during KAJ's occupancy.

11. The Copper Production *Chaîne Opératoire* at KAJ

Through the *chaîne opératoire* analytical method, Ben-Yosef (2010: 881-954) reconstructed the technical schema used in copper production through the Iron Age in Faynan. The principal components in the manufacturing process are diachronically consistent, but five distinct systems, or *chaîne opératoires,* were recognized (Ben-Yosef 2010: 888). The nuances that separate these *chaîne opératoires* are the result of the greater social-historical-economic setting in which they function (Ben-Yosef 2010: 886-887). Relevant to KAJ, Ben-Yosef (2010: Figures 9.6a and 9.6b) discerned two *chaîne opératoires* during the twelfth to tenth centuries BCE in Faynan, Production Systems 1 and 2. These sequences can be simplified to six steps; mining, charcoal creation, smelting, slag treatment, remelting/refining, and trade (trade cycles back to the beginning of the sequence with market forces driving the demand for copper) (Levy et al. 2014a: Figure 1.19). The specific techniques and gestures involved in each of these steps are analogous for both systems, but the infrastructure supporting the system developed temporally (Ben-Yosef 2010: Figures 9.6a and 9.6b). Production System 1, during the twelfth and eleventh centuries BCE, is categorized by a lack of substantial architecture, open-air smelting practices, and small walls/installations for work spaces (Ben-Yosef 2010: Figure 9.6a). In contrast, Production System 2 of the tenth century BCE is architecturally advanced with two-story buildings (Ben-Yosef 2010: 890). From the two excavation seasons at KAJ, it is possible to distinguish the two *chaîne opératoires* from their physical manifestations in the archaeological and archaeometallurgical records; the Area A slag mound contributed to Ben-Yosef’s creation of the sequences which are now corroborated by the 2014 excavation and post-excavation analyses

The first copper production *chaîne opératoire* (Production System 1) developed in Early Iron Age Faynan. Copper metallurgy inherently began with the procurement of locally available copper nodules. KAJ is located in the vicinity of an expansive field of pit mines, the Jabal al-Jariya (JAJ) mines, and additional mining sites along the Wadi al-Jariya (Figure 2) (Ben-Yosef et al. 2014: 856-874; Knabb et al. 2014). The JAJ pit mines exploited high-quality ores from DLS formations in the valleys near the major copper smelting sites (Ben-Yosef et al. 2014: 861-862). The mines' location near KAJ and KEN gives credence to an Early Iron Age attribution (no other smelting sites from other periods are nearby), and this chronology is corroborated by optically stimulated thermoluminescence from one of the pits (Ben-Yosef et al. 2014: 860-861). Thus, with the end of the Late Bronze Age, local miners, probably from KAJ and KEN, procured local DLS ores from the adjacent JAJ mines.

Excluding making charcoal which is difficult to discover in the archaeological record, smelting is the next traceable step in Production System 1 (Ben-Yosef 2010: Figure 9.6a). This initial smelting phase in Faynan includes small tuyères and Group B slags which were seen in both slag mound soundings at KAJ (Ben-Yosef 2010: Figure 9.5a). As described above, Production System 1 differs from the second *chaîne opératoire* through its limited architectural features (Ben-Yosef 2010: Figure 9.6a). A dearth of substantial architectural constructions, open-air smelting, and probable tent dwellings characterize this early phase (Ben-Yosef 2010: Figure 9.6a). Excavations in Area A (Stratum A4) discovered possible post holes from tents connected to Production System 1. Moving into the third link in the operational chain, tap and furnace slags are crushed and disposed or repurposed (Ben-Yosef 2010: Figure 9.6b). The earliest metallurgical period at KAJ is also typified by crushed slags as seen by the deposits above bedrock in both areas. The remelting/refining step in the process is currently intangible in the archaeological record but can be assumed; however, evidence for copper trade, the final step, was discovered outside of Faynan (Yahalom-Mack et al. 2014). Nine copper ingots from Neve Yam on the coast of Israel were dated to the Early Iron Age and sourced to Faynan ores (Yahalom-Mack et al. 2014: 173-174). In addition, recent petrographic investigations on pottery from the Negev highlands discovered slag tempered pottery originating from the Wadi Arabah, an additional indication for possible exchange routes (Martin and Finkelstein 2013: 32; Martin et al. 2013). Analysis of the slag inclusions revealed high manganese content and grain size's similar to those found in the crushed heaps of Faynan (Martin et al. 2013: 3788). This data both confirms Faynan copper exchange into the Levant, and supports the supposed unavailability of Cypriot copper in the Early Iron Age resulting in market forces impacting Faynan; the beginning and end of the production cycle.

The first *chaîne opératoire* continued until roughly 1000 BCE when it transitioned into Production System 2 (Ben-Yosef 2010: Figure 9.6a). As abovementioned, the sequence of production processes is the same, but the development into the second system witnessed increased complexity, efficiency, and innovation (Ben-Yosef 2010: Figure 9.5a). The substantial slag remains covering much of KAJ's surface correspond with an increased efficiency/intensity in the later phases of production. The considerable construction seen on KAJ's surface conforms to the architectural developments of the second phase. The second system ends in 925 BCE with a cessation of the copper industry accompanied by the abandonment of sites (Ben-Yosef 2010: Figure 9.5a). For KAJ, the end of Production System 2 was also the end of its occupation.

The new excavations and archaeometallurgical investigations at KAJ elaborated on the steps within the constructed *chaîne opératoires* and supported the diachronic transition from the first to second production system. Secondary slag processing, one of the six steps in the copper production sequence, was previously identifiable by only a thin layer of crushed slag at the bottom of the Area A slag mound. The metallurgical survey of KAJ in 2014 revealed previously unmapped mounds of crushed slag adjacent to bedrock basins that most likely functioned as mortars. This evidence, along with the significant accumulation of crushed slag at the bottom of the Area C mound, provides insight towards the significant role and specific gestures of this process within the *chaîne opératoire*. The presence of substantial crushed slag both on the surface and in the slag mound probes reiterates its importance and potentially its continued practice in both production systems. The post-excavation lab analyses further support the identified transition to a more efficient second production system during the site's occupation. Slags from the thick accumulation of metallurgical debris on the surface of the Area C slag mound contained elemental compositions with reduced copper and increased manganese contents in comparison to the older crushed slag samples; these results are indicative of an improved copper smelting technology/efficiency. The probable connection between this stratum and the substantial architectural features, like Building 2, conform to the characteristics of the second production system. In addition, the consistently high manganese content in all slag samples collected throughout the site suggest the sustained exploitation of DLS ores through both production systems. Finally, excavations in Area B Building 2 discovered a previously unfounded aspect of the copper production *chaîne opératoire* at KAJ – cult.

11.1 Cult and the Chaîne Opératoire at KAJ

It is not explicitly included it the *chaîne opératoire*, but cultic practices are an additional contributor to the social landscape of production (Ben-Yosef 2010: 948-952). Cult is historically and ethnographically tied to metallurgy (See Afinset 1996 cited in Ben-Yosef 2010 for a contemporary example from copper smelting in Nepal and McNutt 1990 for a historical analysis of iron forging in ancient Israel). As Ben-Yosef (2010: 949) expresses, there is an inherent difficulty in parsing out invisible spiritual components of the *chaîne opératoire* from the material record, and contemporary comparisons to Nepal are somewhat perfunctory when considering the chronological and geographical dissonance to Iron Age Faynan. However, and also noted, there is physical evidence for cultic activities in association with copper production at KEN, and now possibly also KAJ (Ben-Yosef 2010: 950-951; Levy et al. 2014c: 126-127). Area S, a courtyard structure centrally located at KEN, was dedicated to slag crushing; over 350 ground stone tools and thick layers of crushed slag were found in the building and its environs (Levy et al. 2012: 204). Excavations within the structure discovered a casting mold for possible goddess figurines connecting cult and industry (Levy 2008: 249-250; Levy et al. 2014c: Figure 2.96). Outside the northern wall of Area F, a copper smelting facility located within the large fortress at KEN, the ELRAP excavated a circular hearth installation and a standing stone (Levy et al. 2014c: 127). A ceramic sherd from a fenestrated stand was also discovered in Area F; this sherd is comparable to ceramics excavated from the

Edomite shrine, ‘Ain Hazeva (Levy et al. 2014c: 127). Preliminary interpretations consider this a possible altar and ritual space connected to the copper smelting in the Area F structure (Levy et al. 2014c: 131). Both Area S and F provide introductory evidence for a relationship between cult and industry at KEN.

The recent excavations at KAJ contribute to this conceivable ritualistic aspect of Iron Age copper production in Faynan. The hypothesized cultic area in Building 2 of Area B is a possible correlate to the cultic evidence found at KEN. As previously described, Rooms 4 and 6(?) yielded evidence of possible ritual activity including burnt bones, charcoal, ceramics, and a standing stone. The subsequent sealing of this area by intentionally blocked doorways could further reiterate its cultic disposition. Building 2 shows analogies to both Area S and Area F from KEN. The structure is located approximately thirty to forty-five meters from two slag crushing complexes, and central in Room 1 is a bedrock basin and fine grinding slab for probable slag crushing. The artifact assemblage collected from the building was also dominated by stone implements. Like Area S, the ritual attributes of Building 2 appear to be related to the secondary processing of slags. In addition and analogous to Area F, Building 2 contained the standing stone and fired materials including bone and charcoal. This data suggests that at least part of Building 2 was dedicated to a ritual activity most likely related to slag crushing activities within and around the structure. Although these cultic and ritual interpretations of the archaeological record are currently speculative, recent research has further elaborated on the possible emphasis of metallurgy in Edomite religion (Levy 2008; Amzallag 2009). The new evidence from KAJ reiterates the possible cultic aspect of the copper *chaîne opératoire* and the relationship between worker and craft.

12. Discussion – The Copper Production Narrative at KAJ

Out of the economic disruption created by the collapse of the Late Bronze Age and the unavailability of Cypriot copper formed the first copper production *chaîne opératoire* in Early Iron Age Faynan (Ben-Yosef et al. 2010; Ben-Yosef 2010; Yahalom-Mack et al. 2014). In the proposed model, local nomadic tribes populating the region developed KAJ as a smelting facility in the Iron Age landscape alongside KEN and Khirbat al-Ghuwayba. These tent-dwelling technicians opportunistically exploited local copper ores in the JAJ mine fields and along the Wadi al-Jariya (as indicated by the insufficient residential architecture at smelting centers the many camp and mining sites discovered adjacent to the wadi) (Ben-Yosef 2010: 963; Knabb et al. 2014). The deliberate selection of manganese-rich ores (as corroborated by XRF) for its self-fluxing properties demonstrated a dichotomy and technological improvement from Early Bronze Age smelting in Faynan. In addition, the crushed slags directly above bedrock suggest an acute awareness of the copper smelting process; these smiths recognized metallic copper lost during a smelt could be secondarily recovered from the slags. The crushed material was often repurposed for ceramic tempers, fluxes, and architectural foundations. As such, this suggests the site was established by experienced metal workers. The ephemeral habitations and open-air smelting methodology left little architectural mark on the archaeological record outside of post holes (Ben-Yosef et al. 2010: 738; Knabb et al. 2014: 594-597). However, production evidence in the form of finely crushed slags and bedrock basins above and cut into the virgin sandstone is abundant both within the probes and across the site's surface. These bedrock features and their associated crushed slag mounds are located on the northern edge and southeastern fringe of the site suggesting slags were moved to designated crushing areas. The marginality of these locations outside the habitation areas was probably selected because the crushed slags, unless otherwise repurposed, were a waste product. Metallic copper then satisfied local needs or was exchanged in the form of ingots to fulfill demands in the greater Levant region.

Following/contemporaneous with the repurposing of the slag mound areas for habitation and domestic refuse, KAJ copper production transitioned into a second production system on an industrial scale. Large architectural features, such as Building 2, and thick accumulations of Group B slags from this period still cover the sites surface. The metal workers at KAJ continued to procure DLS ores, but interacted with their craft to improve smelting technologies and enhance the metallic yields (as indicated by XRF revealing the reduced copper and increased manganese content in the slags). Slags were, again, not treated as immediate waste but crushed and recycled for secondary functions. During this phase, there may have been a cultic component to secondary slag processing based on Building 2’s ritualistic material culture and association with slag crushing. The connection between cult and craft potentially reiterates the intimate relationship between the metal workers and copper smelting. Metallic copper was cast into ingots for exchange or final products for immediate consumption. Industrial copper production continued until the second half of the tenth century BCE when KAJ was abandoned, possibly as a result of Egyptian campaigns under Sheshonq I (Levy, Munger, and Najjar 2014; Munger and Levy 2014). KAJ then remained uninhabited and predominantly untouched until modern mining and archaeological expeditions. Thus, this recent research substantiates the metallurgical story recounted by the 2006 excavations (for a summary based on Area A, see Ben-Yosef et al. 2014: 813-816), the probable history for the site as a whole. The new excavation results refined the details of this metallurgical narrative at KAJ, emphasizing the predominant role of secondary slag crushing. Moreover, post-excavation lab analyses evaluated the technological developments in copper smelting over the site's history.

13. Conclusion and Future Directions

The renewed archaeometallurgical investigations at KAJ further informed the diachronic narrative of the copper smelting center by revealing the interactive and intimate relationship between metal workers and their craft, beyond a potentially static interpretation of production. The slag mound sondage afforded the time depth to create a full story from occupation to abandonment whereas the excavations in Area B and cross-site metallurgical surveys provided synchronic details. The crushed slag mounds emphasized secondary slag processing in the *chaîne opératoire*, and Building 2 reiterated the site's commitment to production including a potential cultic element (possibly reiterating the close relationship between craftsperson and craft). Stratigraphic XRF analysis contributed additional insights into the particulars of copper production and technological progression. The decrease in copper and increase in manganese contents in the temporally later slags demonstrates a continued development in knowledge and/or technology resulting in greater and purer metallic yields. The metal workers/supervisors were not complacent with producing copper on a large scale, but continued to master their abilities over the site's occupation period.

The 2014 excavation and post-excavation analyses corroborate and parallel the detailed historical and archaeometallurgical account told by the 2006 excavations, reiterating its probable reality. However, while Building 2 contributed a cultic component to the *chaîne opératoire*, it failed to present the anticipated insight concerning production control. Moreover, its distinctive occupation horizons evident by intentionally blockaded doorways added additional complexity to the social and political landscape at KAJ. Thus, the administrative dynamics remain enigmatic: who supervised copper production at KAJ and what warranted this tangible disjunction between occupations? Additional investigations concerning these aspects will further contextualize KAJ in the Iron Age Faynan landscape. Until then, this renewed research contributes valuable and intricate insight into KAJ’s copper production narrative.

14. Appendix

Figure 1: Map of Khirbat al-Jariya in the Faynan region of Southern Jordan (Image created with Google Earth).

Figure 2: Map of geological formations surrounding KAJ. Note the local DLS (labeled as BDS in dark gray) (Map altered from Rabba' 1991).

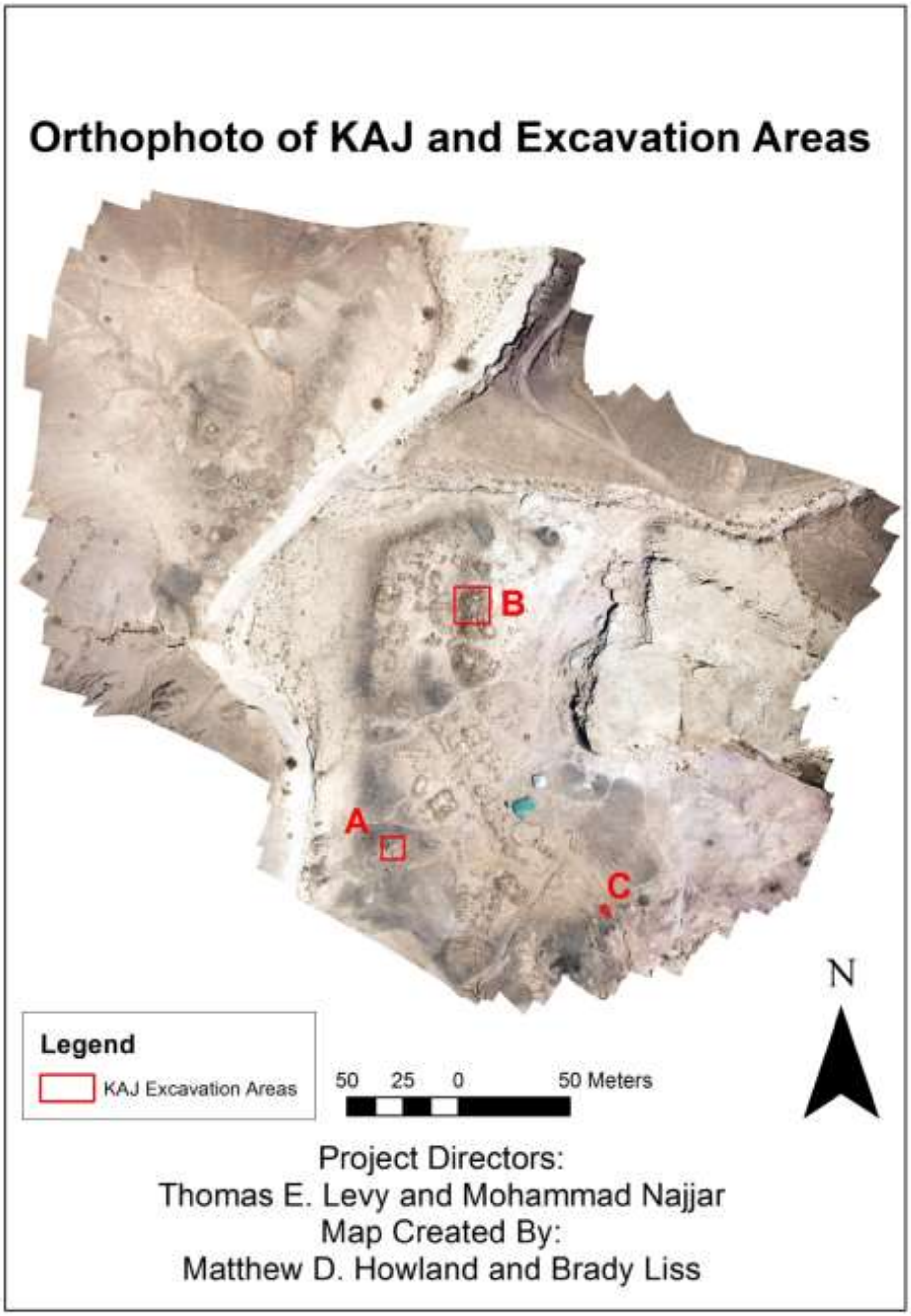


Figure 3: Orthophoto of Khirbat al-Jariya created from balloon aerial photography.

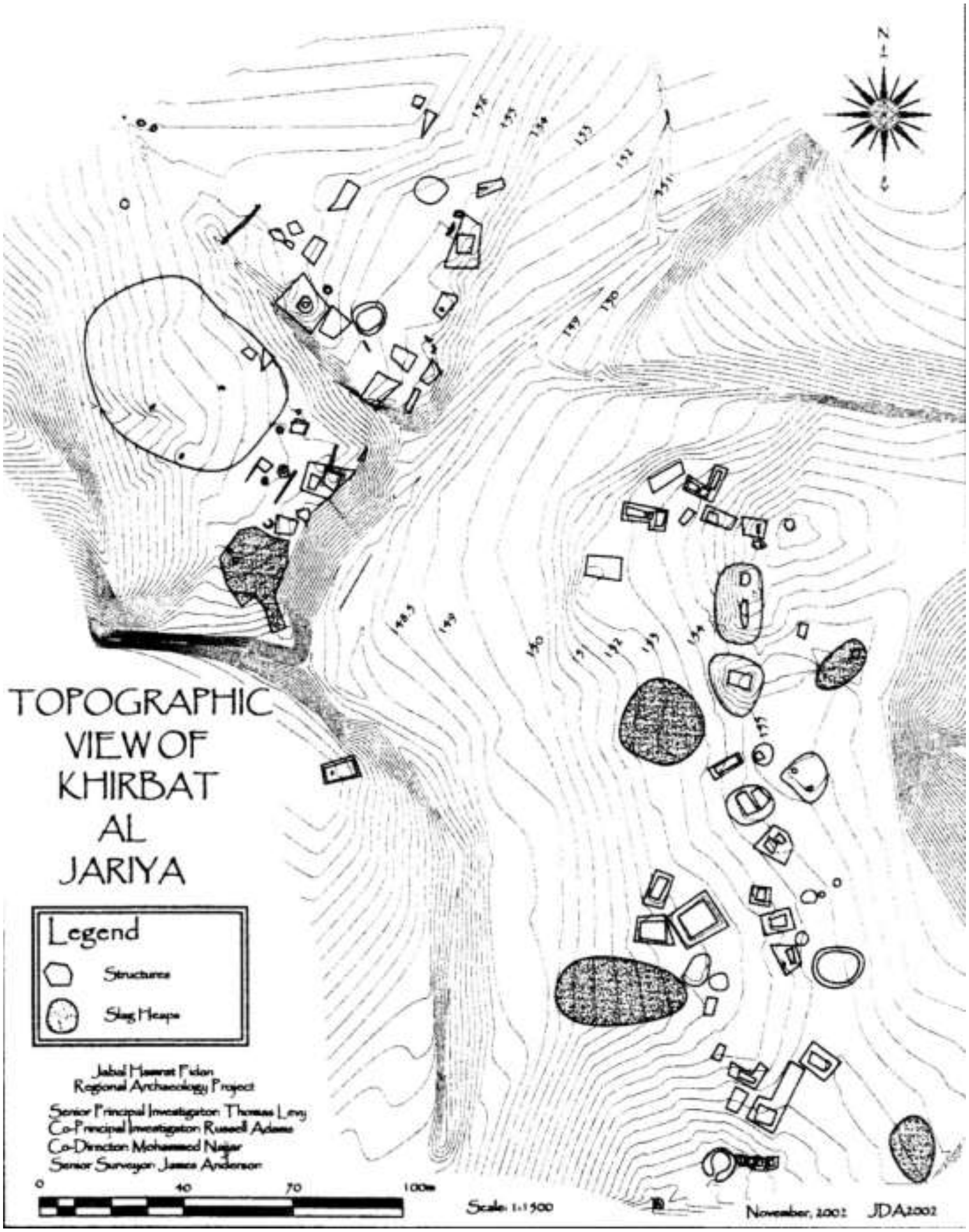
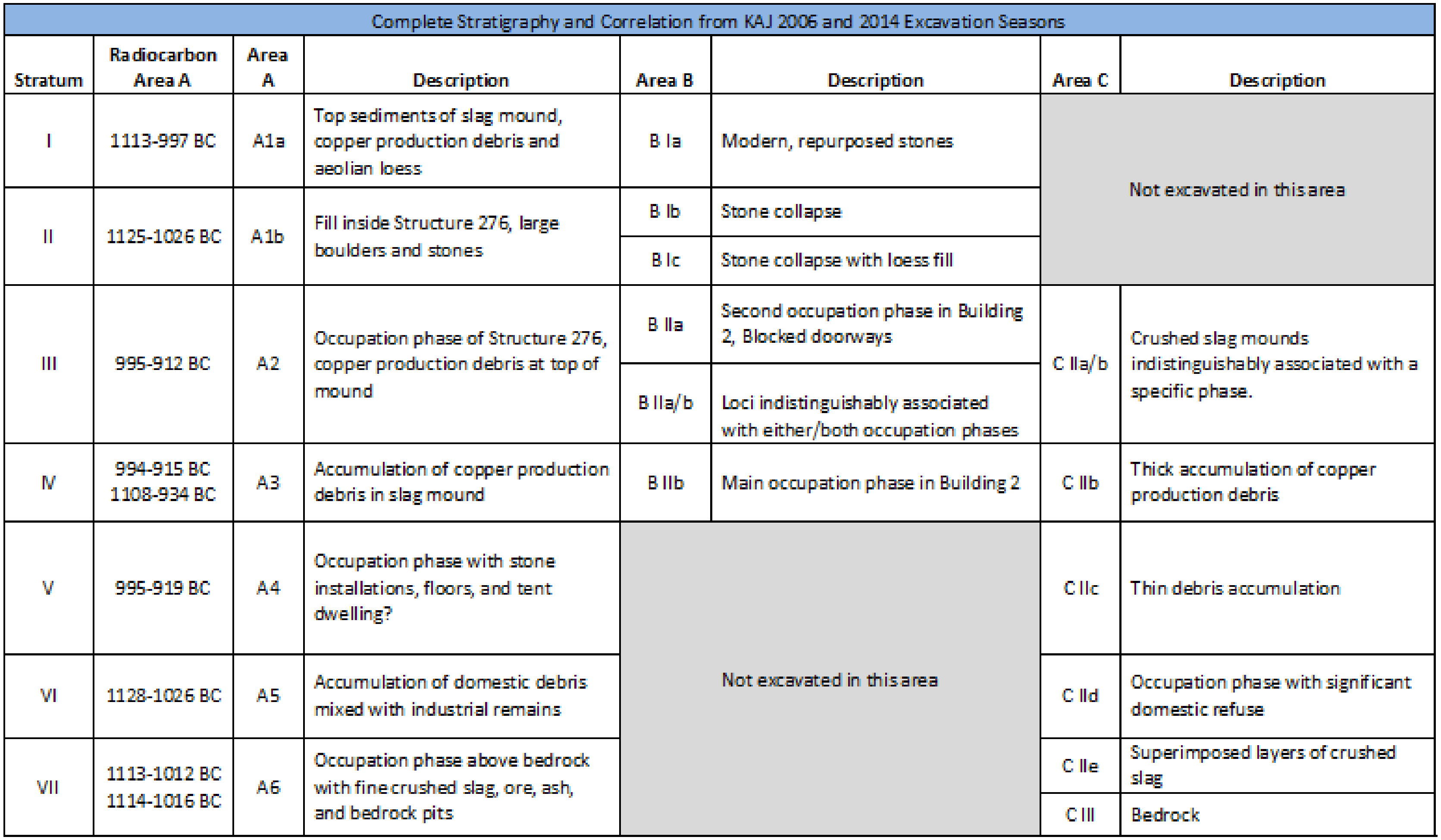


Figure 4: Original topographic map of Khirbat al-Jariya created by Jabal Hamrat Fidan Project (Levy et al. 2003: 274, Figure 16). Many of the architectural structures and metallurgical features at KAJ are missing from this map (Compare to Figure 5).

Table 1: Complete stratigraphy and correlation of KAJ 2006 and 2014 excavation season. The Stratum column provides general strata to consider relationships between the three excavation areas. The anchors for this correlation are the main production phases in the slag mounds (A3 an C IIb), and the assumption that these are associated with the primary occupation phase in Buildin g 2 (This is recongizably speculative and requires further investigation). The stratigraphy, descriptions, and radiocarbon dates from Area A are based on Ben-Yosef et al. 2010: Table 2.



Complete Stratigraphy and Correlation from KAJ 2006 and 2014 Excavation Seasons							
Stratum	Radiocarbon Area A	Area A	Description	Area B	Description	Area C	Description
I	1113-997 BC	A1a	Top sediments of slag mound, copper production debris and aeolian loess	B Ia	Modern, repurposed stones	Not excavated in this area	
II	1125-1026 BC	A1b	Fill inside Structure 276, large boulders and stones	B Ib	Stone collapse		
				B Ic	Stone collapse with loess fill		
III	995-912 BC	A2	Occupation phase of Structure 276, copper production debris at top of mound	B IIa	Second occupation phase in Building 2, Blocked doorways	C IIa/b	Crushed slag mounds indistinguishably associated with a specific phase.
				B IIa/b	Loci indistinguishably associated with either/both occupation phases		
IV	994-915 BC 1108-934 BC	A3	Accumulation of copper production debris in slag mound	B IIb	Main occupation phase in Building 2	C IIb	Thick accumulation of copper production debris
V	995-919 BC	A4	Occupation phase with stone installations, floors, and tent dwelling?	Not excavated in this area		C IIc	Thin debris accumulation
VI	1128-1026 BC	A5	Accumulation of domestic debris mixed with industrial remains			C IId	Occupation phase with significant domestic refuse
VII	1113-1012 BC 1114-1016 BC	A6	Occupation phase above bedrock with fine crushed slag, ore, ash, and bedrock pits			C IIe	Superimposed layers of crushed slag
						C III	Bedrock

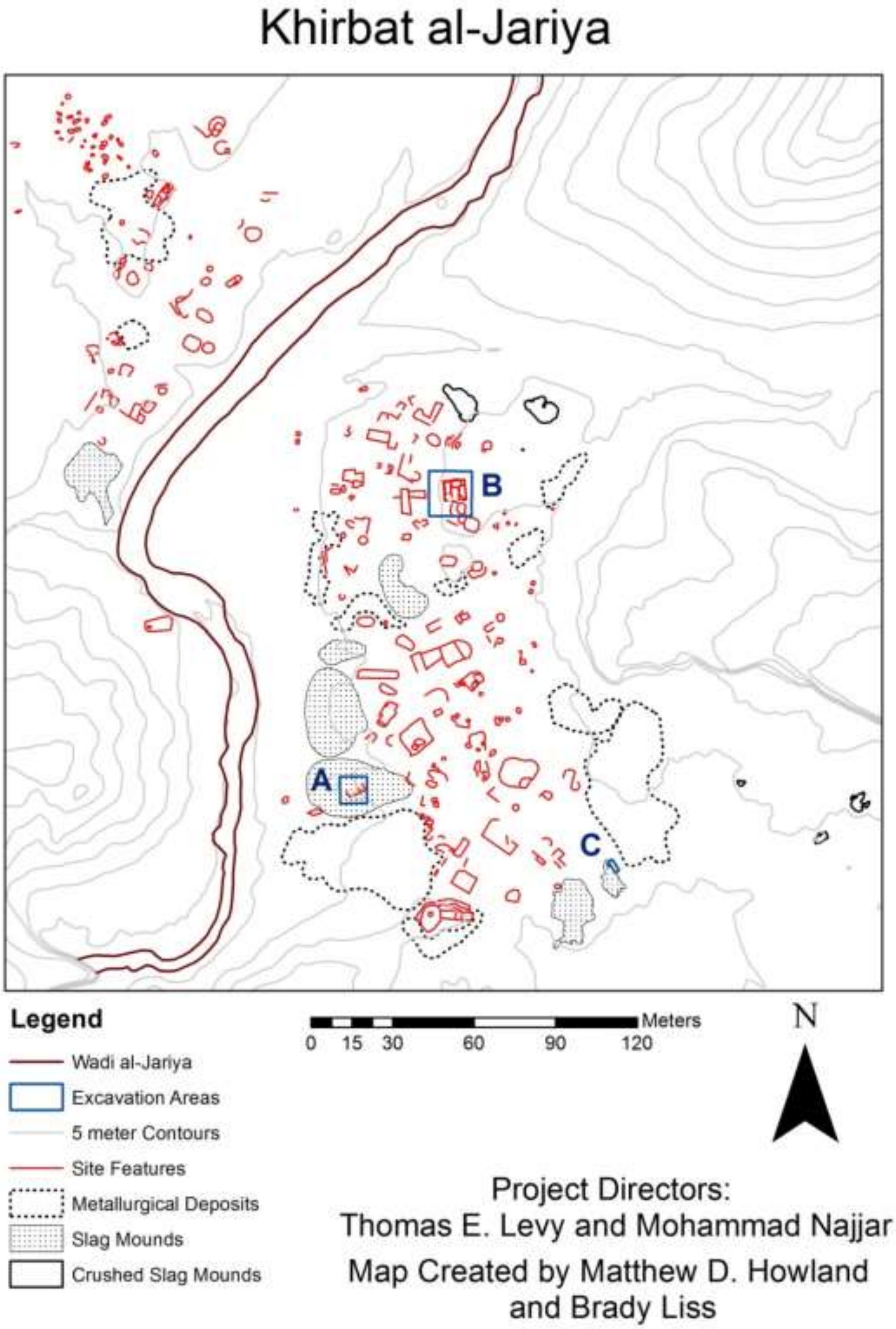


Figure 5: Topographic map of KAJ digitized from an orthophoto of the site. This map provides a complete representation of the site's architectural and metallurgical features.

Figure 6: Building 2 after excavation. Seven possible rooms were discovered (Rooms 1-3 were excavated to bedrock) (Photo by T.E.L. - UCSD Levantine and Cyber-Archaeology Lab).

Figure 7: Intentionally blocked doorways between Room 3 and Rooms 4, 6(?), and 7(?) (Photo by T.E.L. - UCSD Levantine and Cyber-Archaeology Lab).

Figure 8: Possible fallen standing stone in Room 4 of Building 2 (Photo by T.E.L. - UCSD Levantine and Cyber-Archaeology Lab).

Figure 9: The meager remains of a heavily eroded crushed slag mound in Area C (Photo by T.E.L. - UCSD Levantine and Cyber-Archaeology Lab).

Figure 10: Slag Mound 529 in Area C with the completed excavation probe. Note the cuts by the mining roads (Photo by M.D.H. - UCSD Levantine and Cyber-Archaeology Lab).

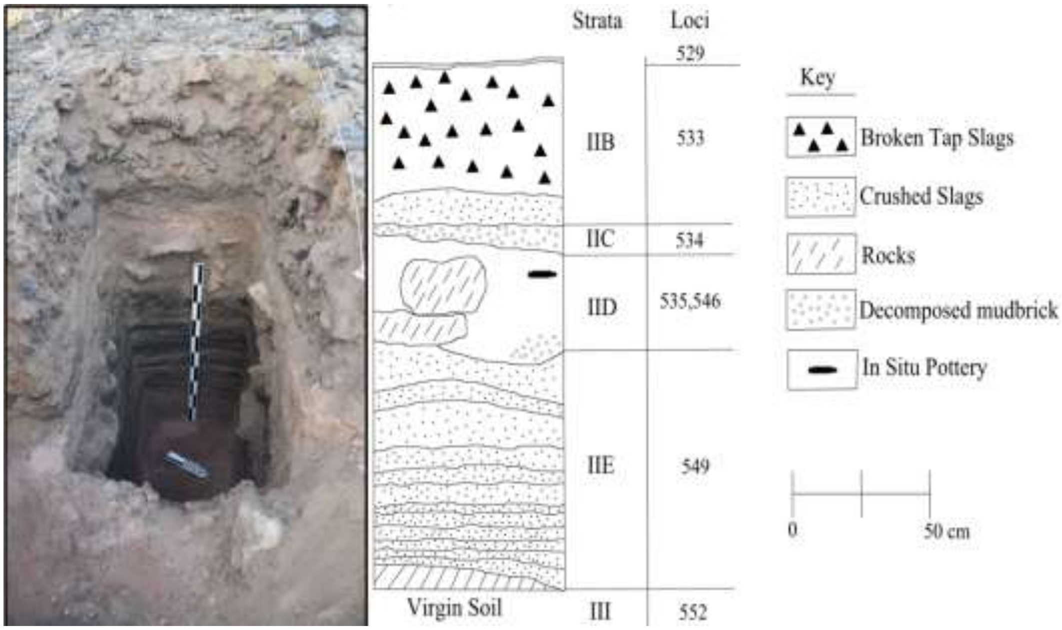


Figure 11: Completed excavation probe into Slag Mound 529 and digitized section drawing (Photo by T.E.L. - UCSD Levantine and Cyber-Archaeology Lab, Drawing by Brady Liss).

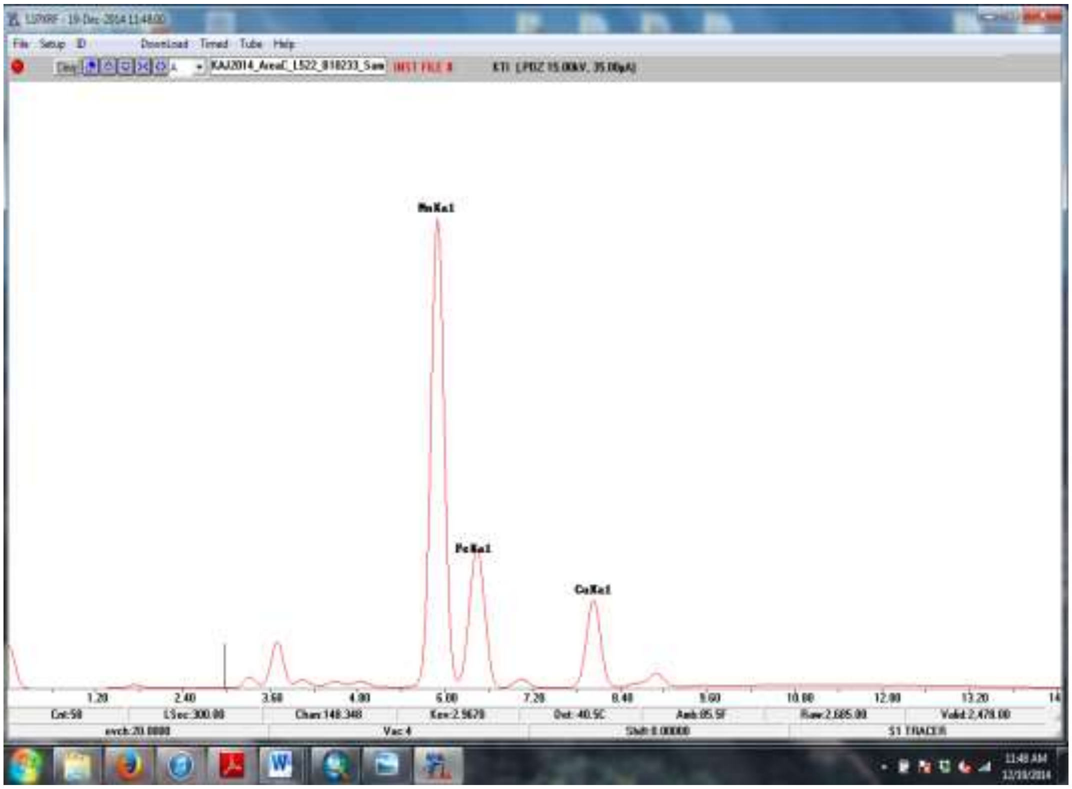
Figure 12: Crushed slag mound north of Area B with bedrock crushing basins in the foreground (Photo by T.E.L. - UCSD Levantine and Cyber-Archaeology Lab).

Figure 13: Sample of crushed slag collected from a crushed slag mound in Area C (Locus 523) (Photo by B.L. - UCSD Levantine and Cyber-Archaeology Lab).

Figure 14: Bedrock basins found to the north of crushed slag mound (Locus 506) (Photo by T.E.L. - UCSD Levantine and Cyber-Archaeology Lab).

Figure 15: Slag samples collected from Crushed Slag Mound 522 in Area C (Photo by T.E.L. - UCSD Levantine and Cyber-Archaeology Lab).

Figure 16: The XRF instrument set up in the UCSD Levantine and Cyber-Archaeology Lab (Photo by B.L. – UCSD Levantine and Cyber-Archaeology Lab).



KAJ2014_AreaC_L522_818233_Sam INST FILE 8 KTI (PDZ 15.00kV, 35.00µA)

Cnt:58 LSec:300.00 Chan:148.348 Kev:2.9670 Det: 40.5C Amb:85.5F Raw:2,685.00 Valid:2,478.00

evch:20.0000 Vac:4 Shft:0.00000 S1 TRACER

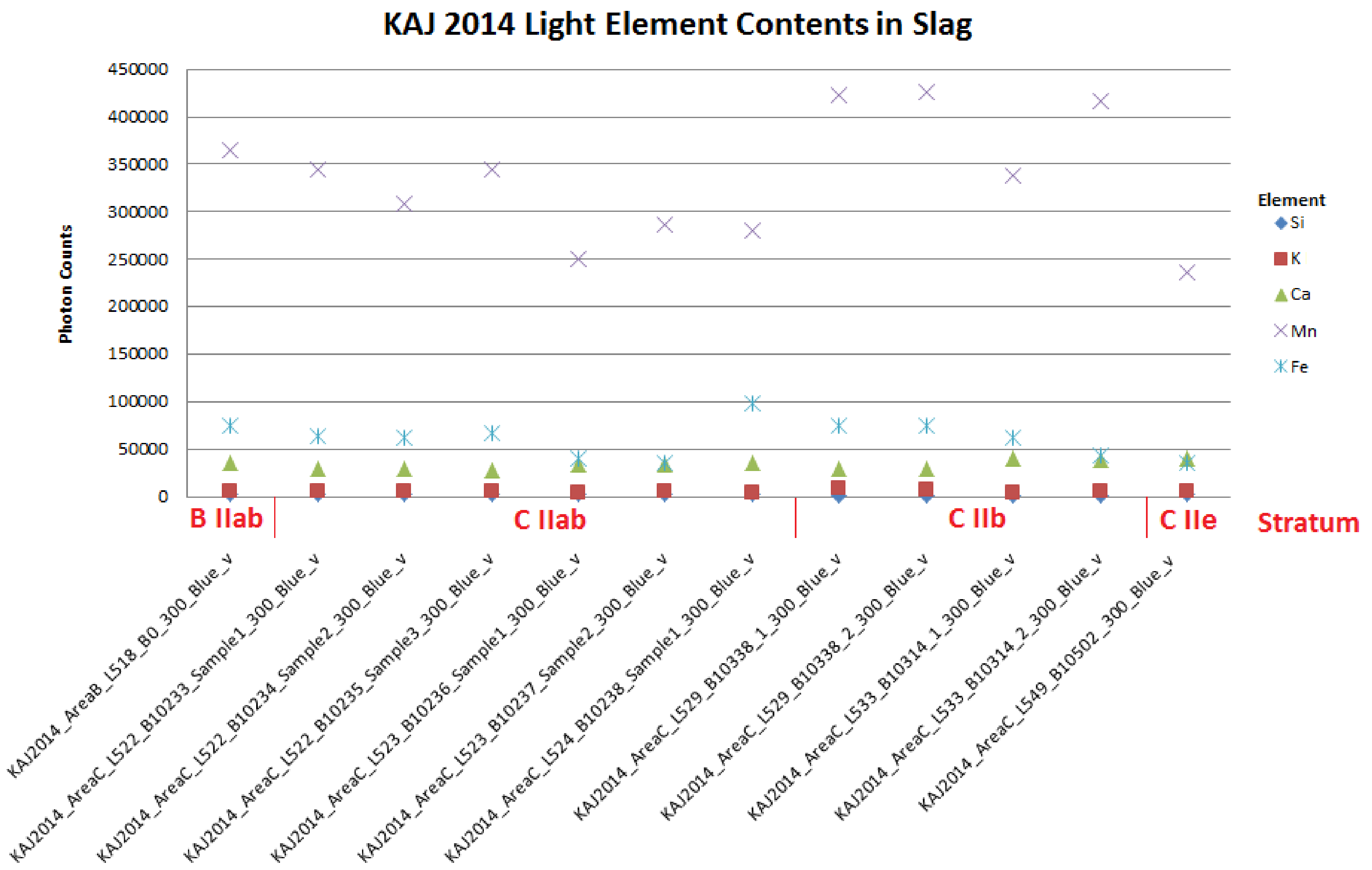
Figure 17: The spectra produced by the XRF instrument and Bruker software when analyzing a KAJ slag sample.

Figure 18: Tap slag samples collected from Area C slag mound probe Stratum C IIb (Photo by B.L. - UCSD Levantine and Cyber-Archaeology Lab).

Table 2: Table of XRF results for slag samples for KAJ 2014. The elements are color coded by the filter used to quantify their amounts. The letter and number beneath the element abbreviation is the electron shell activated during the measurement. All results are presented in photo counts.

Sample Name	Stratum	Description	Si K12	K K12	Ca K12	Mn K12	Fe K12	Ni K12	Cu K12	Zn K12	Pb L1
KAJ2014_AreaB_L518_Basin	B IIab	Bedrock basin	2127	6119	36374	364715	6761	181	8387	428	403
KAJ2014_AreaC_L522_B10233_Sample1	C IIab	Crushed slag mound	2150	6522	29340	345060	5564	114	7964	327	502
KAJ2014_AreaC_L522_B10234_Sample2	C IIab	Crushed slag mound	2190	5733	28964	307829	6503	160	10790	400	511
KAJ2014_AreaC_L522_B10235_Sample3	C IIab	Crushed slag mound	2062	5756	27689	343671	6746	182	9629	349	438
KAJ2014_AreaC_L523_B10236_Sample1	C IIab	Crushed slag mound	1900	5025	34716	250929	3808	174	16132	413	837
KAJ2014_AreaC_L523_B10237_Sample2	C IIab	Crushed slag mound	1959	5536	33986	286739	3183	162	11676	292	848
KAJ2014_AreaC_L524_B10238_Sample1	C IIab	Crushed slag mound	2002	4952	35531	279976	9606	120	9364	347	789
KAJ2014_AreaC_L529_B10338_1	C IIb	Slag mound probe	1798	8308	29113	423076	7355	167	3111	433	476
KAJ2014_AreaC_L529_B10338_2	C IIb	Slag mound probe	1620	7805	29572	425273	7405	174	3315	381	463
KAJ2014_AreaC_L533_B10314_1	C IIb	Slag mound probe	1637	5016	40489	338278	6099	146	950	131	105
KAJ2014_AreaC_L533_B10314_2	C IIb	Slag mound probe	1431	6040	38992	416815	4044	190	845	151	74
KAJ2014_AreaC_L549_B10502_Crushed	C IIe	Slag mound probe	2246	6281	40018	235851	3287	145	6798	321	588

Graph 1: Scatter plot of light element contents in slags for KAJ 2014.


KAJ 2014 Light Element Contents in Slag

Graph 2: Bar graph of copper content in slag samples from KAJ 2014.

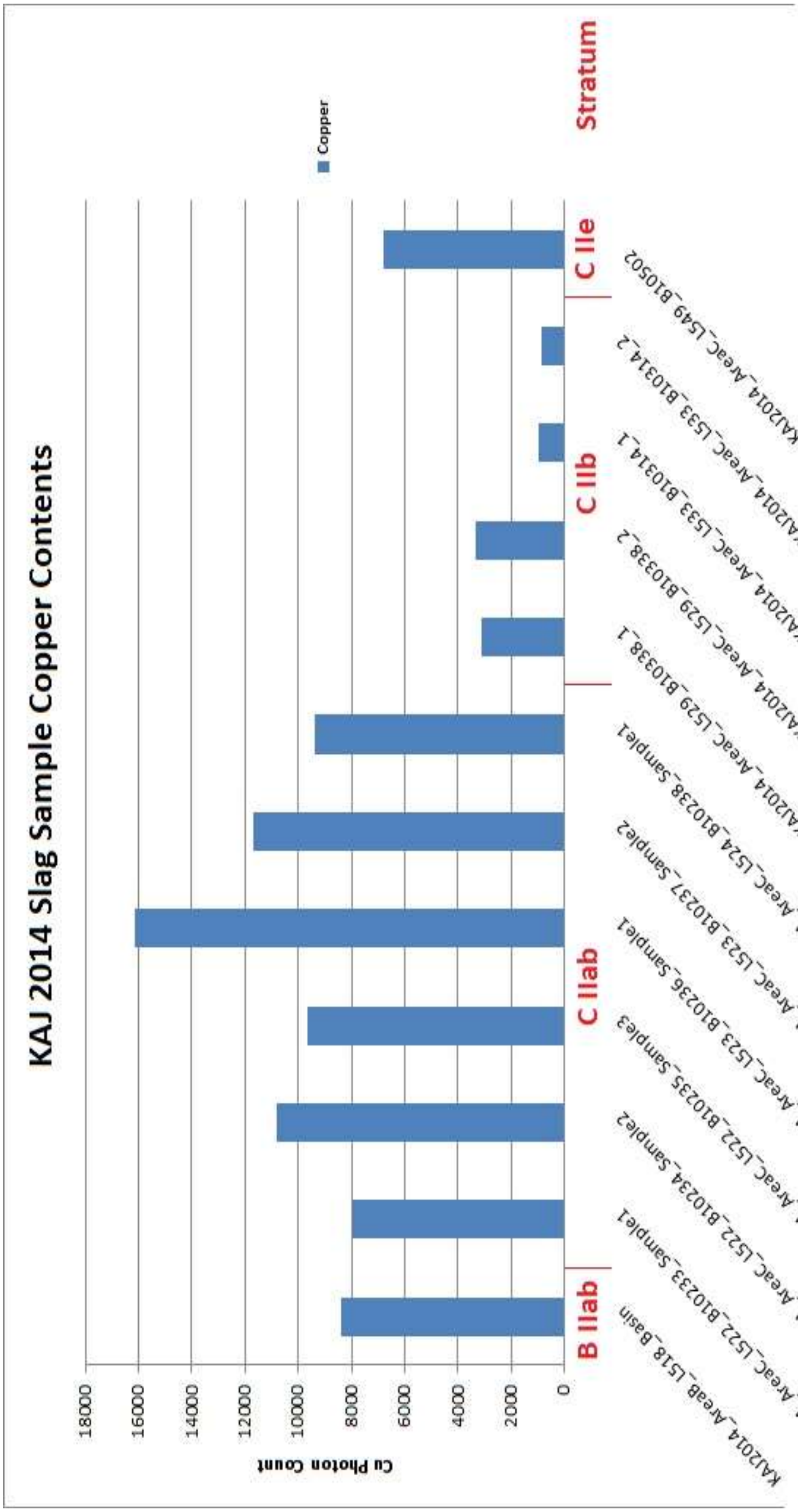
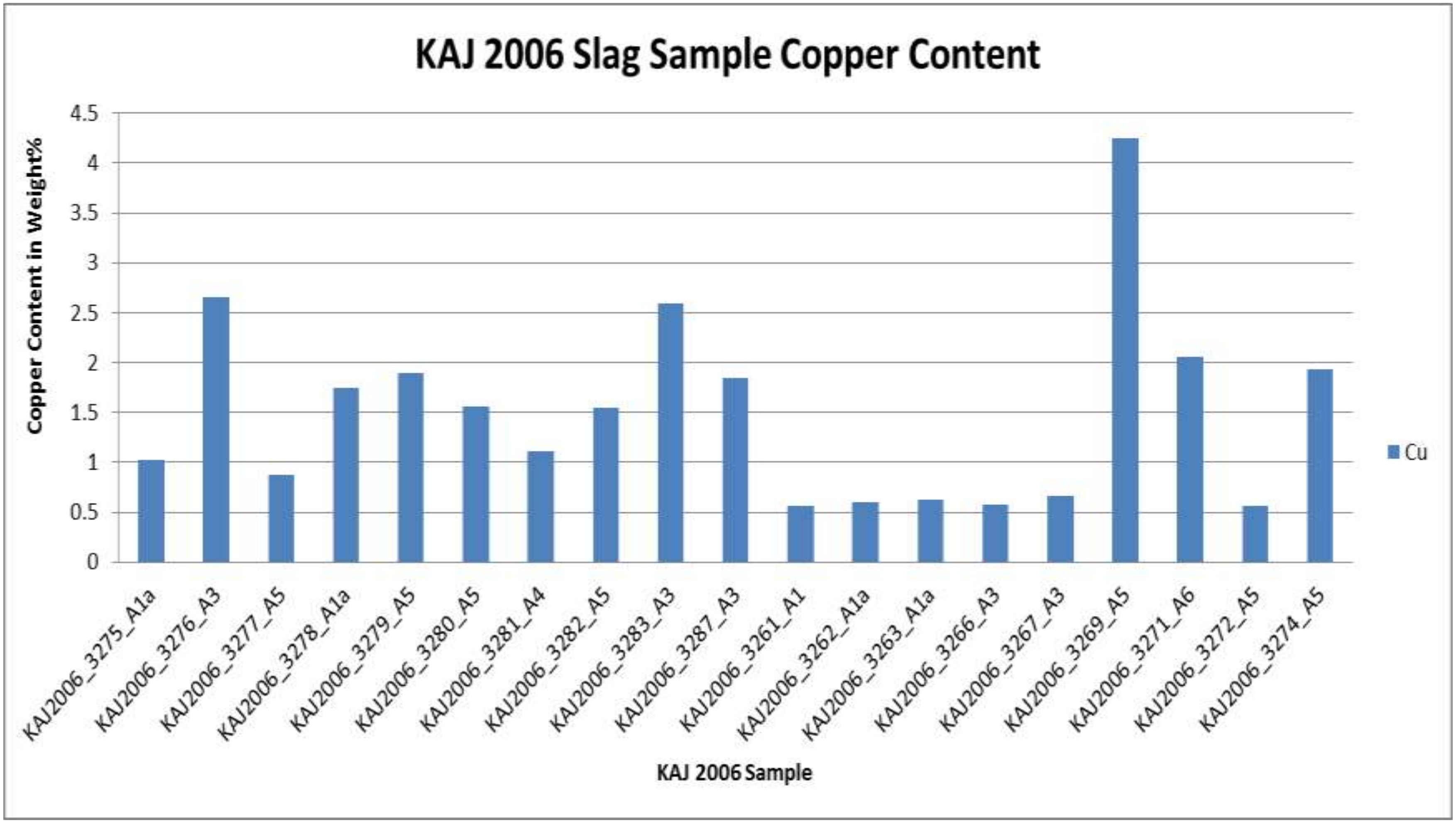

KAJ 2014 Slag Sample Copper Contents
Cu Photon Count
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
Copper
Stratum
B IIab
C IIab
C IIb
C IIe
KAJ2014_AreaB_L518_Basin
KAJ2014_AreaC_L522_B10233_Sample1
KAJ2014_AreaC_L522_B10234_Sample2
KAJ2014_AreaC_L522_B10235_Sample3
KAJ2014_AreaC_L523_B10236_Sample1
KAJ2014_AreaC_L523_B10237_Sample2
KAJ2014_AreaC_L524_B10238_Sample1
KAJ2014_AreaC_L529_B10338_1
KAJ2014_AreaC_L529_B10338_2
KAJ2014_AreaC_L533_B10314_1
KAJ2014_AreaC_L533_B10314_2
KAJ2014_AreaC_L549_B10502
Sample

Table 3: The XRF results from Ben-Yosef's (2010) slag analysis from the 2006 excavation season at KAJ. This table is recreated from Ben-Yosef 2010: 851, Table 2. The elemental contents are presented in Weight%.

Sample	**Stratum**	Si	K	Ca	Mn	Fe	Ni	Cu	Zn	Pb
KAJA_3275	A1a	34.89	2.90	10.86	28.81	2.00	0.08	1.02	0.04	0.04
KAJA_3276	A3	33.37	2.08	4.01	33.37	2.47	0.07	2.65	0.08	0.11
KAJA_3277	A5	33.17	4.44	8.46	38.99	2.13	0.09	0.87	0.04	0.05
KAJA_3278	A1a	34.45	2.14	8.59	21.23	2.12	0.08	1.74	0.06	0.06
KAJA_3279	A5	29.36	3.80	11.05	37.13	2.12	0.07	1.90	0.08	0.06
KAJA_3280	A5	32.52	3.93	10.51	32.99	1.44	0.07	1.56	0.05	0.03
KAJA_3281	A4	36.08	3.33	8.18	31.35	1.49	0.07	1.11	0.04	0.04
KAJA_3282	A5	35.4	3.71	9.08	29.19	2.22	0.08	1.54	0.07	0.08
KAJA_3283	A3	35.67	3.18	11.01	30.05	2.08	0.08	2.59	0.07	0.09
KAJA_3287	A3	31.97	3.58	11.6	21.06	2.20	0.07	1.85	0.06	0.06
KAJA_3261	A1	33.77	2.78	7.54	34.06	3.28	0.07	0.56	0.05	0.03
KAJA_3262	A1a	32.57	3.85	7.62	38.76	3.68	0.08	0.60	0.04	0.03
KAJA_3263	A1a	32.9	3.02	10.16	39.63	2.15	0.08	0.63	0.04	0.03
KAJA_3266	A3	29.44	3.66	11.63	29.38	4.31	0.07	0.58	0.04	0.03
KAJA_3267	A3	31.04	2.88	3.71	31.62	1.80	0.07	0.66	0.04	0.03
KAJA_3269	A5	34.67	3.31	3.85	35.12	4.32	0.06	4.25	0.12	0.24
KAJA_3271	A6	31.53	2.52	11.74	39.52	5.36	0.06	2.06	0.10	0.22
KAJA_3272	A5	33.9	3.19	13.05	28.91	1.46	0.08	0.56	0.03	0.07
KAJA_3274	A5	39.27	2.97	9.46	23.07	2.09	0.08	1.93	0.07	0.09

Graph 3: Bar graph of copper content in slags from the 2006 season. The data for this graph comes from Ben-Yosef 2010: 851, Table 8.7.


KAJ 2006 Slag Sample Copper Content
Copper Content in Weight%
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
KAJ2006_3275_A1a
KAJ2006_3276_A3
KAJ2006_3277_A5
KAJ2006_3278_A1a
KAJ2006_3279_A5
KAJ2006_3280_A5
KAJ2006_3281_A4
KAJ2006_3282_A5
KAJ2006_3283_A3
KAJ2006_3287_A3
KAJ2006_3261_A1
KAJ2006_3262_A1a
KAJ2006_3263_A1a
KAJ2006_3266_A3
KAJ2006_3267_A3
KAJ2006_3269_A5
KAJ2006_3271_A6
KAJ2006_3272_A5
KAJ2006_3274_A5
KAJ 2006 Sample
Cu

15. Works Cited

Al-Shorman, Ahmed H.
2009 *Refractory Ceramic Through the Ages: an Archaeometric Study on Finds from Fenan, Jordan and Other Sites.* Ph.D. dissertation, Ruhu-Universität Bochum, Bochum.

Amzallag, Nissim
2009 Yahweh, the Canaanite God of Metallurgy? *Journal of the Study of the Old Testament* 33 (4), 387-404.

Anfinset, Nils
1996 *Social and technological aspects of mining, smelting and casting copper. An ethnoarchaeological study from Nepal.*, University of Bergen,Bergen.

Barker, Graeme, David Gilbertson, and David Mattingly
2007 The Wadi Faynan Landscape Survey: research themes and project development, In *Archaeology and Desertification: The Wadi Faynan Landscape Survey, Southern Jordan*, edited by G. Barker, D. Gilbertson, and D. Mattingly, pp. 3-24.Oxbow Books, Oxford.

Ben-Yosef, Erez
2010 *Technology and Social Process: Oscillations in Iron Age Copper Production and Power in Southern Jordan.* Ph.D. dissertation, Department of Anthropology, University of California, San Diego, La Jolla.

Ben-Yosef, Erez and Thomas E. Levy
2014a A ‘Small Town’ Discovered Twice: A Forgotten Report of Major H. H. Kitchener. *Palestine Exploration Quarterly* 146(3): 179-184.

Ben-Yosef, Erez and Thomas E. Levy
2014b The Material Culture of Iron Age Copper Production in Faynan. In *New Insights into the Iron Age Archaeology of Edom, Southern Jordan*, edited by T. E. Levy, M. Najjar and E. Ben-Yosef, pp. 887-960. UCLA Cotsen Institute of Archaeology Press, Los Angeles.

Ben-Yosef, Erez, Mohommad Najjar, and Thomas E. Levy
2014 New Iron Age Excavations at Copper Production Sites, Mines, and Fortresses in Faynan. In *New Insights into the Iron Age Archaeology of Edom, Southern Jordan*, edited by T. E. Levy, M. Najjar and E. Ben-Yosef, pp. 767-886. UCLA Cotsen Institute of Archaeology Press, Los Angeles.

Ben-Yosef, Erez, Thomas E. Levy, Thomas Higham, Mohommad Najjar. and Lisa Tauxe.

2010 The beginning of Iron Age copper production in the southern Levant: new evidence from Khirbat al-Jariya, Faynan, Jordan. *Antiquity* 84 (325): 724-746.

Ben-Yosef, Erez, Lisa Tauxe, Thomas E. Levy, Ron Shaar, Hagai Ron, and Mohommad Najjar.
2009 Geomagnetic intensity spike recorded in high resolution slag deposit in southern Jordan. *Earth and Planetary Science Letters* 287: 529-39.

Ben-Yosef, Erez, Lisa Tauxe, Hagai Ron, Amotz Agnon, Uzi Avner, Mohammad Najjar, Thomas E. Levy
2008 A New Approach for Geomagnetic Archaeointensity Research: Insights on Ancient Metallurgy in the Southern Levant. *Journal of Archaeological Science* 35: 2863-2879.

Buck, Caitlin E., William G. Cavanagh, and Clifford D. Litton
1996 *Bayesian Approach to Interpreting Archaeological Data*. John Wiley & Sons, Chichester.

Finkelstein, Israel
2010 A Great United Monarchy? Archaeological and Historical Perspectives. In *One God - One Cult - One Nation: Archaeological and Biblical Perspective*, edited by R.G. Kratz and H. Spieckermann, pp. 3-28. De Gruyter, Berlin.

Finkelstein, Israel
2005a A Low Chronology Update: Archaeology, history and bible. In *The Bible and Radiocarbon Dating: Archaeology, Text and Science*, edited by T. E. Levy and T. Higham, pp. 31-42. Equinox, Oakville.

Finkelstein, Israel
2005b Khirbet en-Nahas, Edom and Biblical History. *Tel Aviv* 32:119-125.

Gidding, Aaron, Yuma Matsui, Thomas E. Levy, Thomas DeFanti, and Falko Kuester
2013 ArchaeoSTOR: A Data Curation System for Research on the Archaeological Frontier. *Future Generation Computer Systems* 29: 2117- 2127.

Glueck, Nelson
1940 *The Other Side of the Jordan*. American Schools of Oriental Research, New Haven.

Glueck, Nelson
1935 Explorations in Eastern Palestine, II. *Annual of the American Schools of Oriental Research* 15: 1-288.

Glueck, Nelson

1934 Explorations in Eastern Palestine and the Negeb. *Bulletin of the American Schools of Oriental Research* 55: 3-21.

Hauptmann, Andreas
2007 *The Archaeometallurgy of Copper: Evidence from Faynan, Jordan*. Springer, Berlin.

Hauptmann, Andreas
2000 *Zur frühen Metallurgie des Kupfers in Fenan/Jordanien*. Der Anschnitt, Bochum, Germany.

Kaiser, Bruce
2010 Draft of Bruker XRF spectroscopy user guide: spectral interpretation and sources of interference: Bruker AXS.

Kassianidou, Vasiliki
2014 Cypriot copper for the Iron Age world of the Eastern Mediterranean. In *Structure, Measurement and Meaning: Insights into the Prehistory of Cyprus. Studies on Prehistoric Cyprus in Honour of David Frankel*, Edited by J.M. Webb, pp. 261-271. Åström Editions, Uppsala

Kitchener, Horatio H.
1884 Major Kitchener's Report. *Palestine Exploration Quarterly* 16: 202-221.

Knabb, Kyle, Ian W.N. Jones, Mohammad Najjar, and Thomas Levy
2014 Patterns of Iron Age Mining and Settlement in Jordan's Faynan District: The Wadi al-Jariya survey in Context. In *New Insights into the Iron Age Archaeology of Edom, Southern Jordan*, edited by T. E. Levy, M. Najjar and E. Ben-Yosef, pp. 577-625. UCLA Cotsen Institute of Archaeology Press, Los Angeles.

LaBianca, O. S. and Randall W. Younker
1995 The Kingdoms of Ammon, Moab and Edom: The Archaeology of Society in Late Bronze/Iron Age Transjordan (ca. 1400 - 500 BCE). In *The Archaeology of Society in the Holy Land*, edited by T.E. Levy, pp. 399-415. Leicester University Press, London.

Lemonnier, Pierre
1992 *Elements for an Anthropology of Technology*. The University of Michigan Museum of Anthropology, Ann Arbor.

Lemonnier, Pierre
1989 Bark capes, arrowheads, and Concorde: on social representations of technology. In *The Meaning if Things: Material Culture and Symbolic Expression*, Edite by I. Hodder, pp. 156-171. Unwin Hyman. Boston.

Lemonnier, Pierre
1986 The study of material culture today: toward an anthropology of technical systems. *Journal of Anthropological Archaeology* 5: 147-186.

Leroi-Gourhan, André
1993 [1964] *Gesture and Speech*. Translated by Anna B. Berger. MIT Press, Cambridge.

Levy, Thomas E.
2013 Cyber-Archaeology and World Cultural Heritage: Insights from the Holy Land. *Bulletin of the American Academy of Arts & Sciences* LXVI: 26-33.

Levy, Thomas E.
2008 "You Shall Make for Yourself No Molten Gods": Some Thoughts on Archaeology and Edomite Ethnic Identity. In *Sacred History, Sacred Literature: Essays on Ancient Israel, the Bible, and Religion in Honor of R. E. Friedman on His Sixtieth Birthday*. Edited by S. Dolanksy, pp.239-255. Eisenbrauns, Winona Lake.

Levy, Thomas E., Erez Ben-Yosef and Mohommad Najjar
2014a The Iron Age Edom Lowlands Regional Archaeology Project: Research, Design, and Methodology. In *New Insights into the Iron Age Archaeology of Edom, Southern Jordan*, edited by T. E. Levy, M. Najjar and E. Ben-Yosef, pp. 1-87. UCLA Cotsen Institute of Archaeology Press, Los Angeles.

Levy, Thomas E., Erez Ben-Yosef and Mohommad Najjar
2014b *New Insights into the Iron Age Archaeology of Edom, Southern Jordan*. UCLA Cotsen Institute of Archaeology Press, Los Angeles.

Levy, Thomas E., Mohammad Najjar, Thomas Higham, Yoav Arbel, Adolfo Muniz, Erez Ben-Yosef, Neil G. Smith, Marc Beherec, Aaron Gidding, Ian W. Jones, Daniel Frese, Craig Smitheram, and Mark Robinson
2014c Excavations at Khirbat en-Nahas, 2002-2009: An Iron Age Copper Production Center in the Lowlands of Edom. In *New Insights into the Iron Age Archaeology of Edom, Southern Jordan*, edited by T. E. Levy, M. Najjar and E. Ben-Yosef, pp. 89-245. UCLA Cotsen Institute of Archaeology Press, Los Angeles.

Levy, Thomas E., Stefan Münger, and Mohammad Najjar
2014d A newly discovered scarab of Sheshonq I: recent Iron Age explorations in southern Jordan. *Antiquity*: on-line http://journal.antiquity.ac.uk/projgall/levy341.

Levy, Thomas E. Erez Ben-Yosef, and Mohammad Najjar
2012 New perspectives on Iron Age copper production and society in the Faynan Region, Jordan. In *Eastern Mediterranean Metallurgy and Metal Work in the*

Second Millennium BC: A conference in honour of James D. Muhly, edited by V. Kassianidou and G.Papasavvas, pp. 197-214. Oxbow, Oxford.

Levy, Thomas E., Vid Petrovic, Thomas Wypych, Aaron Gidding, Kyle Knabb, David Hernandez, Neil G. Smith, Jürgen P. Schulz, Stephen H. Savage, Falko Kuester, Erez Ben-Yosef, Connor Buitenhuys, Casey Jane Barrett, and Thomas DeFanti
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. In *Cyber-Archaeology Today*, edited by M. Forte, pp. 135-153. Archaeopress, Oxford.

Levy, Thomas E., Thomas Higham, Christopher Bronk Ramsey, Neil G. Smith, Erez Ben-Yosef, Mark Robinson, Stefan Munger, Kyle Knabb, Jürgen P. Schulze, Mohommad Najjar and Lisa Tauxe.
2008 High-precision radiocarbon dating and historical biblical archaeology in southern Jordan. *Proceedings of the National Academy of Science* 105: 16460-16465.

Levy, Thomas E. and Neil G. Smith
2007 On-Site GIS digital Archaeology: GIS-based Excavation Recording in Southern Jordan. In *Crossing Jordan: North American Contributions to the Archaeology of Jordan,* edited by T.E. Levy, P.M. Michèle Daviau, R.W. Younker, and M. Shaer, pp. 47-58. Equinox, London.

Levy, Thomas E. and Thomas Higham
2005 *The Bible and Radiocarbon Dating – Archaeology, Text and Science*. Equinox, London.

Levy, Thomas E., Russell B. Adams, Mohammad Najjar, Andreas Hauptmann, James D. Anderson, Baruch Brandl, Mark A. Robinson, and Thomas Higham
2004 Reassessing the chronology of Biblical Edom: new excavations a 14C dates from Khirbat en-Nahas (Jordan). *Antiquity* 78: 865–879.

Levy, Thomas E., Russell B. Adams, James D. Anderson, Mohammad Najjar, Neil Smith, Yoav Arbel, Lisa Soderbaum, and Adolfo Muniz
2003 An Iron Age Landscape in the Edomite Lowlands: Archaeological Surveys along Wadi al-Ghuwayb and Wadi al-Jariya, Jabal Hamrat Fidan, Jorda, 2002. *Annual of the Department of Antiquities of Jordan* 47: 247-277.

Levy, Thomas E., Russel B. Adams and Mohommad Najjar
2001 Jabal Hamrat Fidan. *American Journal of Archaeology* 105:442-443.

Levy, Thomas E., Russell B. Adams and Rula Shafiq
1999 The Jabal Hamrat Fidan Project: Excavations at the Wadi Fidan 40 Cemetery, Jordan. *Levant* 31: 293-308.

MacDonald, Burton

1992 *The Southern Ghors and Northeaast ‘Arabah Archaeological Survey.* J.R. Collis Publications, Sheffield.

MacDonald, Burton, Larry G. Herr, Michael P. Neely, Khaled Moumani, and Marcy Rockman

2004 *The Tafila-Busayra Archaeological Survey 1999-2001, West-Central Jordan*. American Schools of Oriental Research, Boston.

Martin, Mario A.S. and Israel Finkelstein

2013 Iron IIA Pottery from the Negev Highlands: Petrographic Investigation and Historical Implications. *Tel Aviv* 40: 6-45.

Martin, Mario A.S., Adi Eliyahu-Behar, Michael Anenburg, Yuval Goren, and Israel Finkelstein

2013 Iron IIA slag-tempered pottery in the Negev Highlands, Israel. *Journal of Archaeological Science* 40:3777-3792.

Mauss, Marcel

1979 [1950] *Sociology and Psychology: Essays*. Translated by Ben Brewster. Routledge & Kegan Paul, London

Mazar, Amihai

2005 The Debate over the Chronology of the Iron Age in the Southern Levant: Its history, the current situation, and a suggested resolution. In *The Bible and Radiocarbon Dating: Archaeology, Text and Science*, edited by T. E. Levy and T. Higham, pp. 15-30. Equinox, Oakville.

McNutt, Paula

1990 *The Forging of Israel: Iron Technology, Symbolism and Tradition in Ancient Society*. Almond Press, Sheffield.

Muhly, James D.

1987 Solomon, the Copper King: A Twentieth Century Myth. *Expedition* 29(2):38-47.

Munger, S. and Thomas E. Levy

2014 The Iron Age Egyptian Amulet Assemblage. In *New Insights into the Iron Age Archaeology of Edom, Southern Jordan*, edited by T.E. Levy, M. Najjar, and E. Ben-Yosef, pp. 740-465. UCLA Cotsen Institute of Archaeology Press, Los Angles.

Musil, Alois

1908 *Arabia Petraea II. Edom: Topograhischere Reisebericht*. Alfred Hölder, Vienna.

Rabba', Ibrahim

1991 *The Geology of the Al Qurayqira (Jabal Hamra Faddan) Map Sheet No. 3051 II.* Amman: Geology Directorate Geological Mapping Division Bulletin 28.

Rothenberg, Beno

1972 *Were These King Solomon's Mines? Excavations in the Timna Valley*. Stein and Day, New York.

Shaar, Ron, Hagai Ron, Lisa Tauxe, Ronit Kessel, Amotz Agnon, Erez Ben-Yosef, and Joshua M. Feinberg

2010 Testing the accuracy of absolute intensity estimates of the ancient geomagnetic field using copper slag material. *Earth and Planetary Science Letters* 209:201-213.

Smith, Neil G. and Thomas E. Levy

2012 Real-time 3D Archaeological Field Recording: ArchField, an Open-source GIS System Pioneered in Jordan. Antiquity 85(331):on-line http://antiquity.ac.uk/projgall/smith331/.

Tylecote, R.F.

1992 *A History of Metallurgy (Second Edition)*. Maney, London.

Yahalom-Mack, Naama, Ehud Galili, Irina Sgal, Adi Eliyahu-Behar, Elisabetta Boaretto, Sana Shilstein, and Israel Finkelstein

2014 New insights into Levantine copper trade: analysis of ingots from the Bronze and Iron Ages in Israel. *Journal of Archaeological Science* 45:159-177.