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Iron Age Nomads and their relation to copper smelting in Faynan (Jordan): Trace metal and Pb and Sr isotopic measurements from the Wadi Fidan 40 cemetery

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ABSTRACT

The Faynan region in southern Jordan is the largest copper ore resource zone in the southern Levant and was exploited for these ores beginning ca. 8000 years BP. We discuss the relationship between nomadic populations and major copper smelting sites during the Iron Age (ca. 1200–500 BCE) based on mortuary excavations and toxic metal analyses at the Wadi Fidan 40 cemetery, the largest Iron Age mortuary complex in southern Jordan. The Iron Age represents the first industrial revolution in this part of the Middle East. The study presented here is the first to employ chemical and isotopic measurements from a systematically excavated Iron Age mortuary population to determine exposure to Cu and Pb pollution and mobility patterns (based on Sr isotopes). We describe a methodology to control for post-depositional diagenetic uptake of chemical elements in human teeth recovered from the cemetery that has not previously been applied in Faynan in ancient pollution studies. The results suggest that most of the excess of Pb and Cu measured in tooth enamel samples were a product of post-depositional diagenetic addition. Our findings suggest that the majority of people buried at the Wadi Fidan 40 cemetery were not exposed to metal pollution during their lives. The few individuals who were exposed to metal pollution exhibited a spectrum of traits indicative of lifestyle and social status. The results bring into question how severe the ancient pollution impacted the lives of the Iron Age population living in Faynan.

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1. Introduction

The Faynan copper ore region in southern Jordan is the largest such resource zone in the southern Levant (i.e. Jordan, Israel, Palestinian territories, Lebanon, southern Syria and the Sinai Peninsula). The ca. 400 km² area was exploited for lead-rich copper ore used in jewelry and decorative pigment during the Pre-Pottery Neolithic B period, ca. 10,500–8250 BP (Kuijt and Goring-Morris, 2002). Widespread mining and smelting took place in the region from the Early Bronze Age I (ca. 3600 BCE) to Medieval Islamic times (ca. 1400 CE) (Hauptmann, 2007; Levy and Najjar, 2007).

During this long period of time, the peak in copper production

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occurred during the Iron Age, specifically in the 10th and 9th centuries BCE, when the first industrial revolution occurred in this part of the Middle East. Previous research by Hauptmann (2007, Table 5.3, p. 147) showed that there was an exponential increase in the amount of copper slag (and hence, copper metal) produced during the Iron Age, compared to the preceding Early Bronze Age and post-Iron Age), based on the amounts of slag recorded on the surface at copper production sites throughout the Faynan region. Thus, during the Early Bronze I period the total estimate is 2 kg, and in the Early Bronze II period the estimated amount of slag rises to 5000 tons. During the Iron Age the quantity of slag ranges from 100,000 to 130,000 tons of slag. Based on these data, it is possible to characterize the astronomical rise in Iron Age slag as indicative of the first industrial revolution in the southern Levant. Additional data for this exponential rise in smelting activities has been recently obtained through the first stratigraphic excavations of copper production sites in the Faynan regions, most importantly at

the site of Khirbat en-Nahas, a ca. 10 ha production swathed in widespread mounds of copper smelting waste (Levy et al., 2008; Levy et al., 2014a), as well as Khirbat al-Jariya (Ben-Yosef et al. 2010), and other sites in Wadi Faynan (Grattan et al., 2007; Hunt and El-Rishi, 2010 Figs. 8.9 and 8.10, p.130–31, Mattingly et al., 2007). The tight stratigraphic control from the excavations at Khirbat en-Nahas, coupled with the application of high precision radiocarbon dating and Bayesian analyses (Levy et al., 2008) made it possible to obtain sub-century precision to monitor technological change from the 13th to the 9th century BCE at what is perhaps the largest Iron Age copper smelting center in the southeastern Mediterranean (Levy et al., 2012; Levy et al., 2014b). Excavations at Khirbat en-Nahas were carried out as part of the Edom Lowlands Regional Archaeology Project (ELRAP). As part of the surveys and excavations conducted for ELRAP, beginning in 1997, large-scale

excavations were initiated at the site of Wadi Fidan 40 (30.673926N, 35.381107E) near the mouth of Wadi Fidan where it debouches into the Arabah valley that separates modern Jordan and Israel (Fig. 1). Excavations were carried out in 1997, 2003, 2004, and 2009, and revealed a mortuary site utilized by pastoral nomads during the Iron Age II, ca. 10th and 9th centuries BCE (Beherec, 2011; Beherec et al., 2014; Levy et al., 2004a; Levy et al., 1999, 2005). Building on the results of this previous research, this study examines the relationship between nomadic populations and smelting sites evidenced by isotopic and chemical analyses.

As a result of those projects, the ELRAP team discovered and excavated the largest (ca. 3,450 m²) Iron Age mortuary complex in southern Jordan (Fig. 2). High precision radiocarbon dating places the cemetery securely in the Iron Age IIA period. A total of 245 cist graves, as well as other mortuary features, were excavated. The

Fig. 1. Overview map of Iron Age Faynan, Jordan.

Fig. 2. Overview photo of WFD 40 cemetery (Photo – T.E. Levy, UC San Diego Levantine and Cyber-Archaeology Laboratory).

nature of the burial structures and grave goods, coupled with the isolated location of the Wadi Fidan 40 cemetery reflects a mortuary complex that belonged to a nomadic population. These characteristics make the Wadi Fidan 40 cemetery different from other Iron Age cemeteries in the Mediterranean zones of the southern Levant which are found close to settlement sites (Bloch-Smith, 1992; Faust, 2004). Unlike a number of cemeteries in the Wadi Arabah (see for example, the Early Bronze cemetery at Bab edh-Dhrah, Ortner and Fröhlich, 2008), Wadi Fidan 40 is notable for the lack of ceramic grave goods and the presence of wooden bowls (Levy, 2009; Levy et al., 1999, 2005). In addition, tumuli in the desert zones of the southern Levant are primarily linked to nomadic communities and these are part of the Iron Age burial patterns in the Wadi Fidan area (Beherec et al., 2014; Bloch-Smith, 2003). And finally, based on contemporary ancient Egyptian records that span the 15th to 10th century BCE, there were nomadic people who lived in Edom at this time that the Egyptians referred to as Shasu nomads, who were West-Semitic speaking nomads from the southern Levant during the Late Bronze Age and Early Bronze Age (Levy et al., 2004a; Levy et al., 1999). Consequently, ELRAP researchers link the buried population in the Wadi Fidan 40 cemetery with the Shasu nomads (Beherec et al., 2014; Levy et al., 2005). Although the ancient Egyptians referred to these nomads as ‘Shasu’, researchers still do not know what these people called themselves. While there exists a wide range of types of nomadism in the Middle East (Khazanov 1994), our excavations point to the presence of a nomadic population, though much about the exact nature of that occupation remains to be explored.

Of key interest is the relationship of the nomadic populations from Wadi Fidan 40 and the different Iron Age smelting sites in Faynan such as Khirbat en-Nahas (Levy and Najjar, 2006; Levy et al., 2014b), Khirbat al-Jariya (Ben-Yosef et al., 2010), and Khirbat al-Guwayba (Ben-Yosef et al., 2013). This is especially intriguing because each of these sites has widespread evidence not only of smelting, but architecture – one of the attributes rarely linked to nomadic populations. These production sites are located more than 6 km from the cemetery. For example, during the 10th c. BCE at Khirbat en-Nahas, the site included one of the largest Iron Age fortresses in the deserts of the southern Levant, monumental buildings, and specialist craft buildings. No evidence of permanent habitation was found during the ELRAP excavations at the site, but small tent-camps and other ephemeral sites dating to the Iron Age were found in the neighboring Wadi al-Jariya that suggests short-term habitation by nomads (Knabb et al., 2014). Hauptmann

(Hauptmann, 2007, 127) estimates some 50,000 to 60,000 tons of industrial slag that accumulated on the surface of Khirbat en-Nahas that surrounds more than 100 building complexes on the site (Levy et al., 2004b). The study presented here is the first to employ chemical and isotopic measurements from a systematically excavated Iron Age mortuary population to determine exposure to Cu and Pb pollution, and mobility patterns based on Strontium (Sr) isotope analysis. A central question when working with late 2nd – early 1st millennia BCE archaeological data in the desert zones of the Middle East focuses on the nature of subsistence and settlement in these marginal environments. Sr isotopes offer an important proxy for identifying the movement of people over the landscape throughout the world (Bentley, 2006; Gibling et al., 2013). In our research area, Perry et al. (2011) apply Sr and O isotope analysis to human dentin recovered from 4th–6th century CE individuals interred in the Faynan South Cemetery. Their results suggest that all but one of the individuals tested were local to the Faynan region.

Based on the strong evidence for significant copper ore mining spanning the Pre-Pottery Neolithic through Medieval Islamic periods, previous studies in Wadi Faynan have suggested that significant human and environmental pollution occurred as a result. During the Iron Age there is evidence for large-scale global pollution (e.g., Hong et al., 1994; Shoty et al., 1998), and the study presented here contributes to our understanding of this phenomenon in the Faynan region of the southern Levant. In Wadi Faynan specifically, a number of recent studies have demonstrated the effects of ancient metal production on levels of pollution in humans living in this area, both in ancient and in contemporary populations (Barker et al., 2007; Grattan et al., 2007, 2013; Hunt and El-Rishi, 2010; Pyatt et al. 2005a, 2002; Pyatt and Grattan, 2001). These studies were conducted by analyzing a variety of materials, including geological sediment, plant and animal matter, invertebrates, and human remains. Overall, the authors report that there is a significant metal-pollution in sediments near Khirbet Faynan, and argue that this metal-pollution was caused by the mining and smelting activities in Wadi Faynan and surrounding tributaries. The current study focuses on the Iron Age period because of the evidence for large-scale metal pollution at the global and local level at around 3000 BP (Grattan et al., 2007; Hong et al., 1994; Hunt and El-Rishi, 2010; Shoty et al., 1998), and because the Wadi Fidan 40 cemetery, which contains graves of more than 200 individuals buried in the Faynan copper ore resource zone that extends over an area of ca. 400 sq km. Thus, the relationship of this population to Iron Age mining, including exposure to pollution and mobility patterns, are of great interest to the study of ancient mining and metallurgy in the eastern Mediterranean.

In archaeological contexts, controlling for post-depositional contamination of human remains (i.e. diagenetic uptake), is an important aspect of studies involving trace element analysis. Previous studies have shown that comparisons of measurements of soil surrounding bone, as well as the interior and exterior of long bones (cf. Grattan et al., 2005) are an insufficient control for measuring diagenetic uptake (Pike and Richards, 2002). In this study, we present a method to control for post-depositional diagenetic uptake of trace elements versus the bioaccumulation of these elements during the lifespans of the individuals interred at the cemetery. Once it is established that measurements are the result of bioaccumulation rather than diagenetic contamination, we discuss the implications of these results for understanding the relationship of the nomadic population buried at Wadi Fidan 40 to local mining activities, as well as Iron Age mobility patterns in the Arabah valley.

2. Materials and methods

2.1. Grave samples used in study

A cross-section of human remains from the Wadi Fidan 40 cemetery were sampled in this ancient pollution study, in regard to age, sex, and social status as indicated by mortuary architecture and grave goods (Table 1). Tooth samples were selected primarily on the basis of preservation. However, preservation favored complete burials in cists; therefore, more of these were sampled than secondary burials or burials outside of cists. To date, with a sample of 36 individuals (which passed the screening protocol outlined below), this is the largest Iron Age population subjected to an ancient pollution study.

2.2. Chemical and isotopic measurements

The concentrations of toxic metals (e.g., Pb, Ag, and Cu), diagenetic control elements (Ba, Rb, Sr), and major elements (Ca, Mg, Al, Fe, Na, K) and Pb and Sr isotopes in teeth of the people buried in Wadi Fidan 40, Khirbat Faynan, in soils and sediments from their vicinities, and in production slags were measured. To constrain the dating of the samples used in this study, we relied on ^{14}C data obtained in previous studies (Beherec et al., 2014; Levy et al., 2005).

The methodology used in the current study attempts to address all the concerns about the pitfalls of measurements of metals in bones and teeth. Firstly, we took apart the tooth samples and separately analyzed tooth enamel – a tissue considered least likely to be affected by diffusion of external compounds (Patterson et al., 1991), and tooth dentin. We inspected the integrity of the samples

Table 1
Graves Sampled for this Study.^a

Grave	Sex	Age	Position/architecture/grave goods
9	M	Adult	Extended, on back, facing upright in cist. No artifacts recovered. 1 molar, 2 premolars, 1 incisor
17A/B	Unknown	A: Adult; B: Adolescent	A: Fragmentary in cist; B: Semi-flexed, on back facing up in cist. In backfill: 6 ostrich eggshell beads. 3 molars.
22	Male	Adult	Semi-flexed in cist. Wooden bowl, seeds, textile and leather shroud, 1 bead (ostrich eggshell). In backfill: 63 beads in fill and looter's backdirt (ostrich eggshell, dentalium, cupric, carnelian). 2 incisors & 1 premolar
23	Unknown	Adolescent	Semi-flexed in cist. Pomegranates, textile and leather shroud, 1 bead (carnelian). In backfill: 2 beads (carnelian, univalve shell). 3 incisors.
25i/ii	Unknown	Adult	Looted in antiquity; possible semi-flexed burial, two individuals identified in this cist grave. 5 tubular shell beads, pierced bivalve shell, and textile. i: 2 molars & 3 premolars. ii: 1 2molar & 3 premolars.
35B	Unknown	Adult	Secondary burial in cist. 2 beads (ostrich eggshell). 3 incisors & 1 molar.
38A	Male	Adult	Extended burial in cist. Shroud fragments. Looted in antiquity. 3 molars.
43	Female	Adult	Extended burial in cist. 3 beads (flint, ostrich eggshell, shell). 2 beads in backfill (aventurine, flint). 3 molars.
71	Unknown	Young Adolescent	Semi-flexed burial, head to south, on left side facing west. No artifacts recovered. Unidentified teeth
92	Female	Mature adult	Extended burial in cist. 1 scarab, pomegranates, 1 wooden bowl, 2 copper anklets, 1 iron bracelet, 38 beads (glass, agate, calcite, carnelian, cowry, univalve, shell). 1 molar, 2 premolars & 2 incisors.
24	Unknown	Adult	Looted in antiquity; fragmentary in cist. 2–3 beads (cupric). 1 molar.
31A	Unknown	Unknown	Secondary in cist. 2 beads (shell, ostrich eggshell). 4 molars & 2 premolars.
33	Female	Mature adult	Semi-flexed in cist. Wooden bowl, 5 beads (amazonite). 1 bead in backfill (ostrich eggshell). 1 molar & 1 premolar.
35	Unknown	Infant	Flexed in cist. 6 beads (ostrich eggshell). Unidentified teeth.
39	Unknown	Infant	Semi-flexed in cist. 1 bead (ostrich eggshell). Mother of pearl, partially perforated stone, 19 beads (ostrich eggshell, agattype carnelian) in backfill. 1 molar & 1 incisor.
56	Female	Adult	Semi-flexed in partially stone-lined pit. No artifacts. 3 molars, 1 incisor(?), & 1 premolar(?)
58	Unknown	Unknown	Looted in antiquity. In cist. Fragmentary, disturbed. No artifacts. 1 molar.
59	Male	24–34	Extended in cist. Wooden vessel containing pomegranates, worked wood, leather and textile shrouds. 1 molar & 1 premolar.
67	Unknown	Adult	Flexed, head to south, on left side facing west. In cist: 12 beads (agate, amazonite). In fill: Mother of pearl, flint scraper, shell bracelet fragment, 20 beads (amazonite, alabaster, agate, flint). 1 molar, 1 premolar.
74	Unknown	Adult	Secondary in cist. No artifacts. 2 molars.
75	Male	Adult	In cist. No artifacts. 1 molar & 1 premolar.
94	Male	Adult	Semi-flexed, head to south, on left side facing west. In cist: 172 beads (onyx, citrine, ostrich eggshell). In fill and secondary burial: 51 beads (ostrich eggshell, shell), 7 beads associated with secondary above capstones (ostrich eggshell, amazonite, cupric, carnelian). Unidentified teeth.
107/101	Unknown	Adult	Looted in antiquity. Fragmentary in cist. 6 beads (ostrich eggshell, amazonite); 1 bead in fill (ostrich eggshell). 2 molars.
217	Unknown	Adult	Flexed, head to south, on left side facing west. In cist: vegetal mat/textile, In fill: 1 bead (amazonite). 3 molars.
246	Unknown	Unknown	Looted in antiquity; fragmentary in cist. 26 beads (amazonite, carnelian, agate). 2 beads in fill (ostrich eggshell, amazonite). 3 molars.
263	Unknown	Unknown	Looted in antiquity. Fragmentary in cist. 76 beads in fill (flint). 1 molar.
336	Unknown	Adolescent	Semi-flexed, head to south, facing west. In cist: 2 beads (cupric, shell), 1 pottery sherd. 5 molars
345	Unknown	infant	Semi-flexed in cist. Ceramic bowl, 2 copper earrings, 22 beads (fine-grained grey stone, pearl, cowry, univalve shells, shell, ostrich eggshell). 1 unerupted molar, 1 molar, & 1 premolar.
356A	Male	18–22 years	Semi-flexed in cist. Leather shroud, copper metal. 3 molars
361	Unknown	infant	Looted in antiquity. Semi-flexed in cist. No artifacts. 4 unerupted molars.
371	Unknown	6 to 8 years	Semi-flexed in cist. Copper bracelet, three copper earrings, copper spiral pendant, leather and textile shroud fragments. 16 beads (ostrich eggshell) in fill. 2 molars.
540	Male	25 to 29 years	Semi-flexed in cist. Grinding slab, mother of pearl in fill. 3 premolars.
713	Probably male	20 to 30 years	Semi-flexed in stone-covered pit. 1 marine shell fragment. 4 molars.
714A	Male	26 to 70 years	Semi-flexed in cist. 2 beads (amazonite, carnelian), wood fragments. 1 bead (amazonite) in fill. 2 molars & 1 premolar.
724A/B	A: Male; B: Female	Both Adults	Fragmentary, disturbed due to looting. In fill: 1 bead (flint). 2 molars, 1 premolar.
2009	Male	Adult	Semi-flexed in stone-covered pit. 1 flint hammerstone in fill. 2 molars, 1 premolar & 1 incisor.

^a Preliminary identification of age, sex and minimum number of individuals from the Wadi Fidan 40 cemetery are found in Levy et al. (1999, 2005). Sample 2009 was identified by Melanie Beasley, UCSD Levantine Archaeology Osteology Lab.

using fluorescence and spectral microscopy & confocal microscopy systems (Nikon Eclipse TE2000-U; excitation: 488 nm, emission: 515 nm). These techniques allowed us to verify the complete separation of dentin from enamel. This is based on differences in their fluorescence intensities (which in turn reflect the amount of organic matter imbedded in them). Following microscopy inspection, tooth samples that were found suitable for analysis were treated using the methodology of Patterson and co-workers (Ericson et al., 1979; Manea-Krichtchen et al., 1991; Patterson et al., 1991), which involved several steps of sample pre-cleaning and the use of clean laboratory techniques and reagents. Where possible we compared two-three tooth samples from the same person (also to illustrate the expected variation within individuals). We used Ca concentrations in dentin and enamel of the same tooth to test the preservation of the tooth apatite. This is based on the fact that we know from the medical literature (Priest and Van De Vyver, 1990) what are the expected concentrations of Ca. We excluded any samples which had large deviations from the expected concentrations. Then, we used Ca in order to normalize for trace metal contamination. This was done by using TM/Ca mole ratio. All tooth samples were compared to base-line levels of toxic metals in teeth collected from Pre-Pottery Neolithic people (Patterson et al., 1991) and from Chalcolithic people buried in Pekiin cave in northern Israel (provided by I. Hershkovitz of Tel Aviv University). In addition, we compared the concentrations of non-essential/toxic metals in enamel and dentin of the same sample. It is expected that the concentrations of these metals should be lower in enamel than dentin as long as there was no significant addition during burial; (Patterson et al., 1991). We have been focusing on the ratio of Pb_{enamel}/Pb_{dentin} as an indicator, excluding any sample which had value higher than one. Soil samples were dissolved by concentrated, distilled HNO_3 (0.05 g soil sample in 3 ml HNO_3).

After sample dissolution, trace metals (Pb, Ag, Cu, Ba, Sr, and Rb) were analyzed with an ICP-MS (Agilent 7500cx). Prior to the analysis the ICP-MS was calibrated with a series of multi-element standard solutions (Merck ME VI). Internal standard (50 ng/ml Sc, 5 ng/ml Re and Rh) was added to every standard and sample for drift correction. The contribution of metals by the acid used in procedures was determined by measuring procedural blank samples. The blank and four selected standards were re-examined every 30 samples and at the end of the analysis for precision and detection limit estimation. In addition, standard reference samples (USGS SRS T-183, T-175) were examined at the end of the calibration and at the end of the analysis for accuracy estimation. The precision and accuracy of the ICP-MS were $\pm 10\%$ for most samples. Major metals (Ca, Mg, Al, Fe, Na, K) were measured with ICP-OES (Perkin Elmer Optima 3000; calibrated with Merck standards, precision and accuracy: $\pm 5\%$ for most samples). Several samples were selected for Sr isotope analysis in order to trace migration of individuals within a given population (Bentley, 2006; Horstwood et al., 2008; Perry, 2002; Perry et al., 2008, 2011) and for Pb isotope analysis in order to calculate mixing ratios between natural (rock-derived) and ore-derived Pb (e.g., Alfonso et al., 2001; Manea-Krichtchen et al., 1991; Scaif, 1997). The isotopic composition of Pb in the polluted teeth was compared with the isotopic composition of Pb in production slags at Khirbet en-Nahas, Faynan and with soils and sediments from the burial sites (Wadi Fidan 40 and Wadi Fidan 4 – an EB site located across the valley from Fidan 40).

The samples selected for isotopic analysis of Sr and Pb went through ion exchange columns according to the protocols outlined in Erel et al. (2006). Then, the samples were analyzed by a MC-ICP-MS (Nu Instruments) as described by Erel et al. (2006) and Ehrlich et al. (2004). Replicate measurements of $^{87}Sr/^{86}Sr$ of SRM-987 standard over the course of this study yielded $^{87}Sr/^{86}Sr = 0.710284 \pm 26$ (2σ), $n = 6$. Replicate measurements of

$^{208}Pb/^{206}Pb$ and $^{207}Pb/^{206}Pb$ ratios of SRM-981 standard over the course of this study yielded $^{208}Pb/^{206}Pb = 2.1666 \pm 22$ and $^{207}Pb/^{206}Pb = 0.9145 \pm 4$ (2σ), $n = 7$.

3. Results

The elemental concentrations of the tooth and soil samples from Wadi Fidan 40 appear in Table 2. The tooth samples from Wadi Fidan 40 had in general significantly higher concentrations of some trace metals (Cu, Cd, Pb, Mn) than tooth samples from Pekiin and the samples analyzed by Patterson and co-workers (expressed as TM/Ca molar ratio; Table 2). On the other hand the Pekiin samples (found in a karstic cave) and the Wadi Fidan 40 samples have similar concentrations of essential (Na, Mg, Fe) and other trace metals (Cr, Co, Ni, Zn, As, Sr; Table 2).

The reported concentrations of Pb and Cu in Table 2 are similar to concentrations of Cu and Pb in bones of Faynan people reported by Grattan and co-workers (e.g. Pyatt et al., 2005b). Furthermore, both Pb and Cu (and their molar ratio w/Ca) of the Wadi Fidan 40 samples are an order of magnitude higher than the Pekiin samples, which in turn are very similar to Pb/Ca and Cu/Ca background values (Ericson et al., 1979; Patterson et al., 1991). These background values were established independently by Patterson and co-workers in Neolithic people from Meso and North America. So, the Wadi Fidan 40 people are apparently polluted with Cu and Pb (as well as Cd and Mn).

In order to investigate the possibility of post-burial addition of Pb and Cu to the teeth of the people buried in Wadi Fidan 40, we used the methodology discussed by Patterson and co-workers using a combination of elemental ratios (Pb/Ca versus Ba/Ca) and Pb isotopic ratios. Indeed, a plot of Pb/Ca versus Ba/Ca of tooth enamel of the Wadi Fidan 40 people suggests diagenetic addition to most of the Wadi Fidan 40 samples (Fig. 3). Only a handful of individuals (25ii, 38A, and 92) seem to have a significant excess of Pb, while the others who have elevated Pb concentrations also have elevated Ba concentrations, which in turn suggests that both Pb and Ba were added after burial through diagenetic processes (Patterson et al., 1991). Pb/Ca versus Ba/Ca of tooth dentin shows that in addition to individuals 25ii, 38A, and 92, two more individuals (25i and possibly 35B) had excess of Pb, which suggests that these people were exposed to Pb pollution during the second decade of life (Priest and Van De Vyver, 1990). We also analyzed a few bone samples (data not shown), however, the Pb/Ca versus Ba/Ca plot for bone sample indicates that all the analyzed samples were affected by diagenetic addition, and no excess of Pb could be detected.

Three of the samples with Pb excess (upper oval in Fig. 3) and several samples with no apparent Pb excess (lower oval in Fig. 3) were analyzed for Pb isotopic composition along with soil samples from Wadi Fidan 40 (next to the graves, no metal working on site), Fidan 4 (a graveyard across the valley from Wadi Fidan 40, where there is evidence for on-site EB metal working), and two ore slags from Khirbet en-Nahas (Fig. 4).

There is a striking agreement between the Pb/Ca vs. Ba/Ca grouping and the isotopic results (Figs. 4 and 5). All three tooth samples of the three individuals who seem to have real excess of Pb based on Pb/Ca vs. Ba/Ca (Figs. 3 and 5) have isotopic values which are indistinguishable from the isotopic values of the ore slags from Khirbet en-Nahas and DLS values reported by Hauptman (2009) (Fig. 4). At the same time, the samples which have no apparent Pb excess, and their increased Pb concentrations can be attributed to diagenetic addition from the soil, estimated from the corresponding addition of Ba (Fig. 3), have isotopic values similar to the isotopic composition of the soil where the people were buried (Figs. 4 and 5).

The tooth-Pb of many of the people buried in Wadi Fidan 40 can

Table 2a
Concentrations of metallic elements and Pb and Sr isotopes in enamels.

Sample				%			ppb			%			ppb						ppm			ppb				Molar ratio	
	Sr 87/86	Pb 8/6	Pb 7/6	Ca	Na	Mg	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Rb	Sr	Ag	Cd	Ba	Pb	Ba/Ca	Pb/Ca					
9-1E				36	0.81	0.26	495	2953	0.04	106	829	400	89,989		78	536		156	1986	562	1.61E-06	3.01E-07					
9-2E				35	0.80	0.24	202	1903	0.04	78	729	160	60,393		78	644		83	1929	315	1.60E-06	1.73E-07					
9-3E				35	0.78	0.24	257	3999	0.04	84	805	213	69,016		78	662		101	2444	386	2.04E-06	2.13E-07					
9-4E				35	0.69	0.19	1703	7032	0.02	49	280	852	139,538		24	510		85	5827	243	4.89E-06	1.35E-07					
17A-1E				29	0.55	0.21	31	1805	0.02	31	232		79,887		25	210		69	3409	207	3.47E-06	1.39E-07					
17A-2E				29	0.58	0.24		5178	0.02	30	325		53,609		30	159		89	3432	59	3.47E-06	3.96E-08					
17B-1E				41	0.67	0.30		2028	0.02	17	157	41	95,199			199	25	50	1623	215	1.14E-06	1.00E-07					
17B-2E				50	0.74	0.32	86	5238	0.02	43	270	378	100,702			241	32	108	2819	432	1.65E-06	1.68E-07					
17B-3E				44	0.62	0.21	13	5104	0.02	19	156	156	84,545		26	331	6	84	3597	494	2.40E-06	2.18E-07					
22-1E				37	0.72	0.21	15	4461	0.02	30	135	269	84,835	30		329	15	105	3698	479	2.90E-06	2.49E-07					
22-2E				37	0.63	0.20	21	10,992	0.01	21	148	253	88,312	42		420	21	84	4367	443	3.47E-06	2.33E-07					
23-1E				32	0.84	0.28		8617	0.01	35	213	284	110,035			312		71	4184	532	3.85E-06	3.24E-07					
23-2E				41	0.71	0.23	714	13,571	0.01			714	140,000			283			5000	714	3.53E-06	3.34E-07					
24-1E				33	0.61	0.15	283	3744	0.03	50	383	1947	109,234	6	31	655			5722	314	5.07E-06	1.84E-07					
25i-1E		2.071	0.841	39	0.62	0.15	736	3876	0.02	28	184	728	109,406	50		519	21	127	4774	516	3.58E-06	2.56E-07					
25i-2E				41	0.71	0.17	1465	4581	0.02	67	344	1016	112,780	67	15	690	478	172	4006	501	2.85E-06	2.35E-07					
25i-3E				41	0.69	0.16	1250	8141	0.02	47	266	1516	138,562	109		587	47	78	2687	359	1.92E-06	1.70E-07					
25i-4E				52	0.86	0.29		904	0.02			53	84,840		53	328				904		3.35E-07					
25i-5E				25	0.33	0.10	175	5855	0.01		154	1557	112,039	44		289		88		263		2.04E-07					
25ii-1E	0.7077			43	0.69	0.23		1764	0.02	19	170	28	133,679	28	113	282		9	255	1368	1.74E-07	6.17E-07					
25ii-2E				42	0.62	0.20		4442	0.02	21	117	124	105,923			152	200	7	1288	572	9.06E-07						
25ii-3E	0.7077			41	0.67	0.24		1234	0.02	16	135	24	113,774			151	293		804	2723	5.68E-07	1.27E-06					
25ii-4E	0.7076			35	0.58	0.19		4590	0.02	15	116	54	100,309			108	244		8	526	1770	4.35E-07	9.70E-07				
31A-1E				31	0.56	0.16	511	5543	0.02	40	312	375	88,658	40	24	539		120	7332	72	6.88E-06	4.47E-08					
33-3E				43	0.80	0.19	655	9432	0.04	66	808	1987	154,301		44	876		218	7686	240	5.24E-06	1.08E-07					
35B-1E	0.7080			43	0.69	0.19	1057	17,347	0.02	53	338	983	86,808	233		661	11	190	6892	666	4.70E-06	3.01E-07					
35B-1Ea				42	0.71	0.19	711	1923	0.02	12	140	105	73,357	35		560	82	350	1573	140	1.10E-06	6.48E-08					
35B-2E	0.7081			44	0.61	0.16	222	11,820	0.02	15	145	291	124,924	54	8	486	38	367	5321	474	3.54E-06	2.09E-07					
35B-3E				44	0.66	0.18	225	10,600	0.02		150	325	145,325	25		527	50	175	1175	350	7.78E-07	1.53E-07					
35B-4E		2.067	0.843	41	0.48	0.13	544	17,242	0.01	9	148	526	97,417	83		509		812	4197	434	3.00E-06	2.05E-07					
38A-1E				42	0.67	0.20	1812	5862	0.02	44	279	653	106,533	174		627	44	87	5627	192	3.89E-06						
38A-2E		2.117	0.869	43	0.61	0.20	664	17,619	0.02	213	1629	5175	148,747	501		444	1128	727	9085	20,426	6.17E-06	9.18E-06					
38A-3E	0.7081			52	0.95	0.28		8540	0.04	93	1335	342	140,807		62	435		186	10,497	24,534	5.85E-06	9.06E-06					
39-1E				39	0.83	0.26	885	4146	0.03	52	437	312	87,646		42	705		156	3500	427	2.61E-06	2.11E-07					
39-2E				43	0.71	0.22	2500	4888	0.02		243	448	187,313			568	19	112		392		1.76E-07					
43-1E	0.7079			37	0.66	0.22	41	2336	0.03	61	430	307	62,111	82		492	41	143	4939	635	3.90E-06	3.32E-07					
43-2E	0.7079	2.096	0.858	38	0.65	0.21	73	9829	0.03	73	512	854	82,146	98		542	634	195	6073	1122	4.71E-06	5.76E-07					
43-3E	0.7080	2.082	0.852	38	0.68	0.22	91	2111	0.03	71	444	444	74,384	30		509	212	162	3980	646	3.03E-06	3.26E-07					
56-1E				36	0.63	0.15	358	9441	0.04	70	1084	3103	134,965	17	44	585		87	7133	559	5.73E-06	2.97E-07					
56-2E				35	0.66	0.17	1901	9618	0.04	62	658	5276	110,967	51	28	623		163	6541	652	5.39E-06	3.56E-07					
56-3E				37	0.69	0.16	1676	3706	0.02	37	250	4007	88,603	29	29	487		154	4301	419	3.38E-06	2.18E-07					
56-4E				36	0.66	0.17	1244	4268	0.02	31	205	3709	77,197	8	24	456		102	5276	339	4.29E-06	1.82E-07					
56-5E				39	0.71	0.18	1494	6035	0.02	35	259	13,235	111,294	35	35	503		129	5800	671	4.36E-06	3.33E-07					
58-1E				35	0.57	0.14	850	11,350	0.03	33	483	1000	125,783		33	569		283	7567	483	6.40E-06	2.71E-07					
59-1E				39	0.85	0.28		851	0.03	45	385	14,785	82,894		72	345		54	5018	116	3.72E-06						
59-2E				47	0.94	0.32		13,776	0.04	70	839	1259	170,490		70	598		140	7273	559	4.53E-06	2.31E-07					
67-1E				43	0.76	0.20	3898	18,845	0.02	26	394	3005	103,110	236		652	66	486	4646	486	3.18E-06	2.20E-07					
67-2E				43	0.84	0.22	1859	25,592	0.03	49	526	3388	311,513	148		482	16	296	1941	444	1.32E-06	2.00E-07					
71B-1E				34	0.57	0.14	2365	4829	0.04	74	728	2053	56,891	154	33	635		110	10,934	1599	9.27E-06	8.97E-07					
71B-2E				40	0.74	0.19	627	3453	0.03	38	281	320	85,486		26	431		26	8171	678	5.98E-06	3.28E-07					
71B-3E				35	0.62	0.16	714	2048	0.02	29	190	419	84,895		19	370		48	6838	600	5.67E-06	3.29E-07					
71B-4E				40	0.72	0.19	948	4323	0.02	42	208	583	69,417		21	417		52	7771	1000	5.63E-06	4.79E-07					
71B-5E				47	0.93	0.24	1681	4971	0.03	58	391	1536	126,797		29	458		116	7493	580	4.70E-06	2.41E-07					

(continued on next page)

Table 2a (continued)

Sample				%			ppb		%	ppb					ppm					ppb				Molar ratio	
	Sr 87/86	Pb 8/6	Pb 7/6	Ca	Na	Mg	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Rb	Sr	Ag	Cd	Ba	Pb	Ba/Ca	Pb/Ca			
71B-6E				48	0.99	0.24	1222	6855	0.03	45	271	1380	120,520		23	543		68	10,973	837	6.65E-06	3.36E-07			
74-1E				35	0.62	0.17	475	2233	0.02	36	404	499	94,145		24	446		48	3812	356	3.16E-06	1.96E-07			
74-2E				36	0.67	0.19	687	1578	0.03	38	331	369	116,043		25	425		51	3079	229	2.52E-06	1.24E-07			
75-1E				38	0.65	0.15	336	9310	0.03	59	525	1433	122,877	12	29	588		94	7223	601	5.61E-06	3.09E-07			
75-2E				42	0.70	0.16	625	13,141	0.02	89	414	3782	196,429	365	24	542		154	5227	698	3.65E-06	3.22E-07			
75-3E				41	0.68	0.16	415	12,123	0.02	77	385	2385	240,923	77	31	448		108	4969	692	3.56E-06	3.28E-07			
92-2E	0.7080	2.117	0.869	30	0.61	0.18		829	0.01	17	117	67	56,198	92		317	8	17	1859	3099	1.83E-06	2.02E-06			
92-3E	0.7080	2.115	0.869	40	0.73	0.28	18	1605	0.02	35	168	124	80,284	142		345		18	1853	3537	1.34E-06	1.69E-06			
94A-1E		2.058	0.835	39	0.69	0.20	741	3915	0.02	27	182	627	95,350	115	20	609	61	101	6105	499	4.56E-06	2.47E-07			
94A-2E		2.049	0.831	50	0.87	0.32	5542	5237	0.03	45	316	2280	87,573	316	11	639	113	429	5790	1253	3.38E-06	4.84E-07			
94A-3E				41	0.58	0.16	1270	5118	0.02	24	221	1782	116,719	260		618	16	174	4203	560	3.00E-06	2.64E-07			
94A-4E				39	0.67	0.24	421	1841	0.02	19	150	579	72,645	47		454	37	75	1206	196	9.10E-07	9.81E-08			
94A-5E				46	0.76	0.27	417	2865	0.02		182	573	152,031	52		770	1016	104		104		4.34E-08			
101-1E				33	0.47	0.14	666	11,013	0.01	28	185	1998	75,887	327	20	342	8	213	4574	599	4.04E-06	3.50E-07			
101-2E				37	0.64	0.20	360	1163	0.02	16	126	175	52,314	38	16	388	16	120	726	93	5.77E-07	4.88E-08			
101-3E				42	0.74	0.22	210	1294	0.02	9	131	157	80,017		9	391	253	79	1556	122	1.09E-06	5.69E-08			
101-4E				38	0.57	0.19	873	1245	0.02	20	127	480	56,088	78		318	39	108	2716	657	2.07E-06	3.31E-07			
101-5E				36	0.65	0.23		2252	0.01	25	124	74	60,743	347		309	25	25		50					
101-6E				35	0.76	0.22	303	3655	0.02	34	179	471	79,922	258	34	287	22	213	1256	146	1.04E-06	8.01E-08			
217-1E				40	0.66	0.18		16,388	0.02	24	152	120	137,079		8	584	8	193	6533	64	4.76E-06	3.10E-08			
217-2E				35	0.55	0.16		15,539	0.02	11	138	103	137,959			456		149	4622	46	3.84E-06	2.53E-08			
217-3E				37	0.56	0.17		16,779	0.02	17	130	60	123,748			451	9	190	6779	130	5.29E-06	6.69E-08			
246-1E				35	0.61	0.14	628	11,736	0.02	30	229	761	81,019	81	15	398	103	162	11,049	480	9.20E-06	2.65E-07			
246-2E				29	0.55	0.12	132	6603	0.01	23	161	414	84,770	40	23	299	40	80	6224	379	6.35E-06	2.56E-07			
246-3E				37	0.68	0.19	1058	8308	0.02	19	154	519	116,442	154	19	555	58	135	8385	240	6.57E-06	1.25E-07			
263-1E				28	0.55	0.14	1040	17,572	0.02	43	246	11,055	88,598		29	561		347	8873	520	9.25E-06	3.59E-07			
336-1E				45	0.67	0.17	697	7737	0.02	29	266	481	99,138	144	14	411	93	115	7924	726	5.18E-06	3.14E-07			
336-2E				44	0.65	0.17	965	17,029	0.02	38	258	729	104,255	137	15	491	61	114	7340	745	4.92E-06	3.31E-07			
336-3E				46	0.89	0.22	1099	7871	0.03	30	257	545	120,000	129	10	513	59	109	7040	455	4.43E-06	1.90E-07			
336-4E		2.059	0.834	46	0.59	0.16	1981	6967	0.02	75	2476	645	84,125	142	14	434	115	163	5536	617	3.51E-06	2.59E-07			
336-5E				50	0.80	0.21	1223	6559	0.02	24	312	671	110,048	132		552	12	204	6835	803	3.98E-06	3.09E-07			
345-1E				30	0.59	0.20	90	3172	0.02	90	2760	7939	66,918		36	498		197	4086	1380	3.92E-06	8.75E-07			
345-2E				31	0.57	0.18	42	1792	0.02	42	306	9431	71,556		42	469		139	3611	1222	3.45E-06	7.72E-07			
345-3E				41	0.73	0.21	347	6306	0.03	82	653	24,143	86,939		61	707		122	4449	3306	3.17E-06				
345-4E				49	0.99	0.35		2853	0.04	64	705	2756	102,404		64	824		288	5962	2436	3.53E-06	9.55E-07			
356A-1E				42	0.77	0.26		1482	0.03	35	219		78,623		53	389		61	3009	281	2.09E-06	1.29E-07			
356A-2E				44	0.86	0.27		1453	0.03	43	278	85	95,801		64	385		53	2126	246	1.43E-06	1.09E-07			
356A-3E				49	0.81	0.26		2895	0.03	40	283		135,081		61	407		81	2955	283	1.76E-06	1.12E-07			
361-1E				35	0.46	0.12	1026	5422	0.03	62	518	365	52,585	125	28	715		195	13,553	1465	1.15E-05	8.20E-07			
361-2E				40	0.61	0.17	1407	6847	0.02	51	339	1475	60,381	305	25	595		169	8932	1356	6.47E-06	6.50E-07			
361-3E				35	0.56	0.16	1931	7310	0.04	86	940	1336	59,776	129	34	680		198	9586	1543	8.09E-06	8.61E-07			
361-4E				31	0.48	0.13	1168	6353	0.02	58	391	1057	40,418	206	26	472		148	6802	904	6.48E-06	5.70E-07			
371-1E				38	0.81	0.32		7867	0.03	55	394	1225	80,405		88	307		22	10,503	2582	7.97E-06	1.30E-06			
371-2E				36	0.62	0.24		9370	0.03	43	344	9284	91,103		57	264		29	9771	2063	7.82E-06	1.09E-06			
540-E				45	0.58	0.16		17,483	0.03	44	265	419	112,141		44	598		199	13,653	265	8.93E-06	1.15E-07			
540-1E				64	0.85	0.25		29,675	0.05	130	844	649	216,039		65	955		325	18,636		8.56E-06				
540-3E				43	0.65	0.18		20,252	0.03	54	342	396	123,112		27	610		189	12,572	198	8.59E-06	8.94E-08			
713-1E				39	0.76	0.20	2248	10,472	0.02	33	262	2405	80,668	46	33	705		111	7457	151	5.52E-06	7.38E-08			
713-2E				40	0.69	0.17	1177	8067	0.02	36	200	1762	91,512	29	29	600		93	8424	100	6.09E-06	4.78E-08			
713-3E				40	0.73	0.19	1405	3177	0.02	26	187	332	106,133		26	629		51	4744	17	3.46E-06				
714A-1E	0.7080			37	0.64	0.17	82	18,786	0.02	61	469	3184	150,000	92		677	41	235	9653	878	7.57E-06	4.55E-07			
714A-2E				18	0.26	0.07		8916	0.01	27	154	1076	41,274		11	318		119	4840	304	7.87E-06	3.27E-07			
724B-1E				38	0.58	0.17	313	15,619	0.02	24	196	165	125,627	86	8	485	55	337	4875	603	3.71E-06	3.04E-07			
724B-2E				40	0.70	0.22	778	4236	0.02	14	222	375	125,125	56		473	97	444	2361	181	1.74E-06	8.82E-08			
724B-3E				39	0.61	0.18	1275	16,423	0.02	28	240	823	113,124	176		529	18	314	4538	416	3.36E-06	2.04E-07			
2009-1E		2.062	0.834	44	0.65	0.19	570	13,134	0.03	59	530	2633	109,528	128		810	157	108	7593	599	5.				

Table 2b
Concentrations of metallic elements and Pb and Sr isotopes in dentins.

Sample				%			ppb		%			ppb						ppm			ppb			Molar ratio	
	Sr 87/86	Pb 8/6	Pb 7/6	Ca	Na	Mg	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Rb	Sr	Ag	Cd	Ba	Pb	Ba/Ca	Pb/Ca			
9-1D				25	0.37	0.09	6772	13,038	0.04	465	1468	3404	124,085	135	15	1074		575	13,331	4553	1.53391266269357E-005	3.47E-06			
9-2D				24	0.21	0.04	2709	10,821	0.02	253	790	2662	62,662		16	525		395	5766	1951	6.97538656472294E-006	1.56E-06			
9-3D				33	0.35	0.07	5510	17,726	0.05	510	1903	4524	126,334		23	959		615	11,323	4084	1.01112812397375E-005	2.41E-06			
9-4D				39	0.38	0.06	12,170	30,399	0.03	295	1753	12,708	109,618	313	17	913		434	6910	764	5.12172079309133E-006	3.75E-07			
17A-1D				25	0.33	0.09	2021	18,964	0.02	78	415	285	92,694			599		259	9767	1088	1.13542243331128E-005	8.37E-07			
17A-2D				30	0.53	0.14	1500	58,536	0.02	893	1643	3536	128,786	357		1066		750	20,107	1821	1.9666543207275E-005	1.18E-06			
17B-1D				53	0.59	0.18	1021	62,206	0.02	309	526	2361	161,134	134		961	124	619	17,351	2206	9.54952014255862E-006	8.04E-07			
17B-2D				51	0.55	0.19	1406	42,305	0.02	195	820	2422	183,555	39		801	195	547	8906	1602	5.09086490886116E-006	6.06E-07			
17B-3D				21	0.29	0.06		14,140	0.02	64	255	223	58,726			425		223	8376	669	1.14924726328684E-005	6.07E-07			
22-1D				39	0.53	0.13	33	17,417	0.02	50	182	646	167,715	66		500	17	728	10,232	2434	0.000007756	1.22E-06			
22-2D				39	0.51	0.10	70	102,488	0.02	116	326	1023	163,419	93		523	47	512	13,512	2558	1.02043639530904E-005	1.28E-06			
23-1D				35	0.50	0.32	57	4543	0.01	29	171	1343	170,571	171		276		57	7229	2429	6.02163599995811E-006	1.34E-06			
23-2D				41	0.65	0.45	69	4097	0.01		139	556	276,458			321		69	10,069	5903	7.13516136167419E-006	2.77E-06			
23-3D				38	0.56	0.36	38	6788	0.02	38	288	712	227,115	38		342		77	8885	4635	6.86462287983651E-006	2.37E-06			
24-1D				23	0.23	0.03	2241	9754	0.02	172	985	9113	63,645			788		591	10,296	1576	0.000012,807	1.30E-06			
25i-1D				38	0.33	0.05	6123	16,904	0.02	215	879	5786	104,541	537		1010		635	12,695	1729	9.85014722027503E-006	8.88E-07			
25i-2D				38	0.31	0.05	5902	10,239	0.02	275	824	4182	112,366	335		968	6	603	13,100	1786	9.98708078189432E-006	9.01E-07			
25i-3D				24	0.14	0.02	4040	11,860	0.01	20	220	6680	62,940	100		431		160	300	580	3.6492718138196E-007	4.67E-07			
25i-4D				12	0.16	0.11		156	0.01			49,656				78				2875		4.58E-06			
25i-5D				7	0.05	0.01	602	5361			462	4116	24,277	20		133		141		221		5.84E-07			
25ii-1D	0.7077			34	0.48	0.39		800	0.01	19	108	70	115,435		37	244		23	2470	7526	2.10924230378175E-006	4.25E-06			
25ii-2D	0.7077			35	0.46	0.34		405	0.02	12	116	174	135,648			166		23	498	1435	4.14680819961781E-007	7.91E-07			
25ii-3D	0.7077			29	0.40	0.30		585	0.01		67	50	109,732			188				4749		3.22E-06			
25ii-4D	0.7077			36	0.52	0.36		3328	0.02		155	124	141,548			233		31		6734		3.60E-06			
31A-1D				27	0.24	0.06	2279	14,954	0.02	74	726	2362	102,941	239		765		331	6581	175	7.00774692406486E-006	1.23E-07			
33-1D				44	0.41	0.08	16,367	68,345	0.04	180	3309	106,259	250,683	288		1029		4317	9640	2302	6.46757944560502E-006	1.02E-06			
33-2D				22	0.16	0.03	3799	20,654	0.02	107	1738	13,184	78,496	107	10	441		596	3945	830	5.33325911735467E-006	7.43E-07			
33-3D				37	0.32	0.05	6515	42,008	0.03	189	3523	28,674	185,492			1054		871	9659	1932	7.58975851168743E-006	1.00E-06			
35B-1D	0.7080			45	0.29	0.05	6980	66,879	0.02	81	667	6303	85,768	646		846		657	6990	1798	4.57082955587379E-006	7.78E-07			
35B-1Da	0.7081			46	0.39	0.06	13,929	44,722	0.03	79	1230	14,286	153,214	317	278	1039	40	6230	2460	2103	0.000001574	8.90E-07			
35B-2D				41	0.31	0.06	15,218	113,265	0.02	197	3476	15,993	94,354	1469		1005		4537	6442	1612	4.59967012072119E-006	7.62E-07			
35B-4D				66	0.44	0.08	14,417	184,223	0.03	97	2961	14,951	177,136	1262		1491		6117	728	2767	3.23616417773917E-007	8.14E-07			
38A-1D	0.7080			39	0.29	0.05	8089	38,567	0.02	64	637	5191	102,070	1242		871		414	8185	541	6.08855737166712E-006				
38A-2D				39	0.34	0.11	1989	14,937	0.02	495	4358	15,611	166,947	1232		785	21	1789	12,905	18,400	9.7042680618243E-006	9.16E-06			
38A-3D				26	0.25	0.06	391	26,927	0.02	391	3408	5587	169,022			471		1453	9888	22,346	1.10247176703997E-005	1.65E-05			
39-1D				42	0.46	0.09	14,177	5161	0.03	161	1627	6165	112,088	1205		1134		2129	13,715	1365	9.44778998281427E-006	6.23E-07			
39-2D				43	0.38	0.07	30,534	5954	0.02	76	1336	9895	141,508	1574		1017		2424	8302	1221	5.63635347006829E-006	5.49E-07			
43-1D				33	0.39	0.08	1118	7919	0.03	404	1242	4720	101,366	466		760	62	745	12,609	5217	1.13254940856699E-005	3.10E-06			
43-2D				37	0.40	0.09	1213	13,675	0.03	350	1050	3538	103,950	413		839	50	975	13,625	7225	0.000010,766	3.78E-06			
43-3D				42	0.43	0.09	1402	11,438	0.03	366	1205	3661	96,875	446		908	80	1080	14,357	4196	1.00429022058563E-005	1.94E-06			
56-1D				28	0.27	0.05	2529	19,424	0.03	141	1029	14,506	104,306	530	14	1147		326	11,061	1614	1.16045964298751E-005	1.12E-06			
56-2D				30	0.22	0.04	5460	14,822	0.02	56	610	26,520	94,184	460	9	703		750	6886	1867	6.63705077024921E-006	1.19E-06			
56-3D				39	0.31	0.06	12,760	17,341	0.02	70	767	31,938	134,729	814	8	937		1008	8961	2543	6.72128301106144E-006	1.26E-06			
56-4D				41	0.36	0.06	12,595	18,607	0.02	57	630	45,057	137,748	630		987		878	10,611	2099	7.55152157212374E-006	9.89E-07			
56-5D				38	0.31	0.05	10,078	17,826	0.02	61	530	35,243	105,652	722	9	988		757	9687	1591	7.39137863526714E-006	8.04E-07			
58-1D				29	0.18	0.03	5848	28,424	0.02	91	1758	9333	88,909	121		503		1091	6273	1303	6.33285458410586E-006	8.71E-07			
59-1D				41	0.47	0.23		2349	0.03	71	444	90,575	185,685		10	440		161	8357	1542	5.98259561641086E-006	7.31E-07			
59-2D				37	0.38	0.20		3356	0.02	34	342	6712	199,418			351		103	6507	1747	5.07954302256875E-006	9.02E-07			
67-1D				44	0.36	0.06	7370	81,637	0.02	113	847	8995	174,379	440		753	11	1332	4221	1005	2.77113008733745E-006	4.36E-07			
67-2D				42	0.25	0.05	7129	40,584	0.02	59	990	7366	106,337	683		878		7							

(continued on next page)

Table 2b (continued)

Sample				%			ppb		%			ppb					ppm		ppb		Molar ratio	
	Sr 87/86	Pb 8/6	Pb 7/6	Ca	Na	Mg	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Rb	Sr	Ag	Cd	Ba	Pb	Ba/Ca	Pb/Ca
74-1D				29	0.27	0.04	3077	4431	0.02	100	719	2659	76,371	401		714		435	6605	1455	6.5869333463343E-006	9.60E-07
74-2D				30	0.31	0.04	4718	7940	0.02	106	1250	5158	71,180	880	18	751		634	9067	1004	8.73771085439677E-006	6.40E-07
75-1D				38	0.25	0.05	1318	13,159	0.03	107	663	5059	92,657	452	4	974		220	10,203	1343	7.85815658678622E-006	6.85E-07
75-2D				40	0.39	0.07	2638	16,834	0.02	101	678	9347	155,729	25		655		302	6231	1658	4.49894664568233E-006	7.92E-07
75-3D				27	0.28	0.05	1711	13,690	0.01	107	802	7246	118,235	80		428		241	3877	1230	4.14843901303782E-006	8.71E-07
92-1D				38	0.43	0.28	68	1773	0.01	80	841	489	213,182	80		361	11	45	3523	14,932	0.000002713	7.61E-06
92-2D				39	0.52	0.15	21	9170	0.02	62	249	560	130,913	166		426	21	207	7739	11,743	5.84566661499879E-006	5.87E-06
92-3D				36	0.49	0.13		3077	0.02	35	210	455	132,972	175		334		70	4930	14,476	3.98347072592092E-006	7.74E-06
94A-1D				58	0.39	0.06	13,421	47,895	0.02		1053	21,579	161,404	965		1025		1228		3684		1.24E-06
94A-2D		2.058	0.835	59	0.51	0.14	17,419	16,372	0.03	147	1180	17,124	175,369	2257		1440	15	2448	20,472	6785	1.01116668141509E-005	2.22E-06
94A-3D				56	0.41	0.09	6727	11,036	0.03	33	526	9326	134,836	1595		1085		609	5773	1414	3.02548481859194E-006	4.91E-07
94A-4D				34	0.33	0.05	22,071	80,429	0.02		500	23,714	117,857	2143		986		1786		1071		6.04E-07
94A-5D				38	0.37	0.09	26,380	26,380	0.02	195	1948	25,357	138,312	3003		1130	65	1916	12,143	2727	9.38363798963982E-006	1.39E-06
101-1D				38	0.25	0.06	7651	32,035	0.02	50	942	19,271	88,580	1872		713		540	7487	1068	5.69016814345746E-006	5.37E-07
101-2D				40	0.42	0.11	50,901	13,548	0.02	54	645	10,000	112,621	1895		1019		1398	13,683	2513	9.99958135624715E-006	1.22E-06
101-3D				42	0.37	0.08	18,939	9091	0.02		909	17,879	161,212	1515		778		758		1667		7.65E-07
101-4D		2.077	0.847	35	0.43	0.09	23,807	2110	0.02	46	642	11,789	90,780	2202		1146		2156	5092	2248	4.21562594836654E-006	1.23E-06
101-5D				36	0.38	0.05	28,519	1852	0.02		185	6667	82,037	1111		1069		741		370		1.98E-07
107-2D				33	0.23	0.05	4896	42,165	0.02	67	967	8638	102,530	558	7	748		461	7262	3624	6.36623399893776E-006	2.10E-06
107-3D				36	0.25	0.05	9668	45,752	0.02	70	1206	53,601	115,490	524	17	627		664	5804	4598	4.76781359343364E-006	2.50E-06
217-1D				34	0.22	0.04	75	28,483	0.02	50	217	983	143,167			701		467	5392	333	4.56657207632813E-006	1.87E-07
217-2D				40	0.24	0.04		32,884	0.02	42	200	937	162,737	42		705		526	4179	316	3.02276300343429E-006	1.51E-07
217-3D				34	0.20	0.04		29,724	0.02	39	177	896	153,051			627		413	4094	404	3.50834762280968E-006	2.29E-07
246-1D				25	0.22	0.03	9910	34,742	0.02	202	1820	10,933	91,551	753		674		876	7584	2258	8.68960705631869E-006	1.71E-06
246-2D				39	0.29	0.04	5319	56,569	0.02	479	3644	18,590	130,984	1090		858		984	8112	2713	0.000006101	1.35E-06
246-3D				53	0.40	0.08	13,896	34,091	0.03	104	1052	14,091	168,571	2078		911		766	9974	1429	5.51614714859157E-006	5.23E-07
263-1D				26	0.26	0.05	1708	27,208	0.02	42	542	28,542	100,167			526		708	8083	1125	8.91616290224213E-006	8.21E-07
336-1D				41	0.28	0.05	4937	18,765	0.02	89	998	4188	85,829	981		876	4	495	9137	1747	6.54629462254956E-006	8.28E-07
336-2D				34	0.25	0.04	3803	30,759	0.02	70	454	3451	84,194	383		610		376	5313	892	4.60218575106917E-006	5.11E-07
336-3D				45	0.37	0.06	5255	20,190	0.02	58	423	4394	97,883	401	7	742		496	7168	766	4.67022959729408E-006	3.30E-07
336-4D				52	0.51	0.10	7250	42,161	0.03	196	2643	7625	163,375	732		838	1054	6714	2036	3.74860883681985E-006	7.52E-07	
345-1D				23	0.24	0.09	1440	13,152	0.02	217	516	84,049	81,522	489		873		190	13,533	8533	1.72382393073888E-005	7.19E-06
345-2D				27	0.28	0.09	2100	13,459	0.02	211	498	114,773	85,136	604	15	906		211	13,595	8580	1.45686211142976E-005	6.09E-06
356A-1D				42	0.43	0.16		3320	0.03	41	255	265	152,953		20	507		418	7251	1507	5.06918909276946E-006	6.97E-07
356A-2D				41	0.43	0.12		20,433	0.02	66	302	407	162,861		26	578		499	12,126	1864	8.69837256335422E-006	8.85E-07
356A-3D				63	0.63	0.16		18,676	0.04	147	441	294	277,941			583		441	9412	2206	4.37108864599501E-006	6.78E-07
361-1D				40	0.30	0.05	6133	13,147	0.03	130	605	1998	55,613	191	8	841		689	12,795	3583	9.40572435132373E-006	1.74E-06
361-2D				40	0.48	0.11	5000	9711	0.03	83	455	3926	72,769			599		289	7810	2645	5.70166333746074E-006	1.28E-06
361-3D				26	0.23	0.05	2367	6888	0.02	80	612	2128	44,548			395		213	5771	2154	6.52658211686579E-006	1.61E-06
361-4D				33	0.37	0.08	3176	10,026	0.03	131	801	2822	52,415	381	26	655		249	7559	1929	6.71215604397112E-006	1.13E-06
371-1D				41	0.48	0.24		22,311	0.02	79	267	6635	126,651		16	468		63	10,833	6179	7.77577756529285E-006	2.94E-06
371-2D				74	1.01	0.44		12,831	0.06	147	1176	91,581	328,824		37	976		184	24,375	10,625	9.66723722388281E-006	2.79E-06
540-D				41	0.28	0.06	28	18,703	0.03	160	620	2509	136,466		9	906		479	11,109	630	7.82268502176874E-006	2.93E-07
540-3D				43	0.28	0.05		22,361	0.03	185	648	2060	170,417			905		324	10,949	486	7.39489402132904E-006	2.17E-07
713-1D				32	0.26	0.05	8848	21,888	0.02	79	880	5193	139,485	236	7	828		408	6102	200	5.55684675104338E-006	1.21E-07
713-2D				34	0.25	0.04	6283	23,373	0.02	44	494	9111	105,069	275	6	864		275	6446	275	5.5307154750835E-006	1.56E-07
713-3D				32	0.25	0.04	9464	24,748	0.02	71	1017	7106	138,722	244	8	733		544	5765	268	5.33943145791429E-006	1.64E-07
713-4D				37	0.31	0.05	8352	32,358	0.02	55	655	12,066	170,899	229	8	867		386	6207	308	4.83754481932125E-006	1.59E-07
714A-1D				24	0.18	0.04	219	19,263	0.01	146	748	10,225	73,341	107		539	6	321	6316	1164	7.56761252538926E-006	9.23E-07
714A-2D				46	0.28	0.06	151	36,253	0.03	356	1652	19,395	138,985	54	11	1086		832	11,825	2117	7.57640676568655E-006	8.98E-07
714A-3D				45	0.28	0.06	256	34,623	0.02	407	1747	24,518	143,358	211		913		798	6566	2063	4.30706818609781E-006	8.96E-07
724B-1D				40	0.28	0.07	3597	60,604	0.02	165	1209	2503	129,190	211		628	6	872	5832	1317	0.000004296	6.42E-07
724B-2D				40	0.29	0.08	16,894	55,657	0.02	404	9874	20,909	173,485	2298		909	25	3737	5404	1919	3.94154146413662E-006	9.26E-07
724B-3D				42	0.28	0.05	5478	134,890	0.02	110	882	6930	131,103	570		749		1489	3125	1360	2.17416662412892E-006	6.26E-07
724B-4D				44	0.27	0.06	6720	102,660	0.02	98	1037	7801	149,113	957		893		1578	6862	1418	4.50953574798746E-006	6.17E-07
2009-1D				43	0.30	0.05	2845	36,685	0.03	124	815	14,102	111,948	608		934		387	9047	1160	6.14021177804252E-006	5.21E-07
2009-2D				49	0.46	0.09	6405	81,095	0.04	237	1515	40,693	166,971	912		1498		967	16,004	1460	9.62653475964062E-006	5.81E-07
2009-BT1D	0.7081			43	0.26	0.06	2119	48,072	0.04													

Table 2c

Molar ratios of selected metals with Ca in tooth enamel.

	Molar ratio w/Ca in enamel													
	Na	Mg	Cr	Fe	Co	Ni	Cu	Zn	As	Sr	Ag	Cd	Ba	Pb
Faynan	3.04E-02	8.54E-03	1.84E-06	4.23E-04	7.66E-08	6.60E-07	3.27E-06	1.60E-04	1.70E-07	5.62E-04	1.47E-07	1.44E-07	4.18E-06	4.95E-07
	3.03E-02	8.20E-03	1.40E-06	3.71E-04	6.60E-08	4.33E-07	9.51E-07	1.49E-04	1.35E-07	5.65E-04	4.15E-08	1.17E-07	3.78E-06	2.49E-07
	4.1E-03	1.9E-03	1.7E-06	1.5E-04	4.7E-08	7.2E-07	5.9E-06	5.6E-05	1.4E-07	1.8E-04	2.7E-07	1.1E-07	2.3E-06	1.2E-06
Pekiin	14	22	92	35	61	110	179	35	82	32	187	80	56	243
	2.32E-02	8.93E-03	2.08E-06	2.36E-04	3.83E-08	6.87E-07	2.96E-07	1.33E-04	3.50E-07	1.12E-04		9.63E-09	2.88E-05	3.74E-08
	2.51E-03	7.47E-04	3.91E-06	1.85E-05	5.63E-09	3.65E-07	2.19E-07	1.78E-05		1.40E-05		1.89E-10	3.33E-05	2.16E-08
bckgr (Patterson et al., 1991)	11	8	187	8	15	53	74	13		13		2	116	58
							8.5E-07	9.7E-05			2.9E-08			2.1E-08
							6.9E-07	3.9E-05			1.0E-08			1.0E-08
							81	40			36			49

be explained as a mixture of ore Pb with soil Pb, and using simple mixing calculation (Faure, 1986) one can estimate the fraction of ore Pb found in each of the individuals with no apparent Pb excess. In order to perform this calculation, $1/[Pb]$ ($[Pb]$ = Pb concentration in the sample) versus $^{207}Pb/^{206}Pb$ is plotted (Fig. 6). Fig. 6 shows that actually only a handful of tooth samples have Pb mixture of only two end-members (i.e., soil Pb and ore Pb), and that many of the tooth samples require a third source which has soil $^{207}Pb/^{206}Pb$ value and lower Pb concentration than the soils measured in the current study. A lot of discussion has been going on in the literature about the characterization of “mobile” soil Pb which should be relevant to uptake by buried bones and teeth (Erel et al., 1997; Patterson et al., 1991; Teutsch et al., 2001). It is likely that the type of soil dissolution applied in the current study (concentrated HNO_3) overestimated the amount of Pb actually available for uptake during bone and teeth uptake. Hence, a third endmember (soil Pb which is released by water–soil interaction) that contains less Pb than was dissolved by our HNO_3 protocol is very likely to exist and it can explain the data in Fig. 6. Indeed, Pb bound to the carbonate fraction in Mediterranean soils (Teutsch et al., 2001) can serve as the third endmember. Carbonate-bound Pb has lower concentrations but similar isotopic composition to the soil Pb released by HNO_3 (Fig. 6), is much more labile, and is more likely to be released by infiltrating rain water (Teutsch et al., 2001).

In addition to Pb isotopes we measured Sr isotopic composition ($^{87}Sr/^{86}Sr$) of all the teeth with excess Pb and of some of the teeth with no apparent Pb excess. Plot of $1/Sr$ versus $^{87}Sr/^{86}Sr$ reveals a few interesting observations (Fig. 7). All the non-polluted people and the polluted people buried in graves 38A and 92 have $^{87}Sr/^{86}Sr$ values (0.708011 ± 110) which are typical of the Araba valley and the vicinity of Faynan (Perry et al., 2011). The person buried in grave 25ii has $^{87}Sr/^{86}Sr$ values (4 enamel and 4 dentin samples; 0.707680 ± 54 (2σ)) which are significantly lower than local $^{87}Sr/^{86}Sr$ values (Perry et al., 2011) and hence suggest that this

person came from far away, most likely from either a Cretaceous carbonate or Neogene basaltic terrain, either in the Judea – west Galilee hills (Cretaceous carbonate) or from eastern Galilee or the Golan Heights (Neogene basalt) (Perry et al., 2011) and that was affected by metal pollution during his childhood. On the other hand, the non-polluted people plot on a mixing line between local $^{87}Sr/^{86}Sr$ values and lower $^{87}Sr/^{86}Sr$ and higher Sr concentration endmember. This suggests that the non-polluted people were “sampling” in their diet Sr from different terrains, i.e., that these people were nomads or merchants that moved around and spent part of their childhood outside the vicinity of Faynan (Faure, 1986; Bentley, 2006).

4. Discussion

Comparing these findings with their archaeological context gives a new perspective to the lives of Iron Age peoples in the Faynan region. Elevated Pb- and Cu-exposure could indicate occupational exposure to these substances, particularly through mining or processing copper. However, young individuals exhibiting elevated Cu or Pb concentrations may have been exposed due to their parents' occupations during the 10th c. BCE. Alternatively, those with elevated heavy metal concentrations may have ingested these materials in food, which, nevertheless, indicates close proximity to metal working.

Based on the current sample, the majority of people buried in Wadi Fidan 40 cemetery were not exposed to metal pollution as children. It is important to note that there was probably a large ‘support-population’ of people involved in exporting the copper and importing the food and fuel that kept the Faynan operation running. Some of these buried ‘nomads’ may have been engaged in this trade and as they spent much of their lives outside the Faynan should have had a low pollution load. However, those who were exposed were also unusual in other ways possibly indicative of

Table 2d

Concentrations of metallic elements in the soil sampled next to the graves.

Sample	%					ppb			%			ppb			ppm		ppb			
	Pb 8/6	Pb 7/6	Ca	Na	Mg	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Rb	Sr	Ag	Cd	Ba	Pb	
WFD 4 tomb 1 soil	2.090	0.853	12		0.85	3777			2435	8602	83,049	29,634	696	308	10	1048	129,616	13,840		
WFD 40 grave 35B soil	2.053	0.832	9.1			3473			2168	6867	4589	14,266	526	306	7.5	764	121,202	3491		
WFD 40 grave 74 soil	2.061	0.835	7.0			2058			1124	3927	2926	9202	535	266	4.2	312	61,717	2801		
WFD 40 grave 75			7.3			3708			1434	4041	4170	19,393	808	242	13	332	30,071	2924		
WFD 40 grave 246 soil	2.059	0.835	11			2545			2200	7802	6734	16,618	537	288	7.3	1059	170,208	4723		
WFD 40 grave 2009 soil, upper levels of fill	2.052	0.833	10	0.53		5441			2068	7262	7191	13,479	1005	247	26	1115	167,461	5947		
WFD 40 grave 2009 soil, lower levels of fill	2.058	0.832	7.0			1269			1577	3334	2845	5834	383	329	2.0	139	25,337	2107		
WFD 40 grave 2009 soil, just below capstones	2.061	0.835	7.8			4374			1270	3719	4549	6825	962	260	7.6	377	99,323	2546		
WFD 40 grave 2009 soil, mid-torso	2.072	0.840	6.5			1917			944	2421	5609	11,083	559	172	3.7	467	28,551	1585		
WFD 40 grave 2009 soil, inside cranium	2.062	0.834	6.7			3605			1622	4140	5471	12,080	853	175	4.0	210	35,339	2261

Fig. 3. Pb/Ca versus Ba/Ca molar ratios in tooth enamel samples of the people buried in Fidan 40.

Fig. 4. $^{208}\text{Pb}/^{206}\text{Pb}$ versus $^{207}\text{Pb}/^{206}\text{Pb}$ of tooth, Fidan 40 soil, and Khirbat en-Nahas slag samples.

lifestyle and status. The pair of burials in Grave 25 is typical in regard to the burial pattern at Wadi Fidan 40. The primary interment was buried semi-flexed with head to the south, with partial remains of a secondary burial, probably a relative who had died earlier. Individual 25ii was exposed to pollution as a child, while 25i displayed exposure to pollution later in life. The individual in Grave

Fig. 5. Pb/Ca versus Ba/Ca molar ratios in tooth enamel samples of the people buried in Fidan 40 grouped according to their isotopic values. Teeth soil IC = tooth samples which had isotopic composition identical to the isotopic composition of the Fidan 40 samples. Teeth ore IC = tooth samples which had isotopic composition identical to the isotopic composition of the Khirbat en-Nahas slag samples.

Fig. 6. Mixing plot of ore Pb and soil Pb showing how all the tooth samples contain a mixture of both Pb types.

35B may also have been exposed late in life (Fig. 8). This is a secondary burial, an individual who was exhumed and reburied. The defleshed and broken remains of this individual were placed in a small cist built specially for the purpose. Most secondary burials were outside of cists, but this individual was accorded a level of status even as the burial was reinterred.

Only three individuals were exposed to pollution as children: Graves 25ii, 38A, and 92 (Fig. 9). As mentioned above, 25ii was a typical burial, but the other two were not. Grave 38A was the central burial in a mortuary complex. The complex was visible on the surface as a triple-ringed grave circle approximately 4.5 m in diameter, constructed of at least 125 stones. By contrast, most burials in the cemetery were marked with a single stone ring constructed of about 10 boulders. The individuals of Grave 38A and 92 were both buried in an extended fashion. This burial posture accounts for only 13 of the graves at Wadi Fidan 40, and may be indicative of status.

Burial goods are one of the firmest indicators of social status (Baitzel and Goldstein, 2014; Chapman, 1982; Chapman et al., 1981; Robb et al., 2001). Regrettably, Graves 25 and 38A were looted in antiquity. There is no way to assess the level of wealth buried with these individuals. However, Grave 92 was one of the wealthiest graves in the cemetery. This individual was buried with a Hyksos scarab (an hierloom), pomegranates, a wooden bowl, two copper anklets, an iron bracelet, and 38 beads. The beads included glass, agate, calcite, carnelian, cowry, univalve, and shell beads. Glass is one of the rarest bead types in the cemetery, represented by only

Fig. 7. Mixing plot of Sr in tooth samples, showing that only the non-polluted tooth samples plot along a mixing curve.

Fig. 8. Grave 35B, a secondary burial in which the individual buried here was exhumed and reburied in the cist shown here (photo – T.E. Levy, UC San Diego Levantine and Cyber-Archaeology Laboratory).

three examples, and the glass bead of Grave 92 is the most ornate and complicated of these. Thus, one of the wealthiest graves at Wadi Fidan 40 also happened to contain an individual who was one of the few exposed to pollution as a child. Grave 92 contained the remains of a woman, suggesting that females not only could hold significant social status in this population, but also that they may have belonged to a family taking part in work related to metallurgy. Preliminarily, pollution appears to coincide with social status at Wadi Fidan 40 as expressed by grave goods, body position, and labor investment in burial architecture construction. However,

Fig. 9. The Grave 92 burial, one of three individuals exposed to pollution as adults and one of the wealthiest graves excavated in the cemetery, implying elevated social status (Photo – T.E. Levy, UC San Diego Levantine and Cyber-Archaeology Laboratory).

there is no absolute correlation between burial position or status and pollution. This is consistent with the assertion of [Hunt and El-Rishi \(2010\)](#) who point out that at least some of the foodstuffs consumed by the metal-processors at Faynan in the EBA, Iron Age and Classical periods were imported, and that this pointed to the high status of at least some of the metal workers. Also, there might be a few families who were able to transmit metallurgical skills through the generations and thus achieve and transmit high status to their children.

5. Conclusions

1. Combining isotopic data with copper and lead concentrations of the Faynan skeletons could help identify individuals more exposed to toxic substances, likely through working in the mines or by contact with their parents who were working in the mine.
2. Most of the people buried in Fidan 40 were not exposed to pollution (i.e., did not have parents who worked at the mine), at least as children, since their enamel after correction contain no excess Pb and probably other metals. Only 3 individuals (92, 25ii, 38A) were exposed to pollution when they were young children, and two (25i and possibly 35B) were exposed at a later stage in their life (dentin is polluted but enamel is not polluted). The few bone samples that we analyzed were completely affected by burial and therefore cannot attest to the possibility of exposure to metal pollution during adulthood.
3. The characteristics of these polluted individuals: Grave 92 is that of a woman and is the wealthiest grave in the cemetery. This is the grave with the Hyksos scarab, anklets, and pomegranates in wooden bowl. Grave 38A was looted in antiquity, but is that of a man and was within the very complex Grave 38 grave structure. Both 92 and 38 were extended burials – the class that makes up only 13 of the total burials in the cemetery. According to their Sr isotopic composition they were locals. Grave 25 was semi-flexed, and contained only a few beads, but it was looted in recent times. (Excavation of Grave 25 was seen as a salvage operation in 1997). The person buried in grave 25 was a foreigner, coming from either a Cretaceous carbonate terrain or from Neogene basalt terrain.
4. The ancient pollution study presented here demonstrates that members of the nomadic population buried during the 10th c. BCE in the Wadi Fidan 40 cemetery were involved in copper smelting activities and also exposed to toxic metals from living in the vicinity of Iron Age copper production sites. The fact that high status women buried in the cemetery seems to have been actively engaged in copper production indicates just how different ancient Levantine nomadic communities are from 19th and 20th century Bedouin Arab communities recorded by explorers, colonial administrators, and anthropologists ([Levy, 2009](#); [Van Der Steen, 2012](#)).
5. This study has also introduced a rigorous sampling methodology for examining ancient pollution by combining elemental ratios (e.g., Pb/Ca and Ba/Ca) with isotope ratios (Pb and Sr) both in tooth, soil, and slag samples.
6. By taking an interdisciplinary perspective on the Wadi Fidan 40 nomadic population that integrates archaeology, biological anthropology, and geochemistry, new insights are emerging concerning the local organization of metal production in the southern Levant's largest copper resource zone, gender relations, social status, and the nature of ancient pollution during the southern Levant's first industrial revolution.

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