

# Raman analysis of the white pigment used for decorating Caliciform beakers

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**Abstract** – This study tries to identify the component of the white pigment used in the so-called ‘caliciform beakers’, referring to the preliminary pottery analyses conducted by the author using a Raman spectrometer and a microscope. The results of the archaeometric analyses are considered ethnographically to see what pottery vessels were for the people and how a particular pottery decoration technique was conveyed in northeastern Africa during the Neolithic period. This study sheds light on the meaning of pottery vessels for the people and the information flow in northeast Africa during the late Neolithic period.

## I. INTRODUCTION

Caliciform beakers, also known as ‘Tasian beakers’ [1], are thought to have developed in Upper Nubia, i.e. Kerma [2], Kadruka 21 [3], and Kawa in the Northern Dongola region [4] around the first half of the fifth millennium BCE [5]. These beakers have convex bases and flared rims, although a few examples with flat bottoms were also registered [1]. Their surfaces are usually richly decorated with geometric designs that were either incised or impressed [5]. Some examples exhibit the incision or impression inlaid by white pigments (Figures 2 and 4). Caliciform beakers disappeared by the beginning of the fourth millennium BCE, except for some beakers categorised into ‘black incised ware’ in Petrie’s classification system [6].

Caliciform beakers showing inlay decoration have been found only at limited sites, and the currently available radiocarbon dating results suggest they might have appeared slightly later in Central Sudan than in Upper Egypt.

These beakers represent the first kind of pottery to exhibit decoration with colourant pigments in Sudan, Nubia [7, 8], and Egypt, aside from the use of ochre as slip and/or temper [6]. The inlay on caliciform beakers was composed of white or yellow pigments [5, 9]. The report of R12 says that the yellow pigment filling in incised lines on the caliciform beaker was ochre [9], though the materials used as the white pigment remain unknown. The reasons for the selection of white or yellow pigments for the inlay have not been discussed.

The white pigment seen on white cross-lined ware (C-ware) in Petrie’s classification system [10], which appeared in Upper Egypt during the first half of the fourth millennium BCE, is thought to have been calcite or gypsum [11], though it has not been chemically analysed.

## II. PREVIOUS CHEMICAL ANALYSIS OF THE COLOURANT PIGMENT ON NEOLITHIC POTTERY IN NORTHEAST AFRICA

Only one analysis on white pigment has been conducted by the Université de Bordeaux III with cathodoluminescence (CL), x-ray fluorescence (XRF), and x-ray diffraction (XRD) [12]. This study using cathodoluminescence microscopy revealed that the mineral of the whitish surface, caused by post-depositional effects, was calcite. The researchers argue that the white pigment for the inlay decoration on the pottery vessels found at el-Kadada could not be measured by a CL microscope but was measured by an XRF microscope, and subsequently identified the pigment as kaolinite. It is not certain if XRF could properly measure the white pigment since the XRF measurement result is largely affected by the surface preparation of the examined object [13]. One author of this report announced in a later study that the white pigment used for the inlaid decoration on caliciform beakers found at el-Kadruka, a site contemporary with el-Kadada, is ‘gypsum’ [14].

## III. ANALYSIS OF THE WHITE PIGMENT BY RAMAN SPECTROMETRY

### A. Raman Spectrometry analysis of the white pigment on Caliciform beakers from Northeast Africa

Due to the limited number of caliciform beakers with inlaid decoration, the aim of this chemical analysis is not to detect the deposit of material but to identify the material of the white pigment. Based on the following three main reasons, it was assumed that the chemical component or material of the white pigment on caliciform beakers is either kaolinite, as in the previous study [13], or human or animal bones.

- ♦ The white pigment on white cross-lined ware that appeared in Upper Egypt in the first half of the

fourth millennium BCE has been thought to be calcite or gypsum [14], though this hypothesis has not been chemically analysed.

- Most caliciform beakers with inlaid decoration have been discovered in burial pits, while those without the inlaid decoration have been found in other archaeological contexts outside of burial pits. Several researchers have suggested that caliciform beakers are related to nomadic people roaming desertic areas to take refuge in ecologically favourable areas such as the oases and the Nile Valley [14, 15].
- The rock paintings found in the Western Desert of Egypt are the first colourful rock paintings in Sudan, Nubia, and Egypt that also include white pigments [16]. They are thought to be associated with nomadic cultures around 4400–3500 cal. BCE, as they depict cattle herding [16, 17].

The Yixi Portable 785 Raman Spectrometer, YOA-8401-785-02, was used to conduct this component analysis of white pigment.

Case 1: a caliciform beaker found at Grave 113 at Kadero (in Sudan) and stored at the Poznań Archaeological Museum (*MAP/DEP 1992:1/1*).

The white pigment on the incised lines is visible, though it could not be measured because of the whitish surface caused by the post-depositional effect.

Case 2: a caliciform beaker found at Grave 114 at Kadero and stored at the Poznań Archaeological Museum (*MAP/DEP 1992:5/9*) (Figure 2).

One of two caliciform beakers found at Grave 114.

Case 3: a caliciform beaker found at Grave 114 at Kadero and stored at the Museum of Fine Arts Boston (*2014.514*).

Another one was found at Grave 114 together with the one, Case 2.

Case 4: a caliciform beaker found in Upper Egypt (find location is unknown) and stored at the Petrie Museum (UC17869).

This pottery has been published, and Petrie categorised this into ‘black incised ware’ [10, 18].

Case 5: a caliciform beaker found in Upper Egypt (find location is unknown) and stored at the Petrie Museum (UC17870).

This pottery has not been published and is categorised as ‘black incised ware’ in the Petrie Museum’s online catalogue.

Case 6: a caliciform beaker purchased at Luxor (find location is unknown) and stored at the Egyptian Museum in Tahrir (*J. d’E. 62931*) (Figure 4).

This pottery has been published by Brunton [1]. The surface is black, which could be categorised into ‘black incised ware’ in

Petrie’s classification.

Case 7: a caliciform beaker purchased at Luxor (find location is unknown) and stored at the Egyptian Museum in Tahrir (*J. d’E. 62933*).

This pottery has been published by Brunton [1]. The bottom is flat.

Case 8: a caliciform beaker purchased at Luxor (find location is unknown) and stored at the Egyptian Museum in Tahrir (*J. d’E. 62935*).

This pottery has been published by Brunton [1], though Brunton did not mention that this example shows white inlaid decoration.

Only one black-topped pottery vessel was among the vessels dealt with in this study.

The analyses of Cases 1 and 2 were conducted at the Poznań Archaeological Museum in Poznań, Poland. The analysis of Case 3 was carried out at the Museum of Fine Arts Boston, USA. The analyses of Cases 4 and 5 were conducted at the Petrie Museum of Egyptian and Sudanese Archaeology in London, United Kingdom. And, the analyses of Cases 6, 7 and 8 were made at the Egyptian Museum in Tahrir, Egypt. No samples were taken as these analyses were non-destructive.

## B. Results

### An analysis of the results from Cases 1 and 2

The surface of the two specimens from Kadero in Sudan is covered in a whitish-brown colour. Donatella Usai explains that it resulted from the post-depositional alterations of minerals on the pottery surface (personal comm. January 2024). Notwithstanding that the whitish-brown colour prevented the Raman spectrometer from measuring the Raman spectra of the white pigment on the caliciform beaker from Grave 113, the measurements could be conducted on the one from Grave 114 (Figure 2, Case 2).

The Raman spectra of the white pigment show bands of 250–280cm<sup>-1</sup>, 390cm<sup>-1</sup>, 500–520cm<sup>-1</sup> and a missing band around 1050–1100cm<sup>-1</sup> (notice the two middle spectra in Figure 3). From these results, I postulate that calcium carbonate was used as a material for the white pigment used in the inlay decoration seen on some caliciform beakers, at least for the ones found at Kadero. Several kinds of freshwater mussels and snails inhabited the Nile at that time [19], the shells of which are made for more than 90 % of calcium carbonate [20, 21]. Even though calcium carbonate is contained in mammal (e.g. bovid) bones, it accounts for 10% of the total bone constituents [22]. Calcium carbonate (CaCO<sub>3</sub>), as found in shells, freshwater snails, and ostrich eggshells, decomposes on heating to form calcium oxide (CaO) and carbon dioxide from ~650 °C to completion at ~765 °C [23]. CaO is sintered under an inert atmosphere in the temperature range between 700–1400 °C [24]. Calcium oxide reacts with water vigorously. When water is added to calcium oxide, an exothermic reaction

occurs, producing calcium hydroxide ( $\text{Ca}(\text{OH})_2$ ) and a large amount of heat.

The firing temperature of pottery production in the Neolithic period is estimated to have been between 600–900 °C [25]. Therefore, if calcium carbonate from shells had been used for the inlay decoration on caliciform beakers, calcium carbonate could have been decomposed to calcium oxide and even sintered during the pottery firing. In the Raman spectrum of calcium carbonate ( $\text{CaCO}_3$ ) (calcite, aragonite, and vaterite), bands appear at 206–299 $\text{cm}^{-1}$ , 660–750 $\text{cm}^{-1}$ , and 1070–1090 $\text{cm}^{-1}$  [26, 27]. The Raman spectrum of calcium oxide ( $\text{CaO}$ ) indicates most visible at the peaks at 366 $\text{cm}^{-1}$  and 653–700 $\text{cm}^{-1}$  [28]. Sintered  $\text{CaO}$  shows additional peaks at 390 $\text{cm}^{-1}$ , 464 $\text{cm}^{-1}$ , and 522 $\text{cm}^{-1}$ , even though a peak at 1070  $\text{cm}^{-1}$  disappears [28].

It can be estimated that the white pigment was originally carbon carbonate (e.g. ground shell, freshwater snails, and ostrich eggshell). It could have been partially decomposed to calcium oxide and altered to sintered calcium oxide in the firing process of pottery production. The Raman spectra of the white pigment (the two middle spectra out of the four in Figure 3) seem to reflect the transitional phases from carbon carbonate to calcium oxide and sintered calcium oxide.

#### An analysis of the result from Case 3

The whitish-brown colour prevented the Raman spectrometer from measuring the Raman spectra of the white pigment on this caliciform beaker, though another caliciform beaker from the same grave (Case 2) did allow the acquisition of Raman spectra from the white pigment. This indicates that slight differences in surface condition affect the results of the Raman analysis.

#### An analysis of the result from Case 4

The Raman spectra of the white pigment show bands 250–280 $\text{cm}^{-1}$ , 390 $\text{cm}^{-1}$ , 500–520 $\text{cm}^{-1}$  and a missing band around 1050–1100 $\text{cm}^{-1}$ , as the caliciform beaker found at Grave 114 at Kadero (Case 2). The main difference is the lack of a whitish surface caused by the post-depositional effect, which does not exhibit any excitation bands at around 1350 and 1600 $\text{cm}^{-1}$ . On the contrary, Case 2 exhibits these bands, which indicates that the black part is soot. As this vessel was grouped into the so-called ‘black incised ware’ by Petrie [10], the black part of this vessel was the result not of soot but of reduced firing temperature during pottery production.

#### An analysis of the result from Case 5

The Raman spectra of the white pigment show bands 250–280 $\text{cm}^{-1}$ , 410 $\text{cm}^{-1}$ , 500–520 $\text{cm}^{-1}$  and a missing band around 1050–1100 $\text{cm}^{-1}$ , a similar result to Cases 2 and 4 except for the band at around 410 $\text{cm}^{-1}$ . This vessel was grouped into the so-called ‘black incised ware’ on the museum’s online catalogue.

#### An analysis of the result from Case 6

The Raman spectra of the white pigment show bands 250–280 $\text{cm}^{-1}$ , 410 $\text{cm}^{-1}$ , 500–520 $\text{cm}^{-1}$  and a missing band around 1050–1100 $\text{cm}^{-1}$ , a similar result to Cases 2 and 4. Furthermore, weak excitation can be seen at Sintered  $\text{CaO}$  shows additional peaks at 464  $\text{cm}^{-1}$ , and 522  $\text{cm}^{-1}$ , which may indicate sintered  $\text{CaO}$  [28], which might have resulted from the firing process.

#### An analysis of the result from Case 7

The Raman spectra of the white pigment show bands 250–280  $\text{cm}^{-1}$ , 410  $\text{cm}^{-1}$ , 500–520  $\text{cm}^{-1}$  and a missing band around 1050–1100  $\text{cm}^{-1}$ , a similar result to Cases 2 and 4.

#### An analysis of the result from Case 8

The Raman spectra of the white pigment show bands of 250–280 $\text{cm}^{-1}$ , 390 $\text{cm}^{-1}$ , 500–520 $\text{cm}^{-1}$  and a missing band around 1050–1100 $\text{cm}^{-1}$  (notice the two middle spectra in Figure 3).

The Raman spectra of the white pigments yielded similar results in all cases, except for two samples where measurement was not possible due to post-depositional surface alteration (Cases 1 and 3). The Raman spectra indicate that the component of the pigment is sintered  $\text{CaO}$ . The results also suggest that the pigment was inlaid prior to firing the vessels, with the firing temperature exceeding 700°C [24].

Other external factors, such as binders, soot, and post-depositional alteration, can affect the Raman spectrum of the white pigment on caliciform beakers [29].

#### IV. A MICROSCOPIC ANALYSIS OF THE WHITE PIGMENT: METHODS OF THE INLAY DECORATION ON CALICIFORM BEAKERS

A microscope analysis (x20) and observation with the naked eye were conducted on the above-mentioned four caliciform beakers (Cases 1, 2, 4, and 5), as well as the one found at el-Badari, now stored at the British Museum (BM EA 59723) and the one purchased at Luxor, now stored at the Egyptian Museum in Tahrir (*J. D'E* 62931) (Figure 4).

Incised lines in triangles filled with white paste are visible on the surfaces of the caliciform beakers from Upper Egypt. Under the randomly remaining white paste, we can see lightly incised lines. Brunton [1] describes “these triangles were cross-hatched or lightly scored not as a decorative element but to give a grip for a paste of white pigment, and that the pattern meant to be shown was a solid white one.” This means that the potters at el-Badari in the Neolithic period had an intention to inlay the white pigment on the triangles, and they incised the random light lines inside the triangles

as a prior processing. Friedman [30], furthermore, reports on the one (BM EA 59723) as having white-coloured triangles inside the rim that were embellished with a series of dots in red paint.

In the case of Sudan, the incised lines under the white pigment inlay were accompanied by fine dots, as one can see in Figure 2. Each dot's size in the incised lines is about or under 1mm. It is still unclear how these incised lines and fine dots were drawn. Although Arkell and Chłodnicki suggest catfish spines as a tool to make wavy lines decoration on the pottery surface [31, 32], they did not mention the tool for incised decoration on caliciform beakers. As in el-Badari, the incised lines with fine dots on the caliciform beakers from Kadero might have helped keep the white pigment in the lines, perhaps a special preprocessing for the inlay decoration.

El-Badari is dated to c. 4400–4000 cal. BC and the cemetery at Kadero is estimated to have been used between c. 4450 and 3900 cal. BC [33, 34]. They are simultaneous sites even though el-Badari was located in Middle Egypt, while Kadero is near the Sixth Cataract, in modern-day Sudan. This means that the difference in the inlay technique is not a chronological difference but a regional variation.

## V. HOW WAS A PARTICULAR DECORATION TECHNIQUE CONVEYED?

The distance between Kadero and el-Badari is c. 1550 km. How was the decoration technique distributed between the long-distance sites?

Here, I drew a schematic depiction to indicate the possible distribution patterns of a technique in northeastern Africa in the Neolithic period. The Alphabet letters in the depiction indicate the point of origin and the place of receipt of the information, while the numbers mean the person at the source or the recipient. Exchange information is indicated by a cross, and the territorial boundaries by a broken line.

In the Late Neolithic period, there were places such as Oasis where pastoralists and hunting people used. But there is no archaeological record to indicate that such an Oasis played a central role in exchanging information and goods. The first scenario shows that potters or people who could produce pottery travelled 1550 km away and produced pottery vessels even at the place where they moved to. The second scenario shows that potters or people who could produce pottery went to another site, which is 1500 km away from their home site. After they produced pottery or taught how to produce the vessels at the travel destination site, they went back to their home site. The third scenario indicates that the potters from both sites met at arbitrary but water-friendly sites and exchanged their information about pottery production. And they went back to their

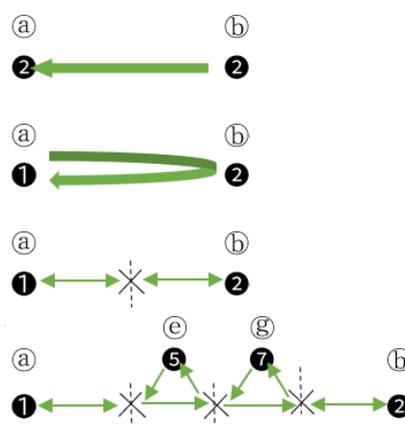


Fig. 1. Four possible modes of transferring information in the northeast African in the Neolithic period.

home site. The fourth scenario expresses that the information regarding pottery decoration method was conveyed from site **a** to site **b** by mobile groups of people who lived at the camp sites between sites **a** and **b** seasonally or periodically. The number of mediating groups can be any in this scenario.

Referring to Binford's theory of residential movements and logistic movements [35], it seems unlikely that a particular hunting-gathering-foraging group in northeastern Africa in the Neolithic period moved over 1500 km or even half of the distance [36]. If so, the first, second and third scenarios are improbable. It can be assumed that the fourth scenario is the most reasonable way in which the pottery decoration technique was conveyed, though **1** and **2** were possible to move somehow like **5** and **7** because Kadero and Badari are estimated to have adopted mixed subsistence strategies [32, 34].

If we think so, the inlay technique could have been passed down by word of mouth between the sites 1500 km apart from each other. As a result, the information of the inlay technique was conveyed partially: the peculiar gourd-like form of caliciform beakers was conveyed, though the neckline of the Egyptian examples is looser than that of the Nubian and Sudan ones. In addition, the inlay decoration with white pigment made of ground shells was seen in both Badarian and Kadero examples, even though the inlay techniques were obviously different.

In Sudan and Nubia, there were only caliciform beakers, the surface colours of which are reddish slipped. In Egypt, there are caliciform beakers with inlay decoration, the surface colours of which are black, black-topped, and red slipped. This could be rather regional differences because blackish or black-topped

surface pottery vessels were presented in Sudan and Nubia, though they were not caliciform beakers.

#### VI. CONCLUDING REMARKS

This Raman study reveals that the white pigment used for the inlay decoration of caliciform beakers was  $\text{CaCO}_3$ , which was not different between the caliciform beakers found in Kadero (Sudan) and those purchased in Luxor or found in Upper Egypt.

Microscopic analyses reveal that the inlay techniques were different between the Kadero examples and those from Egypt. Additionally, the caliciform beakers from Sudan and Nubia have a noticeably slimmer neck compared to their Egyptian counterparts.

This study suggests that the two visually apparent differences between Sudan-Nubia and Egypt may result from the dispersed distribution of information in northeast Africa during the Neolithic period.



Fig. 2. Caliciform beakers from Grave 114, Kadero (Case 2), picture by this author, courtesy of the Poznan Archaeological Museum.

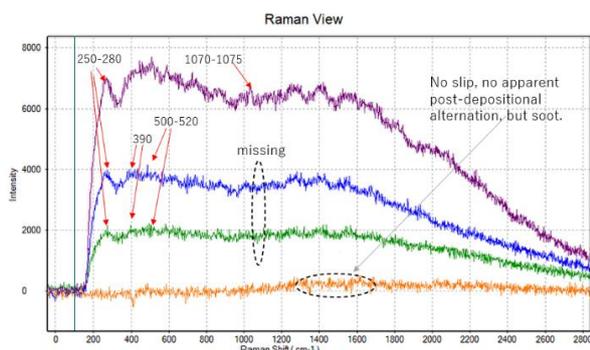


Fig. 3. The Raman spectra of Case 2: the top spectrum is from the whitish surface caused by the post-depositional effect, the second and third ones from the top are from the white pigment inside the incision, and the bottom one came from the shoots on the external wall.



Fig. 4. The caliciform beaker purchased in Luxor, stored at the Egyptian Museum in Tahrir (J. d'E. 62931), picture by this author, courtesy of the Supreme Council of Antiquity.

#### REFERENCES

- [1] Brunton, G. 1934. Some Tasian Pottery in the Cairo Museum. *ASAE XXXIV*: 94-96. Cairo: Service des Antiquités de l'Égypte
- [2] Reinold, J. 1994. Les Sepultures Primitives De Sedeinga Dans Le Contexte Du Néolithique Soudanais. In: C. Berger, G. Clerc, and N. Grimal (eds), *Hommages à Jean Leclant ii. Nubie, Soudan, Éthiopie, (BiEtud 106/2)*: 351-359. Cairo: Institut Français d'Archéologie Orientale.
- [3] Reinold, J. 2001. Kadruka and the Neolithic in the Northern Dongola Reach. *Sudan & Nubia 5*: 2-14.
- [4] Salvatori, S. 2008. Pottery for the Dead: A Survey of the Ceramic Grave Goods. In S. Salvatori, and D. Usai (eds). *A Neolithic Cemetery in the Northern Dongola Reach, Excavations at Site R12, (BAR IS 1814)*: 9-18. Oxford: BAR Publishing.
- [5] Longa, A. 2011. Neolithic Beakers from North-Eastern Africa. *Sudan & Nubia 15*: 13-17. London.
- [6] Sanada, S. 2024. Emulation in Painted Pottery Styles in Egypt in the Prehistoric Period. *Studies in Ancient Art and Civilization 27*: 47-75. Krakow.
- [7] Adams, W.Y. 1977. *Nubia: Corridor to Empire*: 300-303. London.
- [8] Török, L. 2009. Between two worlds: the frontier region between ancient Nubia and Egypt, 3700 BC -500 AD. *Probleme der Ägyptologie 29*. Brill. Leiden.
- [9] Salvatori, S. and Usai, D (eds). 2008. *A Neolithic Cemetery in the Northern Dongola Reach, Excavations at Site R12, (BAR IS 1814)*: 9-18. Oxford: BAR Publishing.
- [10] Petrie, W.M.F. 1921. *Prehistoric Egypt with Corpus*

*of Prehistoric Pottery and Palettes*, (Egyptian Research Account 32 years). London: British School of Archaeology in Egypt, London.

[11] Petrie, W.M.F. and Quibell, J.E. 1896. *Naqada and Ballas*. London: B. Quaritch.

[12] Piponnier, D., Bechtel, F., Schvoerer, M., and Reinold, J. 1995. Concretionnement ou Application Volontaire de Minéraux Sur des Céramiques Néolithiques de La Vallée du Nil Soudanais. *Archéologie du Nil Moyen* 7: 191-201.

[13] Speakman, R.J., Little, N.C., Creel, D., Miller, M.R., and Iñáñez, J.G. 2011. Sourcing Ceramics with Portable XRF Spectrometers? A Comparison with INAA Using Mimbres Pottery from the American Southwest. *Journal of Archaeological Science* 38(12): 3483-3496.

[14] Briois, F., Midant-Reynes, B., Marchand, S., Tristant, Y., Wuttmann, M., De Dapper, M., Lesur, J., and Newton, C. 2012. Neolithic Occupation of an Artesian Spring: KS043 in the Kharga Oasis, Egypt. *Journal of Field Archaeology* 37(3): 178-191.

[15] Hendrickx, S. and Vermeersch, P.M. 2000. Prehistory from the Palaeolithic to the Badarian culture. In I. Shaw (ed.) *The Oxford Illustrated History of Ancient Egypt*: 17-43. Oxford: Oxford University Press.

[16] Riemer, H. 2009. Prehistoric Rock Art Research in the Western Desert of Egypt. *Archéo-Nil* 19: 31-46. Paris.

[17] Zboray, A. 2009. The Rock Art of Jebel Uweinat. Some Results of the Ongoing Survey." *Archéo-Nil* 19: 27-30. Paris.

[18] Midant-Reynes, B. 2014. Prehistoric Regional Cultures. In W. Grajetzki, and W. Wendrich (eds), *UCLA Encyclopedia of Egyptology*. Los Angeles.

[19] Graf, D.L. and Cummings, K.S. 2007. Preliminary review of the freshwater mussels (mollusca: bivalvia: unionoida) of northern Africa, with an emphasis on the Nile, *Journal of the Egyptian German Society of Zoology* 53D: 89-118. Cairo: Cairo University.

[20] Chakraborty, A., Parveen, S., Chanda, D.K., and Aditya, G., 2020. An insight into the structure, composition and hardness of a biological material: the shell of freshwater mussels, *RSC Adv.*: 29543.

[21] White, M.M., Chejlava, M., Fried, B., and Sherma, J., 2007. The concentration of calcium carbonate in shells of freshwater snails. *American Malacological Bulletin* 22(1):139-142. The Sheridan Press. Sheridan.

[22] Supriadi, S., Rahmawati, S., Aminah, S., Ningsih, P., Hastuti, S., Said, I., and Setyawati, A. 2021. Analysis of Calcium Levels in Beef Bones from Kaledo Waste. *Journal of Physics, Conference Series* 1763: 012061.

[23] Bilton, M., Brown, A.P., and Milne, J.S. 2012. Investigating the Optimum Conditions for the Formation of Calcium Oxide, Used for CO<sub>2</sub> Sequestration, by Thermal Decomposition of Calcium Acetate. *J. Phys.: Conf. Ser.* 371: 012075.

[24] Maya, C.J., Chejne, F., Bhatia, S.K., and Gómez, C.A., 2018. Effect of the CaO Sintering on the Calcination Rate of CaCO<sub>3</sub> under Atmospheres containing CO<sub>2</sub>. *AIChE J.* 64: 3638-3648.

[25] Gosselain, O.P. 1992. Bonfire of the Enquiries. Pottery Firing Temperatures in Archaeology: What For? *Journal of Archaeological Science* 19: 243-259.

[26] Donnelly, F.C., Purcell-Milton, F., Framont, V., Cleary, O., Dunne, P.W., and Gun'ko, Y.K. 2017. Synthesis of CaCO<sub>3</sub> Nano- and Micro-Particles by Dry Ice Carbonation. *Chemical Communications* 53: 6657-6660.

[27] Schaible, M.J., Castañeda, A.D., Menor-Salvan, C., Pasek, M.A., Burcar, B.T., and Orlando, T.M. 2023. CaCO<sub>3</sub> Polymorphs as Mineral Catalysts for Prebiotic Phosphorylation of Uridine. *Earth and Space Science* 10(2), e2022EA002577.

[28] Capriotti, L., and Quaini, A. 2012. *High Temperature Behaviour of Nuclear Materials Investigated by Laser Heating and Fast Pyrometry*. Unpublished. Master thesis, Politecnico di Milano.

[29] Sanada, S. forthcoming. Colourant Pigments in Sudan, Nubia and Egypt in the Neolithic Period. *Current Research in Egyptology 2024 Proceedings of the Twenty-Fourth Annual Symposium, University of Liverpool*, 2024: 294-31. Archaeopress.

[30] Friedman, R. 1999. Badari Grave Group 569. In W. V. Davies (ed.), *Studies in Egyptian Antiquities: A Tribute to T.G.H. James*. (British Museum Occasional Papers 123): 1-12, London.

[31] Arkell, A.J. 1949. *Early Khartoum: An Account of the Excavation of an Early Occupation Site Carried out by the Sudan Government Antiquities Service in 1944-5*. Oxford: Oxford University Press.

[32] Chłodnicki, M. 2011. Pottery. In M. Chłodnicki, M. Kobusiewicz, and K. Kroeper. (eds), *Kadero*. (Studies of African Archaeology 10): 215-266. Poznań.

[33] Chłodnicki, M., and Kabaciński, J. 2015. Radiocarbon dates from Kadero Revised. In J. Kabaciński, M. Chłodnicki, and M. Kobusiewicz (eds), *Hunter-Gatherers and Early Food Producing Societies in Northeastern Africa*. (Studies of African Archaeology 14): 195-217. Poznań.

[34] Holmes, D.L., and Friedman, R.F., 1994. Survey and Test Excavations in the Badari Region, Egypt. *Proceedings of the Prehistoric Society* 60: 105-142.

[35] Binford, L.R. 1990. Mobility, Housing, and Environment: A Comparative Study. *Journal of Anthropological Research* 46 (2): 119-152.

[36] Habu, J. 2001. Changes in Subsistence-Settlement Systems Through the Moroiso Phase. In Habu, J., *Subsistence-Settlement Systems and Intersite Variability in the Moroiso Phase of the Early Jomon Period of Japan*: 71-97, International Monographs in Prehistory (Archaeological series 14), Michigan.