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MUSAWWARAT ES-SUFRA — IN SEARCH OF CERAMIC RAW MATERIALS

Abstract: Laboratory analysis of pottery discovered at Musawwarat es Sufra revealed the presence of wares made from wadi clays, hafir clays and alluvial clays. Searching for the source of the raw materials was carried out: 1) within the immediate vicinity of Musawwarat es-Sufra, aimed at obtaining samples of raw materials from various wadis (searching for ceramic raw materials used to produce local pottery, i.e. ceramics attributed to reference groups Mus 1–5); 2) within the immediate and wider vicinity of Musawwarat es--Sufra, aimed at finding raw materials from which samples identified as "probably local" could have been made (these are mostly handmade vessels made of various raw materials with lower levels of aluminium and a higher content of fluxes than samples attributed to groups Mus 1–5); 3) within the Nile valley, aimed at sampling alluvial clays from various locations along the river (searching for ceramic raw materials used to produce local pottery attributed to Clay Type A, i.e. ceramics made from Nile alluvial clays). Collected raw material samples have been the subject of: plasticity test, firing test, chemical analysis, X-ray diffraction analysis. Additionally, laboratory model studies were performed to check what impact the chemical composition of organic tempers and so-called kaolinitic temper has on the chemical composition and thermal behaviour of ceramic sherds and the effect that adding various types of temper has on the mechanical and physical ceramic properties of sherds, and whether their use is attributable to a valid technological reason or simply to tradition.

Key words: Musawwarat es-Sufra, wadi clay, hafir clay, ceramic raw materials, chemical analysis, X-ray diffraction, firing test, mechanical properties

Introduction

The first excavations at Musawwarat es-Sufra were carried out under the direction of Fritz Hintze[1] between 1960 and 1968. In seven seasons of fieldwork he excavated several monuments: the Lion Temple (IIC), the Small Enclosure (IB), the Great Hafir (IIG) and the Great Enclosure (IA), as well as other buildings and a post-Meroitic Cemetery (IF). Excavations in Musawwarat were finished for different reasons in 1968, and the Lion Temple was rebuilt during 1969–70. The results of archaeological fieldwork within the valley of Musawwarat were published in several preliminary reports; a classification of pottery from different areas within the Great Enclosure, the Small Enclosure and the Lion Temple was presented by Karl-Heinz Otto.[2] Archaeological work was

[1] Professor of Egyptology at Humboldt University Berlin between 1951 and 1980; founder of the Institute for Egyptology at Humboldt University, 1957, renamed the Institute for Sudan Archaeology and Egyptology in 1968; see e.g. http://www.sammlungen.hu-berlin.de/dokumente/212/.
[2] Hintze 1962; 1963; 1968; 1971; Otto 1967.

resumed in Musawwarat es-Sufra thanks to the efforts of Steffen Wenig,[3] who was the head of the project between 1993 and 2004. After a short exploration campaign in 1993 and a building campaign in 1994, excavations in Musawwarat started again in 1995, funded by Deutsche Forschungsgemeinschaft (DFG) for several years, and were mainly focused on investigations within the Great Enclosure and on examining the issue of water management, as well as on exploration of the surrounding area and stratigraphic relationships between different structures within the valley of Musawwarat.[4] Next to archaeological fieldwork special attention was also paid to restoration and protection of the monuments of Musawwarat es-Sufra.[5] The results of archaeological and restoration work were published in several articles, which included details of the pottery recovered from different complexes; other pottery finds were only mentioned in several other reports on archaeological fieldwork within the valley of Musawwarat.[6] Anne Seiler prepared an in-depth study of the pottery from the Small Enclosure and studied the pottery from two small trenches [224.8] and [224.9] from courtyard 224 of the Great Enclosure, where, during an architectural survey in the 1995/96 season, a deposit of ash and pottery was found. The deposit was originally excavated [224.12] by David Edwards and Hans-Ulrich Onasch in 1997 and was interpreted as the dump of a pottery workshop; the pottery was studied in detail by David N. Edwards and partly published in 1999.[7] Some of the fineware specimens were studied by thin--section petrography and chemical analysis by Laurence Smith. A comparison with pottery specimens from other sites (Meroe, Wad Ban Naga, Gabati, Qasr Ibrim) and analysis of clays from Lower Nubia and the Meroe area and Gebel Umm Ali in Upper Nubia led him to think that some of the finewares could probably have been produced at Musawwarat.[8] A second set of laboratory analysis was conducted on samples of coarse ware pottery found in the Small Enclosure and Great Enclosure and was carried out by Małgorzata Daszkiewicz and Gerwulf Schneider.[9] The analysed pottery sherds were made from clays of two geologically different regions and represent different workshops. From 2005 to 2015 Claudia Näser[10] led the project and with the inauguration of the Qatar Sudan Archaeological Project (QSAP) in the 2013/14 season, multi-year funding enabled the extension of archaeological research in Musawwarat es-Sufra.[11] In addition to excavations within the Great Enclosure, the research also includes Site Presentation and Management, Protection Work, Restoration/Conservation, as well as a Community Project and the Graffiti Project. Special attention was given to excavations in “pottery courtyard” 224 in the Great Enclosure, the findings of which became the focus of a project under the auspices of the Berlin

[3] Professor of Egyptology and Sudan Archaeology / Meroitic Studies at Humboldt University Berlin between 1984 and 1999 (later names of the Institute: Institute for Sudan Archaeology and Egyptology, Richard Lepsius Institute, now: Seminar for Archaeology and Northeast African Archaeology); see e.g. Lohwasser, Wolf 2014, pp. 7–8, with list of publications of Prof. Wenig, pp. 10–20.

[4] The DFG-funding was used for reprocessing the results of Hintze’s excavations. Fieldwork, see e.g. Wenig, Wolf 1998a, pp. 24–37; 1998b, pp. 38–49; 1999, pp. 24–43; 2000, pp. 28–48. Water management, see e.g. Scheibner 2004, pp. 39–64.

[5] This work was primarily financed by the Sudan Archaeological Society (SAG), founded in 1993 by Prof. Wenig.

[6] E.g. polychrome painted pottery of “waste-pit” K14, Mucha 2005, pp. 7–13.

[7] Excavation, see Edwards 1999, pp. 8–12; pottery, see Edwards 1998, pp. 62–67; Edwards 1999, pp. 14–41; Seiler 1998; Seiler 1999.

[8] Smith 1999, pp. 43–49.

[9] Daszkiewicz, Schneider 2001, pp. 80–91, Gerullat 2001, pp. 64–79.

[10] Junior-Professor at the Seminar for Archaeology and Northeast African Archaeology (AKNOA) at Humboldt University Berlin between 2004 and 2012, see e.g. https://www.topoi.org/person/naeser-claudia/.

[11] Archaeological work in the years between the DFG- and Qatar-funding was primarily financed by the SAG, Auswärtiges Amt (Programm: Kulturerhalt), KAVA (Kommission für Allgemeine und Vergleichende Archäologie des Deutschen Archäologischen Instituts) and Topoi (www.topoi.org/project/a-1-1, www.topoi.org/project/-a-6-5); see e.g. Wenig 2004; Scheibner, Mucha 2009; Näser 2013; Näser, Wetendorf 2014; Näser, Wetendorf 2015.

Cluster of Excellence 264 TOPOI in 2013.[12] To shed further light on pottery production and consumption in Musawwarat, analysis of pottery sherds, raw materials and model analyses[13] were carried out by Małgorzata Daszkiewicz, Gerwulf Schneider and Ewa Bobryk.[14] The analysed fineware and most of the wheel-made coarse ware was made from ceramic bodies of similar chemical and mineralogical composition and could be associated with local production (pottery exhibiting the same chemical composition and thermal behaviour has not been noted at any other sites).[15] Most of the handmade coarse ware samples probably come from other workshops and were not locally produced (in particular, the vessels made from Nile alluvial clays). In order to identify the sources of ceramic raw materials necessary for local ceramic production, clay samples and tempering materials were obtained in 2014 from the immediate vicinity of Musawwarat as well as from the wider surroundings. Analysis of these samples and model analysis using these samples are of utmost importance to identify securely the provenance of ceramic vessels found in Musawwarat.

Research planned as part of Excellence Cluster 264 TOPOI project A-6-5

Taking into consideration all of the published studies mentioned in the introduction, as well as the unpublished results obtained from analysis of pottery and raw materials (carried out by M. Daszkiewicz, E. Bobryk and G. Schneider) recovered from sites located between Khartoum and the Third Nile Cataract, it was concluded that new research should encompass:

a) fieldwork within the immediate vicinity of Musawwarat es-Sufra, aimed at obtaining samples of raw materials from various wadis (searching for ceramic raw materials used to produce local pottery, i.e. ceramics attributed to reference groups Mus 1–5[16]);

b) fieldwork within the immediate and wider vicinity of Musawwarat es-Sufra, aimed at finding raw materials from which samples identified as "probably local" could have been made (these are mostly handmade vessels made of various raw materials with lower levels of aluminium and a higher content of fluxes than samples attributed to groups Mus 1–5);

c) fieldwork within the Nile valley, aimed at sampling alluvial clays from various locations along the river (searching for ceramic raw materials used to produce local pottery attributed to Clay Type A, i.e. ceramics made from Nile alluvial clays).

In addition, the following actions were also planned:

- analysis of materials potentially used as fuel (wood, dung);
- ceramic ethnoarchaeological studies involving sites featuring currently operational pottery workshops within the immediate vicinity of Musawwarat es-Sufra and in the Nile valley, interviews with potters and analysis of the raw materials they use;

[12] Since 2014 the pottery project has been conducted with funding from the Qatar-Sudan Archaeological Project and the Berlin Cluster of Excellence TOPOI. Investigations on pottery from courtyard 224 have been moved to the PhD project of Manja Wetendorf at the Berlin Graduate School of Ancient Studies.

[13] This work was financially supported by the Warsaw University of Technology.

[14] Näser, Daszkiewicz 2013, pp. 15–22; Daszkiewicz, Wetendorf 2014, pp. 99–104; Daszkiewicz *et alii* 2015, pp. 89–91.

[15] Analyses of other ceramic sherds were available for comparison from the SDB. SDB = database for Sudanese ancient pottery: this database of analyses compiled by M. Daszkiewicz (analyses carried out by M. Daszkiewicz, G. Schneider and E. Bobryk) currently encompasses 1235 ceramic fragments recovered from various sites dating from the Mesolithic to the Christian period.

[16] Mus 5 = a new, unpublished, reference group.

- analysis of ancient ceramics from Meroitic/post-Meroitic sites within the immediate vicinity of Musawwarat es-Sufra and samples of pottery said to have a Musawwarat fabric,[17] recovered from other sites in northern Sudan;
- laboratory model studies examining what impact the chemical composition of organic tempers and so-called kaolinitic temper has on the chemical composition and thermal behaviour of ceramic sherds;
- laboratory model studies examining the effect that adding various types of temper has on the mechanical and physical ceramic properties of sherds and whether their use is attributable to a valid technological reason or simply to tradition;
- laboratory model studies examining what impact the chemical composition of ashes derived from various fuels has on the chemical composition and thermal behaviour of samples;
- laboratory model studies examining the alteration effect; in this instance, the studies concern the impact of ambient conditions on pottery sherds taken from a ceramic deposit in courtyard 224 of the Great Enclosure at Musawwarat es-Sufra.

The first stage of the fieldwork has been completed, as have some of the planned analyses and model studies. During the course of fieldwork carried out in November 2014 (M. Daszkiewicz, M. Wetendorf, G. Schneider), a total of 64 samples were taken of materials identified in the field as potential ceramic raw materials. Samples were also taken of fuels (wood from local trees and cow dung) and donkey dung, which is still commonly used as a temper today (ethno-ceramological studies revealed that cow dung is used as a fuel and donkey dung as a temper added to ceramic bodies). Preliminary results from studies on the impact of fuels on the chemical and phase composition of ceramic sherds, and of the alteration effect, have already been published,[18] as have the results of model studies concerning measurement of mechanical and physical properties.[19] The present article details the results of analysis carried out on 27 raw material samples [Fig. 1], of which 23 samples were taken from the immediate vicinity of Musawwarat es-Sufra [Fig. 2] and four from locations along the route of a track running parallel to Wadi Awateb and leading from Naga to a tarmac road. The analysis of four samples of Nile alluvial clays is also discussed.

Raw materials

<u>Sampling</u>

Bearing in mind the appearance of typical Musawwarat fabrics, where white- or whitish-beige--firing aggregates[20] are visible in a sintered matrix, the search for ceramic raw materials was focused on finding:

1) plastic raw materials with the same thermal behaviour as Musawwarat fabrics;
2) non-plastic raw materials which yield white- or whitish-beige-firing aggregates;
3) ceramic raw materials that could have been used, without any further technological measures (addition of aforementioned tempers), for making local pottery.

[17] Daszkiewicz, Malykh, in preparation.
[18] Daszkiewicz *et alii* 2015.
[19] Daszkiewicz *et alii* 2016.
[20] In thin-sections they are described as conglomerates of quartz with white coloured matrix (Daszkiewicz, Schneider 2001, pp. 83, 86, fig. 5).

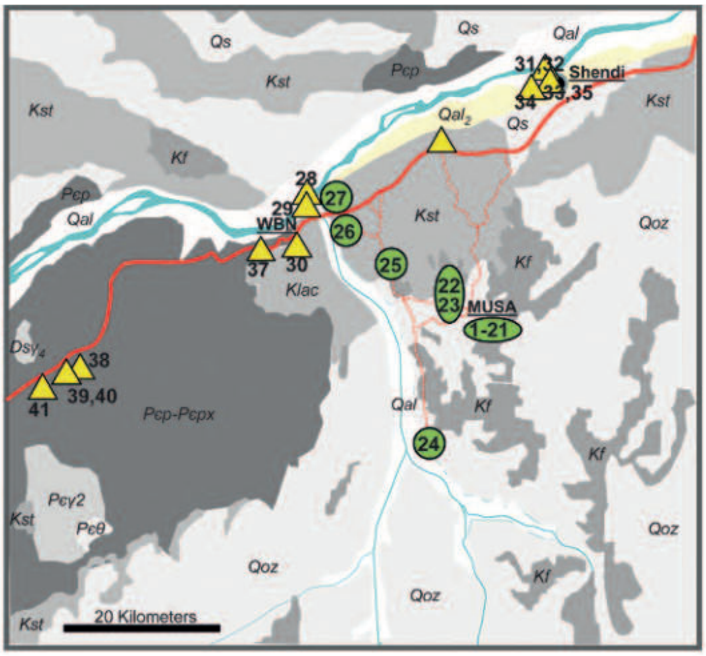


Fig. 1. Locations from which raw material samples were taken in 2014.
Map, amendments made by the authors, showing underlying geology (map created by E. Bobryk).
Samples 1–27 (marked in green) are the focus of this article.
Solid red line = tarmac road; dashed red line = recent main tracks through Butana used by local people.
Kst = undifferentiated fluviatile sandstones and siltstones;
Kf = ferruginous horizons in the Kst sequence; Klac = bioturbated lacustrine silts and mudstones;
Pєp = differentiated Proterozoic metamorphic rocks (Pєpgns = gneissic area; Pєpmg = migmatites);
Pєpx = granulite facies variants of Pepgns;
Pєγ2 = syntectonic granitic intrusions and anatectic migmatites;
Pєθ = undifferentiated Precambrian gabbroic rocks;
Dsγ4 = anorogenic syenitic rocks dated to the Devonian period, ring complexes;
Qal = Quaternary recent alluvium;
Qal2 = Quaternary older alluvium, raised terraces;
Qoz = old, often stabilised dunes at or beyond the current limits of true desert conditions

Fig. 2. Location of raw material samples in relation to the Great Enclosure
(map created by E. Bobryk based on Google Maps)

One of the first objectives of this project was to obtain samples of various wadi clays and Nile alluvial clays. Having made an assessment of the terrain surrounding the site at Musawwarat es--Sufra, it was decided to broaden the range of samples to include recent bottom-sediment from local hafirs. These hafirs were either still partly filled with water or completely dry. Three samples were taken from the Great Hafir, located within the site's immediate vicinity [Fig. 2, points 1–3[21]]: two samples of recent bottom-sediment (a less silty upper layer and a more silty lower layer) and one sample from the topmost layer of the hafir wall — a location indicated by a local potter, Amma, as the site from which she takes clay for making ceramics [Fig. 3]. Further samples of recent bottom-sediment were taken from the Hafir Said, north-east of Gebel es-Sufra [Fig. 4]; a sample of whitish silty clay was also collected from the wall of this hafir [Fig. 5]. In the case of dry hafirs, samples exhibiting significant shrinkage on drying were taken from the middle of the hafir, e.g. from the Hafir Hamad behind Gebel Ma'afer [Fig. 6] and from the hafir in front of Gebel el Ghafalla [Fig. 7]. In the case of wadis, raw materials were sampled from the middle of various wadi beds. They included a loam sample taken from the middle of a wadi north of Gebel es-Sufra [Fig. 2, point 4; Fig. 8], used by local villagers as a building material [Fig. 9]. Two samples were taken from Wadi Ma'afer, near a small quarry: one sample was of a silty clay [Fig. 10, point 10] and the other of a fine clay [Fig. 10, point 11].

Fig. 3. Location of samples taken from the Great Hafir in Musawwarat
(numbers correspond to those used in table 1).
Location no. 3 was indicated by a local potter named Amma
(photo M. Wetendorf)

[21] The point numbers indicate the location of a given sample on the maps in Figs. 1 and 2.

Fig. 4. Location of a sample of recent bottom-sediment taken from the Hafir Said, north-east of Gebel es-Sufra (photo G. Schneider)

Fig. 5. Location of sample of whitish silty clay collected from the wall of the Hafir Said, north-east of Gebel es-Sufra (photo G. Schneider)

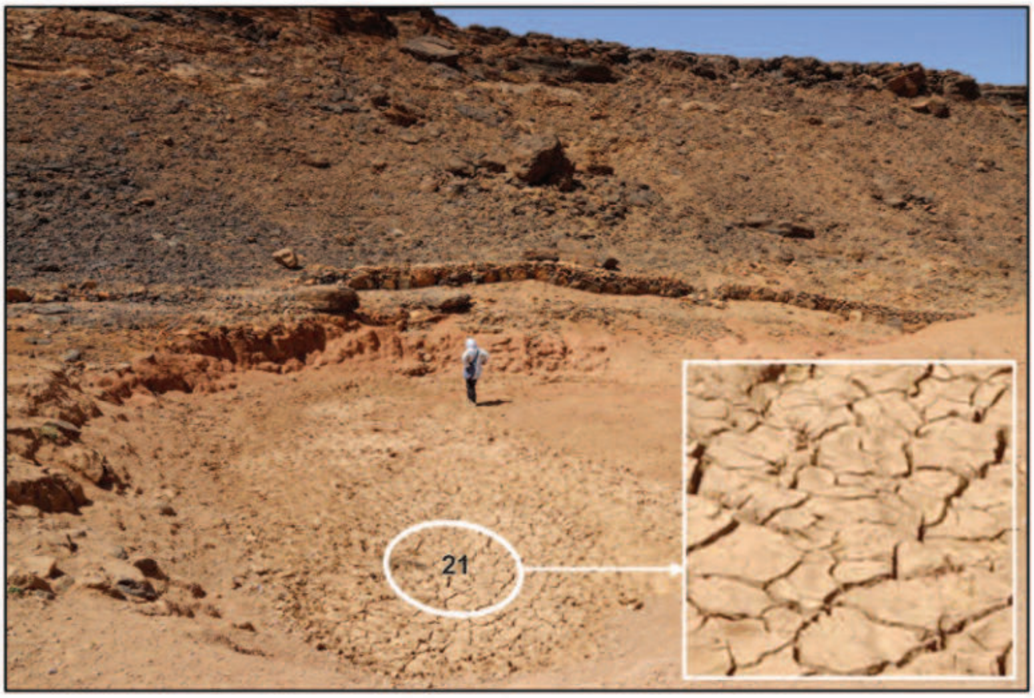


Fig. 6. Hafir Hamad behind Gebel Ma'afer, sample exhibiting significant shrinkage on drying taken from the middle of the dry hafir (photo M. Wetendorf)

Fig. 7. Location of samples taken from a dry hafir in front of Gebel el-Ghafalla (photo M. Wetendorf)

Fig. 8. Loam sample taken from the middle of a wadi north of Gebel es-Sufra
(photo M. Wetendorf)

Fig. 9. Loam (sample shown in figure 8)
is currently used by local villagers
as a building material (photo M. Wetendorf)

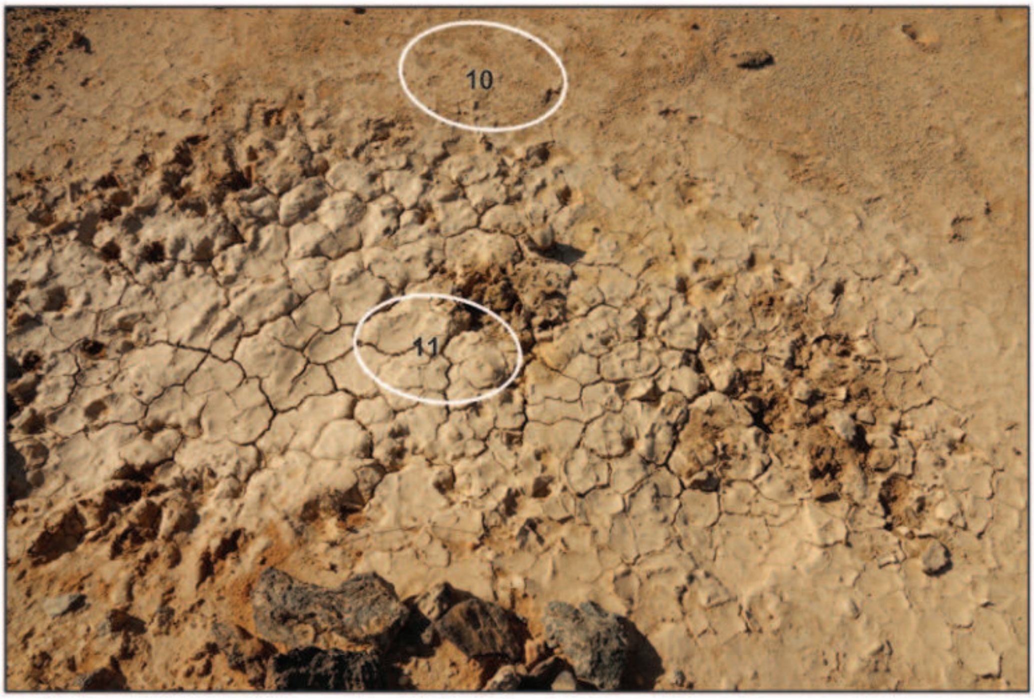


Fig. 10. Location of two samples taken from Wadi Ma'afer, near a small quarry: silty clay (point 10), fine clay (point 11) (photo M. Wetendorf)

Fig. 11. White clayey material sampled from the side wall of the Wadi es-Sufra (photo M. Wetendorf)

As stated above, a white raw material that may have been used as a plastic temper in the ceramic bodies used for making pottery at Musawwarat es-Sufra was sampled from Hafir Said, and a white clayey material was sampled from the side wall of the Wadi es-Sufra [Fig. 11]. White sandstone, which may have been used as a non-plastic temper, was sampled from various locations used during the Meroitic period and referred to as small quarries at the edge of Wadi Ma'afer [Fig. 2, points 8, 9 and 12].

Nile alluvial clay samples were taken from the river bank [Fig. 1, points 28, 31, 32 and 43]; figure 12 shows the location from which alluvial clay was sampled near El-Geili.

The sampled raw materials that may have been used as plastic raw material differ distinctly in colour and in their content of grains of silt, sand and gravel fraction [Fig. 13]. White temper may have been represented by samples of white sandstone, some of which easily break up into sand--sized fragments because the grains are weakly cemented together; in the case of white wadi clay, no sand-sized grains were observed macroscopically [Fig. 14].

Fig. 12. Sampling of Nile alluvial clay. Location from which alluvial clay was sampled near El-Geili (photo G. Schneider)

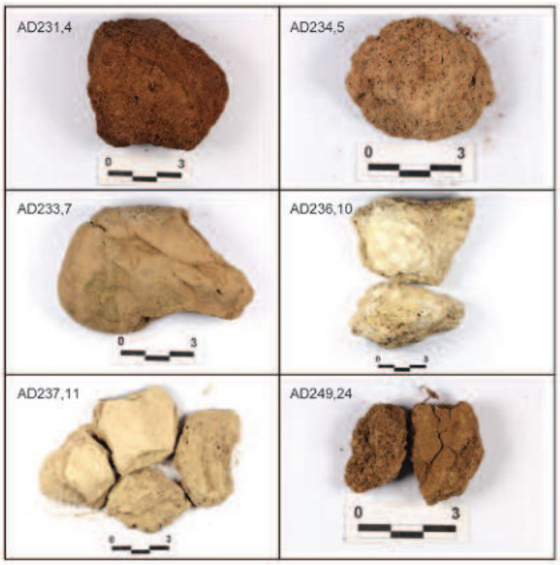


Fig. 13. Raw materials sampled in the area around Musawwarat es-Sufra (photo M. Baranowski)

Fig. 14. Samples of white kaolinitic sandstones (AD230,8; AD235,9; AD239,12) and white kaolinitic wadi clay (AD247,23) (photo M. Baranowski)

Analysis

The first analysis to be carried out was a plasticity test, which included gauging the water of plasticity (make-up water) content. Water of plasticity content was determined in 25 of the clayey raw material samples presented in this paper. Details of these values are given in table 1 in g H_2O per 100 g of dry clay. Water of plasticity is the amount of water required to bring 100 grams of clay material to a plastic state (in practical terms this means that the material can be shaped into a ball which will not feature any cracks, and which can, depending on the type of clay, have a certain amount of pressure applied to it such that the ball will only become misshapen but no cracks will appear). The content of water of plasticity ranges from 11 g to 34 g H_2O per 100 g clay. Three of the raw materials with a content of less than 20 g H_2O per 100 g clay are not suitable for making a plastic mass that can be satisfactorily formed; this is also the case with silty material (AD259,20),[22] which has a high water of plasticity content of 26%. The most plastic of the raw materials analysed, requiring a greater amount of water, are represented by seven samples. These include three samples of wadi clays (AD249,24; AD250,25; AD269,27), two samples of recent bottom-deposits in hafirs (Great Hafir AD265,1; Hafir Said AD233,7) and a Nile alluvial clay sampled near Shendi (AD292,32).

Conducting plasticity tests revealed which raw materials were suitable for making a plastic mass that can be adequately formed, which, of course, does not mean that all of these raw materials would have been used for making local Meroitic pottery. At the same time, non-pliable raw materials may have been used after they had been levigated.

The next stage of the project was to carry out a firing test. Briquettes for this test were formed using a plastic mass and non-porous porcelain moulds which yielded dome-shaped samples; these samples were then dried and fired in a laboratory furnace[23] at nine temperatures (400, 600, 700, 800, 900, 1100, 1100, 1150 and 1200°C). Two briquettes were fired at each temperature. One of the briquettes was left whole, whilst a thin slice was removed from the middle of the second briquette. Cut-sections were not made from briquettes fired at 400°C and 600°C due to the limited amount of available material and because of the fact that none of the 100 analysed fragments of Meroitic pottery deemed to represent local wares produced at workshops in Musawwarat es-Sufra had originally been fired at a temperature below 700°C.[24] Thus, after firing, thermal behaviour could be observed both in whole samples and in cut-section slides (cut-section slides removed from fired dome-shaped samples are the equivalent of cut-section slides removed from fragments of archaeological pottery for the purposes of MGR-analysis). Based on the firing test it was possible to identify which raw materials exhibit similar thermal behaviour to that of Meroitic pottery from Musawwarat es-Sufra.

The firing test is a routine test carried out by potters, allowing them to ascertain vital properties such as shrinkage on drying, shrinkage on firing, or sintering temperature range. This test is also very important in the reverse situation, when trying to identify the raw materials used in making a known ceramic product — as in the case of an archaeological ceramic analysis. In this situation, the thermal behaviour of the pottery is known (MGR-analysis), as is its chemical composition and its mineralogical and petrographic composition,[25] and the aim is to identify the original raw

[22] Each sample has two numbers. AD… is the sample laboratory number, whilst the number after the comma indicates the given sample's location on a map (maps shown in Figs. 1 and 2).

[23] Firing was done in a Carbolite electric laboratory resistance furnace, in air, static, at a heating rate of 5°C/min, a soaking time of 1 hour at the peak temperature, a cooling rate of 5°C/min up to 500°C and then cooling with the kiln for 1 hour.

[24] Unpublished analysis results estimating Teq.

[25] Based on the assumption that it is possible to carry out a comprehensive analysis of ancient pottery sherds.

material(s) that, when used with a specific technology, could have yielded this type of ceramic product. It must be emphasized that without conducting a firing test, the results of chemical analysis and/or thin-section studies alone should not be used as the basis for determining whether or not a raw material would have been suitable for making a particular type of pottery. The firing test was carried out on 25 raw material samples. Figure 15 shows an MGR-chart of the firing test for five raw materials, whilst figure 16 shows examples of briquettes made from 18 raw materials, fired at 1200°C. Despite the fact that plasticity tests indicated the suitability of three samples (AD242,15; AD243,16; AD244,17) for making a plastic mass that could be formed satisfactorily [Table 1], the firing test revealed that they did not meet the criteria of raw materials suitable for the manufacture of local Musawwarat es-Sufra pottery. As expected, when fired at 700°C (or a little higher) the briquettes began to crack, which is linked to the expansion of thermally decomposed carbonates (calcite in this case); the cracking process, which results in splinters breaking off from the briquette, occurred in briquettes fired at up to 1200°C. The deterioration of the samples started to become apparent several days after firing (briquettes kept at room temperature). Figure 16 shows samples without any cracks (photographs taken the day after firing), while figure 15 shows the same samples featuring cracks and splinters. It is interesting that when viewed macroscopically in their unfired state these three raw materials look like the typical Musawwarat fabric; one of them (AD242,15) is also similar in appearance, before cracks/splinters occur, after having been fired at 1200°C [Fig. 16].

Briquettes made of Nile alluvial clays differed very distinctly from all other samples in the firing test. Their characteristic feature is an over-melted matrix type [Fig. 17].

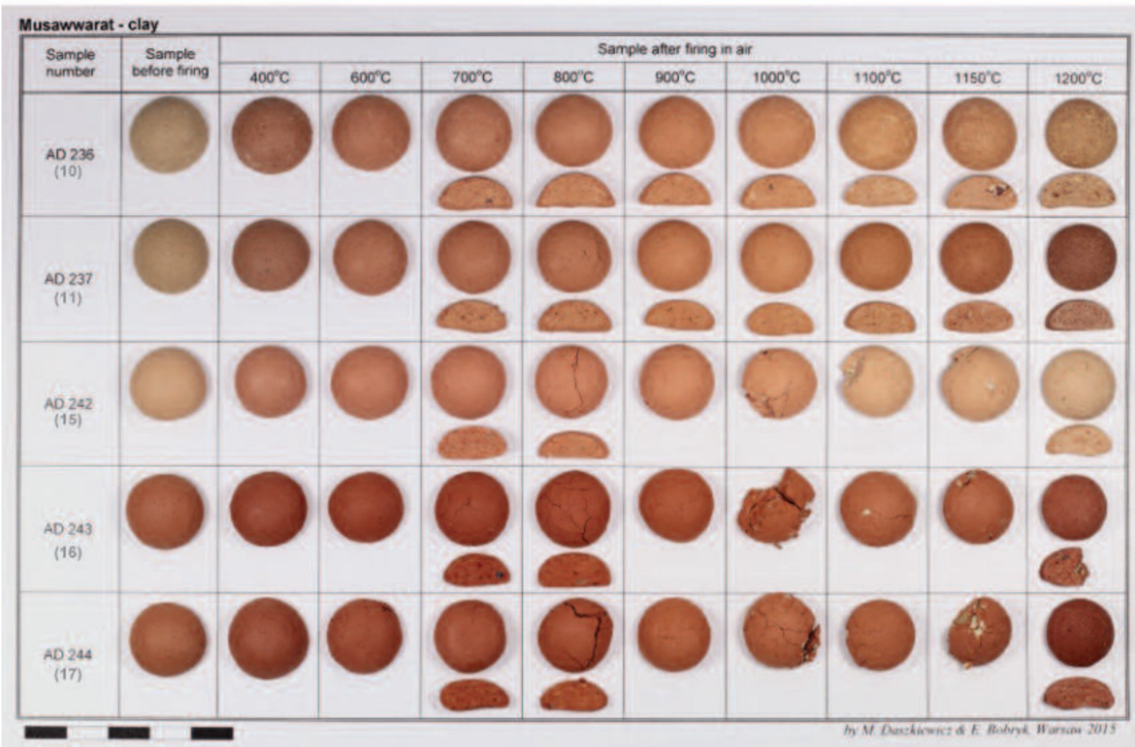


Fig. 15. MGR-chart. Clay specimens before and after firing in air (specimens formed using plastic mass and non-porous porcelain moulds which yielded dome-shaped samples); whole dome-shaped specimens and cut-sections of these specimens (photo M. Baranowski)

Localization	No. on maps	Lab. No.	water of plasticity [g H_2O/100g clay]	suitable for forming from plastic mass	Type of deposit	X-ray diffraction clay minerals	Thermal behaviour after firing at 1200°C		Fraction of non-plastic inclusions (macroscopically)	Suitability after firing test
							colour	matrix type		
	1	AD 265	28	yes	hafir clay (upper part)	K, Sm, Ch	reddish-brown	SN	few sand	suitable
Great Hafir (Musawwarat)	2	AD 266	21	yes	hafir clay (lower part)	K, Sm, Ch	brownish	SN	silt	suitable
	3	AD 291	25	yes	material dug out from hafir		red-brown	SN	silt	suitable (a liitle bit to dark)
North of Gebel es- Sufra	4	AD 231	20	yes	wadi clay	K, *Sm, Ch*	brownish-red	SN	silt, sand, few gravels	after levigation ?
	5	AD 234	15	no	deposit outside wadi	K	brownish-beige	SN	silt, sand	after levigation ?
Hafir Said	6	AD 232			middle part of the wall of hafir	**K**, *Il*				temper
(north-east of Gebel es Sufra)	7	AD 233	29	yes	hafir clay	K, Sm, Ch	brown	SN	vf/isol vfn micas	wrong colour (to dark)
small quarry	8	AD 230			white sandstone	**K**, *Il*	whitish	SN		temper
at the edge of Wadi Ma´afer	9	AD 235			white sandstone		whitish	SN		temper
	12	AD 239			white sandstone	**K**, *Il*	whitish	SN		temper
	10	AD 236	20	yes	adi clay; lower layer of depos	K, *Ch*	eige\(whitish;brownish	SN	hite incl (silt, sand, grave	suitable
Wadi Ma´afer	11	AD 237	20	yes	adi clay; upper layer of depos	K, *Ch*	browish-beige	SN	hite incl (silt, sand, grave	suitable
	13	AD 238	13	no	sandy deposit	K	beige-brownish	SN	silt, sand, gravels	after levigation ?
	14	AD 240			material dug out from hafir (whi	K				temper
Hafir Khalifa	15	AD 242	21	yes	upper part of the wall of hafir	K	pinkish white	SN	cc agg (sand,gravel)	not suitable
(in front of Gebel Ma´afer)	16	AD 243	21	yes	upper part of the wall of hafir	K	pale reddish	SN	cc agg (sand,gravel)	not suitable
	17	AD 244	20	yes	upper part of the wall of hafir	**K**, *Il*	reddish	SN	cc agg (sand,gravel)	not suitable
	18	AD 245	21	yes	hafir clay	K, Sm, Ch	reddish-brown	SN	few sand, isol cc	calcite agg.
on the foot of Gebel Ma´afer	19	AD 241			silty deposit (whitish/grayish)	**K**, *Il*				temper
big quarry (on top of Gebel Ma´afer)	20	AD 259	26	no	silty deposit	K	pale beige	SN	a lot of silt	not suitable
Hafir Hamad (behind Gebel Ma´afer)	21	AD 248	23	yes	hafir clay	K, Sm, Ch	brown-red	SN	silt, sand, few gravels	suitable
Hafir in front of Gebel el Ghafalla	22	AD 246	23	yes	hafir clay	Sm, Ch, K	brown	SN	silt	wrong colour (to dark)
Wadi es Sufra	23	AD 247	26	yes	wadi clay (whitish)	K	v.pale greenish-white	SN	mnv	temper
Wadi Awateb, near Naga	24	AD 249	33	yes	wadi clay	K, Sm, Ch	brownish-red	vst BL mat	silt, few sand	not suitable
wadi, N-W from Musawwarat	25	AD 250	26	yes	wadi clay	K, Sm, Ch	brownish-red	SN	few silt, few sand	suitable
Wadi Awateb	26	AD 251	11	no	wadi clay		beigish-brownish	SN	a lot of silt	not suitable
	27	AD 269	29	yes	wadi clay	K, Sm, Ch	brown	ovF	isl. silt, isl. sand	wrong colour (to dark)
Wad Ban Naga	28	AD 253	25	yes	Nile alluvial clay	Sm, Ch, *Il*	brown	ovM		not suitable
Shendi	31	AD 261	25	yes	Nile alluvial clay	Sm, Ch, *Il*	slightly reddish-brown	sovM		not suitable
Shendi	32	AD 292	34	yes	Nile alluvial clay		reddish-brown	sovM	few silt	not suitable
El-Geili	43	AD 267	24	yes	Nile alluvial clay	Sm, Ch, *Il*	slightly reddish-brown	ovM		not suitable
	33	AD 263	19	yes	body (clay + donkey dung)		reddish-brown	ovM	few silt	
Shendi	34	AD 262	21	yes	clay	Sm, *K, Il*	reddish-brown	sovM	silt	not suitable
	34	AD 278			ashes of donkey dung					
	33	AD 227			ceramics		reddish-brown	ovM		

Tab. 1. List of analysed samples. Plasticity water, X-ray diffraction results, firing test results. Suitable = a raw material that may have been used in making Meroitic pottery found at Musawwarat es-Sufra

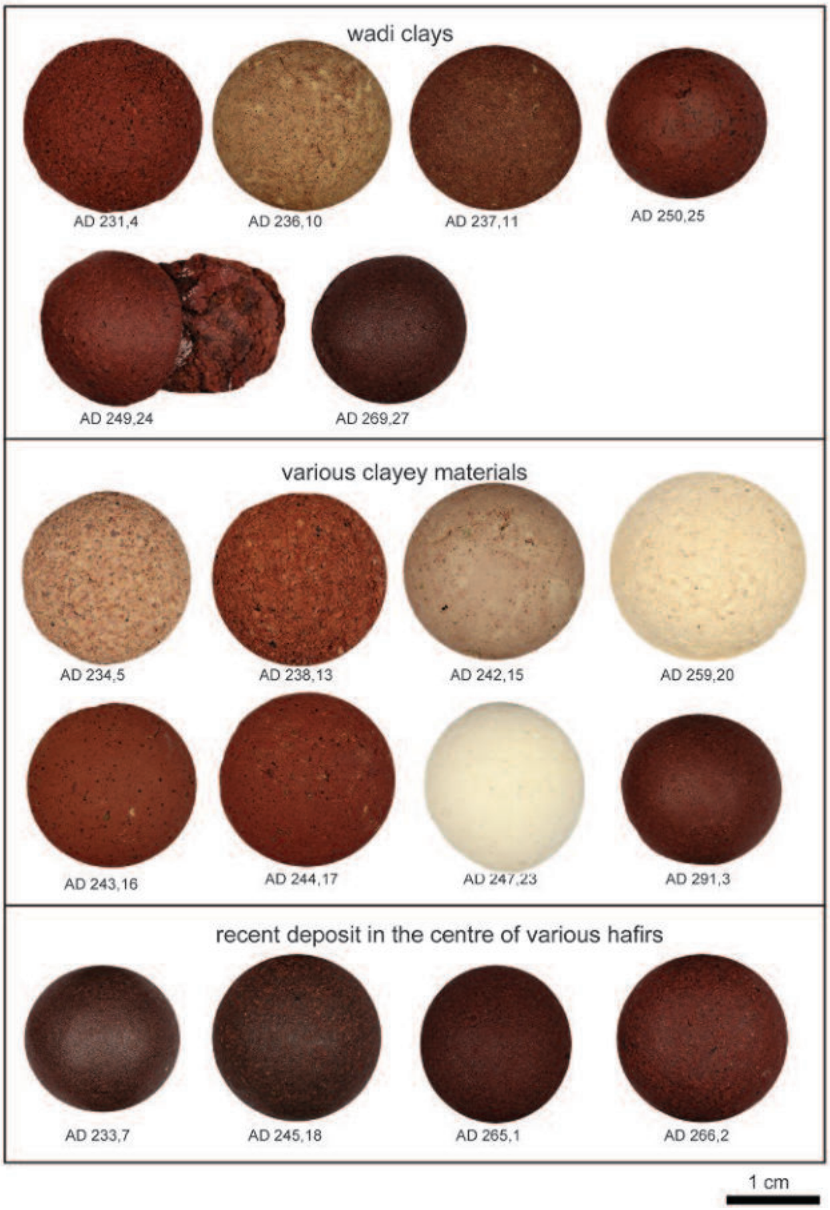


Fig. 16. Specimens of various raw materials fired at 1200°C (macro photos M. Baranowski)

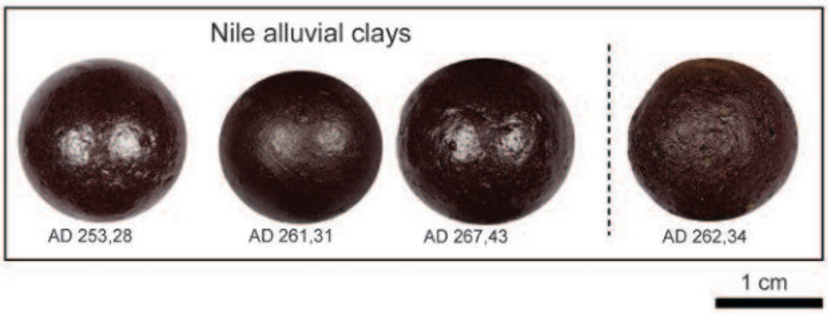


Fig. 17. Specimens of Nile alluvial clays (from left to right: samples taken near Wad Ban Naga, Shendi, El-Geili) and alluvial clay sampled directly from the river bank (AD262,34), fired at 1200°C (macro photos M. Baranowski)

The results of the firing test were taken into account in determining whether individual raw materials would have been suitable for making the pottery discovered in Musawwarat es-Sufra. Three raw material samples may have been used following the prior removal (by sifting or levigation) of any excess non-plastic particles in the form of grains in sand and gravel fraction. Seven raw materials could not have been used for producing pottery found at Musawwarat es-Sufra in view of their distinctly different thermal behaviour.[26] For example, wadi clay sampled from Wadi Awateb near Naga, which is a fat, very high-bloating clay [Fig. 16, AD249,24], can be ruled out because of its thermal expansion. Three samples can be excluded because of their colour after firing, which is far too dark (e.g. AD333,7 [Fig. 16]). Their colour is similar to that of pottery sherds made from Nile alluvial clays, but in contrast to such sherds, these four samples have a sintered matrix type (compare figure 16 with figure 17). Six raw material samples represent raw materials that may have been used by ancient potters to make local ceramics. Those most similar to the Mus 1 – Mus 4 reference groups, both in terms of matrix type and colour after the firing test, are samples of wadi clays AD237,10, AD250,25 and AD236,10 — the last of these following prior removal of grains in coarse sand and gravel fraction. These raw materials do not require the addition of the temper visible in Musawwarat fabrics; they contain naturally occurring whitish-firing aggregates or intrusions of a white-firing raw material visible in the form of bands after firing [Fig. 18].

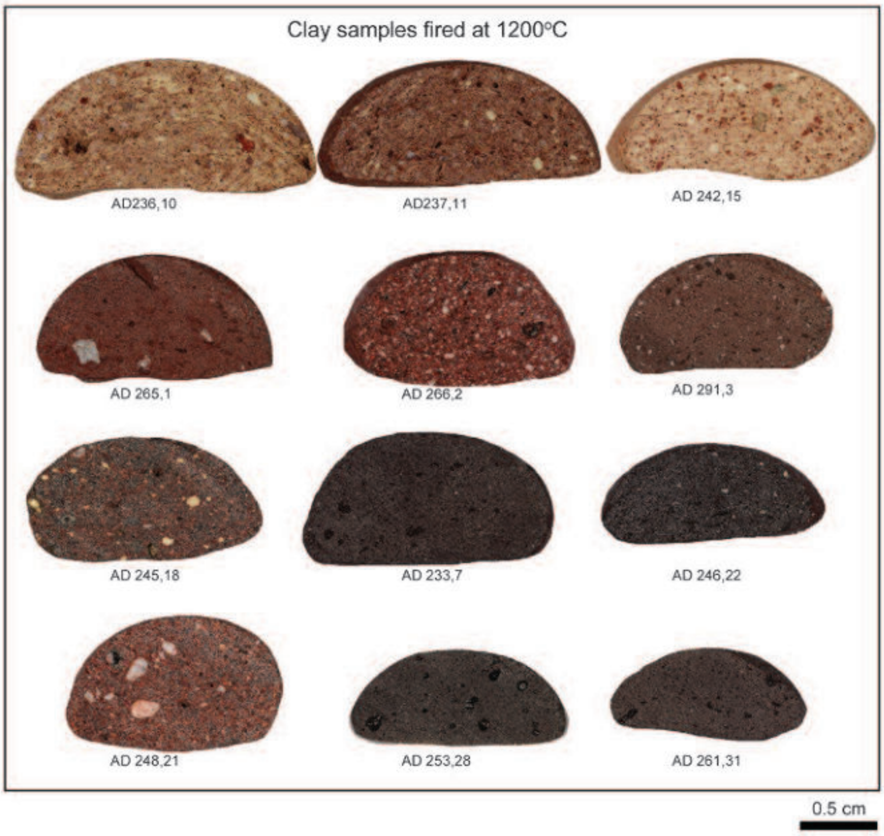


Fig. 18. Cut-sections of specimens of various raw materials fired at 1200°C. Samples of wadi clays AD236,10 and AD237,11 are very similar macroscopically to local Musawwarat fabrics (macro photos M. Baranowski)

[26] In addition, four of these seven samples feature carbonates as non-plastic components, which is not noted in samples of Meroitic pottery found at Musawwarat es-Sufra.

One sample (AD291,3), taken from the upper layer of a hafir wall — very probably material dug out from the Great Hafir at Musawwarat es-Sufra,[27] fires a slightly darker colour than samples Mus 1 – Mus 4, though it is similar to the colour of ceramic sherds referred to as “probably local”.[28] Seven samples may have been used as tempers (whitish aggregates typical of Musawwarat fabrics).

Twenty-eight of the raw material samples were subjected to X-ray powder diffraction analysis,[29] revealing in the case of 25 of these samples from the Musawwarat region [Fig. 1, points 1, 2, 4–25 and 27) that the clay mineral present in every one of them is kaolinite [Fig. 19 and 20]. Kaolinite is not the dominant clay phase in the wadi clay sample taken from Wadi Awateb near Naga (AD249,24). In this instance there is an equally abundant presence of clay minerals of the smectite group, responsible for the earlier mentioned high-swelling of this sample (see firing test). As well as the samples from Wadi Awateb, clay minerals of the smectite and chlorite groups are also present in small quantities in wadi clays AD237,11 and AD231,4 [Fig. 20]. In contrast to wadi clays, all of the samples representing recent bottom-sediments from the centre of the hafir have the same phase composition: smectite, chlorite, kaolinite, muscovite, feldspars, quartz [Fig. 19]. In the other clayey materials, kaolinite was the only clay mineral present [Fig. 19: AD242,15; AD259,20]. Muscovite occurs in most of the samples; plates of muscovite are easily visible macroscopically. Quartz clearly predominates among the non-plastic components. White sandstone sampled from a small quarry at the edge of Wadi Ma’afer is a sandstone in which sand-sized grains of quartz are cemented together with kaolinite. All of the samples of white kaolinitic sandstone and white clayey deposits from Wadi es-Sufra feature weak lines of anatase. Anatase and calcite also occur in three samples taken from the upper layer of the wall of Hafir Khalifa [Fig. 19].

In contrast to the aforementioned raw materials, clay minerals of the smectite group predominate in samples of Nile alluvial clays, with kaolinite occurring as a minor mineral.

In the next step, chemical analysis was carried out on 30 raw material samples to reveal the quantity of major and trace elements[30] [Table 2]. Samples which, after the firing test, were deemed potentially suitable for making Musawwarat fabrics following earlier levigation are characterised by a SiO_2 content of over 80% and by low levels of vanadium (V) and chrome (Cr). Raw materials which had too dark a colour after firing in relation to Musawwarat fabrics are characterised by higher levels of magnesium (Mg) and calcium (Ca) in comparison with the chemical composition of Meroitic pottery local to Musawwarat. The chemical composition of raw materials regarded

[27] This is the clay used by the local potter Amma.

[28] Daszkiewicz, Wetendorf 2014.

[29] Analysis done by G. Kaproń at the Faculty of Geology, University of Warsaw. Powdered, pressed samples, start position [°2θ], 3; end position [°2θ], 85; step size [°2θ], 0.026; scan step time [s], 1197.99; scan type continuous; measurement temperature [°C], 25.00; anode material, Co.

[30] In this instance, chemical analysis by WD-XRF (wavelength-dispersive X-ray fluorescence) was used to determine the content of major elements, including phosphorus and a rough estimation of sulphur and chlorine. Total iron was calculated as Fe_2O_3. Samples were prepared by pulverising fragments weighing ca. 2g (sample size was dictated by the number and size of the non-plastic components), having first removed their surfaces and cleaned the remaining fragments with distilled water in an ultrasonic device. The resulting powders were ignited at 900C (heating rate 200C/h, soaking time 1 h), melted with a lithium-borate mixture (Merck Spectromelt A12) and cast into small discs for measurement. This data is, therefore, valid for ignited samples but, with the ignition losses given, may be recalculated to a dry basis. For easier comparison the major elements are normalised to a constant sum of 100%. Major elements are calculated as oxides. The precision for major elements is below 1%; for trace elements this rises to a maximum of 20% depending on the concentrations. Accuracy was tested by analysing international reference samples and by exchange of samples with other laboratories. For major elements and the most important trace elements, it is between 5 and 10%. Preparation of samples for analysis was carried out by M. Daszkiewicz ARCHEA, measurement using a PANnalytical AXIOS XRF-spectrometer and the calibration of Arbeitsgruppe Archaeometrie by G. Schneider and A. Schleicher in GFZ Potsdam (GFZ = Helmholtz-Zentrum Potsdam, Deutsches Geo-ForschungsZentrum GFZ, Sektion 4.2, Anorganische und Isotopengeochemie).

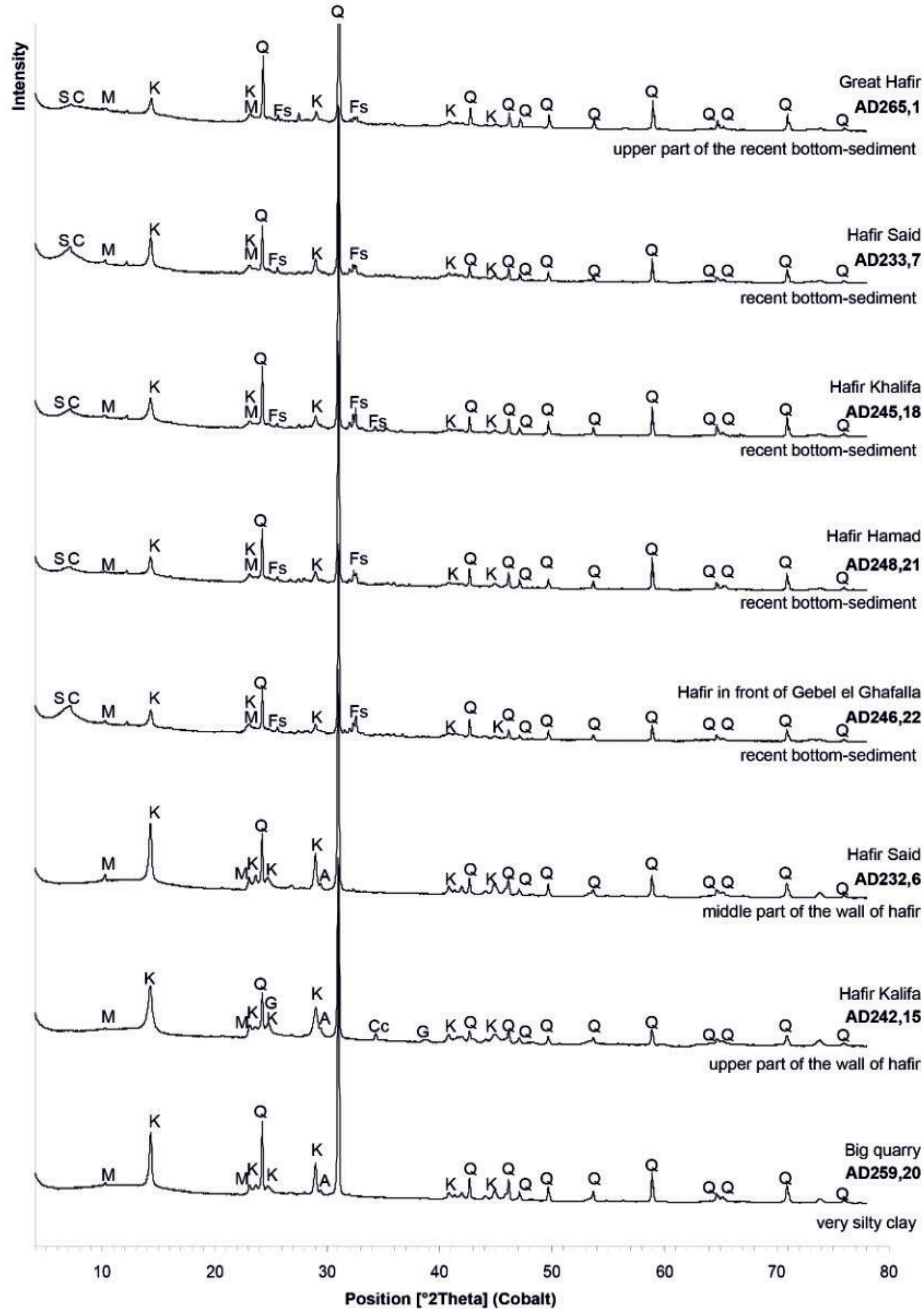


Fig. 19. X-ray powder diffraction analysis of samples taken from various locations:
S = smectite, C = chlorite, K = kaolinite, M = muscovite, Q = quartz,
Fs = feldspars, Cc = calcite, G = goethite, A = anatase

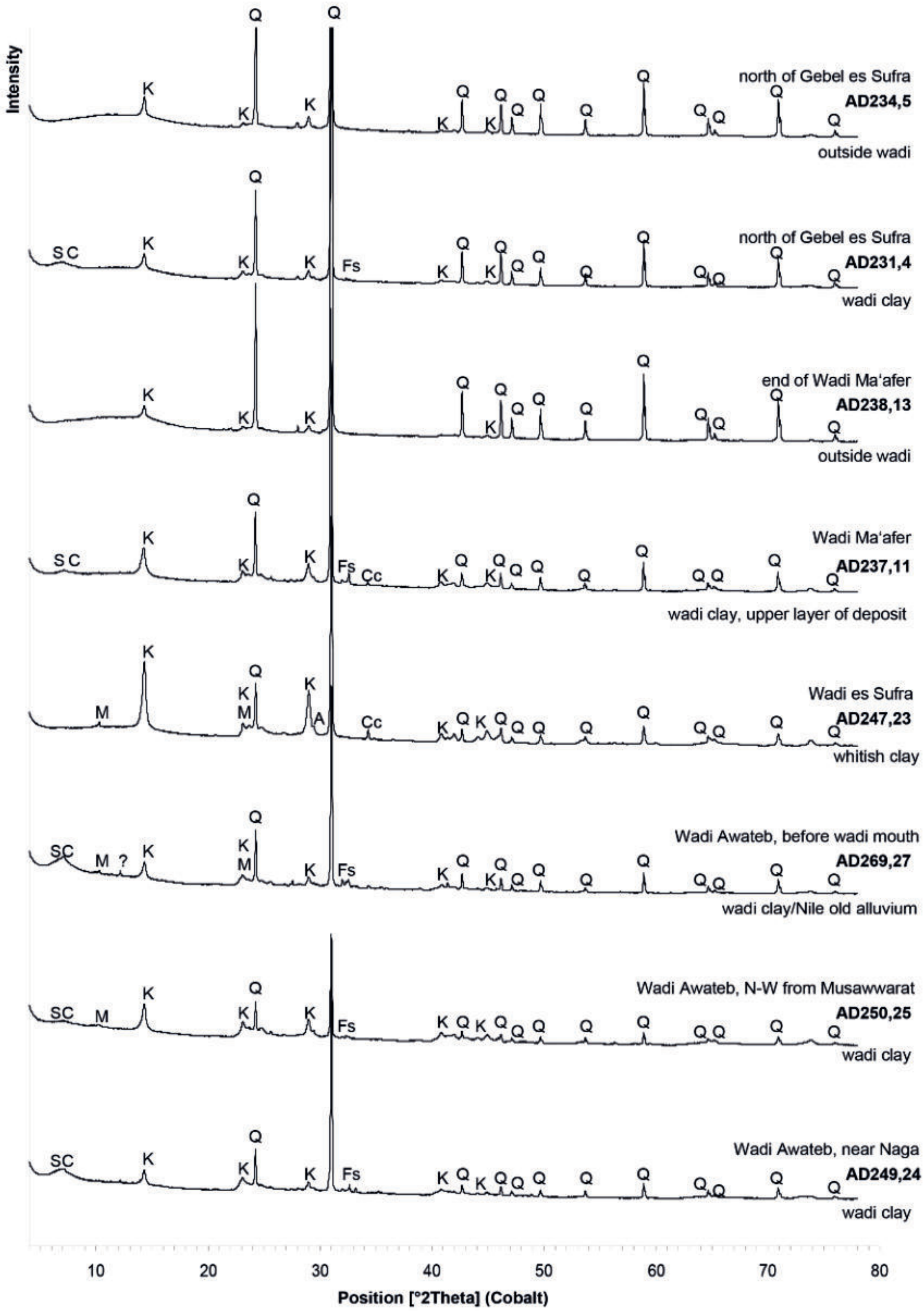


Fig. 20. X-ray powder diffraction analysis of samples taken from various locations: S = smectite, C = chlorite, K = kaolinite, M = muscovite, Q = quartz, Fs = feldspars, Cc = calcite, G = goethite, A = anatase

No. on maps	Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	(La	Ce	Pb	Th	Nd)	l.o.i.	TOTAL
		per cent by weight										ppm																%	%
Raw material samples collected within the vicinity of Musawwarat es-Sufra																													
		raw materials that may have been used in making Meroitic pottery found at Musawwarat es-Sufra.																											
		wadi clays																											
11	**AD 237**	70.88	1.49	19.36	5.22	0.050	0.88	1.23	0.27	0.52	0.11	122	116	50	32	46	19	87	73	343	18	186	22	60	12	13	53	7.93	100.46
10	**AD 236**	75.66	1.42	17.02	4.07	0.036	0.51	0.74	0.15	0.33	0.08	98	99	38	22	31	11	60	62	356	14	129	12	42	10	12	40	6.20	99.64
25	**AD 250**	59.31	1.50	25.15	10.25	0.172	1.28	0.97	0.16	1.08	0.14	190	168	92	60	67	49	91	36	278	20	345	35	92	15	17	48	9.23	99.46
		hafir clays																											
1	**AD 265**	70.52	1.35	16.28	6.97	0.128	1.37	1.38	0.64	1.20	0.17	141	137	58	45	67	41	141	35	276	17	338	30	65	13	8	36	10.81	100.44
2	**AD 266**	73.76	1.30	14.32	6.37	0.099	1.35	1.19	0.41	1.04	0.16	122	122	51	32	53	36	109	28	341	14	271	21	63	8	15	35	5.62	100.48
21	**AD 248**	70.49	1.53	16.43	6.25	0.082	1.49	1.86	0.75	1.00	0.13	148	143	46	30	52	37	164	30	411	17	317	30	46	10	8	19	5.45	100.13
		a little bit to dark colour after firing																											
3	**AD 291**	66.81	1.39	19.93	7.70	0.121	1.34	1.05	0.29	1.17	0.21	160	147	65	46	71	48	107	40	252	18	458	46	84	12	17	50	6.89	100.02
		wadi clays suitable after levigation																											
4	**AD 231**	80.25	0.97	11.77	5.13	0.085	0.73	0.62	0.02	0.37	0.05	89	84	38	22	83	13	49	24	257	11	173	28	70	10	7	39	4.21	98.63
5	**AD 234**	87.43	0.80	8.46	2.30	0.040	0.24	0.42	0.02	0.24	0.04	54	48	14	<5	11	8	26	24	224	7	97	7	40	5	7	5	3.03	101.36
13	**AD 238**	89.31	0.69	6.68	2.38	0.047	0.30	0.37	0.01	0.19	0.03	53	49	17	<5	14	10	28	15	224	6	121	<5	37	5	5	6	2.54	99.38
		raw materials not suitable to be used to produce pottery found at Musawwarat es-Sufra																											
		to dark colour after firing, to high Fe, Mg and Ca																											
7	**AD 233**	65.97	1.60	18.46	7.57	0.130	2.01	2.15	0.80	1.16	0.16	167	155	59	42	72	43	175	41	347	19	360	32	68	10	10	35	6.59	100.20
22	**AD 246**	71.69	1.66	13.72	6.82	0.100	1.78	2.11	0.86	1.11	0.15	141	153	48	32	63	40	178	34	568	17	354	21	67	10	11	60	4.56	100.27
27	**AD 269**	66.51	1.39	17.52	8.08	0.128	2.00	2.30	0.66	1.29	0.14	147	147	67	48	70	51	189	31	282	17	377	37	60	11	15	60	6.67	100.20
		distinctly different thermal behaviour																											
24	**AD 249**	66.85	1.28	18.32	8.32	0.114	2.03	1.54	0.27	1.10	0.17	151	140	72	49	73	48	128	29	277	17	314	35	57	11	13	44	8.39	99.69
26	**AD 251**	90.39	0.56	5.12	2.71	0.045	0.44	0.33	0.02	0.36	0.02	54	50	20	5	15	14	37	12	279	6	142	<5	16	6	<5	13	2.01	100.03
20	**AD 259**	76.26	1.49	18.42	2.92	0.018	0.17	0.25	0.01	0.41	0.06	141	149	24	6	14	12	49	39	509	15	186	27	84	10	9	45	6.37	100.39
15	**AD 242**	60.49	1.50	24.18	8.96	0.008	0.22	4.36	0.01	0.21	0.07	190	134	44	43	22	7	76	105	238	19	164	43	55	9	10	54	11.35	99.96
18	**AD 245**	71.81	1.56	14.76	6.03	0.075	1.44	2.42	0.80	0.99	0.13	137	135	43	27	55	34	168	56	439	15	341	31	62	9	7	56	5.17	100.13
16	**AD 243**	58.12	1.44	23.89	11.77	0.013	0.23	4.00	0.01	0.37	0.16	199	130	72	45	34	10	78	397	241	15	181	142	264	13	14	252	10.89	100.14
17	**AD 244**	61.08	1.41	22.28	10.29	0.024	0.40	3.85	0.09	0.44	0.14	170	123	61	42	42	13	81	289	262	16	191	89	181	12	13	174	10.22	100.36
		white temper																											
		white or whiitsh-grayish clayey materials																											
6	**AD 232**	72.96	1.63	23.54	1.09	0.006	0.14	0.07	0.02	0.50	0.04	109	108	13	<5	7	12	45	70	287	17	199	42	95	9	10	71	7.67	99.71
23	**AD 247**	67.27	1.68	27.29	1.73	0.009	0.09	1.43	0.01	0.44	0.04	122	149	18	7	12	13	60	55	278	20	176	35	70	10	12	77	9.61	100.46
19	**AD 241**	66.97	1.53	26.04	3.68	0.007	0.06	0.93	0.27	0.45	0.06	192	147	20	<5	16	12	67	84	231	20	200	82	91	20	<5	59	9.24	100.40
		kaolinitic sandstone, Hafir Khalifa (in front of Gebel Ma´afer)																											
14	**AD 240**	82.55	1.83	13.71	1.41	0.010	0.00	0.32	0.02	0.08	0.07	80	72	19	<5	11	<5	20	184	472	13	51	114	238	9	<5	196	*na*	99.31
		kaolinitic sandstone, small quarry at the edge of Wadi Ma´afer																											
8	**AD 230**	82.66	1.29	14.29	1.21	0.011	0.10	0.13	0.01	0.17	0.14	53	61	16	<5	8	<5	26	373	271	12	87	218	539	12	<5	521	5.03	99.63
9	**AD 235**	83.84	1.70	12.29	1.95	0.019	0.01	0.06	0.01	0.09	0.02	100	85	14	<5	7	<5	13	49	498	21	32	15	21	6	<5	15	4.71	100.09
Contemponary pottery workshop in Shendi																													
	clay																												
34	**AD 262**	64.84	1.71	15.54	9.40	0.155	2.42	3.53	0.86	1.28	0.27	177	138	66	54	89	49	223	32	338	24	409	23	65	12	13	49	6.60	99.74
	ceramic body (clay + donkey dung)																												
33	**AD 263**	64.53	1.71	15.47	9.47	0.163	2.43	3.67	0.88	1.35	0.32	180	134	65	57	95	54	232	35	348	24	424	28	67	8	12	22	5.84	100.74
	ashes of donkey dung																												
34	**AD 278**	61.96	0.84	8.32	4.21	0.116	3.17	9.01	1.54	6.82	4.01	68	63	49	133	190	47	440	21	139	18	464	*na*	31	11	*na*	*na*	7.43	99.20
	ceramics made from ceramic body AD 263																												
35	**AD 227**	64.05	1.74	15.83	9.56	0.156	2.46	3.54	0.90	1.44	0.33	171	134	67	65	97	52	229	37	348	26	399	46	67	8	11	42	1.42	100.27
Nile alluvial clays (along the river near: Wad Ban Naga (AD 253), Shendi (AD 261 and AD 292), El-Geili (AD 267)																													
28	**AD 253**	54.58	2.85	17.26	13.09	0.206	3.03	6.00	1.30	1.39	0.31	273	166	73	71	126	49	301	36	388	38	480	42	60	9	16	41	8.54	100.37
31	**AD 261**	53.42	2.84	19.11	14.15	0.235	2.78	4.90	1.03	1.24	0.30	279	167	84	81	128	51	257	40	369	40	427	37	79	6	13	51	9.11	100.14
32	**AD 292**	53.09	2.60	20.74	14.43	0.260	2.60	3.95	0.78	1.24	0.31	277	165	94	92	130	60	217	44	372	41	424	46	82	11	19	33	10.35	100.28
43	**AD 267**	56.37	2.50	17.31	12.43	0.196	2.85	5.45	1.24	1.36	0.29	256	153	72	72	118	52	289	39	370	38	519	25	74	10	12	38	8.09	100.67

Tab. 2. Results of chemical analysis by WD-XRF. Analysis of samples ignited at 900°C and melted (preparation by M. Daszkiewicz ARCHEA, measurements by G. Schneider and A. Schleicher GFZ Potsdam)

(after the firing test) as suitable for pottery making is very diverse in terms of the content of both major and trace elements [Table 2]. The main difference in chemical composition between samples of wadi clays and recent bottom-sediments from hafirs is that wadi clays have a higher aluminium content (19–25% Al_2O_3). The levels of MgO, CaO, Na_2O and K_2O in wadi clays are also generally lower than those in hafir clays. An interesting case is sample AD250,25 (wadi clay collected from a wadi north-west of Musawwarat), which has 25% Al_2O_3 and 10% Fe_2O_3. Such a high level of iron is typical of low-melting, much darker-firing Nile alluvial clays. Despite this very high iron content, the colour of this sample does not differ from that of other wadi clays after firing at 1200°C.

Raw materials which the firing test showed to be unsuitable for manufacturing local Musawwarat fabrics are also highly diverse in their chemical composition. Samples AD242,15, AD243,16 and AD244,17, taken from the top layer of the wall of Hafir Khalifa (in front of Gebel Ma'afer), are distinctive in having a higher content of carbonates (expressed as 3.85–4.36% CaO) than any other raw material samples from the Musawwarat area. These samples also have high levels of iron (8.96–11.77%, X-ray diffraction revealed the presence of goethite and/or hematite), which, as in the case of sample AD250,25, did not result in the sample becoming distinctly darker after firing; the colour is probably neutralised by the sample's kaolinite content (22–24% Al_2O_3). Two of these samples (those with more than 10% Fe_2O_3) have very high levels of yttrium (289 and 397 ppm respectively), lanthanum (89 and 142 ppm) and cerium (181 and 264 ppm). The high concentrations of these three trace elements are linked to the presence of monazite. High levels of lanthanum and cerium were noted in one pottery sherd discovered at Musawwarat es--Sufra (AD087),[31] but its yttrium content only amounts to 55 ppm, whilst the high potassium content and low titanium content of this sherd, as well as its different thermal behaviour, preclude its local provenance. In contrast to the aforementioned three samples taken from the top layer of the wall of Hafir Khalifa, the chemical composition of recent bottom-sediments from this hafir only differs appreciably from that of sediments from other hafirs in having a higher CaO content (which is higher than the CaO content noted in all analysed Meroitic pottery sherds attributed to the Musawwarat reference groups).

Chemical analysis of materials that could have served as temper macroscopically visible in the Musawwarat fabrics as white-firing aggregates [Fig. 21] showed that not all types of white sandstone sampled from local quarries would have been suitable for use by Meroitic potters in Musawwarat es-Sufra. Two samples of white sandstone from a small quarry at the edge of Wadi Ma'afer (AD230,8 and AD235,9) were taken for chemical analysis. The first of these is characterised by very high levels of yttrium (Y = 373 ppm) as well as lanthanum, cerium and neodymium (La = 218 ppm; Ce = 539 ppm, Nd = 521 ppm). This sandstone was not used as a non-plastic temper in the ceramic bodies from which Meroitic pottery was made in Musawwarat. The second sample was taken from the opposite side of the quarry. There is nothing distinctive in the chemical composition of this sandstone, and it could have been used as a temper [Table 2]. However, it should be noted that adding this sandstone to a ceramic body will result in an increase in its content of silica rather than aluminium (sample AD235,9: 83.9% SiO_2 and 12.3% Al_2O_3). A high aluminium content (23–27% Al_2O_3) occurs in the white-firing silty clayey materials sampled from the wall of Hafir Said (AD232,6), the foot of Gebel Ma'afer (AD241,19) and the bank of the Wadi es-Sufra (AD247,23).

Nile alluvial clays taken from the vicinities of El-Geili, Wad Ban Naga and Shendi differ distinctly from wadi and hafir clays[32] because of their high levels of titanium (2.5–2.85% TiO_2) and iron (12.4–14.4% Fe_2O_3). Their levels of MgO (2.8–3%), CaO (3.9–6.0%) and strontium (217–301 ppm),

[31] Daszkiewicz, Wetendorf 2014.

[32] Hafir clay = bottom-sediments.

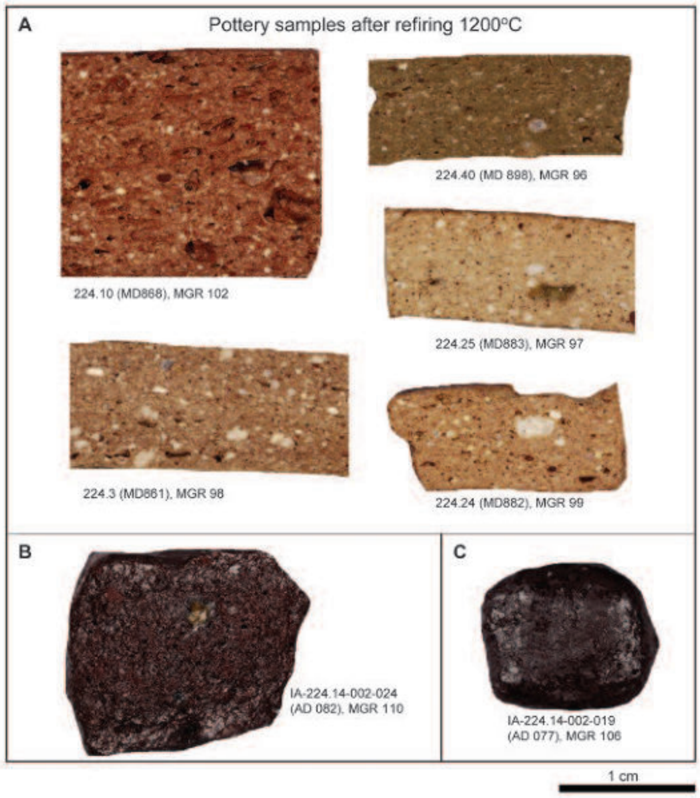


Fig. 21. Pottery fragments after refiring at 1200°C:
A = local pottery made at Musawwarat, B = imports
(macro photos M. Baranowski)

which is geochemically correlated with calcium, are also higher than those noted in wadi clays and hafir clays. Carbonates in the Nile alluvial clays are correlated with a higher strontium content than that observed in clays from around Musawwarat (e.g. sample AD243,16 has 4% CaO and 78 ppm Sr, while sample AD292 has 3.92% CaO and 217 ppm Sr), which is attributable to the calcium being of a different origin. Alluvial clays exhibit similar thermal behaviour to that observed in pottery ascribed to the so-called alluvial group discovered at Musawwarat es-Sufra [cf. Figs. 17 and 21]; however, their chemical composition reveals that they were not the raw materials used for making pottery at Musawwarat.

In figure 22, the results of multivariate cluster analysis[33] are presented in the form of a dendrogram. This analysis[34] takes into account the chemical composition of 85 pottery fragments (57 pottery fragments attributed to Mus 1 – Mus 4, five samples attributed to the Mus 5 reference group,[35] 11 fragments identified as "probably local"[36] and 12 fragments made of Nile alluvial clays) and 12 raw materials (samples selected after plasticity and firing tests). Two major clusters were singled out.

[33] All discriminant, principal components and multivariate clusters analyses were done in ARCHEA using the SYSTEM Package ClusCorr 98 on licence from the Weierstrass Institute for Applied Analysis and Stochastics, Leibniz Institute in Forschungsverbund Berlin e.V.

[34] Analysis using Euclidean distance and average linkage aggregative clustering of a distance, Z-scores transformation of data, elements used: Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K, V, Cr, Ni, Zn, Rb, Sr, Y, Zr, Nb, Ba, La and Ce.

[35] A new reference group; publication in preparation.

[36] Daszkiewicz, Wetendorf 2014, samples were classified as "probably local at Musawwarat or regional".

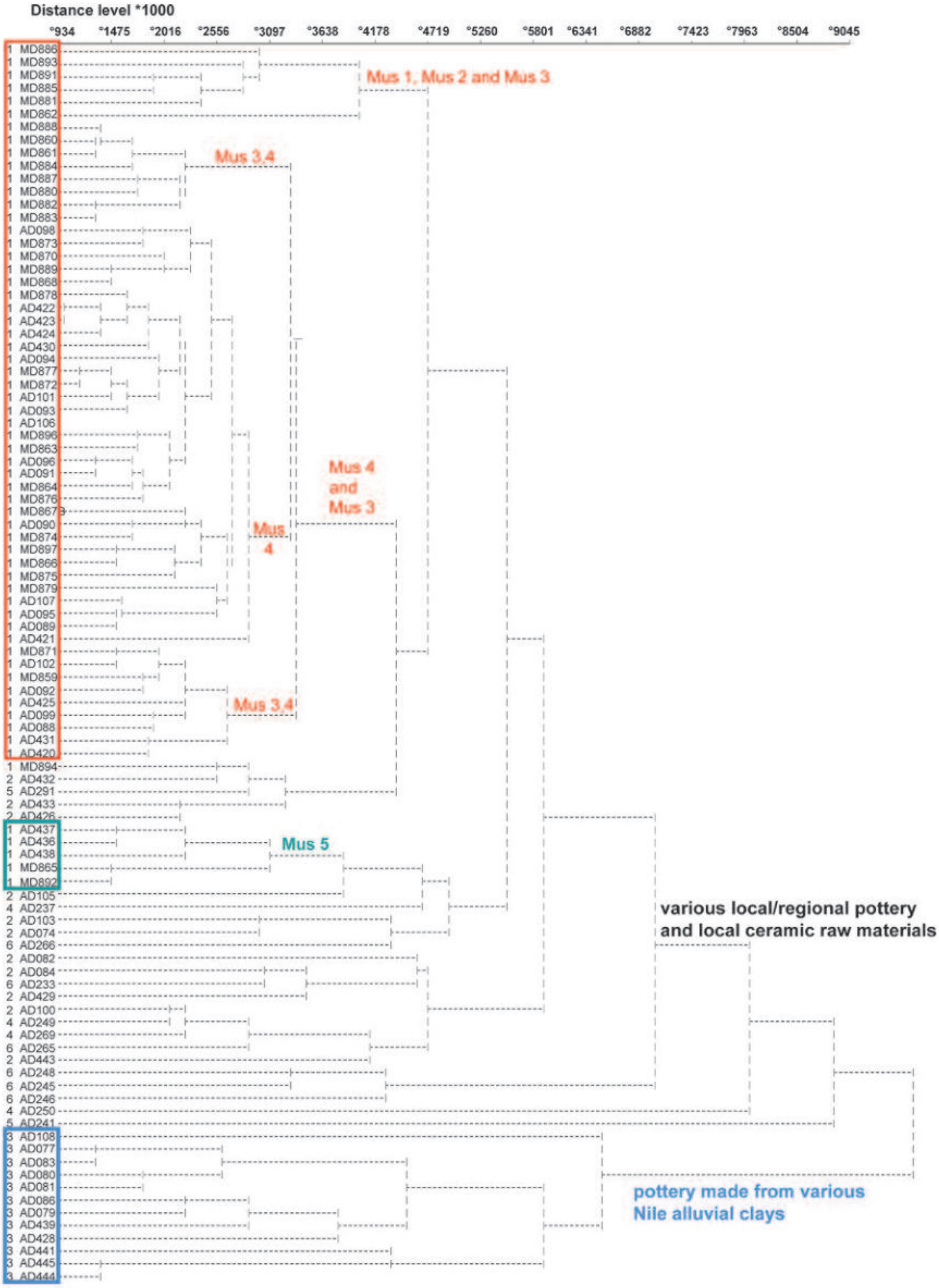


Fig. 22. Dendrogram of cluster analysis. Aggregative clustering of Euclidian distances using average linkage, logged data, elements used: Si, Ti, Al., Fe, Mn, Mg, Ca, Na, K, V, Cr, Ni, Zn, Rb, Y, Sr, Zr, Nb, Ba, La, and Ce. The first column shows cluster numbers used in figures 23–28, see list of abbreviations in figure 23. The second column shows sample numbers

The first of these encompasses all fragments of pottery made from fabrics Mus 1 – Mus 5, "probably local" pottery and all raw materials. The second major cluster is represented solely by pottery fragments made from Nile alluvial clays. This analysis indicates that the greatest similarity with Musawwarat pottery in terms of chemical composition is exhibited by wadi clay AD237,11 and by a raw material used by a local potter[37] (AD291,3). The same picture also emerges when taking into consideration discriminant analysis [Fig. 23],[38] demonstrating the good discrimination of these groups. The same groups are also evident in principal components analysis [Fig. 24]. A loading plot [Fig. 25] attests to the significance of elements such as Ti, Fe, Mg and Ca in grouping the samples.

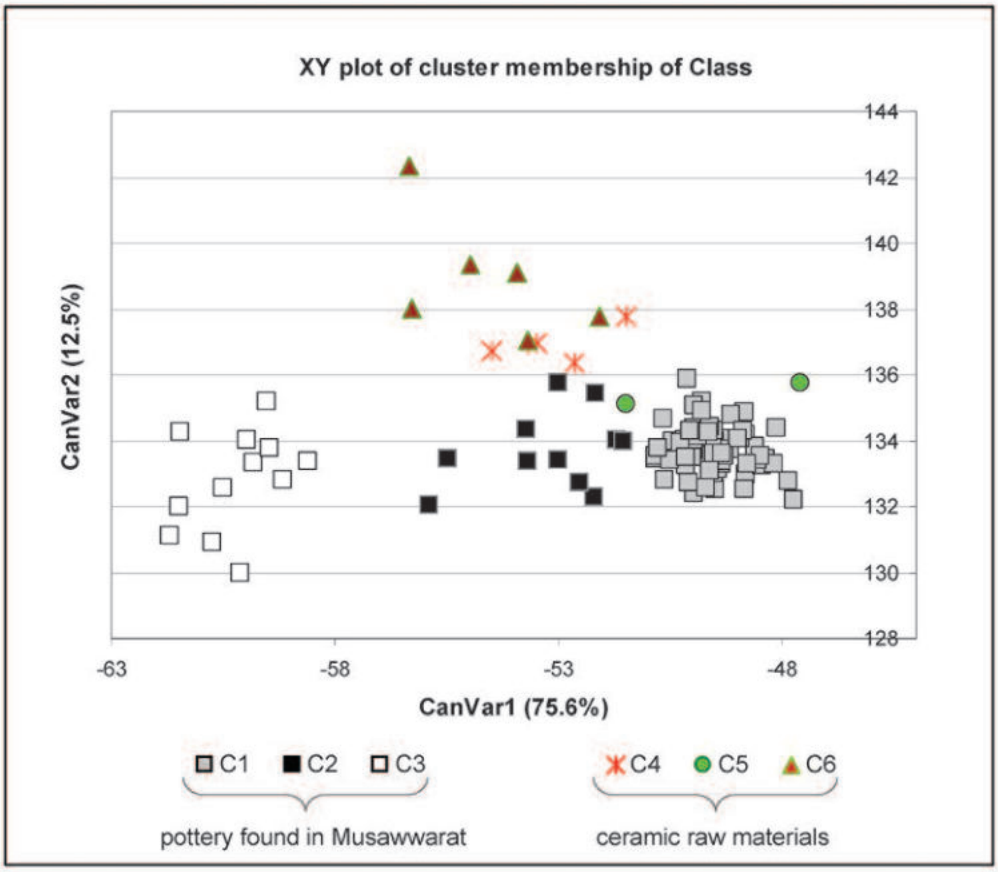


Fig. 23. Discriminant analysis. Plot of the first two canonical variables (CanVar1–CanVar2): C1 = pottery found in Musawwarat es-Sufra belonging to reference groups Mus 1 – Mus 5; C2 = pottery found in Musawwarat es-Sufra made from various clays described as "probably local"; C3 = pottery found in Musawwarat es-Sufra made from various Nile alluvial clays; C4 = wadi clays; C5 = raw materials from hafir walls, including material used by a local potter; C6 = recent bottom-sediments from various hafirs

[37] The earlier mentioned potter named Amma, who lives in a nearby village to the site at Musawwarat es-Sufra.

[38] Uniform coding is used in the dendrogram, discriminant analysis, principal components and biplots: C1 = pottery found in Musawwarat es-Sufra belonging to reference groups Mus 1 – Mus 5; C2 = pottery found in Musawwarat es-Sufra made from various clays described as "probably local"; C3 = pottery found in Musawwarat es-Sufra made from various Nile alluvial clays; C4 = wadi clays; C5 = material from the walls of hafirs; C6 = hafir clay (recent bottom-sediments).

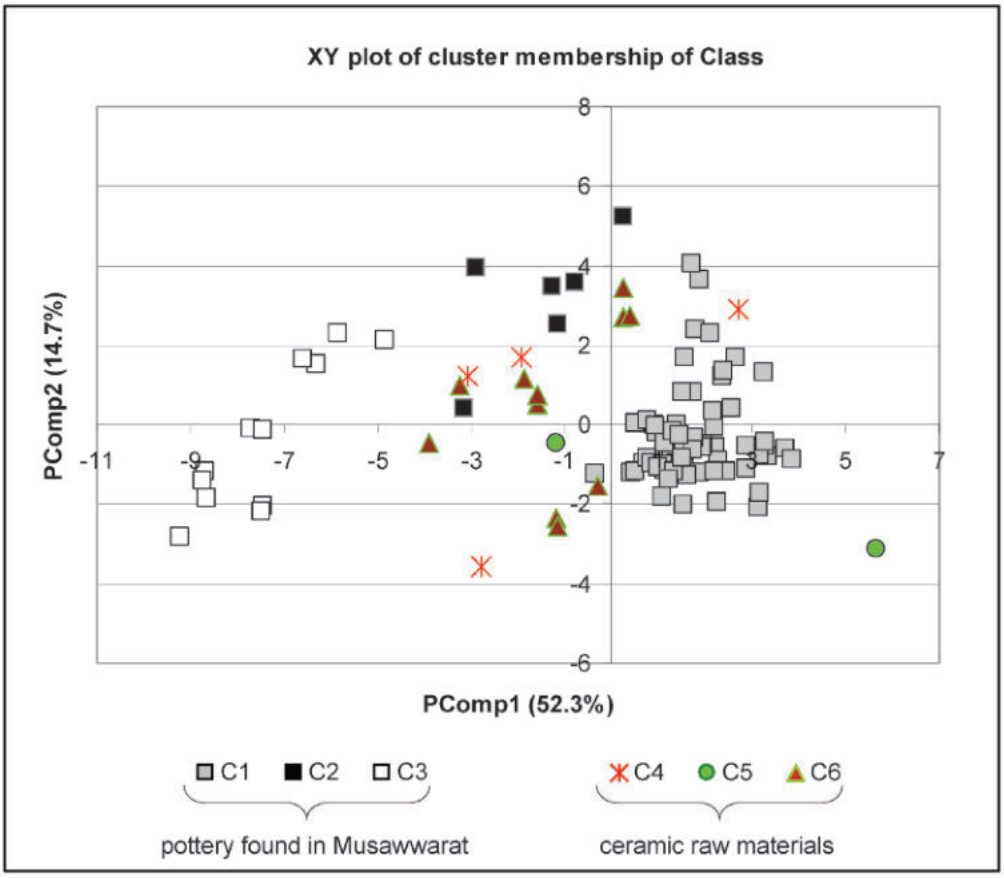
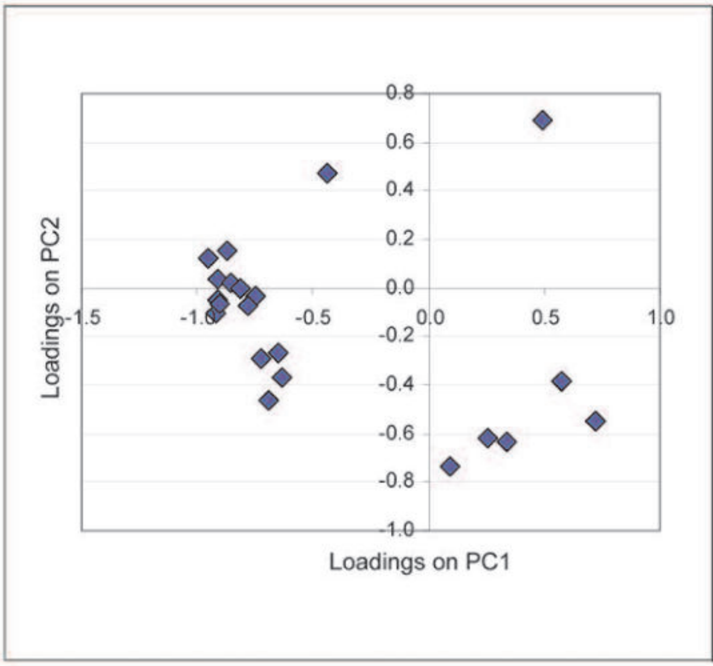


Fig. 24. Principal component analysis. Plot of the first two principal components (PC1–PC2) for potsherds and raw material samples; C1–C6 = see description of figure 23



	PComp1	PComp2
SiO_2	0.492	0.690
TiO_2	-0.636	-0.370
Al_2O_3	0.724	-0.547
Fe_2O_3	-0.924	-0.104
MnO	-0.912	-0.049
MgO	-0.954	0.124
CaO	-0.913	0.040
Na_2O	-0.867	0.151
K_2O	-0.749	-0.033
V	-0.650	-0.270
Cr	0.097	-0.731
Ni	-0.724	-0.294
Zn	-0.907	-0.067
Rb	-0.852	0.018
Sr	-0.816	-0.006
Y	0.575	-0.388
Zr	-0.434	0.476
Nb	-0.691	-0.459
Ba	-0.779	-0.076
La	0.340	-0.633
Ce	0.256	-0.621

Fig. 25. Loading plot for the plot shown in figure 24

Imported pottery (namely samples of ceramics made from Nile alluvial clays) can be clearly distinguished from all other samples, even without the use of multivariate statistics. Figure 26 shows a biplot of iron content versus sodium content. Pottery sherds grouped under "Nile alluvial clays" are distinctive in having higher levels of iron and lower levels of sodium than those noted in other sherds and local raw materials. All of these samples have an over-melted matrix type after refiring at 1200°C, which is linked to higher levels of fluxes. All pottery sherds made from Nile alluvial clays [Fig. 27, C3] have a flux content of more than 15%. None of the local or probably local sherds, nor any of the samples of wadi and hafir clays and clays from hafir walls, have an equally high level of fluxes. Flux content varies in local pottery (C1 = Mus 1–5) from 6% to 10%. The exception to this is one sample (MD894) with a flux content of 11.87%; this is the only sample representing group MGR 103.[39] One raw material sample was attributed to this ceramic group: wadi clay AD237,11. Samples from cluster C2 are characterised by a flux content of 10–14%; here, there is also one exception — sample AD074, which has fewer fluxes (8.80%). It is the only sample representing group MGR 105. A raw material used by a local potter (AD291,3), one wadi clay (AD249) and one hafir clay (AD233) were also attributed to this group. The remaining hafir clays are characterised by the same sum total of fluxes as C2 pottery, but they have a lower Al_2O_3/SiO_2 ratio, which is linked to an increased quantity of sandy and/or silty grains of quartz.

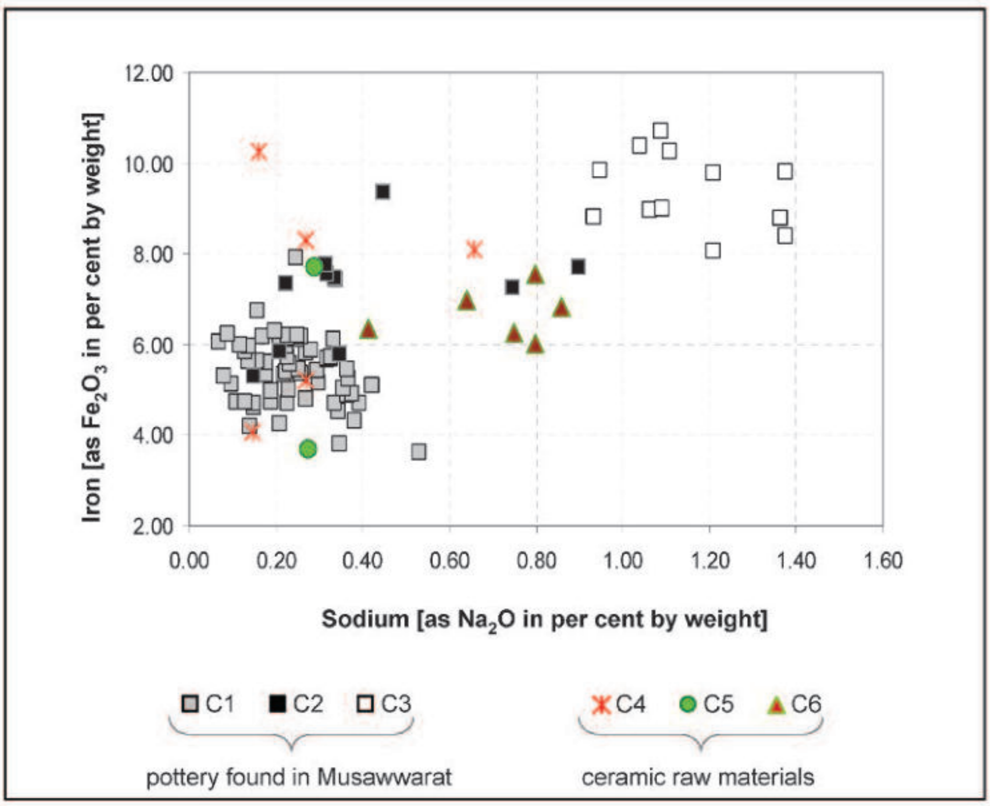


Fig. 26. Biplot showing levels of iron (as Fe_2O_3 in per cent by weight) versus levels of sodium (as Na_2O in per cent by weight); C1–C6 = see description of figure 23

[39] Näser, Daszkiewicz 2013.

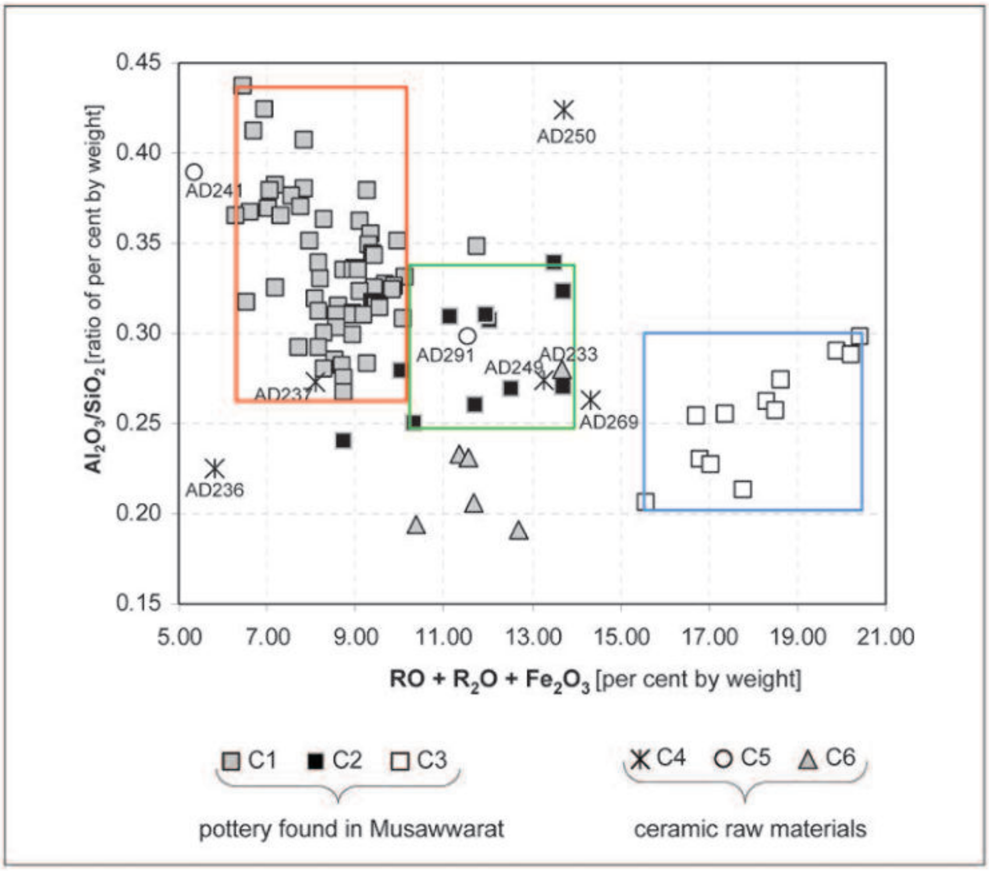


Fig. 27. Biplot showing sum of fluxes (in per cent by weight) versus ratio of Al_2O_3 to SiO_2 (in per cent by weight): RO = MgO + CaO; $R_2O = Na_2O + K_2O$; C1–C7 = see description of figure 23

The biplot shown in figure 28 is used in assessing the technical properties of ceramic materials. It shows the total of fluxes in molar sum versus molar ratio Al_2O_3/SiO_2 (this is known as an Avgustinik diagram). Dashed lines indicate various areas where raw materials with differing technical properties occur. Most of the local pottery and wadi clays correspond to “pottery and terracotta clays”, hafir clays correspond to “clinker clays” and “brick clays”, and pottery made of Nile alluvial clays corresponds to “brick clays”. White-firing iron-poor silty clayey materials and kaolinitic sandstones did not fall within any of these categories because of their low level of fluxes, in this case a low iron content.

Analysis results demonstrate conclusively that pottery classified on the basis of its thermal behaviour and chemical composition as having been made from various Nile alluvial clays was indeed made using clays of this type. None of the raw material samples collected from the vicinity of Musawwarat es-Sufra has a similar chemical composition, thermal behaviour or technical properties (according to Awgustinik). Pottery considered to have been produced at workshops local to Musawwarat es-Sufra is fairly homogeneous in terms of both its chemical composition and thermal behaviour. It was made using wadi clays. Pottery that had hitherto been regarded as “probably local” was made using various locally available raw materials, including both wadi and hafir clays, or materials similar to those sampled from hafir walls.

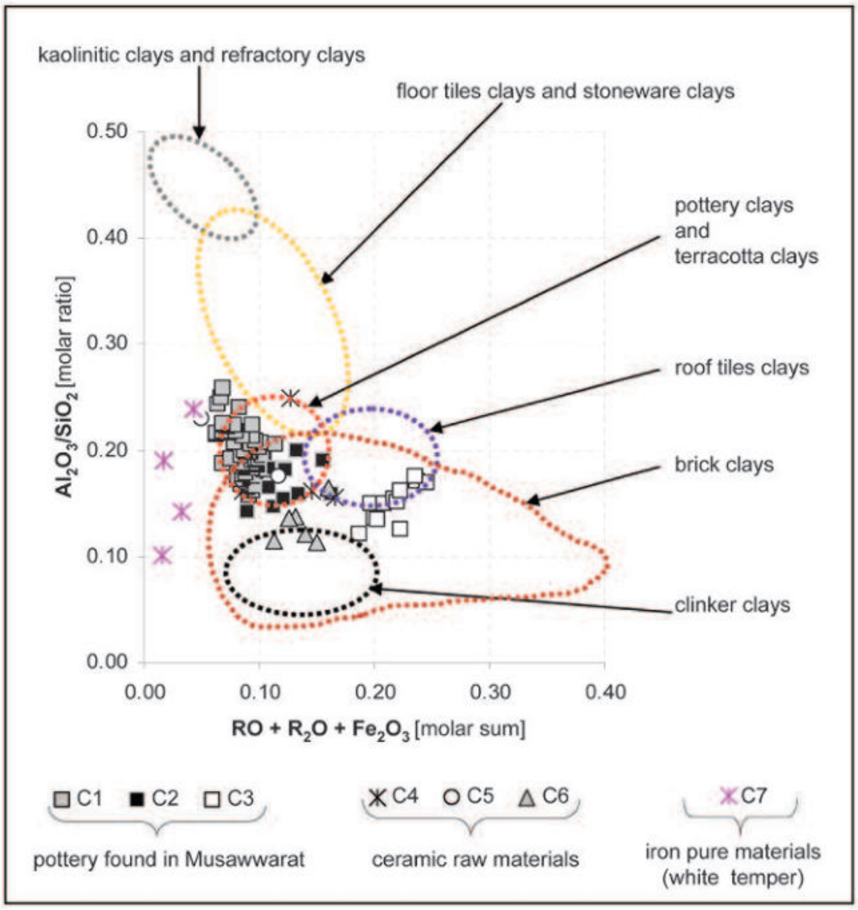


Fig. 28. Biplot showing sum of fluxes (molar sum) versus molar ratio of Al_2O_3 to SiO_2. All local pottery and wadi clays correspond to "pottery clays", deposits from hafirs correspond to "clinker clays" and "brick clays", pottery made from Nile alluvial clays correspond to "brick clays"; C1–C6 = see description of figure 23; C7 = white-firing, iron-poor kaolinitic clayey materials and iron-poor kaolinitic sandstones that may have been used as tempers

Model analysis

Laboratory analysis of pottery recovered from Musawwarat es-Sufra revealed that some of it was made from wadi clays and hafir clays, predominantly tempered with grains of iron-poor, kaolinitic material (white-firing). Organic temper was chiefly found in vessels made from other types of clays, in particular alluvial clays. However, the wadi and hafir clays local to the Musawwarat region do not exhibit significant linear thermal shrinkage. What then was the purpose of adding the white-firing aggregates (grains of kaolinitic sandstone or aggregates of silty kaolinitic clays) visible in Musawwarat fabrics? And what technological reasons were there for tempering pottery with dung? Model analysis was undertaken in search of answers to these questions. This analysis was carried out on briquettes made of wadi clay (AD236),[40] clay from the upper part of a hafir wall (AD291) and Nile alluvial clay sampled from the vicinity of Shendi (AD261) without any intentional temper and tempered with kaolinitic sandstone taken from the foot of Gebel Ma'afer (AD241), as well as with donkey and cow dung collected around Musawwarat es-Sufra [Fig. 29].

[40] After the removal of several grains in gravel fraction.

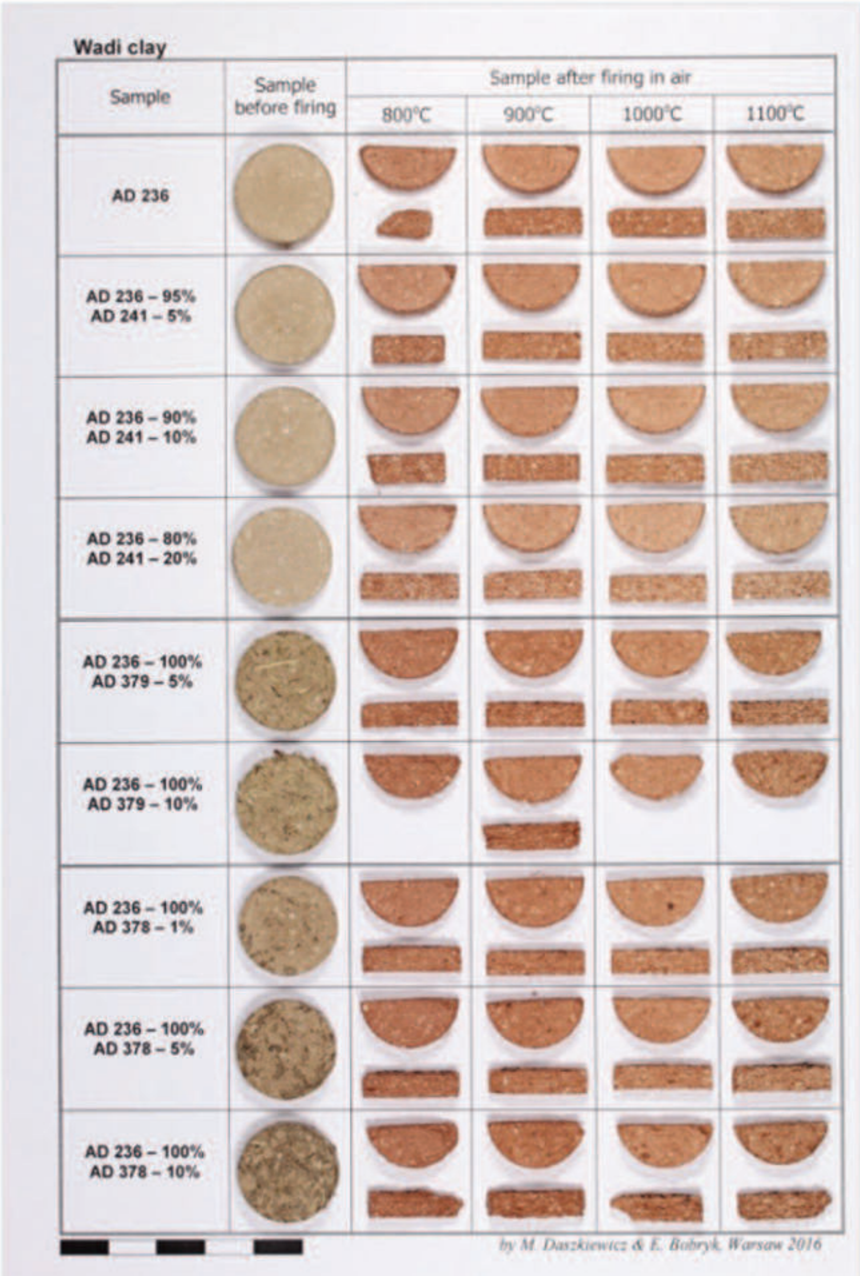


Fig. 29. Briquettes made of wadi clay AD236 tempered with kaolinitic sandstone (AD241), cow dung (AD378) and donkey dung (AD379)

Ethnoceramic studies revealed that all potters using traditional technologies made their pottery from alluvial clays tempered with dried and crushed donkey dung (such temper has no influence on the chemical composition of the sherd, see table 2). When interviewed, these potters confirmed that they only ever used dried donkey dung as a temper, while dried cow dung was only ever used as bonfire fuel. Thus, it was evident that the potters believed that different types of dung have different functional properties. Comparing the fabric of donkey-dung-tempered vessels with sherds of ancient pottery led to some interesting observations. One of them involved a contemporary pot made by a potter in Shendi. The pores of this vessel were identical in appearance to those seen in

Meroitic pottery recovered from the nearby site of Musawwarat es-Sufra. It is usually said that the organic temper used in ancient pottery was either chaff or straw, but perhaps ancient potters also used dung as a tempering material. Its preparation would have been simple, as it only needs to be lightly crushed. This type of organic matter would also have been convenient to use, as it would have already been neatly “chopped up” by the donkey when it chewed its food [Fig. 30]. Whatever the source of the organic temper used in Meroitic pottery found at Musawwarat es--Sufra, what impact this temper had on the properties of the pottery remains an unresolved issue.

Two types of samples were prepared for model analysis:

a) samples with added kaolinite temper

Three selected crumbled clays were used to make ceramic bodies containing 0, 10 and 20% (by weight) kaolinitic sandstone (AD241). Next, a granulated powder for shaping in a uniaxial press was created by adding 7% (by weight) distilled water to each batch, which was then mixed and passed several times through a 0.5 mm gauge nylon sieve. Finally, the samples were formed into disc-shaped briquettes of 20 mm in diameter and ca. 5 mm high in a steel mould at 10 MPa pressure using a hydraulic press.

b) samples with added pore-forming agent

Batches containing a 5% and 10% (by weight) excess addition of dried donkey dung (AD379) and cow dung (AD378), that had earlier been crumbled and fractionated on sieves, were made using three chosen crumbled clays. The 0.5–2 mm fraction selected is the same as that used by a contemporary potter in Shendi. The samples were shaped as described above.

After they had been dried in a laboratory drier, all of the samples were fired in a Carbolite resistance furnace at 800, 900, 1000 and 1100^{o}C, being kept at the peak temperature for 1 hour at a temperature progression of 200^{o}C/h, and then being cooled with the furnace.

Fig. 30. Dried and crushed donkey dung; sample collected from a potter in Shendi (photo M. Baranowski)

Once this process had been completed, the properties of the fired samples were gauged. The apparent density, open porosity and water absorption of the fired samples was determined by hydrostatic weighing. Permeability over time was also assessed (during each measurement the amount of water penetrating the sample was noted after 1, 3, 6, 10, 20, 30, 50, 100, 200, 300, 400 and 1440 minutes), and tensile strength (in [kPa]) was calculated using the Brazilian test as per the following formula: $\sigma = 2F / \Pi Dh$ (where: F = destructive force in [N], D = diameter in [m], h = sample height in [m]. A firing test was also carried out.

Measurement of tensile strength (using the Brazilian test) revealed that, as expected, the mechanical properties of samples without any intentional temper steadily improved as the firing temperature increased. The greatest tensile strength at all temperatures was exhibited by samples made of Nile alluvial clay, and the weakest by those made of wadi clay [Fig. 31]. The addition of temper to Nile alluvial clay increased the tensile strength of the briquettes, but only when fired at 800^{o}C was this increase significant. A 10wt% addition of kaolinitic sandstone had the same effect as a 5wt% addition of donkey dung, the best effect being obtained by a 5% addition of cow dung [Fig. 32].

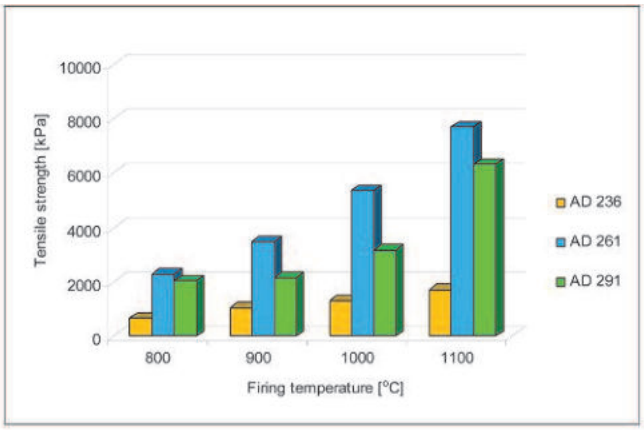


Fig. 31. Tensile strength of briquettes made of wadi clay (AD236),
Nile alluvial clay (AD261), clay used by a local potter and clay
from the upper layer of the Great Hafir in Musawwarat es-Sufra (AD291)
fired at various temperatures (average values of tensile strength, cv<15%)

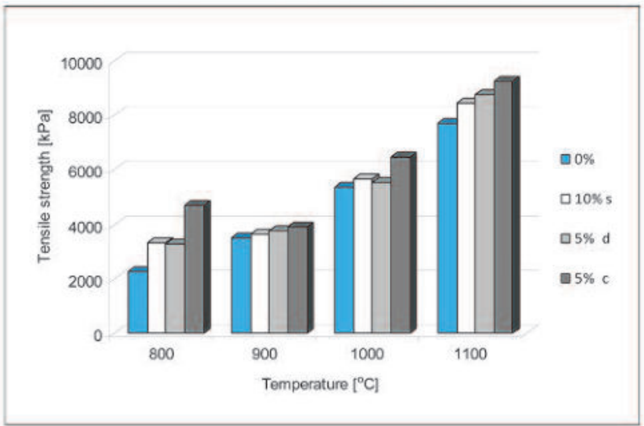


Fig. 32. Tensile strength of briquettes made of Nile alluvial clay (AD261)
tempered with either kaolinitic sandstone, donkey dung or cow dung
fired at various temperatures (average values of tensile strength, cv<15%)

The same tempers added to the ceramic body made of wadi clay had a slightly different effect on the mechanical properties of the fired briquettes. Depending on the firing temperature, greater tensile strength was achieved by adding kaolinitic sandstone or cow dung. Tempering with donkey dung reduced tensile strength regardless of the firing temperature [Fig. 33]. The amount of temper added was also significant. Figure 34 shows the tensile strength values (in MPa) for briquettes made of wadi clay fired at various temperatures with different percentages of added temper. A 5% addition of kaolinitic sandstone had a better effect than a 10wt% addition, except when samples were fired at 1000°C, when the effect was negligible. In the case of both donkey and cow dung there was a distinct reduction in tensile strength after a 10wt% addition[41] of these tempers as opposed to a 5wt% addition [Fig. 34]. This analysis demonstrates that pottery made of wadi clay has the best mechanical properties when tempered with a 5% addition of kaolinitic sandstone and fired at 1100°C. It is interesting that this ceramic material has the same mechanical properties as pottery made of Nile alluvial clay tempered with donkey dung (or kaolinitic sandstone) fired at 800°C.

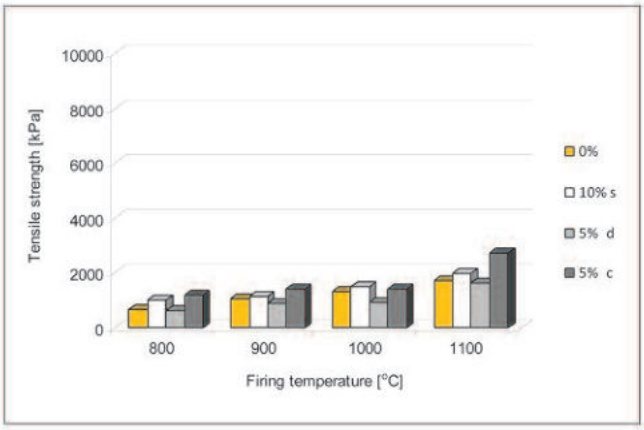


Fig. 33. Tensile strength of briquettes made of wadi clay (AD236) tempered with either kaolinitic sandstone, donkey dung or cow dung fired at various temperatures (average values of tensile strength, cv<15%)

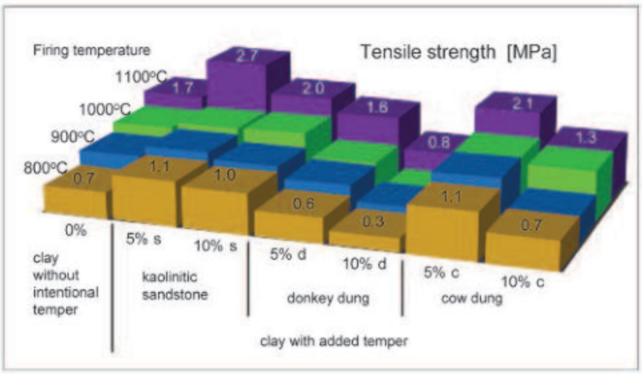


Fig. 34. Tensile strength of briquettes made of wadi clay (AD236) tempered respectively with 5 and 10 weight per cent kaolinitic sandstone, donkey dung or cow dung fired at various temperatures (average values of tensile strength, cv<15%)

[41] Excess addition.

The results of analyses aimed at estimating the original firing temperature of Meroitic pottery found at Musawwarat es-Sufra indicate that it was relatively high-fired. X-ray diffraction analysis revealed the presence of mullite in local wheel-made coarse wares (reference group Mus 4) and both mullite and cristobalite in several samples (e.g. AD093 [Fig. 35]). Fine wares were originally fired at lower temperatures. Inferences about original firing temperatures drawn from the presence of mullite[42] and cristobalite[43] were confirmed by K-H analysis.[44] The curves shown in figure 36a indicate that sample AD093 was originally fired at around 1150°C[45] and sample MD881 at around 950°C [Fig. 36b].

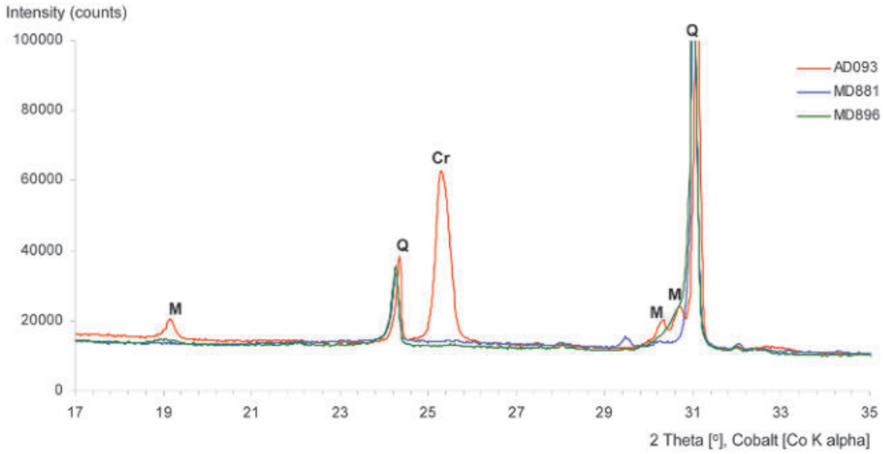


Fig. 35. Diffractograms of X-ray powder diffraction analysis carried out on fragments of local pottery from Musawwarat es-Sufra: M = mullite, Cr = crystoballite, Q = quartz

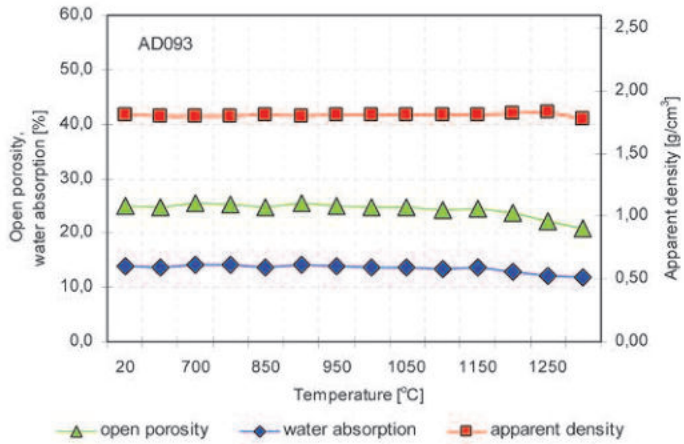


Fig. 36a. Pottery fragment of local Musawwarat wheel-made coarse ware.
Open porosity, water absorption and apparent density values were estimated at room temperature and after refiring. Original firing temperature Teq = ca. 1150°C

[42] Natural mullite is rare in nature; nevertheless, it is a common compound in high-fired ceramic products as this mineral is part of their final phase composition since they are made from aluminium silicate materials. Mullite forms at ca. 1000°C (or higher) depending on the composition of ceramic bodies.

[43] Polymorph of silica forming at high temperature.

[44] For a description of K-H analysis, see Daszkiewicz 2014.

[45] A high firing temperature (1000–1050°C) was detected for Meroitic pottery found in the Fourth Cataract region, among fine wares imported from specialised high-tech workshops (see Daszkiewicz *et alii* 2003). An initial study of firing temperatures for pottery found in Musawwarat-es Sufra did not reveal such high values (Daszkiewicz, Schneider 2001).

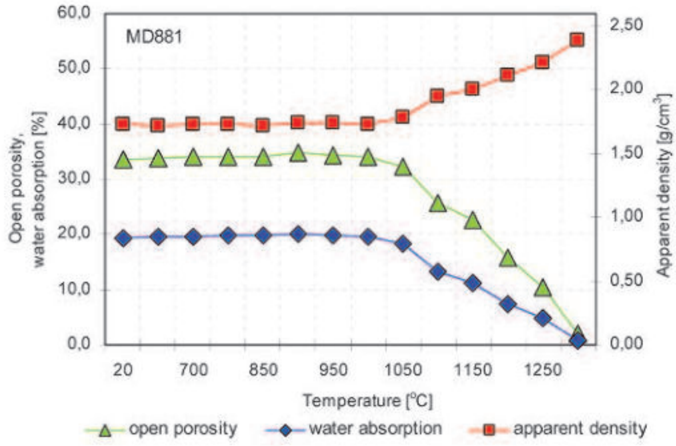


Fig. 36b. Pottery fragment of local Musawwarat wheel-made fine ware.
Open porosity, water absorption and apparent density values were estimated at room temperature and after refiring. Original firing temperature Teq = ca. 950°C

Analysis of functional properties, in this instance water permeability, revealed that the briquettes are permeable regardless of the type of clay and temper used and the temperature at which they were fired. To make a vessel impermeable, its surface must be either slipped or polished, as was the case with Meroitic pottery from Musawwarat es-Sufra [Figs. 37 and 38].

Fig. 37. Slip-coated pottery made at Musawwarat es-Sufra (photo M. Wetendorf)

Fig. 38. Pottery made at Musawwarat es-Sufra coated with a thin layer of slip (photo M. Wetendorf)

Conclusions

1. Ceramic raw materials, the chemical composition and thermal behaviour of which is the same as that of Meroitic pottery found at Musawwarat es-Sufra, are available within the vicinity of this site.
2. Pottery sherds attributable to reference groups Mus 1–4 were made of various local wadi clays (geological horizons Kf and Kst, see Fig. 1).
3. Pottery classified as "probably local" was made of both wadi clays and hafir clays available in the surrounding area (geological horizon Kf, see Fig. 1).
4. In four instances it was possible to verify the provenance of pottery imports found at Musawwarat es-Sufra by comparing them with a database containing samples of ceramics and raw materials collected from various places in Sudan between the Sixth and First Cataracts [Fig. 39]. Two of the Musawwarat samples were made of Nile alluvial clay sourced from the vicinity of es-Zuma; the same clay was also used to make one of the groups of local pottery. One sample belongs to the same reference group (group A2) as local pottery at Hamadab. The fourth sample belongs to the same reference group (group O2) as pottery found at Muweis and Hamadab.
5. The white-firing temper could have been either crushed kaolinitic sandstone or whitish-firing kaolinitic clayey materials from wadis and hafirs. It should be noted, however, that not all locally available kaolinitic sandstone can be taken into consideration as a temper for Meroitic pottery.
6. Model analyses revealed that the mechanical properties of ceramics made from wadi clays improve when tempered with kaolinitic raw materials and when fired at high temperatures (ca. 1100°C). The same is true of pottery made from Nile alluvial clays tempered with dung after firing at lower temperatures (700–800°C). The addition of dung (in particular cow dung) increases the tensile strength of pottery made from hafir clays. This means that pottery made from wadi clay should be fired at higher temperatures than pottery made from alluvial and hafir clays.
7. In order to make vessels impermeable, their surfaces had to be treated (e.g. coated with slip or burnished).
8. The use of cow dung for firing and donkey dung as temper, observed in ethnoceramic studies, is primarily associated with their respective fuel properties.
9. Model analyses demonstrated that the use of tempers represented by whitish-firing aggregates in Musawwarat fabrics made of wadi clays is technologically justified, as it increases the mechanical strength of the pottery.
10. The amount of temper used affects the properties of the pottery. The optimum is to add no more than 5wt% dung or a maximum of 10wt% kaolinitic sandstone.
11. Tempers represented by donkey and cow dung added to a ceramic body have no influence on the chemical composition of a sherd; white kaolinitic sandstone temper results in higher contents of alumina and silica.
12. The results of analysis carried out on Meroitic pottery found at Musawwarat es-Sufra confirm the use of higher temperatures for firing vessels made of wadi clays, with vessels made of alluvial clays being fired at the lowest temperatures. They also confirm the application of surface treatments, such as burnishing and slipping. These analysis results are entirely consistent with the findings of model tests.

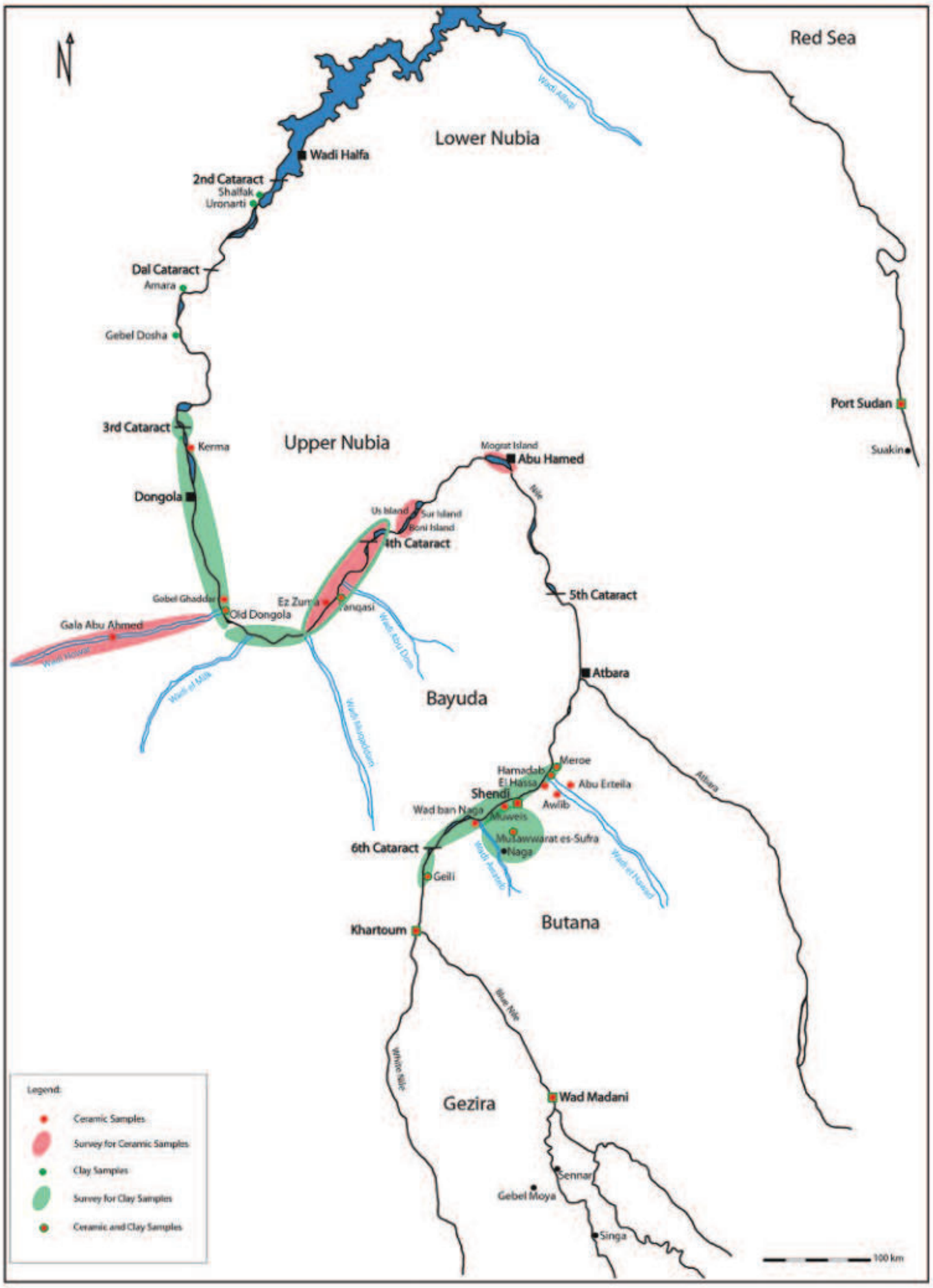


Fig. 39. Locations from which raw material samples were taken in 2008, 2014 and 2017 and sites from where pottery have been analysed in 1997–2017.
Map, with amendments made by the authors (map created by M. Wetendorf)

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Streszczenie

Musawwarat es-Sufra — w poszukiwaniu surowców ceramicznych

Analizy meroickiej ceramiki znalezionej na terenie Musawwarat es-Sufra wykazały, że została ona wykonana z różnych tzw. *wadi* glin, z glin z hafirów oraz nilowych glin aluwialnych. Gdzie mogły znajdować się źródła surowca do wyrobu tej ceramiki? Biorąc pod uwagę wszystkie dostępne opracowania oraz niepublikowane wyniki analiz ceramiki i analiz surowców (autorzy analiz: M. Daszkiewicz, E. Bobryk, G. Schneider) z terenu pomiędzy Chartumem a III kataraktą nilową, przyjęto, że nowe badania powinny objąć: a) badania terenowe w bezpośrednim otoczeniu Musawwarat es-Sufra, mające na celu pobranie próbek surowców z różnych *wadi* (poszukiwanie surowców ceramicznych użytych do wyrobu ceramiki lokalnej, tzn. ceramiki należącej do grup referencyjnych Mus 1–5); b) badania terenowe w dolinie Nilu, mające na celu pobranie próbek glin aluwialnych w różnych miejscach biegu rzeki (poszukiwanie surowców ceramicznych użytych do wyrobu ceramiki należącej do grupy Clay Type A — czyli ceramiki wykonanej z aluwialnych glin nilowych); c) badania terenowe w bezpośrednim i dalszym otoczeniu Musawwarat es-Sufra, mające na celu znalezienie surowców, z których mogłyby być wykonane próbki określone jako „prawdopodobnie lokalne” (w większości są to naczynia robione ręcznie, wykonane z różnych surowców z niższą zawartością tlenku glinu oraz wyższą zawartością topników niż próbki należące do grup Mus 1–5). Ponadto zaplanowane zostały badania materiałów opałowych (drewna, łajna), badania etnoceramologiczne oraz badania modelowe. Pierwszy etap prac terenowych został zakończony, wykonana została również część zaplanowanych analiz oraz badań modelowych. W trakcie prac terenowych przeprowadzonych w listopadzie 2014 roku (M. Daszkiewicz, M. Wetendorf, G. Schneider) pobrano łącznie 64 próbki uznane w terenie za ewentualne surowce ceramiczne. Ponadto pobrano surowce opałowe (drewno z okolicznych drzew i łajno krowie) oraz łajno osła będące po dzień dzisiejszy powszechnie używaną domieszką. W niniejszym artykule przedstawione są wyniki analiz 23 surowców pobranych w bezpośrednim sąsiedztwie Musawwarat es-Sufra oraz wyniki analiz czterech surowców pobranych wzdłuż drogi biegnącej z Naga do szosy asfaltowej równolegle do Wadi Awateb.

Z przeprowadzonych analiz pobranych surowców oraz z badań modelowych wynikają następujące wnioski:

- W okolicy Musawwarat es-Sufra dostępne są surowce ceramiczne mające skład chemiczny oraz zachowanie termiczne takie jak meroicka ceramika znaleziona na tym stanowisku.
- Fragmenty ceramiki należące do grup referencyjnych Mus 1–4 zostały wykonane z różnych lokalnych glin z *wadi*.

- Wyroby ceramiczne należące do grupy „prawdopodobnie lokalnych" zostały wykonane z dostępnych w okolicy zarówno glin z *wadi*, jak i glin z hafirów.
- Naczynia ceramiczne wykonane z różnych nilowych glin aluwialnych są importami na stanowisku, gliny aluwialne pobrane na wysokości El-Geili, Wad Ban Naga i Shendi nie były surowcami do wyrobu tej ceramiki.
- Rolę biało wypalającej się domieszki mogły pełnić zarówno pokruszony piaskowiec ze spoiwem kaolinitowym, jak i biało wypalające się gliny kaolinitowe z *wadi* i z hafirów. Należy jednak podkreślić, że nie wszystkie dostępne w okolicy piaskowce ze spoiwem kaolinitowym mogą być brane pod uwagę jako domieszka do meroickiej ceramiki.
- Badania modelowe wykazały, że właściwości mechaniczne ceramiki wykonanej z glin z wadi poprawiają się po dodaniu do masy ceramicznej domieszki surowców kaolinitowych i wypaleniu jej w wysokich temperaturach (ok. 1100^{o}C) . Takie same parametry mają wyroby ceramiczne wykonane z glin aluwialnych z dodatkiem pokruszonego wysuszonego łajna osła i po wypaleniu w niskich temperaturach (700–800^{o}C). Domieszka łajna (szczególnie łajna krowiego) zwiększa wytrzymałość mechaniczną wyrobów wykonanych z glin z hafirów. Oznacza to, że ceramika wykonana z glin z *wadi* powinna być wypalana w dużo wyższych temperaturach niż ceramika wykonana z glin aluwialnych oraz glin z hafirów.
- Celem otrzymania naczyń nieprzesiąkliwych konieczne jest wykonanie obróbki powierzchni (np. pokrycie slipem czy polerowanie).
- Wyniki analiz meroickiej ceramiki znalezionej w Musawwarat es-Sufra są w pełnej zgodności z wynikami badań modelowych.

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