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Experimental archaeology: first steps to understanding the firing technology of Meroitic pottery from Musawwarat es-Sufra

The archaeological remains of a pottery workshop and the associated ceramics at Musawwarat es-Sufra, a sacral site of the Meroitic period (3rd century BC to 4th century AD) in Sudan, were the focus of a project carried out under the auspices of the Berlin Cluster of Excellence TOPOI to shed further light on pottery production and consumption in Musawwarat.[1]

The results of excavations undertaken between 2014 and 2015 combined with analyses of the ceramic corpus, which forms the core of the research and comprises *c.* 27,000 sherds weighing of *c.* 1000 kg, provided the basis for systematic investigations concerning the extent and organization of pottery production and ceramic technologies. These studies have allowed us to steadily improve our understanding of the development and application of technical knowledge by Meroitic potters and to learn more about the distribution of pottery. A wealth of information regarding numerous aspects of pottery production at Musawwarat es-Sufra has been obtained by integrating archaeological, archaeoceramological and ethnoceramological research with model tests[2] and experimental studies. Abridged results of these analyses have been published in several articles. The principle findings reveal that:

– almost all fine wares and most wheel-made coarse wares were made from ceramic bodies of similar chemical and mineralogical composition; these vessels were produced using different sources of clays (wadi clays, hafir clays), most of which were available in the immediate vicinity of the site[3]
– in contrast, almost all handmade coarse wares are produced of non-local raw materials and must have been imported to the site[4]
– pottery from Musawwarat was not traded or exchanged and was produced primarily for ‚local requirements'
– local coarse ware pottery (Mus 4) was fired at temperatures (Teq) above 1000°C, while local fineware pottery (Mus 1-3) was fired at 900-1000°C (fabrics tempered with white-firing aggregates of kaolinitic sandstone)
– in contrast, ceramics made from clays representing bottom deposits from local water reservoirs (hafirs) or Nile alluvial clays tempered with dung were fired at lower temperatures (700-800°C)[5]
– model tests confirmed that to improve mechanical properties of ceramics made from wadi clays, they should be tempered with kaolinitic raw materials and fired at high temperatures (*c.* 1000°C); pottery made from Nile alluvial clays will have similar mechanical properties if tempered with crushed dried donkey dung and fired at lower temperatures (700-800°C)
– in order to make vessels impermeable (regardless of the clay used) surfaces must be treated, e.g. coated with slip/paint or polished/burnished[6]
– model tests investigating the alteration effect[7] showed that:
  a) depositing a sherd in a layer of Zayal-tree (acacia) ash had no impact on the sherd's degree of vitrification; only a minimal change of shade was noted in the sherd's colour;
  b) depositing a sherd in a layer of Zamur-tree (acacia) ash affected the sherd's properties because glass-forming compounds migrated into the sherd. In consequence, a ceramic sample classified as having a slightly over-melted

1 For more about the research project "Meroitic fine ceramics: production, distribution, use", see http://www.topoi.org/project/a-6-5/. This project was conducted with funding from the Qatar-Sudan Archaeological Project between 2013 and 2015. The Berlin Cluster of Excellence TOPOI has continued to provide funding since 2013.

2 Model tests were carried out in collaboration with Ewa Bobryk of the Warsaw University of Technology (Faculty of Chemistry, Department of Chemical Technology, Advanced Ceramics Team).

3 Daszkiewicz et al. 2017.

4 Näser and Daszkiewicz 2013, Daszkiewicz and Wetendorf 2014.

5 Daszkiewicz et al. 2016.

6 Daszkiewicz et al. 2016.

7 Daszkiewicz et al. 2015.

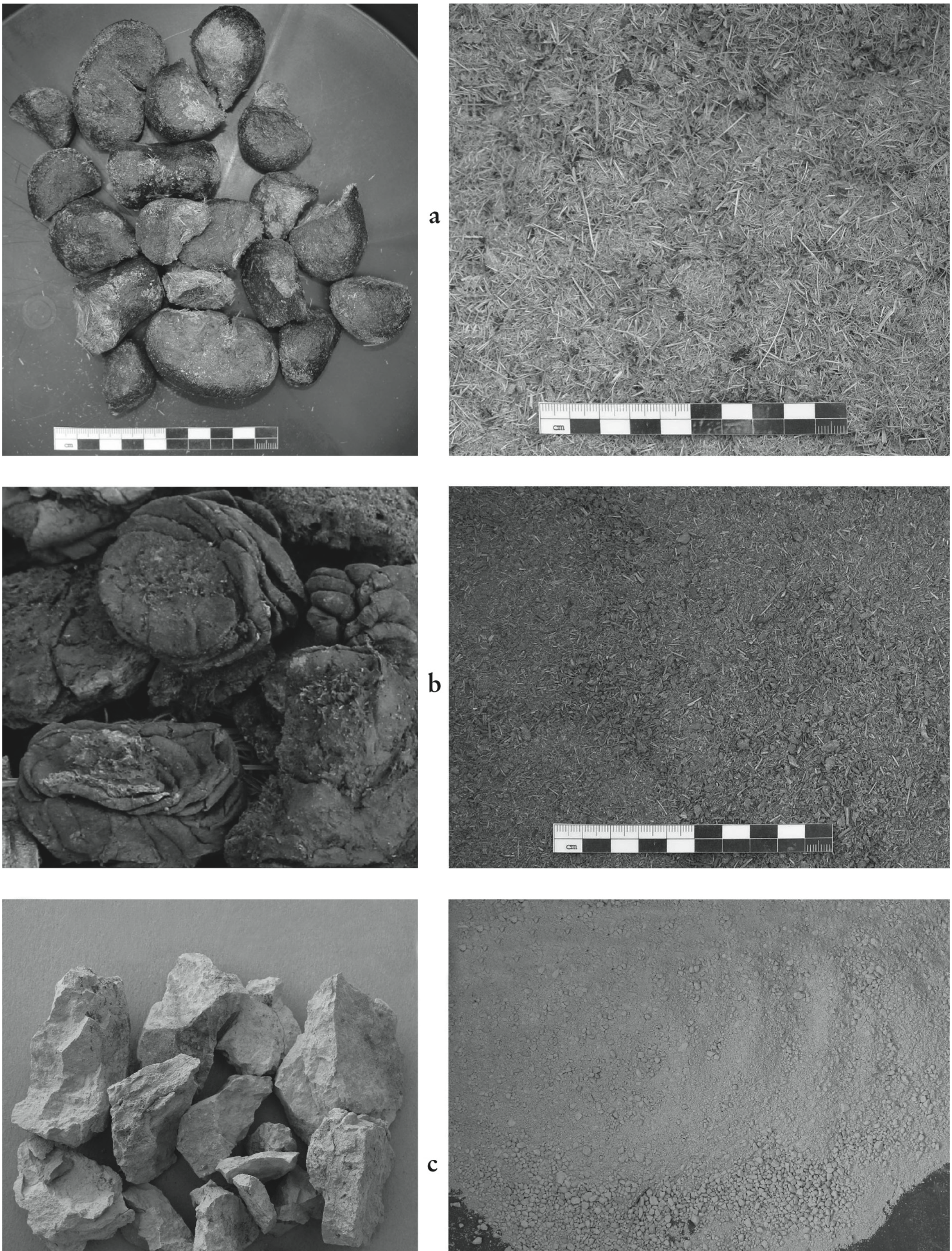

Fig. 1: Tempering materials. Left: original appearance. Right: crushed material added as temper. a = dried donkey dung collected around Musawwrat es-Sufra (AD379), b = dried cow dung collected around Musawwarat es-Sufra (AD378), c = kaolinitic sandstone taken from the foot of Gebel Ma´afer (AD241) (photos: M. Wetendorf).


Fig. 2: Pot done by M. Wetendorf before (left) and after (right) firing. Pot AD 924 (67) was fired in a bonfire fuelled with cow dung. A maximum temperature of 1050°C was measured using a thermocouple positioned in the middle of the bonfire in between the pots (photos: M. Wetendorf).

matrix type developed an over-melted matrix type after the simulation;

c) depositing a sherd in such environmental conditions as within courtyard 224 of the Great Enclosure at Musawwarat es-Sufra had no effect on its chemical composition and thermal behaviour. Identical chemical analysis and MGR-analysis results were obtained for samples both before and after the simulation.

One of the key questions concerning the organisation of pottery production at Musawwarat –namely how ceramic vessels were fired – remains unresolved. Intensive investigations undertaken to find pottery kilns accompanied by geophysical survey proved unsuccessful.[8] Since no pottery kilns were identified, further enquiries focused on whether the pottery could have been fired in bonfires and how temperatures of *c.* 1000°C could have been reached in such a fire. Ethnoarchaeological studies carried out at a contemporary pottery workshop in Shendi and features identified during excavation (wall portions which were heavily affected by fire and burn marks on several floor levels associated with the ceramic workshop area) indicate that the pottery could indeed have been fired on the spot in a bonfire.[9]

The present report details the activities of the autumn 2016 and spring 2017 seasons and discusses the results of investigations regarding the process of firing.

8 Näser and Wetendorf 2015, 67.

9 Näser and Wetendorf 2015

Experiment description

Work consisted of collecting raw material samples (plastic raw materials and materials which could have been used as temper) and various types of fuel, making pots and then firing them.[10] These fired vessels were subsequently analysed in the laboratory.
The following raw materials were used in the experiment:

Plastic materials (clays)

– material dug out from the Great Hafir (II H) at Musawwarat es-Sufra – this raw material is used today by a local potter and is known as hafir clay (AD291);

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Fig. 3: Experimental firing. a = supplying fuel; b = preparing the bonfire; c = positioning the thermocouple; d = firing; b = acacia wood used as fuel, c – d = cow dung used as fuel (photos a – b: M. Daszkiewicz, c – d: M. Wetendorf).

- wadi clays from the foot of the small quarry located in the Wadi Ma´afer to the east of Musawwarat es-Sufra,. Samples were taken from three different spots (upper layer, lower layer of a basin as well as another basin southwest of the first one).

Non-plastic materials (temper)

- kaolinitic sandstone from the foot of Gebel Ma´afer (AD241);
- dried cow dung from various places at Musawwarat es-Sufra (AD378);
- dried donkey dung collected at Musawwrat es-Sufra (AD379).

Figure 1 shows three different types of temper (a = donkey dung; b = cow dung; c = kaolinitic sandstone).

Fuel

- dried cow dung from various places at Musawwarat es-Sufra;
- dried donkey dung from various places at Musawwrat es-Sufra;
- dried twigs/branches of different species of Acacia (Zelam, Zamur and Zayal) from the valley of Musawwarat in front of Gebel Morgul
- dried grasses from the valley of Musawwarat es-Sufra;
- charcoal briquettes bought in Kabushiya.

Vessel preparation

The clays were soaked in bowls by adding 500 ml of water[11] per 1 kg of clay (dry weight) and treated (wedged and punched) to produce a plastic material. Five different ceramic bodies were prepared from each clay type:
T1 = without intentional temper;
T2 = with the addition of donkey dung as a pore-forming agent, excess addition of wt.5%;
T3 = with the addition of cow dung as a pore-forming agent, excess addition of wt.5%;
T4 = with the addition of crumbled kaolinitic sandstone, wt.5%;

11 The vessels were made in Khartoum. Ceramic bodies were made up using water from the mains water supply.

Fig. 4: Experimental firing. a = firing and recording readings; b = firing pots in a bonfire fuelled with acacia wood; c = removing the fired pottery; d = removing ash from the bonfire; the underlying ground is visibly discoloured (photos a – b, d: M. Wetendorf, c = Mohamed Mohamed el-Tayeb Badri).

T5 = with the addition of crumbled kaolinitic sandstone and with the addition of donkey dung as a pore-forming agent, excess addition of wt.5%.

A total of 89 vessels were produced. These were handmade using the pinch technique.

The surface of 68 vessels was left untreated. The outer surface of 21 vessels was coated with slip or paint and/or polished. When the vessels had dried, the height and maximum diameter of each one was measured. Figure 2 shows a vessel made of wadi clay tempered with both donkey dung and kaolinitic sandstone before and after firing in a surface bonfire at a maximum temperature of 1050°C.

Vessel firing

Eleven firings were carried out in total:

- vessels fired in a surface bonfire using various fuels (donkey dung, cow dung, Acacia twigs, dried grasses, charcoal briquettes);
- vessels fired in a surface bonfire using various fuels (donkey dung, cow, dung, Acacia twigs, dried grasses, charcoal briquettes); pottery fragments were placed around the edges of the fire;
- vessels fired in a pit using cow dung as fuel. A bedding layer of fuel was placed at the bottom of an unlined pit. The pots were placed on top of this layer and more fuel was packed over them.

The various stages involved in preparing a surface bonfire for open firing (building a fuel stack directly on the ground surface, arranging vessels on top of it, placing thermocouples in between the pots, covering the whole structure with more fuel), firing pottery and measuring temperature can be seen in figures 3 and 4. Temperature measurements were taken from the moment the fire was lit until the bonfire had cooled down. The vessels were removed from the ashes once the fire had cooled down. Thereafter their height and maximum diameter was measured.

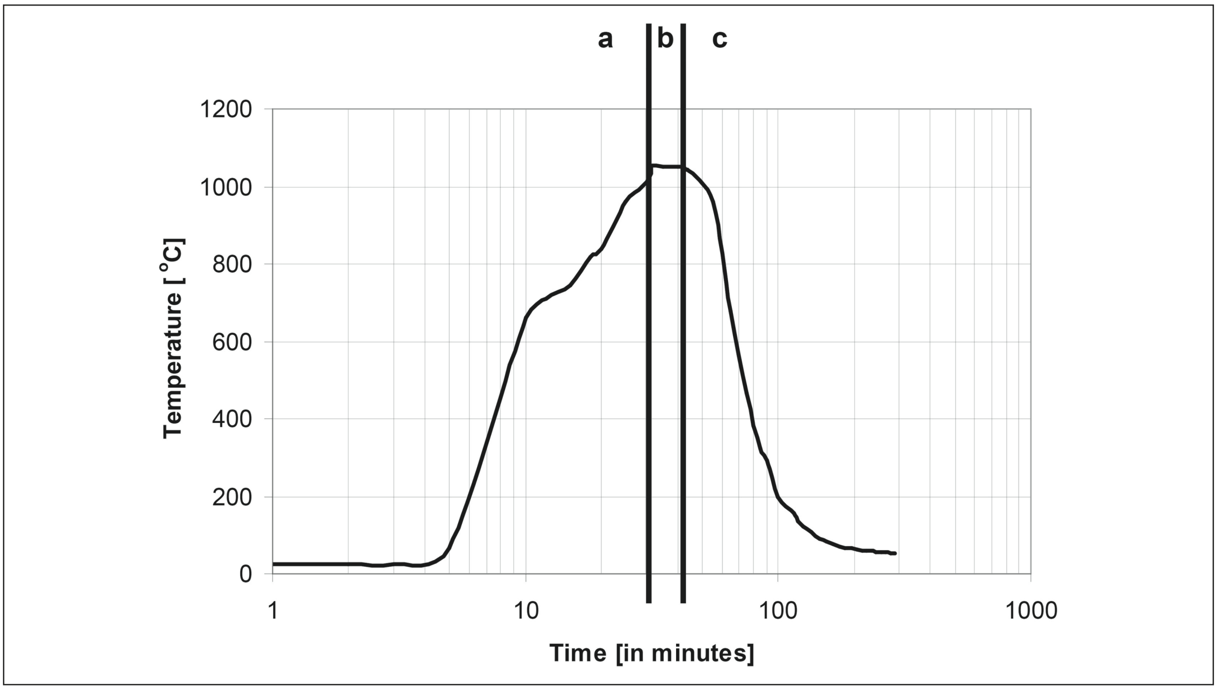

Fig. 5: Results of thermocouple measurements. Bonfire fuelled with cow dung. a = heating phase; b = isothermic heating; c = cooling phase. (M. Daszkiewicz)

Analysis of the fired vessels

The following procedures were carried out: calculation of linear shrinkage, K-H analysis[12], full MGR-analysis, X-ray diffraction and chemical analysis by WD-XRF.

Results

Thermocouple measurements revealed that the highest temperature was reached in a fire fuelled by cow dung. Three firings were carried out using cow dung as fuel; the respective maximum temperatures attained in these bonfires were 1050°C, 1040°C and 975°C. Figure 5 shows a curve illustrating temperature changes over time (time in minutes, logarithmic scale) for the open firing which attained a maximum temperature of 1050°C. The heating phase (Fig. 5a) lasted 35 minutes. Ten minutes after the fire had been lit the temperature reached 660°C. After 30 minutes it had risen to 1000°C and after 35 minutes to 1050°C. Isothermal heating at the peak temperature (Fig. 5b) lasted 10 minutes. The cooling phase lasted 4 hours 10 minutes (Fig. 5c) and the final reading was taken when the temperature had dropped to 50°C.

Using chaff as a fuel yielded a maximum temperature of 760°C. Acacia twigs gave a result of 710°C, donkey dung 825°C, while charcoal produced a maximum temperature of only 635°C.

The experimentally fired vessels were broken up into sherds which were then subjected to the same type of laboratory analyses used for examining archaeological pottery.[13] These included techniques which allowed for an estimation of original firing temperature (Teq). Dynamic methods were employed: K-H analysis and full MGR-analysis. These analyses made it possible to assess the original firing temperature range, the accuracy of the assessment depending on the intervals at which laboratory refiring is carried out (50 or 100°C). The results of these analyses demonstrate that the estimates of original firing temperature are very consistent with the temperatures measured by thermocouple. Figure 6 shows the results of K-H analysis for a vessel fired in a cow-dung-fuelled bonfire which reached a maximum temperature of 1050°C. The curves illustrating open porosity, water absorption and apparent density values gauged after refiring indicate that the vessel was fired at c. 1050°C. X-ray diffraction analysis revealed that the formation of mullite had already occurred in this sample during firing (Fig. 7).

Four pots were fired five times each, on each occasion in a different bonfire, in order to see whether these successive firings would result in a cumulative effect. As expected, the laboratory analyses revealed that in the case of multiply fired vessels the maximum temperature to which they were exposed was identified as the Teq.

12 Daszkiewicz 2014, p. 187-189

13 These analyses have not been completed.

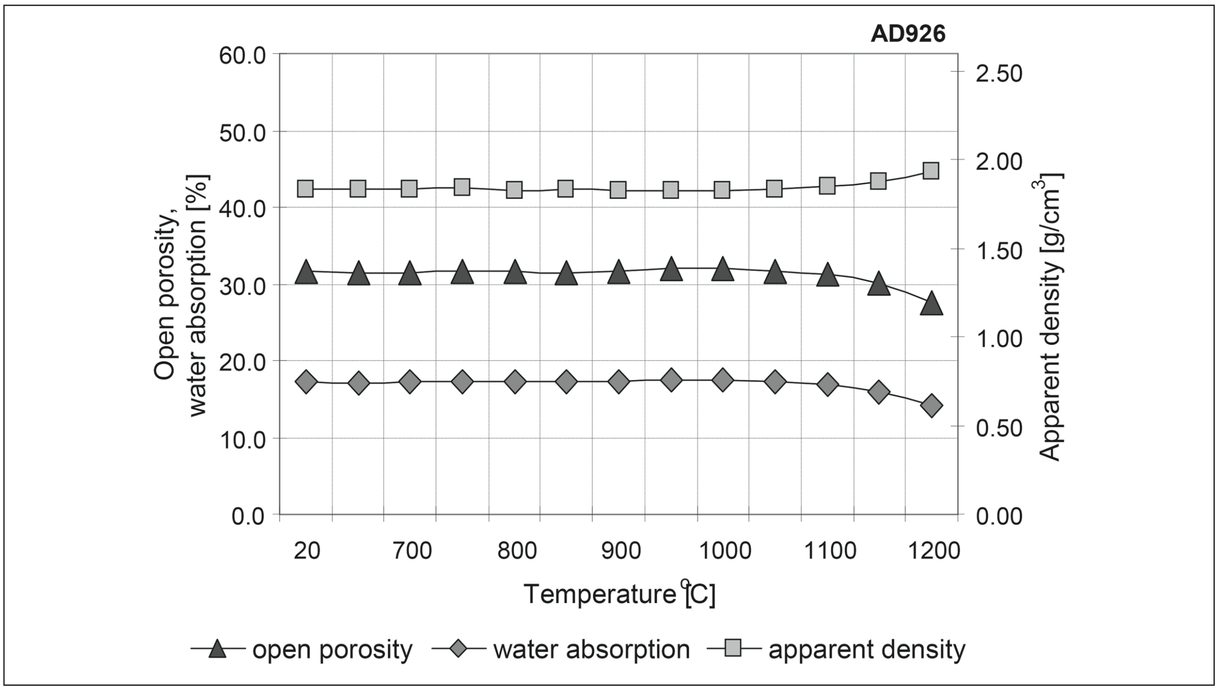

Fig. 6: The results of K-H analysis indicate an original firing temperature (Teq) of c. 1050°C. Measurement performed on pot AD924, fired in a bonfire fuelled with cow dung; maximum temperature of bonfire: 1050°C.

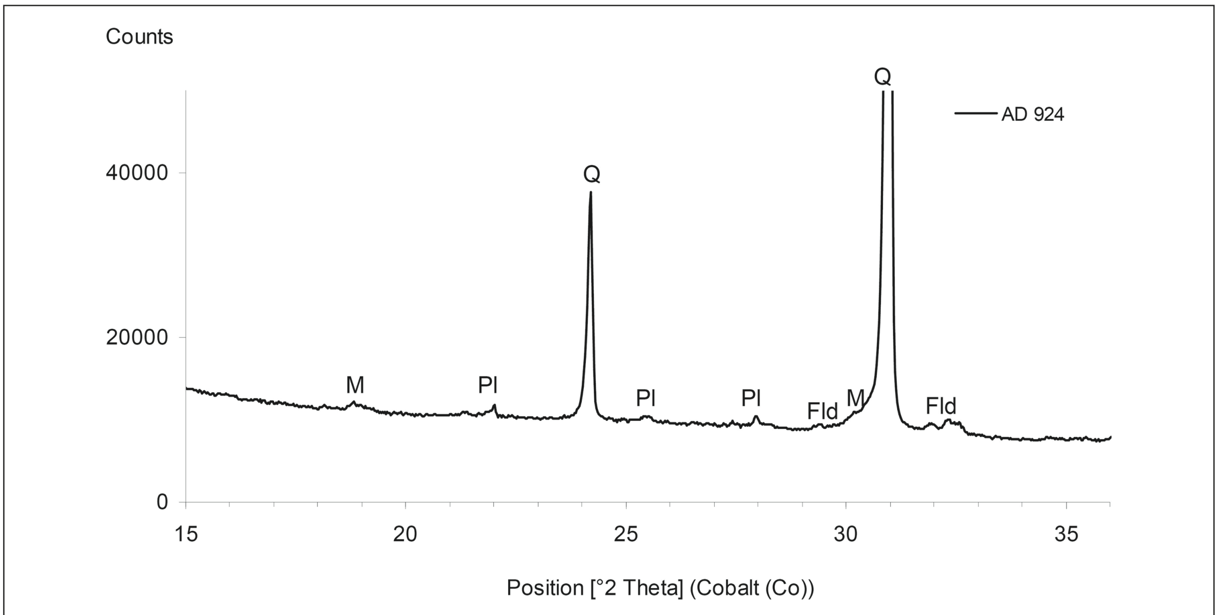

Fig. 7: Results of X-ray diffraction analysis of pot AD924. M = mullite; Pl = plagioclases; Fld = K-feldspars; Q = quartz. (M. Daszkiewicz)

Pots made from wadi clays tempered with kaolinitic sandstone had far less linear shrinkage than vessels made of the same clay tempered with organic matter or without any added temper.

Conclusions

1. The experimental firings demonstrated that it is possible to fire pottery at high temperatures (above 1000°C) in a bonfire provided that a suitable fuel is used, in this case dried cow dung.

2. This experiment shows that the absence of kilns at Musawwarat does not mean that pottery was not fired at this site. It is highly probable that the grey layer in courtyard 224 of the Great Enclosure represents the remains of ceramic kilns. Research aimed at confirming this hypothesis is ongoing.

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Zusammenfassung

Dieser Aufsatz präsentiert die Ergebnisse der Untersuchungen zum Brennverfahren, einer der Schlüsselfragen bezüglich der Organisation der Keramikproduktion in Musawwarat es-Sufra.

Die aktuellen Untersuchungen konzentrierten sich darauf zu klären, ob die für die lokale Grobkeramik ermittelten Temperaturen (Teq) von über 1000°C in einem offenen Brand erzielt werden können und welche Voraussetzungen dafür nötig sind.

Für die experimentellen Versuche wurden aus Wadi-Ton und aus Material aus dem Großen Hafir (Hafir-Ton), unter Zusatz von nicht plastischen Materialien (kaolinitischer Sandstein, getrockneter Esels- und Kuhdung) insgesamt 89 Gefäße im Handaufbau gefertigt. Diese wurden vor und nach dem Brand vermessen, um die lineare Schwindung zu kalkulieren.

Als Brennstoff dienten lokal zur Verfügung stehende Materialien wie trockener Kuh- und Eselsdung, Gras und Zweige unterschiedlicher Akaziengewächse (Zelam, Zamur und Zayal), sowie Holzkohle aus Kabushiya.

Insgesamt wurden elf Brände durchgeführt, deren Temperatur mit Thermoelementen während des gesamten Vorgangs gemessen wurde. Die Brände erfolgten als ebenerdiger offener Brand und ebenerdiger offener Brand mit Randumfassung durch Keramikscherben unter Verwendung von Kuh- und Eselsdung, Akazienzweige, getrocknete Gräser und Holzkohlebriketts, sowie in einer Grube unter Verwendung von Kuhdung als Brennstoff. Die Thermoelementmessungen zeigten, dass die höchste Temperatur in einem mit Kuhdung gefeuerten Brand erreicht wurde (1050°C, 1040°C und 975°C). Alle anderen Brennstoffe lagen in ihrer maximalen Temperatur weit unter der von Kuhdung: trockenes Gras 760°C, Akazienzweige 710°C, Eselsdung 825°C und Holzkohle nur 635°C. Die experimentell hergestellten Gefäße wurden nach dem Brand zerschlagen und die Scherben den gleichen Laboranalysen unterzogen, die zur Untersuchung der archäologischen Keramik verwendet wurden (Berechnung der linearen Schwindung, K-H Analyse, vollständige MGR-Analyse, Röntgenbeugung und chemische Analyse durch WD-XRF). Die Ergebnisse dieser Analysen zeigten, dass die Bestimmung der ursprünglichen Brenntemperatur mit den durch das Thermoelement gemessenen Temperaturen übereinstimmen.

Die experimentellen Versuche demonstrierten, dass es möglich ist, Keramik bei hohen Temperaturen (über 1000°C) in einem offenen Brand zu brennen, sofern ein geeigneter Brennstoff verwendet wird. In diesem Fall getrockneter Kuhdung. Dieses Experiment zeigt weiterhin, dass das Fehlen von Töpferöfen in Musawwarat nicht bedeutet, dass keine Keramik vor Ort gebrannt wurde. Es ist sehr wahrscheinlich, dass die graue Schicht im Hof 224 der Großen Anlage die Überreste vom Keramikbrand ohne Keramikofen darstellt. Die Forschung zur Bestätigung dieser Hypothese ist im Gange.