The technology and craft organisation of Kushite technical ceramic production at Meroe and Hamadab, Sudan

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Abstract

This paper seeks to contribute to the growing knowledge of iron production in ancient Sudan by examining the technology and craft organisation involved in the production of technical ceramics, which were integral to the iron smelting process. The focus of this study are the technical ceramics including tuyères, furnace linings, and furnace bricks, recovered from various slag heaps located at the archaeological sites of the Royal City of Meroe and the Meroitic town site of Hamadab. We used macroscopic examination and thin-section petrography to identify the source of raw materials and methods used in preparing the raw materials, to characterise the level of craft specialisation, and to infer the broader socio-political developments that might have influenced how the production of technical ceramics was organised. The resulting data reveal that changes occurred within the production of technical ceramics throughout different periods of Kushite history (traditionally divided into Napatan and Meroitic) and during the post-Meroitic period, and we argue that the observed changes might have been related to the rise and fall of the Kingdom of Kush. The production of technical ceramics was marked by clear distinctions in raw materials and paste preparation methods used for different types of technical ceramics, and a high degree of compositional and technological homogeneity within each type of technical ceramic during the Napatan and earlier Meroitic periods, coinciding with the time when Kush rose to and was at the height of its power. The production of technical ceramics appears to have exhibited more diversity in terms of the raw materials and paste preparation methods and lower degree of homogeneity during the later and post-Meroitic periods when the economic and political influence and power of the Kingdom of Kush is described as declining and ultimately ceasing to exist. Perhaps the most drastic change in the production of technical ceramics took place in the post-Meroitic period, which was characterised by lower level of specialisation, as well as the possibility of using a different technological approach to iron smelting.

Keywords: Technical ceramics; iron production; Sudan; African archaeology; macroscopic examination; thin-section petrography

1. Introduction

Iron production is argued to have been a crucially important technology for the Kingdom of Kush, which lasted from at least the 8th century BC to the 4th century AD (Haaland, 2014: 658; Humphris, 2014; Humphris and Rehren, 2014; Shinnie, 1985; for a background to the Kingdom of Kush see Török, 1997; Welsby, 1996). Kushite iron production is also argued to have had significant implications on the origin of iron metallurgy in sub-Sahara Africa (Childs and Killick, 1993; Killick, 2015: 310-311; Shinnie and Kense, 1982). However, our present understanding of the nature and scale of Kushite iron production, based on the results of a few previous studies, is far from conclusive (Garstang et al., 1911; Rehren, 1995, 1996, 1997, 2001; Rehren et al., 1995; Shinnie, 1985; Shinnie and Kense, 1982; Trigger, 1969; Tylecote, 1970, 1982). Against this background, UCL Qatar's archaeometallurgical research was initiated to fill important research gaps in current understandings of iron production during different periods of Kushite history by using a multidisciplinary approach (Humphris, 2014; Humphris and Carey, 2016; Humphris and Rehren, 2014; Charlton and Humphris, forthcoming; Humphris and Scheibner, forthcoming). Working within this framework, the investigation presented here was dedicated to the examination of the production of technical ceramics, which were integral to the iron production processes. This study, therefore, serves to differ from previous Nubian ceramic analyses, which largely centered on domestic pottery and/or fine-ware ceramics, by placing our emphasis on technical ceramics (cf. Brand, 2016; Carrano et al., 2009a, 2009b; Daszkiewicz and Schneider, 2011; Daszkiewicz et al., 2005; Dittrich, 2010; Edwards, 1999; Mason and Grzymski, 2009; Smith, 1991, 1995, 1996, 1997, 1999). This study also serves to deviate from past technical ceramic characterisation works, which focused mostly on their refractory properties, by exploring the technology and craft organisation involved in technical ceramic production. In order to address these aspects of production, we focused on the technical ceramics recovered from slag heaps situated at two key Kushite settlements: the Royal City of Meroe (Shinnie and Anderson, 2004) and the Meroitic town-site of Hamadab (cf. Wolf and Nowotnick, 2013; Wolf, 2015). We used macroscopic examination and thin-section petrography to examine the technical ceramics so as to characterise the sources of raw materials and methods used in preparing the raw materials. The resultant compositional and technological variability enabled us to identify the technical practices and choices made by ancient producers, and to highlight the level of craft specialisation in relation to iron production. Ultimately, we aimed at inferring to the socio-political developments of the Kingdom of Kush in which the production of technical ceramics was organised.

2. Background

2.1. Technical ceramics

'Technical ceramics' here refer to ceramic materials that were used for ferrous-technical purposes as opposed to domestic pottery and fine-ware ceramics (Chirikure and Rehren, 2004: 145; Martinón-Torres and Rehren, 2014: 109-110; Veldhuijzen, 2005). We examined a wide range of technical ceramics, including tuyères, furnace lining and furnace bricks, and furnace materials (Fig. 1). Tuyères are the blowpipes that were made of clay to supply and regulate airflow direction and quantity from the bellows to the furnace. Furnace linings are the additional layer of ceramic materials attached to the interior surface of the furnace. Furnace bricks are the blocks or slabs of ceramic materials that were used to build the furnace. Furnace materials refer to the ceramic materials that belong to be a part of the furnace structure and display varying degree of vitrification but cannot be firmly placed into the category of furnace bricks or furnace linings.

Figure 1. Examples of technical ceramic remains (from left to right): tuyère fragments, furnace lining, furnace brick, and furnace material.

2.2. Archaeological Contexts

The technical ceramic remains, together with fragments of slag, iron ore and charcoal, are among the primary constituents of slag heaps, which are found in abundance within the landscape of certain ancient Kushite settlements. The technical ceramics included in this study were recovered from trenches excavated in the following slag heaps: MIS (Meroe Iron Slag) 1/2, MIS2, MIS4, and MIS6 of the Royal City of Meroe, and slag heaps 100-200, 300 and 800 of Hamadab (Fig. 2). Calibration of radiocarbon dates of the slag heaps suggests that they were dated to various phases of the Kushite and post-Meroitic periods (Table 1; periodisation after Török, 2015). In this study, we use the traditional sub-division of Kush into two major periods, the earlier Napatan period from the beginning of the Kingdom until the Meroitic period, which runs from ca. 280 BC to AD 350, although we recognise this division is currently under critique; the term ‘Kushite period’ is used here to subsume both the Napatan and Meroitic periods. Hence, an examination of technical ceramic remains recovered from these slag heaps allows us to trace the development of technical ceramic production during the Kushite period and beyond.

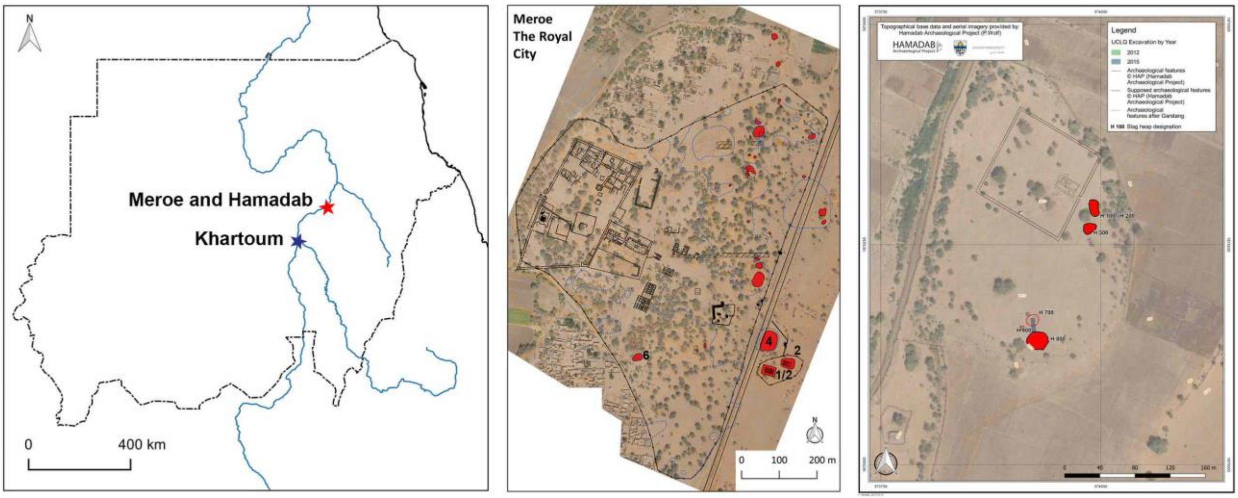

Figure 2. Left: Sudan, with Khartoum marked as the blue star and Meroe and Hamadab (3km apart), marked as the red star; Middle: The Royal City of Meroe with all slag heaps shown in red and the ones mentioned in this study labelled; Right: The slag heaps investigated at the Meroitic settlement of Hamadab shown in red.

Site	Location	Calibrated dates	Period
Meroe	MIS4	ca. 8th – 2nd century BC	Napatan to earlier Meroitic periods
	MIS2	ca. 5th – 2nd century BC	Napatan to earlier Meroitic periods
	MIS1/2	ca. 4th – 1st century BC	Napatan to earlier Meroitic periods
	MIS6	ca. 2nd – 6th century AD	Meroitic to post-Meroitic
Hamadab	300	ca. 3rd – 6th century AD	Later Meroitic to post-Meroitic
	100–200	ca. 4th – 6th century AD	Later Meroitic to post-Meroitic
	800	ca. 4th – 6th century AD	post-Meroitic

Table 1. The calibrated, modelled radiocarbon dates and equivalent archaeological periods of the slag heaps, where the technical ceramics were recovered and included in this study (after Humphris and Scheibner, forthcoming).

2.3. Geological Setting

Most of the Sudan is underlain by Precambrian metamorphic and intrusive basement rocks, with large areas being overlain by sedimentary cover rocks summarised as the so-called ‘Nubian Sandstone’ (Geological Map of the Sudan, 1981). The Nile, with its two main tributaries – the White Nile and Blue Nile – merging at Khartoum, runs through the region. The Atbara River, with its headwaters in Ethiopia, enters the main river system about 300km north of Khartoum. The three tributaries have distinct mineralogical composition, thus contributing to the variation in the mineralogical composition of the confluence area (Garzanti et al., 2006). The White Nile carries rounded monocrystalline quartz with small amount of feldspar, the sediments of the Blue Nile contain mostly mafic volcanic grains, K-feldspar, and biotite, and the Atbara River contributes volcanic rock fragments, augite, and olivine. The Nile alluvium in the areas north of the confluence is described as more homogeneous, containing mineral suites of quartz, feldspars, amphiboles, clinopyroxenes, mica, rounded fragments of basic volcanic rock, and phytoliths of vegetation, which are mainly produced from weathering of the basaltic Ethiopian Highlands (Mason and Grzymski, 2009). In spite of their apparent homogeneity in the mineralogical composition, the grain size of the sediments is described to have decreased with distance from the confluence area (Eisawi et al., 2015: 310).

The archaeological sites of the Royal City of Meroe and Hamadab are both located along the eastern cut banks of the Nile: Meroe is situated ca. 150km north of Khartoum and Hamadab ca. 3km south of Meroe. The geology of both sites is characterised by the presence of the Nile alluvium as described above. In addition to the Nile alluvium, the areas to the north and east of the sites are underlain by granitic gneisses, amphibolites, and hornblende gneisses, with outcrops of granites and basic volcanic rocks. The areas to the south and west of the sites are underlain by sand- and mudstones of the Shendi Formation, the local stratigraphic unit of the 'Nubian Sandstone' (Eisawi et al., 2015: 316-317). Deposits of kaolinitic clays are interbedded with sandstone in the Shendi Formation (Eisawai et al., 2015: 316-317; Robertson, 1992). The geomorphology of the region is also influenced by the seasonal *wadi* drainage systems such as Wadi el-Hawad and Wadi Hadjala, which have the effect of transporting and sorting sediments to the Nile (Wolf, 2015). We acknowledge that the above description of the geology of the areas surrounding the sites is somewhat generalised, and that more detailed description of the variation in the mineralogical composition specific to the sites will require the execution of systematic geological surveying of the region, which is an ongoing effort of the project.

3. Methods

Macroscopic examination and thin-section petrography were used to examine the technical ceramics in this study. Macroscopic examination was carried out to document traits such as shape, dimension and fabric composition of the technical ceramic assemblages, and to select samples for further analysis. Noteworthy is the inherent limitation in the archaeological sampling of tuyères, furnace linings, furnace bricks and furnace materials owing to their fragmentary nature. A stratified sampling strategy was applied to select tuyère samples to ensure the selected samples are representative of the variation that exists within the assemblages, as well as the variation through time and across the sites. The tuyère fragments were divided into macroscopic fabric groups based on variation in fabric colour, size and relative abundance of inclusions. Within each macroscopic fabric group, the fragments were further divided into subgroups according to their context of recovery, diagnostic features (i.e. nozzle end) and shape. Diagnostic fragments were selected from each subgroup, and in case no diagnostic fragment was present in the subgroup, non-diagnostic fragments were chosen instead. The application of the same criteria on selecting furnace lining samples was challenged by the lack of variation observed in their macroscopic fabric composition. Sampling of furnace brick and furnace material samples was equally challenging because the macroscopic composition of furnace bricks and furnace materials appears to be different from fragment to fragment, making it difficult to place the samples into macroscopic fabric groups. Thus, the furnace lining, furnace brick, and furnace material samples were chosen according to their contexts of recovery to ensure that the composition and technological characteristics of different phases of Kushite and post-Meroitic periods were represented. In total, 70 tuyère, 25 furnace lining, 17 furnace brick, and 10 furnace material samples were selected for petrographic analysis (Table 2).

Site	Location	No. of tuyères	No. of furnace lining	No. of furnace bricks	No. of furnace materials
Meroe	MIS4	6	9	2	n/a
	MIS2	3	1	n/a	n/a
	MIS1/2	6	1	1	n/a
	MIS6	21	14	14	n/a
Hamadab	100–200	26	n/a	n/a	7
	300	3	n/a	n/a	2
	800	5	n/a	n/a	1

Table 2. The quantity of tuyère, furnace lining, furnace brick, and furnace material samples selected from each slag heap at Meroe and Hamadab for petrographic analysis.

Since our focus is on the raw materials and methods used in making the technical ceramics rather than their refractory properties, thin-section petrography is the ideal method, as it has been readily used to examine the production of domestic pottery and/or fine-ware ceramics in the region; thus making our data comparable with other ceramic studies (cf. Brand, 2016; Carrano et al., 2009b; Daszkiewicz and Bobryk, 2003; Daszkiewicz and Schneider, 2011; Mason and Grzymski, 2009; Smith, 1991, 1996, 1997, 1999). Thin-section petrography characterises the composition of technical ceramic samples by identifying their mineralogical constituents. By comparing the mineralogical constituents with local geological data, it has also made possible to establish the potential provenance of raw materials used in making technical ceramics. This analytical technique also sheds light on the technology used to make technical ceramics – especially paste preparation method and the level of standardisation involved – by characterising the relative and overall abundance, grain size, shape, and sorting of their inclusions (Freestone, 1991; Quinn, 2013; Whitbread, 1995). We argue that the variation in mineralogical composition and technological traits of the fabrics represents the presence of different ceramic pastes, each of which was unique to particular producers or production groups. The thin-section samples were prepared and analysed at the Laboratories of Archaeological Material Sciences at UCL Qatar. Estimation of the relative abundance of inclusions was made with reference to the percentage chart developed by Matthew et al. (1991).

4. Results

4.1. Tuyères

Macroscopically, where shape is identifiable, the majority of tuyères are cylindrical, but with varying external diameter, bore diameter, and wall thickness. Three variants – cylindrical shape, cylindrical shape with thin wall, and cylindrical shape with thick wall – were identified (Fig. 3a). In addition to the cylindrical shape, some tuyères are square in shape with circular bore (Fig. 3b). It is interesting to note that correlations exist between the shapes of tuyères and their context of recovery. Cylindrical tuyères with thin wall occur in greater frequency in MIS1/2 and MIS2, whereas square-shaped tuyères are associated with MIS4. Cylindrical tuyères with thick wall were only found in MIS6, although the presence of tuyères of other shapes is also common in MIS6. The tuyères recovered from Hamadab are mostly cylindrical shaped, with a few square-shaped ones. The tuyères of same shape class recovered from each context are relatively homogenous in terms of their dimensions (Table 3).

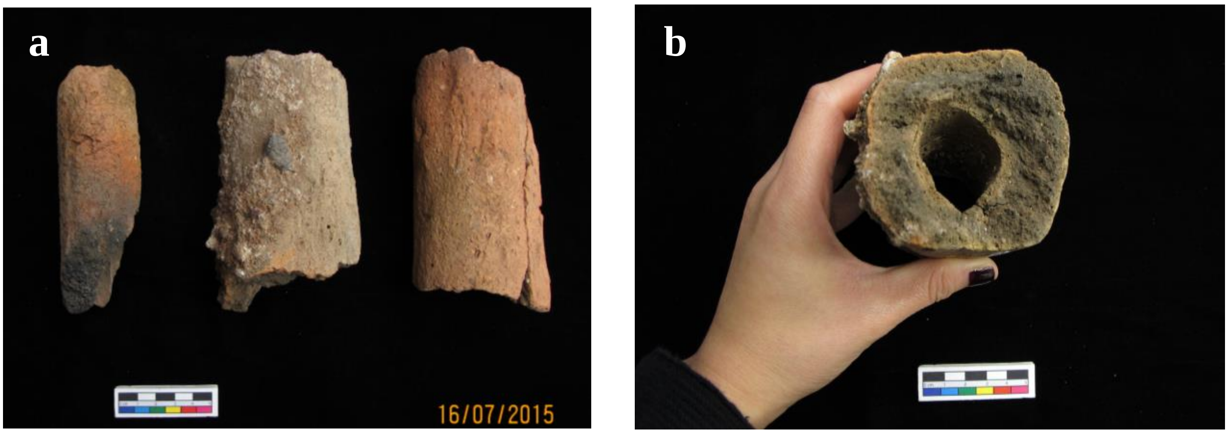

Figure 3. Different shapes of tuyères identified: (a) (from left to right) cylindrical with thin wall, cylindrical, and cylindrical with thick wall, and (b) square-shaped.

Location	**Tuyère shape**	**External diameter**					**Bore diameter**					**Wall thickness**				
		max. (cm)	min. (cm)	mean (cm)	s.d. (cm)	r.s.d. (%)	max. (cm)	min. (cm)	mean (cm)	s.d. (cm)	rsd (%)	max. (cm)	min. (cm)	mean (cm)	s.d. (cm)	r.s.d. (%)
MIS4	Square (n=4)	6.2	5.1	5.6	0.5	**9**	3.9	2.0	2.7	1.0	**39**	2.3	1.7	2.1	0.3	**14**
MIS2	Cylindrical with thin wall (n=3)	4.3	3.4	3.9	0.5	**12**	2.0	1.9	2.0	0.1	**3**	1.0	0.9	1.0	0.1	**6**
MIS1/2	Cylindrical with thin wall (n=3)	4.2	4.0	4.1	0.1	**2**	2.2	1.9	2.1	0.8	**1**	1.3	1.1	1.2	0.1	**10**
MIS6	Cylindrical (n=9)	6.1	4.2	5.4	0.7	**13**	3.8	2.2	3.2	0.7	**21**	2.0	1.4	1.8	2.0	**13**
	Cylindrical with thick wall (n=4)	6.4	6.1	6.2	0.1	**2**	3.6	2.4	3.2	0.7	**22**	3.5	2.0	2.8	0.3	**15**
	Square (n=6)	6.2	5.5	5.9	0.3	**5**	3.8	2.2	3.3	0.6	**19**	2.2	1.6	1.9	0.2	**12**
Hamadab*	Cylindrical (n=21)	6.5	5.1	5.7	0.5	**8**	3.9	2.1	3.1	0.5	**17**	2.3	1.1	1.7	0.3	**19**
	Square (n=4)	5.9	5.3	5.6	0.3	**5**	3.9	3.2	3.7	0.4	**11**	2.3	1.6	1.9	0.3	**17**

Table 3. The maximum value (max.), minimum value (min.), mean, standard deviation (s.d.), and relative standard deviation (r.s.d.) of external diameter, bore diameter, and wall thickness of different tuyère shapes by their context of recovery. Measurements were made on larger pieces of sample with identifiable

shape. *Note that the tuyères from Hamadab were measured altogether as the slag heaps have similar calibrated radiocarbon dates.

On the microscopic level, the petrographic data reveal that the majority of samples (n=64) have quartz grains as the principal type of inclusion. These samples are further divided into four subgroups, primarily based on the variation in paste preparation methods, even though the differences in mineralogical composition and textural characteristics are also taken into consideration. Quartz Subgroup A (n=32) stands out from other subgroups for its fine-grained fabric, consisting of 10 to 15% of quartz and less than 3% of plagioclase feldspar, biotite, amphibole, and Fe-rich nodules in non-calcareous clays (Fig. 4a). The inclusions are homogeneous in grain size, as well as in shape and sorting. They measure between <0.05mm and 1.1mm with a mode size of 0.1mm. The mineralogical constituents of these samples are consistent with the Nile alluvium, pointing to the use of local raw materials in making the tuyères of Subgroup A. Impression of plant fiber (<1%) is identified, but only in a few samples (Fig. 4b). Whereas the plant fiber could have occurred naturally in the Nile clay, it is also possible that plant materials might have been added to the clay as temper, as is evidenced by the presence of elongated pores, accounting for approximately 3% of the matrix. The use of organic materials, which would have burnt out and left voids during use, is argued to have the effect of increasing technical ceramics' resistance to potential fractures due to sudden temperature changes (Martinón-Torres and Rehren, 2014: 123). This refractory property is of particular importance in making tuyères because they would have been exposed to higher temperatures when projected into the furnace close to the combustion zone (Freestone, 1989: 156).

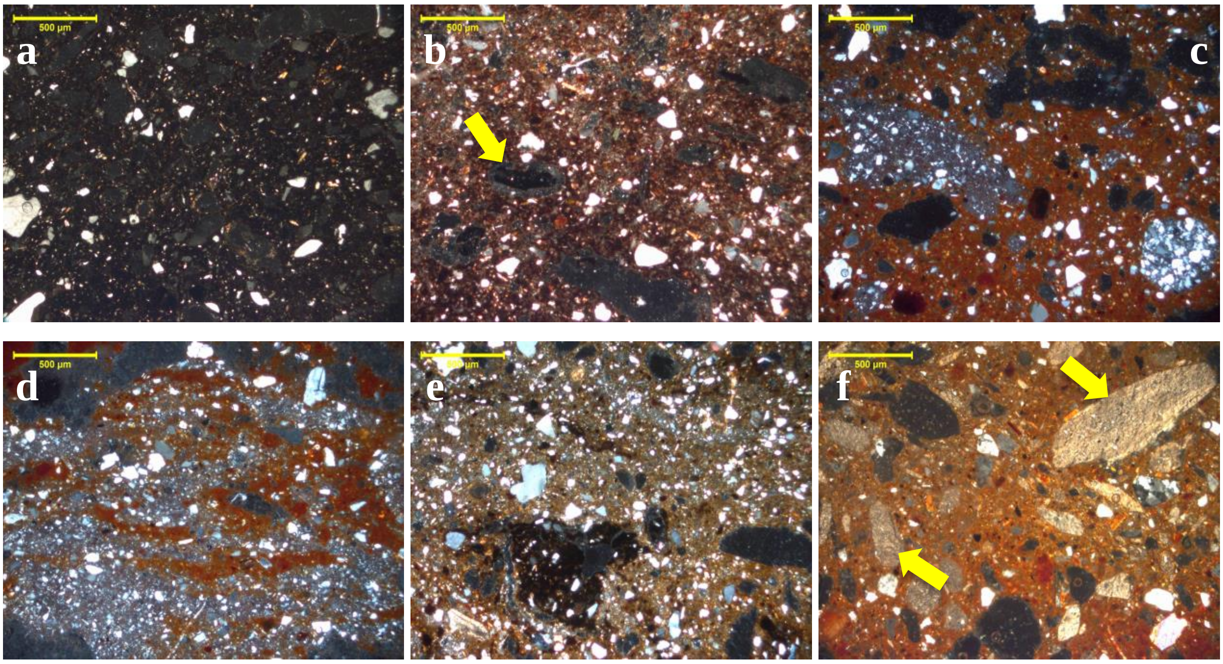

Figure 4. Photomicrographs showing the fabric of (a) Quartz Subgroup A, (b) impression of plant fiber of a sample from Subgroup A (indicated by arrow), (c) Quartz Subgroup B, (d) Quartz Subgroup C, (e)

Quartz Subgroup D, and (f) the Kaolinite-tempered Group (kaolinite fragments indicated by arrows). All photomicrographs were taken in XP at x50 magnification.

The remaining subgroups all exhibit evidence of clay mixing, but each with a different method applied. Quartz Subgroup B (n=13) is marked by the addition of clay pellets to clays (Fig. 4c). The clay pellets have fine-grained quartz inclusions and clear boundaries, which occur in a wide range of sizes (0.1mm to 4.5mm and no clear mode size), relative abundance (5% to 10%) and sorting. The clay pellets were added to non-calcareous clay, consisting of approximately 5% of fine-grained quartz and less than 3% of fine-grained plagioclase feldspar, biotite, amphibole, and Fe-rich nodules. Quartz Subgroup C (n=10) is distinguishable by the presence two or more clays, which were mixed when they were wet, as seen in the lack of clear boundary between the interface of clays (Fig. 4d). The clays are non-calcareous, including an orange-brown clay with 5% of fine-grained quartz and less than 3% of fine-grained plagioclase feldspar, biotite and amphibole, a greyish-brown clay with 10% to 15% of fine-grained quartz, and a brown clay with 5% to 10% of fine-grained quartz and 5% of fine-grained Fe-rich nodules. Quartz Subgroup D (n=9) is characterised by both mixing wet clays and adding clay pellets (Fig. 4e). In these samples, brown clay with 5% to 10% of fine-grained quartz and less than 3% of plagioclase feldspar, biotite, and amphibole was mixed with greyish brown clay, with little to no inclusions of quartz. Quartz grain-rich clay pellets of a variety of size (0.1mm to 3.5mm and no clear mode size), relative abundance (5% to 10%) and sorting were added to the clays. Overall, these subgroups display a great degree of internal heterogeneity, as a result of mixing varying types and proportions of clay pellets and clays. Again, the identification of quartz, plagioclase feldspar, biotite and amphibole in some clays point to the use of Nile alluvium for at least some of the raw materials used to make the tuyères of these subgroups. The identification of clay mixing in these samples has significant implications because such paste preparation method had been commonly used in making domestic pottery and fine wares during the Meroitic period (Brand, 2016: 82; Mason and Grzymski, 2009; Smith, 1997). Thus, it highlights the potential that the same producers were responsible for making technical ceramics, domestic pottery and fine wares, or the existence of cross-craft technological interaction between the producers of technical ceramics and those of domestic pottery and fine wares.

The petrographic data also reveal that there are a few samples (n=6) that can be placed in the Kaolinite-tempered Group. These samples are characterised by the presence of kaolinite fragments as the principal type of inclusion (Fig. 4f). The addition of kaolinite is said to have the effect of increasing the refractory properties of technical ceramics, with its use being reported in making tuyères at several pre-colonial and colonial Eastern African sites (Martinón-Torres and Rehren 2014, 121; Humphris, 2004). The kaolinite fragments of the samples are angular, and measure between 0.2mm and 3.5mm with a mode size of 1.0mm. Approximately 10% to 15% of kaolinite fragments were added to non-calcareous clays consisting of 5% to 15% of fine-grained quartz and less than 3% of fine-grained plagioclase feldspar, biotite, amphibole, and Fe-rich nodules. The presence of kaolinite was reported in various places in Sudan, including the First and Second Cataracts in Lower Nubia (Smith 1997), Meroe in Upper Nubia (Robertson 1975), Umm Ali (Smith 1997), and Musawarat es-Sufra (Smith 1999). The reconnaissance of raw materials in the catchment area of the sites conducted as part of the UCL Qatar research had located several deposits of kaolinite (Fig. 5). Whether or not these deposits of kaolinite were used in making the tuyères requires further analysis on their chemical composition, but this finding, coupled with similarity of the mineralogical constituents of these samples to the Nile alluvium, again suggests the potential use of raw materials procured from the vicinity of the sites in making the kaolinite-tempered tuyères.

Figure 5. Kaolinite deposit in the area adjacent to the archaeological site of Royal City of Meroe.

By comparing the variations observed at macroscopic and microscopic levels, no correlation between the tuyère shapes and fabric groups is observed (Table 4). The same fabric, Quartz Subgroup A, was used to make tuyères of all shapes recovered from all trenches and sites. Three different fabrics, namely Quartz Subgroups A and C, and Kaolinite-tempered, were used to make the cylindrical tuyères with thick wall characteristic of MIS6. All fabrics were used to make the cylindrical tuyères from Hamadab. Conversely, it seems strong correlations exist between the contexts of recovery and fabric groups and their associated paste preparation techniques (Table 4). The production of tuyères recovered from MIS1/2, MIS2 and MIS4 involved no clay mixing, their samples being only associated with the fabric of Quartz Subgroup A. The production of tuyères of MIS6 and Hamadab was marked by mixing clay pellets and wet clays, and adding kaolinite temper, as reflected in the identification of fabrics of Quartz Subgroups B and C and Kaolinite-tempered Group among their samples. The practice of mixing clay pellets and wet clays in the same ceramic paste as seen in the fabric of Quartz Subgroup D appears to be solely related to making the tuyères recovered from Hamadab.

Location	Tuyère shape	Quartz Subgroup A	Quartz Subgroup B	Quartz Subgroup C	Quartz Subgroup D	Kaolinite-tempered
MIS4	Square	4				
	Unidentified	2				

MIS2	Cylindrical with thin wall	3				
MIS1/2	Cylindrical with thin wall	3				
	Unidentified	3				
MIS6	Cylindrical	1	6	1		1
	Cylindrical with thick wall	2		1		1
	Square	1	2	1		2
	Unidentified	1	1			
Hamadab	Cylindrical	8	2	5	5	1
	Square	2		1	1	
	Unidentified	2	2	1	3	1

Table 4. The distribution frequency of fabric groups in relation to tuyère shape and context of recovery.

4.2. Furnace linings

The furnace lining fragments recovered from MIS1/2, MIS2, MIS4, and MIS6 share similar macroscopic features, characterised by dark fabric colour and abundant amount of white inclusions. These fragments also share similar mineralogical composition and texture, as highlighted by the petrographic data. Quartz grains are the principal and only type of inclusion, which are distinctively well-rounded in shape and display a strong mode of 0.8mm in grain size (Fig. 5a and b). Their abundance is consistent across all samples, accounting for approximately 30% of the fabric. The quartz grains are found in a matrix that is highly vitrified and displays microscopic structures reminiscent of slag. A possible explanation to this observation is that the clay component of the furnace linings melted and mixed with slag during smelting. This hypothesis is supported by the identification of fractures within the quartz grains, as well as the presence of fractures between the interface of quartz grains and their surrounding matrix; suggesting that the samples were subjected to high firing temperatures. Based on this finding, we raise the speculation that the furnace linings could have been made deliberately to melt and facilitate the smelting process (Craddock et al., 2007; Crew, 2000; David et al., 1989; Veldhuijzen, 2005; Veldhuijzen and Rehren, 2007: 195), although the verification of this hypothesis warrants further analysis of the chemical composition of slag. Current understanding of the iron smelting technology suggests rather that this lining was added to protect the furnace structures, which were reused numerous times. When destroyed, the lining could be removed and discarded on the slag mounds with the other metallurgical debris, and a new lining applied. The high degree of vitrification of the clay component of the samples has made it difficult to determine the sources of clay used in making the furnace linings. That being said, the roundness and homogeneous grain size of quartz inclusions point to nearby *wadis* as their potential source, as the seasonal stream systems had the effect of sorting and depositing quartz sands. Alternatively, the high degree of homogeneity in the grain size of quartz inclusions might have been attained through sieving or winnowing and adding the quartz as temper in a standardised way. In either case, it appears that the producers were very specific in their selection of quartz temper in making furnace linings to enhance their refractory properties (Kilikoglou et al., 1998; Tite et al., 2001).

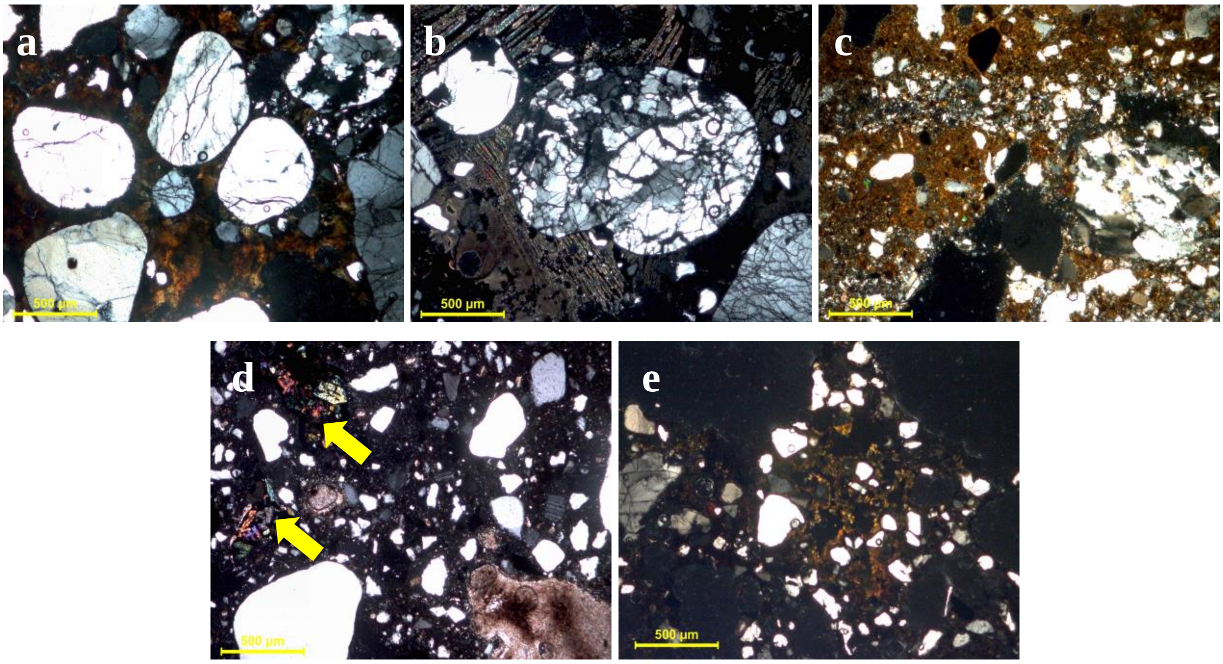

Figure 5. Photomicrographs showing the fabric of (a) furnace lining from MIS2, (b) furnace lining from MIS6 with fractures within quartz grain, (c) furnace brick from MIS4, (d) furnace brick from MIS6 (slag inclusions indicated by arrows), and (e) furnace materials from Hamadab. All photomicrographs were taken in XP at x50 magnification.

4.3. Furnace bricks

Macroscopically, the furnace bricks recovered from MIS1/2, MIS2, MIS4, and MIS6 are identifiable for their pale yellowish brown and/or reddish brown fabric colour and crumbly texture, implying that they were probably unfired. The furnace bricks are also characterised by the presence of different types of inclusions of varying grain sizes and abundance. The petrographic data confirm the compositional and textural variability, which is attributable to mixing different types and proportions of clays; thus making the division of samples into groups difficult. Whereas quartz grains are the principal type of inclusion in all furnace brick samples, just as other types of technical ceramics in this study, the quartz grains of furnace brick samples are coarser-grained (0.2mm and 4.5mm with no clear mode size) and more angular than those of the tuyères and furnace linings (Fig. 5c). In some furnace brick samples, the quartz grains are found together with fine-grained plagioclase feldspar, biotite, amphibole, and Fe-rich nodules. Slag fragments, which measure between 0.4mm and 2.3mm, are also identified in the samples that are exclusively associated with MIS6, even though their occurrence is only very rare (<1%) in each sample (Fig. 5d). The identification of the rare occurrence of slag fragments indicates that they were likely incorporated accidentally rather than added intentionally to the paste for furnace bricks. We, therefore, suggest that the furnace bricks recovered from MIS6 might have been produced at or in close proximity of the site where smelting took place. We further argue that the producers might have used whatever clays and raw materials that were available to make the paste for furnace bricks, including the use of the Nile clays that were also intended for tuyère production. This hypothesis would support the low degree of standardisation involved in preparing the pastes for furnace bricks, as reflected in the high degree of heterogeneity in the grain size, abundance and sorting of inclusions in these samples.

4.4. Furnace materials

Furnace materials, i.e. material displaying a gradual degree of vitrification across the sample, were recovered exclusively from Hamadab. Macroscopic examination of the furnace materials show that they are similar to the furnace bricks in terms of their pale yellowish brown fabric colour and the presence of different types of inclusions of varying grain sizes and abundance. However, the furnace materials do not have a crumbly texture like the furnace bricks, suggesting that they might have been subjected to firing. This observation is supported by the petrographic data, which show that the furnace materials are characterised by the presence of quartz grains with fractures in a non-calcareous clay matrix that is partially vitrified and displays structure similar to slag, just as the furnace linings. However, the quartz grains in the furnace materials lack the high degree of homogeneity in grain size, shape, and sorting as seen in the furnace linings. The quartz grains are angular in shape and display a wide range of sizes, measuring between 0.2mm and 5.0mm with no clear mode size (Fig. 5e). The heterogeneity of quartz inclusions suggests that they were likely procured from sources different from those used in making furnace linings of previous periods as described above, or reflects a low degree of standardisation in preparing the materials with little effort to remove the coarse particles and/or refine the clays. The determination of the potential provenance of the clays used in making furnace materials is difficult owing to the high degree of vitrification of the matrix, as well as the lack of mineralogical constituents in the remaining clay component that are indicative of their geological origins.

5. Discussion

Our analyses reveal that the production of technical ceramics during the entire Kushite and post-Meroitic periods shared a common feature, that is the use of local raw materials, particularly the Nile clays. This finding corresponds with the results of other studies, which demonstrate that Nile clays were procured to manufacture domestic pottery and fine wares in the region (cf. Bourriau et al., 2000; Brand, 2016; Carrano et al., 2009b; Daszkiewicz and Bobryk, 2003; Daszkiewicz and Schneider, 2011; Mason and Grzymski, 2009; Smith, 1991, 1996, 1997, 1999). Whether or not the same clay sources were used in making the domestic pottery and fine-ware ceramics that were found together with the technical ceramics in the slag heaps requires further analyses. Nevertheless, the identification of the use of the Nile clays in making the technical ceramics has emphasised the ability of the producers to acquire local raw materials and work within the constraints of those available in order to maximise their useful properties (Craddock et al., 2007: 8; Freestone and Tite, 1986: 60-61). In addition to this observation, we have highlighted several major trends in the technology and craft organisation involved in making technical ceramics during the Kushite and post-Meroitic periods at Meroe and Hamadab.

5.1. Napatan and earlier Meroitic periods at Meroe

The production of tuyères, furnace linings and furnace bricks was marked by high level of specialisation during the Napatan and earlier Meroitic periods, as represented by the samples from MIS4, MIS2 and MIS1/2. Owing to the absence of direct evidence of production such as ceramic workshops at Meroe and Hamadab to date, we define specialisation by using indirect evidence (Costin 1991, 31-40), particularly the skills and technological know-how of producers, and the degree of standardisation in ceramic fabrics and end products. It is clear that the producers had the knowledge of using specific raw materials and paste preparation methods to make particular types of technical ceramics. As the results of the petrographic analysis confirm, there is no overlap in the fabrics for tuyères, furnace linings and furnace bricks. The fabrics used for making tuyères and furnace linings exhibit a high degree of standardisation, which is reflected in the high degree of homogeneity in grain size, abundance, shape, and sorting of inclusions. The degree of standardisation of the fabrics used for furnace bricks is not as high as the other two types of technical ceramics. We interpret such variation in standardisation of fabrics as further evidence demonstrating the skills and technological know-how of producers. It appears that the producers were aware of the fact that tuyères and furnace linings should have higher thermal shock resistance as opposed to furnace bricks because the collapse of tuyères and furnace linings might inhibit the process of iron smelting (Martinón-Torres and Rehren, 2014: 114). Thus, the raw materials used to make the pastes for tuyères and furnace linings were procured from specific sources and prepared in standardised ways to enhance their thermal stability. As for the tuyères, the same fabric, i.e. Quartz Subgroup A, was used to make the square-shaped examples from MIS4 and the cylindrical ones with thin wall from MIS2 and MIS1/2. This finding suggests that even though there was different preference for tuyère shapes during the Napatan and earlier Meroitic periods, and despite the fact that these slag heaps probably represent the waste of different smelting workshops and cover a relatively long time span, the producers shared the same knowledge in paste preparation, highlighting continuity in tuyères production through time. We have little evidence to explain why different tuyère shapes were preferred at different phases of the Meroitic period. It is premature at this stage to argue that different smelting methods were used on the basis of the variation in tuyère shape and associated bore diameter, as we are unable to estimate whether there was a change in the volume of airflow being channeled into the furnace without the recovery of tuyères in their full length. Nonetheless, the end products of each tuyère shape are highly standardised as shown in the low relative standard deviation value of their respective measurements of external diameter, bore diameter, and wall thickness (Table 3).

5.2. Later Meroitic and post-Meroitic periods at Meroe

Just as the case of the technical ceramics of Napatan and earlier Meroitic periods, the production of technical ceramics during the later and post-Meroitic periods at Meroe continues to exhibit high level of technological know-how of the producers. This is highlighted by the analysis of the samples from MIS6, showing that there is no overlap in the ceramic fabrics used to make tuyères, furnace linings, and furnace bricks. The production of furnace linings and furnace bricks during the later periods, in particular, displays further similarity to their earlier counterparts in the level of standardisation of fabrics. The fabrics for furnace linings are highly standardised, as reflected in their quartz inclusions that are homogeneous in abundance, shape, size, and sorting, whereas the ceramic fabrics for furnace bricks have low level of standardisation. However, the production of tuyères during the later periods appears to have deviated from their earlier counterparts in terms of the level of standardisation of fabrics and end products. The identification of the presence of four fabrics – Quartz Subgroups A, C and D, and Kaolinite-tempered – among the tuyère samples suggests that greater variety of raw materials (i.e. clays of different sources and kaolinite) and paste preparation methods (i.e. clay mixing) were used. With the exception of the samples of Quartz Subgroup A, all samples exhibit heterogeneity in the proportions of clays being mixed, as well as the abundance, size, and sorting of inclusions. Furthermore, a greater variety of tuyère shapes, including cylindrical, cylindrical with thick wall, and square, is identified. Yet in spite of the variation in shape, the bore diameter is consistent across all tuyère shapes, with an average that measures ca. 3.2/ 3.3cm, whereas the outer diameter and wall thickness only vary slightly among tuyère shapes (Table 3). This finding, coupled with the lack of correlation between tuyère shapes and fabrics, has led to two hypotheses. The first hypothesis is that the tuyères discarded at MIS6 were supposed to be similar in shape, but the lack of standardisation in the execution of technical practices might have contributed to the observed difference in tuyère shapes, resulting in some cylindrical tuyères being slightly larger than the others. As for the square-shaped tuyères, they might have been caused by stacking the unfired cylindrical tuyères during drying, as shown by experimental work. The second hypothesis is that different tuyère shapes were used at different phases within the later periods at Meroe, but verification of this hypothesis requires more refined stratigraphic excavation and data analysis. MIS6 spans over a timeframe of roughly 300+ years (Humphris and Scheibner, forthcoming), incorporating the chronological shift from Meroitic to post-Meroitic. It is perhaps therefore unsurprising that a degree of heterogeneity in certain aspects of technical ceramic production is evident, as the social, economic and political environment within which the iron production took place was changing. Overall, by comparing the production of tuyères, furnace linings and furnace bricks, we postulated that the producers still possessed high level of technological know-how, but the level of skill and standardisation involved in executing the production of technical ceramics, especially tuyères, decreased during the later Meroitic and post-Meroitic periods.

5.3. Later Meroitic and post-Meroitic periods at Hamadab

The production of technical ceramics during the later Meroitic and post-Meroitic periods at Hamadab appears to differ from the previous periods at the Royal City of Meroe in at least two main ways. Firstly, the distinction in the ceramic fabrics for different types of technical ceramics is not as clear. Whereas the fabrics used for making tuyères are still separated from those for other technical ceramics, it is difficult to differentiate the fabrics for furnace linings and furnace bricks. Such lack of distinction of fabrics for furnace linings and furnace bricks, as we suggest here, might have implied that furnace linings were used per se and that the furnaces were not designed to be reused at Hamadab as was the case of the previous periods at Meroe. This argument is supported by the type and abundance of metallurgical remains found in the slag heaps at Hamadab, where we see less tapped slag and more furnace material discarded when compared to Meroe, implying a smelting technology less associated with re-useable furnaces. Thus, it is likely that the concept of lining the furnace for reuse that was seen at the Meroe sites was not used as a technological approach at Hamadab, and rather that furnaces were dismantled more frequently at Hamadab. Secondly, the petrographic analysis shows that even greater variety of raw materials were used in making the fabrics for tuyères and furnace materials, and that the fabrics were generally marked by a lower level of standardisation as evident in the great degree of heterogeneity of the abundance, size, shape, and sorting of the inclusions. As for the tuyères, in particular, the end products of cylindrical and square-shaped tuyères are standardised as expressed in the low standard deviation values of their respective external diameter, bore diameter, and wall thickness; but the same fabrics were used to make both types of tuyères. The discrepancy in the level of standardisation between the fabrics and end products of the tuyère samples highlights the possibility that the producers at Hamadab seem to have had similar concepts of what tuyères should look like, but with greater liberty in executing the manufacturing process, especially the selection of raw materials and paste preparation method. Overall, we suggest that the observed variation in the production of technical ceramics at Hamadab and Meroe might be attributed to the changing social, economic and political framework of the Kingdom of Kush, in which the producers at Hamadab, who although operating for a time contemporaneously to the producers at Meroe represented by the earlier levels of MIS6, were not producers at a capital site. Therefore, central control over production might have existed at Meroe (especially in the earlier periods) but never at Hamadab, and while the technology or iron production at Meroe had over a one thousand year history embedded within its practice, the production at Hamadab began only in the final years of the Meroitic period, perhaps these being the only years another site so close to Meroe was allowed to potentially compete for market demand for iron. Alternatively, the Hamadab iron production may have been a reaction to the apparent decrease in scale of iron production at Meroe during the later times (Humphris and Scheibner, forthcoming; Carey et al., forthcoming), creating a situation whereby Hamadab was forced to cater for its own demand, without the degree of knowledge or specialisation that marked but gradually declined in the remains evident at MIS6.

6. Conclusion

We argue that the observed changes in the production of technical ceramics were linked to the broader socio-political developments of the Kingdom of Kush. The higher level of specialisation characteristic of the production of technical ceramics during the Napatan and earlier Meroitic periods at Meroe coincided with the period when the Kingdom of Kush was at its height of power. It has been suggested that iron production might have been controlled by royal elites, as reflected in the close proximity of slag heaps to Royal residence at Meroe (Haaland, 2014; Shinnie, 1985). If this was the case, it was likely that the manufacture of technical ceramics during this period was also organised by elites directly or indirectly as part of their control of iron production, resulting in the evident standardised practices regarding the selection of raw materials and paste preparation methods for tuyères, furnace lining, and furnace bricks. Yet, the level of standardisation involved in the production of technical ceramics appears to have decreased during the later Meroitic period and post-Meroitic at Meroe when the power of the Kingdom of Kush is said to have been in decline. During this time, the elites may have had less control over iron production, including the manufacture of technical ceramics. Subsequently, the producers appear to have greater liberty in the execution of production, even though these producers might have been bounded by similar technological knowledge as those of previous periods. Perhaps the most drastic change in the production of technical ceramics occurred during the post-Meroitic period and is evident in the comparison between Meroe, which technical knowledge was presumably retained, and Hamadab, which appears to have only then begun its own iron production. During this period, it seems that more individuals might have attempted to produce technical ceramics, but improvising with their own technological knowledge and practices; thus contributing to the low level of standardisation that characterised the later Meroitic and post-Meroitic production of technical ceramics at Hamadab.

This study has served to contribute to illuminating the link between iron production and the rise and fall of the Kingdom of Kush, even though cross-referencing with other lines of evidence such as slag and iron ores are necessary to solidify such link. In addition, this study has demonstrated the value of using macroscopic examination and petrographic analysis to address different aspects of technical ceramic production, with particular emphasis on their manufacturing technology and craft specialisation rather than their refractory properties. An important step in the future of this work will be to compare our results with the production of domestic pottery and fine-ware ceramics so as to delineate the inter-craft technological interaction and how the ceramic economy was organised; thus bringing about a more wholesale understanding of different facets of Kushite society.

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References cited

Bourriau, J., Smith, L., Nicholson, P., 2000. New Kingdom pottery fabrics: Nile clay and mixed Nile/ marl clay fabrics from Memphis and Amama. The Egyptian Exploration Society, London.

Brand, M., 2016. Dangeil, a preliminary report on the petrography. Sudan and Nubia 17, 78-89.

Butzer and Hansen, 1968. Desert and river in Nubia: geomorphology and prehistoric environments at the Aswan reservoir. The University of Wisconsin Press, Madison.

Carrrano, J., Smith, S., Herbst, G., Girty, G., Carrano, C., Ferguson, J.R., 2009a. Applying a multi-analytical approach to the investigation of ancient Egyptian influence in Nubian communities: the socio-cultural implications of chemical variation in ceramics styles. Journal of Ancient Egyptian Interconnections 1(3), 11-21.

Carrano, J., Girty G., Smith S.T., Carrano, C.J., 2009b. Re-examining the Egyptian colonial encounter in Nubia through a compositional, mineralogical, and textural comparison of ceramics. Journal of Archaeological Science 36, 785-97.

Charlton, M., Humphris, J., forthcoming. Exploring iron making practice at Meroe, Sudan: a comparative analysis of archaeological and experimental data.

Childs, S.T., Killick, D., 1993. Indigenous African metallurgy: nature and culture. Annual Review of Anthropology 22, 317-37.

Chirikure, S., Rehren, Th., 2004. Ores, furnaces, slags, and prehistoric societies: aspects of iron working in the Nyanga agricultural complex, AD 1300–1900. African Archaeological Review 21(3), 135-52.

Costin, C.L., 1991. Craft specialisation: issues in defining, documenting, and explaining the organisation of production. Journal of Archaeological Method and Theory 3, 1-56.

Craddock, P., Freestone, I., Middleton, A., Van Grunderbeek, M-C., 2007. Early Iron Age iron-smelting debris from Rwanda and Burundi, East Africa. Historical Metallurgy 41(1), 1-14.

Crew, P. 2000. The influence of clay and charcoal ash on bloomer slags, in Cucini Tizzoni, C., Tizzoni, M. (Eds.) Deposits, Mines and Metallurgy from Antiquity to the XVI Century. Proceedings of the Conference, Bienno, Ottobre 1998. Commune di Bienno, Breno, pp. 38-48.

Daszkiewicz, M., Bobryk, E., 2003. Raw material classification of Mesolithic to early Islamic pottery from the Karima – Abu Hamad region (Sudan), in Paner, H. (Ed.) African Reports, Vol.2. Gdańsk Archaeological Museum, Gdańsk, pp. 77-80.

Daszkiewicz, M., Bobryk, E., Schneider, G., 2005. Archaeoceramological study of pottery fabrics from Awlib, Sudan, in: Paner, H., Jakobielski, S. (Eds.) African Reports, Vol.3. Gdańsk Archaeological Museum, Gdańsk, pp. 68-78.

Daszkiewicz, M., Schneider, G., 2011. Keramik aus Meroe und Hamadab. Archäologischer Anzeiger 2, 247-65.

David, N., Heimann, R., Killick, D., Wayman, M., 1989. Between bloomer and blast furnace: Mafa iron-smelting technology in North Cameroon. African Archaeological Review, 183-208.

Dittrich, A., 2010. Using functional aspects for the classification of Meroitic pottery from Hamadab, Sudan. Der Antike Sudan 21, 87-96.

Edwards, D.N., 1999. A Meroitic Pottery Workshop at Musawwarat es Sufra. Otto Harrassowitz, Wiesbaden.

Eisawi, A.A.K., Awad, N.Z., Babikir, I.A.A., Ali, O.E., Khalil, M.A., Adam, A.E., Bussert, R., 2015. Atbara Basin, in: Awad, M.Z. (Ed.) Petroleum Geology and Resources of the Sudan. Sudapet Company Ltd., Khartoum, pp. 308-319.

Freestone, I. 1989. Refractory materials and their procurement, in: Hauptmann, A., Pernicka E., Günther, A.W. (Eds.) Old World Metallurgy. Selbstverlag des Deutchen Bergbau-Museums, Bochum, pp. 155-62.

Freestone, I., 1991. Extending ceramic petrology, in Middleton, A., Freestone, I. (Eds.) Recent Developments in Ceramic Petrology. British Museum Occasional Paper 81, London, pp. 399-410.

Freestone, I., Tite, M.S., 1986. Refractories in the Ancient and Preindustrial World, in: Kingery W.D., Lense, E. (Eds.) High-Technology Ceramics: Past, Present, and Future. The American Ceramic Society, Westerville, pp. 35-63.

Garstang, J., Sayce, A.H., Griffith, F.Ll., 1911. Meroe: The City of the Ethiopians. Clarendon Press, Oxford.

Garzanti, E., Ando, S., Vezzoli, G., Megid, A.A.A., Kammar, A.E., 2006. Petrology of Nile River sands (Ethiopia and Sudan): sediment budgets and erosion patterns. Earth and Planertary Science Letters 252, 327-41.

Geological Map of the Sudan, 1981. Ministry of Energy and Mines, Geological and Mineral Resources Department, Khartoum.
http://eusoils.jrc.ec.europa.eu/esdb_archive/eudasm/africa/maps/afr_sd2001_ge.htj

Haaland, R., 2014. The Meroitic Empire: trade and cultural influences in an Indian Ocean context. African Archaeological Review 31, 649-73.

Humphris, J., 2004. Reconstructing a Forgotten Industry: Iron Smelting in the Buganda Kingdom. Unpublished MA dissertation, UCL Institute of Archaeology.

Humphris, J., 2014. Post-Meroitic iron production: initial results and interpretations. Sudan and Nubia 18, 121-29.

Humphris, J., Carey, C., 2016. New methods for investigating slag heaps: integrating geoprospection, excavation and quantitative methods at Meroe, Sudan. Journal of Archaeological Science 70, 132-44.

Humphris, J., and Rehren, Th., 2014. Iron production and the Kingdom of Kush: an introduction to UCL Qatar’s research in Sudan. Sonderheft MittSAG, 177-90.

Humphris, J., Scheibner, T., forthcoming. A new radiocarbon chronology for ancient iron production in the Meroe region of Sudan.

Kilikoglou, V., Vekinis, G., Maniatis, Y., Day, P.M., 1998. Mechanical performance of quartz-tempered ceramics: part I, strength and toughness. Archaeometry 40(2), 261-79.

Killick, D., 2015. Invention and innovation in African iron-smelting technologies. Cambridge Archaeological Journal 25(1), 307-19.

Mallory-Greenough, L.M., Greenough, J.D., Owen, J.V., 1998. New data for old pots: trace element characterisation of ancient Egyptian pottery using ICP-MS. Journal of Archaeological Science 25, 85-97.

Mason, R.B., Grzymski, K., 2009. Petrography of pottery from Meroe, Sudan. Sudan and Nubia 13, 87-91.

Matthew, A.J., Woords, A.J., Oliver, C., 1991. Spots before the eyes: new comparison charts for visual percentage estimation in archaeological material, in Middleton, A., Freestone, I. (Eds.) Recent Developments in Ceramic Petrology. British Museum Research Laboratory, London, pp. 211-64.

Martinón-Torres, M., Rehren, Th., 2014. Technical ceramics, in: Roberts, B., Thornton, Chr. (Eds.) Archaeometallurgy in Global Perspective. Springer, New York, pp. 107-31.

Quinn, P., 2013. Ceramic Petrography: The Interpretation of Archaeological Pottery and Related Artefacts in Thin Section. Archaeopress, Oxford.

Rehren, Th., 1995. Meroe, eisen und Afrika. MittSAG 3, 20-5.

Rehren, Th., 1996. Meroitische eisenobjekte aus Musawwarat en Sufra, MittSAG 5, 19-27.

Rehren, Th., 1997. Die rolle des kohlenstoffs in der prä-historischen metallurgie. Stahl und Eisen 117/9, 87-92.

Rehren, Th., 2001. Meroe, iron and Africa. MittSAG 12, 102-09.

Rehren, Th., Hauptmann, A., Weisgerber, G., Wenig, St., 1995. Meroitische eisenobjekte von Mussawwarat, Nord-Sudan, in: Benoit, P., Fluzin, Ph. (Eds.) Paleometallurgie du Fer & Cultures. Belfort Cedex, pp. 293-97.

Redmount, C.A., Morgenstein, M.E., 1996. Major and trace element analysis of modern Egyptian pottery. Journal of Archaeological Science 23, 741-62.

Robertson, J.H., 1975. The 74/75 Meroe excavations. Nyame Akuma 6, 25-8.

Roberston, J.H., 1992. History and archaeology at Meroe, in: Sterner, J., David, N. (Eds.) An African Commitment: Papers in Honour of Peter Lewis Shinnie. University of Calgary Occasional Paper, Calgary, pp. 35-50.

Shinnie, P.L., 1985. Iron working at Meroe, in: Haaland, R., Shinnie, P.L. (Eds.) African Iron Working – Ancient and Traditional. Norwegian University Press, Oslo, pp. 28-35.

Shinnie, P. L., Anderson, J. R., 2004. The Capital of Kush 2. Meroe Excavations 1973-1984. Meroitica 20.

Shinnie, P.L., Kense, F.J., 1982. Meroitic iron working, in: Millet, N.B., Kelley, A.L. (Eds.) Meroitic Studies: Proceedings of the Third International Meroitic Conference, Toronto 1977. Akademie-Verlag, Berlin, pp. 17-28.

Smith, L.M.V., 1991. Petrographic and electron probe analyses of ceramics from Soba, in: Welsby, D.A., Daniels, C.M. (Eds.) Soba: Archaeological Research at a Medieval Capital on the Blue Nile. British Institute in Eastern African, London, pp. 333-49.

Smith L.M.V., 1995. Investigation of the provenance of Meroitic finewares: preliminary report on the chemical analysis, in Meyza, H., Młynarczyk, J. (Eds.) Hellenistic and Roman pottery in the eastern Mediterranean : Advances in Scientific Studies: Acts of the II Nieborów Pottery Workshop, Nieborów, 18-20 December 1993. Polish Academy of Sciences, Warsaw, pp. 431-42.

Smith, L.M.V., 1996. Investigation of the provenance of Meroitic finewares: a resume. SARS Newsletter 10, 23-31.

Smith, L.M.V., 1997. Study of clay sources for Meroitic finewares. Azania 32, 77-92.

Smith, L.M.V., 1999. Appendix 2: investigation of the provenance of Meroitic finewares continued, a prospective from Musawwarat es Sufra, in: Edwards, D.N. (Ed.) Museaarart es Sufra II: A Meroitic Pottery Workshop at Musawwarat es Sufra. Meroitica 17(2), 43-52.

Tite, M.S., Kilikoglou, V., Vekinis, G., 2001. Strength, toughness and thermal shock resistance of ancient ceramics, and their influence on technological choice. Archaeometry 43(3), 301-24.

Török, L., 1997. The kingdom of Kush. Handbook of the Napatan-Meroitic Civilization. Leiden, Brill.

Török, L., 2015. The periods of Kushite history, from the tenth century BC to the AD fourth century. Ízisz Foundation, Budapest.

Trigger, B.G., 1969. The myth of Meroe and the African Iron Age. International Journal of African Historical Studies 2, 23-50.

Tylecote, R.F., 1970. Iron working at Meroe, Sudan. Bulletin of Historical Metallurgy Group 2, 23-50.

Tylecote, R.F., 1982. Metal working at Meroe, Sudan. Meroitica 6, 29-42.

Veldhuijzen, H.A., 2005. Technical ceramics in early iron smelting: the role of ceramics in early first millennium BC iron production at Tell Hammeh (Az-Zarqa), Jordan, in: Prudéncio, I., Dias, I. Waerenborgh, J.C. (Eds.) Understanding People through Their Pottery: Proceedings of the 7th European Meeting on Ancient Ceramics (EMAC '03). Instituto Portugues de Arqueologia, Lisboa, pp. 294-302.

Veldhuijzen, H.A., Rehren, Th., 2007. Slags and the city: early iron production at Tell Hammeh, Jordan, and Tel Beth-Shemesh, Israel, in: LaNiece, S., Hook, D.R., Craddock, P.T. (Eds.) Metals and Mines: Studies in Archaeometallurgy. British Museum, London, pp. 189-201.

Welsby, D. A.,1996. The Kingdom of Kush: The Napatan and Meroitic Empires. Markus Wiener Publishers.

Whitbread, I.K., 1995. Appendix 3: the collection, processing and interpretation of petrographic data, in: Whitbread, I.K. (Ed.) Greek Transport Amphorae: A Petrological and Archaeological Study. British School at Athens, London, pp. 365-95.

Wolf, P., 2015. The Qatar-Sudan Archaeological Project – the Meroitic town of Hamadab and the palaeo-environment of the Meroe region. Sudan and Nubia 19, 115-31.

Wolf, P., Nowotnick, U, 2013. Hamadab – eine urbane Siedlung im Mittleren Niltal, in: Wenig, S. and Zibelius-Chen, K. (Eds.) Die Kulturen Nubiens – ein afrikanisches Vermächtnis. J.H. Röll, pp. 429-451.