Sudan & Nubia

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LIBYA
EGYPT
ASWAN
1st cataract
Red Sea
2nd cataract
Korosko Road
Wadi Gabgaba
Wadi Allaqi
Dal
3rd cataract
SUDAN
Kawa
H29
H25
Magashi
4th cataract
Kurgus
5th cataract
Dangeil
Dam-Debba
CHAD
Wadi Howar
Meroe
Hamadab
Musawwarat
es-Sufra
El Milk
Wadi Muqaddam
6th
cataract
Wad
ben Naqa
KHARTOUM
Atbara
ERITREA
Blue Nile
White Nile
Dhang Rial
ETHIOPIA
CENTRAL
AFRICAN
REBUBLIC
SOUTH
SUDAN
Jebel Kathangor
Jebel Tukyi
Jebel Kachinga
Maridi
JUBA
Lulubo
Lokabulo
Ancient sites
Itohom
MODERN TOWNS
Laboré
KENYA
ZAIRE
0
200km
UGANDA

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Front cover: Examining the pharaonic inscriptions at Khashm el-Bab on the Korosko Road, November 2013 (photo: D. A. Welsby).

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Post-Meroitic Iron Production: initial results and interpretations

Jane Humphris

Introduction

Technological processes are embedded within the cultural milieu of any society, and should therefore be considered as one of many manifestations of social practice, as much as they also represent technical achievements in their own right. A process such as iron production, even when performed on a small-scale, is always intertwined within the politics, economics, social relationships and even religious aspects of any given context (Costin 2005, 1037; Signaut 2002, 436). Thus by deconstructing the archaeological record relating to a technology such as iron production, data can be generated that can allow us to understand the decisions made by the artisans involved. By assessing why these choices were made and the consequences of these choices, broader conclusions can be reached about the world in which the technologies were being undertaken (Gosselain 2000; Ingold 1990; Lemonnier 1990; Pfaffenberger 1992; Sillar and Tite 2000, 2). It is this potential of studying past technology that the UCL Qatar research aims to maximise.

In the archaeometallurgical record iron production is represented first and foremost by iron slag: the waste product of iron smelting formed during a smelting episode. Iron slag potentially contains information about many of the ingredients added to the smelt (ore, charcoal, technical ceramics and fluxes), some of the operating parameters of the smelting techniques (for example information about temperatures and reducing conditions reached within the furnace), and even (combined with other details such as an understanding of the ore composition and the methods used by the smelters) information concerning the efficiency and products of the process. A more detailed summary of the requirements and process of iron production has been provided by Humphris and Rehren (2014; see also Crew 2000; Rehren *et al.* 2007; Serneels and Crew 1998 for further details).

To produce iron and slag in significant quantities such as that we see at Meroe and Hamadab, a large workforce and significant levels of resources are required. To illustrate the significance of these requirements, details concerning an experimental iron smelt commissioned by the author in 2007 in central Rwanda can be presented. This single smelting episode was led by head smelter André Nyandwi; over a period of two weeks, approximately 20 men worked to prepare, smelt and smith iron into an object, performing all stages of the *chaîne opératoire*, or operational processes involved (Figure 1). Evidently, each of these individual processes represents a technology in its own right, requiring specialised knowledge, skills, and labour.

No information is available concerning the organisation of smelting at Meroe or Hamadab. Consequently our archaeological work is essential for answering the many questions concerning the social milieu within which this technological process operated. One key question, for example, is 'Were there specific groups responsible for separate stages of the

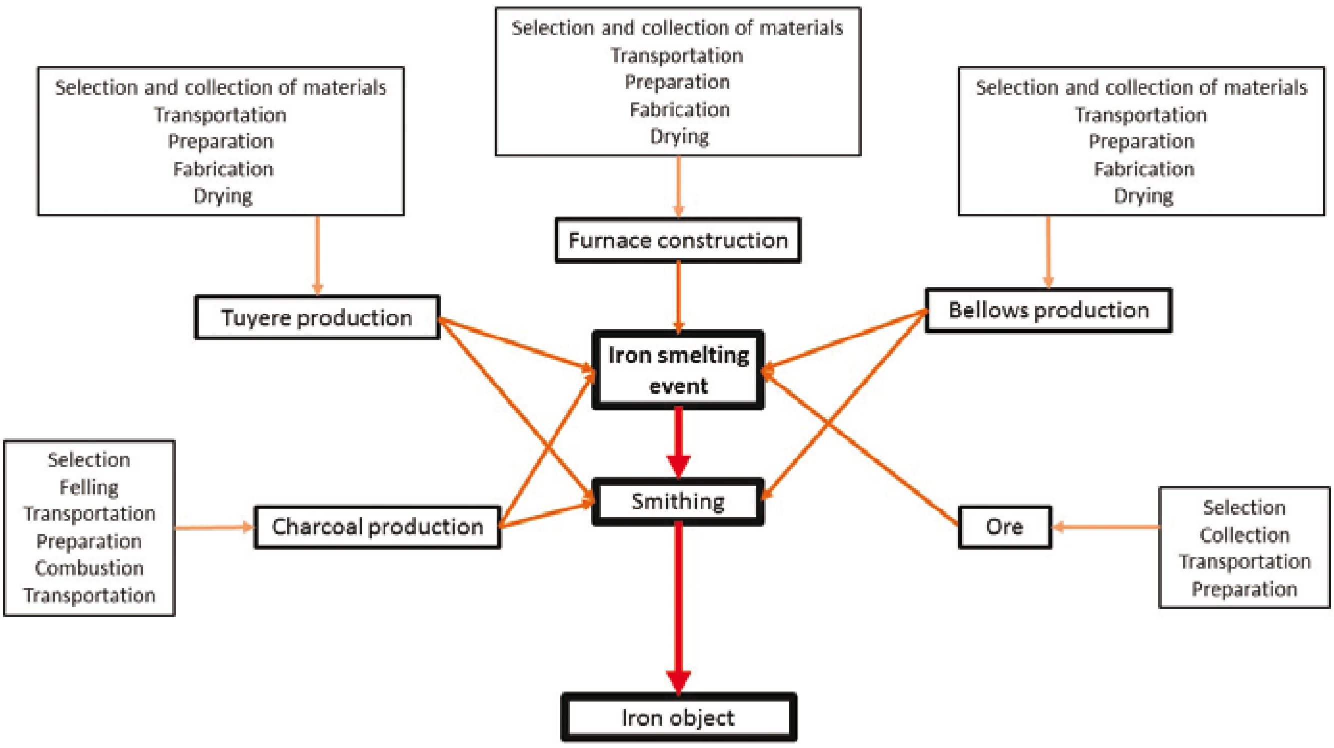

Figure 1. A schematic representation of the chaîne opératoire *of the iron production process (adapted from Humphris 2010, 74).*

chaîne opératoire of iron production?'. Avenues to explore relating to such a question might include:

Were individual smelting groups attached to separate workshops working for head smelters who supplied their iron in competition with each other to the State and local/external markets; alternatively was the process centrally controlled and therefore perhaps producing more uniform waste products?

Did ceramic specialists supply workshops with tuyères and other smelting-related ancillary products?

Did specialised miners or ore-gatherers collect ore from the surrounding landscape?

Alternatively, did those working at specific workshops take responsibility for completing the *chaîne opératoire* in its entirety?

It is this type of socio-technological information that archaeometallurgists attempt to tease out of the metallurgical remains. Such information is significant because it can point to organisational systems that may reflect broader aspects of society, for example the level of State control over production, and the impact of production on society in terms of how many people may have been involved in the processes (significant when considering broader social organisation and roles of individuals in society, and relationships between different groups of pyrotechnologists).

During the iron production event in Rwanda, just over 200kg of charcoal was used to smelt nearly 40kg of processed iron ore within a furnace that was made of nearly 300kg of specially sourced and prepared clay, supplied with air through tuyères made from approximately 30kg of a different type of specially sourced and prepared clay. Approximately 12kg of iron slag and 15kg of iron bloom were produced. One bloom was selected and smithed into a marriage hoe weighing 4.5kg (Plate 1). If we relate these figures back to the Meroitic case, where the most recent estimates suggest that between 5-10,000 tons of iron slag (i.e. the waste product of this process) is present at the Royal City (Rehren 2001, 103), one can start to appreciate the levels of production in terms of resources and labour that would have been involved in this industry, and hence it's fundamental role within broader society. However, until we can appreciate both the time period involved in the production of all of this slag, as well as the quality of the ore and the levels of slag produced per smelt in relation to the amounts of iron produced, further insights are problematic.

Meroitic iron production

The data already obtained from various archaeometallurgical studies at Meroe, most recently summarised in Humphris and Rehren (2014), provide a few key insights into Meroitic iron technologies. These insights are based on a small number of excavations and analyses of iron production remains.

In terms of dating, iron production waste was found within stratigraphic layers dating to the late 6th century BC (Shinnie and Kense 1982, 19), although little is known about the nature of this waste or how much iron slag was found

Plate 1. A Rwandan marriage hoe: the result of two weeks of labour for a large number of men, and using hundreds of kilograms of resources.

within this dated archaeological layer. More is known about iron production at Meroe during the first few centuries AD, when smelting was undertaken in perhaps semi-sunken workspaces of approximately 4 x 3m, demarcated with low walls. Furnace structures were built into the walls at opposite ends of each workshop. Air was supplied to these furnaces through six tapered tuyères powered by ceramic pot bellows situated around the outside of the furnaces (for plans and photographs see Shinnie and Anderson 2004, 73-79; for additional descriptions and discussions concerning the iron smelting technology see also Shinnie and Kense 1982; Tylecote 1970; 1982). It is believed that good quality ore was collected from the hills to the east of the Royal City and smelted in furnaces designed to horizontally tap slag during the smelt. However, the tuyères were situated high enough and the furnace was constructed in a way that slag also accumulated in the bottom of the structures as well. The slag produced was fayalitic in nature with few free iron oxides present, potentially indicating quite an efficient smelting technology (Rehren 2001).

Objects produced include weapons such as arrowheads, and other functional objects such as nails and pins, although Meroitic iron objects are a rarity within the archaeological record (Rehren *et al.* 1995; Rehren 1996; Abdelrahman 2011). The concept of a deliberate expression of a symbolic link between iron production and the power of the ruling family has been recently postulated (Haaland and Haaland 2007), as have potential links and influences between the technology at Meroe and beyond (Haaland 2013).

Considering the number of publications that exist and continue to be written concerning iron production at Meroe, as the brief outline provided above demonstrates, surprisingly little is known about this technology. What information we do have remains superficial and, to a large degree, speculative. Key research questions that the UCL Qatar research hopes to explore in order to address this situation have been recently summarised (Humphris and Rehren 2014) and include topics such as: the origin and type of charcoal that was used; the quality and origin of the ore; the smelting techniques and styles that were employed and whether these changed over time.

Considering that so much of this research relies on the analysis of iron slag, it should be mentioned here that one of the major challenges that has to be overcome for this research to really begin to understand the iron industries represented by the iron slag remains at Meroe and its surrounding landscape lies in the concept of representivity. As has been discussed above and elsewhere (e.g. see Humphris *et al.* 2009; Humphris and Rehren 2014), iron production can be particularly variable in terms of ingredients added, time period of activity, techniques and operational parameters such as temperature and reducing environment. Therefore, the slag produced throughout a single smelting event and between smelting events has the potential to reflect this variability. Consequently, a single arbitrary piece of slag collected from the surface of a Meroitic slag mound, or even 50 pieces collected from a slag mound that may contain tonnes of slag fragments, cannot be said to be representative of one smelt, let alone of the smelting technology of the Meroitic period (unless a statistically defined number of slag fragments are analysed and found to be chemically and microscopically identical).

Methods

This project employs a multidisciplinary approach involving a number of different specialists working together to produce holistic, comparable data. Excavation strategies take into account the fact that the slag heaps are comprised of the bucket-dumping episodes of those tasked with clearing out the furnace workspaces, resulting in a heterogeneous mass of small slag fragments and other metallurgical debris. Consequently the only way to excavate is in spits of defined depths; the sections of the trenches are then documented and studied in detail and samples are taken from each identified archaeometallurgical context. The content of each spit is mixed and then halved, halved and halved again to leave a representative 8th of the original mass. This is weighed, sieved and sorted into the categories of different material. Each category is then weighed and samples are taken. This method allows for statistical modelling of the composition of the slag mounds and the collection of representative samples. An additional aim of the excavations is to attempt to locate and excavate furnace workshops. To assist in these aims, geophysics methods including ground penetrating radar (GPR, carried out by Burkart Ullrich of Eastern Atlas GmbH & Co. KG) and a combination of gradiometry and resistivity (carried out by Dr Chris Carey, University of Brighton) have been successfully used to map the internal nature of slag heaps, identify potential sub-surface slag deposits, and to locate at least one furnace workshop so far.

Dating is a key concern of this project. The aim is to construct a chronology both within slag heaps and between slag heaps, thus precise dating is essential. The dating strategy has been designed in collaboration with Dana Drake Rosenstein from the University of Arizona, who travels to Sudan to run the luminescence strategy outlined below, and also carries out work on the samples in the University of Arizona AMS Laboratory and the Luminescence Laboratory at the University of Washington. Charcoal samples collected from the documented trench sections (preferably found embedded within slag fragments) are sent for archaeobotanical analysis which, as well as identifying the wood species (see below), aims to discount samples which may well be affected by the old wood phenomenon. Multiple AMS dates are produced from charcoal samples taken from defined locations within sections of each excavated trench.

To further refine the AMS dating strategy, a number of dosimeters are set 400mm deep into each section. They remain in place for one year and are then collected alongside samples found in close proximity (ideally right next) to the dosimeter. Some dosimeters are positioned within non-slag deposits (for example within sandy deposits immediately below the metallurgical layers). These are collected for Optically Stimulated Luminescence (OSL) dating and therefore have to be collected at night under a black tarpaulin. Samples for Thermoluminescence (TL) dating (such as tuyère fragments or furnace material) are collected during the day. The samples and their dosimeters are shipped to the laboratory with additional travel dosimeters and based on data concerning the radiation within the travel dosimeters, the section dosimeters, and the samples themselves, the age of the sample can be calculated. The first set of luminescence dates from the site of Hamadab are pending.

Understanding the technical role of ceramics in the iron smelting process – and the social role of the ceramicists themselves – is another important facet of the UCL Qatar research programme. A comparison of domestic and technical ceramics is essential for understanding possible choices that were made by those responsible for producing the ceramics that would have to survive the extremes of temperature and redox conditions to enable a smelt to continue unheeded for a number of hours. Did these people (whether they were the 'normal' ceramicists or artisans tasked with only producing technical ceramics, or perhaps the smelters themselves) specifically select and manipulate material to increase the refractory properties of the tuyères and furnace material? Or perhaps as documented elsewhere in Africa (for example in Cameroon: David *et al.* 1989), these ceramics were specifically made to deliberately melt into the process to act as a fluxing material. Whatever the case, identifying such deliberate choices will reveal much about the technical knowledge held within the communities of the time. Therefore, technical and domestic ceramics are collected and recorded in the field.

They are documented using the same system developed and implemented by the German teams working at the site of Hamadab and Meroe Royal Baths over the last few years to ensure ease of comparability. Certain samples are then selected for laboratory analysis.

As mentioned above, numerous charcoal samples excavated within archaeometallurgical deposits and from non-metallurgical context where available are sent for wood species identification by Dr Barbara Eichhorn (Institut für Archäologische Wissenschaften, Archäologie und Archäobotanik Afrikas, Johann Wolfgang Goethe-Universität in Frankfurt). The results of this work provide the opportunity to consider whether local wood supplies could have met the demands of the iron smelters. If this was the case, possible impacts on the local environment can be explored. If instead it is found that demand would have outstripped supply, further questions concerning trade networks can be considered.

A further set of analyses will be used in the future on samples collected from within iron production workshops. Geochemical sampling strategies led by Dr Chris Carey of the University of Brighton are being employed within the floor areas of smelting workshops. Thorough and systematic sampling takes place at 250mm intervals across the floors in stratigraphic sequence (and numerous samples are also excavated from the furnace structures). These samples will be tested for hammerscale (an indication of smithing/further refining of the bloom), and certain samples will be selected for ICP-MS and lead isotope analysis. By providing an understanding of the trace elements present in the samples and isotopic information for potential sourcing, the organisational use of the workshops, and whether other materials were also worked in these areas, will be revealed.

Hamadab

The site of Hamadab has been excavated since 2001 by Pawel Wolf of the German Archaeological Institute and his team (for example see Wolf and Nowotnick 2005; Wolf *et al.* in press; Wolf *et al.* this volume). Wolf and his team have discovered main phases of the Meroitic occupation within the sub-surface archaeology of the site. The town was walled and included a main street leading from a main gate in the west to a temple situated at the opposite end of this street. On either side, the street was lined with houses and alleyways which were modified and adapted throughout the course of occupation. Evidence is also available for certain administration buildings.

Industry played a role at the site, with evidence that people were producing cotton (D. Fuller pers. comm.), making textiles, as well as producing pottery. Iron slag mounds are present to the west, east and south of the town, and sub-surface slag deposits have recently been found to the north of the town. It was assumed that these deposits related to the main phase of occupation, i.e. the Meroitic period.

Five trenches were excavated into the archaeometallurgical debris at Hamadab: three trenches in the slag mound situated outside the town wall behind the temple (mound 100-200); one trench was excavated in the slag mound positioned just to the south of this (mound 300); and one trench was excavated in mound 800, the most southerly slag mound, approximately 120m south of the walled town (for a map of Hamadab showing the location of the iron slag mounds and trenches mentioned in this paper please see Wolf *et al.* this volume, fig. 2).

Results

Dating

Fifteen charcoal samples were sent for AMS dating (three from a section within each of the five trenches, from the bottom, middle and close to the top of the metallurgical debris). Figure 2 shows the calibrated dates obtained from these samples, and demonstrates that rather than dating to the Meroitic period, the iron production remains at Hamadab were produced during the post-Meroitic period. Furthermore it could be tentatively suggested that these results demonstrate the caution with which isolated radiocarbon dates should be treated. Due to the stratigraphic origins of the samples, there is the possibility that sample 9_12c could be indicative of the old wood effect rather than reflecting the dates of iron production, while the dates produced for samples 12_12a, 12_12b and 12_12c could also be problematic. The implementation of the luminescence strategy was specifically designed to mitigate such problems.

One of the big questions that arose during the excavations of the archaeometallurgical remains at Hamadab was the relationship between the two sites of Meroe and Hamadab in terms of their iron industries. It seemed particularly strange that there would be two iron production centres only a few kilometres away from each other, presumably using the same resources and perhaps even labour, and accessing the same economic markets. A chronological distinction between the two sites was postulated at the time.

Slag

Considering the make-up of the slag mounds themselves, a number of interesting observations were made during excavation. As would be expected, the slag mounds were found to be particularly heterogeneous in composition and display complex internal stratigraphy. Macroscopically, slag produced within a furnace (furnace slag) and slag tapped outside a furnace in a liquid state during the smelting event (tapped slag) can be identified. These two categories have been further refined to include two subcategories but for the purpose of this paper the distinction between furnace slag and tapped slag will be discussed. The presence of the two types of slag indicates that the smelters at Hamadab were employing the same smelting techniques as their predecessors working at Meroe, whereby the furnace was designed in a way that slag both fell to the bottom of the furnace and solidified, and slag was also tapped during the process. An alternative to such a theory is that one type of slag could represent some kind of

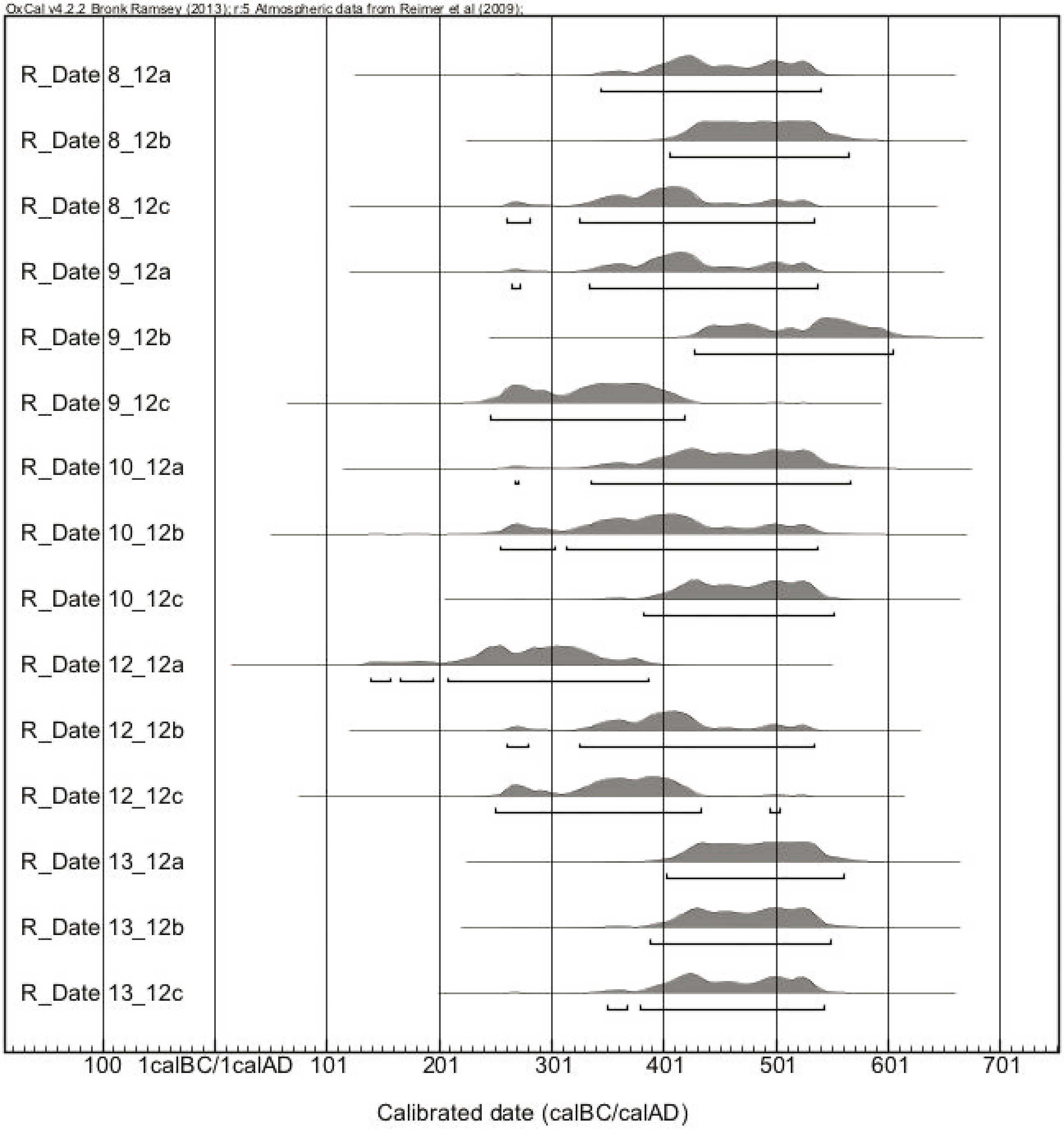

Figure 2. 2 sigma AMS ^{14}C dates obtained from the charcoal samples taken from the metallurgical debris at Hamadab (dates produced, calibrated and presented by Dana Drake Rosenstein).

additional, secondary refining process. Further investigations are required to explore this and other possibilities.

The slag excavated in two trenches at the southern end of slag mound 100-200 was statistically analysed in more detail and compared to statistical analysis from excavations in mounds 300 and 800. Although the sections within mound 100-200 varied in composition significantly, the ratios of the different types of slag collected from these trenches was very similar. From these trenches 65% and 66% of the slag was formed within the furnace as opposed to being tapped from the furnace. That the general ratio of furnace slag to tapped slag is similar between the two trenches could perhaps indicate that this slag mound is formed from the waste produced from one workshop using similar techniques over a period of time, and thus producing similar slag during each smelting episode.

Things becomes more interesting when the results from these two trenches are compared first with mound 300 and mound 800. In mound 300, only 39% of the slag was furnace slag, while in mound 800 this figure was about 51%. This would suggest that perhaps these slag mounds are the waste from different workshops (not unsurprising for mound 800 which is 120m to the south of the town). Perhaps these workshops were making use of slightly different furnace styles and smelting using slightly different operating parameters and techniques.

Laboratory analysis of slag samples from Hamadab is in its infancy, although a number of superficial and tentative conclusions can be reached from samples analysed microscopically and under the SEM-EDS from mound 100-200 and from mound 300. This initial phase of SEM-EDS analysis was carried out by Dr Myrto Georgakopoulou of UCL Qatar. Microscopically the slags appear generally fayalitic in nature with few free iron oxides or iron metal present. As would be expected, the SEM-EDS analysis[1] of five slag samples from mound 100-200 and five samples from mound 300 illustrated that these bloomery slag fragments are compositionally quite similar yet display the variability in major and minor oxides that would be expected when considering tapped slag and furnace slag produced during the bloomery process. The levels of major and minor oxides, as well as the levels of variability between each oxide, is similar between the two slag mounds with no chemical characteristics particularly obvious as distinguishing the smelting ingredients used by smelters using the two mounds. Furthermore, there is no particularly distinguishing chemical signature that can define the tapped slag from the furnace slag, although the tapping layers and phase developments within the microstructures of the tapped slag samples are obvious.

These very preliminary observations are only based on the SEM-EDS analysis of ten samples. As these numbers grow it is hoped that patterns will start to emerge within the chemical and microscopic signatures of the slag mounds that will allow for an understanding of smelting ingredients and techniques and how (or if) these varied and changed between workshops and over time. However, considering that iron ore (as well as to a lesser extent fuel ash and the melting of technical ceramics) will probably be the dominating factor to consider when looking at slag composition, a sound understanding of this aspect of the *chaîne opératoire* of iron smelting is going to be very important (see below).

It should be mentioned that what appear to be smithing beads and smithing cakes were also found in association with the iron smelting debris at Hamadab, indicating that the metallurgists were working iron into objects rather than, for example, exporting the iron as blooms to sell or trade to others for working. Further analysis and testing of bulk samples for hammerscale is required to elaborate on the post smelting processes that may have been carried out at Hamadab.

Technical ceramics

The dozens of tuyère fragments collected at Hamadab are currently being documented before thin section and other analysis will begin on certain samples. However a number of impressions can be mentioned here. First, there seem to be a number of different types of tuyères represented within the assemblage (as was found to be the case at Meroe: Tylecote 1970, 69). One category is quite roughly made and poorly fabricated. Another seems to be more kaolin-rich and well made with smooth outer edges and tapered ends, and fabricated to include all sorts of temper including (potentially) grog, crushed slag, pebble fragments and large quartz grains. Finally, a small number of tuyère fragments appear to have been made to be square or partly squared in section. Most of the tuyères also appear to be relatively heavily tempered with organic material which is a characteristic also noted in certain domestic ceramics found at the site (Wolf pers. comm.). This could indicate a link between the potters and the smelters living and working next to each other. For example, could the potters themselves have been responsible/commissioned for the production of tuyères, or was the incorporation of organic material a tradition the smelters continued in the production of their tuyères? An example of the differences in the tuyères can be seen in Plate 2, which shows a finely made tapered tuyère (excavated from mound 100-200) in comparison to a roughly made tuyère (excavated from slag mound 300).

Plate 2. A comparison between a roughly made tuyère (left) and a finely made tapered tuyère (right).

Another avenue for further exploration involves the dimensions of the tuyères, analysing aspects such as wall thickness, circumference and diameter of blow hole. This work is ongoing, as is the analysis of the material used to construct the furnaces at Hamadab. It would seem likely that the furnace structures were constructed of a clay that was deliberately heavily tempered with comparatively large sand grains, small pebbles, and stone fragments. Presumably the front section of the furnace structure was broken to retrieve the bloom after each smelt and then repaired for the next smelt. This would account for the numerous fragments of furnace material found within the slag mounds. No *in situ* furnace structures have yet been excavated at Hamadab, therefore further conclusions about the furnaces themselves or their operational organisation (i.e. were they still situated within a workshop with two furnace structures at either end, as found dating to earlier times at Meroe and described above), cannot be suggested at this stage. However, it is hoped that targeted excavations based on new geophysics data by the UCL Qatar team at Hamadab in 2015 will reveal furnaces at this site.

[1] SEM-EDS analysis was performed using a JEOL JSM-6610LV scanning electron microscope with an attached Oxford Instruments X-MaxN energy dispersive spectrometer with a 50mm^2 detector running on AZtec software. The instrument was operated at an accelerating voltage of 20kV, a process time (live time) of 60 seconds and a deadtime of about 40%. The working distance was 10mm.

Charcoal

As has been published previously (Humphris and Rehren 2014), 94% of the charcoal samples collected from the metallurgical debris at Hamadab was *Acacia Nilotica* and 4% were classified as *Acacia* type. One species (*Leptadenia Pyrotechnica*) was represented by one sample while one sample was unidentifiable due to its small size. In comparison samples taken from other contexts at Hamadab (including a pottery kiln and cooking hearths), *Acacia Nilotica* was only represented in 7% of samples, while *Acacia* type was found in 72% of the samples. Interestingly the remaining 21% was comprised of four more species types plus a small category of unidentifiable samples.

Interestingly, within charcoal analysed from metallurgical deposits excavated at Meroe Royal City dating to the Meroitic period and earlier, 91% were found to be *Acacia Nilotica*. Thus what is becoming clear is not only that the smelters were particularly selective in their choice of wood for their charcoal (*Acacia Nilotica* being structurally stable and highly calorific and therefore ideal for use in a smelting furnace), but this significantly high degree of selectivity had a long tradition (about 1000 years). Depending on how much iron smelting was occurring in this area per year, it may be the case that this wood had to be brought in from elsewhere if local environmental resources could not sustain the local demand. Alternatively, perhaps some kind of woodland management was being implemented, or it could be the case that if production per year or per decade was relatively small, perhaps local resources were sufficient to sustain this selectivity.

Iron production in a Post-Meroitic context

This is not the place to summarise our knowledge of the late Meroitic and Post-Meroitic periods in detail. Excavations at sites such as Ballana, Arminna West and Qasr Ibrim in Lower Nubia, and el-Hobagi and Soba East further south, are providing insights into what was happening during the 4th, 5th and 6th centuries AD (Welsby 2002, 23-24). It would seem that a combination of internal and external factors led to end of the Meroitic period. Contributing factors include a decline in trade and dispersion of wealth leading to the rise of the nobles, and pressure from the east and the west including desert raiders. Archaeologically the Post-Meroitic period is defined both through changes in material culture (for example seen in burial practices and ceramics) and well as in continuities (for example in the continued use of temples and other buildings). In general, however, the impression is one of a more fragmentary social structure with less in the way of centralised organisation, control or protection (for discussions on these periods see for example Adams 1977, 382-429; Mahmoud el-Tayeb 2010; Lenoble 1999; Török 1997, 476-487; Welsby 1998, 195-205; 2002, 14-30).

What then does it mean that at Hamadab during the Post-Meroitic period we find evidence for reasonably large-scale iron production? As has been described above, to make iron requires access to significant quantities of a variety of different resources, as well as the knowledge and skills to smelt in an economically viable manner, a labour force and probably some kind of local or regional market network within which to exchange the product to justify its production. Furthermore, if certain groups in society are smelting iron for some parts of the year, there has to be other groups available to facilitate the continuation of this technology by, for example, tending to the fields and providing protection. We can, therefore, hypothesise that during the Post-Meroitic period, society remained stable enough that knowledge systems remained in place, access to resources remained possible, and labour forces were of a sufficient size and organised in a manner that the smelting industries were able to operate successfully.

It is currently difficult to estimate exactly how much iron slag is present at Hamadab, although during the next archaeological season in 2015 this question will be addressed with 3D modelling and resistivity of the slag mounds and their surroundings. In addition, as mentioned above, it is hoped that the remains of smelting furnaces will also be excavated. This new information, combined with the results of extensive laboratory analysis on the many archaeometallurgical and associated samples excavated and brought to the materials sciences laboratories at UCL Qatar, will allow a more thorough reconstruction of the iron smelting technologies of Hamadab. Quantifications concerning amounts of resources used and how much iron may have been produced will be provided. Until then it can be suggested that although fundamental aspects of society had changed, during the Post-Meroitic period groups of people who still retained the knowledge of smelting, and who made use of the same resources and smelting techniques that had previously been used for hundreds of years, were living at Hamadab. On a macroscopic level at least, the archaeometallurgical remains appear remarkably similar over time and between sites. This continuity of technological tradition, would seem to point to a continuation of many aspects of society from the Meroitic into the Post-Meroitic period.

Future work

As well as continued excavation of the metallurgical remains at Hamadab, there are two key avenues of future work that will help to ground the results so far obtained and indicate their significance within the wider archaeological context of the periods in question. The first is comparable excavations and analysis at other sites dating to other periods of time to generate data that can produce a diachronic, holistic understanding of the iron industries and their position and role within society. This has already begun with two seasons of excavations at Meroe Royal City. The results produced so far and mentioned above, for example with dating and archaeobotanical analysis, are already helping to reveal the significance of the finds at Hamadab.

The second involves experimental archaeometallurgy. It is only through reconstructing the processes and replicating and reproducing as closely as possible the original smelting conditions, including the materials that were used and the manner in which they were smelted, that we can begin to access information concerning the finer nuances of the iron smelting industries. Of course such experiments and interpretations of the data have to be handled objectively and with care, but through a serious of well-prepared experiments whereby certain variables are changed for each smelting episode, variables can be identified and modified to bring us much closer to the smelters and their technologies than excavation, sampling and laboratory analysis can achieve.

Conclusions

While iron production at Meroe Royal City dates to the Meroitic period and earlier, large-scale iron smelting at Hamadab dates to the Post-Meroitic period. It would seem however that the techniques and resources remained similar. One working hypothesis is that during the Meroitic period and under royal rule, iron smelting and the smelters themselves were controlled by the State, who 'employed' them and provided the labour systems, exchange networks and resources necessary to practice their crafts. Considering the time periods involved, and the fact that it is now been proven that 'slag mounds' can in fact be a relatively small layer of slag sat on top of other archaeological debris, it seems likely that the iron was probably used more for local consumption than external trade. In return for the iron, the iron workers had a position in a well-functioning society, with other groups responsible for other craft and subsistence industries.

It could be suggested that as the capital and those original benefactors declined, smelters were able to move away from the confines of the northern 'quarter' of the Royal City to other locations where they were no longer under the eye of such a controlling influence. Perhaps here they could operate in a freer environment and begin experimenting or reacting to the available resources, changing market demands and access to labour. Perhaps what we see in the differences between the slag mounds are the results of different workshops, while at Meroe more uniform processes and techniques will be identified during the course of this research. Further analysis of iron production sites in the region will allow for such hypotheses to be tested.

Acknowledgements

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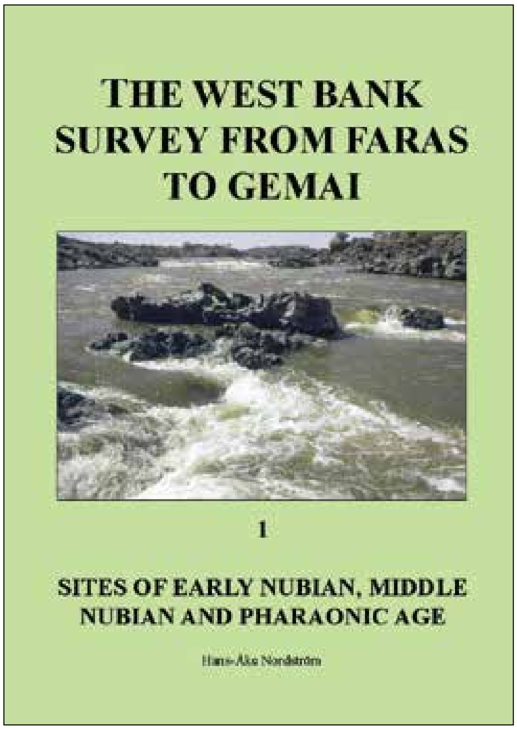

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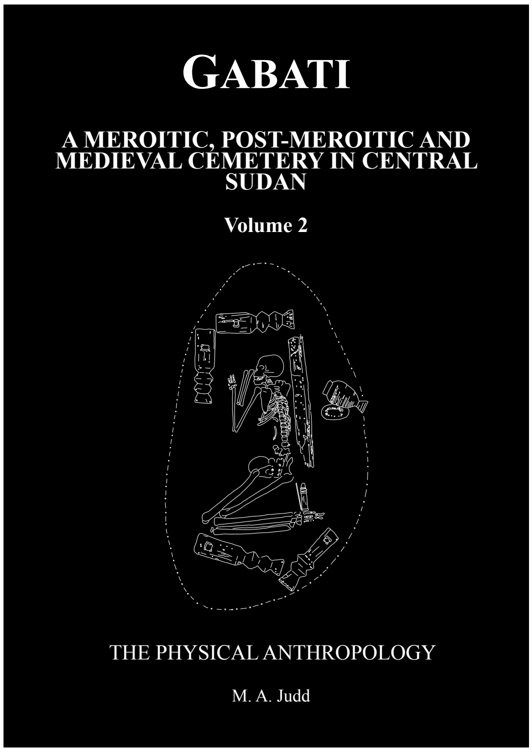

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View upstream along the Wadi Murrat from the late 19th century Anglo-Egyptian fort.
The pharaonic inscriptions are amongst the trees at the wadi *edge in the far centre (photo D. A. Welsby).*

Horus, Lord of the Desert. A natural rock outcrop along the route from Buhen towards Wadi Murrat (photo D. A. Welsby).

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