ABSTRACT  The ‘coming of the age of iron’ (Wertime and Muhly 1980) around 1200 BC is an event of major historical importance. Bringing widespread changes to societies, it gave rise to the subsequent period being called the Iron Age. The Near East is the supposed origin of iron metallurgy, but finds of early production (pre-500 BC) are extremely scarce. So how did iron production start and how did it evolve? How was it embedded in society? Recently excavated early production finds (iron smelting at Tell Hammeh, Jordan; iron smithing at Tel Beth-Shemesh, Israel) present an exceptional opportunity to start answering such questions.

Uniquely studying smelting and smithing together, the chaîne opératoire of both technologies is reconstructed through science-based analyses. This paper treats the difference in material assemblage, layout, location and archaeometry of the two sites in order to discuss their sociocultural and economic frameworks. Emphasis is further placed on the role played by technical ceramics (tuyeres, furnace wall) in this early iron production. Hammeh and Beth-Shemesh indicate hitherto unknown cross-cultural relations through their particular tuyere design. And finally, both together provide a clear picture of what constitutes a smelting and a smithing operation respectively, allowing a reassessment of earlier, often disputed, claims for iron production.

Keywords: iron, metallurgy, Iron Age, Jordan, Israel, smelting, smithing, microstructure, metallography.

Introduction

This paper discusses the recent finds of early iron-smelting operations at Tell Hammeh in Jordan (930/910 ± 40 cal BC), and secondary smithing of iron at Tel Beth-Shemesh, Israel (c. 900 cal BC). These virtually contemporary operations provide a unique opportunity to study the metallurgical and sociocultural characteristics of some of the earliest remains of iron production known thus far. They further allow a unique comparison of both the technology and the organisation of two consecutive processing stages of iron metallurgy: smelting and secondary smithing. Following a brief review and assessment of previously known production sites in the Near East, this paper discusses the characteristics of the Tell Hammeh smelting process and attempts to reconstruct how this activity was embedded in the local society. This is followed by, and compared to, the characteristics of the Tel Beth-Shemesh smithing activities.

Historical background

The origin and early history of iron use are widely debated topics. To date, however, it has proved problematic to reconstruct the innovation and spread of this new technology. This is certainly aggravated by the scarceness of iron artefacts and especially the absence of iron production evidence (see discussions in Curtis et al. 1979; Pleiner 2000: 7–22; Waldbaum 1978, 1989, 1999; Wertime and Muhly 1980). Whereas (possibly) smelted iron artefacts do appear in quite early contexts in the Near East, evidence for their actual smelting and smithing prior to the middle of the 1st millennium BC has hardly been attested with the exception of a few sites with evidence for secondary smithing (Craddock 1995: 259; Pleiner 2000: 7–8; Waldbaum 1978: 65). There are some sites in the Near East where claims have been made in the 1970s and 80s for direct evidence for iron smelting; these, however, are now disputed. The following gives a necessarily very brief summary and assessment of the most prominent of these claims.

Claims for the early smelting of iron

An early claim for iron smelting was made in the 1970s, and concerns a group of sites in the Black Sea coast region (ancient Colchis) in modern-day Georgia (Khakhultaishvili 1976, 2001, 2005). The activities here are often dated somewhere between 1100 BC and 700 BC (Pleiner 2000: 36–7, 58). No detailed archaeometallurgical information is at present available, however, to prove or disprove either these early dates or the exact nature of the metallurgical activity practised at these sites, that is to say, whether they are concerned with iron or copper smelting.

A second claim for early iron-smelting activity concerns Tel Yin’am in northern Israel. The excavators claim that furnace-like structures, surrounded by some iron slag and ochre ore, belong to an experimental stage of iron smelting dating to
the 13th century BC (Liebowitz 1981: 82–4; 1983; Liebowitz and Folk 1980, 1984). Beno Rothenberg, however, invited by the excavators to the excavation, sampled and subsequently analysed some of the presumed slag and ore and concluded that the identification of an early instance of iron smelting was unfounded. His argument here is that the presumed slag contains less than 5 wt% iron oxide, i.e. far too little for any pre-modern iron smelting slag (Rothenberg 1983: 69–70). More recently, Vincent Pigott suggested (in our view) a much more likely interpretation of the finds at Tel Yincam: as a possible production site for red ochre pigments by heating ochreous bog ores taken from a local swamp (Pigott 2003).

A third claim for early iron production, also dating to the 13th century BC, was made in the mid-1980s for the site of Kamid el-Loz in Lebanon. The authors describe how a few minute fragments of iron metal were found in a workshop area near some fragments of slag and lumps of hematite ore, the last furthermore in the vicinity of a furnace structure. They then speculate how this means that the iron was produced here (Frisch et al. 1985: 77–8). The authors further mention that the tiny fragments of slag (0.5–2 cm³) from this area are green, grey-green and black in colour, and bubbly in appearance, but also that, in the field, they classified all material that was neither hematite nor finished product as ‘slag’.

It is difficult to follow the reasoning and evaluate the authors’ interpretation of the actual material, as all data are fragmented over various locations in the publication. Nevertheless, examination of the presented evidence raises strong doubts about an interpretation of any of the material as belonging to iron metallurgy. From an archaeological perspective, the excavators’ own assertion that the ore, slags and especially the iron metal are all found in secondary contexts (Frisch et al. 1985: 77, 96) makes a proposed relation between them doubtful. The chemical and microscopical analysis of the few slag samples shows that all contain significant amounts of copper sulphide (Frisch et al. 1985: 107, 134–46, 161, 178–80, especially tables 149ff in the appendix). The authors propose that their discoveries represent an early attempt at iron smelting based on the existing Bronze Age copper metallurgy.

However, although the co-occurrence of iron and slag originally prompted the idea of iron smelting at Kamid el-Loz, they then went on to speculate about the iron metal resulting

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**Figure 1** Map of the southern Levant, indicating the location of Tell Hammeh, Tel Beth-Shehesh, Mugharet al-Warda, several of the iron production related sites discussed, as well as several of the major sites in the Jordan valley.
from a virtually slag-free process. In our opinion, the Kamid el-Loz material shows no evidence for iron metallurgy besides the presence of a few Late Bronze Age iron artefacts, and even tentative interpretation of experimental iron smelting there is certainly not substantiated by the available archaeological or archaeometric data.

In conclusion, the Lebanese and possibly the Georgian sites are most likely related to copper metallurgy and the Israeli site to pigment production. None produced any quantity of iron-smelting slag or other unequivocal evidence for iron metallurgy. Only from the mid-1st millennium BC onwards does reasonably well-documented evidence exist for iron smelting in the eastern Mediterranean and Middle East, primarily from Greece and Cyprus (Hjärthner-Holdar and Risberg 2003; Muhly et al. 1982; Pleiner 2000, and the references therein). These cases do provide a set of early iron technological data with which new finds can be compared.

**Claims for secondary smithing of iron**

A small number of occurrences of secondary smithing of iron are reported from the Iron Age II (1000–586 BC) in the Near East. Most of these date around 700 BC or later and concern just a few pieces of slag to a few handfuls of slag without any sort of production context. Most lack a proper analysis of the material or closer technical assessment. One of the earlier reported instances is the find of a small number of slags in a room on Tell Afis in Syria, dated to c. 750 BC, but these lack both a production context and a clear determination of the processing stage (Ingo and Scoppio 1992; Ingo et al. 1992a; 1992b: 285–6).

Recently more cases of secondary smithing slag have been reported, such as a few samples of varying nature including some slags, but without a clear production context, from Tell Siukh Fawgani, Syria, dating to the 7th century BC (Luciani et al. 2003). Slags were excavated in 2004 at Tell Ahmar (Til Barsip), Syria and at Tel Hamid in Israel. Both date to the 7th century BC, and where the first is almost certainly related to smithing, the slag and tuyeres from the latter are as yet unassigned.

More secondary smithing slag was found at Tell es-Sa’idiyeh, Jordan, relatively close to Tell Hammeh (Mascelloni 2004), and Khirbet Mudayna, south of Amman (Daviau and Steiner 2000), again both dating to the 7th century BC. Iron metallurgy is also reported from sites such as Tel Dan, Hazor, Megiddo and Tel Masos, all in Israel, but no data on these finds are available in the public domain. Several kilogramms of Persian-period (c. 586–332 BC) secondary smithing slags were found at Tell Dor (Shai 1999).

Clear evidence for secondary smithing was attested at Tel esh-Shari’a (Tel Sera) in the northern Negev, Israel, where an Assyrian smithy (late 7th century BC) was found in the citadel. Here a hearth structure with two tuyeres and four pieces of magnetic slag were found, as well as hammerscale, an iron spike and a completely corroded piece of iron metal (Rothenberg and Tylecote 1991).

In summary, most published evidence for early iron smithing dates to around 700 BC or later, and little systematic archaeometric or contextual data on these finds are available in the literature. It is in the light of both the paucity of actual production finds and the difficult nature of the early claims described above, that the finds at Hammeh and Beth-Shemesh gain importance. Both sites were excavated and studied in parallel, with a specific metallurgical focus and developing and using dedicated metallurgical excavation techniques. The metallurgical finds from both sites were subjected to the same range of widely used analytical techniques to facilitate comparison. The data provide for the first time a clear picture of what, in the early 1st millennium BC, constitutes a smelting site and what constitutes a smithing site.

An important feature of Hammeh and Beth-Shemesh is their dating. Both sites are active at around c. 900 BC, which makes them very early in the regional history of iron metallurgy, and places these activities right at the moment in time when iron is becoming the prime utilitarian metal in the Near East.

**Slags but no city: smelting at Tell Hammeh**

**Chronology and stratigraphy**

Tell Hammeh was excavated by a team from the University of Leiden, the Netherlands and Yarmouk University, Jordan, in three seasons in 1996, 1997 and 2000. The last season (directed by Harald Alexander Veldhuizen), was specifically aimed at the iron production remains. During the fieldwork, dedicated methods of excavation were applied that were later expanded for the excavation of Beth-Shemesh (see below). Close to one tonne of debris from very early iron smelting and primary smithing (bloom consolidation) operations were found, comprising various types of slags, tuyeres, charcoal, molten technical ceramics and possible furnace structures. Radiocarbon analysis of two short-lived olive wood charcoal samples from the production phase (Olea europaea) provides a date at 930/910 cal BC (± 40 years; 1σ ranges of 1000–900 and 940–850 cal BC; accelerated mass spectrometry (AMS) analysis with 13C–12C correction). With due caution (van Strydonck et al. 1999), these dates place Hammeh as the earliest known find of iron smelting in the Near East (Pleiner 2000; Waldbaum 1999). Taking the dating as a terminus post quem together with the archaeological evidence for purely non-metallurgical activity at Hammeh from c. 750 BC onwards, production at Hammeh may cover a period of 100 to 150 years (van der Steen 1997, 2001, 2004; Veldhuizen 2005a, 2005b; Veldhuizen and Rehren 2006; Veldhuizen and van der Steen 1999, 2000).

The site itself is a relatively small tell in the central Jordan valley located where the Zarqa river valley opens into the Jordan valley, close to several larger tells (e.g. Tell Deir ‘Alla, Tell es-Sa’idiyeh). It has access to the natural resources desirable in metal production: water, outcrops of marly clays (see Veldhuizen 2005b: 297) (see Fig. 1), and above all the only iron ore deposit of the wider region at Mughareh al-Warda (Abu-Ajamieh et al. 1988; Bender 1968: 149–51; Pigott 1983; Pigott et al. 1982; van den Boom and Lahloud 1962).

Several periods are attested at Hammeh. From bedrock upward, remains of Chalcolithic (c. 4500–3000 BC) and Early
Bronze Age (c. 3000–2000 BC) occupation were found, followed by more substantial layers of Late Bronze Age (c. 1600–1150 BC) material. Hammeh appears continuously settled through the Late Bronze Age and Iron Age I (c. 1150–1000 BC), up to the start of iron production in the Early Iron Age II (see van der Steen 2004). At that point in time, domestic structures, at least in the excavated areas, cease to exist, and are covered immediately, i.e. without an observable period of abandonment of the site, by a stratigraphically well-defined phase of iron production. This phase has a complex internal layering, probably reflecting seasonal activity over an extended period of time. More extensive excavation of the levels below the iron-production phase is necessary to establish the exact nature and date of this transition (Veldhuijzen 2005a).

Very soon or immediately after iron production ceased, habitation of the site resumed. This later Iron Age II phase seems to form the last extensive occupation of Tell Hammeh. Based on examination of the extensive pottery finds from this post-smelting phase, it can be assumed that the iron-production activities must have ended no later than 750 BC.5

No settlement structures contemporary to the iron-smelting phase are presently known from Tell Hammeh.

**Scale of production and dating**

A substantial part of the original production area was removed from the eastern side of the tell by modern bulldozer activity (see Fig. 2). The iron production-related stratigraphy can be traced along large stretches of the resulting vertical bulldozer-cut face, and radiates at least 20–25 m westward into the tell from there (see Fig. 2). At the cut, the deposit is clearly present both to the north and to the south of square A/B7, but is often disturbed there by later (occupation) phases. A high concentration of iron production-related material was excavated in squares A/B7 to A/D7, which seems to indicate that here (or more to the east, in the lost part of the tell) may have been the epicentre of smelting activity. From the bulldozer cut westwards, as observed in trench 1 (see Fig. 2), the production debris slowly tapers off, but nevertheless does appear in both A/D5 and B/A5.

Based on the elevation levels of the remaining tell, together with the westward stretch of the production layer, it is estimated that half or more of the original production area was removed. No more than 5–10% of that projected production area has been excavated to date. So far, Hammeh has yielded

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**Figure 2** Plan of Tell Hammeh, showing the 1996 and 1997 squares in grey, and the 2000 squares in red (plan based on the survey of the tell by Muwafaq Bataineh, Yarmouk University).
roughly 700 kg of slags, present throughout the entire production layer, and more than 350 individual tuyere fragments, mainly from square A/B7 (see Fig. 3).

In order to assess the scale of operations, the excavated slag quantities were extrapolated to the original production area. The excavated slag quantities and available ore analyses were then used to estimate the yield of iron metal per unit of slag. Iterative mass balance calculations of the Hammeh tap slag and the local Warda ore (Veldhuijzen and Rehren 2006) show that 100 kg of average Mugharet al-Warda ore produces 57.5 kg of slag and c. 47 kg of iron metal, but requires an addition of c. 19 kg clay material as a flux. This means that the excavated 700 kg of slag corresponds to c. 570 kg of iron metal. Assuming that 5–10% of the original total production area has been excavated thus far, this translates to a total production of metal between c. 5.7 to 11.5 tons. Such quantities show that the melting activities at Hammeh were a well-established and substantial operation, as opposed to an early attempt or experimentation with a new technology. Spread over an assumed production period of about 100 years, this equals a production of 50–100 kg iron per annum, requiring something in the order of 100–200 kg of ore, or just a few donkey loads. This scale is more in keeping with a seasonal activity than a full-time specialisation, and would require only a single brief period of ore collection and smelting per year.

From the fact that the metalworkers at Hammeh were able to perform and sustain such an operation over a considerable period of time, one can conclude that they must have had access to the resources necessary in the process, particularly the ore. It seems unlikely that such access was possible without a larger socio-economic structure in which the iron production was embedded, but the political situation for this region at this period is not well enough understood to allow us to say more about the nature of this structure.

**Slags and tuyeres at Hammeh**

The predominant material at Hammeh is slag. Five different types can be distinguished. Placed in a logical order, these are: furnace slags (incompletely reduced ore; c. 30% of the total), furnace bottom slag (<1%), tap slags (c. 60%), ‘slags’ rich in technical ceramic (c. 1%), and primary smithing slags (a few %). It is interesting to compare the chemical composition of these slags to the composition of the local ore, the local clay, the olive wood charcoal, and the technical ceramic of the tuyeres and local clay (see Tables 1 and 2). At the time of analysis, we had access to only two ore samples. Current research on approximately 20 specimens of the Warda ore by Yosha al-Amri at the German Mining Museum in Bochum, however, confirms that our samples reflect the range of composition of that ore as it is found today.

The Hammeh slags range from a compositional similarity to the Mugharet al Warda ore in the furnace slags to a similar-

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**Table 1**

Comparison between the average major element compositions of the Warda ore, the various Hammeh slag types, the local clay and Hammeh tuyeres, and the Hammeh charcoal. In addition, the major elements of the Tel Beth-Shemesh secondary smithing slags are shown. Values are expressed in wt%, and normalised to 100% (except the charcoal which is given as analysed). Analysis by (P)ED-XRF (slag_fun calibration method, April 2005 (Veldhuijzen 2005a, 124–44; 2003)). The accuracy of the method, tested against certified reference materials (BCS-CRM 381, USGS BHVO-2, BCS-CRM 301-1, CCRMP SL-1) is better than 2.5% relative for oxides above 1 wt%. Precision was monitored through three repeat analyses of each sample and was found to be less than 1.5% relative for all oxides above 1 wt%. Although the (P)ED-XRF equipment identifies elements above magnesium at concentrations as low as 10 ppm, we report data only to the level of 0.01 wt% (100ppm).

<table>
<thead>
<tr>
<th>Material type (no. of samples averaged)</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>FeO</th>
<th>TiO₂</th>
<th>MnO</th>
<th>CaO</th>
<th>MgO</th>
<th>K₂O</th>
<th>P₂O₅</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mugharet al Warda hematite ore (2)</td>
<td>4.86</td>
<td>0.17</td>
<td>89.9</td>
<td>0.05</td>
<td>0.05</td>
<td>4.36</td>
<td>0.17</td>
<td>0.01</td>
<td>0.16</td>
</tr>
<tr>
<td>Furnace slags (10)</td>
<td>16.5</td>
<td>3.76</td>
<td>70.8</td>
<td>0.24</td>
<td>0.72</td>
<td>4.25</td>
<td>0.77</td>
<td>1.01</td>
<td>1.3</td>
</tr>
<tr>
<td>Furnace bottom slag (1)</td>
<td>17.6</td>
<td>2.18</td>
<td>69.6</td>
<td>0.13</td>
<td>0.06</td>
<td>8.10</td>
<td>0.99</td>
<td>1.06</td>
<td>0.21</td>
</tr>
<tr>
<td>Tap slags (15)</td>
<td>25.2</td>
<td>5.44</td>
<td>52.5</td>
<td>0.34</td>
<td>1.12</td>
<td>10.9</td>
<td>1.80</td>
<td>1.12</td>
<td>1.20</td>
</tr>
<tr>
<td>Primary smithing slags (1)</td>
<td>33.3</td>
<td>5.35</td>
<td>40.6</td>
<td>0.39</td>
<td>0.97</td>
<td>14.4</td>
<td>1.90</td>
<td>1.67</td>
<td>1.00</td>
</tr>
<tr>
<td>Ceramic-rich ‘slags’ (10)</td>
<td>46.4</td>
<td>5.98</td>
<td>23.1</td>
<td>0.48</td>
<td>0.69</td>
<td>19.6</td>
<td>2.48</td>
<td>1.70</td>
<td>0.74</td>
</tr>
<tr>
<td>Lisan clay + Hammeh tuyere ceramic (3)</td>
<td>57.2</td>
<td>13.2</td>
<td>4.78</td>
<td>0.96</td>
<td>0.07</td>
<td>17.5</td>
<td>2.96</td>
<td>2.84</td>
<td>0.22</td>
</tr>
<tr>
<td>Hammeh (Olea europea) charcoal (1)</td>
<td>0.40</td>
<td>n.d.</td>
<td>0.10</td>
<td>n.d.</td>
<td>0.00</td>
<td>8.40</td>
<td>2.10</td>
<td>2.50</td>
<td>0.10</td>
</tr>
<tr>
<td>Tel Beth-Shemesh secondary smithing slags (5)</td>
<td>24.8</td>
<td>3.94</td>
<td>50.0</td>
<td>0.27</td>
<td>0.08</td>
<td>16.6</td>
<td>1.44</td>
<td>1.85</td>
<td>0.85</td>
</tr>
</tbody>
</table>
ity with the technical ceramics/local clay in the ceramic-rich ‘slags’ (see Fig. 4). The furnace slag is compositionally relatively similar to the ore, except for an increased silica and alumina content; the ceramic-rich ‘slag’ is very similar to the local clay except for an increased iron oxide content (see Table 1).

This apparent relation to two source materials is further seen in the prime indicator of a smelting process, the tap slags. The Hammeh tap slags are chemically similar to typical bloomery slags (e.g. Bachmann 1982; Kronz 1998), but show a distinct iron-oxide-poor and lime-rich composition. Mass balance calculations of the Warda ore and the Hammeh tap slags confirm that simple removal of iron oxide as iron metal (to simulate the smelting process) from the Warda ore by itself cannot result in the formation of Hammeh slags (Veldhuijzen and Rehren 2006). This means that either the smelters used a different (blend of) ore or other materials must contribute to the process. As no other iron ore exists within a very wide radius around Hammeh, the second option seems more plausible. The most likely additional material is the ceramic-rich ‘slags’. These share all the macroscopic characteristics of the tap slags (black/grey glassy with flowing patterns), but are chemically virtually identical to the technical ceramics, their only chemical link to the smelting process found in their elevated iron oxide content, indicating a mixing of molten ceramic material with smelting slag.

The suspected influence of the technical ceramics was tested by further mass balance calculations, iteratively adding technical ceramic to and removing iron oxide from the Warda ore until the calculated hypothetical slag closely matched the actual Hammeh (tap) slags (Veldhuijzen 2005b; Veldhuijzen and Rehren 2006).

The best match was found for an addition of c. 19 kg ceramic material per 100 kg of ore, resulting in the production of c. 47 kg metal and 57.5 kg slag. This substantial addition of ceramic material is necessary to obtain a low melting slag, even though it dilutes the ore and reduces the amount of iron metal extracted from it. Thus, the relatively low iron oxide content and high lime content of the Hammeh slag are a result of the particular nature of the ore body. This requires a silica-rich addition to facilitate slag formation within an Iron Age
technology. It is not a sign of a particularly advanced smelting technology, similar to the much later blast furnace technology with limestone fluxing. From the high number and heavily vitrified state of the tuyeres at Hammeh (see Fig. 7), it seems clear that these, together with the furnace wall, provided the necessary ceramic material (Veldhuijzen 2005b).

In summary, the material found at Tell Hammeh and its archaeological context create a strong impression of a well-established and dedicated iron-smelting operation that forms part of a wider web of activities. The use of sacrificial tuyeres indicates, in our opinion, a clear understanding of the process by the smelters, using and adapting to the particularities of the locally available materials. Iron was produced in quantities that clearly exceeded individual consumption, but fell short of constituting a large-scale regional industrial centre. It is certainly conceivable that other smelting operations were active alongside Hammeh in the Mugharet al Warda area around the same time.

The fact that all charcoal excavated consists of short-lived olive wood, together with the high number of stratigraphic layers within the slag deposit, the absence of contemporaneous habitation of the site, the highly standardised shape of the tuyeres, and the apparent access to resources, strongly suggest a locally coordinated, seasonal activity that is tied in with other activities such as the harvesting and pruning of the olive trees. It takes place close to the necessary resources rather than the eventual consumer.

Slags and the city: smithing at Tel Beth-Shemesh

Location and excavation history

Tel Beth-Shemesh is located in the northeastern Shephelah, Israel, approximately 20 km west of Jerusalem and c. 75 km southwest of Tell Hammeh (see Fig. 1). It lies at what once formed the border area between the Philistine territory of the lower Shephelah and coastal plain, and the Judean hill country.

Three major expeditions have conducted excavations of the tell. The first, in 1911 and 1912, was directed by Palestine Exploration Fund archaeologist Duncan MacKenzie (MacKenzie 1914), the second by Elihu Grant (Grant and Wright 1939), from Haverford College, Haverford, Pennsylvania, in the late 1920s and early 1930s. Both exposed large areas of the site, digging deep trenches reaching down to bedrock. Shlomo Bunimovitz and Zvi Lederman from Tel
Aviv University initiated a third series of excavations in the early 1990s (Bunimovitz and Lederman 2003).

**Discovery and excavation of the smithy**

In 2001, work started in Area E (see Fig. 8), a narrow area in the southwestern part of the site that had remained unexcavated between a 1912 MacKenzie trench and a 1930 Grant trench. In both large public buildings had been excavated. Area E contained several phases of industrial and commercial activity. After several phases of these activities were excavated, evidence for metallurgical activity began to appear in square E/T48, at which point the directors approached the present authors. Excavation of the smithy took place in July 2003 and June 2006 using specific and pre-developed excavation techniques.

The assemblage of metallurgical debris excavated at Beth-Shemesh consists of technical ceramics, metal artefacts, a single type of morphologically homogeneous slag: concavo-convex ‘smithing hearth bottom’ (SHB) slag (or PCB: ‘plano-convex bottom’ slag), and very fine magnetic material (i.e. hammerscale) (on smithing technology, see Serneels and Perret 2003).

Intriguingly, the Beth-Shemesh tuyeres are virtually identical to the Hammeh ones in all macroscopic aspects, from size, colour, feel and temper to shape. Less abundant here (c. 30 specimens) than at Hammeh, they are all square and approximately 5 × 5 cm in section, with a bore of c. 10 mm in diameter (see Fig. 9; see also Fig. 7). Radiocarbon analyses of three burned olive pits from the smithy resulted in a date of c. 900 cal BC (± 45 years; AMS analysis with 13C–12C correction).

From the nature of the material recovered in 2001, and especially the fact that only one type of slag, i.e. SHBs, was present, subsequent excavation of the workshop in 2003 and 2006 began on the assumption that the workshop at Beth-Shemesh represented a secondary smithing operation, as opposed to iron smelting and/or primary (bloom-)smithing. To confirm or deny this assumption, dedicated excavation techniques were developed, expanding the normal archaeological stratigraphical approach.

**Dedicated metallurgical excavation techniques**

The development of these metallurgical excavation techniques drew on the experience at Hammeh as well as English Heritage guidelines (Bayley et al. 2001). With these methods, we sought to find and record the minute magnetic material associated with an iron-related metallurgical workshop, which is not recovered using standard archaeological excavation methods. This magnetic material, i.e. hammerscale and slag prills, is an important indicator of the type of metallurgy practised (Bayley et al. 2001: 14). It furthermore assists in determining otherwise invisible use of space and location of activities within the metallurgical workshop, e.g. the location of a hearth or anvil, by plotting its distribution within the workshop. A grid system of 25 × 25 cm was laid out over square E/T48. In the northern part of E/T48 the grids were bundled to 50 × 50 cm as this part was already excavated further (see Fig. 10).

The surface that was previously exposed in 2001 was used to test and refine the magnet-dragging techniques. Then, the soil from each unit (arbitrary vertical spits of 5 cm) within each grid (horizontal location, e.g. H15) was put in a separate bucket with a label, and subsequently spread out on a plastic sheet. A magnet held in a small sealable sample bag
Figure 10 The excavation of the 25 × 25 cm grid in square E/T48 at Tel Beth-Shemesh. Soil from each grid is recovered separately. The inset shows the dragging of a magnet above the soil surface of a previously excavated grid to recover magnetic material.

Figure 11 Distribution of hammerscale in square E/T48 (created in ArcGIS 8.3 using Spatial Analyst). Please note that the plotting spills over into the empty grid row 8/9 for both units 1 and 2.
was then dragged just over or lightly touching the soil for a minute and a half. The soil was then jumbled up by hand, and a second round of dragging, again for a minute and a half, was performed.

Several structures were discovered in the second unit (see Fig. 10). The exact function or sequence of these intersecting structures is as yet unknown, and is one focus of the (ongoing) 2006 excavations. Although they show no vitrification or similar indicators for metallurgical use, several contain ash, and all contain hammerscale. Two ridges (in I12–J12, and in J15, see Fig. 11) contain a large ash lens between them.

**Use of space in the Beth-Shemesh smithy**

The magnetic debris at Beth-Shemesh consists predominantly of hammerscale. Whereas hammerscales can also occur in the context of primary smithing, larger quantities of scales are usually associated with the more prolonged and extensively oxidising circumstances of secondary smithing (Jones 2001: 14).

To determine whether a spatial pattern could be discerned in the hammerscale scattering, the weights were plotted, per excavated unit, on the grid plan of E/T48 (see Fig. 11). The highest concentration of hammerscale coincides with the large ashy area observed archaeologically in all units excavated (see Fig. 1; compare Fig. 10). High concentrations can be expected inside a smithing hearth and in the vicinity of the anvil. When such structures or objects are no longer present or are difficult to identify, patterns within the hammerscale distribution may help the archaeological reconstruction of a workshop (Jones 2001: 14). At Beth-Shemesh, the observed correlation between high concentrations of hammerscale with those of ash in the same location suggests that this concentration reflects the (final) hearth structure rather than the location of an anvil.

**Slags and tuyeres at Beth-Shemesh**

Smithing slags are often very similar to bloomery smelting slags in general chemical composition (see Tables 1 and 2) and microstructural composition (Pleiner 2000: 255). The morphology, size and uniformity of the Beth-Shemesh slag all point towards secondary smithing (see Figs 12 and 13). In total, 65 complete cakes and more than 150 fragments were found, all belonging to a single type: mostly round, concavo-convex shapes with a diameter of up to 10 cm, with rust adhering to the top and soil embedded at the bottom.

These morphological features form a classic example of a ‘smithing hearth bottom’ (SHB) or ‘plano-convex bottom’ (PCB), where each specimen probably represents a single smithing operation (Serneels and Perret 2003: 473). Five samples were selected for further analysis. In their overall composition (see Tables 1 and 2), these slags compare quite well to other smithing slags discussed in the literature (e.g. Kronz 1998: 225), except that their lime content is considerably higher (c. 16 wt% compared to a more regular content between c. 0.5 and 5 wt% elsewhere). Their average iron oxide content is also lower than might be considered regular (almost 50 wt% compared to between 50 and 80 wt%). In contrast, the
Beth-Shemesh slags are quite similar in composition to both the Hammeh smelting (tap) and primary smelting slags, suggesting the use of similar materials and methods. The main discrepancies are in the lower manganese and sulphur levels in the Beth-Shemesh slags, as expected for secondary smelting slags, and the much higher barium concentrations; the latter may simply reflect locally different trace elements in the clays used to build the smelting hearth(s) and tuyeres. Work is ongoing to characterise these in comparison to the finds from Tell Hammeh. The relatively large quantities of free iron oxide in the form of wüstite in some areas of the SHBs (see Fig. 14) are probably due to the incorporation of hammerscale during the smelting operation.

Summary

At Beth-Shemesh, a picture emerges of a smithing workshop that is operated regularly and at considerable (local) scale within the confines of one of the larger cities in the Iron Age Levant, catering to the needs and wants of that settlement. Plotting of the magnetic remains has created a picture of the spatial layout of the workshop, with the likely position of the hearth (i.e. the last hearth in use). The quantity of SHBs, where each specimen represents a separate smelting operation, cycle or workday (Serneels and Perret 2003: 472), indicates that the smithing work at Beth-Shemesh must have been a regular operation, as opposed to an experimental or just an occasional one. The choice of location of the Beth-Shemesh smithy, near substantial public buildings, may reflect the status of this relatively new metal as well as being determined by a desired closeness to the consumer, rather than by considerations such as the availability of raw materials.

Assuming that each SHB represents a single workday of smithing, the Beth-Shemesh smithy was most probably a workshop for the creation and/or repair of iron (and perhaps bronze) artefacts for strictly local consumption, as opposed to a centre of secondary production for the wider area.

Conclusions

With the integrated excavation and analysis of both an early smelting and a smithing site, the sites discussed in this paper provide a template for distinction between the primary and secondary stages of iron-production technology, both during fieldwork and in subsequent analysis of the material, as well as for the re-evaluation of ‘older’ evidence and in the interpretation of future finds. Both sites are clearly distinct in terms of workshop layout, the nature and variety of material found, as well as the choice of location. The identification as either smelting or smithing slag is mostly based on their characteristic shape and archaeological context. The chemical and phase analyses support these interpretations, but would not on their own permit unambiguous assignment.

It is often suggested that the political fragmentation of the Iron Age I and II in the Levant stimulated local industries to exploit locally available raw materials (see Stech-Wheeler et al. 1981; van der Steen 2004). This is exactly the picture that emerges from Hammeh, where local people use and adapt their technology to local materials. In our opinion, it is very likely that Hammeh represents a seasonal smelting operation, taking place close to the necessary resources and in synchronisation with the equally seasonal pruning of olive trees to obtain fuel for the furnace. The lack of contemporary habitation on the tell raises interesting questions about ownership, organisation and control of space, know-how and resources in the region, which are beyond the scope of this paper.

The smithing at Beth-Shemesh shows a quite different choice of location as it takes place within the confines of a large city, which corresponds with other finds identified as smithing in the region. Here the choice of location probably reflects a desire to be close to the consumer, rather than being close to resources.

The identical design characteristics of the Beth-Shemesh and Hammeh tuyeres are probably indicative of cross-cultural contacts, shared technological characteristics, or even a possible socio-ethnic link between the people conducting two consecutive processes at two different sites. The square cross-section of the tuyeres is certainly not a technological requirement for their use. This shape may therefore represent a technological choice, i.e. a choice not guided by technological constraints, but one made by the person performing the technological activity based on, for example, social or cultural considerations, perceived requirements or local traditions. The largely uniform size and shape of all the tuyeres further suggests organisation of production and standardisation (see discussions in, among others: Costin 2001; Costin and Wright 1998; Dobres and Robb 2000; Killick 2004; Lechtman 1977, 1988, 1999; Lechtman and Steinberg 1979; Lemonnier 1986, 1989; Paffenberger 1988, 1989, 1992).

In the light of ethno-archaeological observation from sub-Saharan Africa (e.g. Chirikure and Rehren 2004; MacKenzie 1975), it is tempting to speculate about smelters (seasonally) smelting on a site near the required resources (Hammeh), and then travelling around the surrounding area, smithing their product near the consumers, i.e. in settlement contexts such as Beth-Shemesh and perhaps Tell Deir ‘Alla or Tell es-Sa’idiyeh, where this travel is reflected in identical tuyere design. Neither the Beth-Shemesh smithing nor the Hammeh smithing shows any sign of innovation or development of the technology practised. Both sites represent well-established technological processes of a considerable scale and with indications of standardisation. This clearly suggests that iron production and working were known and practised in the region prior to the start of iron smelting at Hammeh around 930 BC, and the smithing at Beth-Shemesh in c. 900–850 BC.

Notes

1. John Russell and Elizabeth Hendricks, pers. comm.
2. Samuel Wolff, pers. comm.
3. Adi Behar, pers. comm.
4. Eleni Asouti, pers. comm.
5. Gerrit van der Kooij, pers. comm.
References


Shai, N. 1999.écriture et métiers du fer (The work of a smith at Tel-Dor). *Archéologie et Natural Sciences*, 7: 38–49.


**Authors’ addresses**

- Corresponding author: Harald Alexander Veldhuizen, Institute of Archaeology, 31–34 Gordon Square, London WC1H 0PY, UK (h.veldhuizen@ucl.ac.uk)
- Thilo Rehren, Institute of Archaeology, 31–34 Gordon Square, London WC1H 0PY, UK (th.rehren@ucl.ac.uk)