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Wheel-made pottery of the Przeworsk culture in the light of digital radiography examinations. Preliminary study of vessels from the microregion to the east of the lower Raba River

ABSTRACT

The article presents the results obtained by examining wheel-made pottery with the use of digital radiography. As exemplified by selected fragments, the possibilities offered by this method of studying the production techniques applied in Przeworsk culture ceramics are presented. Vessel sherds from the younger and late Roman period from workshops located in the microregion east of the lower Raba River (sites in Strzelce Małe and Bessów) were analysed. Analysis of X-radiography images offers some insight into the features of the primary forming techniques used and the structure of the clay fabric.

KEYWORDS

ancient pottery, digital radiography, forming techniques, Przeworsk culture, radiography, wheel-made pottery

I. INTRODUCTION

Pottery fragments are the most common discoveries at archaeological sites. Among the many issues related to this category of finds, the variety of techniques used in pottery-making is of particular interest is. Macroscopic analyses are the basic method used to research this issue (Courty, Roux 1995; Roux, Courty, 1998; Roux 2019). Thin-section analysis (Quinn 2013, 174–181) and ultrasonic examinations (Dobrzańska, Piekarczyk 1999–2000, 2005, 2008) are the main laboratory techniques used. Recently, pore texture analysis and density index examinations have also been proposed to study forming techniques (Daszkiewicz *et al*. 2017). Additionally, radiography is also used to analyse pottery-making. Th This method has a long tradition in research on archaeological pottery (Rye 1977; Carr 1990, 1993; Middleton 2005; Berg 2008, 2009; Berg, Ambers 2016, full literature there). Notwithstanding, so far it has not actually been adapted for research on Przeworsk culture pottery.[1]

II. STATE OF RESEARCH

In the Przeworsk culture of the younger and late Roman period and the early phase of the Migration period, ceramics were largely produced on a potter's wheel. Depending on the individual sites, the percentage of hand-made pottery varies but is generally much less common than wheel-produced. From the beginning of the studies on pottery production in the above mentioned cultural environment, attention was paid to the method of forming vessels. Historical literature contains theories regarding both the complete turning of vessels on a potter's wheel from one piece of clay (Reyman 1936, 147; Buratyński 1949, 638; Żaki 1952, 347; Wirska-Parachoniak 1968, 105) as well as handcraft techniques of primary forming – e.g., by building the lower part of the vessel from a single piece of clay or by joining coilings, and then throwing on the potter's wheel as secondary forming (Wirska-Parachoniak 1968, 105; Pazda 1972, 61; Dobrzańska 1986, 135–136; 1990, 15; Rodzińska-Nowak 2006, 54–55). It was noted that the choice of the forming method may have been

1 In the publication by Dobrzańska and Piekarczyk is mentioned, that radiographic analyses were also used, however, they were considered ineffective (Dobrzańska, Piekarczyk 1999–2000, 90).

connected with the characteristics of the pottery mass used (Dobrzańska 1990, 19; Rodzińska-Nowak 2006, 56). Forming exclusively on a potter's wheel was supposed to be used solely for the production of small forms, mainly made of paste with no added temper (Hołubowicz 1950, 110; Gajewski 1959, 108; Dobrzańska 1990, 18). According to this approach, coarse pottery (both kitchenware and storage vessels made of clay with a significant amount of mineral temper) was supposed to be made by using combined techniques (pinching or coil-building with wheel-forming) (Dobrzańska 1990, 19; Rodzińska-Nowak 2006, 56). At present, it is assumed that different forming techniques were used simultaneously in the manufacture of Przeworsk culture pottery. At the same time, it is widely believed that the production method combining the coiling technique with the potter's wheel prevailed. This is confirmed by means of thin-section analyses (Wirska-Parachoniak 1968, 105, 106) and, mostly, ultrasonic examinations (Dobrzańska, Piekarczyk 1999–2000, 2008). The macroscopic analysis of the pottery from Jakuszowice showed that the lower parts of the vessels were made using the coiling technique. The upper part was added as an additional band of clay. A vessel formed using this technique was subsequently wheel-shaped (Rodzińska-Nowak 2006, 54–56). Similar conclusions were obtained for some of the vessels from Zofipole (Dobrzańska, Piekarczyk 2008, 234).

The diversity of the forming method techniques in the Przeworsk culture also manifests itself in the terminology used in Polish-language literature. In older publications, ceramics bearing traces of potter's wheel rotation were referred to as "wheel-thrown" (understood as made entirely on a potter's wheel). Currently it is referred to as "pottery made on a potter's wheel", or "wheel-made" (made with the use of a potter's wheel at least in one of the preparation stages, wheel-shaped) (see: Rodzińska-Nowak 2006, 39).

III. AIM OF THE STUDY

As mentioned above, thin-section analysis and ultrasonic examinations have been used so far in research on the techniques used to produce vessels made on a potter's wheel by the Przeworsk culture. With regard to the results of studies by researchers using radiography to research primary and secondary techniques of pottery forming (Berg, Ambers 2016, full literature there), a decision was taken to implement this method in the research on the wheel-made pottery of the Przeworsk culture. A look at the literature suggests that this research can potentially supplement and contribute to current knowledge on pottery production in the mentioned area. This non-destructive method may significantly facilitate analysis of bulk finds such as wheel-made pottery. Thus the main aim of the undertaken research was to observe traces of vessel forming techniques via radiographic imaging. In addition, the research would enable the observation of the structure of pottery clay fabric, and above all the types and fractions of the tempers and impurities used. It should be emphasised that examined ceramics from the pottery workshops excavated in the micro-region east of the lower Raba River were subjected to chemical and physicochemical analyses (Okońska *et al.* 2018). No mineralogical and petrographic analyses have been undertaken so far.

IV. EXAMINED MATERIAL

The research used pottery material from workshops excavated in the microregion east of the lower Raba during expeditions in 1995 and 2000 (Cetera, Okoński 1994; Kordecki, Okoński 1999; Okoński 1999–2000, 2001; Okońska 2018; Okońska-Bulas *et al.* 2021). Selected samples (pottery sherds) of 62 vessels came from the Strzelce Małe 13 (Brzesko district), and Bessów 2 and 3 (Bochnia district) sites, where pottery was produced[2]. For this publication, 27 of the most representative samples were selected (Fig. 2–8).

All the materials are dated to the younger and late Roman period. The analysis covered wheel-made sherds of fine ware, coarse ware and storage vessels, which represent follow macroscopic groups distinguished for the materials from the microregion east of the Raba: I – wheel-made, fine ware with

2 Site 13 in Strzelce Małe is the most examined site in the microregion east of the Raba so far. During the three seasons of excavation work, a total of 5 pottery kilns and the remains of a pithouse, most likely a pottery workshop, were unearthed. The non-invasive surveys carried out in recent years at the site have enabled the identification of further pottery kilns (Okońska-Bulas *et al.*, in press, literature there). Site 3 in Bessów was excavated during three seasons. The remains of one pottery kiln and a pottery workshop from younger and late Roman period were unearthed there. Furthermore, some remains of Early Roman period and Medieval settlements were excavated (cf.: Okoński 1999–2000; Szpunar, Szpunar, Okoński 2000; Okońska 2018). Site 2 in Bessów was located nearby. During one excavation, the remains of three pits filled with fragments of characteristic Krausengefäss vessels were unearthed (Kordecki, Okoński 1999).

easily abradable surfaces; II – wheel-made, fine ware with non-abradable surfaces, soft and easily breakable; III – wheel-made, fine ware, with non-abradable, hard and burnished surfaces, corresponding to group I according to Godłowski, Dobrzańska and Rodzińska-Nowak (Rodzińska-Nowak 2006, 52); IV – wheel-made, coarse ware, with a significant addition of a mineral temper of various types and sizes; VI – hand-built and wheel-finished thick-walled storage vessels, with a significant addition of a mineral temper of various types and sizes, with orange surfaces (for a more specific description of the technological group see: : Okońska 2018, 354). Selected fine ware and coarse ware fragments had specific rillings on the inner sides (resulting from the rotation on the potter's wheel), while just a few fragments of storage vessels had visible traces of wheel-finishing or wheel-shaping. As a comparative material, one fragment of a hand-made vessel was also examined (with no traces of processing on a potter's wheel), which corresponded chronologically to the remaining materials.

The pottery sherds chosen for research represent various parts of the vessels. It was important to select fragments, whose location within the height of the vessel was evident . Therefore, bottoms, upper parts (with rims), and fragments of bellies from lower vessels' parts were selected. In particular, fragments of bottoms were considered important due to the fact that they best indicate how the vessels began to be built and formed.

V. METHOD OF RESEARCH

Radiography using various types of radiation is one of the oldest research methods used in the study of historical objects. Images (radiographs) of the examined object are recorded on radiosensitive material with penetrating radiation (X-ray, gamma, electron, neutron) to visualise the internal structure and texture of the object. Depending on the applied radiation, radiography is divided into X-ray, gam- ma-ray, electron-graph, or neutronography. Radiography is a basic non-destructive testing technique, which means that it plays a key role in examining historical and archaeological objects. It is possible to determine the structure of an artwork or an archaeological find, as well as its internal structure. It also enables the study of objects made of various materials. For many years, X-ray has been one of the basic research techniques used by the most famous museums in the world to examine both images and various types of historic three-dimensional objects. Along with technological development, the traditional X-ray was replaced by digital X-ray. The new technique provides several great advantages such as low cost, speed and, above all, the possibility to use software to process the obtained photos.

It is crucial that an X-ray can observe the internal structure of the vessel walls. First of all, it enables the observation of the arrangement of voids within the vessel's body. Each method of primary forming leaves its own characteristic traces within the vessel structure (Rye 1977, 206; Middleton 2005, Fig. 4.8, 4.10–4.14; Berg 2008, Fig. 1). Some of them may be obliterated as a result of the secondary forming technique, especially paddle and anvil (Berg 2009, 138, 139; Berg, Ambers 2016, 547). In addition, radiography can also reveal the pottery fabric – the type, amount, size and differentiation of the temper, as well as the presence of voids in the paste (Middleton 2005, 78–83; Berg, Ambers 2016, literature there).

The X-rays presented below were taken at the Department of Conservation Chemistry and Physics at the Faculty of Conservation and Restoration of Works of Art in the Academy of Fine Arts in Krakow, using the ULTRA 100 HF apparatus with the Carestream Vita LE intermediate digitisation system. Different device parameters (voltage, time and current) were used to take X-ray images (45, 47 or 50 kV and 40 mAs in every case). The parameters depended on the wall thickness of the analysed samples. The images were recorded on a radiographic cassette that was scanned after each exposure with the Carestream Vita LE intermediate digitisation system. The image of each exposure after scanning was observed on the computer screen. If necessary, the photos were duplicated or edited using software to increase the contrast. The pottery sherds were positioned as adjacent as possible to the radiographic cassette. If necessary, the fragments were set at different angles to the cassette and the pictures were repeated (like f.e. Fig. 4: 2b, 2c, 3b, 3c; Fig. 7: 3b, 3c).

VI. RESULTS

The research was preliminary. Therefore, only a relatively small series of fragments have been selected so far. Each of the 62 radiographic images were analysed based on the literature. As mentioned, 27 samples were selected for this publication. It was considered that at the current stage of research, such a sample might present the method's capabilities. The aim of the work was to check the possibilities offered by the method in the context of a specific archaeological material. The obtained results are not quantitative, so the selection of results for publication does not affect the result of the research. It must be admitted that the authors' interpretation of the results was not unambiguous in some cases.[3] In some samples, voids were completely unrecognisable because of the density of internal structure of sherds or the arrangement of the voids was ambiguous in interpretation (see: Table 1). Examples of such fragments are also presented (see: Fig. 7).

Forming techniques

In the analysed fragments of various technological groups, it was possible to observe traces of several forming techniques used by potters. The results are presented in Table 1 (briefly, for all analysed fragments) and Table 2 (detailed, for selected 27 samples). The fragments tend to present features of coiling with wheel-shaping as well as wheel-throwing. Also, the technique of hand-made production followed by wheel-shaping was observed.

In the analysed assemblage, the most frequently occurring forming technique was coiling combined with shaping on a potter's wheel (wheel-coiling or coiling with wheel-forming), which is considered as the most popular forming technique in wheel-made pottery of the Przework culture (see: Dobrzańska, Piekarczyk 2008). This technique is indicated by the horizontal arrangement of voids visible in the internal structure of vessel walls from X-ray imaging (Carr 1990, fig. 1; Berg 2009, 144–145; 2011). Traces of the coil used for body making were visible both in the lower and upper parts of the fragments tested (Fig. 2, 3: 1, 2; Table 2: Samples No. 1–7). The wheel-coiling technique was used both for the production of fine and coarse pottery. Moreover, some forms or rim types an additional portion of clay to be formed. It is also visible in the internal structure of some specimens, mostly in flange-rime bowls (Fig. 3: 3a–c) and in storage vessels with massive rims (Fig. 8: 2b, 3b, 4c). Moreover, the place where the handle is attached to the belly is also legible (Fig. 3: 3a–c).

The wheel-throwing technique may be recognised from characteristic diagonal voids, with a slightly spiral arrangement, in the internal structure of

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3 The authors would like to express their gratitude to Dr Ina Berg from the University of Manchester for all her valuable comments and remarks, as well as for helping and reviewing the correctness of interpretations of most of the X-ray imaging presented in the article.

the pottery walls (Carr 1990, Fig. 1; Berg 2009, 143–144; Fig. 1: 1) This type of void was observed both in the fragments of fine ware and coarse ware, in the upper as well as lower parts of vessels (Fig. 4, 5:1, 2; Table 2: Samples No. 9–13).

Interesting observations were provided by the analysis of the image of the internal structure of jugs. Fragments of two wheel-made jugs and one hand-made jug-type vessel were analysed (Fig. 4: 2, 5: 3, 4; Table 2: Samples No.10, 14, 15). It is believed that the necks of the wheel-made jugs were formed separately and attached to the belly (Dobrzańska, Piekarczyk 2008, 234). In the case of one of the specimens, the arrangement of the voids indicates that it was wheel-thrown. There are no clear traces of the belly being connected with the neck. The entire structure of the vessel is uniform and shows no signs of coils (Fig. 4: 2). At the same time, in the case of the second specimen (part of the neck), there are no traces of wheel-shaping in the internal structure (Fig. 5: 4). Traces of wheel action are visible only in the macroscopic view (Table 2: Sample No. 15). The voids are arranged irregularly and in different directions through the internal structure. This arrangement indicates forming by hand (cf. Carr 1990, Fig. 1; Berg 2008, Fig. 1).

For comparison, very characteristic traces of hand-forming are legible in an unusual jug-type vessel, made of clay fabric typical of storage vessels. The vessel has no traces of processing on the potter's wheel, which is confirmed by the macroscopic view. It has very clearly visible traces of connecting the separated neck with the rest of the body (Table 2: Sample No. 14; Fig. 5: 3).

Features characteristic of hand production (by drawing or pinching) are visible in the radiographic imaging of several tested sherds. Vessels were made by hand and then processed by wheel-shaping, like in the case of wheel-coiling. Examples of this type of forming occurred both among fine ware and coarse ware (Fig. 5: 4, 5; 6: 1; Table 2: Samples No. 15–17).

Some specimens have features suggesting that more than one forming technique was used (Fig. 6: 2–4; Table 2: Samples No. 18–20) One legible example, well readable, is a fragment of the bowl with a coarse surface (Fig. 6: 2, Table 2: Sample No. 18). The internal structure view indicates the use of two techniques for base forming. Numerous regular oblique voids are visible in the upper part. Slightly below the height of the plastic-strip decoration, the voids present a more irregular arrangement. This indicates that the lower part of the vessel was made by hand, and an additional clay coil was added to the top of the body, which was then wheel-thrown.

Among some samples of fine ware and coarse ware it was not possible to interpret the results observed with certainty (Fig. 7, in some parts also

Fig. 6: 3, 4; Tabele 2: Samples No. 19–23). Some of the tested fragments did not have any clear traces of voids, or they were so diverse that they did not allow the authors to clearly define the techniques of primary formation. It should also be emphasised that properly positioning the fragments during the measurements is crucial for obtaining the expected results. In some cases – for example, samples No. 21 or 23 (Fig. 7: 1b, 3b, 3c) – an unambiguous definition of the forming technique based on the radiographic imaging was difficult due to the angle of the pottery sherds.

Storage vessels production is a slightly different issue in the context of vessel forming. It is commonly believed that Krausengefäss-type storage vessels were hand-made (mostly by means of the coiling or slide-band technique) and had their upper parts wheel-turned. This is confirmed by the presence of grooves on the inner side or on both sides of the upper parts of this type of vessels. The conducted research made it possible to clearly visualise the traces of connections of the wide coils or clay bands in the upper parts of the bodies, as well as additionally attached clay portions for rim making (Table 2: Samples No. 24–27; Fig. 8). The fact that the traces of connections are not readable in some cases poses an interesting observation. This suggests that vessels were formed by the use of the coiling or slide-band technique and then hardened by paddle and anvil, which, due to the strong bilateral pressure on the clay, may blur traces of primary forming (Rye, 1981; Middleton 2005, 88; Berg, 2009, 138, 139; Berg, Ambers 2016, 547). At the same time, the irregular arrangement of the voids within some of the specimens indicates a hand-made construction (Fig. 8: 3).

Characteristics of clay fabric (identifying temper and impurities)

The analysis also offered the possibility to observe the structure of clay fabric. Of particular interest are the results obtained for the fine pottery. Most of the analysed fragments of fine ceramics belong to I or III raw materials and technological group for the microregion east of the lower Raba (see: Okońska 2018, 354). In the radiographic pictures, the pottery clay fabric used for the production of vessels classified as group I is internally differentiated (Fig. 9). In the macroscopic view, however, this group is technologically consist- ent and does not clearly manifest such large differences. The X-ray images obtained indicate a different way of preparing paste in terms of the temper used. There are examples with almost no inclusions (Fig. 9: group I: a), as well as ones with varied types of temper or inclusions (sand? grog? ash?) Fig. 9: group I: b, c).

Similar observations apply to the pottery of group III (Fig. 9). This shows that tableware, despite its prevailing standardisation in terms of the appearance of the external surfaces, might have been manufactured from various materials, even in the same workshop.

Also, the same observations may be made for the internal structure of coarse pottery (coarse ware and storage vessels) (Fig. 9: group IV and VI). X-ray technology can produce images of the various types of temper used, their granularity and quantity used in the paste (see: Middleton 78–82; Berg 2008, Fig. 6). Of course, mineralogical and petrographic analyses are required to confirm and accurately determine the type of temper in each technological group.

VII. CONCLUSIONS

As a result of the research, it was established that wheel-made pottery from the site of the microregion east of the lower Raba was produced with diverse forming techniques. It was confirmed that both the wheel-throwing technique and coiling technique with wheel-shaping were used. Moreover, handcrafting was confirmed to have been used as a primary forming technique. There were also some fragments presenting traces of two methods of handcrafting (e.g., combining the addition of a coil followed by forming on a potter's wheel). The results obtained for locally produced storage vessels are in line with the current findings. X-ray imaging confirms that it was produced by joining clay coils or wider tapes. The locally produced storage vessels were handmade or coiled, and coils or clay bands were joined probably by pinching or the paddle and anvil technique. The upper parts of the vessels were turned on the potter's wheel, as indicated by the marks on the outer and inner surfaces visible in the macroscopic view.

To some extent, the results complement current discoveries on the techniques used to make Przeworsk culture ceramics. This partially coincides with the results obtained for the ceramics from Zofipole. However, in comparison with these vessels, a fairly large series of wheel-thrown vessels are thought to have been formed entirely on the potter's wheel. They include both fine ware and coarse ware.

It should be noted that the only material subjected to analysis so far is pottery sherds, rather than whole forms. This, of course, affects the results obtained and indicates the technique of forming only at a particular level of the vessel's body examined, not the whole specimen. As shown by individual examples, as well as the results obtained for other sites (cf. Zofipole, Jakuszowice and analysed samples No. 18–20), the vessels can present two or even more different forming techniques. At the same time, even the results obtained for the fragments show both the potential of research using digital radiography and the diversity of the techniques used by ancient potters. The fact that there is no correspondence between the type of paste and the forming technique used constitutes an interesting observation. Both fine ware and coarse ware could have been wheel-thrown.

Taking into account the small selection of pottery sherds for the research undertaken so far, from among the thousands of pottery fragments from workshops in Strzelce Małe and Bessów, further research is needed, along with radiography and laboratory analyses. Also, in the context of discovery of the new pottery production workshops in the area of Przeworsk culture, it seems reasonable to conduct more extensive research on a larger group and to carry out comparative analyses between sites and regions. Perhaps this would help identify differences in the frequency of using particular techniques depending on a given production workshop.

The results of the observation of the clay paste structure may be an important element of research on the technology of pottery production in the Przeworsk culture, but not only. Taking into account the observations, it seems justified to use the digital radiography technique as a method preceding the mineralogical and petrographic analyses in order to select various clay fabrics for precise determination by means of microscopic analyses.

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TABLE 1. The number of fragments (samples) indicating the use of varied primary forming techniques (coiling, wheel-throwing, hand-building, combined techniques and samples uncertain in interpretation), visible on radiographic images

	wheel-thrown	wheel-coiled	combined techniques (fe. upper part coiled, and upper part thrown)	handmade and wheel-shaped or wheel-fashioned	primary forming technique uncertain
fine pottery (group I, II, III)	8	8	2	4	11
coarse pottery (group IV)	6	7	1	5	3
storage vessels (group VI)	-	4	-	3	-
in total	14	19	3	12	14

TABLE 2. Detailed characteristics of the selected pottery sherds, including a description of the sample and the features of the used forming technique visible in the radiographic images

No	Site	Sherd description	Techno-logical group (after: Okońska 2018)	Features of the forming technique visible in radiographic imaging	Forming technique used for making the particular part of the vessel's body	Figure
1	Strzelce Małe 13	Upper part of an ornamented bowl with flange-type rim. Fine, brown surface. Outer side: abrasive. Inner side: abrasive, with grooves. Wall-thickness: 7-10 mm	I	Horizontal arrange-ment of voids	Coiled and wheel-shaped (wheel-coiled). The body was made by coiling. Shaping and thinning is on a wheel	Fig. 2:1a, b
2	Strzelce Małe 13	Upper part of the ornamented bowl with flange-type rim. Fine, black surface. Outer side: nonabra-sive, burnished. Outer side: nonabrasive; rilling. Wall-thickness: 7-9 mm	III	Dense structure, horizontal arrange-ment of voids	Coiled and wheel-shaped (wheel-coiled). The body was made by coiling. Shaping and thinning is on a wheel	Fig. 2:2a, b
3	Strzelce Małe 13	Lower body section of the pot or bowl. Coarse, grey surface. Outer side: coarse, nonabrasive. Inner side: rilling. Wall-thickness: 8 mm	IV	Mostly horizontal voids	Possibly coiled and wheel-shaped (wheel-coiled)	Fig. 2:3a, b
4	Strzelce Małe 13	Belly, lower part of the vessel. Coarse, light brown surface. Outer side: nonabrasive. Inner side: nonabrasive, rilling. Wall-thickness: 6-9 mm	IV	Horizontal arrange-ment of voids	Coiled and wheel-shaped (wheel-coiled). The body was made by coiling. Shaping and thinning is on a wheel	Fig. 2:4a, b
5	Strzelce Małe 13	Upper part of the ornamented bowl with flange-type rim. Fine, grey surface. Outer side: nonabrasive, burnished. Outer side: nonabrasive; rilling. Wall-thickness: 7 mm	III	Horizontal arrange-ment of voids	Coiled and wheel-shaped (wheel-coiled). The body was made by coiling. Shaping and thinning is on a wheel	Fig. 2:5a, b
6	Strzelce Małe 13	Upper part of the ornamented bowl or biconical pot. Coarse, grey surface. Outer surface: coarse, nonabrasive, slight grooves. Inner side: rilling and grooves. Wall-thickness: 7 mm	IV	Horizontal arrange-ment of voids	Coiled and wheel-shaped (wheel-coiled). The body was made by coiling. Shaping and thinning is on a wheel	Fig. 3:1a, b
7	Strzelce Małe 13	Lower body section and bottom of the bowl. Fine, brown surfaces. Outer side: nonabrasive. Inner side: slightly abrasive, lighter. Partially obliterated rilling and grooves. Wall-thickness: 15 mm	II	Horizontal arrange-ment of voids	Coiled and wheel-shaped (wheel-coiled). The body was made by coiling. Shaping and thinning is on a wheel	Fig. 3:2a, b

cont. Table 2

cont. Table 2

No	Site	Sherd description	Techno-logical group (after: Okońska 2018)	Features of the forming technique visible in radiographic imaging	Forming technique used for making the particular part of the vessel's body	Figure
8	Strzelce Małe 13	Upper part of the ornamented bowl with flange-type rim and a handle. Fine, grey surface. Outer side: abrasive. Inner side: abrasive, with grooves. Wall-thickness: 8 mm	I	Horizontal arrangement of voids visible only in rim-part. The body: unreadable, very dense structure	Forming technique of the body uncertain. Two extra coils added to make a rim	Fig. 3:3a, b, c
9	Strzelce Małe 13	Upper part of the ornamented bowl with flange-type rim. Fine, light brown surface. Outer side: abrasive. Inner side: abrasive, partially obliterated rilling. Wall-thickness: 7-8 mm	I	Diagonal arrangement of voids	Wheel-thrown	Fig. 4:1a, b
10	Strzelce Małe 13	Upper part of the ornamented jug (belly with the lower part of the separated neck). Fine surface Outer side: abrasive, light brown. Inner side: abrasive, light grey, with perceptible sand-temper; rilling not very legible, obliterated. Wall-thickness: 8 mm	I	A few diagonal voids, visible in the structure of the upper part of belly and the neck. No traces of joining the neck with the belly	Wheel-thrown?	Fig. 4:2a, b, c
11	Strzelce Małe 13	Lower body section of the bowl. Fine, grey surface. Outer side: partially abrasive, partially covered by layer of coating. Inner side: abrasive surfaces; rillings. Wall-thickness: 7-13 mm	I	Diagonal arrangement of voids	Wheel-thrown	Fig.1:1 Fig. 4:3a, b, c
12	Strzelce Małe 13	Bottom part of the bowl or pot. Coarse, grey surface. Outer side: slightly abrasive. Inner side: slightly abrasive, rillings. Wall-thickness: 7 mm	IV	Spiral, diagonal arrangement of voids	Wheel-thrown	Fig. 5:1a, b
13	Strzelce Małe 13	Belly, lower part of the vessel. Fine, grey surface. Outer side: abrasive, with some postdepositional damaging (scratches). Inner side: abrasive surfaces; rillings. Wall-thickness: 8 mm	I	Diagonal arrangement of voids	Wheel-thrown	Fig. 5:2a, b

cont. Table 2

14	Bessów 3	Upper part of handmade, untypical jug or storage vessel. Part of belly with separated neck. Surfaces coarse. Outer and inner side orange, nonabrasive. No traces of wheel-action on surfaces. Clay material used is typical for storage vessels. Wall-thickness: 9-12 mm	VI / VII	IIrregular, multidirectional arrangement of voids.	Fully handmade. The neck was joined to the body	Fig. 5:3a, b, c
15	Strzelce Małe 13	The neck of a jug. Fine, brown surface. Outer side: abrasive, with some postdepositional damaging (scratches). Inner side: abrasive; grooves, partially obliterated. Wall-thickness: 7 mm	I	Uneven, multidirectional arrangement of voids	Handmade and wheel-fashioning	Fig. 5:4a, b
16	Strzelce Małe 13	The entire profile/half of the ornamented bowl. Fine, grey surface. Outer side: nonabrasive, burnished. Outer side: nonabrasive; rilling in lower section, grooving in upper section. Wall-thickness: 7-9 mm	III	Very dense structure, voids almost unreadable..	Handmade and wheel-shaped?	Fig. 5:5a, b
17	Strzelce Małe 13	Lower body section of the pot. Coarse, orange and brown surface. Outer side: nonabrasive. Inner side: rilling. Wall-thickness: 8-10 mm	IV	Uneven, multidirectional arrangement of voids	Handmade (drawing or pinching) and wheel-fashioning or wheel-shaped	Fig. 6:1a, b
18	Strzelce Małe 13	Upper body section of the pot or bowl. Coarse, brown and light-brown surface. Outer side: nonabrasive. Inner side: grooves. Wall-thickness: 7 mm	IV	Different arrangement of voids in body structure. Rim and upper part of belly: diagonal voids. Lower part of belly (below plastic ornament): irregular arrangement of voids	Lower part of belly: handmade. In upper part of belly (slightly below the plastic ornament) extra layer of clay added and then thrown. Wheel-shaped	Fig. 6:2a, b
19	Strzelce Małe 13	Belly, lower part of the vessel. Fine, grey surface. Outer side: abrasive, with some postdepositional damaging (scratches). Inner side: abrasive surfaces; rillings. Wall-thickness: 9 mm	I	Different arrangement of voids in lower and upper part. In lower part: diagonal; in upper part: uneven	Partially wheel-thrown (in lower part). In upper part: uncertain	Fig. 6:3a, b
20	Strzelce Małe 13	Almost the entire profile of the ornamented bowl (without bottom). Fine, grey surface. Outer side: abrasive. Inner side: abrasive, partially obliterated rilling. Wall-thickness: 7 mm	I	Diagonal arrangement of voids	Wheel-thrown in lower part. In upper part uncertain (requires side view)	Fig. 6:4a, b

No	Site	Sherd description	Techno-logical group (after: Okońska 2018)	Features of the forming technique visible in radiographic imaging	Forming technique used for making the particular part of the vessel's body	Figure
21	Bessów 3	The entire profile of the bowl. Fine, light brown surface. Outer side: nonabrasive. Inner side: slightly abrasive; rilling in lower section, obliterated. Wall-thickness: 5-7 mm	II	Numerous voids, both horizontal and diagonal	Uncertain (requires side view)	Fig. 7:1a, b
22	Strzelce Małe 13	Almost the entire profile of the ornamented bowl (without bottom). Fine, grey surface. Outer side: abrasive. Inner side: abrasive surfaces; partially obliterated rilling. Wall-thickness: 5-6 mm.	I	Very dense structure, voids unreadable	Unclear	Fig. 7:2a, b
23	Strzelce Małe 13	Lower body section of the pot. Coarse, grey. Outer surface: coarse, nonabrasive. Inner side: rilling and grooves. Wall-thickness: 6-9 mm	IV	Differently arrange-ment of voids in body structure. On the bottom: rather diagonal. On lower and upper part of body: uneven	Unclear (requires side view)	Fig. 7:3a, b, c
24	Strzelce Małe 13	Upper part of storage vessel, with massive rim. Coarse surface. Outer and inner side: orange, with grooves and some fingerprints. Wall-thickness: 21 mm	VI	Horizontal arrange-ment of voids	Coiled/slide-band and wheel-fashioned	Fig. 8:1a, b
25	Bessów 2	Upper part of storage vessel, with massive rim. Coarse, orange surface, slightly abrasive. Outer and inner side: no traces of wheel-finishing, very proba-bly obliterated. Wall-thickness: 23 mm	VI	Horizontal arrange-ment of voids	Coiled/slide-band and probably wheel-fashioned	Fig. 8:2a, b
26	Bessów 2	Upper part of storage vessel, with massive rim. Coarse, orange surface, slightly abrasive. Outer and inner side: no traces of wheel-finishing, very proba-bly obliterated. Wall-thickness: 19-22 mm	VI	Voids both horizon-tal and irregular in body internal struc-ture. Well-readable horizontal voids on the rim	Handbuild or coiled and probably wheel-fashioned	Fig. 8:3a, b
27	Bessów 2	Upper part of storage vessel, with massive rim. Coar-se, orange surface, slightly abrasive. Outer and inner side: no traces of wheel-finishing, highly probable obliterated. Wall-thickness: 20 mm	VI	Horizontal arrange-ment of voids	Coiled/slide-band and probably wheel-fashioned	Fig. 8:4a, b, c

cont. Table 2

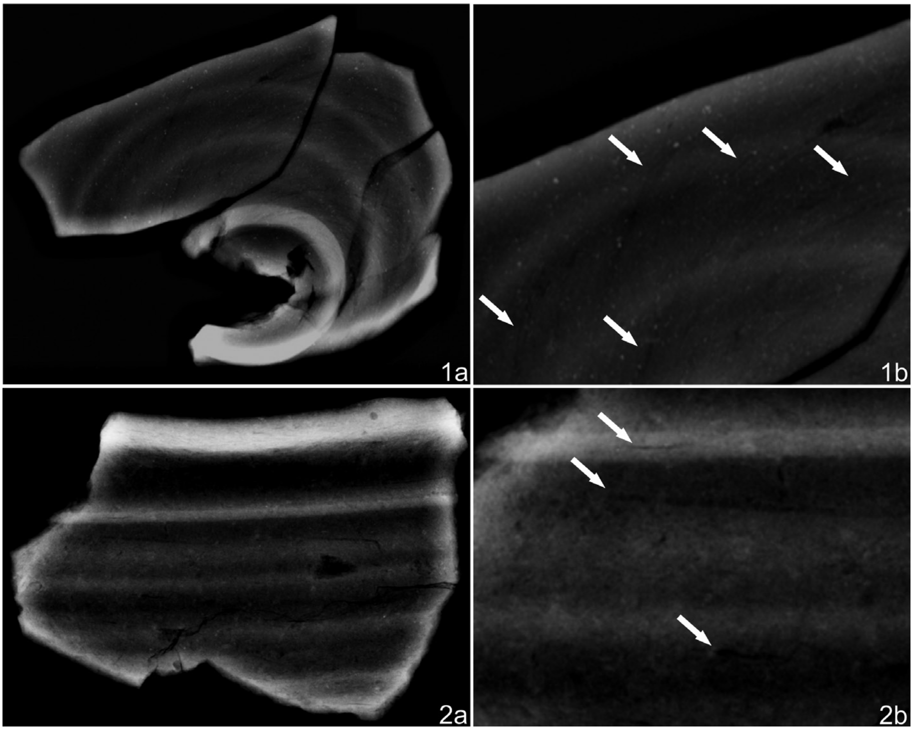

FIG. 1. Radiographic features of two different forming techniques: 1a - bottom part of a wheel-thrown vessel; 1b - diagonal arrangement of voids (in zoom); 2a - vessel built in the coiling technique and formed on a potter's wheel; 2b - horizontal arrangement of voids (in zoom) (radiographic images by A. Mikołajska)

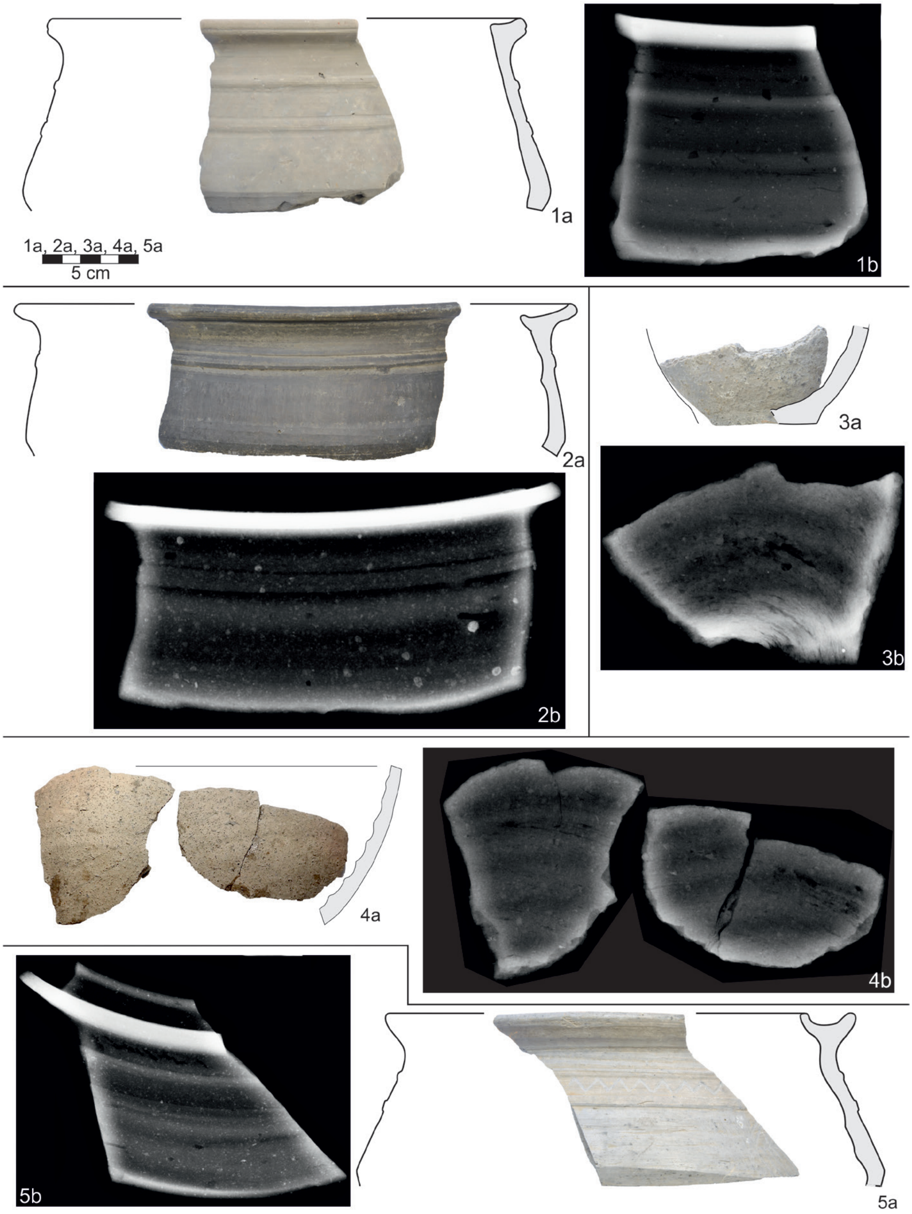

FIG. 2. Selected pottery fragments and their radiographic images: 1-5 - examples of the coiling technique combined with shaping on a potter's wheel. Negative radiographic images with no scale. Parameters (mAs, kV) varied for individual images. Some pictures are software-enhanced (pottery photos and drawings by M. Okońska- Bulas, radiographic images by A. Mikołajska)

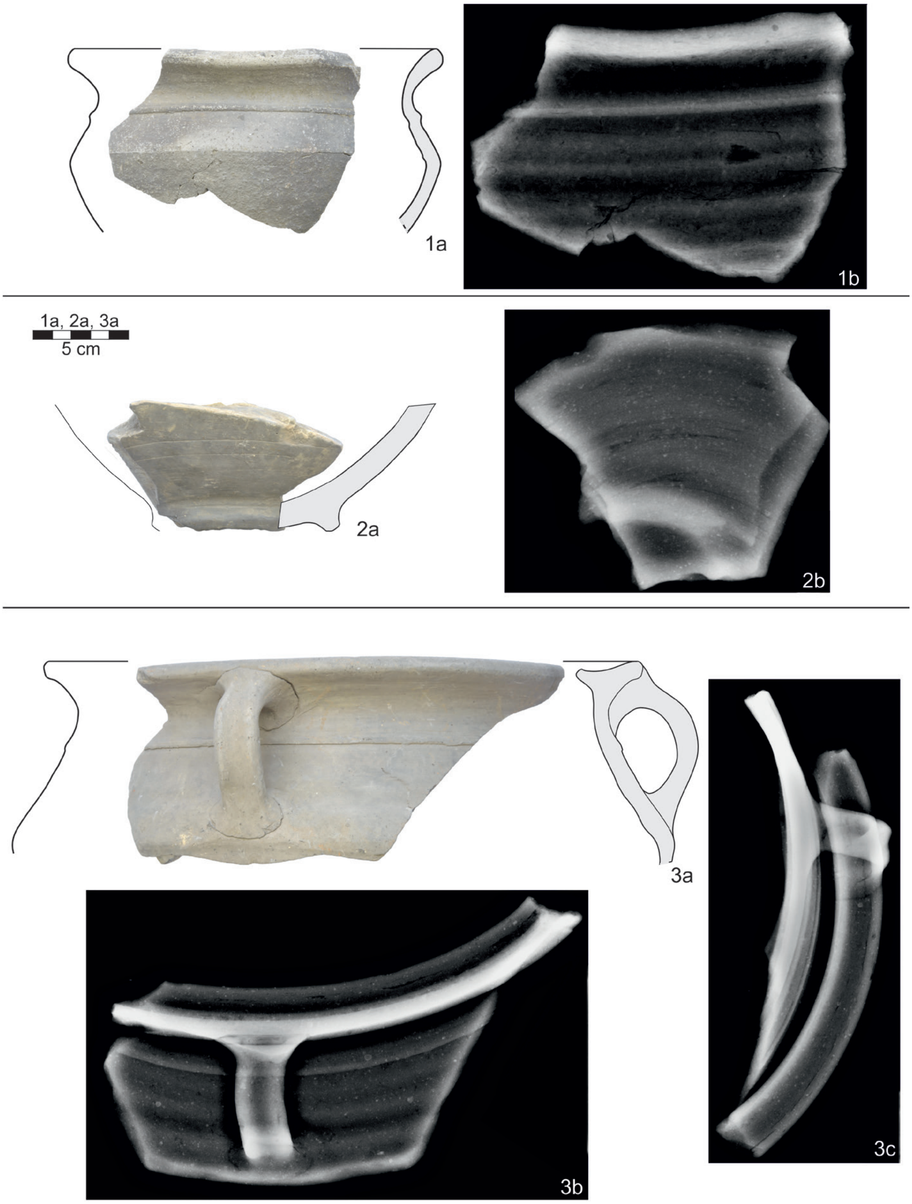

FIG. 3. Selected pottery fragments and their radiographic images: 1, 2 - examples of coiling technique combined with shaping on a potter's wheel, 3 – forming technique of the body uncertain, rim made by two extra coils. Negative radiographic images with no scale. Parameters (mAs, kV) varied for individual images. Some pictures are software-enhanced (pottery photos and drawings by M. Okońska-Bulas, radiographic images by A. Mikołajska)

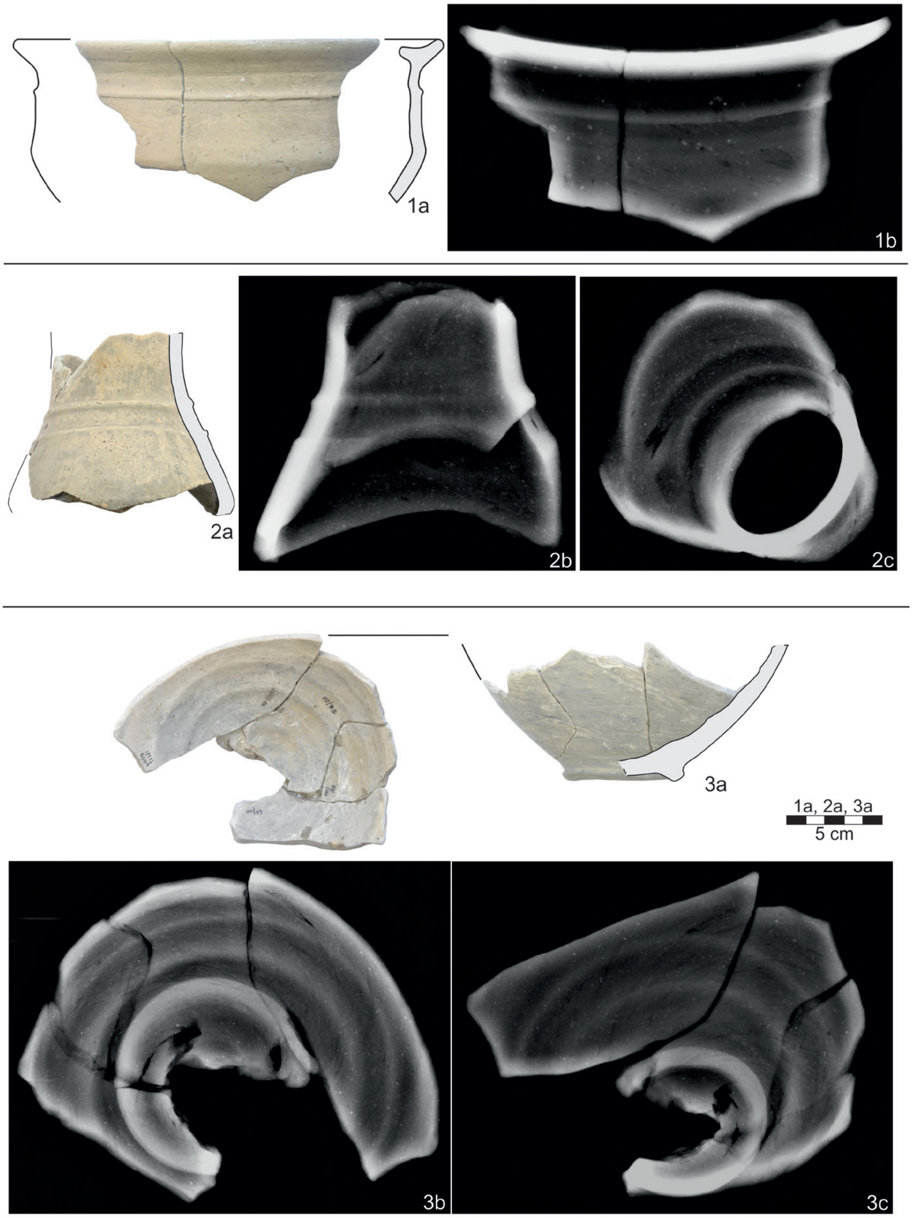

FIG. 4. Selected pottery fragments and their radiographic images: 1-3: examples of wheel-throwing technique. Negative radiographic images with no scale. Parameters (mAs, kV) varied for individual images. Some pictures are software-enhanced (pottery photos and drawings by M. Okońska-Bulas, radiographic images by A. Mikołajska)

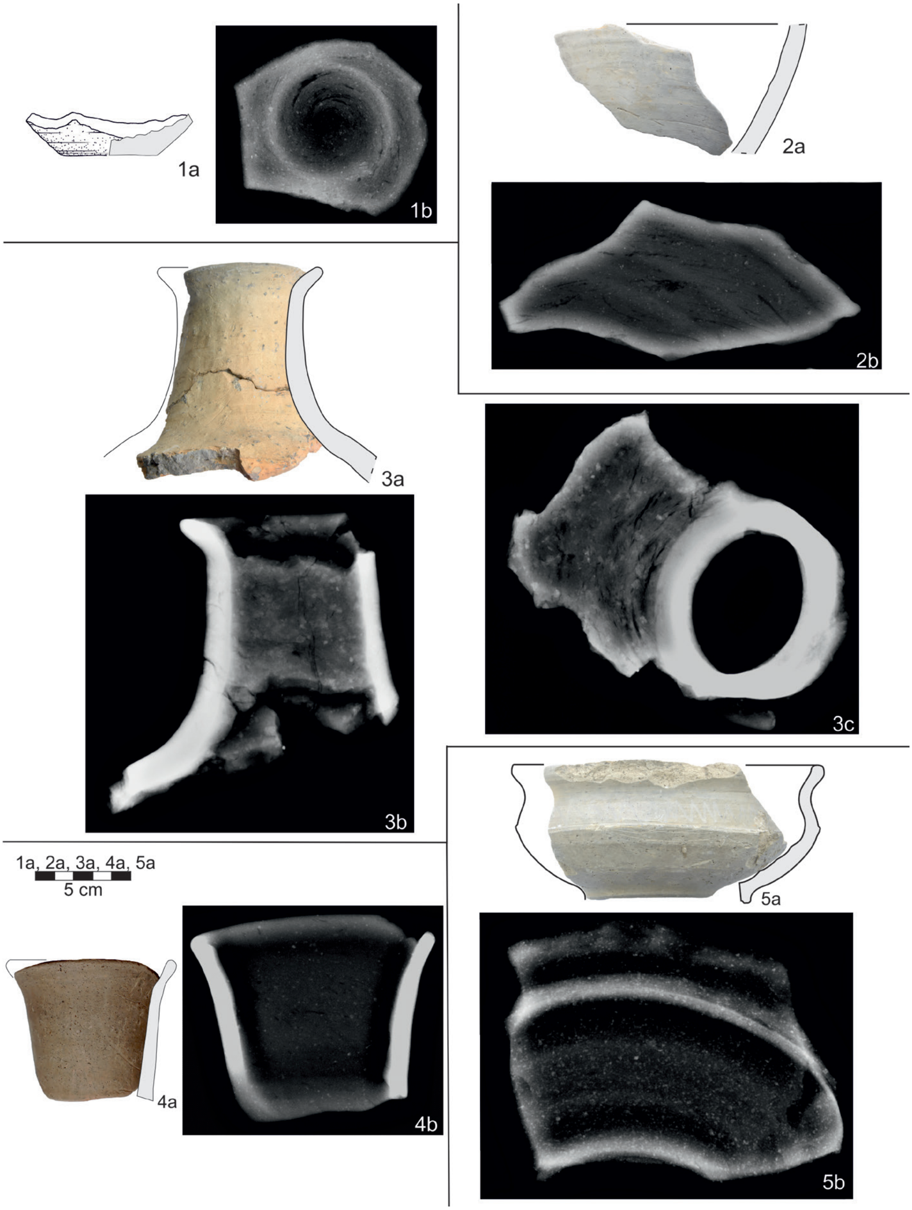

FIG. 5. Selected pottery fragments and their radiographic images: 1, 2 - examples of wheel-throwing technique, 3 – example of fully hand-made vessel; 4, 5 - examples of combined hand-making and wheel-shaping. Negative radiographic images with no scale. Parameters (mAs, kV) varied for individual images. Some pictures are software-enhanced (pottery photos and drawings by M. Okońska-Bulas, radiographic images by A. Mikołajska)

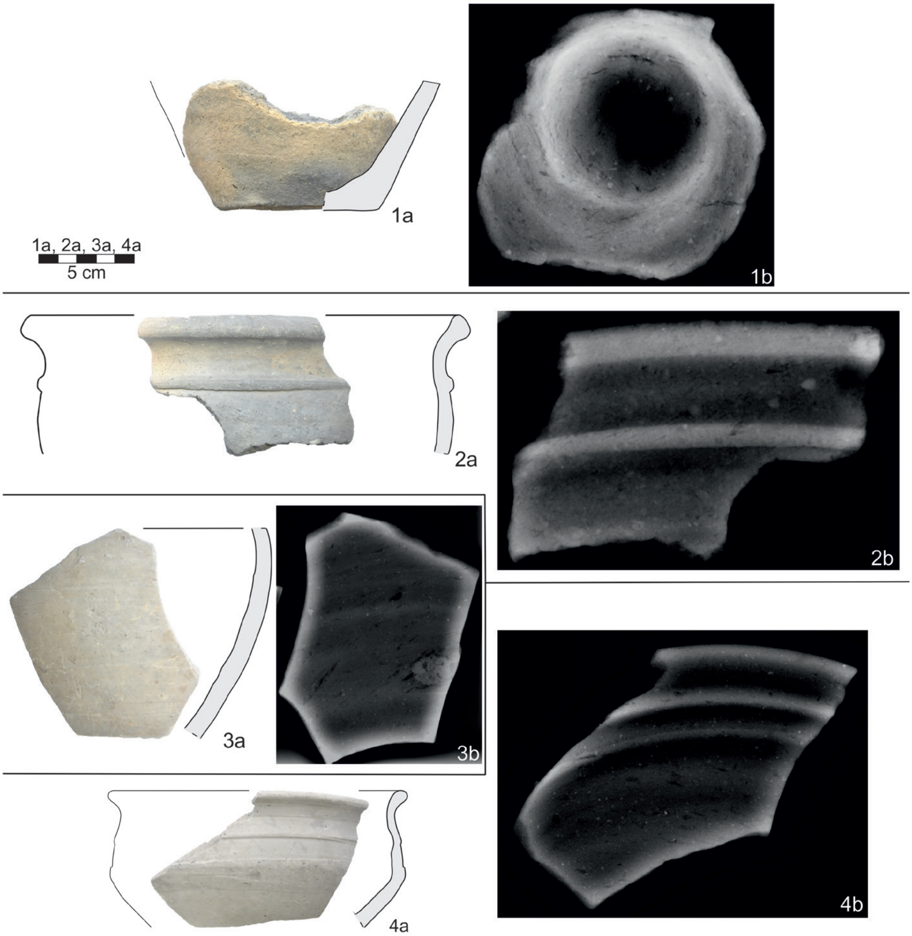

FIG. 6. Selected pottery fragments and their radiographic images: 1 – example of combined hand-making and wheel-shaping; 2-4: combined techniques. Negative radiographic images with no scale. Parameters (mAs, kV) varied for individual images. Some pictures are software-enhanced (pottery photos and drawings by M. Okońska-Bulas, radiographic images by A. Mikołajska)

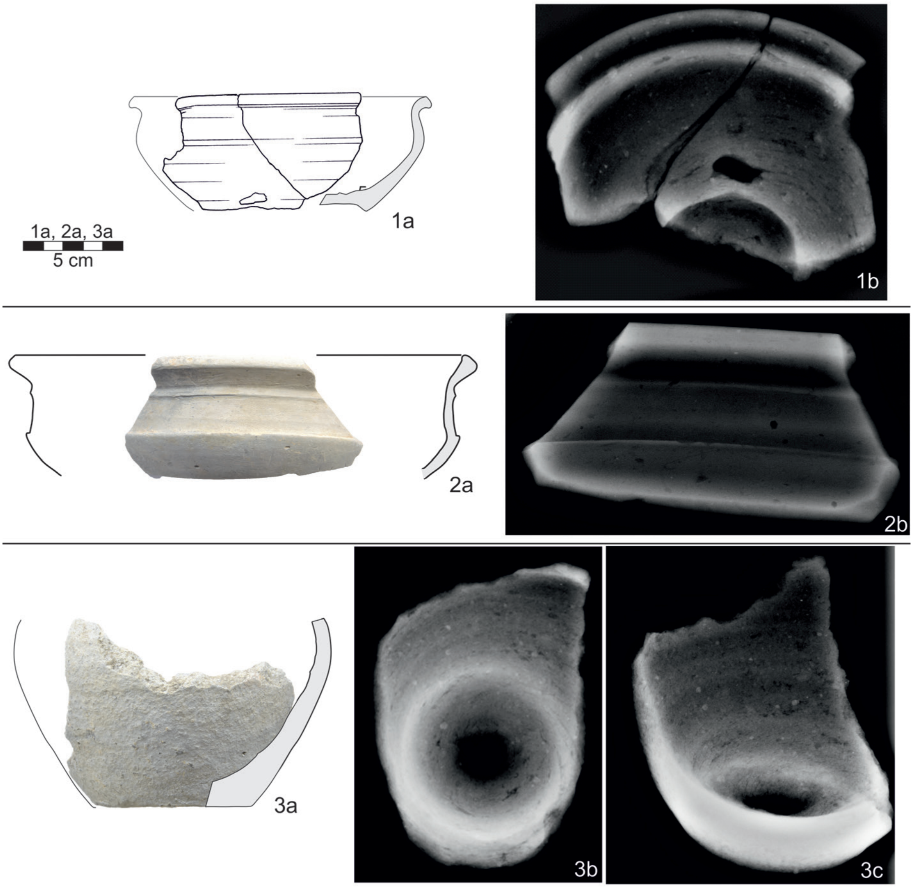

FIG. 7. Selected pottery fragments and their radiographic images: 1-3: examples of fragments uncertain in interpretation. Negative radiographic images with no scale. Parameters (mAs, kV) varied for individual images. Some pictures are software-enhanced (pottery photos and drawings by M. Okońska-Bulas, radiographic images by A. Mikołajska)

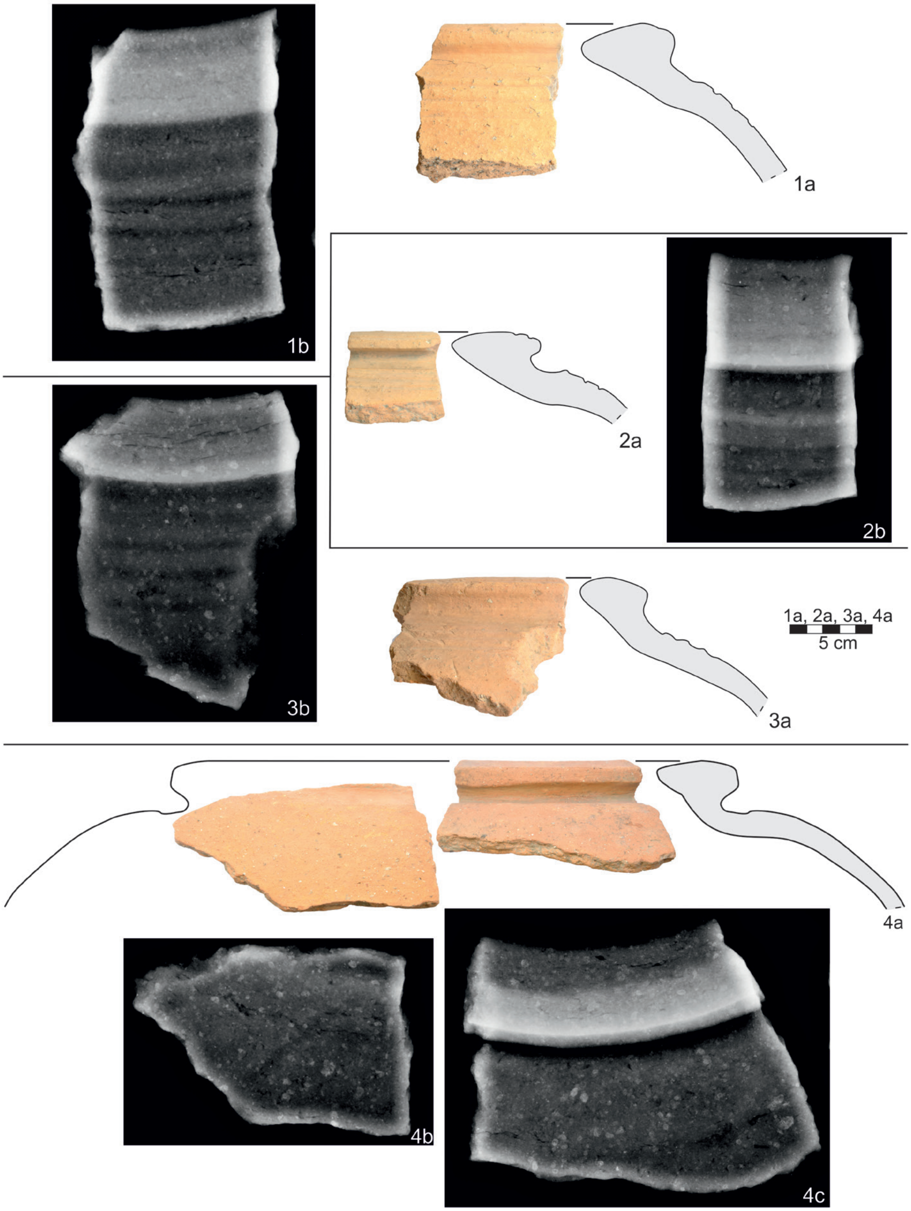

FIG. 8. Selected pottery fragments and their radiographic images. Examples of storage vessels: 1, 2, 4 – coiled or slide-band primary forming technique, 3 –handcrafted or coiled as primary forming technique. Negative radiographic images with no scale. Parameters (mAs, kV) varied for individual images. Some pictures are software-enhanced (pottery photos and drawings by M. Okońska-Bulas, radiographic images by A. Mikołajska)

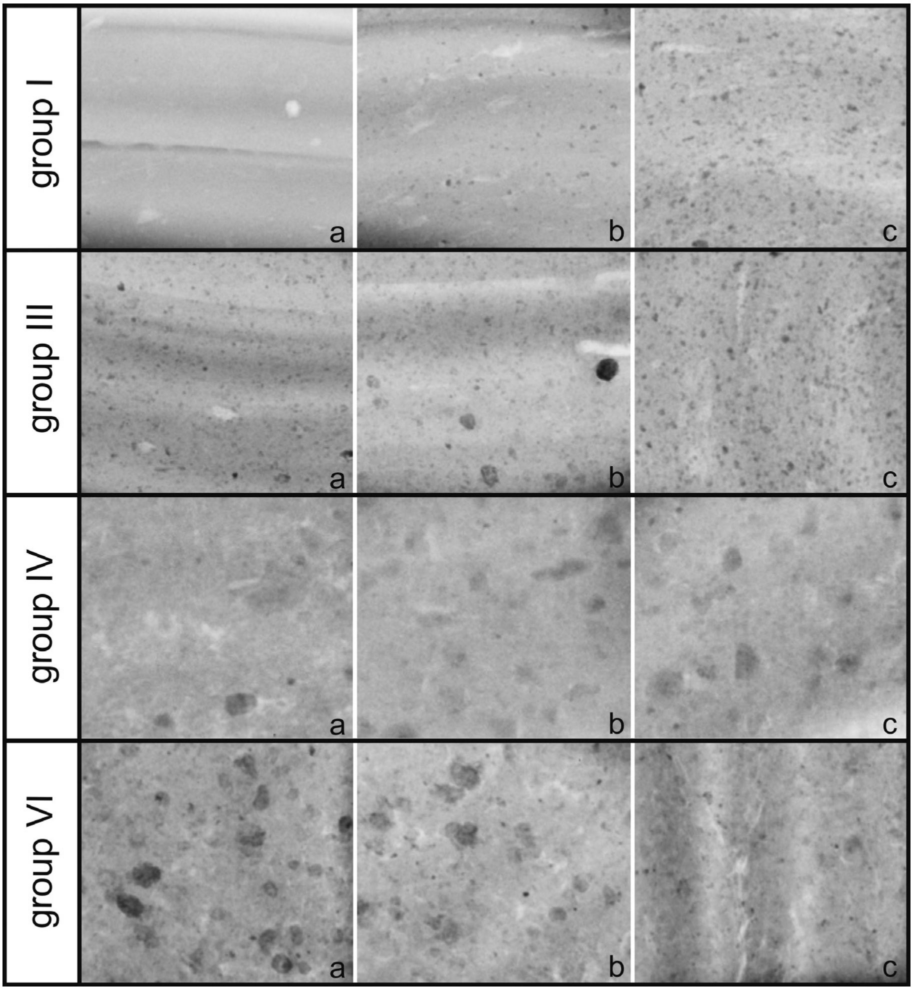

FIG. 9. Differentiation of clay fabrics within selected technological groups separated based on macroscopic view. Enhanced positive radiographic images (in zoom, no scale)