11. Of Slag and Scales; Micro-Stratigraphy and Micro-Magnetic Material at Metallurgical Excavations

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ABSTRACT
The discoveries of early iron smelting evidence at Tell Hammeh in Jordan, and of a contemporaneous iron smithy at Tel Beth-Shemesh, Israel, provide the first and unique information on the nature of early iron technology in the entire Near East. The importance of these discoveries obviously demands meticulous attention to both the finds themselves and their archaeological and stratigraphical context.

At both sites however, the nature of the metallurgical debris and their stratigraphical matrix were such that regular stratigraphical excavation was not sufficient, leading to the development of dedicated metallurgical excavation methods and techniques, which allow for highly detailed retrieval and recording of the metallurgical finds, without compromising the required standard of stratigraphical excavation.

This article discusses the development of these dedicated metallurgical excavation methods using grids and units, and the technique of magnet-dragging excavated soil, which were employed at both sites over various seasons. It presents how and why these methods were used, and discusses potential drawbacks and clear advantages. It is indicated how the techniques are easily applied as well as adapted in differing circumstances, thus providing a valuable tool for any excavation faced with (iron related) metallurgical finds.

1. Introduction

Over the past decade, I have directed intensive excavation of two sites that feature remains of metallurgical activity, i.e. iron smelting at Tell Hammeh, Jordan, and iron smithing at Tel Beth-Shemesh, Israel (Fig. 2). Even though the Near East is the supposed birthplace of iron metallurgy (Wertime and Muhly 1980; Waldbaum 1999; Pleiner 2000; Veldhuijzen and Rehren 2007), the entire region is characterised by a virtual absence of
technological evidence on iron production.

In this light, the discoveries at Tell Hammeh and Tel Beth-Shemesh clearly demanded meticulous attention to both the finds and their context. A wide variety of analytical research has been performed on the Tell Hammeh and Tel Beth-Shemesh iron production finds, and the resulting data and interpretation is reported elsewhere (e.g. Veldhuijzen 2005; 2009a, b; Veldhuijzen and Rehren 2007; Blakelock et al. 2009).

In the field, at both sites, it turned out that both the nature of the metallurgical debris and the stratigraphical matrix that contains this debris demanded a specific approach in excavation. This has led to the development of a dedicated metallurgical excavation method, which allows for highly detailed retrieval and recording of the metallurgical finds, without compromising the required standard of stratigraphical excavation. In addition, the method developed is ‘simple and cheap’, and can be easily adapted to differing situations one may encounter on different sites.
This article tells the story of how the initial application of grids and units at Tell Hammeh for stratigraphical reasons, through development of the system at Tel Beth-Shemesh to trace smithing activities, led to the fully developed approach applied at both Tell Hammeh and Tel Beth-Shemesh in the spring of this year.

2. Excavating Iron smelting at Tell Hammeh, 2000

In the rescue seasons of 1996 and 1997 (Van der Steen 2004, 147-58), remains of iron production were first uncovered at Tell Hammeh. After analysis and initial interpretation of this material (Veldhuijzen 1998; Veldhuijzen and Van der Steen 1999), it was decided to hold a full-scale excavation season in 2000. This time the research question specifically concerned recovering as much information as possible on the very early iron smelting activities that had been identified at the site.

In the 2000 season, a formal division was applied to the site, analogous to the system used at Tell Deir ʿAllā (Van der Kooij and Ibrahim 1989), dividing the tell into four main areas (A-D), with each area consisting of 5x5 m squares (Fig. 3). The squares are numbered alphabetically along the north-south axis and numerically along the east-west axis of the grid, with both numberings ascending from the central point of the tell outwards. Balks 50 cm wide were left standing on the northern and western side of each square.

Squares were opened adjacent to the main 1996 and 1997 find spots of metallurgical activity, and trenches (trench 1 and trench 2) of 1x4.5 m parts were projected to try and track the distribution of the material within the south-eastern quarter of the site, and to try and identify possible different uses of space within this part of the tell. A third trench of 1.5x4 m parts (A/C7 and A/D7) was opened near the end of the season to connect trench 1 to the square with the highest density of production remains (A/B7).
During the 2000 season, a few hundred of kilograms of slag and some 300 tuyère fragments - not to mention technical ceramics, charcoal, or pottery - were excavated from square A/B7 alone, prompting the need for very careful recording. However, the complex deposit of metallurgical materials here proved to be of very loose consistency, considerably hampering proper stratigraphic excavation. Any attempt to follow regular stratigraphic techniques such as opening a small part of the square to inform subsequent excavation strategy, or creating intermediate sections within the square to clarify stratigraphic connections failed. The loose soil would simply slide into any newly dug opening. In combination with the ash/charcoal rich environment, this led to a ‘stratigraphic black-out’, and a different approach was clearly needed.

The vertical sections of square A/B7 did indicate a complex layering of the iron production debris during, but largely only after excavation. This layering is interpreted as the likely result of seasonal activity taking place over an extended period (c. 930-850 BC). However, due to the soil conditions described above, it proved impossible to establish the exact stratigraphy within this layering, or thus to assign locus numbers to this stratigraphy.

In order to capture the very likely present but invisible stratigraphy, a grid system of 75x75 cm was devised (Fig. 4), and set out using triangulation. These ‘mini-squares’ were termed grids and subsequently excavated in 5 cm deep arbitrary spits that were called units. With this terminology it was attempted to prevent confusion with existing stratigraphic terms, e.g. the term unit was used rather than spits, to avoid confusion with
11 - OF SLAG AND SCALES, MICRO-STRATIGRAPHY AND MICRO-MAGNETIC MATERIAL

The grids were given co-ordinates using the same system as the tell’s squares, i.e. with letters ascending from the central point of the tell along the north-south axis, and numbers ascending from the central point of the tell along the east-west axis. The 5 cm deep units ascend in given number as excavation progresses. In the notation used during registration, grids and units were added to the regular notation as shown in figure 5.

A choice was made for a grid-size of 75x75 cm, as this was deemed to create a logical division of the excavated part of the squares (6x75 cm forming 4.5 m), and small enough to capture distribution of material whilst still being large enough not to stifle excavation progress. A depth of 5 cm was deemed the largest possible depth in relation to the soil conditions.

The division of square A/B7 in 75x75 cm grids and separating the unseen stratigraphy within them by excavating in arbitrary units of 5 cm deep brought a range of advantages to the retrieval and recording of metallurgical material. First and foremost, thanks to this subdivision, it was possible to stay in control of the vast quantities of material recovered in the square. It allowed for example the ‘bulk’ removal of tuyères and slag, whilst the virtually exact location of these finds was still easily recorded.

Furthermore, in the same way as the division of the entire site into easily identifiable squares provides easy orientation, the grid system allows easy insight into the original location of material during subsequent study and analysis. The 5 cm units provide the possibility to later examine the pottery found in the metallurgical layers, and determine whether an absolute dating can be assigned to the different layers (or rather to the units) based on differences in pottery in the different units.

It will be clear that the application of grids and units during the 2000 season at Tell Hammeh was prompted by stratigraphical considerations only, albeit that these considerations were prompted by metallurgical questions.


The solely stratigraphical reason for a grid and unit system changed during the preparation for the 2003 excavation of the suspected iron smithy at Tel Beth-Shechem, Israel (Fig. 2), first found in 2001 (Bunimovitz and Lederman 2003; Veldhuijzen 2009b). This time, a strong metallurgical component was added to the method.

The aim of the excavation of square E/T48 (Fig. 7) was to determine the nature, lay-out, and use of space in what was assumed to be a secondary smithing workshop. Drawing on the then brand new ‘Archaeometallurgy’ brochure by English Heritage (Bayley et al. 2001), which discusses methods for retrieval of metallurgical material, and the experiences at Tell Hammeh in 2000, the dedicated excavation techniques were now further

Fig. 6. Meitar Lederman dragging a magnet above the surface of a grid in E/T48 to recover hammerscale. The surface scanning helped to determine the exact technique and duration of the magnet-dragging method
developed to encompass identification of the process and reconstruction of the lay-out and use of space, and, as before at Tell Hammeh, to recover as much metallurgical information as possible from the remains.

The techniques applied were tested, refined, and adapted in the field. Before actual digging work started, a grid system of 25x25 cm was laid out over square E/T48 as shown in figure 7. The southern half of E/T48 was least excavated in the 2001 season, and the surface here was first examined. This was done by dragging a magnet over each of the 25x25 cm grids to retrieve all magnetic material (Fig. 6).

In the northern part of E/T48, which was more extensively excavated in 2001, the grids were bundled to 50x50 cm. The northern part of E/T49, which is stratigraphically connected to the smithy in E/T48, was also scanned for magnetic material in 50x50 cm units, but revealed only minor quantities of magnetic material.

The magnets were held inside small sealable sample bags, to facilitate removal of the magnetic material being collected. Lifting the magnet within the bag creates sufficient distance between the magnetic field and the material collected on the outside, so the latter drops down into a receptacle. At Tel Beth-Shemesh, Styrofoam bowls were used to collect the material, which was then transferred to plastic sample bags. These bags were labelled with the regular excavation notation of Tel Beth-Shemesh: area, square, layer, bucket, followed by the metallurgical grid data: grid number and unit.

For the surface scanning, it was decided that an arbitrary two minutes per grid should suffice, especially since the surface could be presumed to be quite contaminated or at least disturbed after two years of exposure to the elements. It was found that retrieval of magnetic material decreased significantly after a minute and a half. To a certain extent, the work on the surface was used to build up necessary experience on which to base the subsequent magnet work in freshly excavated layers. When actual excavation of the grid started, in units of (at first) 5 cm analogous to Tell Hammeh, the soil from each grid was put in a separate bucket with a separate label. The contents of each bucket were then spread out on a large plastic sheet. A magnet was subsequently 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.

Fig. 7. Plan of square E/T48, showing the 25x25cm grid system, various partial potential hearth structures, concentrations of ash, and the large stone wall.
Several times, tests were performed to see if additional or continued dragging would recover more magnetic material. This turned out not to be the case, proving the two times 1.5 minutes approach very efficient. The aim of the grid based magnet work was to create a very detailed mapping of the distribution of magnetic material such as hammerscale and hammer spheres (slag prills) that are commonly associated with secondary smithing work (Serneels and Perret 2003). Mapping their distribution allows interpretation of the use of space within the presumed smithy, and potentially the identification of the hearth location(s) or the position of an anvil. Similar to Tell Hammeh, the grids were excavated individually and as described above the small subdivision in grids and units was now also aiming to retrieve and later establish the quantities of micro-magnetic material (Fig. 8). During excavation of the second unit, several features started to appear (Fig. 7). The archaeological necessity of following and recording the stratigraphy of the workshop, led to the abandonment of the strict 5 cm depth of the units, and it was decided to excavate unit 2 to a depth of 10 cm, and to leave the features intact until future excavation in the 2006 and 2009 seasons. They are interpreted as having been used in relation to the smithing activities, e.g. as storage bins for charcoal, billets or finished artefacts.

To determine whether a spatial pattern could be discerned in the hammerscale scattering, the clean weights were plotted, per excavated unit, on the top-plan of E/T48 and E/T49. As can be observed in figure 9, the highest concentration of hammerscale coincides with the large ashy area observed archaeologically, in all units excavated.

As mentioned above, the presence of hammerscale in an excavation carries several meanings. Larger quantities of scales are usually associated with the more prolonged and extensively oxidising circumstances of secondary smithing (Bayley et al. 2001, 14; Serneels and Perret 2003). But not only does hammerscale help in the determination of the nature of the metallurgical activities that are taking place, it also can be indicative of the location of these activities (Bayley et al. 2001, 14).

Concentrations of hammerscale are found inside a smithing hearth or in the vicinity of the anvil. When such structures or objects are no longer present or difficult to identify, possible patterns within the hammerscale distribution may help the archaeological reconstruction of a workshop. As hammerscale is easily trampled into the workshop floor can allow the survival of a pattern even after extensive or repetitive sweeping or cleaning of the smithy.

The fact that at Tel Beth-Shemesh the highest concentration of hammerscale coincides with high concentrations of ash in the same location, suggests that this concentration reflects the (final) hearth structure rather than the location of an anvil (Veldhuijzen and Rehren 2007; Veldhuijzen 2009b; Bunimovitz et al. in prep.).
Whereas the fine 25x25 cm grid system provided a magnificent tool for retrieval and recording of micro-magnetic material as shown above, it became clear very quickly that 25x25 cm does slow excavation down considerably. After the high precision approach of the 2003 season, it was therefore decided to work in 50x50 cm grids in the subsequent 2006 and 2009 seasons at Tel Beth-Shemesh. With the detailed reconstruction of use of space in hand, it was deemed that this would still provide the necessary detail and precision, but would allow for faster progress of the excavation.

During the 2006 season, and especially during the final season in early summer 2009, the excavations in the smithy of Tel Beth-Shemesh revealed that an earlier phase of the smithy was present underneath the units excavated in 2003. The material recovered in 2009 using the grid and unit method combined with magnet...
dragging is currently being studied. It will be very interesting to see how the distribution pattern of micro-magnetic material in this earlier phase will relate to the features excavated there, and how it may differ from the later phase.

4. EXCAVATING SMELTING AT TELL HAMMEH, 2009

In May and June of 2009, excavation resumed at Tell Hammeh, once more with elucidation of early iron metallurgy as the driving research question (excavated squares, see figure 3). With the data from the earlier excavations and a large corpus of analytical results and interpretations, the 2009 season set out with a range of very specific metallurgical aims. In the context of this paper, the application of magnet-dragging within the grid and unit excavation system is the most important.

As discussed above, the grid and unit system was originally developed to solve a - metallurgical debris related - stratigraphical problem. As it turned out, the system of applying grids and units proved eminently applicable to the proper investigation of an iron workshop at Tel Beth-Shemesh. Here, the method was further developed, and integrated with the magnet-dragging technique which allowed for the determination of the nature of the technology practised, as well as a reconstruction and interpretation of use of space within the workshop.

In spring 2008, analogous to the surface scanning at Tel Beth-Shemesh, the author performed some tests to establish the presence of micro-magnetic material at Tell Hammeh. This was clearly present in abundance, and only in locations on the site known to be related to the iron smelting activities. On returning to Tell Hammeh in the early summer of 2009, the combined techniques of digging in grids and magnet-dragging were applied here (Fig. 10).

Several factors concerning the grid system and the magnet-dragging were re-evaluated, tested and amended in the field. With excavation taking place in seven squares, it was clearly unfeasible to excavate in a grid as small as 25x25 cm. For that reason as well as a desire to be able to match the 2009 results with the 2000 season data, it was decided to use the existing 75x75 cm grid-size.

Two things were immediately evident. Due to the grid-size, much larger quantities of soil were now taken from each grid. Furthermore, it became apparent that most grids contained far more micro-magnetic material per unit than found at Tel Beth-Shemesh for the same quantity of soil. The magnet-dragging method therefore needed adjustment. The originally established timing of two times a minute and a half was clearly insufficient, and was increased to two times two and a half minutes of dragging. Furthermore, as the magnets would soon clog up with magnetic material due to the sheer quantities, they needed to be cleaned at intervals during the dragging (Fig. 11).
At the moment of writing, the material thus collected still needs to be processed, but it was clear in the field that there was a clear correlation between areas with high concentrations of micro-magnetic material and find spots with high concentrations of slag and charcoal, clearly demonstrating the relation between the two. It was also clearly visible that the micro-magnetic material recovered at Tell Hammeh is very different from that found at Tel Beth-Shemesh. Whereas the Tel Beth-Shemesh material consist predominantly of hammerscale, the Tell Hammeh material appears to consist mainly of what could be termed ‘micro-slag’ basically either very small entire slags, or tiny fragments broken off larger pieces of slag.

This fragmentation of slag material could tie in with the observed demolition of furnaces after smelting at Tell Hammeh, but definite conclusion required further analysis. Lesser amounts of hammerscale and possibly some slag prills are also present. Ratios and exact nature of all micro-magnetic material present remain to be determined, but it is feasible to propose that an iron smelting site has a pronouncedly different collection of micro-magnetic materials present that a secondary smithing site.

5. Conclusions

The excavation method outlined in this article comes with a few drawbacks. Especially at a 25x25 cm grid-size the techniques can be considered ‘micro-stratigraphy’ and tend to slow down excavation to some extent. As the excavators are also bound by the boundaries of the grids, and two people can usually not work on adjacent grids at the same time, this could potentially have an influence on the overarching stratigraphical approach in a square. Care therefore needs to be taken not to revert to simply digging one unit after the other, hoping to connect the data at a later stage. These potential negative aspects, which were avoided at Tel Beth-Shemesh and Tell Hammeh by adapting the method where stratigraphy demanded this, are vastly outweighed by the benefits of the method.

First of all, the method is virtually without cost, only large amounts of string, sample bags, magnets, marker pens, and patience are required, and could therefore be applied at any expedition faced with metallurgical remains, regardless of budget or terrain. The exact methodology and application can (and should) be adjusted to each specific situation whilst still providing comparable results. The data retrieved if of very high detail and precision, allowing for determination of the technological stage found as well as interpretation of use of space within the excavated area. It furthermore provides easy and exact sampling and localisation of finds both during excavation and subsequent laboratory analysis. Last but not least, it is easy to carry out, and the slower pace of digging allows for close supervision of the logistics involved and monitoring of what is found, so several people can excavate multiple grids simultaneously.
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