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THE TRANSITION FROM BRONZE TO IRON IN CANAAN: CHRONOLOGY, TECHNOLOGY, AND CONTEXT

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ABSTRACT. In the framework of the European Research Council–funded project, "Reconstructing Ancient (Biblical) Israel: The Exact and Life Sciences Perspective," we carried out multiple analyses on iron and bronze objects from provenanced contexts in Israel, as well as on previously unidentified metallurgical remains from the production of both metals. In addition, we counted anew iron and bronze objects from well-stratified contexts and studied metalworking sequences at major sites, which included those that had undergone the bronze/iron transition. This enabled us to clarify some of the issues related to the bronze/iron transition in the southern Levant. Using this evidence, we showed that iron was not used for utilitarian purposes before the Iron I (late 12th century BCE) and that iron only became dominant concurrently with the beginning of its systematic production during the Iron IIA (10th–9th centuries BCE). A strong correlation between iron and bronze production suggests that during the Iron I local independent bronzesmiths adopted the new iron technology. Under local administrations that developed during the Iron IIA, workshops that previously produced bronze turned to iron production, although they continued to manufacture bronze items as a secondary venture. Significantly, at some of the major urban centers iron production was an independent industry that included the entire operational sequence, including the on-site smelting of the ore. This development appears to have been a major contributor to the transition to systematic production of iron.

INTRODUCTION

The transition from a bronze- to iron-based metal technology has been the subject of much discussion. Initially, the understanding of the development of iron technology was mainly based on the synchronic and diachronic distribution of objects as a means to determine when and where iron took precedence over bronze (Waldbaum 1978, 1980, 1982; Snodgrass 1980; McNutt 1990). The artifactual evidence, combined with textual sources, indicated that iron was produced in eastern Anatolia since as early as the late 3rd millennium BCE. The only earlier evidence is of isolated iron objects that were probably made of meteoric rather than smelted iron (for bibliography see Waldbaum 1999). During the Late Bronze Age, roughly the second half of the 2nd millennium BCE, there was a substantial increase in the number of iron objects and in their distribution, which ranged from Mesopotamia to Greece, as well as the Levant, Anatolia, and Egypt. There is also a recurring mention of iron in Hittite texts and, to a lesser extent, in contemporary Assyrian records (Pleiner and Bjorkman 1974; Curtis et al. 1979; Muhly et al. 1985).

Towards the end of the 2nd millennium BCE, iron began to be used for utilitarian purposes in Cyprus and the Levant (see below). In other regions, such as the Aegean, Anatolia, Caucasia, and Egypt, utilitarian iron use began during the 1st millennium BCE (see bibliography in Veldhuijzen 2005; for Caucasia see Khakhutaishvili 2009; Erb-Satullo et al. 2014). Noteworthy is the occurrence of utilitarian iron in western Iran during the very beginning of the 1st millennium (Pigott 1980, 1989), and the significant textual evidence for iron use in Assyria during the 9th century BCE (Pleiner and Bjorkman 1974).

With the lack of evidence for actual iron production, technological investigations have concentrated on the analysis of iron objects (see bibliography in McConchie 2004:21–33). Analysis of several iron objects from Cyprus and the Levant appeared to indicate the use of advanced heat treatments, such as quenching, lending support to the idea that Cyprus played a role in the dissemination of iron in the late 2nd millennium BCE (Stech-Wheeler et al. 1981; Maddin 1982; Smith et al. 1984; Davis et al. 1985; Astrom et al. 1986; Muhly et al. 1990; Muhly 2006; but see McConchie for criticism).

The Iron Age in Israel: The Exact and Life Sciences Perspective
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In general, the discussion of the introduction of iron focused on questions of ethnicity (who introduced the technology? the Philistines?) and necessity (why was it necessary to replace bronze with iron? e.g. ecologic or economic circumstances, such as shortage of raw materials and wood for the production of bronze) (Snodgrass 1971; Muhly 1982; Wertime 1982; Muhly et al. 1985; Waldbaum 1989, 1999; see also McConchie 2004). The discussion gradually shifted to considering the social, economic, and political circumstances that were behind this crucial transition (Pigott 1989; Sherratt 1994; Mirau 1997; Pickles and Peltenburg 1998).

In the course of the discourse, evidence for iron production dating to the Iron IIA surfaced in two excavations: Tell Hammeh in Jordan, where smelting activities were performed, and at Tel Beth-Shemesh in Israel, where the finds were interpreted as representing smithing activity (Veldhuijzen and Van Der Steen 1999; Bunimovitz and Lederman 2003; Veldhuijzen and Rehren 2007; Veldhuijzen 2009). Analysis of these finds yielded new interpretations of the chain of events that led to the precedence of iron over bronze, and demonstrated the importance of discovering production venues in any attempt to reconstruct this process (Veldhuijzen 2005, 2012; Bunimovitz and Lederman 2012).

In the framework of the ERC-funded project, "Reconstructing Ancient (Biblical) Israel: The Exact and Life Sciences Perspective," we were granted the opportunity to generate new data that could be used for a broader reconstruction of the bronze to iron transition. The research program entailed the systematic collection of varied data, both artifactual and in excavations, in order to study the production and utilization of both bronze and iron in the relevant periods (Late Bronze and Iron Ages). Our goals included the following:

1. Studying of the composition of bronze throughout these periods.
2. Detecting the origin of the copper through lead isotope analysis of objects and ingots.
3. Analyzing the distribution, technology, and style of bronzeworking remains.
4. Identifying iron-production venues by sampling and analyzing potential contexts, using metallurgically oriented excavation methods developed specifically for this purpose.
5. Studying the microstructure of a large number of well-dated iron objects in order to address questions regarding carburization, quenching and tempering.
6. Studying iron production remains from ongoing and past excavations in order to determine the type of process represented (smelting, refining, or smithing).
7. Compiling an updated catalog of bronze and iron objects from well-stratified contexts in order to refine and update the study of the development of iron use (utilitarian vs. precious or ceremonial, tools vs. weapons, etc.).

In this review, we wish to summarize the new evidence for iron use and production obtained from our studies, as well as from several other recent investigations (such as excavations at Faynan and Timna), which yielded significant relevant information that allows us to provide a more informed reconstruction of the bronze-to-iron processes.

THE DEVELOPMENT OF IRON USE

In her seminal study of the development of iron use, Waldbaum (1978) compiled a list of iron objects from Canaan, showing how their numbers gradually increased from the 12th to 10th centuries BCE. Based on this data and other available data from regions surrounding the Mediterranean, Snodgrass (1980) suggested three broad stages for the development of iron technology. According to his scheme, during most of the Bronze Age iron was used rarely and only for prestige and ceremonial purposes (Phase 1), while in the early Iron Age, it was used for the first time for utilitarian purposes but was still outnumbered by bronze (Phase 2). Only during the 10th century BCE or later did iron became dominant (Phase 3). McNutt (1990), in order to re-evaluate the hypothesized Philistine monopoly of iron technology, compiled an updated list of iron objects and was able to show that excavations in Philistia did not yield more iron items than any other contemporary region. A more updated version of this inventory, including bronze objects in addition to iron ones, was published by Gottlieb (2010). Her study targeted the uniformity of the transition, showing that sites with a strong Canaanite bronzeworking tradition adopted iron later than others.

In order to refine our understanding of the development of iron use, and in light of recent excavations at various sites that yielded additional bronze and iron objects (i.e. Tel Rehov, Khirbet Qeiyafa, Megiddo, and Hazor), we compiled an updated, comprehensive database of bronze and iron objects (Yahalom-Mack et al., forthcoming). The database includes bronze and iron objects from settlement sites throughout Israel, dating from the Late Bronze III (henceforth "LBIII")[1] until the end of the Iron Age. Only well-dated objects from secure stratigraphic contexts were included, so that some of the objects included in Waldbaum's study were excluded, resulting in a relatively smaller, but much more reliable data set.

We are well aware of the inherent methodological problems in comparing the number of iron objects with the number of bronze, as there is a major difference in the preservation of these materials (bronze objects, unlike iron ones, were naturally remelted; iron, on the other hand, corrodes, sometimes to full disintegration or loss of shape), and due to contingency of excavation (Yahalom-Mack et al., forthcoming). Despite this, the artifactual evidence remains a significant, and sometimes the only, indicator for the advent of iron.

Following is a summary of the development of iron use from its earliest appearance in the Late Bronze Age until its dominance in the Iron IIA, according to the three stages determined by Snodgrass (1980), enhanced by the results of the present study (Figure 1).

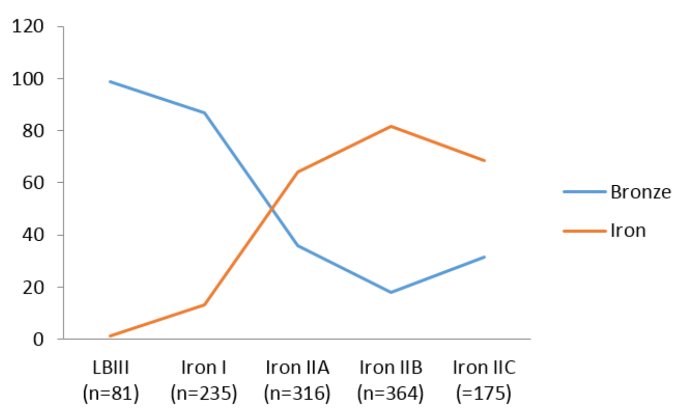

Figure 1 Percentage of iron tools and weapons from LBIII to Iron IIC

1. This term, used to describe the period of the 20th Dynasty occupation of Canaan during most of the 12th century BCE, is referred to by others as Iron IA (Stern 1993:1529; Mazar 2011:105). For the subsequent period, which begins with the withdrawal of the Egyptians from Canaan in the late 12th century BCE, we use the term Iron I. This period is also termed Iron IB (Stern 1993:1529; Mazar 2011:105).

Phase 1 (LBII)

The earliest iron objects in the Levant have been dated to the Late Bronze Age (Waldbaum 1980:76). However, while several Syrian sites, such as Ugarit, Minet el-Beida, and Alalakh, yielded iron objects (more than one each), in Canaan the number of iron items dating to this period is limited: an LBII burial at Megiddo yielded an iron ring (Guy and Engberg 1938:162, pl. 128:19, Figure 176.7), and a contemporary burial in Pella in the eastern Jordan Valley yielded a corroded iron bracelet (Notis et al. 1986). Other scarce iron finds originated in other burial contexts that are said to be related to the Late Bronze Age, but are not securely dated (Smith et al. 1984; but see Muhly 2006 for a revised dating; for the disturbed context of the iron knife from T 113 at Tell es-Sa'idiyeh see Green 2006:308, footnote 13). The small jewelry items and trinkets from the Hathor shrine at Timna are often quoted as LBII examples of iron products. However, these could be dated anywhere between the time of Seti I and Ramesses V (late 14th to mid-12th century BCE), as shown by a recent re-evaluation of the stratigraphy and chronology at that site (Avner 2014:110, footnote 79).

Thus, careful scrutiny of the iron objects found in Late Bronze Age contexts in Canaan shows that the miniscule number of objects that have been discovered might very well have been imports, and in fact, there is no convincing evidence for iron production in Canaan during the Late Bronze Age.[2]

Phase 2

The second phase in Snodgrass' original scheme, which pertained to the introduction of iron for utilitarian purposes, although still subordinate to bronze, covered a long period of time, the 12th to 10th (and even 9th) centuries BCE, that is, the LBIII, Iron I, and Iron IIA in relative chronology terms. Our study has shown that this development has significant substages, which are divided here into an early and a late phase.

Phase 2 Early (LBIII)

The new database in the present study shows that there were no utilitarian iron objects during the entire LBIII. The only iron objects that could be securely considered for this period are in fact a relatively large number of iron bracelets found in burials dated from the 12th century BCE and possibly two bi-metallic knives (see details below), which were not included in our database as they came from burials. Notably, these are prestige items and indicate an independent stage in the development of iron technology, in which routine production of iron, but *not* for utilitarian items, is inferred. This phenomenon cannot be related to the first stage of iron use in the Levant (see above, Phase 1), when iron objects were unique and rare; also not to the second stage of development, which includes the limited production of objects for utilitarian purposes (see below, Phase 2 Late). As we were reluctant to introduce a new terminology for the process, and since this phase continues during the Iron I and therefore overlaps with the appearance of utilitarian iron objects, we have decided to divide Snodgrass' second stage of development into two parts: the routine production of iron jewelry during the LBIII is termed Phase 2 Early.

More than 30 iron anklets/bracelets were found in a LBIII tomb in the Baq'ah Valley, Jordan (Notis et al. 1986; Waldbaum 1999:32–4). Significantly, these were found together with high-tin bronze jewelry of similar types (McGovern 1986). Similar iron jewelry items were found in a contemporary burial cave at Pella in the Jordan Valley (Waldbaum 1999:33, following McGovern 1988:52). It

2. At two sites dating to the Late Bronze Age, iron smelting has been hypothesized: Lachish, where an amorphous lump from Level S-2 was identified through analysis as speiss, and Tel Yin'am, where ironworking remains were allegedly found (Liebowitz 1983; Rothenberg 1983; Liebowitz and Folk 1984; Pigott 2003; Shalev 2004a; Veldhuijzen and Rehren 2007). The validity of this evidence cannot be authenticated without further study.

may be that the iron objects from the Hathor shrine at Timna should be dated to the same time (as noted above) and are related to the same phenomenon. This relatively large number of iron anklets/bracelets suggests that even though they might have been considered precious as a result of their use and context, they were certainly neither rare nor unique; on the contrary, they appear to have been quite routinely produced.

Based on the near absence of imported material in the Jordanian Baq'ah burials, the similarity of the iron bracelets in these burials to those made of bronze, and the proximity to iron ore deposits in the area of Ajlun and Wadi Zarqa, Notis et al. (1986:277) suggested that the iron bracelets were locally produced, although the initial impetus may have come from outside.

The phenomenon of iron jewelry in Canaan in the LBIII recalls the contemporary production of bi-metallic knives (iron blades with ivory handles and bronze rivets) in neighboring Cyprus and suggests that in both regions, a routine production of prestige iron objects of specific and singular types preceded the production of iron for utilitarian purposes. Not all scholars agree that the iron knives in Cyprus were prestige items (Pickles and Peltenburg 1998; Muhly 2006). However, their wide occurrence in burials certainly suggests that even if used daily, these were not strictly utilitarian objects (Sherratt 1994, 2003). Bi-metallic knives similar to those abundant in Cyprus were found in 12th–10th century BCE contexts in the southern Levant (Dothan 1989, 2002). However, none of those dated to the 12th century BCE originate in well-dated contexts. The earliest stratified example is probably the one found in a Philistine temple (Building 319) of Stratum XII at Tell Qasile (Mazar 1985:6–8, Figure 2; Dothan 2002). The cultic nature of the context further emphasizes the nonutilitarian nature of these knives, which may well have been brought from Cyprus rather than locally produced.

The question of whether iron technology had disseminated from Cyprus has been widely discussed and will not be repeated here (Stech-Wheeler et al. 1981; Maddin 1982; Snodgrass 1982; Waldbaum 1982, 1989, 1999; Wertime 1982; Sherratt 1994, 2003; Muhly 2006). However, had this been the case, then we would expect the production of iron knives rather than bracelets in this early phase, as at that time this was the main type of object produced from iron in Cyprus. As this is not the case, a Cypriot impetus for the production of iron bracelets seems unlikely for this early stage.

In summary, utilitarian iron objects did not appear in the first half-to-middle of the 12th century BCE as previously suggested; only prestige items were produced during this time.

Phase 2 Late (Iron Age I)

The major development in the Iron I was that iron objects were no long restricted to burials or cultic contexts. Archaeologists were finding for the first time, albeit in small numbers, utilitarian objects made of iron in settlement sites throughout the country. These included both tools and weapons, such as a chisel from Stratum IB at Taanach, a large implement from Stratum VII at Tel Rehov, a sickle from stratum XVII at Tel Yokneam, a dagger and a needle from Stratum VIA at Megiddo, and several other objects. Iron bracelets/anklets and bi-metallic knives continued to be unearthed. According to the updated database, during the Iron I, iron tools and weapons comprised ~13% of the total objects of these categories. As these included the aforementioned bi-metallic knives, some of which were not strictly utilitarian during this time, the relative number of iron objects termed utilitarian may be even lower. This figure shows that iron was secondary to bronze at this time, while the occurrence of bi-metallic knives and the continued production of iron bracelets suggest that iron maintained its value as a precious metal, alongside its limited use for more functional items.

Phase 3 (Iron IIA)[3]

During the Iron IIA, a significant change occurred as iron became dominant, comprising an average of over 60% of the metal tools and weapons. At several sites where an early Iron IIA phase could be discerned, the average number of iron tools and weapons in this early phase alone reached only ~40%, suggesting that the process was gradual and that iron became dominant only in the later part of the Iron IIA. Notably, at those sites that were newly established in the early part of the Iron IIA, such as Arad Stratum XII and Beer-Sheba Stratum VII in the Beer-Sheba Valley and Khirbet Qeiyafa in the Elah Valley, iron was the dominant metal, while at contemporary sites with a Bronze Age bronzeworking tradition, the average amount of iron was smaller (such as Tel Masos and Megiddo; see also Gottlieb 2010). The situation at Qeiyafa is even more interesting, as it is earlier than Arad XII and Beer-Sheba VII, and is dated either to the very early Iron IIA or transitional Iron I/IIA.[4]

The increase in the number of iron tools and weapons (the latter in particular) continued and reached its peak during the Iron IIB, comprising over 80% of the metal assemblage (not counting over 300 iron arrowheads from the Assyrian siege of Lachish in 701 BCE). The absolute number of iron tools and weapons dropped considerably during the Iron IIC and their relative proportion fell to below 70%. It should also be noted that our results show that throughout the Iron Age, over 80% of the jewelry was made of bronze. As will be indicated below, there is a clear association between the sharp increase in the average number of iron utilitarian objects during the Iron IIA and evidence of iron production within the urban centers during this time (see below).

DEVELOPMENT OF IRON PRODUCTION: CHRONOLOGY AND CONTEXT

We currently have evidence for iron production (smelting and/or smithing) from nine Iron Age sites (Figure 2); in six of these (Hazor, Megiddo, Tel Rehov, Tell Hammeh, Beth-Shemesh, and Tell es-Safi/Gath), this industry dates as early as the Iron IIA (described below). At Beer-Sheba, evidence for iron production is dated to the Iron IIB (Eliyahu-Behar et al. 2013), and at Dor and Tel Sera' to the Iron IIC (Rothenberg and Tylecote 1991; Eliyahu-Behar et al. 2008). In some cases, iron production remains were identified after the excavation had already been completed (Hazor, Beer-Sheba, Tel Rehov), while in others, iron production was identified during the course of excavation and was exposed using metallurgically oriented field methods (Tell Hammeh, Beth-Shemesh, Tell es-Safi/Gath, Megiddo). The latter enabled a much more complete evaluation of the iron-producing process. The accumulated new evidence allows a glimpse into the relative and absolute chronology of the adoption of iron in the southern Levant and its context.

Tel Hazor

Excavations in Area A at Hazor (1989–2006) produced 45 complete and many more fragmented slag cakes and other iron-production remains in Iron II contexts (Strata XA–V). These originated mainly from a series of buildings along the Strata X–IX city wall, not far from the six-chambered gate (Ben-Ami 2012). The earliest production remains consist of two slag cakes found on a Stratum Xa (Iron IIA) floor (Yahalom-Mack et al. 2014). In Stratum IX, several concentrations of slag cakes were found. Below the floor of one structure of Stratum IX (Building 9127), which contained iron slag cakes, were bronzeworking remains. This is significant, as it indicates an official(?) decision to replace bronzeworking with iron production. In Stratum VIII (transitional Iron IIA–B), with the expansion of the city and change in its layout, iron production expanded into the center of the acropolis. In Strata IX–V, square tuyère fragments were found associated with slags and

3. For absolute chronology of the Iron IIA according to the Modified Conventional Chronology, see Mazar (2011). For the absolute dates according to the Low Chronology, see Finkelstein and Piasetzky (2011).

4. The substantial use of iron in this unique administrative settlement will be discussed elsewhere.

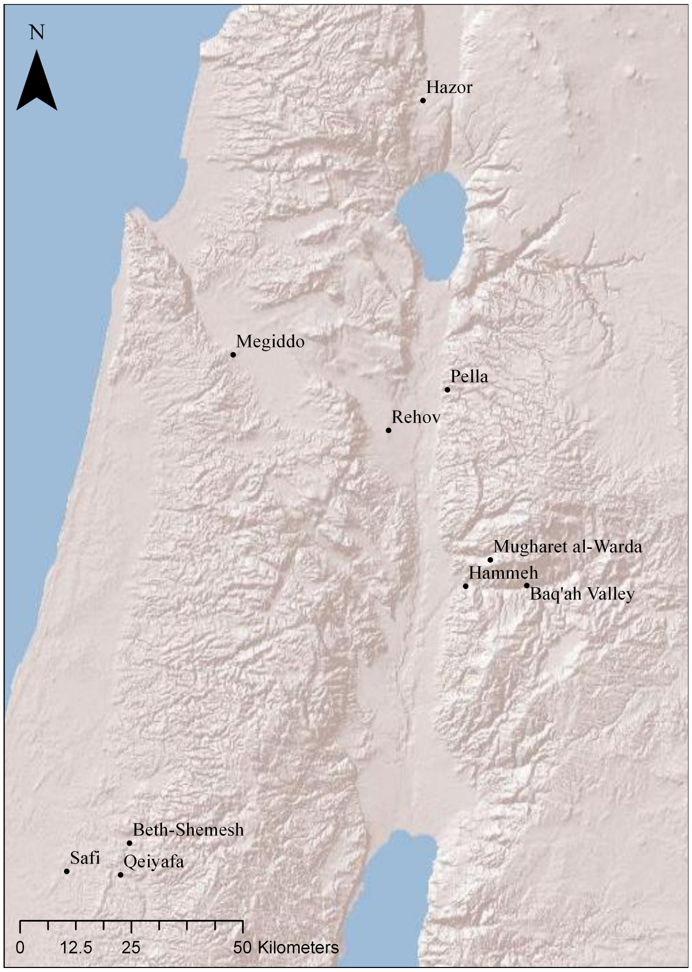

Figure 2 Map showing selected sites with evidence of iron production.

with various installations and accumulations of ash. Notably, bronzeworking debris was associated with iron-production remains in various strata, indicating interaction between the two technologies during the Iron II (Yahalom-Mack et al. 2014).

Tel Megiddo

Iron production remains were found during the 2012 excavation season in the southeastern part of the mound. The earliest remains comprise a single iron slag cake found in Area Q, Level Q-5 (University of Chicago's Stratum VB) on a floor together with bronzeworking debris. In Level Q-4 (Stratum VA–IVB), near the northeastern corner of pillared Building 12/Q/95, a dark layer of sediments, ~10 cm thick, with hammerscales and a considerable amount of charcoal, was found. Chemical analysis showed that the sediments were contaminated by copper. A couple of tuyère fragments, square in cross-section, were found in the same building at approximately the same level. In the 2014 season, excavations east of the building unearthed considerable evidence for iron production, with over 30 iron slag cakes, numerous iron hammerscales and prills, as well as tuyère fragments. The remains appear to originate in a sequence of hearths related to Levels Q-5-2, located next to large tabuns. These finds, which still await detailed investigation, support Schumacher's reports of an iron smithy in a room adjacent to the outer side of the eastern wall of the courtyard of Palace

1723, located just a few meters away from the iron production remains in Area Q (Schumacher 1908:130–2, Figures 191–194, plates XXIX and XLII). It is thus indicated that iron production was performed east of the palace. Notably, in this part of the mound, bronzeworking was practiced nearly continuously throughout the Late Bronze and Iron Ages. Since bronzeworking was practiced in domestic contexts, the shift to iron production associated with public architecture indicates the involvement of a central administration in the transition from bronze to iron production at Megiddo.

Tel Rehov

In Area E at Tel Rehov, both iron and bronze production debris were uncovered, including two iron slag cakes and other iron production debris alongside bronze spatter and prills, as well as a large amount of iron and bronze scrap. The evidence comes from Stratum E-1b (Stratum V, Iron IIA) in a context that served as an open-air sanctuary in the subsequent Stratum E-1a (Stratum IV, also Iron IIA), including a *bamah* with *masseboth*, as well as an offering table and a pottery altar. Even though it was not securely determined whether the area had already served as a sanctuary in Stratum E-1b, the continuity of activity within the courtyard and surrounding building suggested that this is highly likely (Mazar, forthcoming; Yahalom-Mack, forthcoming).

Tell es-Safi/Gath

A smithy in Area A at Tell es-Safi/Gath was exposed in a controlled, metallurgically oriented excavation (Eliyahu-Behar et al. 2012). The evidence included two different features, a black depression and an orange pit, each representing a different *in situ* activity related to iron production, inferred by the presence of hammerscales, slag prills, and smelting slag. This indicated that the entire process of iron production, from the smelting of the ore to the forging of the final product, was conducted at the site. In addition, analyses showed that a crucible found on top of the orange pit was used for bronze production and that sediments from the smithy were contaminated by copper. These suggested that both iron and bronze were produced/worked at the smithy. Notably, tuyères, both round and square in cross-section, were found in and around the two features. The smithy was related to Stratum A-4 (early Iron IIA) and was probably associated with cultic activity identified nearby. Radiocarbon dates obtained from grape seeds found in the black hearth gave calibrated 2σ dates of 935–800 BCE (93.4% probability).

In the 2014 season, excavations in the lower city, Area D, unearthed a relatively large collection of slag (more than 15 complete, and many more fragments), very similar in appearance to the molten slag found *in situ* in Area A. In association with the slags, a pile of more than 10 tuyère fragments, both round and square in cross-section, was unearthed. These remains, yet to be analyzed, were found in a postdestruction layer of the 9th century and thus appear to be later than the workshop identified in Area A.

Tell Hammeh

Tell Hammeh is a relatively small mound located in the central Jordan Valley close to the Zarqa River and to the iron ore deposit at Mugharet al-Warda. Excavations at the site uncovered extensive remains of iron smelting and primary smithing operations, with no indication of contemporaneous habitation or other nonmetallurgical use of the site (Veldhuijzen and Rehren 2007). Large quantities (more than 700 kg) of various types of slags and some 350 tuyère fragments, charcoal, and some possible furnace(?) structures were identified in a clear stratigraphic context evidently used strictly for metallurgy. About 60% of the slags were identified as tapping items, while the remainder were various forms of slag cakes (rusty lumps of heterogeneous slag material and partly or hardly reduced hematite ore formed at the bottom of the hearth), and other byproducts, all attesting to smelting activities. No secondary smithing slags (resulting from the forging of end products) were identified (see discussion of the technological sequence and the schematic figure below). ^{14}C analysis of two short-lived olive wood charcoal samples from the production phase provided 1σ dates ranging between 1000–900 and 940–850 calibrated BCE (Veldhuijzen 2005:92; Veldhuijzen and Rehren 2007:191).

Tel Beth-Shemesh

Excavations in Area E revealed several phases of industrial and commercial activity next to large public buildings (Bunimovitz and Lederman 2003). Evidence for metallurgical activity was identified; therefore, during the 2003 season a metallurgically oriented excavation was initiated. The assemblage of metallurgical debris consisted of at least 65 individual round concavo-convex slag cakes (together with many more fragments), hammerscales, numerous fragments of square tuyères together with other technological ceramic and metal artifacts (both iron and copper). Based on the analysis of slags, and especially on the fact that tapping slags were absent, Veldhuijzen concluded that the activity at Tel Beth-Shemesh represented a secondary smithing operation, as opposed to iron smelting and/or primary bloom-smithing (Veldhuijzen 2005; Veldhuijzen and Rehren 2007).

From the pottery assemblage, it appears that none of the iron production remains at Beth-Shemesh predate the Iron IIA, and that the majority in fact date to the later part of this period. ^{14}C dating of three burned olive pits from the smithy yielded a ~900 BCE date.

In summary, at both Hazor and Megiddo, long sequences of metalworking were exposed. At both sites, there appears to be an association between iron production and public buildings. This was also the case at Tel Beth-Shemesh (Bunimovitz and Lederman 2012). At Hazor, some of the iron production remains from Stratum IX were found immediately above bronzeworking debris. This indicated that an official decision was possibly involved to replace bronzeworking with iron production. At Megiddo, in Late MB–Iron I domestic contexts, bronzeworking was identified. When a change in the town layout occurred during the Iron IIA, a time during which public buildings were erected, iron production took precedence over that of bronze. At Beth-Shemesh, too, bronzeworking during the Iron I had taken place mostly in and between domestic houses (Yahalom-Mack 2009).

While it has been suggested, based on ethnographic studies, that metalsmiths working in domestic contexts are more likely to be independent specialists, while those working in association with public building may be "attached specialists" (e.g. Costin 1991), it is nevertheless necessary to support such a scenario for the Iron Age with further evidence. In the case of Megiddo, the occurrence of iron production remains in the vicinity of Palace 1723 renders it likely that the formerly independent metalsmiths were now attached to the ruling elite at the same time that they shifted from mainly bronze to mainly iron production.

At Tell es-Safi/Gath, the joint iron and bronze smithy was located just outside a possible shrine. At Tel Rehov, joint iron and bronze metallurgy was most likely practiced in an open cult place. This suggests a strong association between cult and metalworking at these sites. The presence of metalworking debris within cultic contexts was attested at a number of sites, e.g. the Middle Bronze Age standing-stone complex at Hazor (Yahalom-Mack et al. 2014) and the Late Bronze or early Iron Age Hathor shrine at Timna in the Arabah Valley (Rothenberg 1988).

DEVELOPMENT OF IRON TECHNOLOGY

The production of iron is a long process that can be roughly divided into three main stages: the smelting (reduction) of the ores to produce a bloom, the refining of the bloom (primary smithing) to produce a more compacted metal (a bar ingot), and the forging of the end product (secondary smithing) (e.g. Tylecote 1980; Maddin 1982). All of these stages together can be performed at the smelting site near the ores, or elsewhere, in and around settlement sites. Alternatively, iron could be smelted near the ore deposit and traded in the form of a bar to urban or rural smithies, where secondary smithing would be carried out until the final product is formed. Figure 3 shows a schematic representation of the described sequence.

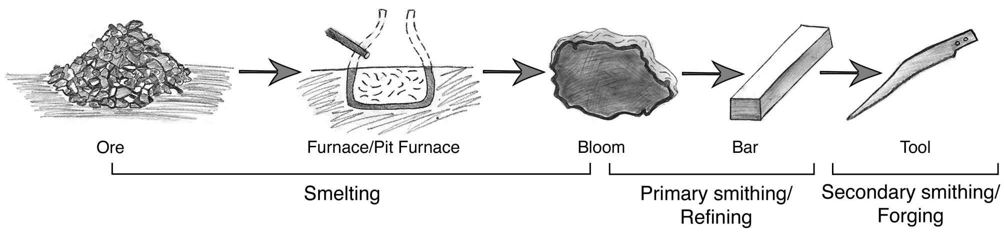

Figure 3 A schematic representation of the iron production processes: smelting, refining, and forging

This sequence, termed "the bloomery process," produces a variety of byproducts: tapping slag, slag cakes, bloom fragments ("gromps"), hammerscales, and other associated paraphernalia, such as tuyères.

Smelting

Iron smelting (similar to copper smelting) requires a controlled reducing environment obtained with the help of an air-supply system. In Europe, it appears that, initially, pit furnaces were used; these were domed and later developed into shaft furnaces (Tylecote 1980; Joosten 2004; Paynter 2006). Tapping furnaces, in which slag was liquefied and tapped outside the furnace through a hole, were a later development (Tylecote 1987). In the southern Levant, no complete smelting furnace that would enable a full reconstruction of the furnace shape[5] has been preserved; nevertheless, this type of smelting technology can be deduced from the remaining slag. The choice of smelting technique (pit/shaft/tapping furnace) might be related to the available knowledge, and/or to the initial amount of raw material (ore) processed, and will determine the type of slag formed (Tylecote 1987).

Tapping furnaces produce characteristic slags with a typical smooth surface that shows clear flow patterns, which result from fast cooling rates outside of the furnace. In the Iron Age southern Levant, Tell Hammeh is the only site that produced tapping slag (Veldhuijzen and Van Der Steen 1999; Veldhuijzen and Rehren 2007).

Smelting in pit furnaces results in rounded slag cakes with a concavo-convex cross-section. These are also formed at the bottom of smithing hearths (Bachmann 1982; Paynter 2006). In contrast to tapping slags, which are clearly associated with smelting based on their morphology, the macroscopic appearance of slag cakes cannot be used to determine whether they are the byproducts of smelting, primary smithing, or secondary smithing activities. However, microscopic analysis of such slags may be used in order to differentiate the stage at which they were formed.

In a recent study (Eliyahu-Behar et al. 2013) aimed at defining the iron production activity at settlement sites, whether smelting or smithing, we analyzed iron slag cakes from Iron IIA contexts at

5. An attempt at such a reconstruction was proposed for the remains of a 7th century BCE furnace at Tel Sera' (Rothenberg and Tylecote 1991).

Hazor, Beer-Sheba and Tel Rehov, as well as amorphic artifacts that we subsequently identified as bloom fragments. Analysis of the slag cakes showed that these were likely the byproducts of smelting. This was based on the analysis of small vesicular inclusions/formations of a white material, a key element identified in almost all the analyzed slag cakes. Detailed analysis of these inclusions and the iron oxide matrix surrounding them (which is characterized by a fine line texture showing preferred orientations, typically characteristic of an ex-solution phase) showed that the iron oxide matrix and the white inclusions were formed at a high temperature, possibly by the reaction of some Ca-rich material and the iron ore during smelting.

When viewed in light of the occurrence of bloom fragments at Beer-Sheba and Hazor, we suggest that all stages of iron production, including the smelting of iron ores, were performed within these urban centers. Ore then would have been brought to the settlement sites and knowledge of smelting would have been in the possession of the urban metalsmiths during the Iron IIA-B.

Smithing

Following smelting, primary and secondary smithing are conducted. In primary smithing, the bloom is hammered when red-hot to form the consolidated metal. In secondary smithing, the metal is forged into a final product. The process comprises the repeated heating of the iron metal in a charcoal bed (a hearth) and hammering it on an anvil in order to create the desired shape. These steps involve various techniques and heat treatments, including carburization, quenching, and tempering that will influence the mechanical properties of the product, rendering it into steel.

It has been suggested that iron became widely used for utilitarian purposes only when it gained technological superiority over bronze (e.g. Maddin 1982; Muhly et al. 1985; Waldbaum 1999; Muhly 2006). As carbon content alone does not ensure hardness greater than that of bronze, additional heat treatments are required in order to achieve the desired result (see McConchie 2004:58, Figure 2).[6] Assuming that a technological breakthrough was achieved in the course of the Iron Age that resulted in the dominance of iron over bronze in the Iron IIA, we would expect that iron objects dating to the LBIII and Iron I would show technological inferiority. However, this is not indicated by our analyses of iron objects (unpublished data).

Carburization

Carburization is a term used in order to indicate a deliberate action by which an iron object, already in its final form, is heated in a carbon-rich atmosphere for a prolonged period of time, increasing its carbon content in order to produce steel (Maddin 1982; Notis et al. 1986:277). Scott and Eggert (2009) refer to the act of deliberate carburization as "secondary carburization" and to the spontaneous absorption of carbon into the bloom during smelting as "primary carburization." The notion that steel could only be made by "secondary carburization," although it prevailed in the early years of research, has gradually been replaced by the realization that "primary carburization" could occur by direct reduction in the bloomery smelting furnace.

The carbon content of steel may vary between 0.02 to 1.2 weight percent (wt%) and will determine the mechanical properties of the metal (Scott and Eggert 2009). Low-carbon ($C < 0.5$ wt%) steel will leave the metal quite soft, ductile, and weak, while excess carbon will result in a harder but brittle metal ($C > 1.2$ wt%) (Sauveur 1912:Lesson IV; Reed-Hill 1973). Significantly, the carbon content

6. The hardness of Late Bronze Age daggers with ~10% Sn can reach up to 290 Hv (Shalev 2004b:Appendix 2), while for example the hardness of low-carbon steel ≤0.5% C without heat treatments ranges between 80–120 Hv, and after quenching can increase up to 800 Hv (Scott and Eggert 2009:16).

in some areas of the aforementioned bloom fragments that were analyzed was estimated to be as high as 0.6–0.7 wt% carbon, indicating that carburization occurred spontaneously (see discussion in Eliyahu-Behar et al. 2013).

The most obvious way to distinguish between primary and secondary carburization is when a gradient of the carbon content can be observed from the surface of an object to its interior (Maddin 1982). Unfortunately, this is hardly relevant for ancient iron objects that have undergone severe corrosion that consumed their entire outer surface. Hence, in most cases, a gradient is not apparent and we therefore are not able to differentiate between deliberate and spontaneous carburization based on this criterion alone (Maddin 1982 and see below).

A major aim in our research was to address the question of carburization and related heat treatments through systematic analysis of objects from the late 2nd and early 1st millennia BCE. For this purpose, 60 iron objects from several major Iron Age urban centers in Israel, including Tel Hazor, Tel Rehov, Khirbet Qeiyafa, Tel Megiddo, and Tell es-Safi/Gath, were sampled and metallographically analyzed. The assemblage included various tools and weapons, as well as a few bracelets. The objects were chosen carefully from well-stratified and securely dated contexts spanning the Iron I and Iron IIA (with the majority of the items naturally dating to the latter period). Among the objects were three bi-metallic knives (two from late Iron I Megiddo and one from Khirbet Qeiyafa dated either to the late Iron I or transitional Iron I/IIA).

Significantly, none of the objects subjected to this analysis were fully preserved in metallic form and, in fact, the opposite was observed. All the objects had undergone considerable swelling due to corrosion. Following sectioning and polishing, secondary corrosion layers were identified at their outer perimeters and within cracks throughout the samples. The outer layers of the objects were usually consumed by corrosion and therefore deliberate carburization treatment could not be inferred.

In many of the objects, only very small islands of metallic iron were preserved, from tiny specks on the order of a few microns to some larger ones, up to several hundred microns. The largest island of about 3 mm metallic iron was preserved in a single tool from Megiddo. Despite this poor metallic preservation, we were able to observe "ghost structures" (i.e. pseudomorphs preserving the original metallic structure, see Knox 1963; Notis 2002) in almost all the objects. Our conclusions are therefore based mainly on the study of these structures and are occasionally reinforced by etching experiments performed on the micrometallic remnants preserved in isolated objects.

The results showed that "ghost structures" of pearlite, clearly indicating the presence of carbon, were present in almost all the objects (excluding three), demonstrating that almost all were made of steel. The carbon concentrations reflected a range of compositions from low-carbon hypoeutectic steel to high-carbon and hypereutectic microstructures. Many of the samples showed a homogeneous distribution of the pearlite content, though in some cases variable carbon concentrations were estimated in different parts of the sample. In addition, high-carbon content (estimated as over 1%) was observed in three of the samples, in which the pearlite grains were surrounded by cementite, indicating a highly brittle metal.

Previous analyses of iron objects revealed that many were in fact steel (Stech-Wheeler et al. 1981; Smith et al. 1984; Notis et al. 1986; Maddin et al. 1987; Muhly et al. 1990). Gradients of carbon content were almost never observed, except in three extraordinary well-preserved objects from Kinneret and Taanach.[7] No convincing correlation was reported between carburization, or the lack of it, and certain object types. Nevertheless, the authors concluded that the objects were carburized, in the sense that a deliberate action was performed (secondary carburization). Notis, in his analysis of the LBIII steel bracelets found in the Baq'ah, could not identify definitive evidence for surface carburization treatments, and thus raised the possibility that the steel had been produced spontaneously during smelting (Notis et al. 1986:277). Thus, carbon content alone cannot be taken as indication that the Iron Age metalsmith was aware of the benefits of placing an object in charcoal fire for a prolonged period of time. This and the fact that carburized objects already occur during the LBIII suggest that deliberate carburization was unlikely a crucial development in iron technology that was responsible for rendering iron dominant.

Quenching and Tempering

In order to produce high-quality steel, which would be considerably harder than bronze, carburized iron from a temperature exceeding 723°C was immersed into water or oil for extremely rapid cooling (quenching). This action generated a rearrangement of atoms to form martensite, which resulted in a much harder though brittle metal. In order to relieve the brittleness caused by quenching, reheating (tempering) was required (Maddin 1982; Notis et al. 1986:278).[8]

Such martensitic structures were possibly identified in two or three of our samples (unpublished data). Notably, these are not easily identified in ghost structures. However, from the evidence at hand, it appears that quenching was not routinely performed. The earliest examples of quenching originated in exceptionally well-preserved objects from 12th century BCE Idalion, Cyprus (Tholander 1971; Maddin 1982). After re-examining the photo micrographs of these objects, McConchie (2004:31–5) claimed that the evidence for quenching was not convincing. Moreover, based on the poor state of preservation of the 60 objects analyzed for this study, we have expressed our doubts (see footnotes 8 and 9) concerning the date of exceptionally well-preserved objects, such as those from Idalion.

In summary, our data suggest that a range of steels existed during the Iron Age, indicating the lack of systematic, deliberate carburization. In general, as no difference was found between earlier and later objects or between different regions, it appears that there is no indication that a technological breakthrough was achieved during this period and it seems that the process was more *ad hoc* than deliberately planned. These conclusions coincide with the results of earlier analyses of iron objects from different regions throughout the Ancient Near East, which suggested, according to McConchie (2004:33), that "the iron was generally low in carbon, occasionally varying in composition to quite high-carbon contents, and usually not thermally treated." With the lack of heat treatments, iron was not necessarily superior to bronze and thus the "superiority of iron over bronze" claim certainly cannot be used to explain the bronze/iron transition (see also Pigott 1989; McConchie 2004).

7. In light of the overall poor state of preservation of the sampled objects, exceptionally well-preserved iron objects remain an enigma and should be dated independently. Naturally, this can be done using the ^{14}C dating method (see footnote 8).

8. The question of quenching and tempering was raised mainly in relation to an iron pick from Mt. Adir, as it had been fully preserved in metallic form, and based on metallographic analysis, had undoubtedly been both quenched and tempered (Davis et al. 1985). Although dated by the excavator to the Iron Age, the typology of the object did not have a single Iron Age parallel and its exceptionally good state of preservation cast doubt on this date. It was therefore recently subjected to ^{14}C dating, which yielded a date with 95.4% probability in the 2nd century BCE (Sariel Shalev and Elisabetta Boaretto, personal communication). These results were never published because of the remaining possibility that tannin used in the conservation of the object had affected its dating, even though the sample had been drilled from the core. It thus appears that the object, which had been considered one of the earliest examples of steel, can no longer be regarded as relevant to this topic. Recent salvage excavations conducted by the Israel Antiquities Authority near Ein Shadud yielded an identical iron pick of the Roman period (Ron Beeri, personal communication). The pick is extremely heavy, suggesting a good preservation of its metal. Future analyses will enable a comparison between this pick and the one from Mt. Adir.

COPPER PRODUCTION AND BRONZEWORKING

As noted earlier, bronze production continued during the entire period of introduction of iron technology into the southern Levant and is therefore relevant for understanding the process. The number of sites with evidence of bronzeworking at the time of the 19th and 20th Egyptian Dynasties' presence in Canaan (such as Tel Rehov and Tel Mor)[9] is considerably smaller than the number of sites that existed following their departure. Widespread bronzeworking during the Iron I is indicated by the distribution of metallurgical production remains, which were found at 12 sites in different regions. Notably, bronzesmiths during this time appear to have been located in or between domestic units (e.g. Tel Megiddo, Beth-Shemesh, Tel Dan, Tel Dor, Tell Qasile) and/or concentrated in industrial quarters (Tel Dan, Tel Yokneam), rather than in the vicinity of public buildings (Yahalom-Mack 2009).

The results of excavations at sites in Wadi Faynan and the renewed excavations at Site 30 in Timna suggest that copper production flourished in the Arabah between the 11th and 9th centuries BCE, *after* the Egyptian withdrawal from Canaan; this is based on a large number of ^{14}C dates (Levy et al. 2004, 2008; Ben-Yosef et al. 2012). Particularly for Timna, this conclusion is a major conceptual change, as the mining and smelting operations there were previously attributed mainly to the Egyptians of the 19th and 20th Dynasties, with a hiatus during the 11th century BCE (Rothenberg 1988, 1990). The supposed abandonment of the site during the Iron I, a short while after the Egyptian withdrawal from Canaan, fit well with the "shortage of supplies" theory for the adoption of iron (see Introduction). The renewed dating suggests exactly the opposite; copper was in fact widely available when the first utilitarian iron objects appeared. Significantly, lead isotope analysis of bronze objects and crucibles from Iron I contexts showed that copper from the Arabah was indeed used at settlement sites during this time (Yahalom-Mack and Segal, forthcoming).

Thus, the departure of the Egyptians, who had previously controlled at least some of the bronzeworking during the Late Bronze Age, coupled with decentralized political structure and the availability of copper from the Arabah Valley, may have created advantageous circumstances for the adoption of iron technology.

With respect to the question of tin availability for the production of bronze, analysis of 95 copper-based artifacts from LB II–Iron II contexts showed that tin-bronze was continuously used and that the average tin (Sn) content (5–6 wt%) was maintained throughout the periods (unpublished data).[10] This supports earlier studies that showed there was no shortage of tin during the transition period—a shortage that would have driven Iron Age smiths to shift to iron (Waldbaum 1989, 1999; Pickles and Peltenburg 1998).

One of the most significant results of the present study is the material evidence provided for the association between bronze and iron production during the Iron II. We can point to some indirect evidence suggesting that bronzesmiths adopted iron technology during the Iron I and were producing iron in addition to bronze in their workshops. One example stems from Megiddo Hoard 12/Q/76,

9. The bronzeworking practice uncovered at Tel Rehov (13th century) and Tel Mor (early 12th century) incorporates the use of canals, which were probably used to contain the crucible, which is very similar to bronzeworking activities found at Qantir/Pi-Ramesses in the Egyptian Delta (Yahalom-Mack 2009). Significantly, at Tel Mor, several such installations were found adjacent to a monumental 20th Dynasty stronghold (Barako 2007). This seems to indicate that at some point or in some locales, the Egyptians were reluctant to use local Canaanite bronzesmiths and decided to bring their own metalworkers from Egypt (Yahalom-Mack 2009).

10. The chemical and lead isotope analysis was performed in collaboration with Irina Segal, Israel Geological Survey, and will be published elsewhere.

found in Stratum VIA in Area Q in the southern part of the mound (Hall et al., forthcoming). This example traces evidence of continuous metalworking during the Late Bronze and Iron Ages (bronzeworking and later ironworking along with bronzeworking). The hoard contained bronze artifacts, several iron blades, and significantly, bi-metallic knives, together with many beads made of semi-precious stones, some of which remained unworked. The bronze rivets and several other bronze objects were analyzed for their chemical and lead isotope composition. The results showed that all the objects, the rivets among them, were made of copper that likely originated in the Arabah but certainly not in Cyprus. The context and contents of the hoard suggest that it belonged to a local metalsmith engaged in the production of jewelry, as well as iron, bronze, and bi-metallic objects, both prestige and utilitarian in nature.

DISCUSSION

As we have shown, considerable new information can now be added to the existing data related to the bronze/iron transition in Canaan. The economic and sociopolitical background for the crucial years (~1200–800 BCE) is now much more coherent, especially with regard to copper/bronze production and trade. The study of well-dated bronze and iron objects from sites throughout the region provides a higher resolution of our understanding of the development of iron use. In addition, significant evidence for iron production, which was almost completely missing from past discussions of the subject, is now available. The scope of this evidence and its analysis thus allows a better understanding of the process, the level of craftsmanship and its context, but raises new questions and reopens old ones.

Origin of Iron Technology

Based on the evidence from Transjordan, we know that, although not common, routine production of iron jewelry for funerary deposits began during the LBIII. While iron jewelry was likely produced locally, the technical knowledge seems to have come from elsewhere. Since jewelry dominated the iron assemblage in Transjordan, while mainly knives were being produced during this time in Cyprus, there is no reason to suspect that the knowledge had disseminated from Cyprus.

It has been suggested that iron technology traveled with (Assyrian? Hittite?) metalsmiths from collapsed Late Bronze Age palatial centers. Based on texts and finds, we know they were producing or experimenting with iron (e.g. Muhly et al. 1985). Zaccagnini (1990) strongly objected to the notion of “itinerant smiths” disseminating iron technology, but at the same time described, also based on texts, craftsmen fleeing palaces and being re-absorbed in nonpalatial settlements. There is no evidence for this in the archaeological record; however, it is perhaps worth mentioning the double-jar adult burials dated to the second part of the 13th century BCE that were found at the Tell es-Sa‘idiyeh cemetery, located in the Jordan Valley. As these are rare in the southern Levant and common in central Anatolia during the 13th century BCE, it has been suggested that they belonged to refugees from the disintegrating Hittite empire (Gonen 1979; Negbi 1991). Although in the rich Late Bronze Age tombs of Tell es-Sa‘idiyeh no iron bracelets were found, this can illustrate the movement of people into the southern Levant in general and into this region in particular.

Where and by Whom was Iron Produced during the Iron I?

There is no direct evidence, in the form of iron slag cakes or other metallurgical remains, for iron production during the Iron I. As we know that iron was in fact used during this time, albeit in relatively small amounts, and assuming that the objects were not imported (see below), production must have taken place either in or around settlement sites or near iron ore deposits. Regarding the latter, the only iron ore deposit for which we have evidence for exploitation is Mugharet al-Warda in Transjordan, and it is dated no earlier than the Iron IIA. In the search for iron production remains, we recommend exploring Iron I bronze workshops within settlement sites, as we know that iron production (smelting and/or smithing) during the Iron IIA took place in the traditional bronzeworking areas (as exemplified at Hazor and Megiddo). Notably, iron production remains from Tell Tainat in the Amuq Valley, dated to the 12th century BCE, were found in a workshop together with bronzeworking remains (Roames 2010). We are discouraged by the fact that tuyères, square rather than round in cross-section, which are always associated with ironworking, are entirely absent from Iron I contexts. We are nevertheless encouraged by finds such as Hoard 12/Q/76 from Megiddo (see above) that provide indirect evidence for the engagement of bronzesmiths in iron production during the Iron I.

The possibility, although unlikely, that iron was imported into Canaan during the Iron I, needs to be addressed. There are in fact indications that some bi-metallic knives were imported from Cyprus. One example is the bi-metallic knife from Philistine temple Building 350 at Tell Miqne/Ekron, which was found together with a bronze wheel of a miniature Cypriot stand (Dothan 2002). However, using lead isotope analysis of bronze rivets of three bi-metallic knives from Megiddo and Qeiyafa, we were able to show that copper from the Arabah rather than Cyprus was used in their production (unpublished data). These knives were likely local imitations and attest to local iron production during the late Iron I.

Iron Production during the Iron IIA

Iron became dominant during the Iron IIA. Evidence shows that iron smelting and/or forging activities were now conducted in urban centers by metalworkers likely attached to local administrations. As far as we can conclude from the analyses of the objects, no major breakthrough in forging techniques was achieved in the course of the Iron Age, which could have accounted for the full adoption of iron technology. It is unlikely that the dominance of iron during the Iron IIA is the result of newly developed heat treatments.

One important element that appears to have enabled the systematic production of iron is the ability of urban metalsmiths to smelt (and not merely forge) iron. The identification of the production activity as involving the smelting of iron raises some questions on related aspects, including the feasibility of transporting iron ore into the urban centers, the variability of smelting techniques, and the possibility of identifying iron producers as former bronzesmiths.

The idea that iron ore was transported into settlement sites during the Iron Age at first appears unlikely. However, this is mainly because of the prevailing analogy to copper, which ever since the Chalcolithic period was smelted near the mines (e.g. Levy and Shalev 1989). To date, we do not know which iron ore deposits, excluding Mugharet al-Warda in the Ajlun highlands, were used during the Iron Age and what the distances were between the various deposits and the workshops. The iron ores of Mugharet al-Warda were smelted at nearby Tell Hammeh during the Iron IIA and this was certainly not the only iron ore source at the time, as has been demonstrated by Blakelock et al. (2009), who showed, based on the analysis of slag inclusions, that the artifacts from Beth-Shemesh could not have been made from the Ajlun iron ores. Needless to say, identifying relevant iron ore sources and the ability to provenance iron objects remains a major challenge in the study of the development of iron technology in the southern Levant during the Iron Age.

Based on the analysis of iron slag, three different smelting technologies existed simultaneously during the Iron IIA: pit smelting resulting in molten slag, pit smelting resulting in slag cakes, and the use of tapping furnaces. This diversity in smelting techniques is intriguing but appears to be characteristic of the bloomery process in general (Killick 1991; Craddock 1995:234–85). Notably, square in-section tuyères of the same type were found in association with all of these iron smelting techniques. Based on the existing evidence, it may be suggested, however, that pit smelting is associated with urban metalworking while tapping furnaces are linked with smelting in the vicinity of an iron ore deposit. This diversity may be thus related to production scale. This is reinforced by the use of tapping furnaces for copper smelting at Timna and Faynan.

We have suggested that bronzesmiths were smelting iron within their bronze workshops. In the following lines, we wish to explain how they adapted to a technology very different from their own. Bronzeworking and copper smelting appear to be separate activities during the Iron Age. It has been demonstrated that smelting in the Arabah was likely conducted by local tribal groups (Levy et al. 2008; Ben-Yosef 2010), while bronzeworking at settlement sites was handled by local Canaanite bronzesmiths. Based on the evidence from bronze workshops, we know that the bronzesmiths were not involved in copper smelting. Instead, they were regularly melting, refining, alloying, and casting copper/bronze in crucibles to produce the artifacts in demand (Yahalom-Mack 2009). These processes entailed crucibles, usually placed in simple pits; charcoal; and the inflation of air using bellows and tuyères. Iron smelting merely required, according to our reconstruction, a simple pit (possibly domed), charcoal, and an air supply. These were already available for the bronzesmith. The required temperature for Iron Age iron smelting, around 1100–1300°C, is only slightly higher than that needed by the bronzesmith, and could have been obtained with the available air system. What bronze workers lacked in order to smelt iron was the understanding of the smelting/reduction concept in general (as they were not copper smelters) and knowledge of the bloomery process in particular. The latter was essentially a compromise, in which iron is smelted without fully liquefying the metal.

It may be concluded that while the smelting of iron required only minor changes in the realm of physical conditions, major conceptual changes and a whole new body of knowledge were needed. Albeit beyond the scope of this paper, we must note that this new understanding explains, more strongly than ever, why the bronze/iron transition changed so profoundly the symbolic and ideological comprehension of the smiths and their role in society (Forbes 1950:79ff; McNutt 1990; Bunimovitz and Lederman 2012, and bibliography therein).

We have shown that once bronzesmiths adopted the new technology, an official initiative that came with statehood brought on the full transition from bronze to iron, probably benefiting from the availability and low cost of the iron ore and most significantly, from full control over the process (see also Bunimovitz and Lederman 2012). At least in some of the urban centers, this process included the entire *châine operatoire*, from smelting to forging. These administrations had the authority and the organizational skills to carry out this type of production and the ability to allocate the manpower imperative in iron production (Pigott 1989).

The accumulating production and artifactual evidence show that the major development in the bronze/iron transition occurred during the Iron IIA. The situation in the southern Levant appears to coincide with that in other Near Eastern regions, where this transition is not as well evidenced in the material culture. The connection between the full adoption of iron, the rise of states and great empires such as Assyria, and the consolidation of their armies during the early 1st millennium (e.g. Waldbaum 1978; Pigott 1989; Bunimovitz and Lederman 2012) is now based on hard evidence from the southern Levant. This notion is reinforced by the current artifactual evidence that shows that the number of iron objects, weapons in particular, increased during the 8th century BCE, in the face of the Assyrian threat, and decreased (also in proportion to bronze) after the Assyrian conquest.

Many questions still remain, including the following:

1. The relationship with Cyprus. Even though we stated that the initial phase of iron production in the southern Levant need <u>not</u> be associated with iron production there, the subsequent imitation of bi-metallic knives and their manufacturing procedure, which may have included quenching, suggests that the southern Levant was influenced to some extent by Cyprus. The lack of production remains on Cyprus does not at this time provide an opportunity for comparison.

2. Since the material in Cyprus is derived mainly from cemeteries, a comparison with the material from the settlement sites in the southern Levant is difficult. The dominance of iron in the Cypro-Geometric I cemeteries suggests that this metal remained a prestigious item during this period.

3. How do the copper industry activities in the Arabah, which peaked during the 10th–9th centuries BCE according to ^{14}C dating, relate to iron production in the urban centers during this time? How did the systematic production of iron influence, if at all, the fate of the mining and smelting activities in the Arabah?

CONCLUSIONS

The initial phase of iron production in the LBIII included the routine production of precious objects, namely jewelry for funerary deposits. We have shown that only after the withdrawal of the Egyptians from Canaan and with the beginning of intense copper production in the Arabah during the Iron I, iron began to be produced for utilitarian purposes. This production was likely carried out by independent bronzesmiths. Iron became the dominant metal by the Iron IIA. It took an administrative decision, possibly related to increasing threats from Aram and later Assyria, to produce iron systematically. The impetus for the breakthrough in the transition from copper to iron was the technical ability to smelt iron locally under the auspices of the urban administration. The economic feasibility, and particularly the ability to control all steps in the *châine operatoire* on a local level, soon made iron, despite its inferiority to bronze, the much preferred metal throughout the Levant.

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REFERENCES

Astrom P, Maddin R, Muhly JD, Stech T. 1986. Iron artifacts from Swedish excavations in Cyprus. *Opuscula Atheniensia* 16:27–41.

Avner U. 2014. Egyptian Timna reconsidered. In: Tebes J, editor. *Unearthing the Wilderness: Studies on the History and Archaeology of the Negev and Edom in the Iron Age*. Leuven: Peeters. p 103–62.

Bachmann HG. 1982. *The Identification of Slags from Archaeological Sites*. London: Institute of Archaeology.

Barako T. 2007. *Tel Mor: A Late Bronze Age Egyptian Outpost in Southern Canaan. The Excavations Directed by Moshe Dothan 1959–1960*. Jerusalem: Israel Antiquities Authority.

Ben-Ami D. 2012. The Early Iron Age II (Strata X-IX). In: Ben-Tor A, Ben-Ami D, Sandhaus D, editors. *Hazor VI. The 1990–2009 Excavations*. Jerusalem: Israel Exploration Society. p 52–153.

Ben-Yosef E. 2010. Technology and social process: oscillations in Iron Age copper production and power in southern Jordan [PhD thesis]. San Diego: University of California.

Ben-Yosef E, Shaar R, Tauxe L, Ron H. 2012. A new chronological framework for Iron Age copper production at Timna (Israel). *Bulletin of the American Schools of Oriental Research* 367:31–71.

Blakelock E, Martinon-Torres M, Veldhuijzen HA, Young T. 2009. Slag inclusions in iron objects and the quest for provenance: an experiment and a case study. *Journal of Archaeological Science* 36(8):1745–57.

Bunimovitz S, Lederman Z. 2003. Tel Beth-Shemesh, 2001–2003. *Israel Exploration Journal* 53:233–7.

Bunimovitz S, Lederman Z. 2012. Iron Age iron: from invention to innovation. In: Webb JM, Frankel D, editors. *Studies in Mediterranean Archaeology: Fifty Years On*. Uppsala: Astrom. p 103–12.

Costin CL. 1991. Craft specialization: issues in defining, documenting, and explaining the organization of production. *Archeological Method and Theory* 3:1–56.

Craddock PT. 1995. *Early Metal Mining and Production*. Washington: Smithsonian Institution Press.

Curtis JE, Stech-Wheeler T, Muhly JD, Maddin R. 1979. Neo-Assyrian ironworking technology. *Proceedings of the American Philosophical Society* 123(6):369–90.

Davis D, Maddin R, Muhly JD, Stech T. 1985. A steel pick from Mt. Adir in Palestine. *Journal of Near Eastern Studies* 44(1):41–51.

Dothan T. 1989. Iron knives from Tel Miqne-Ekron. *Eretz Israel* 20:154–63.

Dothan T. 2002. Bronze and iron objects with cultural connotations from Philistine temple Building 350 at Ekron. *Israel Exploration Journal* 52:1–27.

Eliyahu-Behar A, Shilstein S, Raban-Gerstel N, Goren Y, Sharon I, Gilboa A, Weiner S. 2008. An integrated approach to reconstructing primary activities from pit deposits: iron smithing and other activities at Tel-Dor (Israel) under Neo-Assyrian domination. *Journal of Archaeological Science* 35(11):2895–908.

Eliyahu-Behar A, Yahalom-Mack N, Shilstein S, Zukerman A, Shafer-Elliott C, Maeir AM, Boaretto E, Finkelstein I, Weiner S. 2012. Iron and bronze production in Iron Age IIA Philistia: new evidence from Tell es-Safi/Gath, Israel. *Journal of Archaeological Science* 39(2):255–67.

Eliyahu-Behar A, Yahalom-Mack N, Gadot Y, Finkelstein I. 2013. Iron smelting and smithing in major urban centers in Israel during the Iron Age. *Journal of Archaeological Science* 40(12):4319–30.

Erb-Satullo N, Gilmour BJJ, Khakhutaishvili N. 2014. Late Bronze Age and Early Iron Age copper smelting technologies in the South Caucasus: the view from ancient Colchis c. 1500–600 BC. *Journal of Archaeological Science* 49:147–59.

Finkelstein I, Piasetzky E. 2011. The Iron Age chronology debate: Is the gap narrowing? *Near Eastern Archaeology* 74:50–4.

Forbes RJ. 1950. *Metallurgy in Antiquity*. Leiden: Brill.

Gonen R. 1979. Burial in Canaan of the Late Bronze Ages as a basis for the study of population and settlements [PhD thesis]. Jerusalem: Hebrew University.

Gottlieb Y. 2010. The advent of the age of Iron in the Land of Israel: a review and reassessment. *Tel Aviv* 37:89–110.

Green JDM. 2006. Ritual and social structure in the Late Bronze Age and Early Iron Age Southern Levant: the cemetery at Tell es-Sa'idiyeh [PhD thesis]. London: University College London.

Guy PLO, Engberg RM. 1938. *Megiddo Tombs*. Chicago: University of Chicago.

Hall E, Eliyahu-Behar A, Yahalom-Mack N. Forthcoming. An Iron I hoard from Area Q. In: Finkelstein I, Cline E, Martin M, editors. *Megiddo VI: The 2010–2014 Seasons*. Institute of Archaeology Monograph Series. Tel Aviv: Institute of Archaeology.

Joosten J. 2004. *Technology of Early Historical Iron production in the Netherlands*. Amsterdam: Vrije Universiteit.

Khakhutaishvili DA. 2009. *The Manufacture of Iron in Ancient Colchis*. Oxford: BAR International Series.

Killick DJ. 1991. The relevance of recent African iron-smelting practice to reconstructions of prehistoric smelting technology. In: Glumac PD, editor. *Recent Trends in Archaeometallurgical Research*. Volume 8. Philadelphia: The University Museum, University of Pennsylvania. p 47–54.

Knox R. 1963. Detection of iron carbide structure in the oxide remains of ancient steel. *Archaeometry* 6(1):43–5.

Levy TE, Shalev S. 1989. Prehistoric metalworking in the southern Levant: archaeometallurgical and social perspectives. *World Archaeology* 20(3):352–72.

Levy TE, Adams RB, Najjar M, Hauptmann A, Anderson JD, Brandl B, Robinson MA, Higham T. 2004. Reassessing the chronology of biblical Edom: new excavations and ^{14}C dates from Khirbet en-Nahas (Jordan). *Antiquity* 78(302):865–79.

Levy TE, Higham T, Ramsey CB, Smith NG, Ben-Yosef E, Robinson M, Munger S, Knabb K, Schulze JP, Najjar M, Tauxe L. 2008. High-precision radiocarbon dating and historical biblical archaeology in southern Jordan. *Proceedings of the National Academy of Sciences of the USA* 105(43):16,460–5.

Liebowitz H. 1983. Reply to Beno Rothenberg. *Bulletin of the American Schools of Oriental Research* 252:71–2.

Liebowitz H, Folk R. 1984. The dawn of iron smelting in Palestine: the late Bronze Age smelter at Tel Yin'am. *Journal of Field Archaeology* 11(3):265-80.

Maddin R. 1982. Early iron technology in Cyprus. In: Muhly JD, Maddin R, Karageorghis V, editors. *Early Metallurgy in Cyprus, 4000–500 B.C.* Nicosia: Pierides Foundation. p 303–14.

Maddin R, Muhly JD, Stech T. 1987. An iron axe from Tell Qiri. In: Ben Tor A, Portugali Y, editors. *Tell Qiri: A Village in the Jezreel Valley. Report of the Archaeological Excavations 1975–1977 (Qedem 20)*. Jerusalem: Institute of Archaeology. p 244–5.

Mazar A. 1985. *Excavations at Tell Qasile, Part Two (Qedem 20)*. Jerusalem: Institute of Archaeology.

Mazar A. 2011. The Iron Age chronology: Is the gap narrowing? Another viewpoint. *Near Eastern Archaeology* 74(2):105–11.

Mazar A. Forthcoming. Area E: stratigraphy and architecture. In: Mazar A, editor. *Excavations at Tel Rehov*. Jerusalem: Institute of Archaeology.

McConchie M. 2004. *Archaeology at the North-East Anatolian Frontier, V: Iron Technology and Iron-Making Communities of the First Millennium BC*. Louvain: Peeters.

McGovern PE. 1986. *The Late Bronze and Early Iron Ages of Central Transjordan: The Baq'ah Valley Project, 1977–1981*. Philadelphia: University Museum.

McGovern PE. 1988. The innovation of steel in Transjordan. *Journal of Metals* 40(7):5–52.

McNutt PM. 1990. *The Forging of Israel: Iron Technology, Symbolism and Tradition in Ancient Society*. Sheffield: Bloomsbury.

Mirau NA. 1997. Social context of early iron working in the Levant. In: Aufrecht WA, Mirau NA, Gauley SW. editors. *Urbanism in Antiquity: from Mesopotamia to Crete*. Sheffield: Academic Press. p 99–115.

Muhly JD. 1982. How iron technology changed the ancient world – and gave the Philistines a military edge. *Biblical Archaeology Review* 8(6):42–54.

Muhly JD. 2006. Texts and technology: the beginning of iron metallurgy in the Eastern Mediterranean. In: Tassios TP, Polyvou C, editors. *Ancient Greek Technology: Proceedings of the 2nd International Conference on Ancient Greek Technology (Oct. 2005)*. Athens: Greek Ministry of Technology. p 19–31.

Muhly JD, Maddin R, Stech T, Ozgen E. 1985. Iron in Anatolia and the nature of the Hittite iron industry. *Anatolian Studies* 35:67–84.

Muhly JD, Maddin R, Stech T. 1990. The metal artifacts. In: Fritz V, editor. *Kinneret: Ergebnisse der Ausgrabungen auf dem Tell el-Oreme am See Gennesaret 1982–1985*. Wiesbaden: Harrassowitz. p 159–75.

Negbi O. 1991. Were there Sea Peoples in the central Jordan Valley at the transition from the Bronze Age to the Iron Age? *Tel Aviv* 18:205–43.

Notis MR. 2002. A ghost story: remnant structures in corroded ancient iron objects. *Materials Research Society Symposium Proceedings Volume* 712. Warrendale: Materials Research Society. p 259–68.

Notis MR, Pigott VC, McGovern PE, Liu KH, Swann CP. 1986. The metallurgical technology: the archaeometallurgy of the Iron IA steel. In: McGovern PE, editor. *The Late Bronze and Early Iron Ages of Central TransJordan; The Baq'ah Valley Project, 1977–1981*. Philadelphia: University Museum. p 272–8.

Paynter S. 2006. Regional variations in bloomery smelting slags of the Iron Age and Romano-British periods. *Archaeometery* 48(2):271–92.

Pickles S, Peltenburg E. 1998. Metallurgy, society and bronze/iron transition in the East Mediterranean and the Near East. *Report of the Department of Antiquities, Cyprus*. p 67–100.

Pigott VC. 1980. The Iron Age in Western Iran. In: Wertime TA, Muhly JD, editors. *The Coming of the Age of Iron*. New Haven: Yale University Press. p 417–61.

Pigott VC. 1989. The emergence of iron use at Hasanlu. *Expedition* 31(2–3):67–79.

Pigott VC. 2003. Iron and pyrotechnology at 13th century Late Bronze Age Tel Yin'am (Israel). In: Stollner T, Korlin G, Steffens G, Cierny J, editors. *Man and Mining: Studies in Honour of Gerd Weisgerber on Occasion of his 65th Birthday* (Der Anschnitt Beiheft 16). Bochum: Deutsches Bergbau-Museum. p 365–75.

Pleiner R, Bjorkman JK. 1974. The Assyrian Iron Age: the history of iron in the Assyrian civilization. *Proceedings of the American Philosophical Society* 118(3):283–313.

Reed-Hill RE. 1973. *Physical Metallurgy Principles*. New York: Van Nostrand.

Roames J. 2010. The Early Iron Age metal workshop at Tell Tayinat, Turkey. Paper presented at the 2010 Materials Research Society Fall Meeting, Boston.

Rothenberg B. 1983. Corrections on Timna and Tel Yin'am in the bulletin. *Bulletin of the American Schools of Oriental Research* 252:69–70.

Rothenberg B. 1988. *The Egyptian Mining Temple at Timna*. London: Institute for Archaeo-Metallurgical Studies.

Rothenberg B. 1990. *The Ancient Metallurgy of Copper*. London: Institute for Archaeo-Metallurgical Studies.

Rothenberg B, Tylecote RF. 1991. A unique Assyrian iron smithy in the northern Negev (Israel). *Institute for Archaeo-Metallurgical Studies* 17:11–4.

Sauveur A. 1912. *The Metallography of Iron and Steel*. New York: McGraw-Hill.

Schumacher G. 1908. *Tell el-Mutesellim I*. Leipzig: R. Haupt.

Scott DA, Eggert G. 2009. *Iron and Steel in Art: Corrosion, Colorants, Conservation*. London: Archetype.

Shalev S. 2004a. Metallurgical analyses: two metal lumps. In: Ussishkin D, editor. *The Renewed Archaeological Excavations at Lachish (1973–1994)*. Tel Aviv: Institute of Archaeology. p 2656–65.

Shalev S. 2004b. *Swords and Daggers in Late Bronze Age Canaan*. Stuttgart: Steiner.

Sherratt S. 1994. Commernce, iron, and ideology: metallurgical innovation in 12th-11th century Cyprus. In: Karageorghis V, editor. *Proceedings of the International Symposium: Cyprus in the 11th Century B.C*. Nicosia: AG Leventis Foundation and University of Cyprus. p 59–108.

Sherratt S. 2003. The Mediterranean economy: "globalization" at the end of the second millennium B.C.E. In: Dever WG, Gitin S, editors. *Symbiosis, Symbolism and the Power of the Past: Canaan, Ancient Israel and their Neighbors from the Late Bronze through Roman Palestina. Proceedings of the Centennial Symposium W.F. Albright Institute of Archaeological Research and the American Schools of Oriental Research Jerusalem, May 29–31, 2000*. Winona Lake: Eisenbrauns. p 37–62.

Smith RH, Maddin R, Muhly JD, Stech T. 1984. Bronze Age steel from Pella, Jordan. *Current Anthropology* 25:234–6.

Snodgrass AM. 1971. *The Dark Age of Greece: An Archaeological Survey of the Eleventh to the Eighth Centuries BC*. Edinburgh: University Press.

Snodgrass AM. 1980. Iron and early metallurgy in the Mediterranean. In: Wertime TA, Muhly JD, editors. *The Coming of the Age of Iron*. New Haven: Yale University Press.

Snodgrass AM. 1982. Cyprus and the beginning of iron technology in the Eastern Mediterranean. In: Muhly JD, Maddin R, Karageorghis V, editors. *Early Metallurgy in Cyprus, 4000–500 B.C*. Nicosia: Pierides Foundation. p 285–95.

Stech-Wheeler T, Muhly JD, Maxwell-Hyslop KR, Maddin R. 1981. Iron at Taanach and early iron metallurgy in the Eastern Mediterranean. *American Journal of Archaeology* 85(3):245–68.

Stern E, editor. 1993. *The New Encyclopedia of Archaeological Excavations in the Holy Land*. Jerusalem: Carta.

Tholander E. 1971. Evidence for the use of carburized steel and quench hardening in Late Brone Age Cyprus. *Opuscula Atheniensia* 10:15–22.

Tylecote RF. 1980. Furnaces, crucibles, and slags. In: Wertime TA, Muhly JD, editors. *The Coming of the Age of Iron*. New Haven: Yale University Press. p 183–228.

Tylecote RF. 1987. *The Early History of Metallurgy in Europe*. London: Longman.

Veldhuijzen HA. 2005. Early Iron production in the Levant; smelting and smithing at early 1st millennium BC Tell Hammeh, Jordan and Tel Beth-Shemesh, Israel [PhD thesis]. London: University College London.

Veldhuijzen HA. 2009. Red hot; the smithy at Tel Beth-Shemesh. *Near Eastern Archaeology* 72:129–31.

Veldhuijzen HA. 2012. Just a few rusty bits: the innovation of iron in the Eastern Mediterranean in the 2nd and 1st millennia BC. In: Kassianidou V, Papasavvas G, editors. *Eastern Mediterranean Metallurgy and Metalwork in the Seconds Millennium BC, A Conference in Honour of James D. Muhly, Nicosia, 10th-11th October, 2009*. Oxford: Oxbow Books. p 237–50.

Veldhuijzen HA, Rehren T. 2007. Slags and the city: early iron production at Tell Hammeh, Jordan and Tel Beth-Shemesh, Israel. In: La Niece S, Hook DR, Craddock PT, editors. *Metals and Mines - Studies in Archaeometallurgy*. London: Archetype. p 189–201.

Veldhuijzen HA, Van Der Steen E. 1999. Iron production center found in the Jordan Valley. *Near Eastern Archaeology* 62(3):195–9.

Waldbaum JC. 1978. *From Bronze to Iron: The Transition from the Bronze Age to the Iron Age in the Eastern Mediterranean (SIMA 54)*. Göeteborg: P. Astroms Forlag.

Waldbaum JC. 1980. The first archaeological appearance of iron and the transition to the Iron Age. In: Wertime TA, Muhly JD, editors. *The Coming of the Age of Iron*. New Haven: Yale University Press. p 69–98.

Waldbaum JC. 1982. Bimetallic objects from the eastern Mediterranean and the question of the dissemination of iron. In: Muhly JD, Maddin R, Karageorghis V, editors. *Early Metallurgy in Cyprus, 4000–500 B.C*. Nicosia: Pierides Foundation. p 325–50.

Waldbaum JC. 1989. Copper, iron, tin, wood: the start of the Iron Age in the Eastern Mediterranean. *Archaeomaterials* 3:111–22.

Waldbaum JC. 1999. The coming of iron in the eastern Mediterranean: thirty years of archaeological and technological research. In: Pigott VC, editor. *The Archaeometallurgy of the Asian Old World*. Research Papers in Science and Archaeology 16. Philadelphia: University Museum. p 27–58.

Wertime TA. 1982. Cypriote metallurgy against the backdrop of Mediterranean pyrotechnology: energy reconsidered. In: Muhly JD, Maddin R, Karageorghis V, editors. *Acta of the International Archaeological Symposium Early Metallurgy in Cyprus, 4000–500 BC, Larnaca, Cyprus 1–6 June 1981*. Nicosia: Pierides Foundation. p 351–61.

Yahalom-Mack N. 2009. Bronze in the beginning of the Iron Age in the land of Israel: production and utilization in a diverse ethno-political setting [PhD thesis]. Jerusalem: Hebrew University.

Yahalom-Mack N. Forthcoming. Bronze and iron production and utilization. In: Mazar A, editor. *Excavations at Tel Rehov*. Jerusalem: Institute of Archaeology.

Yahalom-Mack N, Gadot Y, Eliyahu-Behar A, Bechar S, Shilstein S, Finkelstein I. 2014. Metalworking at Hazor: a long-term perspective. *Oxford Journal of Archaeology* 33(1):19–45.

Yahalom-Mack N, Segal I. Forthcoming. The origin of the copper used in Canaan during the Late Bronze–Iron Age transition. In: Ben-Yosef E, editor. *Papers in Honor of B. Rothenberg*. Tel Aviv: Institute of Archaeology.

Yahalom-Mack N, Gadot Y, Shalem S, Finkelstein I. Forthcoming. The development of iron use: an updated count of bronze and iron objects from the southern Levant. *Tel Aviv*.

Zaccagnini C. 1990. The transition from Bronze to Iron in the Near East and in the Levant: marginal notes. *Journal of the American Oriental Society* 110:493–502.