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EXPERIMENTAL ARCHAEOLOGY: TO WHAT EXTENT IS IT POSSIBLE TO RECONSTRUCT ANCIENT POTTERY FORMING TECHNIQUES?

Abstract: Identifying a vessel as either coil-built and wheel-finished or wheel-thrown frequently has significant cultural and historical implications. The authors therefore conducted an experiment in a potter's workshop, using various techniques to produce 60 vessels from ceramic bodies made of the same clay tempered with quartz grains, crushed granite or grog. After having been fired in a laboratory furnace at 900°C in air, the vessels were then broken into 600 pieces and subjected to accelerated alteration processes (soil-conditioned). Next, an experiment to see, if specific forming techniques could be identified macroscopically, was carried out with the help of a group of archaeologists. The results of their macroscopic assessments (which were erroneous in many cases) gave rise to the following question: can standardised laboratory analysis be applied to identify the forming technique used for a given sherd (a sherd rather than a vessel, as various techniques were often used in forming a single vessel)?

Model tests were carried out to examine the hypothesis that vessel-forming techniques correlate to the relative density of sherds. A He-pycnometer was used to ascertain bulk density, whilst the density index was calculated from the apparent density (estimated by hydrostatic weighting) to bulk density ratio. In addition, Reflectance Transformation Imaging was used to try and identify evidence of forming, and an assessment was made of how forming technique and temper affected pore patterns in planes perpendicular and parallel to the vessel's main axis.

Key words: ancient pottery, forming technique, shaping technique, coiling, handmade, wheel-made, experimental archaeology

Introduction

Deciding whether a vessel was formed by coiling and then wheel-finished or formed using the innovative technique of wheel-throwing often carries significant cultural and historical implications. Therefore, when trying to determine the forming technique used in a pottery vessel's manufacture, as with all types of analysis, the aim should be to achieve results with the smallest possible error. In reality, in most cases the analysed material consists of ceramic sherds of various sizes rather than complete vessels. Consequently, identifying pottery vessel forming techniques based on macroscopic observation of the features of the inner vessel surface only — as is usually done by archaeologists — can sometimes be difficult and, therefore, may be erroneous.[1] But is it enough to divide pottery into only two groups (handmade and wheel-made) when recording descriptions

[1] E.g. interpretation of rilling, see Doherty 2015, p. 73.

of excavated sherds? Changes in ethno-economic-chronological aspects might be reflected in changes in forming techniques, but this would require recognising more than only hand- and wheel-made methods of vessel forming. It should also be remembered that several techniques may have been used to make a single vessel: the pot may have been coil-built, with the coils joined and thinned using a paddle and anvil (working with a wooden paddle on the outer face of the vessel and a stone or ceramic anvil on the inside) and its rim shaped on something serving as a potter's wheel.[2] How can we recognise such procedures from only a small fragment of a vessel, or even from a whole vessel? Generally, it is virtually impossible to tell if a vessel was coil-built or formed from a single lump of clay, and thus conclude that it was a *handmade* pot.

To recognize the forming method and techniques used in pottery manufacturing by ancient potters we usually need ethnographic studies and experimental forming of vessels. The possibilities of recognising forming techniques by comparing ancient sherds with experimentally made vessels have been the subject of studies such as that by Roux and Courty,[3] who examined pottery surface features and microfabrics under a polarizing microscope. The results of these studies have shown that the debate concerning the adoption of particular forming methods and techniques should be continued. It is especially important to find macroscopic parameters for recognising forming techniques. Ancient ceramics are the most common artefacts found during excavation, and archaeologists need a quick means of describing a large number of sherds in a short time, with laboratory tests being reserved only for selected samples. Because similar traces (parallel striations) occur on vessels that have been wheel-thrown and wheel-shaped (on a fast wheel), a different macroscopic parameter is needed to distinguish particular methods and techniques. This could be a considerable help in studying special relationships in terms of socio-economic changes over various cultures and periods.

We must, however, ask ourselves whether it is possible to determine forming and shaping techniques accurately, and solely on the basis of macroscopic analysis of vessel walls and fresh fracture surfaces. An experiment was carried out in order to try and answer this question. In the experiment, various techniques were used by the authors at a pottery workshop in Velten [Figs. 1 & 2] to produce 60 vessels from ceramic bodies comprising the same clay tempered with quartz grains, crushed granite or grog. The vessels were fired in a laboratory furnace at 900^{o}C in air, then broken into 600 pieces and subjected to accelerated alteration processes (soil-conditioned). Next, a team of archaeologists was asked to take part in an experiment designed to ascertain whether particular forming techniques could be identified macroscopically. The macroscopic assessment was erroneous in many cases: generally, forming by coiling with wheel-finishing was not distinguished from wheel-throwing. This means that forming techniques as described by Roux and Courty[4] could not be recognised and nor could moulding or the paddle and anvil technique. The results of this experiment prompted the following question: can standardised laboratory analysis be applied to identify the forming technique used for a given sherd (a sherd rather than a vessel, as a single vessel was often formed using various techniques)? At the same time, the authors decided to evaluate/create a method for ancient pottery analysis that would not be based on the study of images, like analysis of thin-sections or polished sections,[5] or analysis using X-rays and xeroradiography, as proposed by S. H. Doherty[6] (which, notably, yields very good results). In addition to this, tests were also conducted to see, if forming and shaping techniques could be identified by analysis of pore texture (image analysis).

[2] Observations of potters at work in Mexico (M. Daszkiewicz and G. Schneider) and in Ecuador (G. Schneider) have shown that a sherd from an old pot, manually rotated with one hand, could serve as a substitute for a potter's wheel.

[3] Roux, Courty 1998.

[4] Roux, Courty 1998.

[5] E.g. Ther 2016; Daszkiewicz, Bobryk, Schneider 2010.

[6] Doherty 2015.

Fig. 1. Wheel-thrown vessel made on a fast wheel (upper image) and on a slow wheel (wheel-head operated with one hand – lower image). M. Wetendorf and M. Daszkiewicz at the Malenz ceramic workshop in Velten (Brandenburg, Germany) (photos G. Schneider)

Fig. 2. Various forming and shaping techniques:
a and b = wheel-shaping on a fast wheel, forming from coils (technique 2);
c = wheel-shaping on a slow-wheel (technique 2 = coils are laid without rotative kinetic energy, bonding of coils and thinning with rotative kinetic energy);
d = handmade from coils;
e = handmade by pinching;
f = moulding on a fast wheel.
M. Wetendorf at the Malenz ceramic workshop in Velten (Brandenburg, Germany) (photos G. Schneider)

The analysis presented in this article was carried out on ceramics made from various clays or bodies.[7] However, the authors have used the term "clay" in all of the theoretical descriptions as well as in descriptions of archaeological pottery that cannot be reliably identified as having been made from a body.

Forming and shaping: methods and techniques[8]

The term **"vessel forming"** is used to mean "making a vessel begin to exist", in other words, constructing a specific form of vessel using clay. The term **"vessel shaping"** means creating a vessel's shape or silhouette[9] (e.g. not all bowls have identical proportions, angles, rims). The term "shape", as used by the authors of this article, does not include vessel decoration. In the case of wheel-thrown vessels, the forming and shaping processes take place simultaneously.

Forming and shaping methods can be divided according to whether the use of rotative kinetic energy (RKE for short) is used or not. Various shaping techniques can be identified within each of the shaping methods. The same shaping methods (or techniques) can be applied to pots built using various forming techniques.

The term **"hand-making"** vs **"wheel-making"** corresponds to the distinction between clay-fashioning techniques made by Valentine Roux[10] based on the source of energy (muscular energy as opposed to rotative kinetic energy) used to create a rough vessel form; in other words, the distinction between a roughout produced without the use of RKE as opposed to with RKE.

The following modes of **pot-making (forming and shaping)** can be distinguished based on the forming and shaping methods and techniques used:

1) hand-making = forming and shaping a vessel **without the help of rotative kinetic energy**.
This excludes all manner of rotating stands; the vessel is rotated solely with the use of the hands; vessels can be formed from one clay lump or from coils (successive courses of coils are laid and bonded, and the vessel walls are thinned applying discontinuous pressure; shaping techniques: pinching, paddle and anvil [Fig. 3].
2) orbiting[11] = the vessel is both **formed and shaped using the orbiting technique**.
Forming (from coils or one piece of clay) takes place without the help of rotative kinetic energy; the vessel is built and shaped by the **potter moving around the stationary vessel (PRKE)**; this technique is used to this day in central Africa, in Sudan and in Yemen [Fig. 4].

[7] Nowadays, a wide range of materials is used to make ceramics. However, for thousands of years the principal materials used in the production of ancient ceramics were clay raw materials (clay minerals, mixtures of aluminosilicates, silicates, quartz and carbonates). Quartz ceramics (e.g. Egyptian faience and Islamic quartz pottery) were the only type not made from these raw materials, and these represent only a small percentage of ancient pottery. Archaeological ceramics can be made from: clay — raw materials suitable for pottery making without any special treatment; a ceramic body (or just "body" for short) — raw materials requiring processes such as levigation or the addition of temper; or paste — in contrast to clay or body, this is a mass in which the content of clay raw materials is less than 20–40% (for example, quartz ceramics are made using a paste). Some authors refer to "body" using the term "paste"; however, in this instance this is not the correct term.

[8] The classification presented in this article is based on new evidence from ethnographic ceramic studies and differs slightly from the classification outlined at the archaeometric conference in Bochum (Daszkiewicz, Bobryk, Schneider 2010).

[9] Shape is not infrequently used as a synonym for form, but this is an incorrect use of terminology (see Hamer, Hamer 1975).

[10] Roux 2017, p. 104.

[11] This method was described as "durch Umrunden gedreht" (Daszkiewicz, Bobryk, Schneider 2010), but the authors have chosen to adopt the term "orbiting" after P. M. Rice (Rice 1987, p. 143).

3) wheel-making = forming and shaping or only shaping a vessel **with the help of rotative kinetic energy**.

3a = wheel-making by shaping on a **slow wheel**;[12]

3b = wheel-making by **shaping on a fast wheel** [Fig. 5].

Wheel-made pottery can be subdivided further by technique:

3-1 wheel-throwing[13] = forming and shaping of the vessel is done simultaneously from one clay lump applying continuous pressure;

3-2 wheel-shaping = forming by pinching from one clay lump or by coiling; shaping is done with the application of discontinuous or continuous pressure.

Wheel-shaping of coiled vessels can be divided into several techniques according to how the superimposed coils have been laid and bonded and how the walls of the vessel have been thinned:[14]

- technique 1 = coils are laid and bonded applying discontinuous pressure, without the help of RKE; thinning is done with the help of RKE [Fig. 6];
- technique 2 = coils are laid applying discontinuous pressure, without the help of RKE; RKE is used in bonding the coils and thinning the vessel walls;
- technique 3 = in contrast to technique 2, coils are laid and bonded and the vessel walls are thinned with the help of RKE, after which the wheel is stopped and the next coil is added [Fig. 7].

4) moulding = forming and shaping simultaneously; techniques: slipcasting or hand-pressing (e.g. relief sigillata bowls) with or without the help of rotative kinetic energy (the mould is turned on a wheel whilst pressing the clay or is kept stationary).

Fig. 3. Handmade. Shaping using the paddle and anvil technique, Laos 1994 (photo G. Schneider)

[12] Differences between slow and fast wheels are connected with the number of revolutions per minute of the wheel-head regardless of how it is set in motion (electric-wheel, kick-wheel, stick-wheel or hand-wheel).

[13] Wheel-thrown vessels are not necessarily made on a fast wheel. Experiments done by Wetendorf and Daszkiewicz have shown that wheel-throwing was also possible using a manual wheel-head operated by one hand. S. K. Doherty reports that not only was it possible "to create thrown pottery at speeds lower than the suggested 50–150 r.p.m." but also "at the speed of 20 r.p.m." (Doherty 2015, p. 109). Doherty suggests that "such terms as fast and slow wheel need to be readdressed, if they should exist as a distinction at all". Using RTI (see section on the RTI technique) on the experimental pottery produced by the authors of this article made it possible to distinguish vessels that had been wheel-shaped on a fast wheel from those shaped on a slow wheel, therefore the authors suggest that the terms "slow" and "fast" should not be rejected.

[14] The description of the first two techniques is generally the same as that proposed by V. Roux and M.-A. Courty (Roux, Courty 1998, p. 748).

Fig. 4. Orbiting. Potters move around a fixed vessel during both the forming and shaping process. Two pottery workshops at a pottery centre in Wad Medani. Sudan 2008 (photos M. Daszkiewicz)

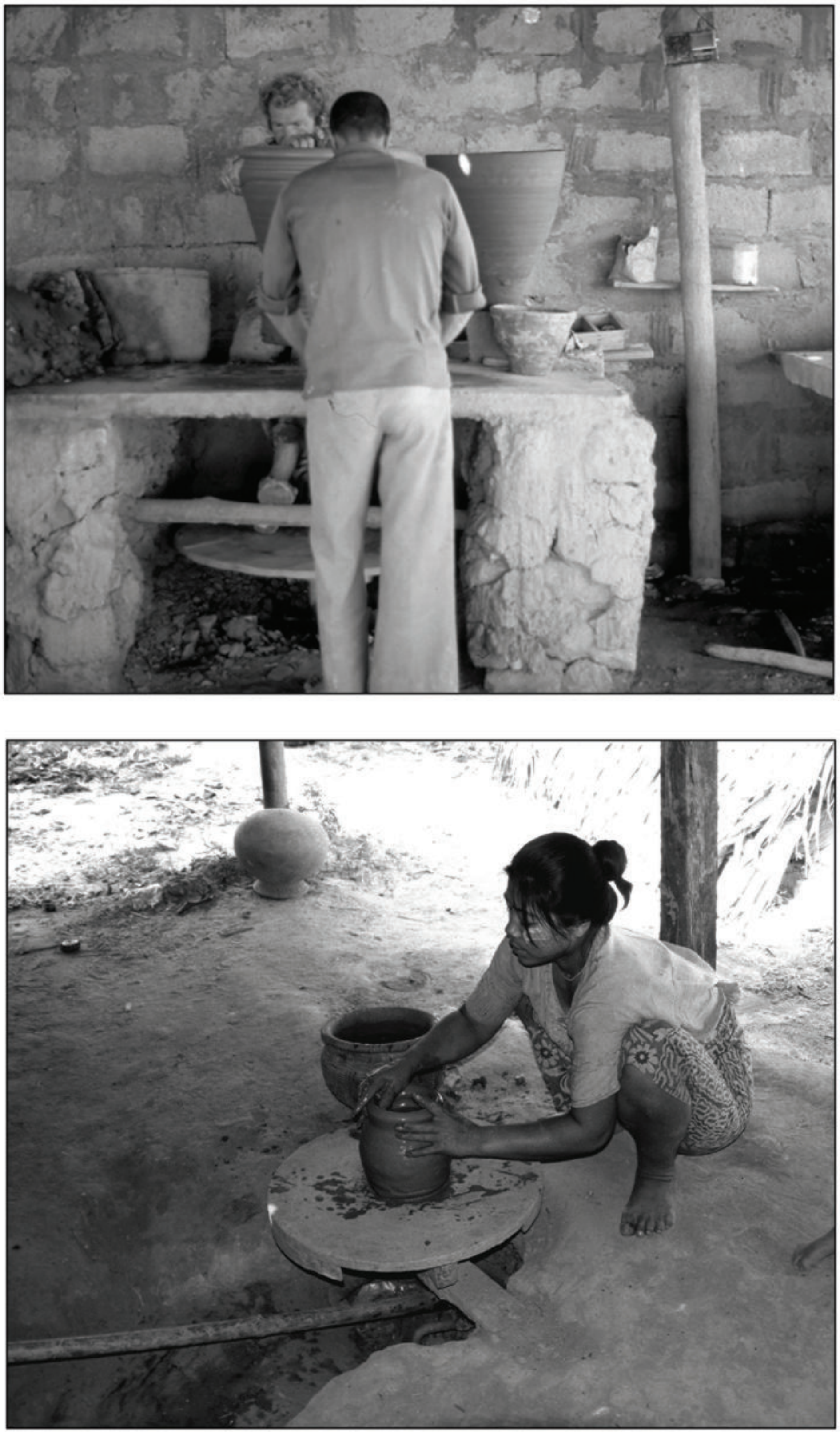


Fig. 5. Wheel-thrown. Kick wheel (upper image, Syria 1984), wheel turned with a stick applied to the underside (lower image, Laos 1994) (photos G. Schneider)

Fig. 6. Wheel-shaped. Coiling: the vessel is built of coils, which are bonded by applying discontinuous pressure, without the help of rotative kinetic energy; thinning and shaping is done with the help of rotative kinetic energy. Hand-operated turntable. Laos 1994 (photos G. Schneider)

Fig. 7. Wheel-shaped. Coiling: coils are laid and bonded on the wheel and the vessel walls are thinned with the help of rotative kinetic energy, after which the wheel is stopped and the next coil is added. Wad Medani, Sudan 2008 (photo M. Daszkiewicz)

Reconstruction of forming technique by pore texture analysis (FTPT)

Theoretically, information concerning forming methods and techniques should be fixed in the structure and texture of pores after the firing of a pottery vessel. However, it has been discovered that vessels such as Roman kitchenware from Novae with the same parallel striations (wheel-thrown vessels) and made from a similar raw material have totally different pore distributions: pores are elongated and parallel to the vessel wall or slightly elongated in a net pattern.[15] This discovery provided the impetus for a study on developing a method to estimate the original forming technique by macroscopic (or binocular) observation of pores (FTPTS = Forming Technique by Pore Texture and Structure analysis).[16] FTPT is based on the analysis of pores (shapes, orientation, pattern, size, distribution within the vessel wall) in two dimensions: in the plane perpendicular to the axis of the vessel and in the plane parallel to the axis of the vessel [Fig. 8]. The texture

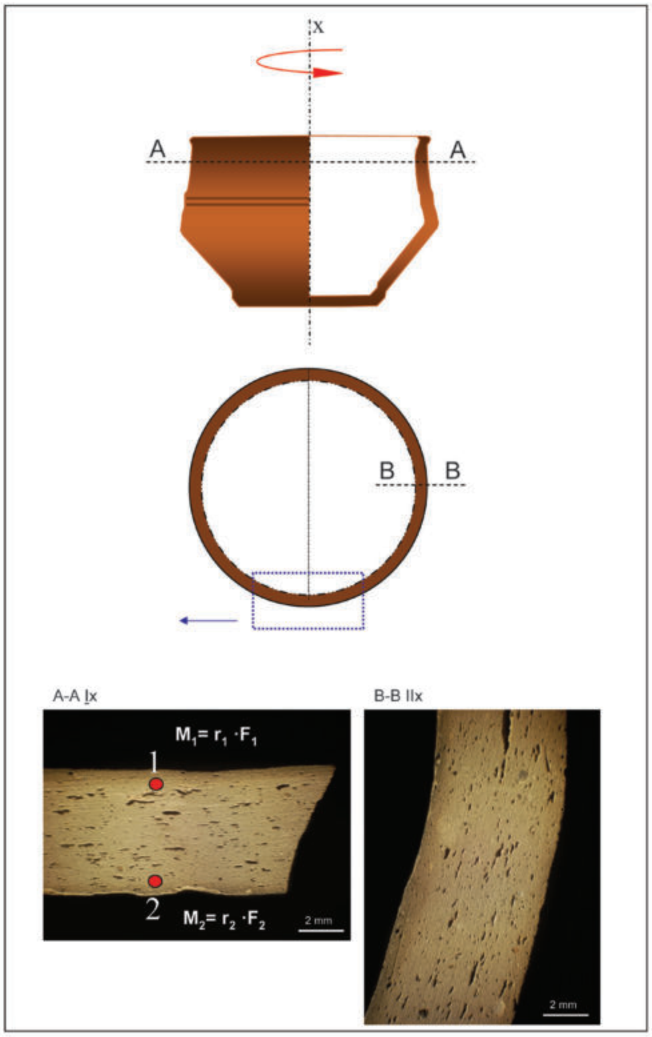


Fig. 8. Pore distribution in a wheel-made vessel. At point 2 pores will be thinner than at point 1 or will disappear due to fact that $M_2 > M_1$. x = axis of vessel; A–A = plane perpendicular to axis of vessel; B–B = plane parallel to axis of vessel; M_1 = moment of force in point 1; M_2 = moment of force in point 2; F_1 and F_2 = pressure exerted by the potter's hand; r_1 and r_2 = radius

[15] Baranowski, Daszkiewicz 2009.
[16] Daszkiewicz, Bobryk, Schneider 2010.

and structure of pores should be correlated to the vectors of forces occurring during the forming process (the forming process of the vessel as well as the forming process of the coils [Fig. 9]). To date, in addition to theoretical background studies, experimental firing of wheel-thrown and coiled vessels has been carried out. The results of experimental work have been compared with the Roman Imperial period wheel-made pottery from Brandenburg. A preliminary study has been done on eight pottery sherds found in Brandenburg (sites: Görlitz and Briesnig).[17] This study shows that these vessels were formed using the wheel-throwing technique as well as the wheel-shaping technique [Fig. 10]. Comparison of the results of FTPT analysis and provenance studies[18] has shown that most probably these few wheel-thrown vessels were not made locally.

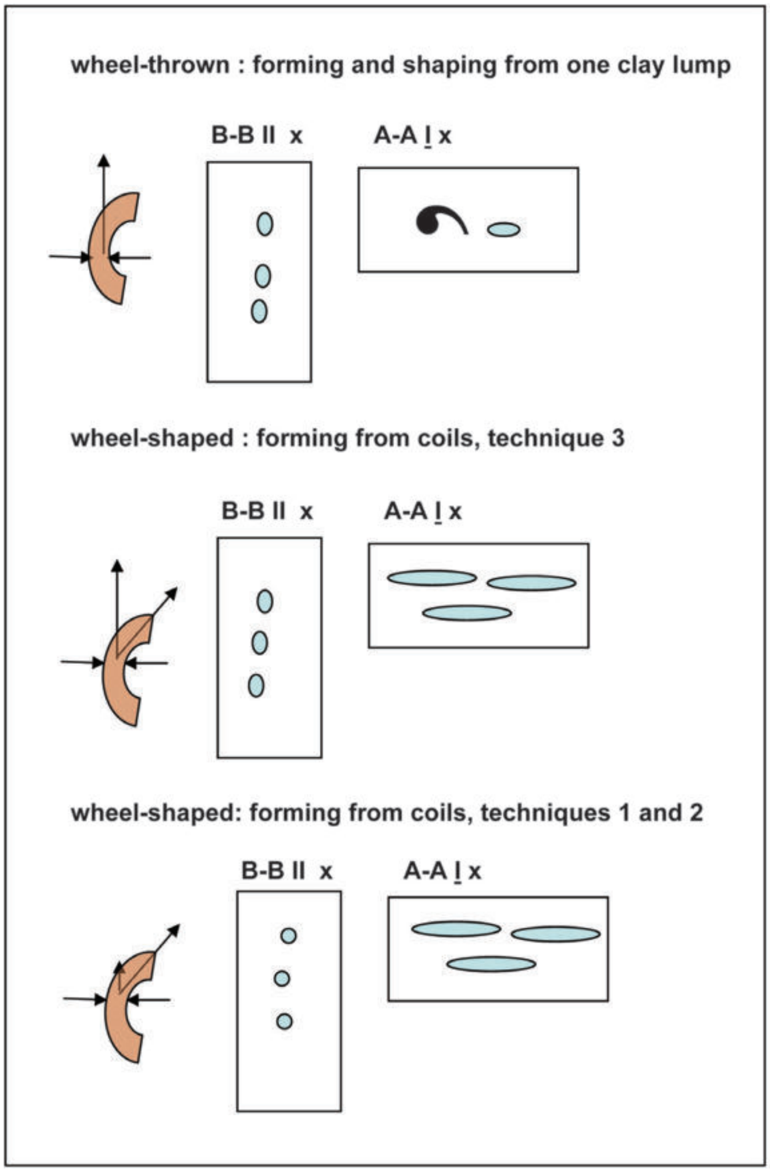


Fig. 9. Theoretical texture and structure of pores correlated to the vectors of forces occurring during the forming process

[17] Samples provided for analysis by M. Meyer and M. Hegewisch.
[18] Daszkiewicz, Schneider 2011.

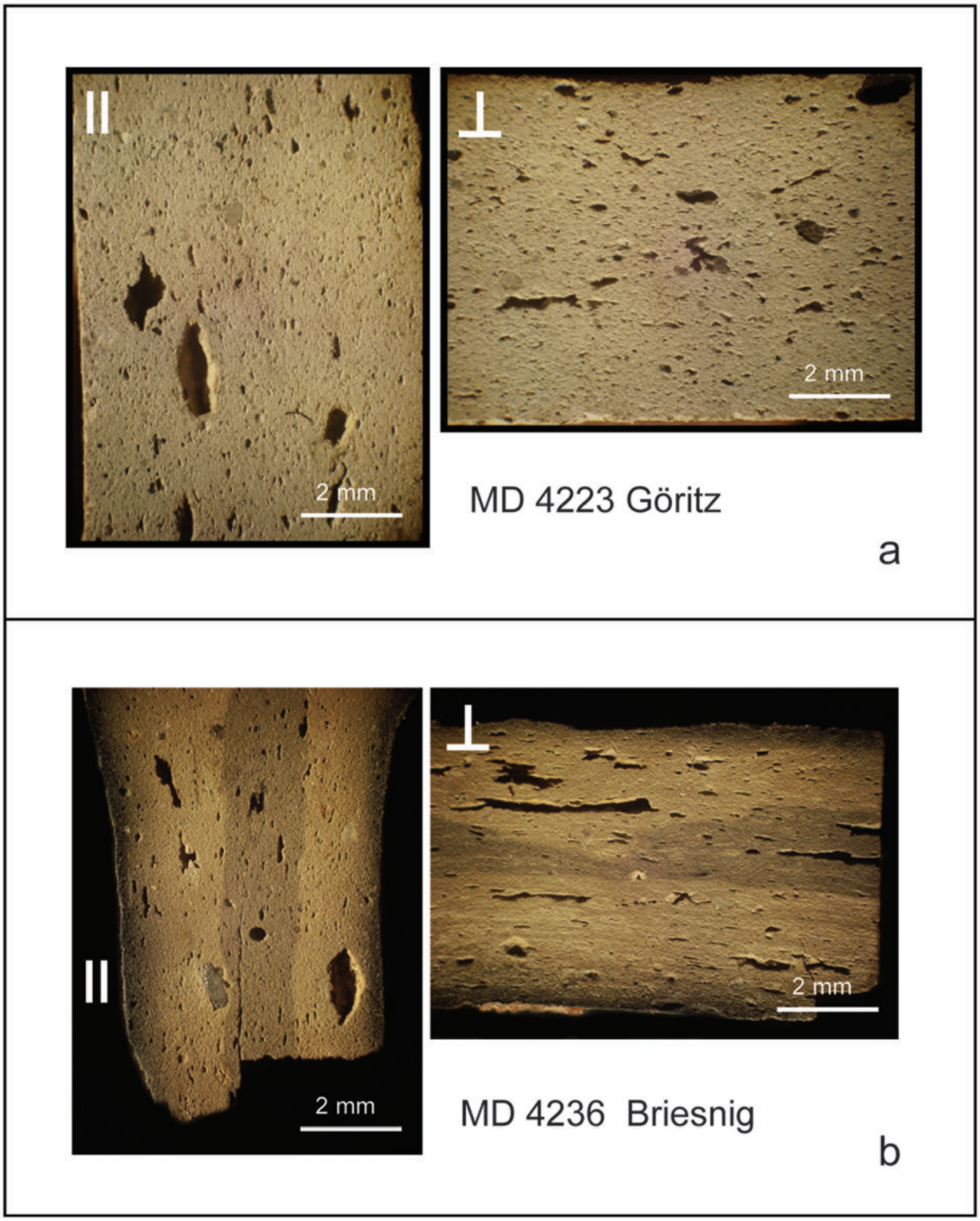


Fig. 10. Pore texture analysis:
a — wheel-thrown vessel;
b — wheel-shaped vessel formed from coils (samples from Brandenburg, Germany)
(photos E. Gałaj)

Reconstruction of forming technique by density index estimation (FTDX)

With some exceptions, ceramic materials are invariably porous to some extent. Ceramic clay bodies, no matter how carefully prepared, are impossible to produce free of pores (it should be remembered that totally removing air from a clay body exacerbates problems with forming). Air or gases are entrapped between and within the grains of the body, or they may fill pores within the structure, which results in the external volume of the body being much greater than the actual volume of the material of which it is composed. Thus, the body has an apparent density which is simply the ratio of the total weight to the external volume. This means that if a material has a porous texture it will necessarily have a low apparent density because a considerable portion of the volume will be occupied by the lightweight air in the pores. Values of apparent density and bulk density (true density) are similar only for a material in which there are few pores. The porosity of materials may be influenced by: the shape, size and grading of the particles, the nature of the material and the relative position of the particles. A fact often overlooked is that if all other things are equal, a clay body with large sized sand particles will have lower porosity than a body composed of pure clay. But this changes during firing, as in high temperatures small-particle materials fuse more rapidly than coarser-grained bodies. In the case of the same raw material, the porosity of the clay body is influenced by the method used in the material's manufacture, and the porosity of the resultant ceramics are greatly influenced by the method/technique used in the forming and firing process. This means that when using the same raw material, body preparation method and firing temperature, a considerable reduction/increase in porosity can be achieved by employing a specific shaping technique. This is reflected by changes in relative density. Analysis of modern ceramic products, such as contemporary stoneware dinnerware formed from the same plastic mass by wheel-throwing and by casting in gypsum moulds, shows differences in relative density (density index) and apparent density, in the relation of open-total-closed porosity and in microstructure (volume, size and distribution of pores) connected with the forming technique.[19] Is it possible to recognize and reconstruct ancient forming techniques by estimation of relative density? Model tests were carried out to confirm or refute the hypothesis that ancient vessel-forming techniques correlate to the relative density (density index) of sherds. Bulk density was determined using a He-pycnometer. The density index was calculated from the apparent density (estimated by hydrostatic weighting) to bulk density ratio. In addition, image analysis by Reflectance Transformation Imaging was used to identify evidence of forming seen on vessel surfaces, and to assess how forming technique and temper affected pore patterns in a plane perpendicular and parallel to the vessel's main axis observed in cut sections. Various ancient ceramics were also analysed independently of the model tests.

<u>Procedure for hydrostatic weighing</u>: samples were boiled in distilled water for two hours so that all open pores were fully saturated with water; the samples were then cooled to room temperature and weighed twice: in the first instance the samples were weighed immersed in water, and in the second the wet samples were weighed in air; after having been dried to a constant mass in a dryer at 105°C and cooled to room temperature in a desiccator, the samples were then weighed for a third time in air. This process yielded three values: ms – mass of dry sample; mw – mass of wet sample weighed in air; mww – mass of sample weighed in water (with pores saturated by boiling in water). The values of physical ceramic properties were then calculated.

<u>Procedure for the He-pycnometer</u> (Accupyc 1340): powdering in agate mortar, 0.040 mm sieve, drying 48 h at 130°C, 1 cm^3 sample chamber; weighing of sample (sample not smaller than 0.5 g), 50 cycles per sample, time of measurement 2–3 h.

[19] Wodnicka, Zych, Gołek 2010.

Procedure for sample preparation for model tests and experimental pottery manufacturing: specimens for model tests as well as vessels (bowls and pots) were produced from the same two clays: an iron-rich clay low in calcium (Rheinzabern-595) and from a clay low in calcium and low in iron (Weltzow clay). Specimens were prepared from a plastic mass with distilled water as the make-up water and were formed using two techniques. The plastic mass was prepared manually and rolled out to the appropriate thickness using a wooden roller (equivalent of coiling). The specimen was then cut out using a cutter made of glass or formed by hand in a porcelain mould. The third variety of specimen was made from granules pressed into shape using a hydraulic press (5 MPa — this type of preparation in model tests is deemed to equate to the increase in density of vessels turned on a fast wheel). All specimens were dried on blotting paper. No temper was added to the Rheinzabern clay briquettes, whilst briquettes made of Weltzow clay had either no temper or were tempered with quartz grains, grog or crushed granite respectively. The same recipes were used to prepare the ceramic bodies from which pottery vessels were then made. The laboratory-made specimens were fired at 400, 600, 700, 800, 900, 1000, 1100 and 1200°C (an average of 20 specimens were fired at each temperature) and density, open porosity and water absorption were determined for each specimen. K-H analysis was then carried out at the same temperatures. K-H analysis was also conducted on sherds of the experimental pottery and their bulk density was determined using a He-pycnometer.

Results of FTDX analysis

At the time this article was submitted for publication, only specimens and vessels without added temper had been analysed. As expected, specimens made of the same ceramic body, formed using the same technique, fired in the same conditions (atmosphere, heating rate, soaking time at the peak temperature) and cooled in the same conditions had the same open porosity (Po), water absorption (N) and apparent density (dv) values. In the case of dv, the coefficient of variation (cv%) is below 1% and up to 3% for Po and N. For example, 21 specimens formed by coiling have an average dv of 1.65 g/cm^3 and this estimate has a cv of 0.85%. Sintering behaviour, as predicted, varied depending on how the specimen had been formed. Specimens attained their maximum apparent density after firing at 1150°C. Pressed specimens (= wheel-thrown) had the highest dv (dv = 2.31 g/cm^3), while handmade specimens had the lowest (2.13 g/cm^3). Maximum dv values are correlated with the method used to prepare the ceramic body (plastic mass versus pressed granules). In contrast, the density index (relative density) is correlated with the forming technique at each firing temperature, though the difference between coil-built and handmade specimens is small. Because ancient pottery was fired at various temperatures and because of the need to standardise the analytical procedure, the authors deemed it optimal to estimate the relative density of vessels when refired at 1200°C. Table 1 shows the apparent density, open porosity and water absorption values as well as the bulk density and relative density of various experimental vessels made at the workshop in Velten from Rheinzabern-clay. Estimates were made for each vessel using sherds removed from below the rim, from the body and the base. As predicted, base sherds can be analysed to ascertain the method used in preparing the ceramic body, but naturally they should not be used for the analysis of forming techniques.[20]

This analysis is best carried out on body sherds, either alone or in combination with rim sherds. The results obtained from analysis of experimental vessels and laboratory specimens were compared with the results obtained from an analysis of ancient pottery. The analysis was carried out on Roman Imperial period pottery found in Olbia (samples provided by E. Schultze) and in Brandenburg (samples provided for analysis by M. Meyer and M. Hegewisch) and Roman pottery found

[20] It is interesting that although in any individual vessel the base always has the highest relative density, this density differs depending on the particular forming technique used.

Vessel			after refiring at 1200°C					Experimental vessels made at the workshop in Velten from Rheinzabern-clay (R-0)
type	No.	part	dv [g/cm³]	Po [%]	N [%]	dHe [g/cm³]	dv/dHe [%]	
jar	2	bottom body rim	1,84 1,81 1,82	0,9 1,0 0,9	0,5 0,5 0,5	2,57 2,57 2,57	71,5 70,3 70,8	R-0-T1 wheel-made **wheel-thrown, fast wheel**
bowl	39	bottom body rim	1,58 1,37 1,44	1,0 1,0 1,6	0,6 0,7 1,1	2,56 2,56 2,56	61,8 53,5 56,4	R-0-T2 wheel-made **wheel-thrown, slow wheel**
jar	5	bottom body rim	1,79 1,52 1,60	0,8 1,4 1,1	0,5 0,9 0,7	2,56 2,56 2,56	69,8 59,2 62,5	R-0-T3 wheel-made **wheel-shaped, fast wheel** **wheel forming (coiling technique 3)**
jar	6	bottom body rim	1,72 1,42 1,51	0,9 3,8 0,9	0,5 2,7 0,6	2,56 2,56 2,56	67,1 55,5 59,2	R-0-T4 wheel-made **wheel-shaped, slow wheel** **wheel forming (coiling technique 3)**
jar	8	bottom body rim	1,67 1,45 1,55	0,9 1,8 1,1	0,5 1,2 0,7	2,56 2,56 2,56	65,1 56,7 60,4	R-0-T6 wheel-made **wheel shaped, slow wheel** **hand forming (coiling technique 1)**
bowl	41	bottom body rim	1,59 1,29 1,52	1,2 1,1 1,0	0,7 0,8 0,6	2,56 2,56 2,56	62,2 50,4 59,5	R-0-T5 wheel-made **wheel-shaped, slow wheel** **hand forming (one clay lump)**
jar	10	bottom body rim	1,61 1,31 1,51	0,7 1,1 1,1	0,4 0,9 0,8	2.56 2.56 2.56	62,9 51,2 58,9	R-0-T7 hand-made **hand forming and hand shaping (one clay lump)**

Tab. 1. Physical ceramic properties, bulk density (He density) and relative density of experimental vessels. Po = open porosity, N = water absorption, dv = apparent density

Project	Sample No.	N [%]	Po [%]	dv [g/cm³]	d [g/cm³]	dv/d x 100% [%]
wheel-made						
	wheel-thrown					
Olbia	ES-KOZ-30	9,6	19,3	2,02	2,62	**77,1**
Olbia	ES-Koz-81	11,4	22,0	1,93	2,53	**76,3**
Olbia	ES-Koz-86	10,9	21,6	1,97	2,66	**74,0**
Olbia	ES-AK-21	14,0	26,7	1,91	2,65	**72,1**
Olbia	ES-AK-19	13,1	25,1	1,91	2,69	**71,2**
Aguntum	MD 4968	9,1	19,6	1,95	2,56	**76,2**
Aguntum	MD 4935	11,9	25,0	1,84	2,59	**71,2**
Aguntum	MD 4944	13,1	27,5	1,83	2,61	**70,2**
Aguntum	MD 4943	11,9	25,3	1,87	2,66	**70,2**
Brandenburg	MD 4215	7,6	14,1	1,86	2,33	**79,9**
Brandenburg	MD 4223	11,0	21,0	1,91	2,61	**73,1**
Brandenburg	MD 4227	14,5	25,7	1,78	2,46	**72,5**
Brandenburg	MD 4224	13,6	23,8	1,75	2,44	**71,8**
Brandenburg	MD 4214	12,1	21,8	1,81	2,58	**70,3**
	wheel-shaped (forming by coiling)					
Brandenburg	MD 4235	14,3	24,7	1,73	2,53	**68,5**
Brandenburg	MD 4236	13,9	21,6	1,55	2,38	**65,1**
Brandenburg	MD 4222	20,4	33,2	1,63	2,54	**64,3**
Aguntum	MD 4961	13,6	28,5	1,81	2,71	**66,9**
Aguntum	MD 4936	16,1	33,3	1,74	2,62	**66,5**
Aguntum	MD 4941	14,4	29,7	1,77	2,67	**66,4**
Aguntum	MD 4946	15,3	29,3	1,62	2,50	**64,7**
Aguntum	MD 4940	18,4	35,9	1,59	2,65	**60,1**
hand-made						
Aguntum	MD 4939	18,7	35,8	1,55	2,55	**60,9**
Aguntum	MD 4955	23,7	41,7	1,35	2,50	**53,8**
Aguntum	MD 4942	23,6	40,5	1,32	2,55	**51,7**
Aguntum	MD 4945	23,9	41,1	1,31	2,55	**51,2**
Aguntum	MD 4934	27,7	47,8	1,25	2,48	**50,2**
Aguntum	MD 4937	33,7	52,5	1,04	2,40	**43,1**

Tab. 2. Physical ceramic properties, bulk density (He density) and relative density of archaeological vessels

at the Roman site Aguntum in Austria (samples submitted for analysis by M. Auer), see table 2. There is a close correlation between the results of model tests and experimental vessels and the results obtained from analysis of ancient pottery. Figure 11 shows the relative density ranges for ancient pottery and experimental pottery.

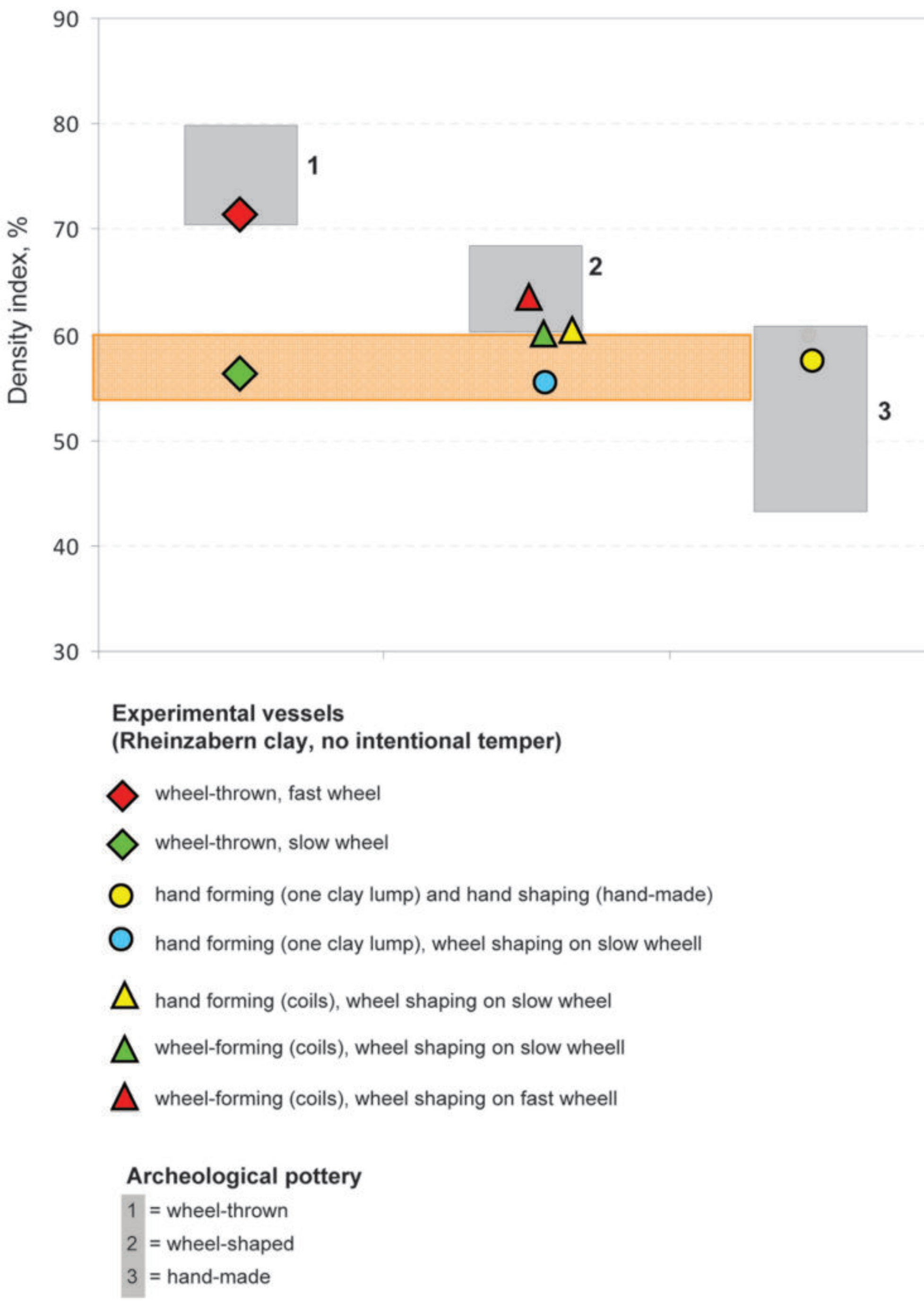


Fig. 11. The relative density ranges for ancient pottery and experimental pottery.
Grey column = pottery identified by archaeologists as: 1 — wheel-thrown; 2 — questionable (after pore analysis identified as coiling); 3 — handmade. Experimental vessels: all markers represents average values. Slow wheel refers to a wheel head moved with one hand

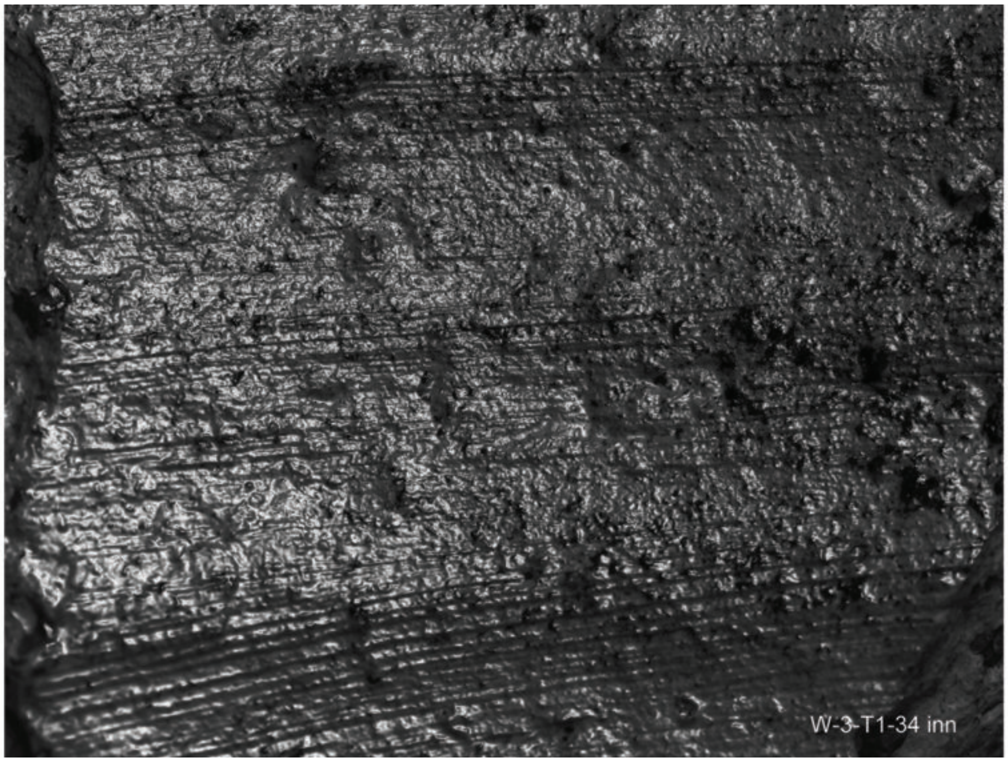
Reconstruction of shaping method/technique using reflectance transformation imaging (RTI) technique

The RTI technique for interactively displaying objects under varying lighting conditions to study surface phenomena can be a very useful tool in identifying pottery vessel-shaping methods and techniques based on observation of the features of the inner vessel surface. An automated sphere, with 57 diode LED for registration of images was used to observe the surfaces of experimentally built vessels. Figures 12–14 show examples of potters' fingerprints on the inner surfaces of wheel-thrown (fast and slow wheel) vessels, of a wheel-shaped vessel formed from coils (slow wheel) and of handmade vessels (formed from one clay lump and from coils). It is impossible to reconstruct forming techniques. Wheel-shaping on a slow wheel results in the same fingerprints regardless of the forming technique used. Furthermore, wheel-shaping on a slow wheel results in the same fingerprints as those noted on wheel-thrown vessels made on a slow wheel. These prints do, however, differ markedly from those left on vessels made on a fast wheel (wheel-thrown and wheel-shaped).

General conclusions

1. Estimating forming techniques by pore analysis requires cut-sections to be made in two planes. These cut-sections should be long enough so that the observed pores yield a representative result. As with all visual methods (image analysis), this is subject to significant personal error and not all ancient forming/shaping techniques can be recognised.
2. Estimation of physical ceramic properties (open porosity, water absorption, apparent density) and bulk density can provide information about the preparation of the body and the forming techniques.
3. Body preparation includes de-airing, which is very individual to each potter. It is a very time-consuming process and as such is less susceptible to random problems. This can be analysed by estimation of physical properties at a temperature representing the end of sintering.
4. Relative density (density index) is correlated with forming/shaping techniques, but not all ancient techniques can be recognised by such standardised estimation.
5. The base of the vessel can be used for body preparation analysis, but should not be used for forming technique analysis.
6. The RTI technique is a very good tool, adding new insights to information obtained from observation of vessel surfaces through close-up digital photographs.
7. Shaping techniques (shaping on a slow or a fast wheel, shaping without rotative kinetic energy) can be easily recognised by observation of potters' fingerprints using RTI (but forming techniques cannot be easily recognised).
8. Optimal results in the reconstruction of ancient forming and shaping techniques are achieved using two types of analysis: FTPTS with RTI or FTDX with RTI.

No relative density estimates were made for pots with burnished surfaces. The hypothesis that burnishing has a significant impact on the relative density of pottery is currently being tested.



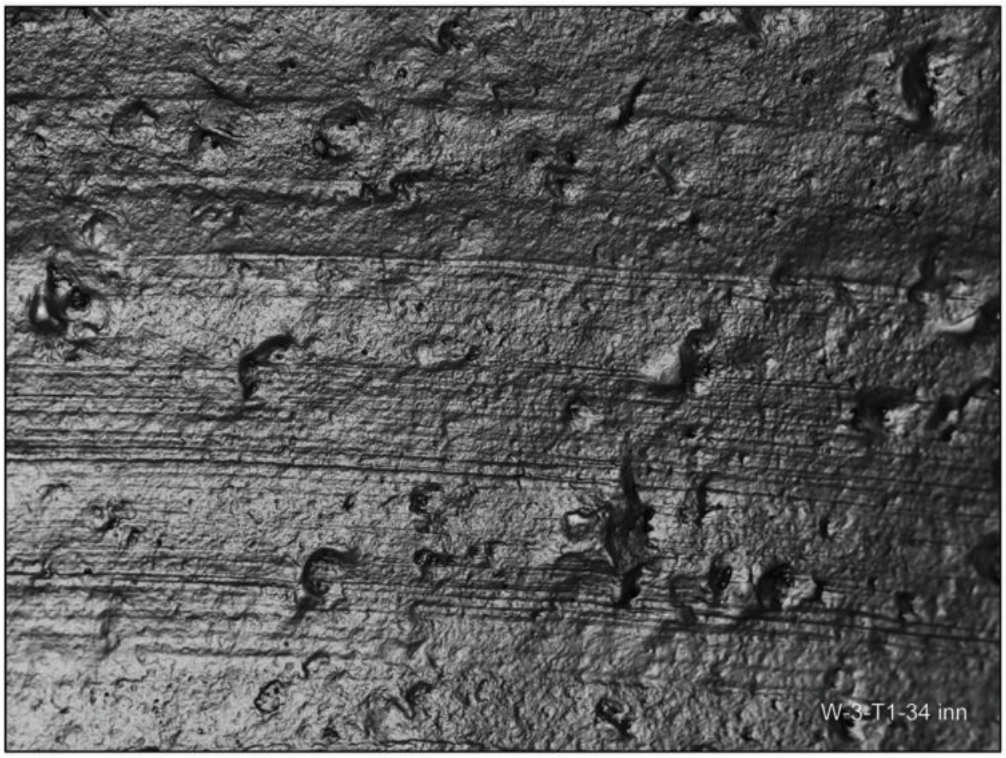


Fig. 12. Images of the inner surface of a wheel-thrown (fast wheel) experimental vessel prepared from Weltzow clay tempered by crushed ceramic fragments (grog). RTI registration and generation of data for analysis by M. Baranowski for ARCHEA

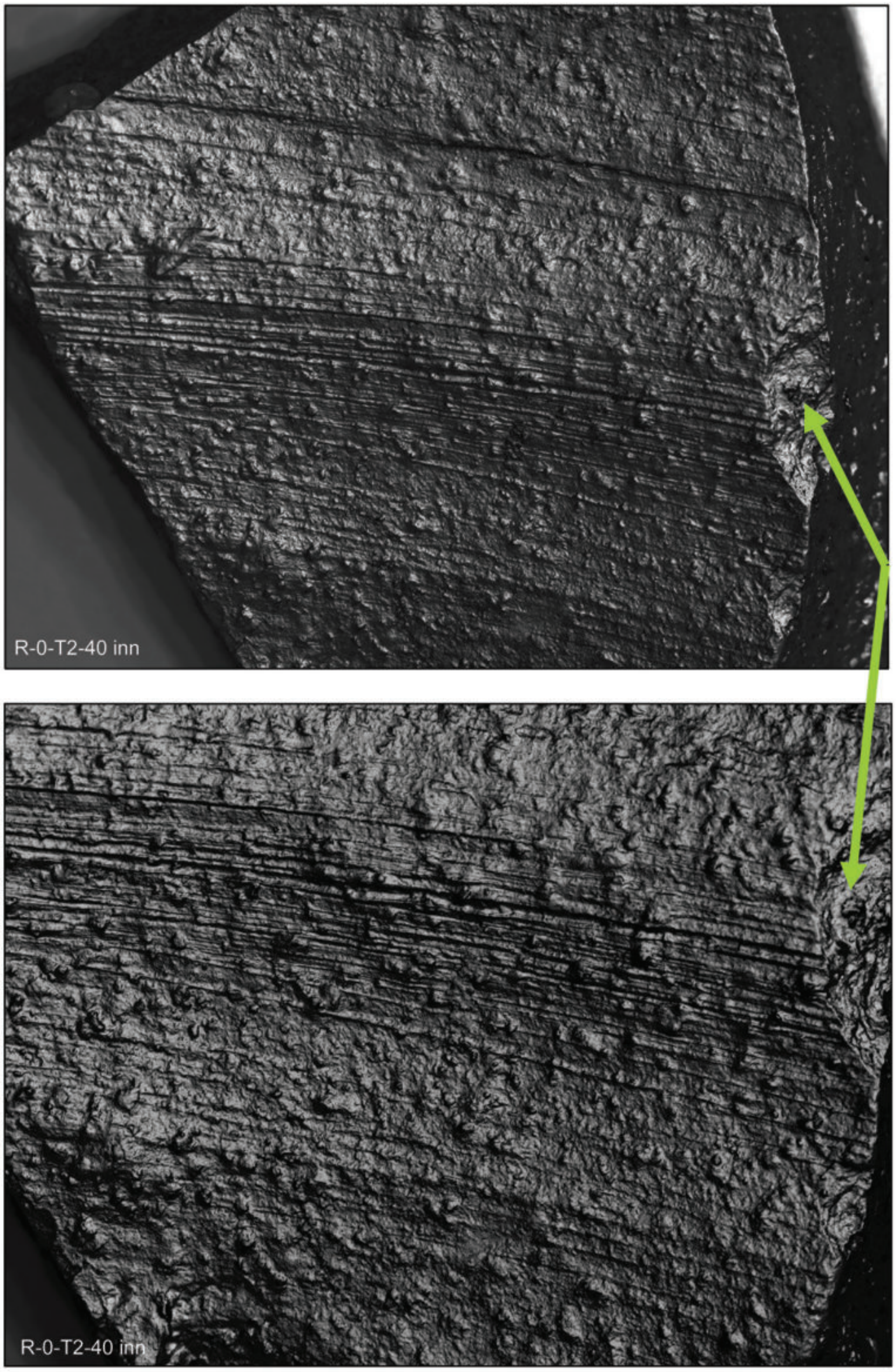


Fig. 13. Images of the inner surface of a wheel-thrown (slow wheel) experimental vessel prepared from Rheinzabern clay. RTI registration and generation of data for analysis by M. Baranowski for ARCHEA

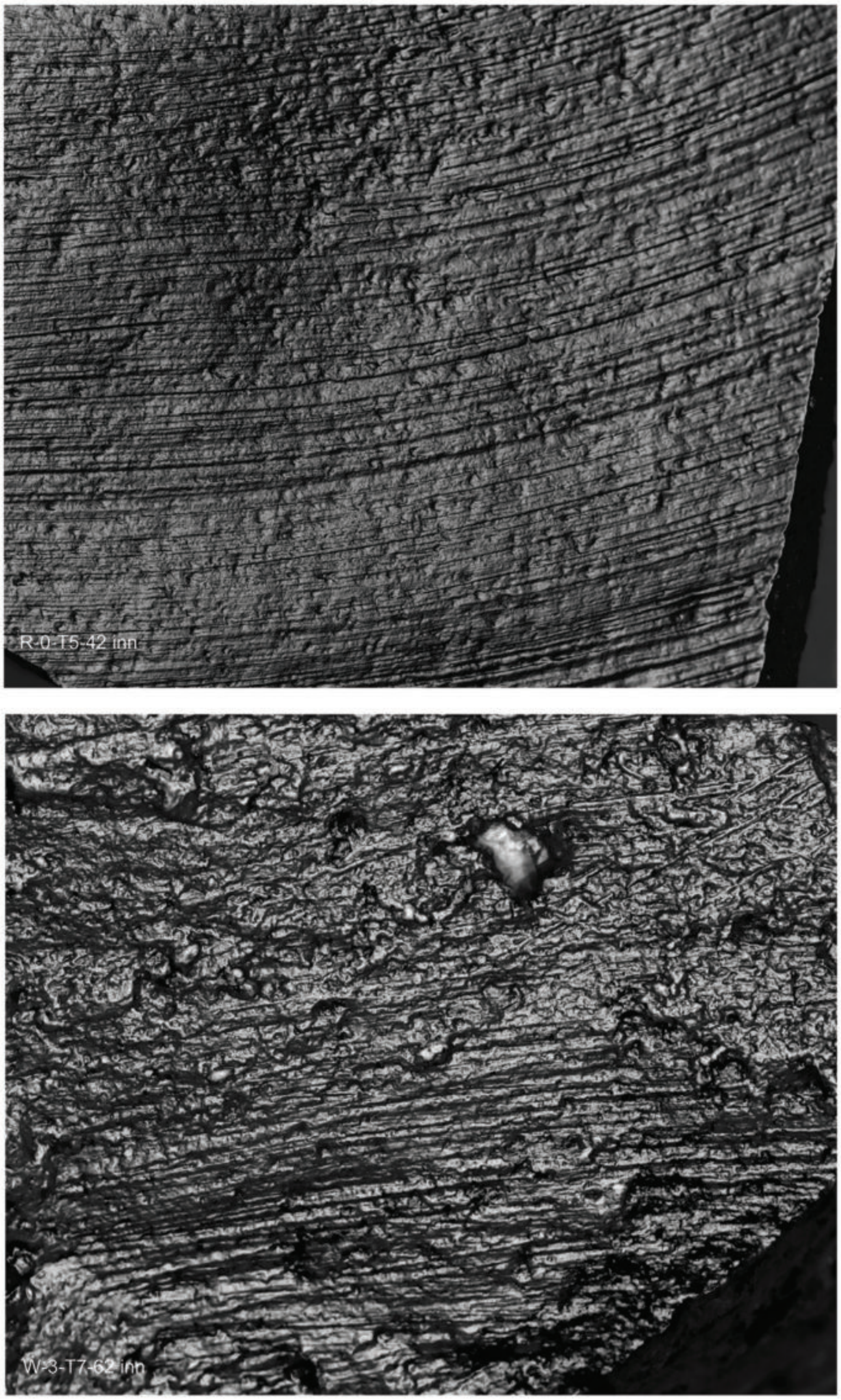


Fig. 14. Images of the inner surface of experimental vessels. Upper image: vessel hand-formed (from one lump of clay), wheel-shaped, slow wheel, Rheinzabern clay. Lower image: handmade vessel: hand-forming and hand-shaping (from one lump of clay), Weltzow clay tempered by crushed ceramic fragments (grog). RTI registration and generation of data for analysis by M. Baranowski for ARCHEA

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Streszczenie

Archeologia eksperymentalna: na ile możliwe jest odtworzenie starożytnych technik formowania ceramiki?

W artykule przedstawiono możliwosci i ograniczenia trzech metod w analizie technik formowania ceramiki zabytkowej. Pierwsza z metod jest metodą obrazową polegająca na obserwacji tekstury oraz struktury porów w przekrojach wykonanych w płaszczyźnie równoległej i prostopadłej do osi naczynia (FTPTS analiza). Druga metoda polega na określeniu stopnia zagęszczenia czerepu (FTDX analiza). Oparta jest ona na założeniu, że różny sposób wykonania naczynia manifestuje się różnym jego zagęszczeniem. Metoda ta jest dużo bardziej czasochłonna i wymaga oznaczenia zarówno gęstości pozornej, jak i właściwej. Trzecia z metod polega na analizie śladów na powierzchni naczynia z zastosowaniem techniki RTI. Przeprowadzone eksperymenty wykazały, że optymalne wyniki daje połączenie dwóch technik: FTPTS z RTI albo FTDX z RTI.

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