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Technological variability in foragers' pottery productions at the early-mid Holocene site of Sphinx, western part of Jebel Sabaloka, Sudan

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Abstract

The site of Sphinx (SBK.W-60) is located about 3.5 km from the present Nile in the western part of Jebel Sabaloka, upstream of the Sixth Nile Cataract, in Sudan. This site uniquely includes Early Khartoum (Mesolithic) artifacts with no intrusive elements and has been dated from the ninth to the end of the sixth millennium cal BC. Excavations at Trench 7, in particular, brought to light a 1.2-m thick deposit with the quantitatively and qualitatively richest artifactual materials. Analysis and classification of the pottery assemblage from this site have been conducted with the aim of observing manufacturing techniques from a broad perspective correlating pottery production to cultural change and chronological variability. Analyses of the ceramic assemblage regarded visual examinations of the manufacturing techniques combined with petrographic (optical microscopy, OM) and chemical analyses (instrumental Neutron Activation Analysis, iNAA), observations of manufacturing and decorative techniques, and gas chromatography-mass spectrometry (GC-MS) and gas chromatography-combustion-isotope ratio mass spectrometry (GC-C-IRMS) on absorbed organic residues. The vertical distribution of the ceramic assemblage reveals consistent technological variability through the timespan of occupation of the site.

Keywords
Pottery production, technological variability, Jebel Sabaloka, Sudan, Early Khartoum culture, Mesolithic

1. The research area, site of Sphinx and Trench 7

The Early Khartoum culture (or Khartoum Mesolithic; Arkell, 1949), dated from the ninth to the end of the sixth millennium cal BC, constitutes the typical early to mid-Holocene archaeological unit of central Sudan, extending from south of Khartoum along the Nile down to the junction of the Nile with the Atbara River. Within this province, Jebel Sabaloka, a small volcanic mountain situated near the Sixth Nile Cataract ca. 80 km north of Khartoum, has a significant potential for studying Early Khartoum hunter-gatherers. Archaeological exploration launched in this region in 2009 by the Charles University Sabaloka Expedition recorded 30 Early Khartoum sites in the western part of the mountain (Fig. 1; Suková and Varadzin, 2012; Suková et al., 2014) and

established that this area was occupied by hunter-gatherers whose cultural remains attest to low residential mobility, high occupational density, and long-term occupation of at least some of the localities. Burials indicate the presence of large cemeteries (Suková and Varadzin, 2012; Varadzinová and Varadzin, 2017) and other burial grounds of unknown scale (Varadzinová et al., 2019). The density of settlements reasonably imply intensive exploitation of resources. Faunal data suggest year-round and scheduled exploitation of animal and fish/mollusc protein sources (Sůvová 2017). Numerous bedrock grinding features and portable grinding stones found in the context of Early Khartoum settlements attest to intensive grinding activities in Jebel Sabaloka.

The site of Sphinx (SBK.W-60), located at the western edge of the mountain some 3.5 km from the Nile River, is of particular significance (Fig. 2). It occupies the top of a hill formed of granite rocks and boulders that encircle the elevated settlement platform (940 m^2) and divide it naturally into three parts of more or less equal size (southern, central and northern) and two narrow zones called "shelters" (Fig. 3). Eleven trenches were excavated between 2011 and 2019 (48.7 m^2 in total) and all the finds indicate intensive occupation of the site solely by Early Khartoum hunter-gatherers who used the platform as a settlement and, for a certain period, also as a burial ground (Varadzinová and Varadzin, 2017). Unlike many other Early Khartoum locations in central Sudan, the site of Sphinx appears to have escaped the intense transformations caused by settlement or burial activities during Neolithic or historical periods and to have preserved an intact Early Khartoum anthropic deposit, which, in some parts of the settlement, reached over 1 m below the present ground (Varadzinová Suková et al., 2015). Fifteen AMS 14C dates from Trenches 1, 2, 5 and 6 published so far attest to nearly continuous occupation of the site from 8200 to 5000 cal BC (Varadzinová and Varadzin, 2017), and a series of other, so far unpublished dates from Trenches 2, 5, 6, 7 and 10 complete the sequence and push the beginnings of occupation of the site back to the first half of the ninth millennium cal BC (Varadzinová et al., forthcoming).

Of the eleven trenches excavated at the site, Trench 7 (3×3 m, maximum depth 1.2 m) in the southern part of the settlement (Fig. 2) contained the thickest deposits and, at the same time, the least disturbed by more or less contemporary burials. The surface of this trench was formed of a ca. 5-cm-thick layer comprising coarse fraction with abundant finds of lithics accumulated in consequence of deflation (stratigraphic unit 1, SU1). Beneath this layer, there was a light grey-brown to brown-grey deposit 1.13 m in thickness which consisted of a mixture of small clasts of weathered granite (50–70%) and silt which, near the bottom, changed into lightly silty granite eluvium or lay directly on the granite bedrock (SU2). This grey deposit appeared largely homogenous and did not feature any unequivocally distinguishable stratigraphic units, possibly as a consequence of bioturbation and secondary mobilization of chemical elements (*cf.* Varadzinová Suková et al., 2015). Because of secondarily precipitated carbonates, the deposit was lighter in colour in its lower part and harder as one approached the bottom of the trench.

Trench 7 was divided into nine sectors A–I (each 1×1 m) and excavated in altogether 16 artificial cuts down to the bottom of the trench, while respecting any contingent stratigraphic interfaces. Each of these cuts, designated as "mechanical units" (MU1–MU16), measured 3–11.7 cm in thickness (mean 3.7 cm) within an apparently continuous level through the entire trench. All the excavated sediment was dry-sieved on a 4-mm mesh and all finds, including pottery, above this size were collected for analyses.

The thickness of the individual MUs and the quantity of finds collected from these units differed. In order to facilitate basic quantitative comparisons of the finds across the grey deposit, we expressed the quantity of finds from each MU in the form of volumetric densities (number of finds from each MU per unit of volume); this calculation was not performed for the lowermost MU16, for which the volumetric density could not be established due to unevenness of the bottom of the trench (this MU contained the smallest number of ceramic finds – 14 sherds, 0.29%). It turned

out that, regardless of the thickness of the artificial cuts, the density of ceramic finds in the different levels is quite variable, with the largest number of finds in MU2 (2327 sherds/m^3) and the smallest in MU15 (87 sherds/m^3) (Fig. 4). The volumetric densities varying throughout the grey deposit indicate changes in depositional and post-depositional evolution. Because these changes are evidently horizontal in character (*cf.* Fig. 4), we suppose that they may signal existence of diverse layers which we were unable to identify in the field.

The existence of broadly undisturbed stratigraphic layers in this trench is suggested by the distribution of other representative classes of artifacts, most distinctly the remains of production of ostrich eggshell beads in the form of unworked fragments and unfinished beads in different stages of production, which only occur in MU10-MU16 and have been dated to the ninth millennium cal BC (MU13 and MU14; unpublished data). As far as the deposits in the other trenches are concerned, their character is in principle identical to the deposit in Trench 7. Nevertheless, the degree of natural post-depositional processes in these other trenches was usually greater (they were the most marked in Trench 5; Varadzinová Suková et al., 2015). Also, settlement deposits in the trenches in the southern part of the site and in the northern shelter (Fig. 3: Trenches 2, 5, 6, and 9) were disturbed by burying more significantly as compared with Trench 7.

This text is a pilot study in which analysis of pottery from SU1 and the individual MUs within SU2 in Trench 7 forms the basis for (1) independent verification of the hypothesis of the presence (impossible to identify using the usual field documentation) of stratigraphic deposits, and, combined with samples from other trenches excavated in 2014 and 2015, for (2) capturing the main trends in the development of local pottery production and use.

2. The ceramic assemblage from Sphinx

Analysis and classification of the ceramic assemblage were conducted with the aim of observing manufacturing techniques from a broad perspective. Various analytical methods have been used for this purpose: visual examinations of the manufacturing techniques have been combined with petrographic (optical microscopy, OM) and chemical analyses (instrumental Neutron Activation Analysis, iNAA), as well as gas chromatography-mass spectrometry (GC-MS) and gas chromatography-combustion-isotope ratio mass spectrometry (GC-C-IRMS) on absorbed organic residues.

Following some preliminary information (Garcea, 2017), this paper provides the first results of the study of the ceramic material from Trenches 5–8 and 10 (Fig. 3) excavated in 2014 and 2015 (Varadzinová and Varadzin, 2017). Trench 7 yielded the highest quantity of pottery from Sphinx (5511 sherds, or 67.7% of the total pottery). While analysis of decorative techniques presented in this paper is only focused on the assemblage from this trench, which constitutes 60–71.6% of the analytical samples, petrographic, chemical and organic residue analyses concerned quantitatively smaller samples, but from all the trenches mentioned above. .

The assemblage from Trench 7 exhibits different preservation conditions throughout the different levels, confirming the long chronology of this site, which suggests either a long occupation or repetitive occupations of the same spot. Occasionally the sherds show manganese and calcium carbonate stains and/or a silty-clayey patina, attesting to post-depositional events. However, in spite of the natural events that affected the visibility of the stratified deposit, several sherds join together, indicating that they were not substantially moved from their primary position and no damaging trampling or other severe mechanical disturbances occurred at the site (see also Varadzinová Suková et al., 2015).

3. Petrographic composition

A first batch of 20 ceramic samples was selected for optical microscopy (OM) and was later submitted for instrumental Neutron Activation Analysis (iNAA). The samples were chosen from different stratigraphic and mechanical units in order to represent the chronological variability of the archaeological deposit. The sampling strategy was based on the macroscopic classification of the assemblage, taking into account the full range of textural (i.e., pastes, macroscopic fabrics) and stylistic categories (i.e., decoration techniques and motifs; Table 1). They were prepared at the Institute of Geology of the Czech Academy of Sciences in Prague as standard thin sections at a thickness of 30 microns. Petrographic observations were performed with a Zeiss Axio Lab.A1 polarized light microscope at the laboratories of the Department of Earth and Environmental Sciences - Section for Mineralogy, Petrology and Geochemistry of the Ludwig-Maximilians-Universität München (LMU). Their description considered non-plastic inclusions (NPIs), matrix and porosity. Abundance of NPIs and macro-porosity was visually estimated using comparison charts (see www.usgeosupply.com/reference-charts/328-grain-size-card-translucent.html).

Overall, the samples present a non-calcareous clay matrix, containing abundant mica and iron oxides. The matrix is mostly optically active with lighter and darker areas, which correspond to clay domains at different stages of extinction. A high degree of birefringence of the clay minerals indicates firing temperatures up to approx. 850°C. Porosity is generally very low with voids making up from about 1 to 10% of the assemblage.

The framework is dominated by silicate minerals of quartz and feldspar (mainly alkali feldspar) together with biotite, amphibole (traces) and white mica. Some samples also contain large plutonic rock fragments (PRF), such as granite, whereas some others possibly incorporate pieces of porphyritic rhyolite (Fig. 5, fabric 2). The inclusions of alkali feldspar are commonly angular to sub-angular in shape and frequently exhibit a perthitic texture (microperthitic microcline). Micrographic or granophyric textures are also characteristic. Furthermore, most feldspars display significant degrees of weathering in the form of sericitization, epidotization and accumulation of clay minerals.

The size distribution of non-plastic inclusions appears to be generally poorly to very poorly sorted and most samples present a seriate, inequigranular texture. Differences in firing atmosphere and in the size and proportion of the mineral phases of Group 1 (K-feldspar and quartz-rich samples) allowed the differentiation of four different sub-groups that are very similar in terms of composition, but represent different granulometric classes, ranging from the finest in Group 1a, to the coarsest in Groups 1c and 1d (Fig. 5). The samples in Group 2 (K-feldspar and quartz-rich samples + microcrystalline aggregates/rhyolite?), Group 4 (K-feldspar and quartz-rich samples + Plutonic Rock Fragments (PRF)) and Group 5 (quartz-rich samples) have a bimodal texture. Finally, Group 3 is made up of only one sample that shows specific features and therefore is provisionally considered as a *unicum*.

Overall, the textural data suggest that the clay and tempers used as raw materials for making these ceramics originated locally as mixed weathering products from the igneous Sabaloka Complex. This complex mainly consists of granitic and granitoid rocks crossed by aplitic/pegmatitic veins, which explain the micrographic structures observed in some specimens. This raw material was possibly seasonally mobilized by rainwater and collected in different parts of the wadis, which also incorporated coarser silts and sands, resulting in a naturally mixed clayey deposit and containing additional quantities of angular grains of feldspar, granitoid rocks and occasionally rhyolite fragments from local outcrops, in diverse proportions and grain sizes (J.-P. McCool, personal communication).

A preliminary interpretation of the provenance of the rounded quartz grains of the samples in Group 5, which are quartz-rich with no elements from the igneous Sabaloka uplands, might be explored in the wadis that drain areas to the west underlain by the Nubian Sandstone Formation.

Interestingly, the pottery in this group comes from the low levels (MU13 and MU15) of the sequence of Trench 7 and provides hints of a different manufacturing technique or raw material exploitation strategy at the very beginning of pottery production within the Early Khartoum period (see below). Conversely, the samples in Group 4 come from a later phase of the Early Khartoum occupation of the site.

4. Chemical composition

A total of 116 sherds were sampled and analyzed by instrumental Neutron Activation Analysis at the TRIGA MK II research reactor at the Atominstitut of the Technische Universität Wien, in Austria. Sampling was performed by breaking off pieces of approximately 5x5 mm and subsequent homogenization in an agate mortar. 120 mg of sample material were weighed into Suprasilglass vials and irradiated for 35 hours in the reactor at a neutron flux density of $1 \cdot 10^{13}$ cm^{-2}s^{-1}. Two measurements after decay times of 5 and 30 days, respectively, yielded the elemental concentrations of Na, K, Sc, Cr, Fe, Co, Ni, Zn, As, Rb, Sr, Zr, Sb, Cs, Ba, La, Ce, Nd, Sm, Eu, Tb, Yb, Lu, Hf, Ta, W, Th, and U (see Sterba, 2018 for further details on the experimental setup, including limits of detection).

Statistical analysis of the resulting data was performed by applying a filtering algorithm based on the best relative fit factor and a modified Mahalanobis distance measure, as developed in Bonn and specifically intended for ancient ceramic assemblages (Mommsen et al., 1988; Beier and Mommsen, 1994; Mommsen and Sjöberg, 2007a). The initial application of this procedure resulted in four groups of two or three samples each. All other samples appeared to be chemical loners. In contexts characterized by large and standardized productions, which do not occur in Early Khartoum contexts, this picture would theoretically indicate ceramics manufactured in different regions (i.e., with different geographical provenances). However, in the specific archaeological context of the site, the exceptionally ancient chronology of the assemblage coupled with its overall basic technological features rather suggests the presence of a specific production system.

With this proposition in mind, it was possible to consider a much larger "natural" spread of the chemical composition of the individual samples in order to allow much larger distances for the initial grouping. The subsequent application of the statistical filter produced a single large group of 54 samples. Further, a second, smaller (8 samples) and very similar group was found. All remaining samples were loners. To further support this supposition, Figs. 6 and 7 show the distribution of the Mahalanobis distances between each sample before (Fig. 6) and after grouping, in comparison to a χ^2 distribution, which is the expected distribution of the distances. In Fig. 6 the calculated distribution falls far to the right of the expected distribution. This indicates, as proposed above, that the natural spread or differences between individual samples are much larger than expected. The bimodality of the distribution also indicates that at least one group is present in the dataset. In Fig. 7 the calculated distribution of the samples within the groups are now to the left of the expected distribution, indicating that, indeed, valid groups have been formed. The sharpness of the distribution, as well as the position far to the left of the expected χ^2 distribution, emphasizes the importance of applying the best relative fit factor for iterative grouping.

The Principal Component Analysis (PCA) of the corrected data (Fig. 8) confirms the picture illustrated above and shows that the two groups (respectively with dots and triangles on the plot) are fairly close to each other and all other samples ("Singles", with squares) are distributed with large distances between individual specimens.

All in all, the picture reflected by the analysis of this first batch of samples points to neither singular (nor multiple), wellnarrowed and defined compositional groups but rather to the existence of an apparently largely spread heterogeneous group. A preliminary interpretation for

these results would suggest that the composition of these ancient ceramic pastes somehow mirrors the chemical fingerprint of the local geological environment. In other words, their overall composition would correspond to the natural variability of the local clay sources and tempers in an effective range from the habitation site. Thus, the basis of the local pottery system could be searched in an opportunistic "gradient" along available natural resources, resulting in a ceramic product fairly homogeneous in terms of its general composition, but at the same time unevenly differentiable according to punctual chemical signals (large spread within the group and significant number of chemical loners). Although we can assume that the gradient was rather static in geomorphological term, the exploitation of sources possibly changed during time following the successive potters' generations and their knowledge of the landscape, as well as of their technological expertise.

5. Vertical distribution of the ceramic assemblage in Trench 7
Vertical distribution took into consideration the entire assemblage from Trench 7 (5511 potsherds) consisting of classifiable (decorated and undecorated) and unclassifiable specimens (Fig. 9a). The former was classified according to shaping and techniques of surface decorations. The frequency of unclassifiable pottery (2672 sherds, 48.5%) remains rather stable throughout the deposit (Fig. 9b) and therefore excludes higher damage or worse preservation conditions in the earlier levels.

With regard to shaping, the size of the sherds is too small in order to distinguish vessel forms apart from generally globular shapes. Wall thicknesses of the vessels did not vary through time from the lower to the upper deposits (Fig. 10). In all levels, their major frequencies span between 6 and 10 mm, indicating a constant production of thick vessels.

Undecorated pottery is generally uncommon (238 sherds, 4.3%), but its distribution is vertically and chronologically significant: it is almost entirely represented in the upper levels, dropping below MU3 and vanishing below MU8 (Fig. 11). By contrast, surface treatments with impressed and incised motifs were common practices since the earliest pottery production, making up 47.2% (2601 sherds) of the assemblage. Observations of surface decorations considered decorative techniques and motifs according to a classification system widely applied to Saharan and Sudanese pottery assemblages produced by late hunter-gatherers and early pastoralists (Caneva, 1987, 1988; Caneva and Marks, 1990; Garcea, 1998, 2001, 2005, 2006a, 2006b, 2008, 2013; Garcea and Hildebrand, 2009; D'Ercole, 2017; D'Ercole et al., 2017a, b).

Decorations are made according to five different techniques: rocker, alternately pivoting stamp, simple impression, roulette, and incision, but rocker largely predominates with 87.9% (2287 sherds). Early Khartoum potters employed the rocker technique all the time (Fig. 12), but did not always make the same motifs. Dotted wavy lines (Fig. 13.1-3) are common in the upper levels, particularly in SU1 and in MU1-MU5 of SU2, and disappear below MU11 (Fig. 14). By contrast, in the lower levels, decorations made with the rocker technique are usually made with combs with serrated edges producing packed zigzags (Fig. 13.4-5), spaced zigzags (Fig. 13.6), or zigzags with spaced dots (Fig. 13.7). Occasionally, rocker decorations can also be made with plain combs (Fig. 13.8).

Incision is the second most common technique, although it only occurs with 4.7% (123 sherds). Even if it is absent in the lowermost levels (MU14-MU16), it was in use since the early occupation of the site and became significant beginning with MU5 (Fig. 15). However, differences exist: the earliest incised decorations only consist of motifs with single and parallel lines (Fig. 16.1-2), but no wavy lines (Fig. 16.3-4), which only appear in MU10 and above and stand out between MU4 and MU2 (Fig. 17).

Simple impressions (Fig. 18) are almost equally represented as incisions (119 sherds, 4.6%), but their vertical distribution is reversed compared to the other techniques (Fig. 19). They were

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made since the lowermost level and considerably increase in the subsequent lower levels, whereas they drastically decrease above MU10, becoming negligible above MU4.

The alternative pivoting stamp (Fig. 20) is the fourth technique (62 sherds, 2.4%). Considering its paucity, it did not really typify the ceramic assemblage from Trench 7, until the upper levels, MU4 and especially MU3, showing that it was a late technological acquisition (Fig. 21).

The fifth and last technique is roulette (Fig. 22), which is rare (10 sherds, 0.4%), but is present at the site. It is another lately introduced technique and is totally lacking below MU7 (Fig. 23). Reused sherds are common. Some of them were reworked with notches on one edge and were possibly used as combs for pottery decorating (Fig. 24).

To sum up, simple impressions characterize the earlier occupation, decreasing above MU10 and dropping above MU4 (Fig. 25). Also incision was in use since the early occupation of the site (MU13) and became significant beginning with MU5, although wavy line motifs only appear in MU10 and rise between MU4 and MU2. Conversely, the rocker stamp technique predominates in the upper levels, drops below MU4 and become ephemeral below MU10. Within the rocker technique, dotted wavy line motifs are also common in the upper levels and disappear below MU11. The alternatively pivoting stamp equally appears in the upper levels, becoming significant only above MU5. Roulette follows a similar trend to the alternately pivoting stamp, emerging in MU7 and rising in MU4. Finally, also undecorated pottery predominates in the upper levels, drops below MU3 and vanishes below MU7.

6. Organic residues
6.1 Brief overview of organic residue analysis
Organic residues occur widely in association with pottery, offering a remarkable sink of information relating to vessel use, resource acquisition/exploitation and ancient technologies. On a broader scale, lipid residue analyses can provide insight into dietary and environmental reconstruction, animal management practices and the domestication of plants and animals. Organic residues survive widely in association with ceramics, often enduring over considerable timescales (Evershed, 2008b; Roffet-Salque et al., 2016).

Based on the 'archaeological biomarker' concept, the technique involves the extraction of absorbed organic residues (namely, organic molecules called lipids, the fats, waxes and resins of the natural world) from ceramic vessels, generally originating from the original contents either stored or processed in the vessels, whether as single use or as an accumulation of individual use events in a vessel over its life history (Evershed, 2008a, b).

Organic residue analysis uses the techniques of gas chromatography (GC), gas chromatography-mass spectrometry (GC-MS), gas chromatography-combustion-isotope ratio mass spectrometry (GC-C-IRMS) to identify, at a molecular level, specific archaeological biomarkers that allow us to identify a considerable range of commodities. These include terrestrial animal fats (ruminant adipose and dairy) as proxies for carcass processing and secondary product exploitation (Evershed et al., 1997a; Dudd and Evershed, 1998; Mottram et al., 1999; Copley et al., 2003), marine animal fats (Copley et al., 2004; Craig et al., 2007; Cramp and Evershed, 2014), plant waxes (Evershed et al., 1991; Dunne et al., 2016) and beeswax (Evershed et al., 1997b; Roffet-Salque et al., 2016).

6.2 Method summary
Lipid analyses were performed using established protocols described in detail in earlier publications (e.g., Dudd and Evershed, 1998; Correa-Ascencio and Evershed, 2014). All solvents used were HPLC grade (Rathburn) and the reagents were analytical grade (typically > 98% of

purity). Briefly, ~2 g of potsherd were sampled and surfaces cleaned with a modeling drill to remove exogenous lipids. The cleaned sherd powder was crushed in a solvent-washed mortar and pestle and weighed into a furnaced culture tube (I). An internal standard, typically 20 µL, was added to enable quantification of the lipid extract (*n*-tetratriacontane; Sigma Aldrich Company Ltd). Following the addition of 5 mL of H_2SO_4/MeOH 2 - 4% ($\delta^{13}C$ measured), the culture tubes were placed on a heating block for 1 hour at 70°C, mixing every 10 min. Once cooled, the methanolic acid was transferred to test tubes and centrifuged at 2500 rpm for 10 min. The supernatant was then decanted into another furnace culture tube (II) and 2 mL of DCM extracted double distilled water was added. In order to recover any lipids not fully solubilized by the methanol solution, 2 x 3 mL of hexane was added to the extracted potsherds contained in the original culture tubes, mixed well and transferred to culture tube II. The extraction was transferred to a clean, furnaced 3.5 mL vial and blown down to dryness. Following this, 2 x 2 mL hexane was added directly to the H_2SO_4/MeOH solution in culture tube II and whirl-mixed to extract the remaining residues. This was transferred to the 3.5 mL vials and blown down under a gentle stream of nitrogen until a full vial of hexane remained. Aliquots of the fatty acid methyl esters (FAMEs) were derivatised using *N, O*-bis(trimethylsilyl)trifluoroacetamide (BSTFA) containing 1% *v/v* trimethylchlorosilane (TMCS; Sigma Aldrich Company Ltd.; 20 µL; 70°C, 1 h). Excess BSTFA was removed under nitrogen and the derivatised FAME was dissolved in hexane prior to analysis by gas chromatography (GC), gas chromatography–mass spectrometry (GC–MS) and gas chromatography–combustion–isotope ratio mass spectrometry (GC–C–IRMS).

All FAMEs initially underwent high-temperature gas chromatography using a gas chromatograph (GC) fitted with a high temperature non-polar column (DB1-HT; 100% dimethylpolysiloxane, 15 m x 0·32 mm i.d., 0.1 µm film thickness). The carrier gas was helium and the temperature program comprised a 50°C isothermal hold followed by an increase to 350°C at a rate of 10°C min^{-1} followed by a 10 min isothermal hold. A procedural blank (no sample) was prepared and analyzed alongside every batch of samples. Further compound identification was accomplished using gas chromatography-mass spectrometry (GC-MS). FAMEs were then introduced by autosampler onto a GC-MS fitted with a non-polar column (100% dimethyl polysiloxane stationary phase; 60 m x 0.25 mm i.d., 0·1 µm film thickness). The instrument was a ThermoFinnigan single quadrupole TraceMS run in EI mode (electron energy 70 eV, scan time of 0·6 s). Samples were run in full scan mode (*m/z* 50–650) and the temperature program comprised an isothermal hold at 50°C for 2 min, ramping to 300°C at 10° min^{-1}, followed by an isothermal hold at 300°C (15 min). Data acquisition and processing were carried out using the HP Chemstation software (Rev. C.01.07 (27), Agilent Technologies) and Xcalibur software (version 3.0). Peaks were identified on the basis of their mass spectra and gas chromatography (GC) retention times, by comparison with the NIST mass spectral library (version 2.0).

Carbon isotope analyses by GC-C-IRMS were also carried out using a GC Agilent Technologies 7890A coupled to an Isoprime 100 (EI, 70eV, three Faraday cup collectors *m/z* 44, 45 and 46) via an IsoprimeGC5 combustion interface with a CuO and silver wool reactor maintained at 850°C. Instrument accuracy was determined using an external FAME standard mixture (C11, C13, C16, C21 and C23) of known isotopic composition. Samples were run in duplicate and an average taken. The $\delta^{13}C$ values are the ratios $^{13}C/^{12}C$ and expressed relative to the Vienna Pee Dee Belemnite, calibrated against a CO2 reference gas of known isotopic composition. Instrument error was ±0.3‰. Data processing was carried out using Ion Vantage software (version 1.6.1.0, IsoPrime).

6.3 Results

A total of 80 sherds (56 from Trench 7, the remaining from Trenches 5, 6, 8, 9 and 10), mostly rimsherds, were supplied for analysis after examination by one of the authors (EAAG) of the entire ceramic assemblage. The majority contained high abundances of contaminants and were not carried forward for further analysis. Six of them (one from Trench 5 and five from Trench 7) yielded interpretable lipid profiles (Evershed, 2008a). Lipid concentrations were low with the mean lipid concentration from the sherds (Table 2) being 0.07 mg g^{-1}, with a maximum lipid concentration of 0.19 mg g^{-1} (SAB314). This suggests that the vessels were not intensively used to process foodstuffs although this could also relate to a feature of preservation at the site. The five sherds from Trench 7 (SAB1919, SAB2300, SAB2301, SAB2305 and SAB2312) comprised lipid profiles which demonstrated free fatty acids, palmitic (C_{16}) and stearic (C_{18}), typical of a degraded animal fat (Fig. 26a), were the most abundant components (e.g. Evershed et al., 1997a; Berstan et al., 2008).

GC-C-IRMS analyses were carried out on the 6 FAMEs (fatty acid methyl esters) (Table 2 and Fig. 27) to determine the $\delta^{13}C$ values of the major fatty acids, $C_{16:0}$ and $C_{18:0}$, and ascertain the source of the lipids extracted. The $\delta^{13}C$ values of the $C_{16:0}$ and $C_{18:0}$ fatty acids reflect their biosynthetic and dietary origin, allowing non-ruminant and ruminant adipose and ruminant dairy products to be distinguished (Copley et al., 2003; Dunne et al., 2012). Furthermore, the foods that animals eat exhibit characteristic isotopic signatures (Gannes et al., 1997) and isotopic analyses ($\delta^{13}C$) of fatty acids extracted from archaeological potsherds are therefore a reflection of the consumed diet, providing information about the environment in which the animals foraged (Copley et al., 2003; Mukherjee et al., 2005; Dunne et al., 2012). The $\delta^{13}C_{16:0}$ values range from -24.6 to -19.0 ‰ and the $\delta^{13}C_{18:0}$ values range from -24.7 to -19.9 ‰, suggesting the animals producing the fats were subsisting on a C_3 graze or browse diet but with some contribution from C_4 plants. The $\Delta^{13}C$ values show that one vessel plots in the ruminant range (-0.9 ‰, SAB2312), two plot in the non-ruminant (or, possibly, plant) range (0.7 and 0.5 ‰ for SAB1919 and SAB2301, respectively) and two plot between the ruminant and non-ruminant ranges (-0.2 and 0.1 ‰ for SAB2300 and SAB2305, respectively), suggesting either the mixing of animal fats contemporaneously or during the lifetime of use of the vessel (Mukherjee, 2004; Mukherjee et al., 2005). Aside from SAB314, these data suggest that these vessels were used to process products from hunted wild fauna. The non-ruminant products are likely to originate from warthog or bushpig (Suidae were found at the site, Sůvová, 2017) but the source of the ruminant products cannot be determined although small-sized antelopes (including oribi), medium-sized antelopes, large-sized antelopes, Bovidae and others are known to have been present in the area (Sůvová, 2017).

The $\delta^{13}C_{16:0}$ value of potsherd SAB314, which was loosely associated with a burial in Trench 5, was too low to measure so this could not be plotted. However, this vessel displayed a different lipid profile, comprising a sequence of even-numbered long-chain fatty acids, containing C_{20} to C_{28} acyl carbon atoms, dominated by the C_{24} and C_{26} fatty acid (Fig. 27). These LCFAs are strongly indicative either of an origin in leaf or stem epicuticular waxes (Kolattukudy et al., 1976; Tulloch, 1976; Bianchi, 1995; Kunst and Samuels, 2003) or, possibly, suberin (Kolattukudy, 1980, 1981; Walton, 1990; Pollard et al., 2008), an aliphatic polyester found in all plants. It should be noted that although epicuticular waxes are primarily found on the surface of plant leaves, sheaths, stems and fruits, waxes are also found associated with other plant organs, i.e. seed oils and coats, flowers, bark and husks (Bianchi, 1995). However, these LCFAs are not diagnostic to families of plants and so cannot be used as anything other than a general indicator for plant processing. This specific distribution of lipids is entirely consistent with the processing of plant material, likely leafy plants, within vessel SAB314. The $\delta^{13}C$ values of these LCFAs (Fig. 26b) suggest that the plants processed in this vessel are of C_3 origin.

7. Conclusions

The long sequence of the archaeological deposit at Sphinx with its chronologically representative classes of artifacts confirms the hypothesis of existence of broadly undisturbed stratigraphic layers at the site of Sphinx. The lower frequency of pottery in the lower levels of Trench 7 could suggest less stable occupation or a lower number of occupants at Sphinx, who adopted a different manufacturing technique of pottery production with the use of rounded quartz possibly derived from wadi that drain areas to the west underlain by the Nubian Sandstone Formation (Group 5 fabric) instead of clayey sediments derived from the igneous Sabaloka Complex.Apart from this exception, the general composition of the rest of the Early Khartoum pottery production appears fairly homogeneous in terms of petrographic and chemical features and vessel shapes (i.e., thicknesses) with an opportunistic "gradient" along raw material acquisition and shaping. Generally speaking, the low variability in the production stages of pottery manufacturing may suggest that the hunting-fishing-gathering groups who settled in the area of Sphinx and its surroundings exploited local raw materials and were organized according to a markedly low mobility settlement systems (if not fully sedentarized) that preserved technological traditions of pottery manufacturing almost unchanged over several millennia.

While the chemical composition of the pastes remained basically unchanged through the nearly four thousand years of occupation of the site, the vertical distribution of the decoration techniques reveals consistent technological and stylistic variability. Simple impressions and incisions, particularly straight parallel lines, characterize the earlier occupation, whereas the rocker, including dotted wavy lines, alternately pivoting stamp and roulette techniques typify the later occupation together with undecorated vessels. Other classes of artifacts typify the lower levels, such as remains of production of ostrich eggshell beads in the form of unworked fragments and unfinished beads in different stages of production; the series of AMS 14C dates on these finds is of significance as it suggests, inter alia, that the incised wavy line did not appear before the ninth millennium cal BC. In sum, distinct pottery styles appeared over time by increases or decreases of certain decoration techniques and/or motifs, which may signal a continuous development, but also alternation of cultural identities of the local inhabitants, with which the pottery styles are likely to have been connected.

Concerning the use of the ceramic vessels, analyses of organic residues provided consistent information. Although small in number and apart from one exception (SAB314), the data only came from the lower part of the deposit in Trench 7 at Sphinx (MU10-MU16). They suggest that the earliest Early Khartoum pottery was predominantly used to process ruminant and non-ruminant carcass products, likely from wild animals, suggesting that hunting was a significant part of their subsistence economy. The stable carbon isotope values from the fatty acids suggest the animals producing the fats were eating mainly C_3 plants, demonstrating how pottery lipid residues can also indicate humid environmental conditions.

Finally, one sherd (SAB314) from the fill of a Mesolithic burial B.33 excavated in Trench 5 provided exceptional evidence with some specialization of vessel use for wild plant processing. Evidence of this use is of considerable interest for the pottery production from this part of Africa.

To sum up, the long sequence of the archaeological deposit at Sphinx reasonably imply a basic trend in the development of production and use of pottery at the site. Potentially it provides one of the rare proxies for the development of the entire Early Khartoum period in central Sudan. Nevertheless, before it is possible to compare this development with sequences from other regions within or outside the province of Early Khartoum culture, it will be first necessary to verify the sequence established at the site of Sphinx by exploration at other sites in Jebel Sabaloka.

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List of captions

Figure 1. Jebel Sabaloka at the Sixth Nile Cataract with location of the site of Sphinx in the Early Khartoum settlement landscape. Black line: concession area of the Charles University Sabaloka Expedition; black arrow: location of the cataract (background: ESRI Base Map – World Imagery Source: Digital Globe, processed by J. Pacina, completed by authors).

Figure 2. View of the site of Sphinx showing the southern part of the elevated settlement platform from southeast.

Figure 3. Plan of the settlement platform at Sphinx with location of the trenches excavated between 2011 and 2019. The trenches that provided pottery for the analyses presented in this paper are shown in black (background: J. Pacina 2014, updated by authors).

Figure 4. Volumetric densities of potsherds in artificial levels (MU = mechanical unit) projected onto the northern section of Trench 7. The densities vary from 87 sherds/m^3 in MU15 to 2327 sherds/m^3 in MU2 (no density was established for MU16). Stones are marked in black.

Figure 5. Petrographic groups/fabrics.

Figure 6. Distribution of the calculated individual modified Mahalanobis distances between each sample within the first and second group (solid and dotted line) compared to the expected distribution of a χ^2 distribution with the same number of degrees of freedom (22, dashed line). The position of the maxima of the measured values to the left of the expected values strongly indicates that the samples within the groups are even closer together than would be expected in a random sample from a group.

Figure 7. Distribution of the calculated individual modified Mahalanobis distances between each sample in the dataset (solid line) compared to the expected distribution of a χ^2 distribution with the same number of degrees of freedom (22, dashed line). The position of the maximum of the measured values to the right of the maximum of the expected values indicates that not all samples belong to the same group.

Figure 8. Principal Component Analysis (PCA) of the dilution corrected data. Total variance included in the two principal components is 32.2% and 21.4%, respectively. While the samples belonging to the two chemical groups plot together very closely, the chemical loners (singles) are fairly evenly distributed with large distances between each sample.

Figure 9. Unclassifiable pottery from Trench 7: a. Frequency; b. Stratigraphic distribution.

Figure 10. Wall thicknesses of the vessels from Trench 7 (y-axis: number of sherds, x-axis: thickness in mm).

Figure 11. Vertical distribution (%) of undecorated pottery in Trench 7.

Figure 12. Vertical distribution (%) of the rocker technique in Trench 7.

Figure 13. Rocker stamped decorations: 1-3. Dotted wavy lines; 4-5. Packed zigzags; 6. Spaced zigzags; 7. Zigzags with spaced dots; 8. Plain zigzags.

Figure 14. Vertical distribution (%) of dotted wavy line decorations in Trench 7.

Figure 15. Vertical distribution (%) of the incision technique in Trench 7.

Figure 16. Incised decorations: 1-2. Parallel lines; 3-4. Wavy lines.

Figure 17. Vertical distribution (%) of wavy lines in Trench 7.

Figure 18. Decorations with simple impressions.

Figure 19. Vertical distribution (%) of the simple impression technique in Trench 7.

Figure 20. Alternately pivoting stamped decorations.

Figure 21. Vertical distribution (%) of the alternately pivoting stamp technique in Trench 7.

Figure 22. Roulette decorations.

Figure 23. Vertical distribution (%) of the roulette technique in Trench 7.

Figure 24. Sherds modified into combs.

Figure 25. Vertical distribution (%) of all decoration techniques in Trench 7.

Figure 26. Partial gas chromatograms of trimethylsilylated FAMEs from pottery extracts. a. SAB2300; b. SAB314. Circles, *n*-alkanoic acids (fatty acids, FA); IS, internal standard, C_{34} *n*-tetratriacontane.

Figure 27. Graphs showing the $\Delta^{13}C$ ($\delta^{13}C_{18:0} - \delta^{13}C_{16:0}$) values. The ranges shown here represent the mean ± 1 s.d. of the $\Delta^{13}C$ values for a global database comprising modern reference animal fats from Africa (Dunne et al., 2012), UK (animals raised on a pure C_3 diet) (Dudd and Evershed, 1998), Kazakhstan (Outram et al., 2009) , Switzerland (Spangenberg et al., 2006) and the Near East (Gregg et al., 2009), published elsewhere.

Table 1. Samples selected for optical microscopy (OM).

Table 2. Laboratory number, assemblage number, provenance, sherd type, lipid concentration (μg g^{-1}), total lipid concentration in extract (μg), $\delta^{13}C$ and $\Delta^{13}C$ values, and attributions of pottery lipid residues.