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Publication Date

2016-08-01

DOI

10.1016/j.jas.2016.05.010

Peer reviewed

Intended for: *Journal of Archaeological Science*

Early Bronze Age copper production systems in the northern Arabah Valley: New insights from archaeomagnetic study of slag deposits in Jordan and Israel

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Abstract

This paper presents results of an archaeomagnetic study of slag from four Early Bronze (EB) Age copper production sites in the Faynan Copper Ore District and the northern Arabah Valley (modern Israel and Jordan). The results provide age constraints for metallurgical activities at these sites. Together with previously published data, they indicate copper production around ca. 2900 cal. BCE (EB II-III transition) and between ca. 2600-1950 cal. BCE, spanning the later part of the EB III and the entire EB IV period. These data strongly suggest a direct link between Faynan and the Old Kingdom of Egypt, which is reflected in the most significant phase of copper production and trade in the northern Arabah prior to the Iron Age, and in a settlement wave in the Negev Highlands. In addition, the results indicate that during the late EB II copper was smelted up to 40 km away from the mines. This is evident at the unique cultic site of Ashalim, located on the main road between Faynan, southwest of the Dead Sea, and the settled areas in the core of Canaan.

Highlights

- The application of archaeomagnetic experiments for constraining age of copper smelting and casting sites is demonstrated.
- New archaeomagnetic age constraints are provided for key sites in the Early Bronze Age copper production systems in the Faynan Copper Ore District and the northern Arabah Valley (modern Israel and Jordan), including the central manufacturing site of *Khirbat Hamra Ifdan*.
- Probable link between the northern Arabah copper production and the Old Kingdom of Egypt is presented.
- Key issues in establishing absolute chronology for desert sites are discussed.
- First mapping and dating of the recently discovered unique cultic/smelting site of Ashalim are provided, adding an important link between Faynan and the urban centers of Canaan.

1. Introduction

Increasing understanding of changes in the Earth's magnetic field has important implications for dating archaeological sites from the Holocene period. The Earth's magnetic field is constantly changing. Even on short time scales ("secular variations", SV) the changes in its intensity (strength) and directions are substantial, demonstrating an unstable and fluctuating behavior (e.g., Korhonen, et al., 2008). For periods earlier than modern instrumental recording, reconstructing the geomagnetic field's properties depends on geological and archaeological materials that acquired a stable remanent magnetization, usually at the time of their last cooling episode (e.g., Valet, 2003). The record of these fluctuations can, in principle, be used as a dating tool by comparing data from objects of an unknown age to regional reference curves (e.g., Sternberg, 1997).

In recent years, the potential of archaeomagnetic dating has increased dramatically as a result of improvements in resolution and precision of regional reference datasets for the Holocene (e.g., Lanos, 2003, Pavon-Carrasco, et al., 2011). This includes the dataset for intensity changes in the Levant (e.g., Ben-Yosef, et al., 2008b, Gallet, et al., 2014), which can be used as a reference for dating un-oriented heat-impacted samples. Even taken outside of correlating remanent magnetization to the known historical fluctuations in intensity, identifying differences in magnetic intensities implies different periods of deposition.

In the following we present results of an archaeomagnetic study on slag samples from four copper production sites in the northern Arabah Valley (modern Jordan and Israel) (Fig. 1). The main goal of the study was to use archaeomagnetic data to place these sites in their chrono-cultural context, a fundamental step towards reconstructing copper production and trade systems in the northern Arabah when urbanism first emerged in this part of the Middle East. The sites have attributes that broadly place them in the EB Age; however, as the EB cultures cover more than a millennium, ancient geomagnetic intensity values retrieved directly from slag are used to further constrain the absolute age of the sites. This was done based on comparison to the most updated Levantine Archaeointensity Curve (LAC, Fig. 2; after Shaar, et al., 2016) and to recent data from EB Age Syria (in particular the well-studied site of Ebla [Tell Mardikh], Gallet et al. 2014). This is a new approach to dating southern Levantine EB Age sites, especially where organic samples suitable for radiocarbon dating are lacking and material culture remains are relatively scant and do not enable clear typo-technological dating. The results are correlated using the newest absolute chronology for the EB Age southern Levant published recently by Regev et al. (2012a, 2012b) based on its division into the EB I, II, III and IV by pottery typology.

2. Geomagnetic archaeointensity research of slag deposits

The most commonly used material in archaeomagnetic studies is baked clay (pottery, kilns, and mud bricks) (Thellier, 1938, Valet, 2003). However, recently Ben-Yosef et al. (2008a) pointed out the advantages of slag material in such studies, and Shaar et al. (2010) demonstrated its high reliability as an archaeointensity recorder. Slag samples can have a relatively high success rate in archaeointensity experiments owing to its glassy texture (abundant single domain grains) and high resistance to alteration in the laboratory. Slag samples are rarely found in their original cooling position; therefore, they are ideal only for retrieving intensity values (and not directions). For the Levant (including Israel, Jordan and Cyprus), dozens of slag samples from various periods were analyzed for archaeointensity by Ben-Yosef et al. (2008a) and Shaar et al. (2011, 2015). The results, complied with data obtained from pottery samples by several other studies, comprise the current Levantine archaeointensity curve (LAC, Fig. 2). The resolution of the LAC was recently improved for the EB Age with data from Ebla, Syria (Gallet, et al., 2014:, see above) and for the early Iron Age (1100 – 800 BCE), with data on decadal intervals obtained from stratified slag deposits in Jordan and Israel (Ben-Yosef, et al., 2009, Shaar, et al., 2011). The Iron Age data demonstrate a double peak in intensities ('archaeointensity spikes') reaching values not documented before (Shaar et al., 2016). These very high values for the period around 1000 BCE have recently been found in nearby Turkey by Ertepinar et al.(2012), and are also documented in the current study.

3. Smelting sites and sample collection

Three smelting sites in the northern Arabah Valley (‘Ein Yahav, Giv’at Hazeva and Ashalim) and one metallurgical manufactory (Khirbat Hamra Ifdan) in the Faynan copper ore district were investigated as part of the current research (Fig.1). All of these sites should most probably be associated with the ore deposits of Faynan (Hauptmann, 2007), as the next closest major ore source is located more than 100 km to the south (in Timna, southern Israel).

3.1 *Khirbat Hamra Ifdan (KHI) (30°39’39’’N, 35°23’34’’E)*

Khirbat Hamra Ifdan is a large (ca. 1.5 ha.) EB metal refining and casting workshop, the largest and best preserved of its kind currently known in the Ancient Near East. Since first discovered in the 1970s, it has been surveyed (Raikes, 1980), sampled (Adams, 1992, Adams, 1999, Adams, 2000, Hauptmann, 2007:134-136, Corbett et al., 2014: 653-654) and excavated on a large scale (Levy, et al., 2002). The excavations reported on here were conducted by the expedition of the University of California San Diego and the Department of Antiquities of Jordan over a number of years (1999, 2000, 2007, 2011, under the direction of T.E.L. and M.N. – the first two seasons with R. Adams). The 2007 excavations (supervised by A. Muniz) at Areas E and D (Fig. 3) were specifically designed for obtaining slag samples for archaeointensity investigation. KHI represents primarily EB III and EB IV occupation, as indicated by typical ceramic assemblages and radiocarbon dates (see below). Additionally, limited EBII activity has been reported from the lower strata (Levy et al. 2002). The EB III-IV sequence at KHI spans two disparate socio-political organizations in the settled regions of the southern Levant, with a sharp transition from the first urban societies during the EB II-III (e.g., Gophna, 2003:, and references therein) to a period of non-urban societies during the EB IV (e.g., Dever, 2003:, and references therein). While the EB ceramic typology has been defined early on in the archaeological research of Palestine (Albright, 1949:, there EB IV is referred to as Middle Bronze I, and see more on culture history of these periods and their terminology in Mazar, 1990), absolute chronology for the sub-phases of the EB Age followed only later, with a major revision published recently (e.g., Regev, et al., 2012a, Regev, et al., 2012b). For identifying and characterizing synchronic copper production and trade systems in the northern Arabah Valley during the EB Age, we retrieved archaeointensity estimates from slag associated with different contexts at KHI.

The samples used from KHI derive from mixed EB fills below the Iron Age layers, as it was hard to isolate better contexts (e.g., floors). The archaeological accumulation in Area E consists of two distinct types of slag: large fragments of black tap slag densely scattered on the surface, dated to the Iron Age by typological considerations (advanced tapping technology first introduced to the region towards the end of the second millennium BCE, see Hauptmann, 2007), and small grayish pieces sparsely scattered in the fills and occupation levels of the lower strata, associated with EB Age pottery (Fig.4). Samples of the two slag types were collected for archaeointensity inspection. In addition, slag samples were collected from EB Age contexts at Area D (also mostly from fills with loose association to ceramic markers). The exact location and context of slag samples that yielded successful archaeointensity results is shown in the supplementary materials (Supplementary Material #1, KHI Harris Matrix).

3.2. *'Ein Yahav (30°36'22''N 35°12'05''E)*

'Ein Yahav is located on a crescent-shaped hill in the western margins of the northern Arabah Valley, 1.5 km southeast of the small spring of 'Ein Yahav and ca. 14 km west of the copper mines of Faynan (Fig. 1). Small black pieces of slag mixed with ash and furnace debris are scattered on the hilltop and on the northwestern slopes. The smelting remains are associated with sparse datable ceramic and organic materials, indicating a predominantly EB Age occupation and possibly some Roman activities (Vardi, et al., 2008, Yekutieli, et al., 2005). Results of a small excavation conducted in 2003 by Yekutieli et al. (2005) included one radiocarbon date (3615±40 BP; 2028-1925 BCE 68.2% and 2131-1883 BCE 95.4% probability; OxCal v.4.2, © Ramsey 2013, Cf. Fig. 10) and a diagnostic pot sherd, both indicating activity during the later part of the EB IV. Yekutieli et al. (2005) also report some copper ore with manganese impurities, typical to the Faynan mines.

We collected surface slag samples from various locations, including the area identified by Yekutieli et al. (2005) as an EB IV smelting workshop. One sample (t) from the latter was subjected to archaeointensity experiments.

3.3. *Giv'at Hazeva (30°45'00''N 35°15'33''E)*

Similar to the site of 'Ein Yahav and ca. 17 km to the north, the site of Giv'at Hazeva (Site 260 in B. Rothenberg's unpublished survey, Site 15 in Hazeva Map [#213] of the Archaeological Survey of Israel, www.antiquities.org.il/survey/new) is located on a hill on the western margins of the northern Arabah Valley (Fig. 1). Also here slag, ash and furnace debris are scattered on the hilltop and on the slopes that face the local western winds. The site has not yet been systematically investigated (Ayalon, 1978); however, the metallurgical remains and their context (wind-blown furnaces on hilltops) suggest EB Age activity, similar to the excavated site of ‘Ein Yahav (Yekutieli, et al., 2005:35) and wind-blown furnaces documented in several sites in Faynan (Hauptmann, 2007:, and see below).

We collected surface slag samples from the southern face of the hill. Except several Roman to Early Islamic coins of unclear provenance (Israel and Nahlieli, 1983), the site lacks any datable ceramic and seems to represent exclusively copper smelting activities.

3.4. *Ashalim (31°03’35’’N 35°20’15’’E)*

The site of Ashalim (also Nahal Ashalim) was discovered in 1964 by a survey team of the Masada expedition headed by Y. Tsafrir, and re-surveyed in 2002 by Y. Israel (both unpublished). It is located west of Mt. Sodom, ca. 40 km northwest of the Faynan copper ore district (Fig.1). Three slag scatters, located at the center of the site, constitute the most distant such deposits from the mines of the Arabah Valley known today. The dominant feature at Ashalim is numerous lines of standing stones, or *Masseboth* (examples in Fig. 5, features 13, 17), indicating that the site had an important cultic function in addition to its metallurgical one. The *Masseboth* are reported by U. Avner (2002:65 and Table 11) as part of his monumental study of cultic sites in the deserts of the southern Levant. The site of Ashalim is unique, both in having a large amount of *Masseboth* at one location (we recorded 99 independent examples) and a wide variety of types (5 out of 7 types and 10 out of 18 sub-types in Avner’s classification are present at the site). The *Masseboth*, in general, are considered to represent ancestors or gods, and were worshipped typically by desert societies of the Ancient Near East during the 6^{th} – 3^{rd} millennia BCE (Avner, 1984, Avner, 1993, Avner, 2001). Similar to other sites, also here the *Masseboth* are systematically facing east, towards the rising sun (Avner, 2002:66).

The three slag scatters, *Masseboth* and other architectural features at the site were surveyed and mapped by our team during 2008 – 2009, and a few dozens of slag samples were collected (from all scatters) for archaeomagnetic studies (Fig.6a-b, and supplementary material #2 [KMZ file of mapped features]). The slag spatial relation with the stone features, together with the unique location of the site and lack of stratification, suggests that all finds belong to the same chronological phase. As not a single sherd of pottery or any other datable artifacts was found, the archaeomagnetic study is a key for dating this enigmatic site of copper production and cult.

4. Experimental procedure

The experiments for retrieving geomagnetic intensity values from thermally impacted materials are most commonly based on the Thellier-Thellier method (Koenigsberger, 1936, Thellier and Thellier, 1959), in which the natural remanent magnetization (NRM) is gradually replaced by an artificial thermal remanent magnetization (or TRM) in the laboratory using an oven with a controlled magnetic field. In more recent practice of the method, the gradual replacement is done in successive temperature steps and a series of tests are conducted to verify that the mechanism of acquisition of remanent magnetization did not alter throughout the experiment and that the requirements of the method are met (e.g., lack of so-called pTRM tails, and present of single component magnetization). For the current study we use the IZZI experimental protocol of Tauxe and Staudigel (2004).

A total of 71 samples from the sites described above were subjected to archaeointensity experiments. The samples were cut into 332 specimens, each a few mm in diameter. These were placed in small glass tubes, wrapped in silica filter papers and glued into place with *KaSil* for processing. The experiments were conducted at the paleomagnetic laboratory at the Scripps Institution of Oceanography. The protocol is based on alternating between heating and cooling the specimens in a known magnetic field (in-field step [I]) and in zero field (zero field step [Z]). We included the so-called pTRM-tail check of Riisager et al. (2000) and the pTRM check step (Coe, et al., 1978). In addition, all successful specimens (98) were subjected to either anisotropy of anhysteretic remanence or anisotropy of thermal remanence correction (AC-AARM and AC-ATRM respectively) in order to compensate for possible bias resulting from non-random alignment of the magnetic minerals (Selkin, et al., 2000). Here, we test whether the tensors derived from the anisotropy experiments are significantly anisotropic (based on the F test of Hext (1963), see also Chapter 10 in Tauxe (2010)). Specimens for which isotropy could not be rejected at the 95% level of confidence were not corrected, but the method (AC-ISO) is noted in the specimen table in the Supplemental Material #3. Due to the fast cooling rate of slag material, there was no need for cooling rate corrections (see Ben-Yosef, et al., 2008a).

There is no standard procedure for selection of archaeo- or paleo- intensity data (Paterson, et al., 2012) and there are a large number of selection criteria in common use. Here we adopt the same selection criteria used by Ben-Yosef et al. (2009) and detailed in Table 1. These criteria define the quality of a specimen (i.e., its reliability as an archaeomagnetic recorder) based on its behavior during the experiment. The changes in magnetic remanence on a specimen level during the experiment are commonly presented graphically (Fig. 7), and some of the selection criteria are based on calculations related to these graphs. For example, β (Tauxe and Staudigel, 2004) indicates the scatter about the best-fit slopes (green lines in the Arai plots, Fig. 7) and MAD the scatter about the best-fit line from the demagnetization data (end-point diagrams in Fig. 7) (Kirschvink, 1980). For further explanation on the experimental procedure and data processing see in general Tauxe (2010), and in particular for slag material Ben-Yosef et al. (2008a).

5. Results

5.1. *Archaeointensity results*

Out of a total of 332 specimens, 107 met the strict selection criteria listed in Table 1. The experimental data and results of all specimens will be uploaded into the MagIC online database (https://earthref.org/MAGIC/); the data for the successful specimens are provided in Supplementary Material #3. Only sample averages based on at least 2 specimens with standard deviations within 5 μT or 15% are considered here (Table 2). Over half of the results have moderate field intensities of less than 90 ZAm^2 (the present field is approximately 80 ZAm^2, [Z=10^{21}]), but 10% have field values in excess of 150 ZAm^2, an unusually high field intensity found in less than 2% of published dipole moment data in the MagIC database. These high values are characteristic of the Levantine Iron Age and have not been detected in the Levant at any other time period.

5.2. *Archaeointensity spike recorded in slag deposits at KHI and Giv'at Hazeva*

The overall field intensity during the Iron Age in the Levant was unusually high (140-150 ZAm^2). Superimposed on this high field, "spikes" in field intensity in excess of 170 ZAm^2 were recently recorded by several studies (Ben-Yosef, et al., 2009, Shaar, et al., 2011, Shaar, et al., 2016). High values at approximately the same age were also found recently in nearby Turkey (Ertepinar, et al., 2012). The current study provides further support for this unique feature in the history of the geomagnetic field. One sample from KHI (b62610a) met our strict selection criteria with VADM in excess of 200 ZAm^2 (Table 2, Fig. 7). An unprecedented extremely high value was recorded in Giv'at Hazeva (sample p, Table 2), in an undated slag fragment. This value (more than 300 ZAm^2) most probably represents the peak of one of the Iron Age spikes. The new intensity values agree with data published by Ben-Yosef et al. (2009), which included VADM estimates greater than 200 ZAm^2 (and up to 250.8 ZAm^2).

5.3. *Archaeomagnetic age constraints on smelting sites in the northern Arabah valley*

According to the data available to date for the Levant (LAC, Fig. 2), the high archaeointensity estimates (above 140 ZAm^2) retrieved from Giv'at Hazeva and KHI (Table 2) indicate Iron Age copper smelting activities in both sites. Although the context of the one sample from Giv'at Hazeva (sample p) lacks any supporting contextual evidence for this age, its extremely high intensity value correlates only with the Iron Age spikes (see section 5.2 above). It is not likely that the unprecedented high value from Giv'at Hazeva represents a new, yet unrecorded spike from a different period, as the Iron Age spikes are associated with a unique period of high field intensity (Fig. 2) which is probably a precondition for this phenomenon (Shaar, et al., 2011). Moreover, the sample from Giv'at Hazeva is probably the peak of the earlier and higher spike, dated to around 980 BCE (Fig. 8).

At KHI, the high intensity values were retrieved only from the non-EB tap slag of the upper strata (Fig. 4) that was tentatively dated to the Iron Age by its technology. Evidence at the site that supports an Iron Age date includes a surface find of an Egyptian scarab carrying the name of Pharaoh Shoshenq I (late 10th c. BCE) (Munger and Levy, 2014) and a radiocarbon date of a charcoal obtained from the excavations at Area L (2910±41 BP; 1192-1021 BCE 68.2% and 1261-995 BCE 95.1% probability; OxCal v.4.2, © Ramsey 2013; Stratum IIIA, L. 3034, B.45344, RC23) (Levy, et al., 2012). However, only the archaeointensity data provide direct dating for the slag itself, avoiding problems of context (the charcoal, excavated at the adjacent Area L [Fig. 3], is not directly associated with the slag layer but with a mixed context of EB Age IV pottery, bones and loose sediments) and typology (slag type can at best be used as a *terminus post quem* (cf. Ben-Yosef, et al., 2010)). Moreover, as the archaeointensity estimates include the unique values of the spikes (226±6 ZAm^2), we suggest that smelting activity here was conducted around 980 BCE, similar to Giv'at Hazeva (Fig. 8).

Our archaeointensity estimates for EB Age slag from KHI form two tight groups (Table 2, Fig. 9) with chronological significance. The higher group, averaging 93±9 ZAm^2 VADM, most probably represents copper production activities starting at the end of the EB III and running through the EBIV, while the lower group, averaging 68±1 ZAm^2 VADM, most probably represents copper production activities during the transition from the EB II into the EBIII. The magnetic results from the slag of 'Ein Yahav (88±6 ZAm^2 VADM) correspond to the higher (i.e. *later*) group and probably date to the later part of the EBIV, in accordance with the previously obtained radiocarbon date for the site (Section 3 above). Giv'at Hazeva yielded very similar magnetic results to 'Ein Yahav (87±6.5 ZAm^2 VADM), probably indicating concurrent activity. The site of Ashalim yielded archaeointensity values that are in an excellent agreement with slag that corresponds to the earlier group at KHI (67±11 ZAm^2 VADM). This most probably indicates that metallurgical activity at Ashalim took place around the EB II-III transition.

In addition, previously published archaeomagnetic data for slag from EB Age Faynan should be reexamined in light of the new data from Syria (Gallet, et al., 2014) and the new absolute chronology for the EB Age suggested by Regev et al. (2012a, 2012b) (Fig. 9). The site of Faynan 15 (Hauptmann, 2007) yielded archaeomagnetic intensity values of 99.3±1 and 100±15 ZAm^2 (Ben-Yosef, et al., 2008b:Table 2) and should most probably be dated to the late EB III – EB IV (and not EB II-III as previously published). In addition, the site of Timna 149 yielded values of 85.5 ± 8.59 ZAm^{2,} VADM, matching the same time span (Ben-Yosef, et al., 2008b:Table 2). On the other hand, with intensity values of 68.6±10.2 ZAm^2 the previously published sample from KHI (Table 2, sample JS08a, cf. Ben-Yosef, et al. 2008a, 2008b) should now be dated to the EB II-III transition (and not to the EB IV).

6. Early Bronze Age copper production in the northern Arabah in light of the new archaeomagnetic data

The Faynan region (Fig.1) is the largest copper ore district in the southern Levant. Together with the smaller ore districts of Timna and southern Sinai, located 100/300 km to the south (respectively), it played a role in the history of the region as a provider of copper, displaying intermittent exploitation efforts throughout the millennia (e.g., Hauptmann, 2007, Levy, et al., 2014). Current data do not allow to directly connect the northern Arabah copper production center (Faynan and related sites) to its counterpart in the southern Arabah (Timna and related sites) before the Iron Age (Ben-Yosef, 2010). Particularly, the major sites of Tall al-Magass and Hujayrat al-Ghuzlan (Khalil and Schmidt, 2009), dated to the late 5th – early 4th millennia BCE, did not yield any evidence linking them to the north (Hauptmann, et al., 2009).

In Faynan, the earliest evidence of smelting activity comes from the early EB I site of Wadi Fidan 4 (inset to Fig. 1) (Adams and Genz, 1995, Genz, 1997, Genz, 2000, Genz and Hauptmann, 2002, Hauptmann, et al., 1996). This represents a major transition from long distance ore transport and trade intended for the smelting centers in the northern Negev's Beersheva valley (e.g., Levy and Shalev, 1989, Shalev, 1994) to the first local control of copper production within Faynan. The early EB I smelting activities in Faynan correspond with significant refining and casting workshops in the southern coastal plain (e.g., the metallurgy at the site of Afridar (Fig.1), and see overview in Avner, 2002:39-64, Milevski, 2011, Segal, et al., 2004), indicating a period of active copper production and trade.

The earliest substantial evidence for copper production in Faynan during the Early Bronze II (ca. 3100 – 2900 BCE) is at Barqa el-Hetiye (Adams, 2003, Adams, et al., 2010, Fritz, 1994) (inset to Fig. 1). There, slags of copper smelting were recorded on top of nearby hills, while evidence of refinement and further processing of the metal into ingots was documented in association with architectural remains (Hauptmann 2007). Similar to Barqa el-Heitye, KHI has evidence of secondary processing of raw copper in association with architecture. The sites, which are ca. 5 km apart, were responsible for channeling and processing copper produced by wind-operated furnaces on hilltops in their 'territory'. From the two separate centers, copper was exported in the form of ingots and/or final tools to the settled centers to the north and north-west of Faynan. The location of Barqa el-Hetiye and KHI was probably dictated by the nearby water sources (Ein Fidan and Bawarde springs respectively) that enabled more permanent activities and various aspects of the secondary metallurgical processing in these important centers.

Our study shows that the site of Ashalim was probably active during the late EB II, including substantial smelting of ore (most probably from Faynan) and possibly other metallurgical activities. The site is located far from the mines, on the main road between Faynan and the urban center of Arad west of the Dead Sea (Fig. 1). A segment of this road, where it overcomes the western escarpment of the Dead Sea Rift Valley (the Zohar Ascent), was thoroughly studied by Yekutieli (2006a, 2006b), including associated road facilities and pottery dated to the EB II-III transition (Yekutieli, 2009:226-229). While Yekutieli's assumption that this road connected the Arad region with the main cities of the Ghor east of the Dead Sea (e.g., Bab edh-Dhra, Fig. 1), it is now evident that a southern branch was active, and given the significance of copper this branch may have been the more important one. Ceramic correlations between KHI and Arad (Gidding, forthcoming) further testify to the role played by the Faynan region as a supplier of copper to Arad and beyond, in accordance with recent suggestions (Adams, 2003, Gophna and Milevski, 2003, Hauptmann, et al., 1992, Hauptmann, et al., 1999), and contra the previous view of southern Sinai as the *only* source of copper in this period (Amiran, et al., 1973).

It should be stressed, however, that while the Zohar Ascent is clearly associated with material culture remains originating in the cultural milieu of the settled regions to its north and west (Canaan), the unique site of Ashalim is culturally set within the framework of desert cultures (i.e., the "Timnian"; e.g. Rosen, 2011), with its lack of pottery and abundance of typical *Masseboth* installations. This suggests that if indeed the sites are contemporaneous, Ashalim and Zohar Ascent represent the contact zone between the desert cultures engaged in the production and transport of copper from the

Arabah and the settled-region culture of southern Canaan, represented most clearly at the site of Arad (Amiran, 1978, Amiran and Ilan, 1996).

The production at Barqa el-Hetiye seems to have stopped after the Early Bronze II. At some point, probably toward the later part of the EB III (ca. 2600), KHI became the prominent copper-processing site in the region, as indicated by both pottery typology, radiocarbon dates (Table 3, Fig. 10) and archaeointensity estimates of the present study (Fig. 9). This role continued uninterruptedly into the early EBIV (third quarter of the 3rd millennium BCE). During this period, KHI served as a hub for several smelting sites on nearby hilltops, containing wind-operated furnaces, which yielded radiocarbon dates spanning the late EB III – early EB IV sequence (Fig. 10, Table 3, Hauptmann, 2007).

The late EB III – early EB IV copper production is accompanied by a substantial wave of settlement in the central Negev (Cohen, 1999). The connection of these settlements to the Faynan copper industry has been established by various studies (e.g., Goren, 1996, Haiman, 1996, Segal, et al., 1999). In some of these sites fragments of copper ingots from Faynan were found (Hauptmann, et al., 2015), as well as evidence of secondary metallurgical activities (probably production of tools, Segal, et al., 1999). However, the Negev Highland sites were considered exclusively as an EB IV phenomenon based on ceramic correlation to the settled provinces to the north, in contradiction to radiocarbon data obtained from the sites themselves (Fig. 10, Table 3, Cohen, 1999). The dates from the Negev sites broadly range between 2700 to 2200 BCE, in excellent agreement with the dates from Faynan (Fig. 10).

Until recently, the beginning of the EB IV was placed around 2200 BCE, leading scholars to link the intense copper production and trade network revealed in Faynan and the Negev Highlands with Egypt during the First Intermediate Period (e.g,. Haiman, 1996, Yekutieli, et al., 2005). However, the new archaeomagnetic results, coupled with radiocarbon data from Faynan and the Negev sites, strongly suggest linking the copper activity with the rise and fall of the Old Kingdom of Egypt (ca. 2680 – 2180 BCE) (cf. Barta, et al., 2001). The new absolute chronological framework of the EB Age for the settled regions of the southern Levant (Regev, et al., 2012a, Regev, et al., 2012b), which places the beginning of the EB IV around 2500 BCE, further supports this suggestion by pushing back the date of common EB IV pottery found in the Negev sites (cf. Shahack-Gross and Finkelstein, 2015:262). Nonetheless, we argue that this production and trade system started already in late EB III (see above), clearly evident at KHI but has yet to be typologically distinguished in the Negev sites (and see Sebanne, et al., 1993). It is worth emphasizing that no copper smelting sites in Faynan and the northern Arabah have diagnostic pottery. The Faynan-Negev copper production and trade activities should be regarded as a distinct system, peripheral to the social processes of the fertile areas of the southern Levant, which is reflected in the continuity in production during the late EB III – early EB IV, in contrast to the dramatic upheavals in the transition between the periods in the fertile region (e.g., Dever, 1989, Dever, 2003, Miroschedji, 2009).

The radiocarbon date from ‘Ein Yahav, together with ceramic evidence from KHI (Gidding, forthcoming) and a few dates from the Negev sites (Table 3) suggest that limited copper production occurred also in the later part of the EB IV, with similar smelting technologies. The archaeointensity data (Fig. 9) do not allow for distinguishing between production phases within the EB IV. The decrease in demand for copper resulting from the demise of the Old Kingdom (contra Haiman, 1996) is reflected in this limited and less integrated phase of production.

After the EB IV copper production in the Arabah Valley ceased for ca. 700 years. The industry's revival in the Late Bronze Age is also related to Egypt, although in a much smaller scale and probably only in Timna, in the southern Arabah (Yagel, et al., forthcoming).

7. Conclusions

Archaeointensity estimates are a useful tool for providing age constraints on heat-impacted archaeological materials. In this study, we retrieved archaeointensity data from ancient copper slag samples that were collected in both surveys and excavations at four EB Age copper production sites in Faynan and the northern Arabah Valley. These data, when compared to the LAC and analyzed according to their archaeological setting, provide the following insights regarding EB Age copper production in the largest ore district of the southern Levant:

- KHI was the hub of copper processing and distribution of copper metal in the center of Faynan copper production system, channeling raw copper from smelting sites in its vicinity for further refining and casting of ingots and tools. The first small scale activity took place during the later part of the EB II, contemporaneous to the copper processing site of Barqa el-Hetiye. However, the main phase of activity was during the late EB III – early EB IV, with probable limited activity also in the late EB IV.
- The main phase of copper production in EB Age Faynan strongly coincides with the rise and fall of the Egyptian Old Kingdom. This connection is best manifested in the settlement wave of the Negev Highlands, which predominantly reflects transport of copper in an east-west direction. This phase is the first large scale copper production in the region.
- Copper metallurgy at the site of Ashalim is probably dated to the late EB II. The site, located on the main road between Faynan and Arad, is probably related to copper trade between Faynan and the fertile region of the southern Levant. This unique site includes, in addition to the metallurgical remains, dozens of standing stones, evidence of cultic activity that might be related to copper smelting and/or trade.
- In addition, our study provides new data from two different sites (KHI and Giv'at Hazeva) that support the unique Iron Age archaeointensity 'spikes' (Ben-Yosef, et al., 2009, Shaar, et al., 2011). The archaeointensity values from Giv'at Hazeva are the highest recorded to date (exceeding 300 ZAm^2), and add to our understanding of the geomagnetic field, one of the more enigmatic phenomena of the Earth.

Acknowledgments

We would like to thank the Israel Antiquities Authority and the Departments of Antiquity of Jordan, ACOR, the ELRAP staff and student volunteers, Jason Steindorf for the magnetic laboratory measurements, and Adolfo Muniz for his work in the field. We also thank Uzi Avner for sharing his knowledge about the Ashalim site. We would also like to thank the Israel Mapping Center for providing corrections for our differential GPS. This research was partially supported by NSF grants #: EAR 0944137 and EAR1141840, BSF grant #2012359, and Marie Curie FP7-PEOPLE-2012-CIG grant #334274.

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Tables

Table 1: Summary of acceptance criteria used in the archaeointensity experiments

DRATS	MD%	Z	β	F_{vds}	MAD	DANG	σ [σ%]	N_{min}
20	5	2	0.1	0.7	10	10	5 μT [15%]	2

σ [σ%]: standard deviation cut-off for sample means [expressed as percentage of mean of specimens per sample]; β is the scatter statistic defined by Tauxe and Staudigel (2004); MAD is the maximum angular deviation of the demagnetization data of Kirschvink (1980); N_{min}: minimum number of specimens per sample (for further explanations and references see Ben-Yosef, et al., 2008a).

Table 2: Successful* slag samples by archaeological context

Locus/ Context (for KHI, cf. supp. material #1)	Sample	N_B	B (uT)	s_b	s_b\%	VADM (ZAm^2)	s_vadm	Context average (VADM)
KHI: EB Age - low intensity group								
L.3068	b62579a	2	34.63	1.23	3.6	67.12	2.38	68±1
L.3031	b62341a	2	34.85	1.25	3.6	67.54	2.42	
	JS08a**	5	36	5.328	14.8	68.6	10.2	
KHI: EB Age - high intensity group								
L.3069	b62596a	2	41.57	5.53	13.3	80.57	10.72	93±9
L.3032	b62306a	3	45.48	9.32	20.5	88.15	18.06	
L.3079	b62425a	3	48.44	1.18	2.4	93.88	2.28	
L.3104	b62704a	2	49	2.99	6.1	94.97	5.8	
L.3024	b62214a	2	49.42	1.8	3.6	95.78	3.49	
L.3020	b62100a	2	54.87	0.21	0.4	106.3	0.4	
KHI: Upper stratum (Iron Age, see text)								
L.3024	b62006b	3	68.79	7.89	11.5	133.3	15.29	149.5±12
L.3024	b62206a	3	69.54	4.1	5.9	134.8	7.94	
L.3083	b62630a	2	72.54	10.25	14.1	140.6	19.87	
L.3053	b62391b	2	78.83	7.67	9.7	152.8	14.87	
L.3053	b62356a	4	79.58	12.87	16.2	154.2	24.94	
L.3017	b62071c	4	79.95	10.78	13.5	155	20.89	
L.3083	b62655a	2	83.15	8.39	10.1	161.2	16.27	
L.3056	b62448a	3	84.52	3.57	4.2	163.8	6.93	
L.3077	b62610a	2	116.5	3.19	2.7	225.8	6.18	226±6
Ashalim:								
surface find	ash01a	3	30.83	2.48	8.1	59.45	4.79	67±11
surface find	ash01b	4	38.85	2.71	7	74.91	5.22	
Giv'at Hazeva:								
surface find	h	4	42.67	8.18	19.2	82.61	15.84	87±6.5
surface find	r	7	47.4	6.76	14.3	91.76	13.09	
surface find	p	2	187.7	10.95	5.8	363.4	21.2	363±21
'Ein Yahav:								
surface find	t	9	45.21	2.99	6.6	87.65	5.79	88±6

* Excluded from this table are Samples b62656a (no AARM correction) and b62492a (undefined, mixed context, KHI locus 3062)

** Sample published in Ben-Yosef et al. (2008a)

N_B: number of successful specimens; estimates of ancient field intensity are given in micro-Tesla (B) and Virtual Axial Dipole Moment (VADM, ZAm^2), with their respective standard deviation (s_b and s_vadm).

Table 3: Compilation of EB II-IV radiocarbon dates from Faynan, the northern Arabah and the Negev Highlands (cf. Fig. 10)

Context	Sample	Age BP (uncalibrated)	±	Calibrated BCE (2-Sigma)		Reference
				From	To	
Copper Production Sites (Faynan and northern Arabah)	**Barqa al-Hetiye**					
	HD13975	4376	57	-3326	-2891	(Fritz, 1994)
	HD13976	4267	43	-3013	-2701	(Fritz, 1994)
	Khirbat Hamra Ifdan (KHI)					
	HD-16533	4044	40	-2848	-2470	(Adams, 1999)
	Beta-143811	4020	70	-2865	-2342	(Levy, et al., 2002)
	Beta-143810	3970	40	-2579	-2346	(Levy, et al., 2002)
	Beta-143813	3960	50	-2581	-2295	(Levy, et al., 2002)
	AA68210	3949	52	-2579	-2289	Unpublished
	AA68206	3934	37	-2565	-2297	Unpublished
	AA68207	3932	42	-2566	-2294	Unpublished
	HD-16534	3914	45	-2564	-2214	(Adams, 1999)
	AA68212	3850	47	-2467	-2153	Unpublished
	Beta-143812	3650	60	-2201	-1884	(Levy, et al., 2002)
	Fenan 9					
	HD10577	4140	109	-3011	-2459	(Hauptmann, 1989)
	HD10993	3981	50	-2828	-2309	(Hauptmann, 1989)
	HD10994	3973	85	-2858	-2206	(Hauptmann, 1989)
	HD10584	3812	77	-2470	-2036	(Hauptmann, 1989)
	Wadi Ghuwair 4					
	HD10573	4059	55	-2864	-2470	(Hauptmann, 2007)
	Ras en-Naqb					
	HD10574	3971	67	-2837	-2215	(Hauptmann, 2007)
	Fenan 16					
	HD10579	3923	61	-2573	-2209	(Hauptmann, 2007)
	Ein Yahav					
	RTT-4683	3615	40	-2131	-1884	(Yekutieli, et al., 2005)
Settlement Sites (Negev Highlands)	**Ein Ziq**					
	RT-885A	3960	90	-2858	-2201	(Cohen, 1999)
	RT-885B1	3880	60	-2559	-2149	(Cohen, 1999)
	RT-885B	3850	50	-2468	-2151	(Cohen, 1999)
	RT-2514	3700	45	-2266	-1951	(Cohen, 1999)
	Beer Ressisim					
	RT-2346	4085	70	-2872	-2484	(Cohen, 1999)
	RT-2347	4050	50	-2859	-2469	(Cohen, 1999)
	RT-2468	3930	40	-2565	-2294	(Cohen, 1999)
	Har Dimmon					
	RT-1557	3845	50	-2467	-2147	(Cohen, 1999)
	RT-1558	3565	60	-2124	-1744	(Cohen, 1999)

Figures

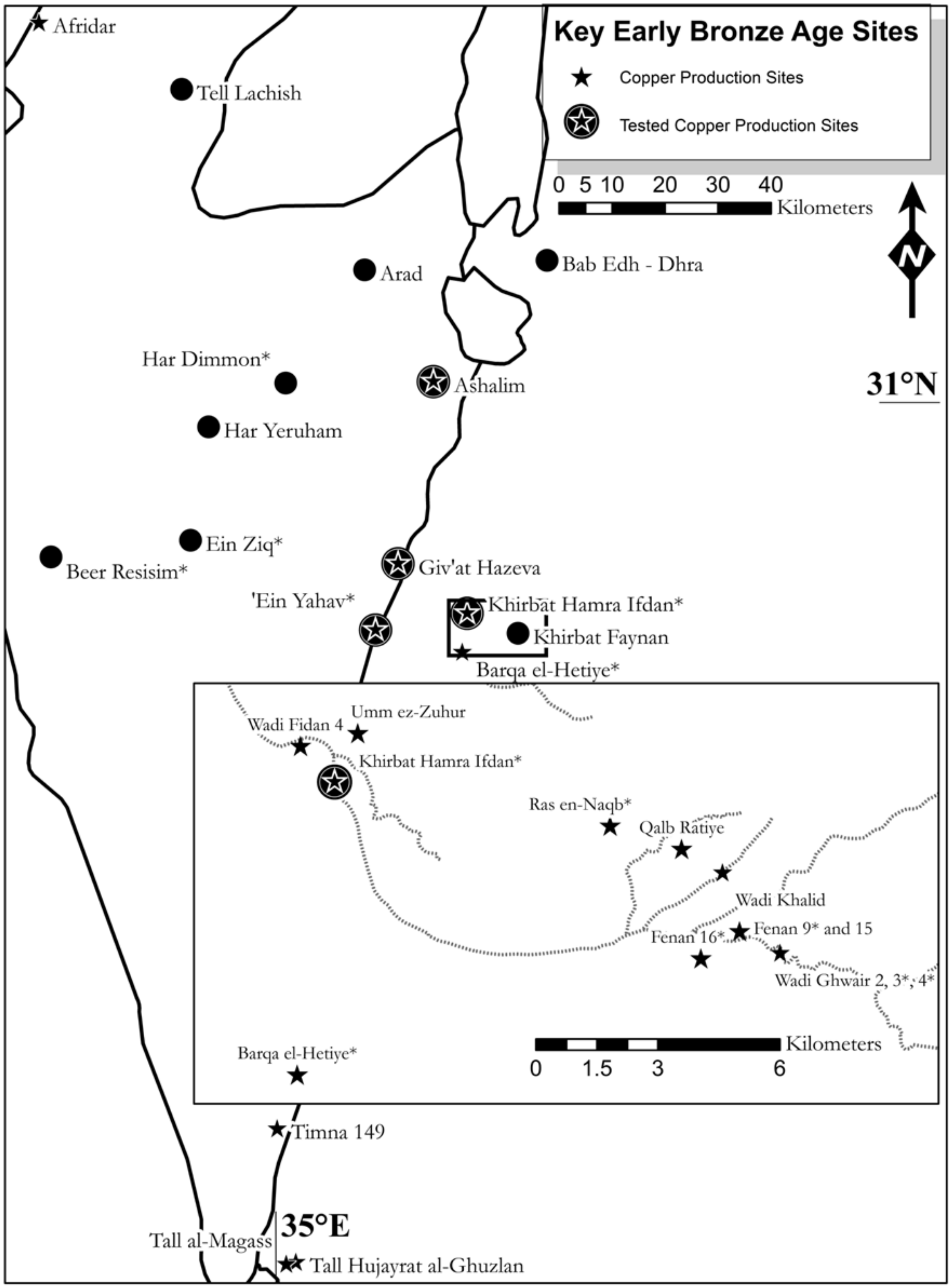

Figure 1: Early Bronze Age sites in the Negev Highlands and the Arabah Valley, with smelting sites tested in the current study emphasized. The inset presents EB Age copper mining, smelting and processing sites within the Faynan copper ore district. Sites with asterisk (*) are EB II – IV with published radiocarbon dates (cf. Fig.10, and Table 3).

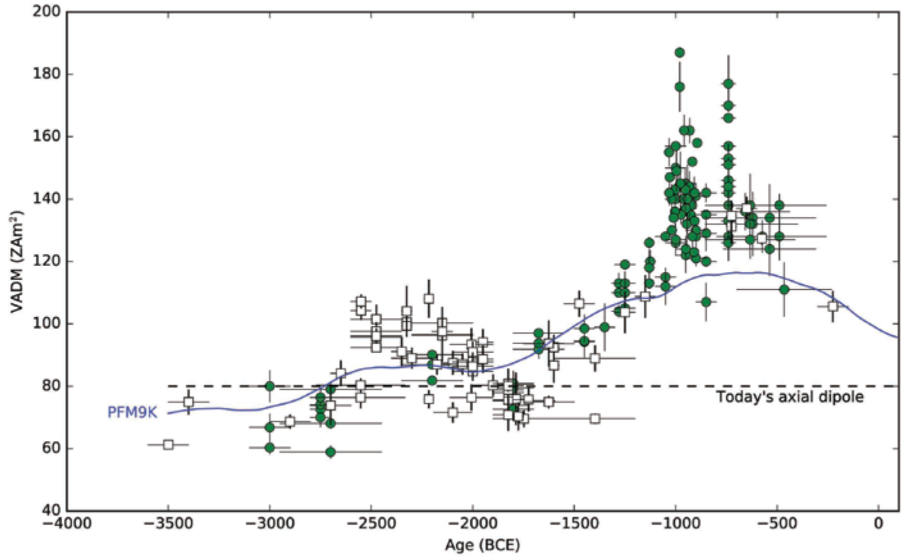

Figure 2: The Levantine archaeomagnetic intensity curve (in Virtual Axial Dipole Moment, VADM; $Z=10^{21}$), compiled with data from the southern and northern Levant (after Shaar, et al., 2016:, and see full references therein). The reference curve (thin blue line) is from the PFM9K model of Nilsson et al. (2014). All data, including results of the current study, are available in the MagIC database (earthref.org).

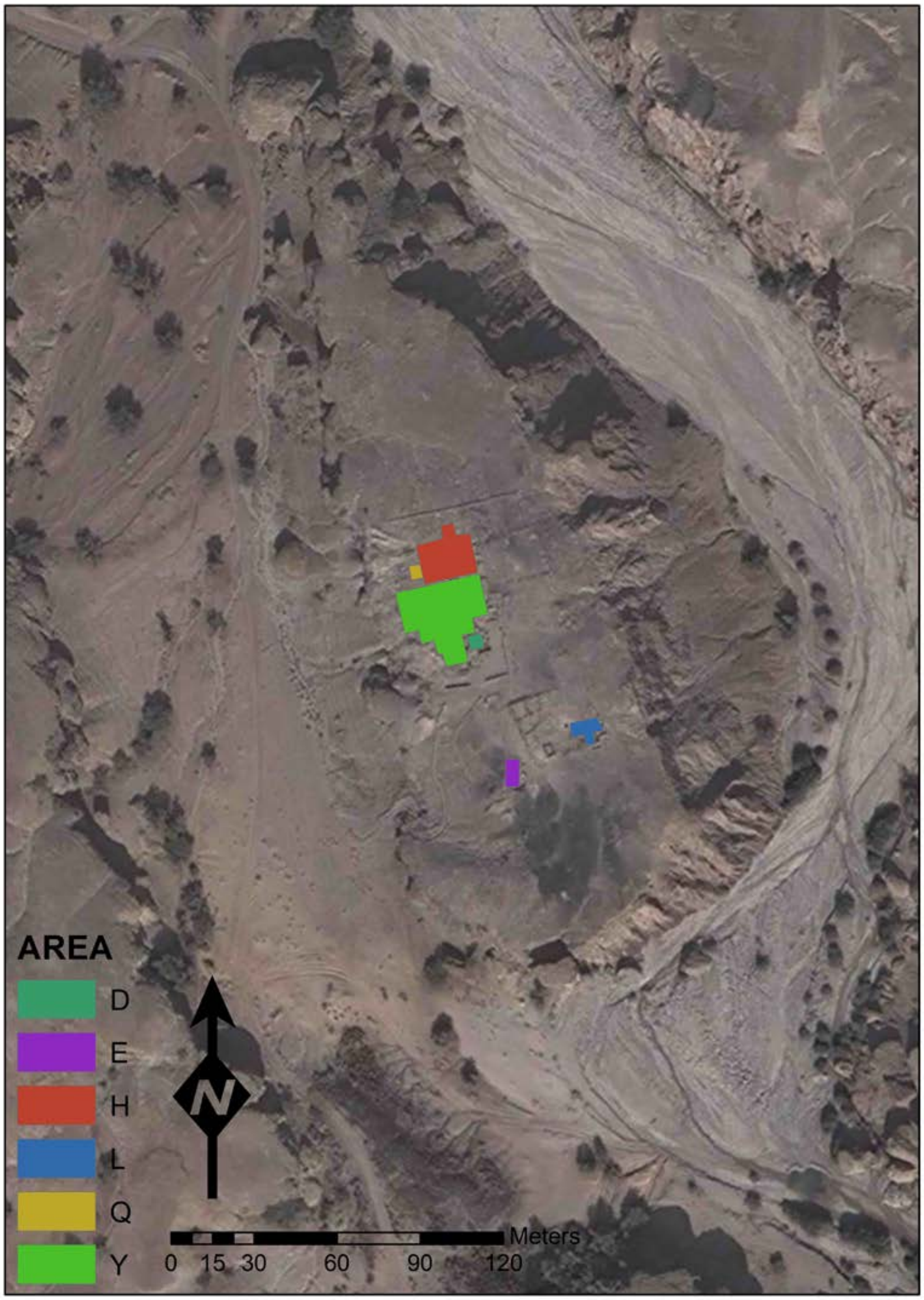

Figure 3: General map (based on Google Earth image) of the excavated areas at Khirbat Hamra Ifdan, an EB Age copper processing center located at the heart of the Faynan Copper Ore District (cf. Fig.1). The site is situated on a small inselberg to the west of Wadi Fidan near the oasis of ‘Ein Fidan; the black patch at the southern portion of the site is an Iron Age slag mound (see text for details).

Figure 4: Khirbat Hamra Ifdan (KHI), a section in the excavation of Area E. The distinct stratigraphy is reflected in different types of slag: broken fragments of black solid tap smelting slag at the top layer, and small greyish fragments of melting slag mixed in bright soil at the lower part.

Figure 5: Architectural features at the Ashalim Site. F48: a tumulus on the ridge, looking east; F78: stone features on the ridge. In this area the main scatter of small slag fragments is located. F17: lines of standing stones (*Masseboth*) facing to the east; F13: standing stones mapped in the current project.

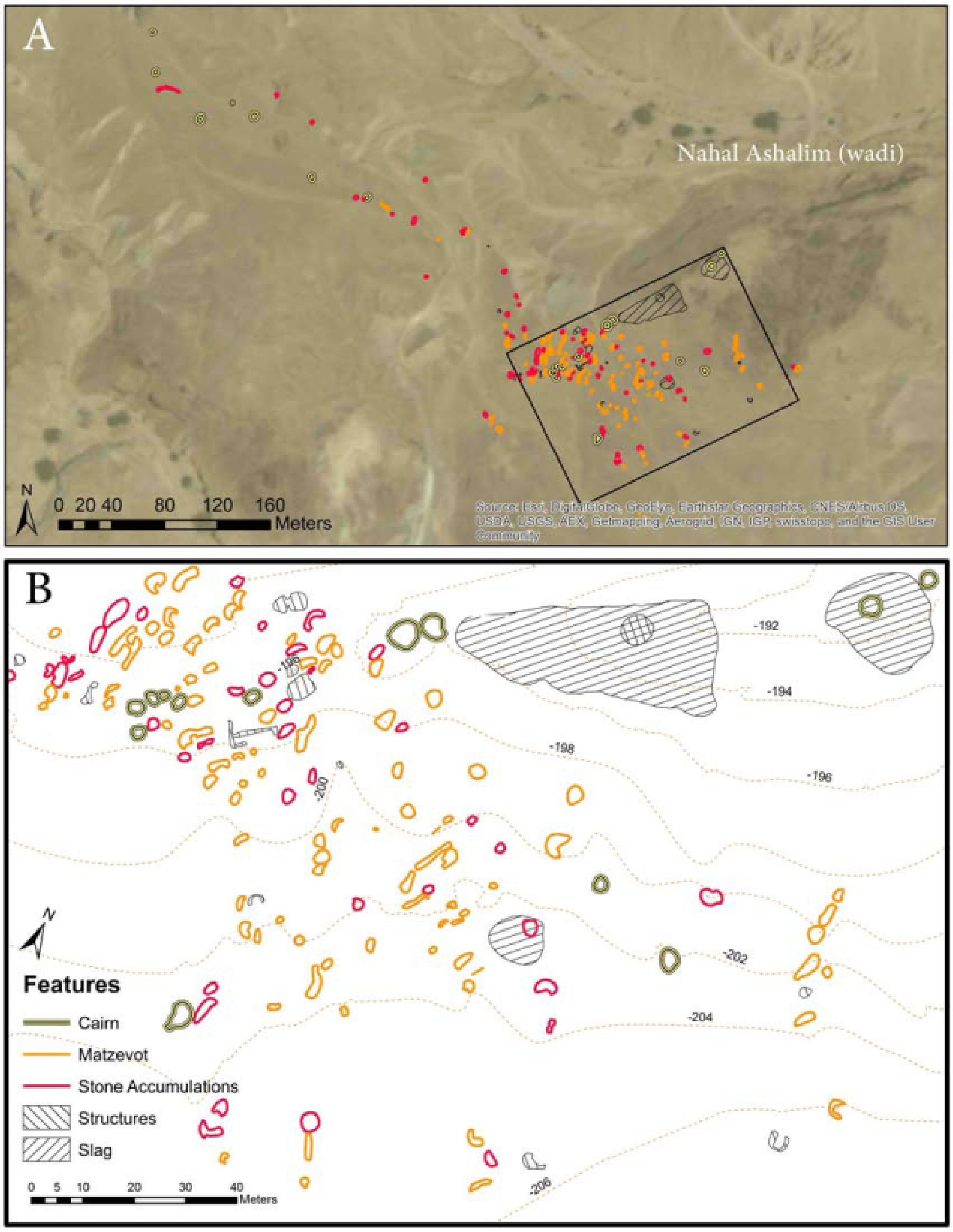

Figure 6: Map of the Ashalim Site on a satellite image (A). The various stone features are located on a low ridge along the southern / southwestern bank of Nahal Ashalim (Wadi Umm Tarafa in Arabic; its dry streambed is indicated by the vegetation on the upper right side of the image). Note the slag scatters, mostly centered at the highest location on the ridge. The center of the site is detailed in figure 6B, where it is noticeable that the standing stones (or *Masseboth*) are aligned north-south, as they are facing east (in some we recorded offering tables to the east of the stone lines).

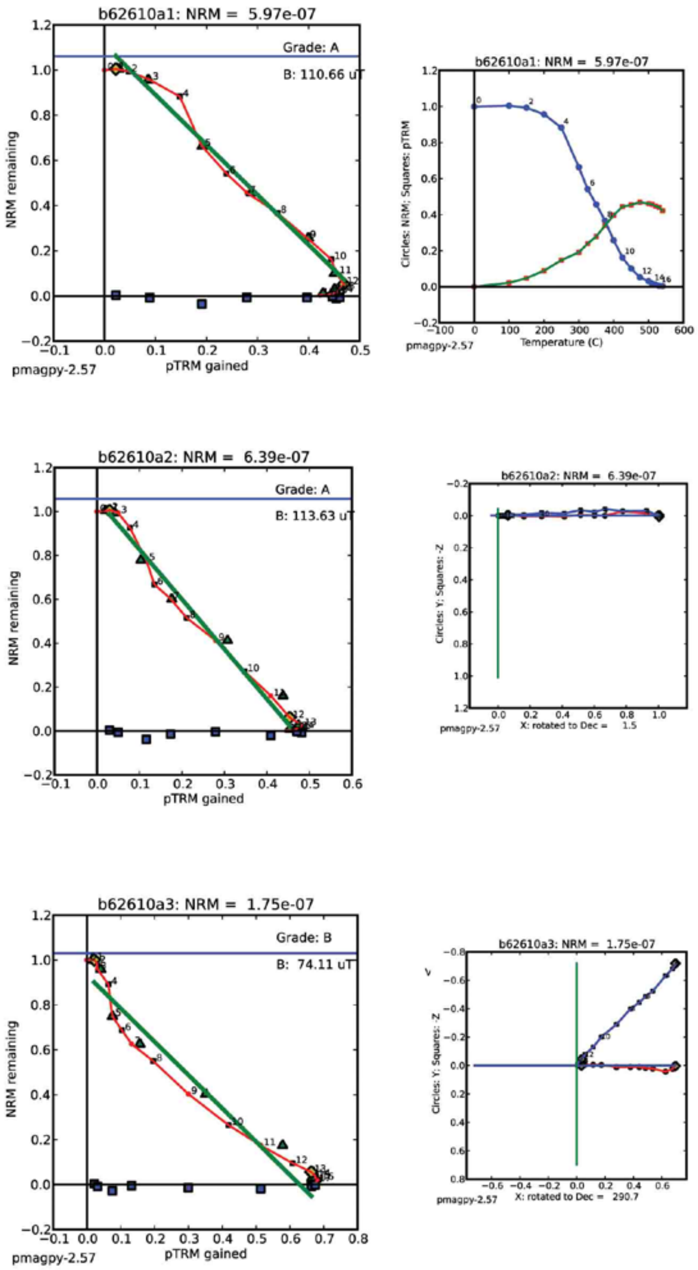

Figure 7: Example of results from archaeointensity experiments on slag sample from KHI. The three pairs of diagrams show results from three specimens obtained from one slag sample. Each point represents a temperature step and the resulting curves the behavior of the specimen throughout the archaeointensity experiment. The two upper specimens demonstrate excellent behavior (Grade A), in contrast to the lower specimen that was rejected because of its low quality (high scatter about the best fitting slope of the left diagram, Grade B). The two specimens indicate an extremely high intensity value for the ancient geomagnetic field (B in the left diagrams; cf. Fig.2 and Table 2 – there in VADM units = 226 ± 7 ZAm^2), probably the 'archaeointensity spike' identified by Ben-Yosef et al. (2009) around 980 BCE. The left plots are Arai diagram (Nagata, et al., 1963) and the right plots are vector end-point diagrams. For detailed explanation of these plots see Tauxe (2010).

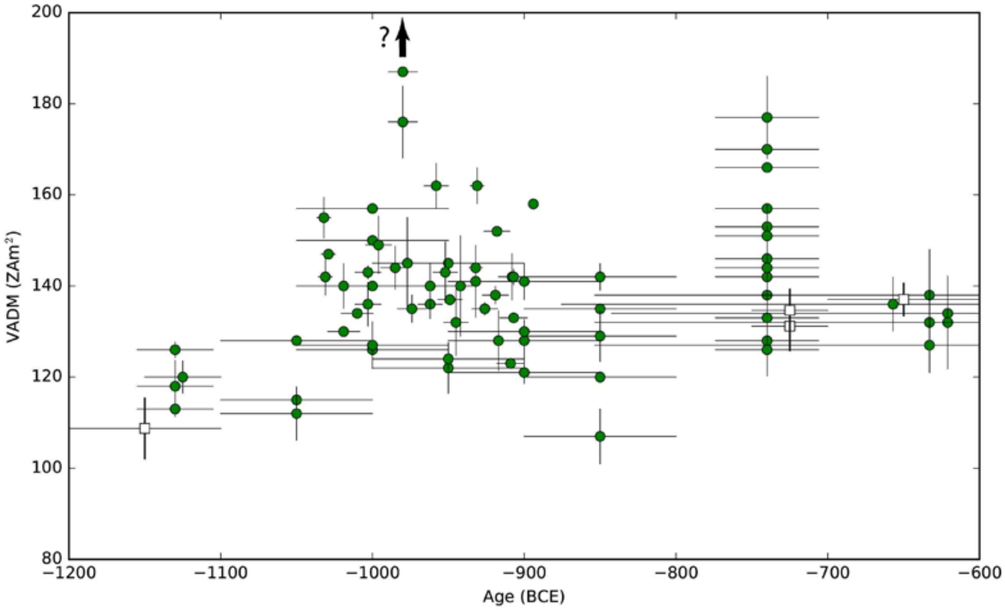

Figure 8: High resolution archaeointensity curve for the early Iron Age Levant indicating two ‘spikes’ of more than 170 ZAm^2 (after Shaar, et al., 2016). Data from the current study suggest that the earlier spike (around 980 BCE) might have reached intensity values of more than 200 ZAm^2(cf., Ben-Yosef, et al., 2009) (see text). In turn, they also indicate Iron Age smelting at KHI and Giv’at Hazeva.

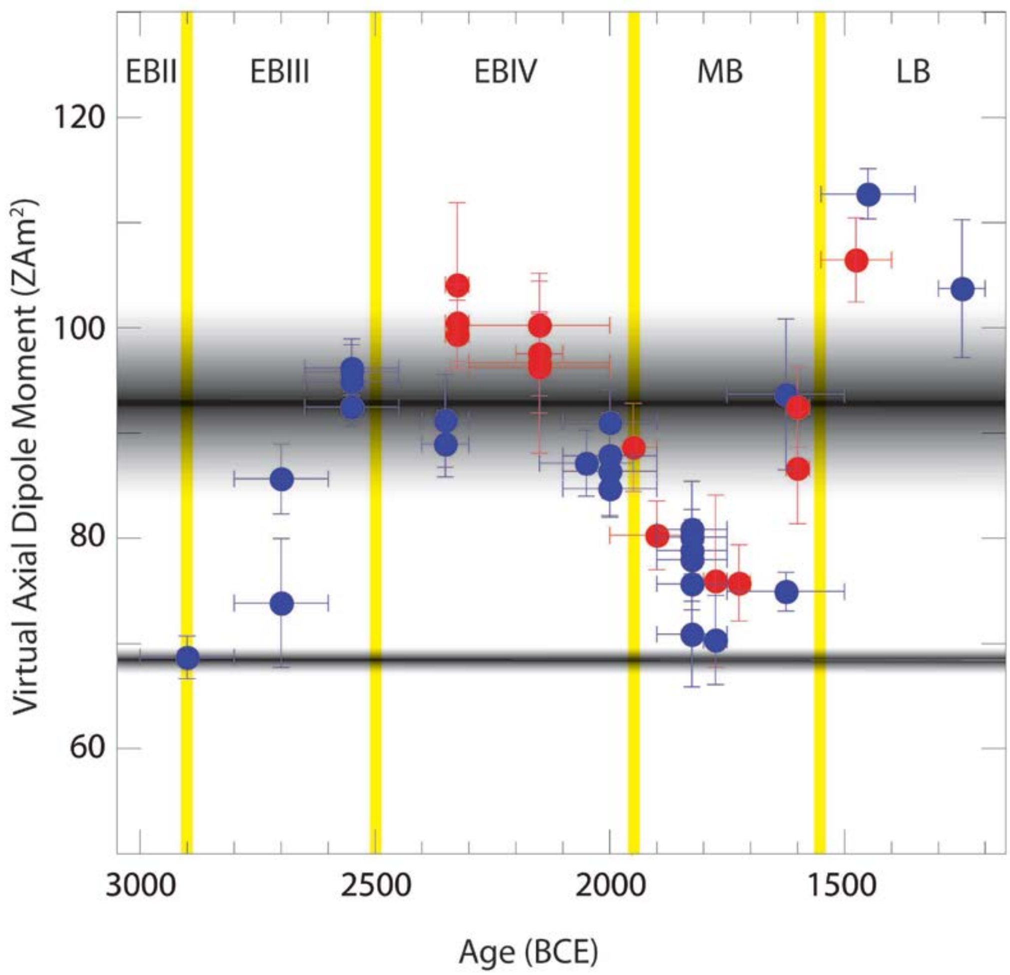

Figure 9: Results of the archaeomangnetic experiments of the current study plotted against geomagnetic values for the EB Age from Syria (Gallet, et al., 2014:, in red data from Ebla and in blue from other sites). The EB II-III and EB III-IV boundaries are after the new absolute dating of Regev et al. (2012a, 2012b). The geomagnetic values from the EB Age copper production sites of the southern Levant fall into two tight groups, of high intensities (around 90 VADM ZAm^2), and low intensity (around 68 VADM ZAm^2). The shading represents standard divination of the general mean; cf. Table 2.

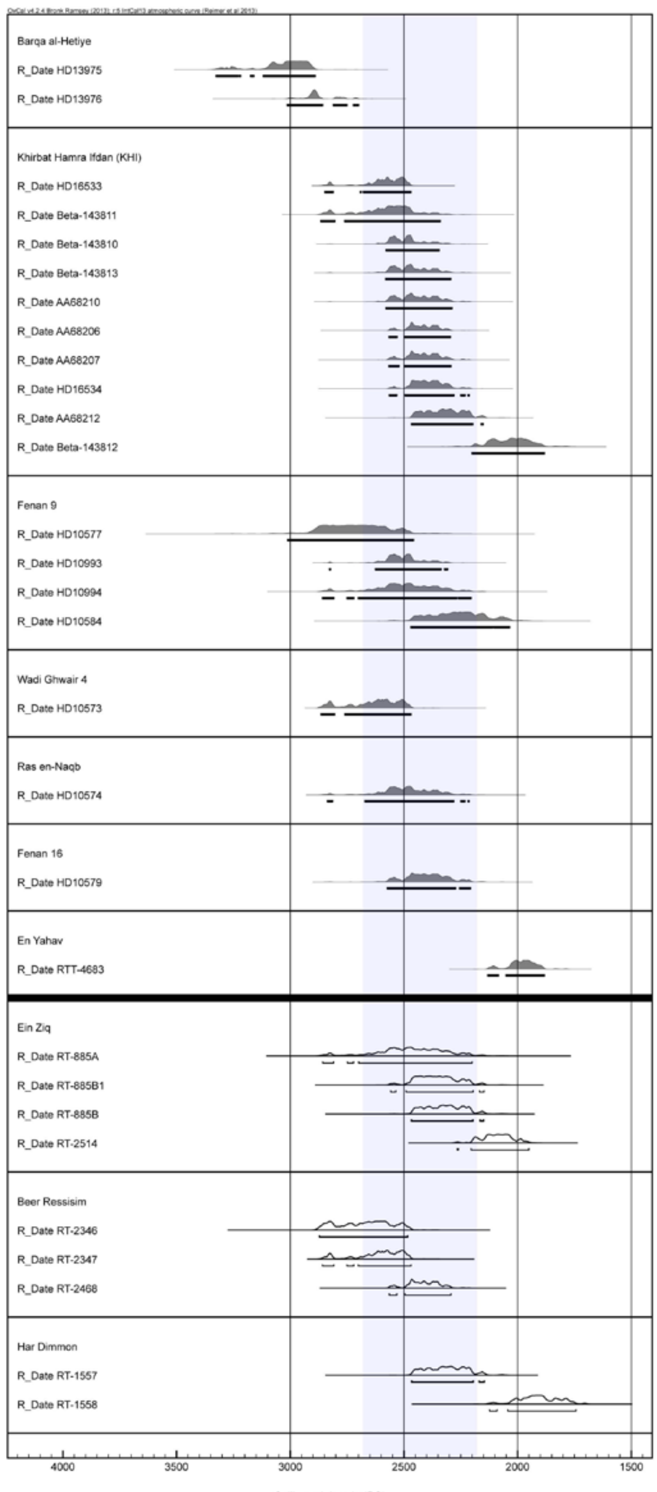

Figure 10: Compilation of calibrated radiocarbon dates (2-sigma) from EB II-IV copper production sites in Faynan and the northern Arabah (solid gray plots, including new dates from KHI), and the Negev Highlands sites (empty plots) (calibrated by OxCal v.4.2, © Ramsey 2013, cf. Table 3) (note that KHI probably does have EB II phase that is not represented by 14C dates). The plot emphasizes the connection between the Negev sites and the copper industry, and suggests that the main production phase is related to the Old Kingdom of Egypt (indicated by shaded blue).