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Studying vessel biographies from the Heuneburg

An experimental approach

Annelou van Gijn, Loe Jacobs, Nicholas Groat, Nicole de Koning, Dennis Braekmans & Annemieke Verbaas

Summary

In the context of the BEFIM project ("Meanings and Functions of Mediterranean Imports in Early Iron Age Central Europe") the life histories of (drinking) vessels from the Early Celtic hillfort settlements of the Heuneburg were examined, studying the way of production and use. In order to do so, we set up an extensive experimental program of dozens of experiments directed at a better understanding of the way this pottery was made and used. The participation of an experienced potter allowed us to reproduce exact replicas of the supposed drinking ware and explore in detail the traces of production and the effect of temper, firing temperature and so forth on the development of production traces and wear. Especially variations in the temper material, like the frequently observed addition of calcite in the archaeological pottery, strongly affected the characteristics of the use-wear marks that developed from the preparation of different products (grape wine, honey wine, different kinds of porridge etc.). The influence of alcohol production, including fermentation, on the pottery was explored. We also tested the effect of different gestures of preparing food and drink (mixing, stirring, pounding), different ways of storage and handling, and the manner of consumption like decanting using various kinds of utensils. The traces we observed on the experimental vessels, using an integrated low and high power approach, formed the basis for our interpretation of the archaeological vessels from the Heuneburg.

Keywords: *experiment, pottery function, microwear analysis, drinking habits, manufacturing traces, Early Celtic pottery*

Zusammenfassung

In: Philipp W. Stockhammer/ Janine Fries-Knoblach (Hrsg.), Was tranken die frühen Kelten? BEFIM 1 (Leiden 2019: Sidestone Press) 77-99.

Im Rahmen des Projektes BEFIM („Bedeutungen und Funktionen mediterraner Importe im früheisenzeitlichen Mitteleuropa") wurde die Biographie von (Trink)Gefäßen aus den eisenzeitlichen Siedlungen der Heuneburg untersucht, indem die Herstellungs- und Gebrauchsarten betrachtet wurden. Zu diesem Zweck wurde ein umfangreiches Versuchsprogramm mit Dutzenden von Experimenten aufgelegt, das ein besseres Verständnis der Herstellungs- und Verwendungsweise der Keramik zum Ziel hatte. Die Mitwirkung eines erfahrenen Töpfers erlaubte die Herstellung exakter Repliken der mutmaßlichen Trinkgefäße und eine detaillierte Erforschung der Herstellungsspuren sowie der Auswirkungen der Magerung, Brenntemperatur, etc. auf die Entstehung von Produktions- und Abnutzungsspuren. Besonders Variationen im Material der Magerung wie die häufig beobachtete Beimischung von Kalzit in der archäologischen Keramik beeinflusste stark die Beschaffenheit der Gebrauchsspuren, die bei der Zubereitung verschiedener Lebensmittel entstanden (Traubenwein, Honigwein, verschiedene Breiarten etc.). Die Auswirkungen von Alkoholherstellung, einschließlich der Fermentierung, auf die Keramik wurde untersucht. Wir testeten auch die Folgen verschiedener Körperbewegungen bei der Zubereitung von Speisen und Getränken (Mischen, Umrühren, Stampfen), verschiedene Arten der Lagerung und Handhabung sowie Konsumweisen wie das Umfüllen mit verschiedenen Utensilien. Die Spuren, die wir auf den experimentellen Gefäßen feststellten, indem wir einen integrierten Ansatz mit geringer und hoher Krafteinwirkung verfolgten, bildeten die Grundlage für unsere Interpretation der archäologischen Keramik von der Heuneburg.

Schlüsselwörter: *Experiment, Keramikfunktion, Gebrauchsspurenanalyse, Trinksitten, Herstellungsspuren, Frühkeltische Keramik*

Reconstructing vessel biographies

Introduction

Pottery constitutes the vast majority of our archaeological assemblages from the Neolithic onwards. Pottery shape and decoration form the basis for typologies, which in turn are the defining criteria for most of our archaeological cultures, many of which are actually named after a characteristic and ubiquitous type of vessel occurring in that time and place (e. g. Corded Ware Culture, Globular Amphora Culture). Pottery types thus provide essential chronological information. At the same time, the typological designations of pottery vessels are frequently based on their resemblance to present-day vessel shapes, like beaker, cup, bowl or pot, resulting in implicit assumptions about their former function. However, such assumptions about past function have rarely been tested. Within the project "Bedeutungen und Funktionen mediterraner Importe im früheisenzeitlichen Mitteleuropa" (hereafter referred to as BEFIM, led by Philipp W. Stockhammer), that was exactly what we intended to do: were the supposed drinking vessels like cups and bowls from the Early Iron Age site of the Heuneburg near Herbertingen-Hundersingen, distr. Sigmaringen, in Southern Germany really associated with the drinking habits of the Celtic elite as was always assumed?

In order to examine the function of the supposed drinking vessels we approached the artifacts from the perspective of their biography or life history: from the making of the pot, to its use and last, to what happened to it after deposition. First, we attempted to reconstruct the production sequence of each archaeological vessel: what were the type of clay and temper used to make the various vessels, which shaping technique was employed and how were they fired. The traces of production like those from smoothing, scraping, and burnishing were carefully documented in order to be able to distinguish them from traces of treatment and use such as those from stirring and decanting or even modifications of the surface caused by the interaction of the clay with the actual substances that were contained inside the vessels like grape wine. All these traces, both those from the production sequence as well as those from use and handling, were studied both macro- and microscopically.

This article presents a summary of the research that took place at the Laboratory for Material Culture Studies (encompassing the Ceramic Laboratory and the Laboratory for Artefact Studies) at Leiden University by a team of researchers and students. It concerns a series of experiments directed at the production and possible uses of the range of vessels found at the Heuneburg. Through interpretation of production traces on the archaeological finds we reconstructed vessels according to the authentic methods of production with comparable clays and tempers. The replicated vessels are thus new and are allowed to be damaged; their virgin surfaces form a basis for further use-wear experiments which in turn act as a reference for the interpretation of the use alterations on the Heuneburg pottery.

Dr. Angela Mötsch and Dr. Birgit Schorer, both members of the BEFIM team, selected the archaeological samples from the Heuneburg that constituted our research focus. It concerned a wide repertoire of locally made vessel shapes, like bowls, cups, amphoras, cone-necked vessels and goblets, which could possibly be connected to drinking feasts held by the Celtic elite. The sample we examined included coarsely made pottery and finely produced local ware (N=112).

Studying pottery technology

The production of vessels has been studied extensively since the 1960s. It was during this period, with traditional peoples all over the world rapidly incorporating western technology, that ethnoarchaeology became a central methodology to study traditional crafts and subsistence (Longacre et al. 1991). The observation of ceramic vessels in action in ethnographical context, enabling archaeologists to observe the actual production, function, and deterioration of pots, led to a number of important insights into the life histories of vessels (Skibo et al. 1989). In the context of this interest in ceramic technology, the Ceramic Laboratory of the Faculty of Archaeology at Leiden University was established in 1961. The objective was to reconstruct production sequences by means of microscopic fabric analysis and a detailed examination of the traces of production, the way of finishing and the firing method and temperature. The inferred production sequence was then tested by reproducing the shape of the vessel as accurately as possible, using as much as feasible the same clay and temper as well as the same shaping, finishing, and firing techniques. This combined approach, often referred to as the Leiden School (a. o. Franken/Kalsbeek 1984), is very much directed at technological details and specifics and makes it possible to go beyond shape and decoration and arrive at an understanding of the technological choices a potter made in the past (van der Leeuw 1993; 1994). The Leiden Ceramic Laboratory is unique in that it has always employed a highly skilled ceramic technologist and has a long history of ethnoarchaeological investigations (van As et al. 2010).

Microwear analysis of pottery

Microwear analysis of archaeological artifacts is a relatively recent methodological development. Already in the 1930s several researchers were aware that using stone or bone tools caused the development of traces of wear, but it was not until the appearance of the translation of Semenov's 1934 work into English in 1964 (Semenov 1964) that microwear analysis gradually became established world-wide (Fullagar 1988; Keeley 1974; 1980; Mansur-Franchomme 1983; Odell 1981; van Gijn 1990; Yamada 1986). Microwear analysis, also referred to as use-wear analysis or traceology, is now rapidly becoming standard archaeological practice. It has been demonstrated that different activities cause different wear traces that can be distinguished microscopically. Depending on the material the tool is made of, use-wear traces include edge removals, striations and grooves, rounding of the used edge, abrasion or attrition of the used surface and polish. The specific combination of different types of traces, and the directionality that is indicated by striations, grooves and polishes, are indicative of the contact material that was involved and the motion that was executed. Obviously, post-depositional surface modification and post-excavation damage can sometimes make such interpretations impossible, but we can frequently infer the functions of archaeological objects and the treatments they underwent during their life history.

Initially most analyses were directed at flint tools, but examination of used tools and objects made of materials other than flint, like bone, shell, coral, and non-flakeable stones, makes clear that they, too, develop traces of wear (Hamon 2004; Kelly/van Gijn 2008; Lammers-Keijsers 2007; Maigrot 2000; van Gijn 2007). Microwear analysis of pottery is a relatively recent development although it has been demonstrated for some time that ceramic sherds were used as tools in the past, mostly for pottery production (López Varela et al. 2002; van Gijn/Hofman 2008; Vieugué 2015). The ethnographic and ethnoarchaeological studies of pottery led several researchers to examine the surface modifications of complete vessels that were a result of use (Arthur 2002; Skibo 2015). These included soot and other carbonization patterns on cooking pots (Skibo 2013, 1-25), traces from fermentation (Arthur 2003; Vuković 2009), and attrition from various processes that occurred during the life history of the vessel. Skibo's work is now being followed up by various researchers who are interested in vessel function (Vieugué 2014). Our use-wear study incorporates aspects of Skibo's approach, which is based on visual examination of surface modifications, and our own experience with high power microscopy as this is commonly applied to flint, shell and bone tools. We make use of a Leica M80 stereomicroscope with incident and oblique light options as well as a Leica DM2700 metallographic microscope (magnifications ranging from 50-200x) with a free arm allowing the study of large pottery. Photos were taken with a Leica MC120 HD camera.

The production sequence of the Heuneburg pottery: an experimental approach

Materials

Although some mineralogical studies have been done for the Heuneburg (Balzer 2009, 126 f.) to indicate the source of the clays, within the limitations of the present research project it was not possible to pursue this further. As a consequence we instead opted for using commercially available clays for the reconstructions. These clays were adapted to resemble the clay and temper observed in the archaeological material from the Heuneburg by adding different types and quantities of tempering sands, like quartz, muscovite, basalt and calcite. A clay mixture or clay body which was prepared for the reconstruction of wheel-made pottery was tempered with 25 % of fine sand with a maximal grain size of 0.25 mm. For the category of fine handmade pottery a somewhat coarser mixture with a maximal grain size of 0.5 mm was applied. Finally, for the coarse pottery a clay naturally rich in organic materials was prepared by adding 25 % of grains up to 1 mm in size. To this mixture calcite grains were added, as well as a fraction of crushed pottery sherds (grog) (Fig. 1). The addition of the mineral calcite to clays for pottery production, seen in a lot of the Heuneburg vessels, was probably done on purpose. In the Near-East and the Mediterranean area this material was traditionally added to clays intended for certain pottery types associated with food preparation (Franken 1992, 109; London/Shuster 2011; Santacreu 2014).

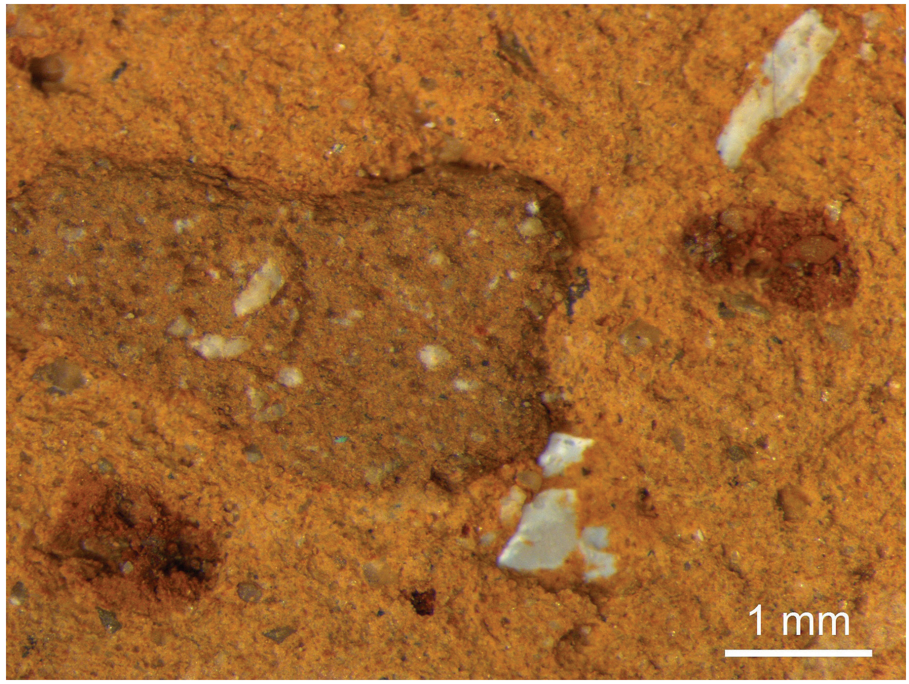


Figure 1: Grainy materials, like grog and calcite, were certainly partly added to the clay in order to improve workability properties, but they may also have been intended to influence properties of use (© Laboratory for Material Culture Studies Leiden University).

Reconstruction of the shaping techniques

Making the vessels

On the basis of traces found on the original pottery, basically two shaping methods could be distinguished. A relatively small part of the studied material seems to have been wheel-made. Such a wheel had enough momentum for continuous rotation and, if only during part of the production, allowed a rotation speed of more than 40 revolutions per minute (Fig. 2). However, the majority of the pottery from the Heuneburg consists of handmade objects, some of which were remarkably well made. The most frequently applied shaping technique for the production of hand-made pottery was coiling. Only for the making of the coarsely tempered tiny thumb pots and other small vessels was the pinching method applied. To make the bottom part and lower wall part of coiled pottery, often a support-form or mold was used (Fig. 3).

As a mold one could simply use already existing ceramic bowls. Clay coils were put in the mold and pressed against the inner wall. By doing so, the lower part of the vessel was made identical to the inner shape of the mold. The upper section of the vessel which, depending on its morphology, eventually tended to develop inwards, was leaning on to this and as such built on top of the part that rested in the support (Fig. 4). As a next step and after the clay had dried a bit, the vessel wall was at the same time reinforced, thinned, corrected and thus given its proper shape, by scraping with several tools (Fig. 5). The aim of scraping is three-fold: connecting the coils firmly with each other, correcting the shape of the vessels and finally removing excess clay in order to make the wall thinner and the vessel lighter (Fig. 6). During scraping the stance of the tool and the condition of the clay are determining factors. The use of differently shaped scrapers eased the making of the desired curves (Fig. 7). Not all the pots were constructed like this since, for the greater part of the collection, only a simple coiling technique was employed, without the use of a mold (Fig. 8).

Figure 2: Making a reconstruction on the fast potter's wheel (© Laboratory for Material Culture Studies Leiden University).

Figure 3: The lower part of certain vessel types was made by putting clay coils in a mold and by pressing these against the porous wall (© V. Brigola).

Figure 4: While the mold provided the necessary firmness, the vertical wall was built on it by adding, fixing, pinching and smearing of several clay coils (© V. Brigola).

Figure 5: The lower part was fashioned with one or more scrapers which eased the making of the desired curves (© Laboratory for Material Culture Studies Leiden University).

Figure 6: The surface is scraped to correct the shape and to remove excess clay (© Laboratory for Material Culture Studies Leiden University).

Figure 7: The use of differently shaped scrapers eased the making of the desired curves. During scraping the stance of the tool and the conditions of the clay are determining factors (© Laboratory for Material Culture Studies Leiden University).

Figure 8: Some reconstructions represent a specific category of coarse ware. The surface finish of the big pot is called slap and pat ("beschmissen") (© Laboratory for Material Culture Studies Leiden University).

Surface finish

After scraping several surface finishes that were observed included smoothing (Fig. 9) or, alternatively roughening, like slap and pat, a seemingly carelessly applied layer of thick clay slurry on the surface of some types of coarse ware (cf. Fig. 8). Next to that slipping (Fig. 10), burnishing (Fig. 10), polishing (Fig. 11), and in certain cases also graphitizing may occur. Smoothing was done by sweeping the surface with the fingers (Fig. 12), or with some soft material (Fig. 13), mainly in a horizontal direction. In some cases a striking similarity to the surface of wheel-made pottery was obtained this way (Fig. 14). With respect to the smaller archaeological sherds, it was sometimes difficult to identify the executed techniques. In order to apply graphite to a vessel surface, it should first be smoothed and burnished, but in a leather-hard state, so that its surface is still slightly tacky. This surface is then smeared by hand with finely pounded graphite powder (Fig. 15). As a last step the surface is polished again with a pebble (cf. Fig. 11). Graphitizing thus provides a blackish-silver gloss, which gives the treated objects a metal-like appearance. The most lustrous and metallic appearance of the surfaces is achieved in combination with pebble burnishing (Kreiter 2014).

Firing

Generally speaking we distinguish oxidizing versus reducing as opposite modes of firing. They respectively result in mainly clear and light colored pots and in dark, eventually spotted pottery in the other situation, where the penetration of air during firing is restricted.

Graphitized pots need to be fired under reducing conditions in order to prevent the coating of fine carbon particles from burning away. By creating reduced conditions (Fig. 16), one could also avoid that calcite grains in the fabric convert into lumps of quick-lime, a process which may result in "lime spalling" and tends to be destructive.

Figure 9: Example of a surface belonging to a vessel classified as coarse ware. Scraping was followed by smoothing with the fingers (© Laboratory for Material Culture Studies Leiden University).

Figure 10: The cone-necked vessel on the right was provided with differently colored clay slips in order to create contrasts. The coarse ware vessel on the left has a rough surface of thick clay slip applied by the method of slap and pat. The small goblet in the front is burnished and the one in the middle of the first row is graphitized. The bottle in the background is an example of wheel-made pottery (© Laboratory for Material Culture Studies Leiden University).

Figure 11: The leather-hard surface was polished with a polishing stone which consolidated the graphite. The pebble neatly fits in the curves in order to reach the entire surface (© V. Brigola).

Figure 12: Smoothing was done by sweeping the surface with the fingers (© Laboratory for Material Culture Studies Leiden University).

Figure 13: Alternatively, smoothing was executed by sweeping the surface with a soft material (© Laboratory for Material Culture Studies Leiden University).

Figure 14: In some cases of hand-made pottery, there is a striking similarity to the surface of wheel-made pottery (© Laboratory for Material Culture Studies Leiden University).

Figure 15: The application of graphite by rubbing the leather-hard surface with the powdered material (© V. Brigola).

Figure 16: A way of creating reduced firing conditions: vessels are nested, filled and packed with burnable organic materials (© Laboratory for Material Culture Studies Leiden University).

Another example in which reduced firing is involved, are the remarkable so called "cone-necked" vessels. The outer surface provided with a band of decoration (cf. Fig. 10) had to be exposed to oxygen in order to obtain a color contrast and make the abstract motifs visible, whereas the inner surface at the same time needed to be fired under reducing conditions so as to avoid that calcite grains in the fabric of some of these vessels cause the destructive "lime spalling". The result of a well-controlled firing process was a sherd colored light at a thin zone on the outer surface and dark-grey reduced for the rest of it. One could reach this remarkable result by filling the vessels with organic matter. During firing they were entirely covered with burnable material to prevent air from penetrating. Only at the end of the firing process the vessels were uncovered, and air was allowed to oxidize the outer skin of these pots during a limited span of time. These examples are making clear that the Celtic potters had good control of their production and firing processes. Reconstructing part of the pottery repertoire thus gave us a detailed view of aspects of this technology (Fig. 17).

Figure 17: Part of the reconstructed pottery repertoire (© Laboratory for Material Culture Studies Leiden University).

The use of Celtic pottery from the Heuneburg

The experimental program

An initial analysis of several pots and sherds from the Heuneburg excavations revealed a range of possible use alterations. The hypotheses formulated on the basis of these observations formed the basis for the experimental program that was subsequently carried out. The use alterations that developed on the experimentally used vessels would subsequently be compared with the traces seen on the Heuneburg ceramic ware. Although some experiments with ceramic materials were already present in the reference collection of the Leiden Laboratory for Artefact Studies, it is essential to have replicas as close as possible to the archaeological vessels. Pottery surfaces vary a great deal in terms of their surface texture, the kind and size of temper used, and the type of finishing. All of these factors will influence the kind of use alterations that will develop as a result of different activities. The experimental vessels made by potter Loe Jacobs therefore served a dual purpose for the microwear analysis carried out. First, their making shed light on the production process and the resulting traces of manufacture, so that we could distinguish these from traces of use. Second, these vessels also constituted replicas as close as possible to their archaeological counterparts from the Heuneburg, which made them suitable for carrying out more realistic experiments (Lammers-Keijsers 2005; Mathieu/Meyer 2002).

Obviously the range of experiments that can potentially be carried out with vessels is endless. As the central focus of the BEFIM project was on drinking patterns, some of the experiments focused on the production, storage and consumption of alcoholic beverages. Other experiments explored different gestures associated with the preparation of different foods, like stirring, drinking, cleaning, and covering the vessels with cloth. The wear patterns that resulted from handling, like shoving the pots on a surface, or from the vessels touching each other during storage, were also explored experimentally. Cooking experiments were rather limited as no use alterations from cooking were observed on the Heuneburg sherds that were examined in Leiden. In total 55 experiments were carried out so far, on a total of 48 vessels.

The production and storage of alcoholic beverages

Fermentation

The initial study of the Heuneburg pottery pointed to two handmade samples (HB-VB-012 and HB-VB-014) with evidence for inclusion loss and roughness, features which have been associated with fermentation (Arthur 2003; Skibo 2015, 194; Vuković 2009). Modern ethnographic data of ceramic use-wear traces resulting from fermentation and alcohol production frequently cite "pitting" signatures or more generalized "deterioration" traces (Arthur 2002; 2003; Hayashida 2008, 168). However, the enormous variation in ceramic fabrics suggests that more research is necessary as each of them can react differently to the range of fermentation processes. It is evident that the processes leading to fermentation-trace development have not yet been sufficiently investigated, let alone the vast range of traces caused by other actions involved in alcohol production. Hence, our experimental program used examples from the Heuneburg collection as a starting point to explore a possible range of fermentation traces that may be noted on the archaeological materials. The following is a summary of the experiments and research that was related to fermentation (Groat 2017). A more extensive paper will be published in the third BEFIM volume.

One almost complete handmade vessel (HB-VB-024) displays a rough surface at the interior base and in the lower interior body. The rim was also very rounded, suggesting prolonged contact with some sort of cover, most likely a piece of textile that was fixed in the depression underneath the rim. It is known from ethnographic sources (Hayashida 2008, 167) that yeast is sometimes stored in the pores of fabrics or vessels and can be used over and over again for the production of alcoholic beverages. Therefore, the hypothesis was that the inner surface of this vessel may have been left rough on purpose, to store a desired yeast culture. As this pot was almost complete, it was chosen for replication in order to explore the effect of fermentation on the pottery surface. As residues of bee products were found in many of the Heuneburg specimens (Schorer et al., this volume; Mötsch et al., this volume), it was decided to focus on honey-wine production.

We undertook a set of exploratory experiments that tested the impact of fermentation period (between 14-30 days), production stage separation (e. g. ingredients prepared and fermented in the same vessel or separately), and involvement of other contact materials (e. g. tools used for decanting). This approach explored the development of fermentation traces, and the variables that affected their creation. We concluded that ceramic use-wear signatures connected with alcohol production are more varied than a single diagnostic fermentation trace, as suggested by previous researchers. In some examples, fermentation traces appeared to be small, isolated groups of rounded pits, which do not exactly match fermentation traces seen on the Heuneburg archaeological materials. Larger rounded pits that may have been created following the dislodging of inclusions in the ceramic fabric or dissolving of calcite were also observed, though it is unclear if these were linked to fermentation. Conversely, traces plausibly connected with fermentation were most notable on samples that had been left to ferment for longer and that had experienced less contact with other "actions" or tools. Notably, decanting methods tend to greatly destroy fermentation traces. It is thus evident that traces can be caused by fermentation, yet it is inconclusive whether we may find them on archaeological materials in many contexts. Furthermore, fermentation traces may not exist in all contexts, which may be particularly the case at Heuneburg if the vessels were used for alcohol production alongside other purposes.

The effect of wine on the interior of the vessel

Several of the Heuneburg sherds displayed small pits, where the temper apparently had disappeared (HB-VB-008, HB-VB-012, HB-VB-014 and HB-VB-021) (Fig. 18). Calcite was used as temper in many of the clays current at the Heuneburg. It was hypothesized that the pitting seen on a number of vessel interiors was due to a chemical reaction between the calcite in the clay and its acidic contents (like wine). We therefore performed three experiments in which an acidic substance was poured into a small bowl and left there for several weeks, being refilled on a regular basis if needed. As we expected a chemical reaction to take place between the calcite in the clay and the acidic substances, the pH level of the fluids in the pot was monitored throughout the experiment. The experiments were performed using red wine (pH 3), white wine (pH 3), and honey (pH 4.5). The wines were bought in the supermarket. The honey was bought from a small, traditionally working beekeeper.

The pH of the honey stayed the same throughout the experiment and no changes in the surface of the pot could be observed after the experiment. With the wine however, a chemical reaction was visible, when the wine was poured into the cups, in the form of bubbles coming to the surface. Subsequently the pH rose over the course of several days

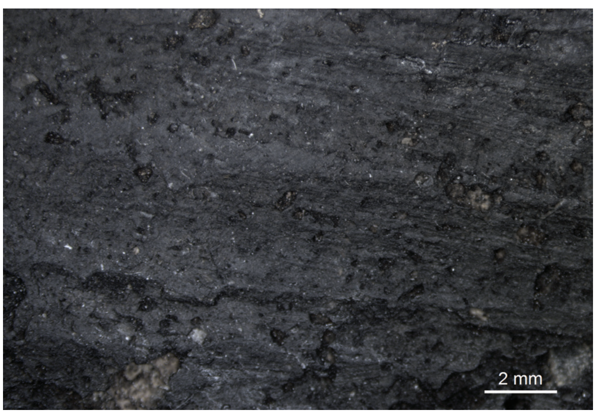


Figure 18: Pitting due to dissolved temper on the bottom of HB-VB-012 (© Laboratory for Material Culture Studies Leiden University).

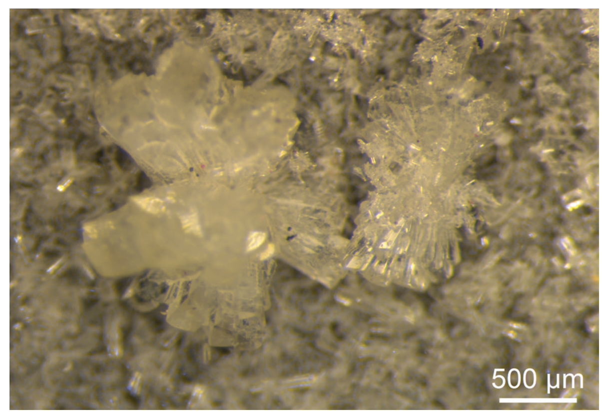


Figure 19: Crystals in the experimental bowl in which white wine was stored (© Laboratory for Material Culture Studies Leiden University).

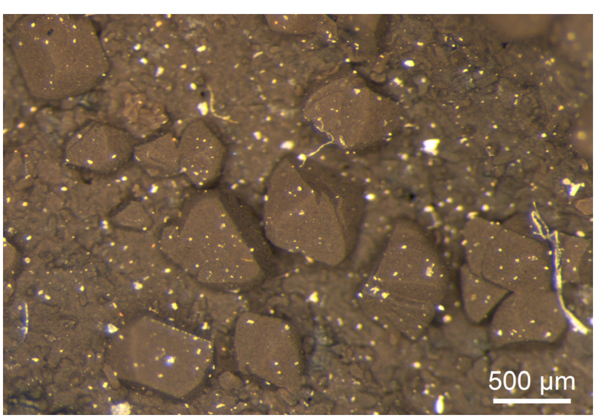


Figure 20: Crystals in the experimental bowl in which red wine was stored (© Laboratory for Material Culture Studies Leiden University).

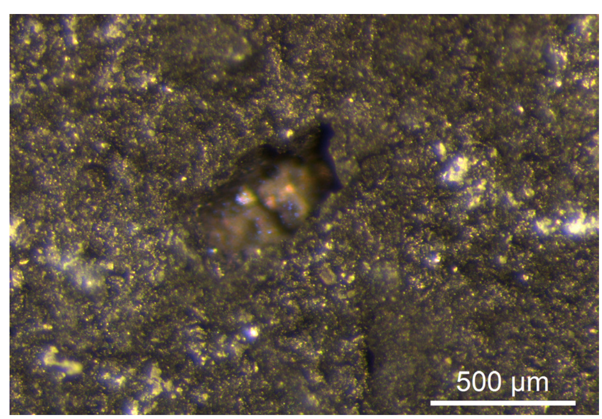


Figure 21: Pitting due to dissolved calcite crystals in experimental bowl in which red wine was stored (© Laboratory for Material Culture Studies Leiden University).

to pH 5. As the wine evaporated, mainly through the surface of the cups, these had to be refilled regularly. Every time wine was added or refreshed, the pH eventually rose again to pH 5 and then stayed stable. After a week, crystals started to grow on the surface of the vessel. The crystals are different in shape for the red and the white wine (Fig. 19 and 20). After the experiment it was hard to remove these crystals, so it was impossible to observe the complete inner surfaces of the bowls. In some locations the crystals did dislodge, and pitting was visible (Fig. 21). This pitting is similar to the pitting seen in the archaeological examples from the Heuneburg (cf. Fig. 18), and can thus be interpreted as a possible indication for wine consumption from these vessels.

The porosity of many of the analyzed sherds suggests that they were not suitable for storing beverages as our experiments have shown that, even though the bowls were covered with Para film, the wine disappeared very quickly, being absorbed by the vessel. Permeability experiments with fourteen vessels of identical shape but with different surface textures, are under way, in order to test this. However, the fact that Rageot has found a considerable number of sherds with evidence for bee products (Mötsch et al., this volume; Schorer et al., this volume), has led us to postulate that the pots were impregnated with a layer of beeswax to prevent the surface of the vessels from soaking up the liquid and to make them more suitable for longer term storage. When hot beeswax is poured on a hot sherd, this impregnates the ceramic surface thoroughly, without leaving a layer of beeswax on the inner surface. For long term storage of fluids impregnation seems a more plausible solution than accepting the loss of contents through evaporation. When a pot is covered in wax the disappearance of calcite crystals is no longer to be expected.

Preparing and consuming food, cleaning and handling

The range of experiments

Pottery vessels were used a lot in daily life to prepare and consume a wide range of foodstuffs. Activities related to food or beverage preparation could include whisking, pounding, and vigorous stirring, as well as covering the pot with a lid or cloth. The Heuneburg vessels showed traces that were possibly related to these activities, so several experiments were carried out that focused on food preparation. We also performed experiments that replicated different ways of consuming the contents of the vessels: drinking or decanting with spoons and ladles made of different materials. After consumption the vessels obviously needed to be cleaned. Last, pots and bowls were handled, moved around, stacked, and covered on a regular basis, causing pots to bump into each other and be subject to abrasion. It is important to better understand what kind of wear patterns develop as a result of these somewhat elusive actions, as we may expect such traces to be mixed with and superimposed on traces from food preparation and consumption. So these experiments look into the abrasive damage of the rims, exterior walls, bottoms of pots and bowls as a result of different ways of handling.

Obviously, the vessels can display traces from all of these various stages in their biographies, with some overlying and obliterating traces from other activities. As it is beyond the scope of this paper to discuss all the experiments and the traces observed, we will illustrate by means of one example from the Heuneburg how our experimental results figure in the interpretation of the life history of one particular find.

An archaeological example from the Heuneburg: bowl HB-VB-048

HB-VB-048 is a handmade bowl with a diameter of 23 cm. It is finely made, and the temper consists of a very fine fraction of calcite. The bottom is worn both outside and inside, causing it to be very thin (4 mm), while the wall thickness is 6-7 mm. On the interior bottom of the bowl the clay surface has been abraded. The temper is exposed and temper particles are dislodged, resulting in small holes (Fig. 22).

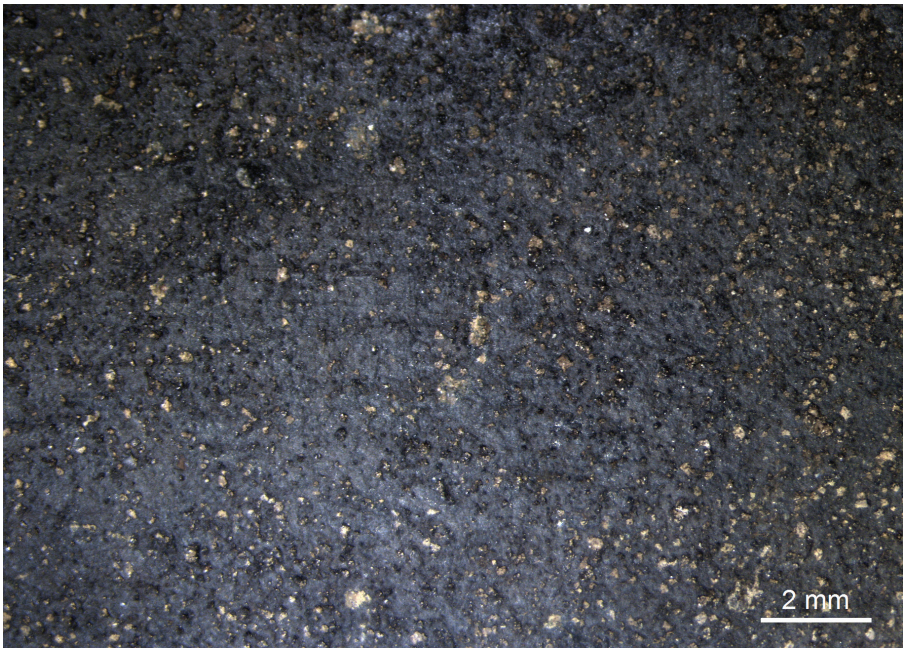


Figure 22: Wear and disappeared minerals on the inside bottom of HB-AS-048 (© Laboratory for Material Culture Studies Leiden University).

On the internal surface small, relatively short, slightly curving scratches can be discerned. These scratches are visible all over the bottom of the bowl and vary in direction. There are two ways these traces can be explained. The first possibility is that they were caused by stirring or eating with a spoon or other utensil. The second is that they are due to cleaning the vessel. During the experiments different materials were stirred and consumed using different kinds of spoons and whisks. The predominant type of wear that we see on these experimental vessels is surface attrition of the interior. In a first stage, the traces of manufacture disappear and subsequently a layer of ceramic material is removed, revealing the temper that was incorporated in the clay paste. Scratches occur only sparsely. The experiments with cleaning vessels using different tools (a cloth rag, a handful of grass, a heather brush, and a hog bristle) resulted in traces that are very similar to those from stirring in and eating from a bowl. The main difference is that scratches and striations occur more regularly with cleaning activities and have a slightly more predominant directionality. Therefore the traces on the internal bottom of this archaeological artifact can best be explained as the result of a combination of stirring/spooning and cleaning, a conclusion that is not too surprising from the perspective of the gestures and habits associated with these vessels. The exterior of the bottom is worn completely flat, and the calcite temper is clearly visible as white dots (Fig. 23).

The two experiments that were performed to replicate the kind of wear seen on the bottom of a vessel do not resemble the archaeological traces on any of the finds from the Heuneburg that we studied. These experimental pots were shoved around on a dried clay and on a wooden surface. The Heuneburg bowl HB-VB-048 had clearly been shoved over a surface, but this must have been a different one than the ones we tested experimentally. More experiments will have to be performed.

The rim of this bowl also sustained wear, but much less than the internal and external bottom. Although there is one highly worn location (Fig. 24), the rest of the rim shows only lightly developed traces of use, with some vertical scratches on the inside of the rim. This wear pattern can be caused either by repeatedly resting a spoon or other tool against the rim or, alternatively, by hanging a spoon from the rim. This last activity can also explain the vertical scratches. A possibility that combines both explanations is a spoon with a bulge, preventing the spoon from falling into the pot. The one location on the rim

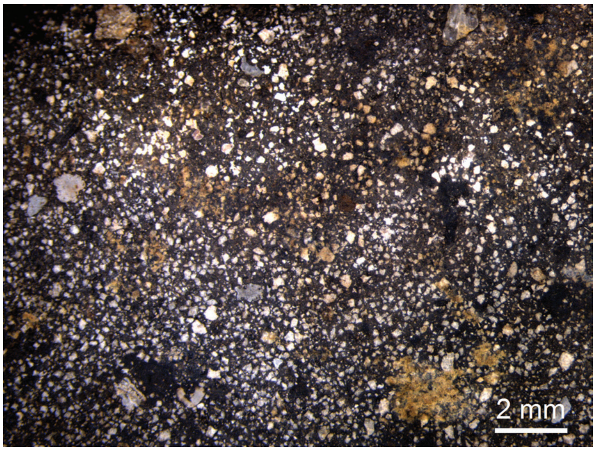


Figure 23: Highly worn bottom of HB-AS-048 with temper clearly visible (© Laboratory for Material Culture Studies Leiden University).

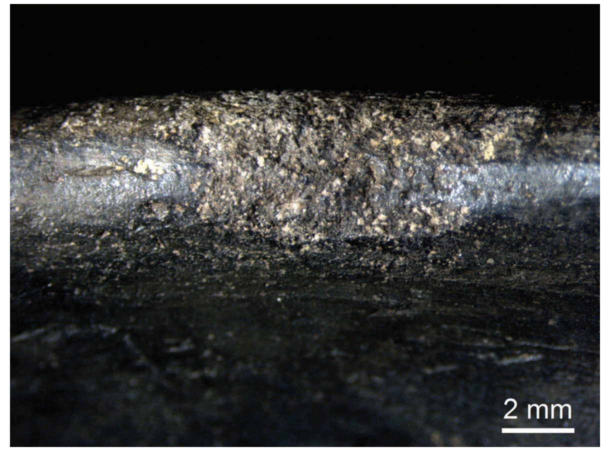


Figure 24: Severe wear with vertical scratches on the rim of HB-AS-048 (© Laboratory for Material Culture Studies Leiden University).

that displays extensive wear traces is harder to explain. Similar traces have been seen on a pot that was covered with a pottery lid and on a pot that was stacked with another pot. The wear on the rim therefore seems to be the result of a combination of resting a tool against the rim and covering the pot or stacking it for storage.

Post-depositional and post-excavation damage

An important aspect, which has not yet been discussed, is the range of modifications that vessels and pot sherds may undergo after deposition and subsequent to their excavation and storage. Post-depositional surface modifications are an important issue in microwear analysis (Levi Sala 1986; Plisson 1985; Venditti et al. 2016) and this certainly also applies to ceramics (Skibo 2015; Skibo/Schiffer 1987). Depending on clay composition, size, and character of temper and firing temperatures, the hardness of ceramics may vary a great deal. Still, compared to for example flint, which has a hardness of 7 on Mohs' scale, all ceramics can be regarded as relatively soft. Certainly slip layers are very vulnerable. Although tumbling experiments, mimicking the effect of different kinds of sediments on material surfaces, have been done on several different materials, this has so far been lacking on ceramics. Skibo has experimentally explored the effect of a variety of post-depositional processes, like the effect of water on ceramic surfaces (Skibo/Schiffer 1987). In our case we will explore the effect of such processes on use-wear traces by breaking the used vessels. The sherds will subsequently be subjected to trampling and tumbling experiments in different sediments. It should be mentioned that we consider most of the Heuneburg sherds that we examined to be in good condition, which is obviously due to the fact that those were the ones included in the initial study sample.

Another, and we think more serious problem is the way archaeological finds are treated during and after excavation. We often encounter traces of metal on finds, mostly due to contact with the sieves that are of course frequently used in archaeological projects. Trowels and shovels also inflict damage, but it is the subsequent cleaning, and especially the scrubbing, often with hard brushes, that definitely does a lot of damage: slip layers are removed, and the sherds get scratched. The extent of such deterioration is of course very much dependent on the hardness of the sherd. Still, we would suggest to only rinse the sherds and refrain from using hard brushes if there is an interest in microwear analysis (and of course no washing at all if residue analysis is to be done as well).

The next stage of find processing, packing the finds, is also a point at which many ceramic sherds get damaged. Often sherds are packed by the dozens in one bag, continually abrading and scratching each other. In order to examine the contents of a bag of sherds, the bag is turned upside down and the finds are dropped on the table, with fractures as a result. Last, registration leaves a mark: stickers, glue, and very large, written registration numbers are covering extensive parts of the surface of sherds, obliterating any use alterations that may have been present. Frequently several numbers can be found on one sherd as finds are renumbered during the reorganizations of storage facilities. Removal of these numbers will often damage the sherds as well. Handling, drawing, photographing (including positioning the sherd on a clump of clay to hold it in position) and fixing objects for exposition also do a lot of damage. Here clearly lies a task for museum curators. In the meantime we intend to use a series of sherds from our intentionally broken experimental vessels to explore the extent of damage that results from bagging and extensively handling the sherds. These experiments will be reported in the third BEFIM report.

An alternative way of assessing vessel function: provenance and failure mechanics research design of the Heuneburg ceramics

This part of our study of the Heuneburg ceramics is focused on the use and, by extension, the possible failure of the attested ceramics as well as the reasons for their deposition in the archaeological record. This particular part of the BEFIM project started in 2017 and aims to be concluded in 2018. At the moment of writing the work is still in full progress and will be reported on as such. In this paper the methodological approach will be outlined and preliminary results on the thin section analyses will be provided.

The main goal of this project is to define the innovation mechanisms and development of ceramic production. Instead of optimizing materials as a driver in modern engineering (the original objective of this particular methodology), here we wish to innovatively use similar methodologies, but aim to solve questions on advancement in the past fabrication process - and thus ultimately understand the key issues of a less successful or unsuccessful design and subsequent improvement by local communities.

The social-economic relevance relates to the direct choices that potters make in their production process, wherein certain clays are valued over others due to their qualities, suitability and optimization of the invested energy (Tite et al. 2001). Compositional variabilities can influence significantly the raw material behavior and the related mechanical properties for pottery production and later functionality of the vessel. This subproject is therefore essentially embedded within a full-fledged experimental research as set up by the Leiden Material Culture group.

The general outline of the research is constructed around three main phases:

1. The accurate composition and textural analysis of selected ceramics;
2. The reconstruction and experimental composition;
3. The modeling and fractographic analysis of the study.

Thin-section petrography was utilized as a major technique for characterizing both the structural as well as mineralogical composition of the ceramic wares (Braekmans/ Degryse 2016). Additionally, various features of both matrix and inclusions can directly point at past practices - and choices - in pottery production. A total of 21 samples were prepared and analyzed for their composition. The composition of the different ware groups clearly point at very different provenances. It concerns especially a carbonate and mixed materials group opposed to two groups with clear metamorphic and igneous-related substrates (Figs. 25, 26, 27 and 28). This indicates at least two very different geological origins of the clay raw materials and, by extension, production of the ceramics within this assemblage.

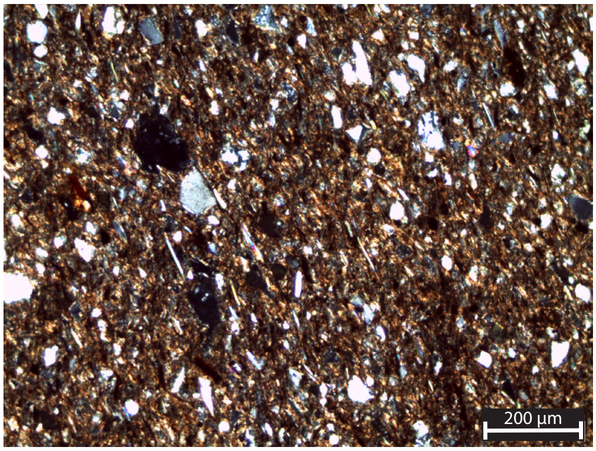


Figure 25: Micrograph of muscovite rich group (HB-VB-30) (© D. Braekmans).

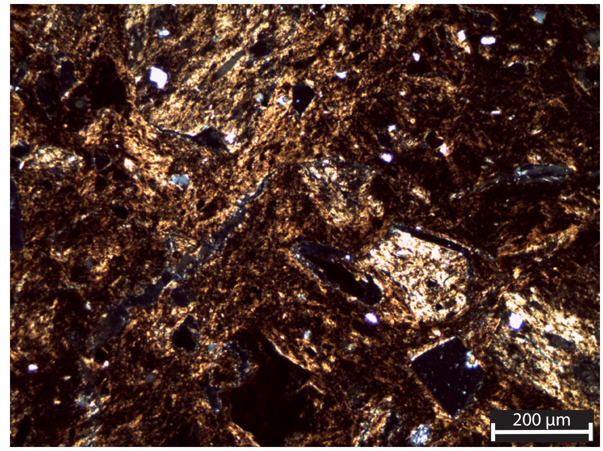


Figure 26: Micrograph of quartzite enriched group (HB-VB-07) (© D. Braekmans).

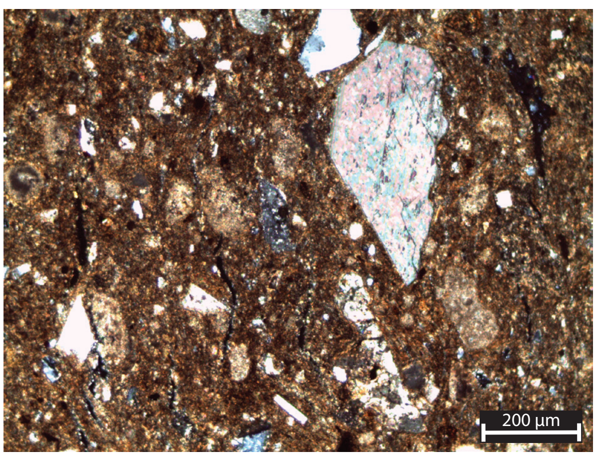


Figure 27: Micrograph of a carbonate-limestone group (HB-PL-10) (© D. Braekmans).

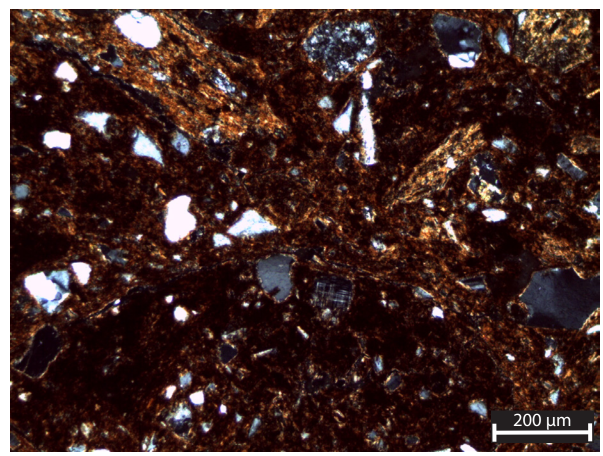


Figure 28: A mixed sedimentary and carbonate group (HB-AS-07) (© D. Braekmans).

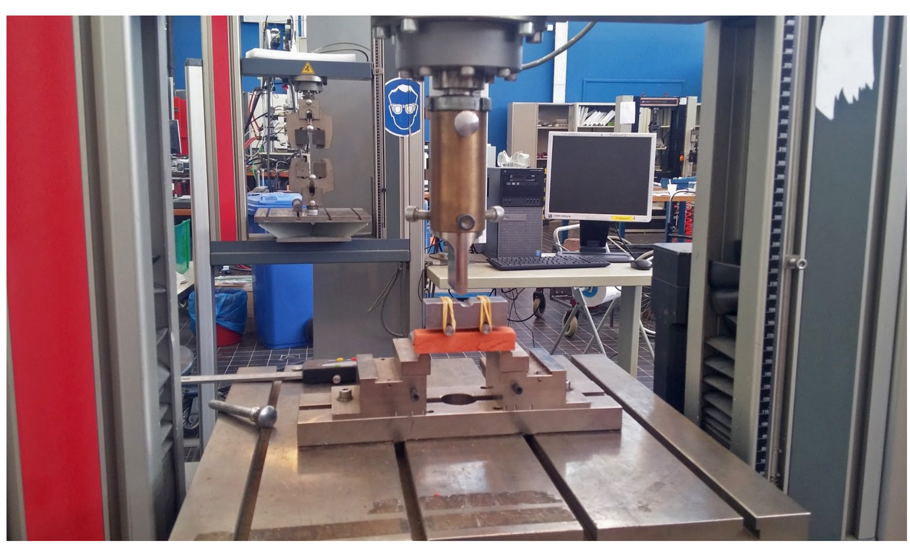


Figure 29: Four-point bending test of test bar with known composition utilizing a custom made pressure block (© TU Delft - Mechanical Test Facility).

The construction of replicated test bars mirroring both clay and mineral composition will be carried out in a next phase at the Ceramics Laboratory of the Material Culture group at Leiden University (2018). The creation of a vast number of samples and test bars (both reference materials as well as exact compositions based on thin section analysis) will be created; c. 100-200 samples following a semi-automated production process for original compositional pieces and reference materials in order the match the observations made during macroscopic and microscopic analysis.

The reconstruction and measuring of mechanical properties aims at contributing to identifying past use, and especially the failure and extent of usage. Failure of ceramics can have a multitude of causes, mostly originating from natural flaws, void propagation and use. The methods used will include both the use of three-point and four-point bending tests (Fig. 29). Especially the "transverse rupture strength", Young's modulus (elasticity) and fracture toughness are essential to quantify for brittle materials such as ceramics. A sub selection of the samples will be submitted to thermal shock and various heating/cooling sequences to simulate production and the various uses and will subsequently be analyzed with regard to their mechanical values.

The influence of the particular geometry of archaeological ceramics will be studied by modeling all obtained data through analytical software which can virtually apply multiple forces on a vessel. In this way, these various forces, stresses and their effects allow for the determination of the functionality and durability of the ceramic vessels. Finite element analysis (FEM) (Kim/Sankar 2008) will be applied to calculate the strain and stress state distribution in the various specimens, varying the position of the defect and the loading configuration. An FEM methodology was

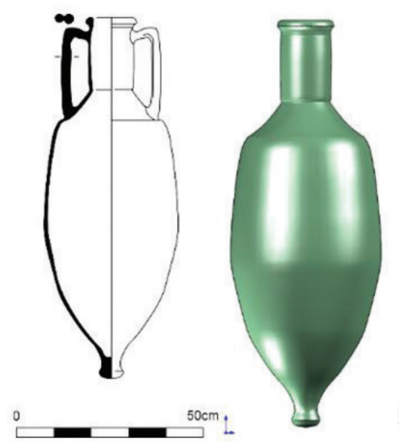
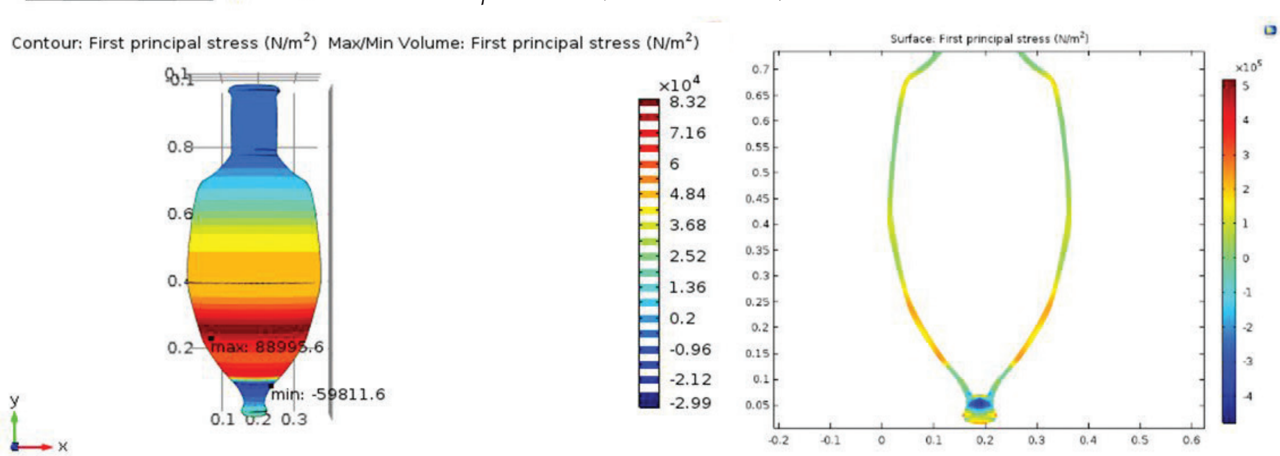


Figure 30: Examples of graphical representation of the procedure from line drawing to multiphysics analysis, which will be carried out on the Heuneburg samples with test bar analyses incorporated as parameters (© D. Braekmans).



successfully applied to a selection of ceramic materials (transport ceramics) from Greece (Hein/Kilikoglou 2014; Kilikoglou/Vekinis 2002), and now needs its large-scale implementation and exploration in archaeology to reach its full potential.

The general mechanical strength of a ceramic material depends on the size of the major flaw (or the weakest link), which can be highly variable due to the heterogeneous nature and past utilization of this type of materials. Therefore, the best way to predict these phenomena is through probability functions, and thus statistical analysis. The fracture statistics of (brittle) ceramic materials reflect the size distribution of flaws in this type of materials. This statistical processing is carried out in order to understand the fracture mechanisms. By incorporating experimental results on morphological modeling, multiaxial loading results for ancient ceramics are compared to stress state predictions (Fig. 30).

From a methodological point of view, the application of these methods on heterogeneous ancient ceramics provides a new challenge that needs exploration to unlock the potential for the study of cultural, historic and archaeological ceramic materials. The proposed approach includes methodologies from both fracture mechanics and fractography. While these techniques have primarily been developed for modern materials science applications, the use for archaeology is to gain direct knowledge on ancient product development and failure, which has enormous potential for the understanding of material production and design in general. This subproject was sparked by the BEFIM project and will run during 2018 to further reconstruct the composition, use and failure of the ceramics attested at the Heuneburg.

Conclusions: why use-wear analysis of ceramic vessels?

This paper intended to give an overview of the kind of research that was done by the Leiden University team affiliated with the BEFIM project. Two MSc theses resulted from this participation (Groat 2017; De Koning 2017), both of which will be published in the third BEFIM volume. The unique cooperation between a highly skilled ceramic technologist (Jacobs), two microwear specialists (Van Gijn and Verbaas), and an archeometrist (Braekmans) made it possible to carry out a realistic experimental program that was relevant for the analysis of the Heuneburg material. Pottery is probably even more varied in terms of physical and chemical properties than the various kinds of non-flakeable stone, due to variations in temper, clay composition, baking temperature and so forth, all of which are of considerable influence on the development and character of the use-wear traces. The most important conclusion of this paper is therefore that pretty much every new ceramic assemblage will require a new set of experiments in order to have valid analogies between experimental and archaeological use-wear traces. In this sense, this article is also a cautionary tale.

It should also be stressed that use-wear analysis does not result in identifications of vessel function, only in interpretations thereof (Van Gijn 2012; 2014). We may microscopically see a range of empirically observable features like scratches, abrasion, polish, attrition, pitting and so forth. On the basis of our experimentation we know which attributes result from which activity, but we can never be certain that these same features did not result from a task we have not yet experimentally explored. Moreover, features we believe to be distinctive for particular actions, do not always develop and may be much more ambiguous than we initially think. This is especially so with pottery, due to its enormous variability in material properties. The fermentation experiments by Groat (2017), summarized above, have clearly shown that the same activity can lead to different traces of wear.

Still, the type of holistic vessel study presented here constitutes an important addition to the traditional typo-chronological approach of ceramic studies. By looking at these vessels in (microscopic) detail, we can infer (parts of) their life history, and shed some light on past people's interaction with their material surroundings. Although residue analysis is clearly a more appropriate method to explore the contents of vessels, use-wear analysis can sometimes yield evidence about the possible vessel contents as well. The pitting on vessels from contact with acidic substances like wine, and the, albeit subtle, traces of fermentation show the potential of such an approach. Use-wear traces can also provide evidence for food preparation (stirring, whisking), handling (stacking, storage) and consumption (spooning, decanting, drinking). As the example described above of the bowl from the Heuneburg (HB-VB-048) has shown, vessels could have undergone several of these actions, resulting in traces overlying or even obliterating each other. The complexity of use-wear traces seen on such a vessel thus provides us with a more detailed insight into human gestures and behavior that is otherwise not obtainable.

Acknowledgements

Foremost, we would like to thank Professor Philipp W. Stockhammer for inviting us into this project. It was a daring move on his part as this type of research had not been done at this scale and the outcome was uncertain. We are also grateful to the entire BEFIM team for the exciting discussions and the stimulating meetings we have had over the years, introducing us to the world of the Celts. In Leiden we owe a lot of gratitude to Eric Mulder for his endless patience with drawing and photographing the finds.

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