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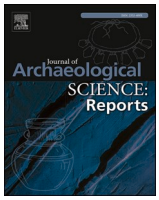

More than one way to perform archaeometric analyses on pottery. Case studies from prehistoric to Bronze Age Sudan☆

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ABSTRACT

Sudanese archaeology boasts a long-standing tradition of studying pottery technology, including through archaeometric analyses. In the early 1970s, several international and Sudanese scholars conducted the first petrographic and geochemical studies on Sudanese Mesolithic and Neolithic ceramic assemblages. More or less contemporaneously, the first attempt to classify ancient Egyptian ceramic fabrics was organised into the 'Vienna system' which became the backbone for the classification of clays and fabrics based on certain physical and technological properties. Building on such past studies, current archaeometric approaches to Sudanese pottery commonly integrate a wide range of organic (e.g., ORA) and inorganic (e.g., OM, XRF, iNAA) analyses to reconstruct the *chaîne opératoire* of the ceramic assemblages, local traditions, and ceramic ecologies, considering both the natural and anthropological spheres. The following paper compares different archaeometric studies from key contexts of Sudanese archaeology. The selected case studies range chronologically from the Mesolithic to the Bronze Age. In particular, we demonstrate that shared standard research methods allow for the successful comparison of ceramic assemblages from different chronological and geographic contexts, despite varying sampling strategies, analytical techniques, archaeological challenges, and research objectives. All of which can be calibrated based on the specific ceramic assemblage, site chronology, as well as the topographical and cultural landscape.

1. Introduction: the advent of archaeometry in Sudan

Sudanese archaeology boasts a long-standing tradition of studying pottery technology and conducting archaeometric analyses of ceramics, as evidenced by publications on ceramic manufacturing and petrography produced by the early 1970s (see below). A turning point for Sudanese archaeology was the construction of the Aswan High Dam and the International Rescue Campaigns to Save the Monuments of Nubia (for a critical examination of this event see Carruthers, 2022). While the UNESCO campaign focused on the preservation of monumental stone buildings, such as the temples of Abu Simbel, it also facilitated significant advancements in the study of Sudanese ceramics.

One of the outcomes of the international effort was the analysis and classification of a large collection of ceramic sherds from both settlement sites and cemeteries. These were systematically recorded and excavated by, among others, the members of the Scandinavian Joint Expedition (SJE) and the Combined Prehistoric Expedition (CPE). As part of which, William Adams's analysis of Meroitic, X-Group, and Christian pottery in Nubia introduced a groundbreaking taxonomic approach to ceramic studies (Adams, 1962), which was followed a decade later by Hans-Åke Nordström's seminal publication on Early Nubian cultures (1972).

The work of two pioneers in the field of ceramic ecology, Anna Shepard (1956) and Frederick Matson (1960), were a clear inspiration for Adams's and Nordström's studies. They would also have been influenced by the contemporary theories disseminated by the American School of Processual Archaeology (or New Archaeology), particularly in terms of their rigorous scientific methods, terminology, and a strong focus on the reconstruction of the past environment. Meanwhile, by the late 1960s, the prehistoric ceramics of eastern and southern Africa were also being approached with similar methods to conduct more structured analyses and develop taxonomies (for a summary on this, see D'Ercole,

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2021; for Eastern Africa, cf., also Ashley and Grillo, 2015). It is within this theoretical framework that a structured approach to the analysis of significant features in both prehistoric and historic pottery could be established. This systematic approach extended beyond the basic examination of the morphometric and stylistic traits of ceramics to incorporate a comprehensive evaluation of the clay's composition and texture, as well as its non-plastic components. These elements collectively constituted the first formal definition of what is now known as *pottery fabric* (Nordström, 1972, 40; cf., also Adams, 1962, 247; 1964, 129).

Meanwhile, a major advance in the study of ceramics in ancient Egypt was the *Vienna System,* the first unified classification system for Egyptian clay and fabric analysis (Nordström and Bourriau, 1993; see also Bourriau, 2016; Ownby, 2016). This marked a major shift in the way Egyptian ceramics were categorised, focusing not only on their decorative and morphological aspects, but also on their physical and technological properties, which provided a better understanding of the production and function of pottery. While Nordström played an influential role in the study of Early Nubian cultures, the Vienna System further developed the concept of fabric as outlined above, connecting the classification of Egyptian and Sudanese pottery. Moreover, by focusing on both the compositional and technological aspects of pottery, the Vienna System established an important link between Egyptian and Sudanese ceramics. This connection is particularly relevant during the New Kingdom period, when Egypt colonised Nubia, leading to the production of Egyptian style pottery alongside Nubian style pottery throughout the Middle Nile (Budka, 2019a).

Half a century after the inception of archaeometric studies on Sudanese ceramics, this paper aims to review the state of this increasingly important field of research and to summarise some of the major achievements of a range of laboratory approaches in the analysis of ceramic production and provenance. Moreover, through representative case studies, we aim to stress the importance of adopting a multi-scale diachronic, anthropological, and environmental perspective. Ultimately, drawing on the concept of the *chaîne opératoire*, we argue for the integration of diverse analytical methods to capture the cultural complexity and interaction of past societies, moving beyond restricted frameworks that focus solely on stylistic or culture-biased interpretations.[1]

2. Materials and methods

2.1. A literature review and statistical analysis

For this study, a comprehensive review of existing literature was conducted, with a focus on publications in the field of archaeometry related to Sudanese ceramics. A range of sources from the prehistoric period to the present day were collected using platforms such as Google Scholar, Academia, and ResearchGate, as well as reference collections, for example, the Online Egyptological Bibliography. Our analysis focused on publications that presented detailed archaeometric laboratory data, including chemical analysis, petrographic analysis, and other investigations of inorganic and organic materials that employ a quantitative approach. We excluded purely qualitative macroscopic studies, such as those that describe ceramic fabrics based solely on visual observations. We also did not include work which focused solely on geological samples, but did include comparative research conducted between pottery and soil samples.

Subsequently, we developed a set of statistical metrics using queries in Google Sheets (for details, see Supplementary Material) to identify patterns and gain insights into the distribution of research topics, geographical focus, and trends in the archaeometric study of Sudanese ceramics. This review resulted in over 90 entries, creating a robust dataset for analysis. Overall, the majority of the sources (N = 67) are research articles published in internationally recognised interdisciplinary journals (Fig. 1). The following statistics focus specifically on articles from these journals, which make up a significant portion of the scholarly output and offer a snapshot of the academic landscape in the field. The decision to exclude book chapters, dissertations and conference proceedings from the metrics was to avoid data duplication.

2.2. Archaeometric studies of ceramics from Sudan

In addition to the literature review, we revisited our broad range of archaeometric studies of ceramics from Sudan. Our joint material includes prehistoric and New Kingdom samples from Sai Island (D'Ercole et al., 2017a) and prehistoric to Medieval samples from the Attab to Ferka region (Budka, 2019b). The methods applied to these sets of samples include instrumental neutron activation analysis (iNAA), powder X-ray diffraction (XRD), optical microscopy (OM) and Raman spectroscopy as well as organic residues analyses (ORA) (see Budka et al., forthcoming).

Lessons to be learned from these case studies will be presented in the Discussion (3.).

3. Results

3.1. The advance of archaeometric research on sudanese pottery: trends in publication patterns

Since Hays and Hassan's first publication in 1974, archaeometric research on Sudanese pottery has witnessed a gradual yet consistent expansion, with a notable intensification of scholarly output in recent years. This growth has been particularly pronounced in the last decade, with a markedly increased number of articles published since 2017 (Fig. 2).

A review of the data indicates that archaeometric research in Sudan has historically lacked a unified strategy for publication. Instead, studies have been distributed across more than 30 academic journals, with each providing a distinct context for the research. This reflects the interdisciplinary nature of the field, whereby ceramics are analysed not only within the domain of archaeology, but also through the lenses of chemistry, geology, and other related disciplines. Nevertheless, a good proportion of initial studies of Sudanese pottery was published in region-specific journals, including *Archéologie du Nil Moyen*, *Sudan and Nubia*, *Der Antike Sudan*, and *African Archaeological Review*. These publications were invaluable resources for scholars engaged in the study Sudan and Nubia, but the dissemination of significant findings were mostly limited to regional-specialists who shaped the initial discourse on Sudanese

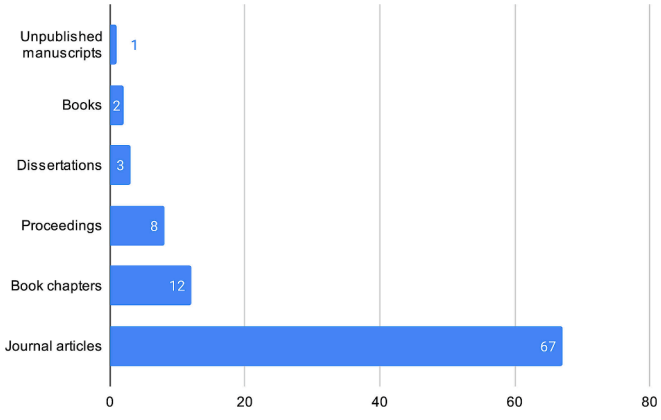

Fig. 1. Distribution of archaeometric publications on Sudanese ceramics.

[1] This paper is part of the Special Issue Scientific Analysis on Pottery Finds from Africa: Challenges and Perspectives for Petrographic and Geo-chemical Studies edited by Dirk Seidensticker, Zoila L. Epossi Ntah, and Hannah B. Page.

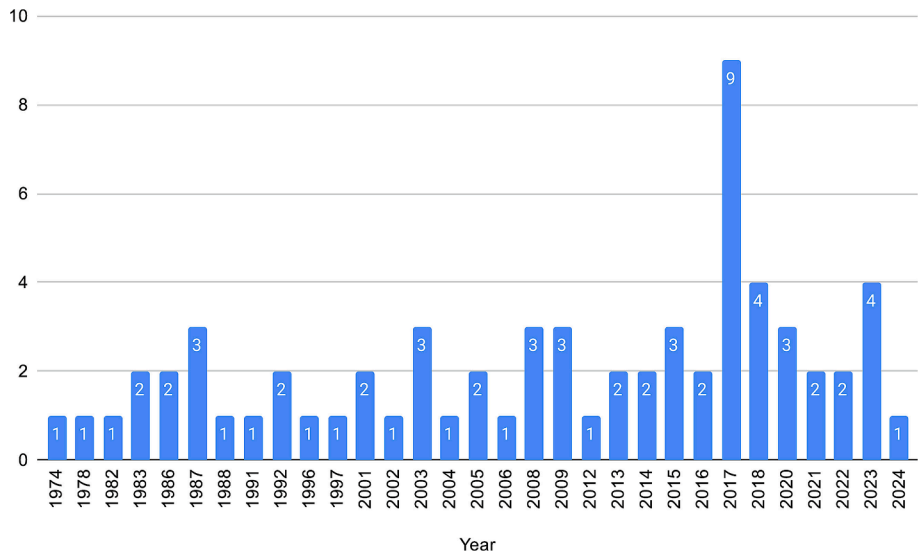

Fig. 2. Number of journal articles published over the years, from 1974 to the present.

ceramics. In recent years, however, there has been a notable shift towards publications in more global and diverse venues, with the *Journal of Archaeological Science: Reports* (JASR) being the most represented (Fig. 3). This reflects the growing international recognition and visibility of Sudanese pottery studies and the increasing integration of archaeometric methodologies into global archaeological research.

3.2. Site focus, periods, and regional clusters

The initial studies in the field of archaeometric analysis of Sudanese pottery, exemplified by the work of Hays and Hassan (1974), frequently adopted a comprehensive chronological and geographical perspective. This was achieved through the analysis of potsherds from a vast array of regions, including the Second Cataract, the Dongola Reach, the region of Khartoum, and even locations outside of Sudan such as the Tassili and Tibesti areas. This approach, although now perceived as somewhat anachronistic, was pivotal in establishing the foundations of the field. It permitted the first typological and technological comparative analyses of pottery across a wide range of regions and periods. The underlying intention of identifying patterns of cultural interaction and differentiation reflects the archaeological assumptions prevalent at the time (i.e., the idea of a *'Khartoum Horizon Style'* or the definition of *'Khartoum Techno Complex'*) (cf., D'Ercole, 2021).

More recently, the focus of research has moved towards more localised studies, with an increased concentration of archaeometric analyses conducted on individual sites. This has enabled researchers to investigate in greater depth aspects such as variations in clay sources, production techniques, and the functions of pottery within specific communities. Moreover, by focusing on a more limited geographical area, these studies provide more comprehensive insights into the cultural practices, traditions, and technological innovations of specific regions.

Overall, our analysis revealed that the majority of research is conducted at a specific site or within a particular context. Conversely, publications that consider multiple chronological periods or encompass multiple sites remain a minority within the field of study (Figs. 4 and 5). It is even rarer to find works that adopt a diachronic approach, examining changes across different periods or multi-regional contexts. The dearth of such comprehensive studies, which would facilitate broader comparisons of long-term cultural and technological developments across Sudan, indicates an area where future research could be expanded, thereby facilitating a more holistic understanding of the

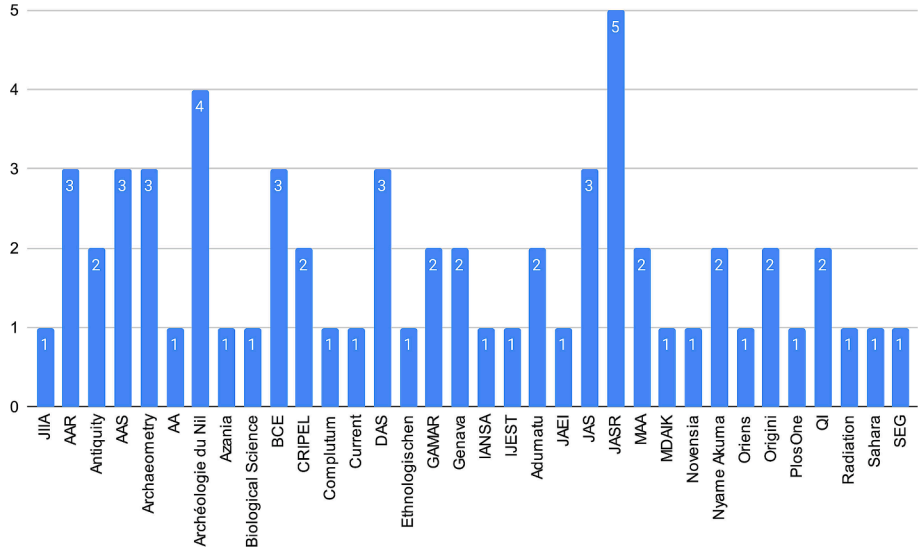

Fig. 3. Number of contributions published in scientific journals.

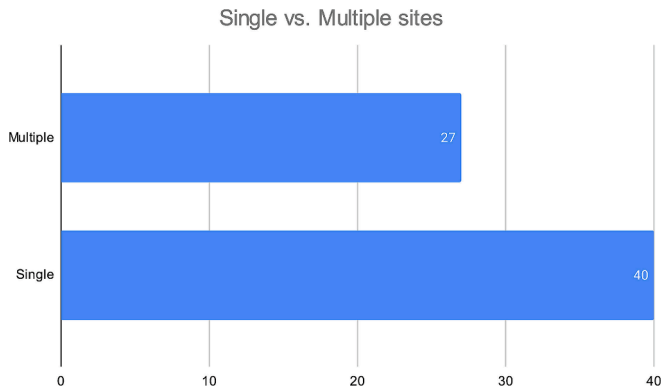

Fig. 4. Articles on single sites/areas (= n. 40) compared to those on multiple sites or research contexts (= n. 27).

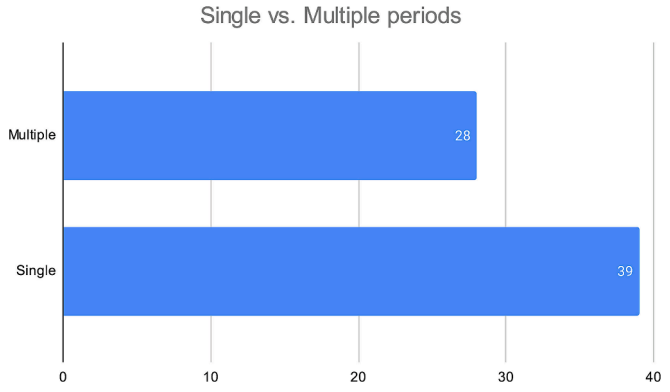

Fig. 5. Articles on single periods (= n. 39) compared to those on multiple periods (n. 28).

advancement of Sudanese ceramics over time and across diverse regions.

In terms of chronological focus, the majority of archaeometric research in Sudan has concentrated on the prehistory of the country (Mesolithic and especially Neolithic period, c. 9000–3500 BCE), with studies on the Meroitic period (approximately 400 BCE–350 CE) representing a significant secondary area of interest (Fig. 6). This emphasis on prehistory may be attributed, at least in part, to the initial development of the archaeometric approach, which was traditionally linked to ceramic ecology and processual archaeology.

Concerning the geographical focus of these studies, specific clusters of sites have been identified as the subject of the majority of investigations. These include pivotal locations in the Middle Nile, such as Sai Island, Hannek, and Tombos, as well as other important sites further south, including Meroe, El-Kadada, Sourourab, and Esh-Shaheinab. In addition, the Butana region's Musawwarat es-Sufra and the Al-Khiday site on the White Nile have also been the subject of extensive research (Fig. 7). These sites are typically part of larger-scale, long-term field projects and the concentration of archaeometric studies in these locations indicate that they have become focal points for archaeological research in Sudan, driven by their cultural significance and the richness of the material evidence they have provided over the years. Furthermore, the paucity of research conducted at sites outside the Nilotic region is indicative of the logistical challenges associated with conducting fieldwork in these areas.

3.3. *From provenance to function: A shift toward combined inorganic and organic approaches*

The early archaeometric studies of Sudanese pottery were primarily centred on mineralogical and compositional analyses to identify the sources of clay raw materials and tempers employed in the production of ceramic artefacts. In many cases, these studies were supported by robust geomorphological data and, in some instances, the investigation of ceramic specimens was complemented by the analysis of soil samples. These works mostly employed petrochemical methodologies, integrating polarizing microscopy on thin sections with bulk analysis of major, minor, and trace chemical elements. The main objectives were to (1) trace the geological sources of clays and tempers in the ceramics, (2) distinguish between local and non-local materials, and, ultimately, (3) investigate the distribution of similar pottery styles but potentially disparate fabrics (see, for example, Hays and Hassan, 1974; also Francaviglia and Palmieri, 1983).

In recent decades, while optical microscopy has remained the most widely utilised analytical method — due to its relatively high information yield at a low cost and a relatively short processing time —studies have increasingly employed a wider variety of analytical techniques. As such, works that combine multiple methods have become more prevalent than those relying on single analysis (Figs. 8 and 9). Overall, this trend reflects a broader change in the field of archaeometry toward more comprehensive and multidisciplinary approaches to understanding Sudanese ceramics.

Furthermore, the most recent publications emphasise an increased focus on the reconstruction of all the stages of the manufacturing sequence of pottery. This encompasses not only the selection, preparation, and mixing of clay and tempering agents, but also the successive stages of production, firing, and use of the vessels. Specifically, studies have incorporated additional analytical techniques, such as organic residue analysis (ORA) on lipids, studies on charred macro-botanical remains (i.e., seeds and cereals) and plant impressions on pottery, and micro-botanical analysis on phytoliths.

These techniques are increasingly performed in conjunction with inorganic analyses, indicating a remarkable expansion of laboratory expertise in response to the current scientific inquiry into the functional aspects of pottery. This includes, in particular, the role of ceramics in identifying culinary practices, and their connections to dietary habits and nutritionary practices. Furthermore, the new trend to combine inorganic analyses of ceramic pastes with organic analyses of their contents represents a significant change from material science or archaeometry *tout court* towards a more targeted approach of biochemistry and molecular archaeology. Ultimately, an approach grounded in food archaeology allows for a deeper investigation of past societies' economic and technological innovations and their adaptive strategies for coping with critical environmental changes or food crises, with a particular emphasis on active engagement.

4. Discussion: case studies for the longue Durée approach

Two case studies that the team of authors analysed in recent years with a *longue durée* approach are presented here. While on Sai Island the corpus analysed from various sites focused on one hand on prehistoric pottery and on the other hand on New Kingdom pottery, the aim for the Attab to Ferka region within the Munich University Attab to Ferka Survey Project (MUAFS) was a more continuous focus on pottery production through the millennia, from the Mesolithic to Islamic times. As such, the MUAFS project continues, and expands, the questions that were raised during work on Sai Island (see also Budka, 2020).

4.1. *Sai Island*

A *longue durée* approach was first applied to a large collection of ceramics dating from the eighth millennium BCE (locally called Khartoum Variant) to the second millennium BCE (Egyptian New Kingdom Eighteenth Dynasty) from five different archaeological sites on Sai Island (for further information, see D'Ercole et al., 2017a; Garcea, 2020). It demonstrated that continuities were more common than discontinuities over this long time period, and that the ceramic recipe established

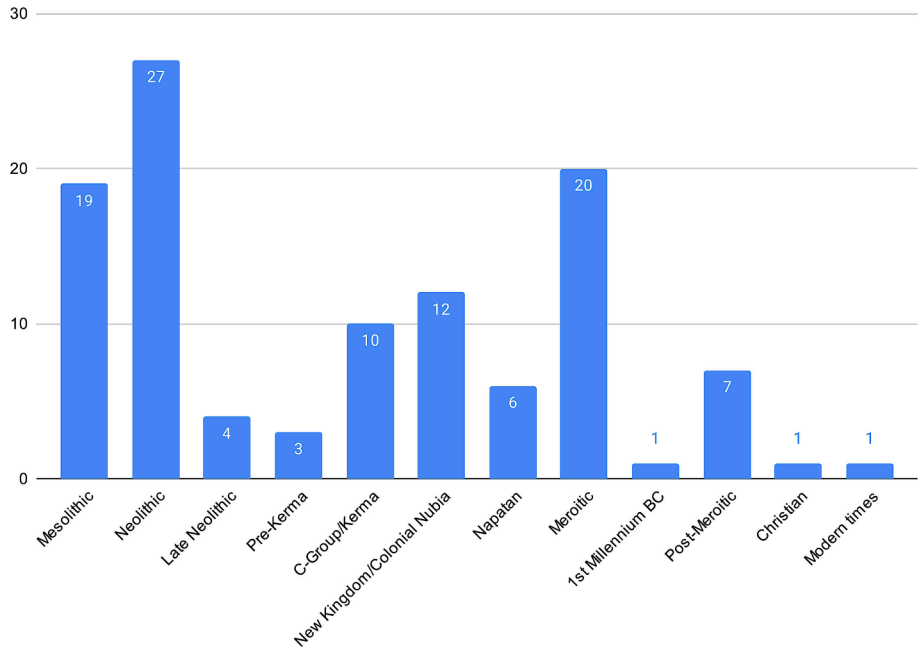

Fig. 6. Distribution of contributions for different chronological periods, from prehistory to the present.

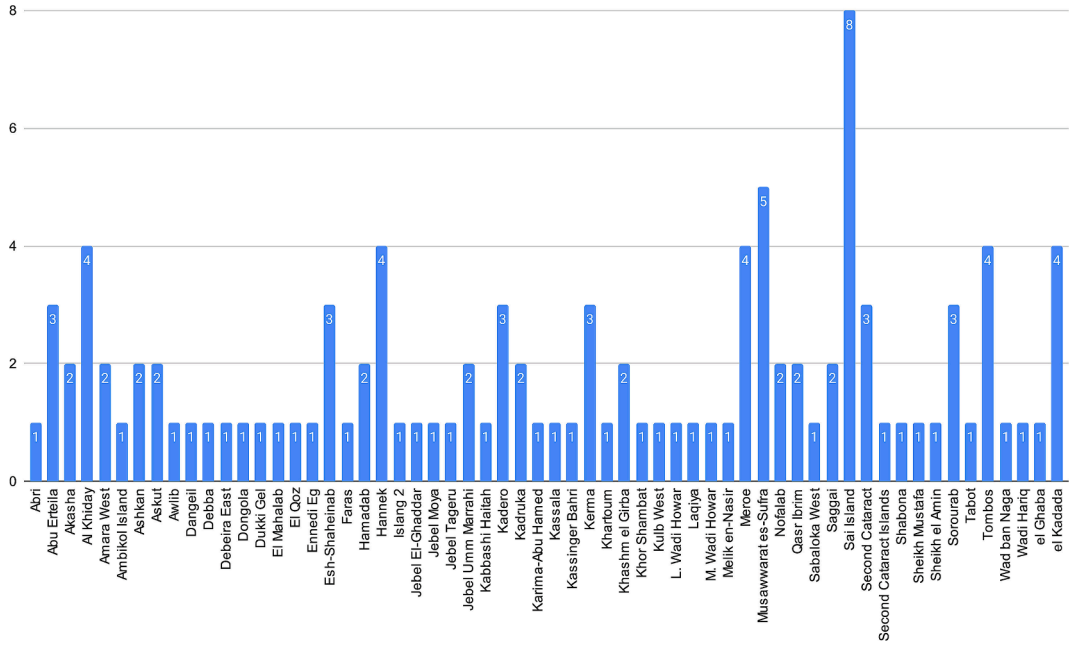

Fig. 7. Distribution of contributions for different sites/areas.

for Neolithic pottery (locally called Abkan, 5500–3700 BCE) continued to be used throughout the following four millennia (for further information, see D'Ercole et al., 2017b; Garcea, 2020).

Closer scrutiny of the different assemblages studied shows that those making the earliest pottery (Khartoum Variant, 7600–4800 BCE in the area) lacked sophisticated manufacturing skills and made ceramic vessels with coarse pastes and poorly sorted inclusions. Despite lacking the necessary skills, there are clear attempts by these early potters at imitating non-local ceramic decorations, such as impressed zigzags and dotted wavy lines made with the rocker technique, which were widely spread across Sudan and continued to be used in later periods. At Sai Island, Abkan potters entirely replaced Khartoum Variant manufacturing techniques and introduced pottery making as part of their social and economic ensemble. This coincided with the introduction of food production on the island. Similar methods of Abkan ceramic production (vessels produced in locally available alluvial Nile clay with the addition of organic inclusions) became standard systems and were also used by subsequent communities on Sai Island. This included Pre-Kerma potters who adapted aspects of Khartoum Variant decorative motifs and the Abkan production sequence to suit their particular needs and larger corpus of vessel types (Fig. 10).

4.2. *The Attab to Ferka region*

The Munich University Attab to Ferka Survey Project (MUAFS) concession area covers a region of over 337 km^2 in Upper Nubia

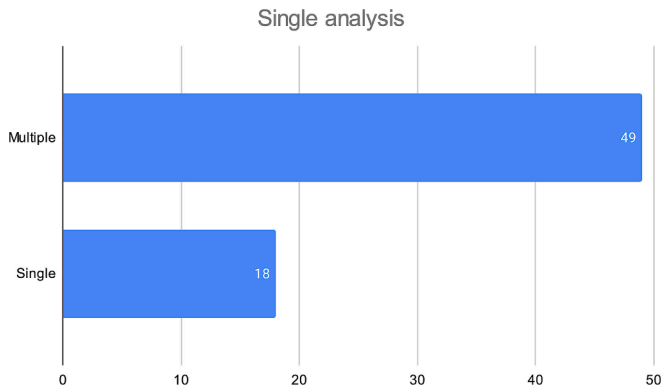

Fig. 8. Articles focusing on single analyses (true = n. 18) compared to those which employ multiple analytical methods (= n. 49).

(Fig. 11) and includes the districts of Attab, Ginis, Kosha, Mograkka, and Ferka. The Sudan Antiquities Service, in conjunction with the French Archaeological Unit, directed by André Vila, conducted a preliminary survey of this part of the Nile Valley in the 1970 s (Vila, 1976a; 1976b; 1977a; 1977b). They documented multiple sites, from the Stone Age to the Post-Medieval period, comprising settlements and funerary remains, as well as rock art, fortresses and churches. The results of the survey highlighted this region as a frontier in terms of cultures, representing a bridge between Lower and Upper Nubia from Prehistory all the way to the Ottoman period (see Budka, 2019b).

The major goal of the MUAFS project is to apply the novel approach of 'contact space biography' (see Budka et al., 2025) to reconstruct within a *longue durée* approach biographies of landscapes, shaped by humans, human activities, technologies, and materiality as well as animals (Kolen and Renes, 2015). We aim to decode through our interdisciplinary studies — including a range of archaeometric studies (see Budka et al. forthcoming) — the economic role of the Attab-Ferka region for urban centres, such as Sai Island, as a production area, and as land for animal husbandry and agriculture. Through the project we also challenge the well-established categorisation of sites and finds as either 'Egyptian' or 'Nubian' through the application of contact space biographies and considering evidence of cultural fluidity (see Budka et al., 2025).

At the start of the MUAFS project, the aim was to export a collection of lithics and ceramics from Sudan for archaeometric analyses. Unfortunately, for various reasons, the export-licence was only granted in March 2023, a month before the outbreak of the still ongoing war in Sudan and the consequent looting of the offices and museum of the National Corporation for Antiquities and Museums in Khartoum. As a consequence, this sample collection never left Khartoum and unfortunately only macroscopic observations and no photographs or drawings are available for these ceramic sherds, which date from the Khartoum Variant to the Medieval period. Nevertheless, this set of samples found across the MUAFS concession area (Fig. 12) has significant potential in addressing the role of pottery in storage and cooking technology, as well as in the diachronic study of culinary traditions from a single region in Sudan (cf. D'Ercole et al., 2024) which showcases cultural fluidity.

In 2019, we were able to identify and re-locate many of the prehistoric sites documented by Vila in the districts of Attab and Ginis West and to attribute them respectively to the Khartoum Variant and Abkan cultural horizons based on the occurrence of diagnostic pottery (D'Ercole, 2019). All prehistoric evidence is indicated by concentrations of eco- and cultural artefacts, the maximum density of which represents the centre of the site. Interestingly, the Khartoum Variant sites, in particular, appear to be characterised by large concentrations of artefacts, including grindstones and millstones as well as numerous ceramic sherds, lithic tools and debitage. Remains of stone structures — which may represent features such as possible huts and/or ancient hearths — have also been identified. Continuity can occasionally be observed between neighbouring sites, as was already noted by Vila (see e.g., samples 175 and 176 from site 2-S-55 and samples 167–170 from 2-T-64 in Attab West; Vila, 1977b, 56 and 90). This might represent a distinctive characteristic of the prehistoric evidence from this area, not observed in the insular context of Sai.

The material from 2-T-64, classified by Vila as a Neolithic campsite, is particularly pertinent. Sample 168 comprises 18 sherds of which 16 are of the Khartoum Variant and two are possible Abkan sherds. The Khartoum Variant sherds have a sand-tempered fabric (mostly containing quartz inclusions and possibly some organics) with levigated/burnished inner surfaces and they mainly show zonal/banded decoration produced with the rocker stamp technique. One of the sherds was re-used as a comb for making the decoration on other pottery vessels. One of the Abkan sherds is a rim and decorated with the rocker stamp technique (straight zig-zags, starting from the lip). Sample 169 from the same site only comprises five sherds, four Khartoum Variant and one possible Abkan sherd. The Khartoum Variant pottery, possibly a cooking pot, has a fine fabric and is decorated with notched impressions on the rim and rocker stamp impressions on the body (typical banded

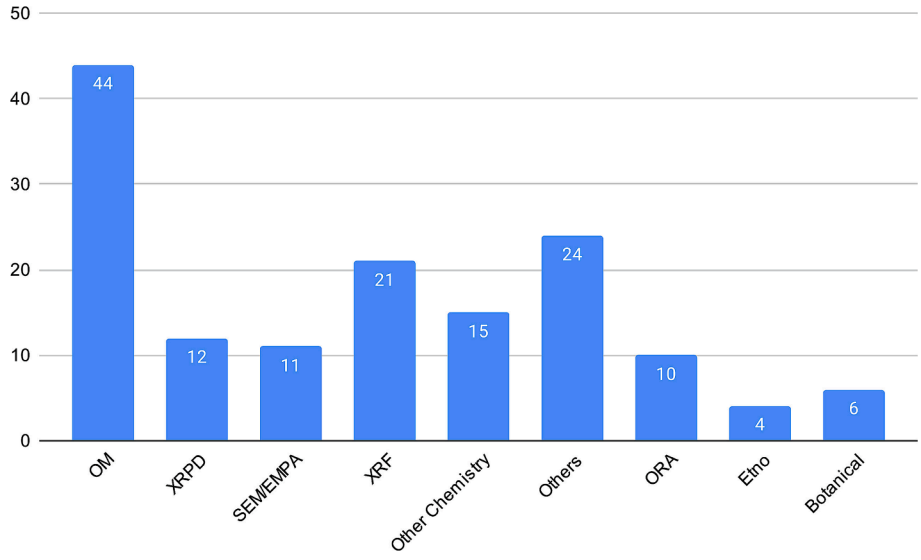

Fig. 9. Range of analytical techniques applied in the different contributions.

Fig. 10. Khartoum Variant (no. 1–4), Abkan (no. 5–6), and Pre-Kerma (no. 7–10) pottery from Sai Island and Amara West. Photos by R. Ceccacci. Photo no. 2 is a Khartoum Variant sherd re-used as a comb for decorating pottery.

decoration/comb with unevenly serrated edge-check).

The co-presence within the same site of both Khartoum Variant and Abkan ceramics, visible at 2-T-64 and other sites, is significant and indicates that Khartoum Variant and Abkan populations occupied the same site. Whether this also indicates an overlap between the two cultural horizons and a possible co-habitation phase remains unclear without C14 data. However, a similar scenario was observed at site 8-B-76 on Sai Island (Garcea et al., 2016; see also D'Ercole, 2017, 156).

Overall, the changes observed in the ceramic assemblages between the Khartoum Variant and the Abkan period at Sai were also recognised in the assemblages from the MUAFS concession area. The preliminary visual analysis of the prehistoric ceramics suggests the existence in the region of two distinct traditions that stylistically and technologically can be associated with the Khartoum Variant and Abkan cultural horizons (see D'Ercole, 2019). However, this material also has many traits in common with the Mesolithic and Neolithic of the El Barga/Kerma region (Honegger, 2014), as well as with the Early Neolithic and Neolithic cultures of the Egyptian Western Desert (Gatto, 2002). Since the MUAFS concession area is in the immediate surroundings of the Arkinian site 2-R-66 in the Amara West district (Garcea et al., 2016) — which yielded some of the earliest evidence of pottery in northern Sudan, dating to the mid-ninth millennium BCE — it also has considerable potential regarding the emergence of pottery in the region.

The Pre-Kerma pottery found in 2019 in the MUAFS concession area seems to mainly belong to a "late" Pre-Kerma phase. Decorations often show geometric motifs organised into herringbone patterns. Similar motifs also occur on Sai Island, at site 8-B-10A, and are also characteristic of the recent Pre-Kerma period (c. 2700–2600 BCE) at the site of Boucharia II in Kerma (Honegger, 2014; cf., also D'Ercole, 2017, 162). It should be noted that in the MUAFS concession area, Pre-Kerma ceramics were often found in association with Early Kerma and/or Abkan ceramics, in sites defined either as *'Site d'occupation'* (occupation sites) or

Fig. 11. Map of Northern Sudan showing the location of the MUAFS concession area and the sites of Sai Island, Amara West and the Dal cataract. Map: H. Aglan, ©DiverseNile project.

'*Site de campement*' (camp sites) and dated as either '*Nubien ancient*', '*Nubien moyen*' or '*Néolithique*' by André Vila.

Of the Bronze Age[2] pottery collected in the MUAFS concession in 2019, sample 129 from site 2-S-54 in Attab West (Vila, 1977b, 85), consequently labelled as AtW 002 by the DiverseNile Project in 2023 (see Budka et al., 2023; 2025), is of considerable importance. AtW 002 is a small domestic site located on the northern edge of the main palaeochannel, categorised by Vila as an Egyptian New Kingdom habitation site. All of the pottery found at the site is associated with a rectangular structure made of a mix of mud-brick and dry-stone architecture. Sample 129 is the base of a wheel-thrown Nile clay dish, which corresponds macroscopically to a variant of the Nile B2 fabric from the Vienna System (see Budka, 2017, 122). However, its general appearance and the finishing of the base suggest that it was produced locally (for chemical analysis of New Kingdom Nile clay wares see D'Ercole and Sterba, 2018). The archaeological context of this sample, which compares well to MUAFS 524–4/2023 (Fig. 13), is in this case particularly pertinent. The architecture and artefacts found at AtW 002 (which was excavated in 2023, see Budka et al., 2023) makes it likely that the site was used by a mixed community being associated with both Egyptian and Kerma traditions. As such, AtW 002 illustrates the problematic labelling of sites in the region as e.g. Kerma or Egyptian. Such cultural categories have been developed primarily for urban centres in the region, such as Sai Island, and are therefore less applicable to rural communities (see Budka, 2019b; Budka et al., 2025).

Sample 129 can be readily compared to samples 177–184. These are both hand-made Classical Kerma sherds and early Eighteen Dynasty

[2] The term Bronze Age is frequently used for Kerma and New Kingdom remains in Nubia in the anglophone world, see, e.g. recent studies listed by Budka, 2025, 64, fn 57. For arguments supporting the term Bronze Age, see also Budka 2019, 24, for those opposing it, see Jesse, 2025; for a general discussion, see also de Souza, 2023.

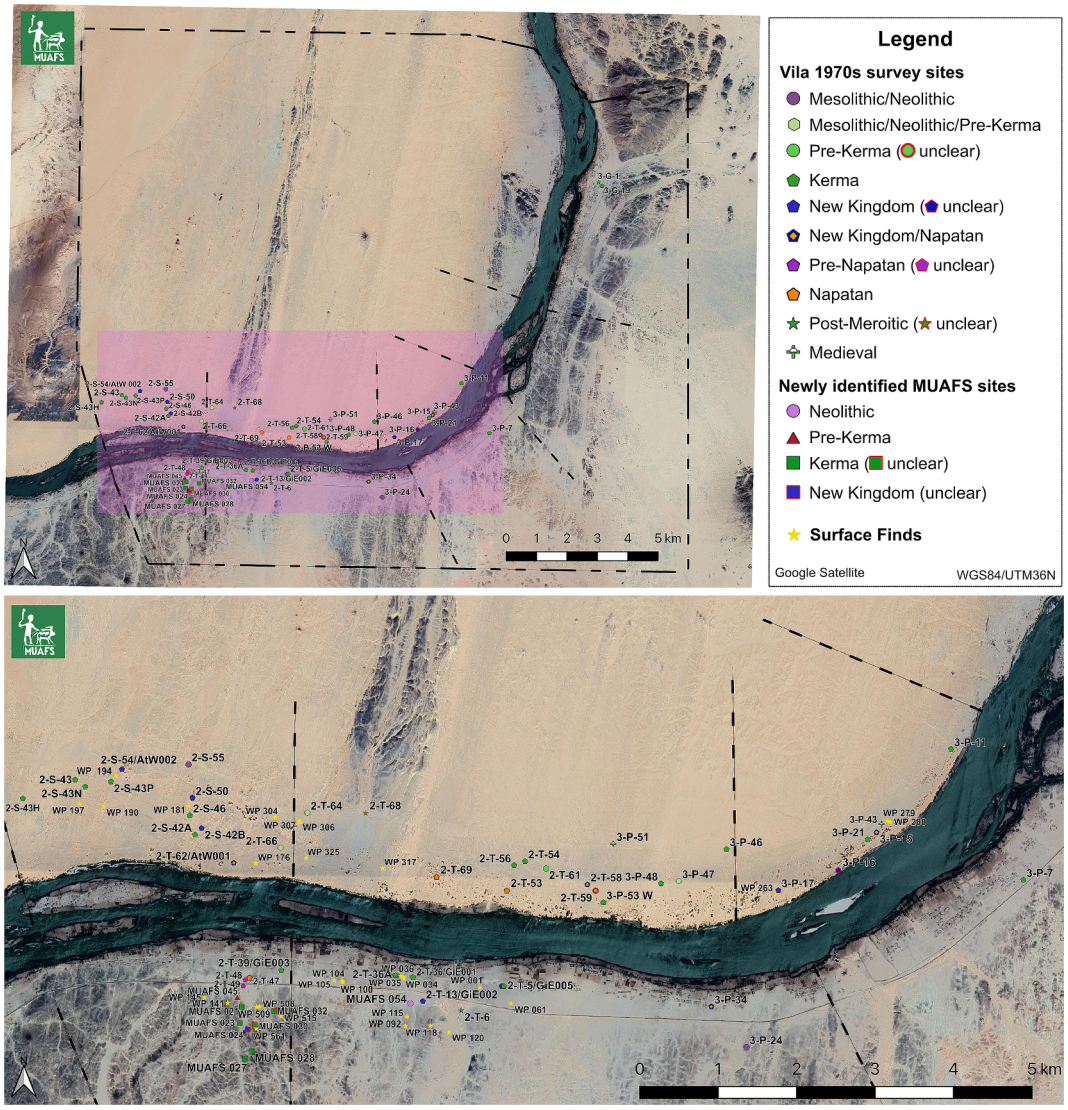

Fig. 12. Distribution of find locations of samples taken in the MUAFS concession area in 2020 (archaeological sites and surface finds from different periods). Map: C. Ward, ©DiverseNile project.

vessels in the Egyptian wheel-thrown tradition, collected from different features from site 2-S-43 in Attab West (Vila, 1977b, 66-71). This site is composed of a series of dry-stone structures and was attributed to the Kerma culture by Vila. However, this is another example of problematic categorising and the material record does not actually permit the site to be simplistically classified as either Egyptian or Nubian (Budka, 2019b). This became even clearer during the 2025 survey; at the fortified structure 2-S-43N, not only Egyptian but also Kerma sherds and some that are more likely to belong to the Pan-Grave horizon were collected (Fig. 14).

To conclude, the ceramics from the Attab to Ferka region allow us to address cultural diversity in this region throughout the ages and to reconstruct contact space biographies. Questions of trade and production but also social practices and taskscapes can be raised and are materially assisted by the analysis of the pottery — in particular, through a multi-disciplinary analysis with archaeometric applications (see Budka et al. forthcoming).

5. Final remarks

In the early days of archaeometric ceramic studies in Sudan, the focus was on reconstructing the geomorphological context of pottery production and to trace the sourcing of clay raw materials. These studies were typically conducted by scientific experts, such as geologists or chemists (see, for example, early publications by De Paepe and Francaviglia and Palmieri). More recently the focus has shifted to more complex and nuanced studies around the required technological skills of pottery manufacture and the social role of ceramic production, typically conducted by archaeologists themselves but sometimes in cooperation with scientists (see, for example, the works by Carrano, D'Ercole, de Souza). Nevertheless, most of studies have maintained a single-site focus and a narrow chronological scope.

The authors' decade-long cooperation and long-term perspective have allowed the recording of various relevant aspects that would not otherwise have been assessed. These aspects include, but are not limited to, the acceleration of change related to increased social complexity from the eighth (Khartoum Variant or local Mesolithic period) to the second millennium BCE (New Kingdom or Late Bronze Age), the variation in supply and demand, and the increase in vessel diverse performances and functions. This shift is not necessarily driven by a mandatory quest for technological variation or by a need to accommodate change or innovation. Instead, it is argued that a more nuanced and fluid approach is required to understand the times and ways of ceramic production, taking into account all the social dynamics of interplay,

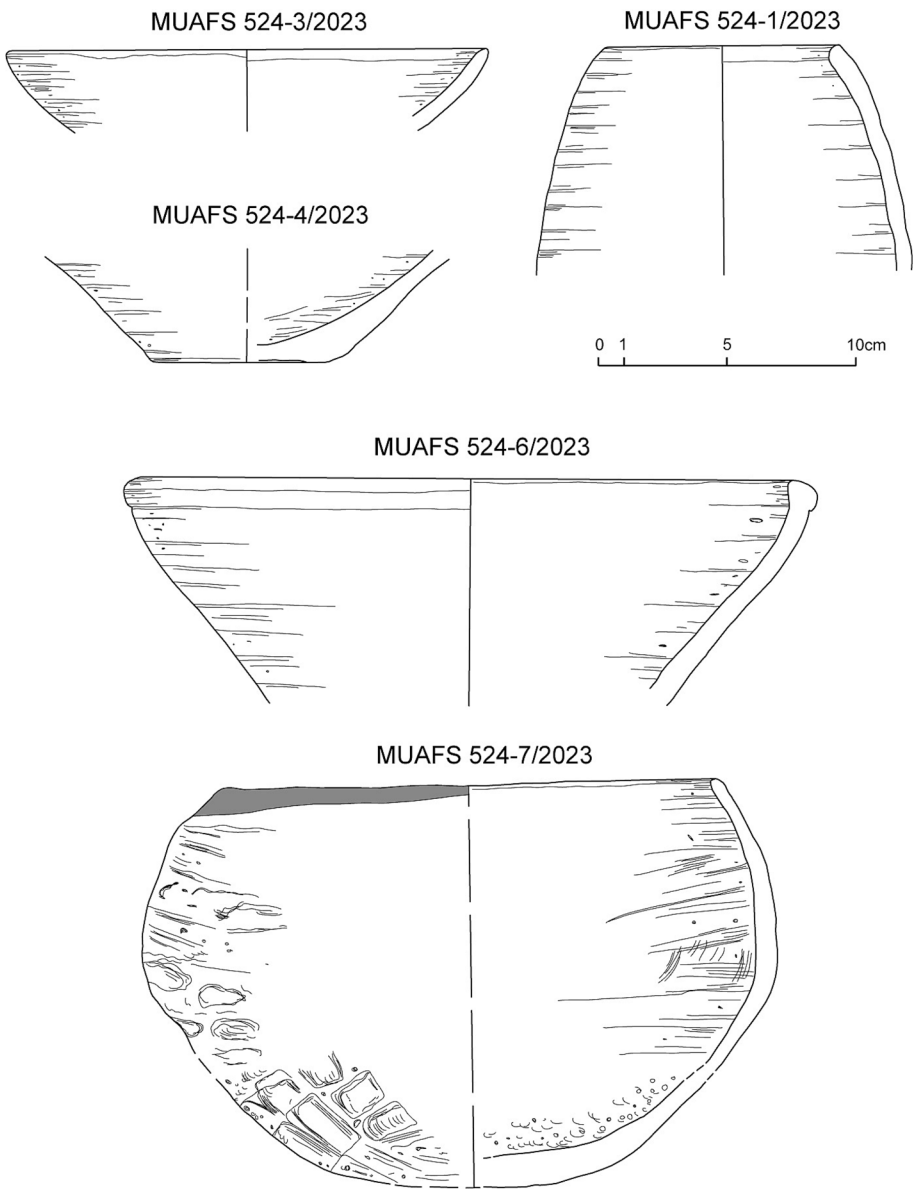

Fig. 13. Examples of Egyptian style and Kerma style pottery from site Attab West 002 (MUAFS 524/2023). Drawings by J. Budka.

entanglement, blending, as well as those of cultural (and technological) continuity and preservation.

Overall, our *longue durée* study shows that certain technological traditions not only persevered over several millennia, but also within communities/societies with very different social and hierarchical complexity and settlement organisation. Examples include the use of Nile alluvial clay from the Abkan through to the Pre-Kerma and later historical periods, as well as the invention of burnishing, a commonly used surface treatment in most Nubian wares no matter the period.

Furthermore, it is interesting to observe that, despite the fact that populations producing Khartoum Variant ceramics and members of the Abkan culture probably re-occupied the same settlements (at least in the Attab-Ferka region) and may even have coexisted at certain times — as evidenced by the chronologies of sites 8-B-76 and 8-B-10C at Sai Island — their ceramic traditions appear to differ in numerous respects (choice of clay raw materials, technological and decorative styles). This suggests that any relationship between those producing Khartoum Variant ceramics and the Abkan population did not noticeably effect their respective material culture (or at least not in a way that is traceable in the archaeological record) and these groups possibly lacked any meaningful social interaction and cultural permeability. Conversely, the material evidence from the Late Bronze Age period, as observed at the colonial town of Sai Island and in its hinterland points to a certain degree of social learning and fluidity in ceramic traditions among Nubians and even between Egyptians and Nubians (particularly in the selection of raw materials and clay preparation while to a lesser extent in decorative style and surface treatments of the vessels). This observation leads us to speculate that during this later period — characterised by enhanced social complexity — cultural entanglement and the transmission of technological knowledge may have been more pronounced. It is reasonable to assume that this had already begun during the period of the A-Group and Pre-Kerma cultures, and continued during the Middle Nubian C-Group, Pan-Grave, and Kerma periods in Sudan (cf., de Souza and Ownby, 2022).

Regarding the geographical scope of our study, it is noteworthy that in the sites situated in the MUAFS concession area, Abkan pottery has been found in relatively large quantities. This is in stark contrast to the limited amount of Abkan sherds on Sai Island, suggesting a potentially more prominent Abkan presence in the Attab-Ferka region, which requires further exploration in order to understand the reasons behind this

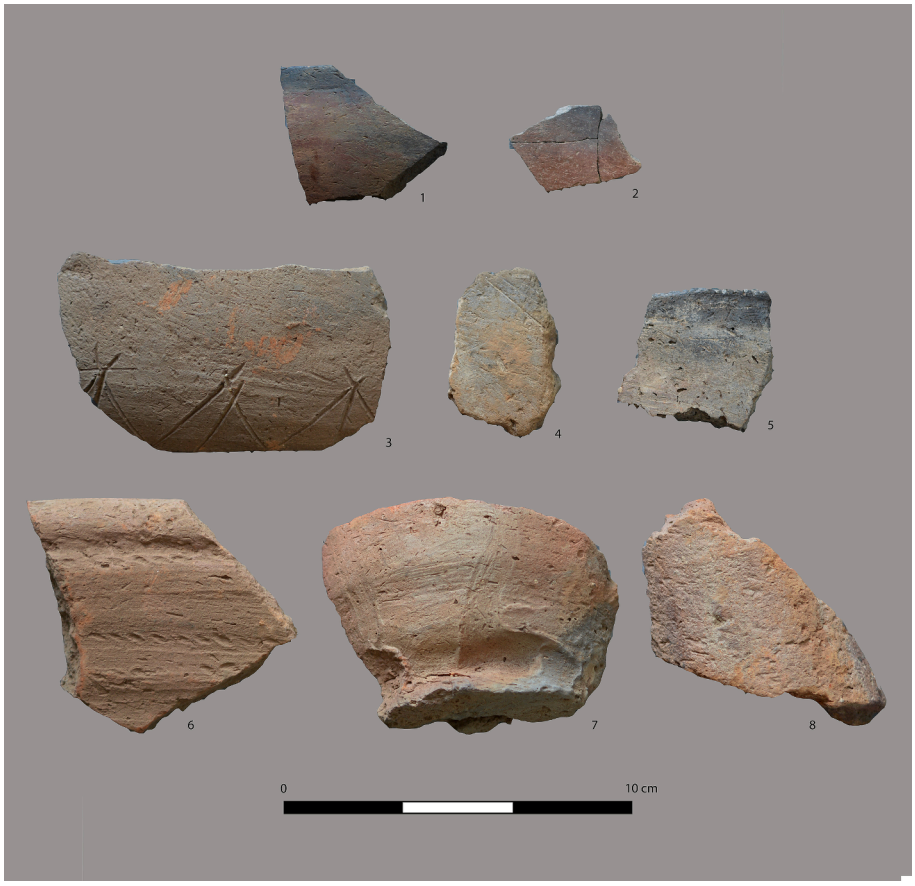

Fig. 14. Examples of Nubian style (top, middle) and Egyptian style (bottom) sherds from site 2-S-43N. Photo by G. D'Ercole.

uneven distribution and perhaps different settlement strategies.

It is evident, given the range and potential of laboratory techniques for ceramic studies, that bulk compositional analyses — such as instrumental neutron activation analysis (iNAA) — are effective for the analysis of a large dataset encompassing a broad historical and geographical context. However, in instances where the sample is limited in size and scope, whether in terms of chronology or geography, this technique may not yield effective results. In such cases, it is advisable to resort to alternative methods, such as optical microscopy and mineralogical analysis, to obtain more reliable and informative results. Generally, it is through repeated experience and analysis that we recognised the significance of implementing a comprehensive range of archaeometric analyses — both inorganic and organic — in order to better understand technological and cultural shifts (and continuities) across a vast temporal and geographical expanse.

CRediT authorship contribution statement

Giulia D'Ercole: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Julia Budka:** Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Elena A.A. Garcea:** Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2025.105232.

Data availability

Data have been shared as Supplementary File.

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