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The diversity of ceramic raw materials used in the production of Neolithic vessels in the upper Vistula basin near Krakow

Abstract

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Specialist analysis of ceramics helps to identify the raw material used for their production and to determine whether the material was chosen deliberately for its specific parameters. The present study of Neolithic vessels and of sampled raw materials has shown that Linear Pottery population tended to use plastic Miocene clay, but silty alluvial loam was equally popular. A comparison between the types of vessels and ceramic bodies has proven that thin-walled vessels were more often made of material with a high content of grains of silty fraction, while thick-walled vessels were usually shaped from heavy clay. This suggests that there were certain rules to be observed when preparing the paste, despite the local diversity of raw materials.

Key words: early Neolithic, raw materials, ceramics, petrography, Małopolska

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Introduction

Besides flint and stone tools, ceramic raw materials rank among the most numerous artefacts recovered from archaeological excavations. This provide evidence that the farming populations used resources available to them and that knowledge of these resources resulted from familiarity with the local environment, while the choice of the raw material depended on the level of expertise in vessel production.

Specialist analysis of ceramics helps to identify the raw material used for their production and to determine whether the material was chosen deliberately for its specific parameters. Studies of this kind have become a standard archaeological procedure. This text presents the results of mineralogical and petrographic analyses of raw materials and ceramic fragments related to early Neolithic cultures in the upper Vistula basin near Krakow. Diversity in the use of clay is illustrated here with several examples taken mostly from the sites from which complete set of data have been obtained, i.e. Site 5 in Modlnica, Site 62 in Mogiła (north of the Vistula River) and Site 17 in Brzezie (south of the Vistula River). Some of the results have already been published in descriptions of the individual sites (Rauba-Bukowska 2014; Rauba-Bukowska 2011) and in a report on a research grant (Czekaj-Zastawny and Rauba-Bukowska 2013). The publications are complemented by the analysis of clay materials sampled in the vicinity of Site 5 in Modlnica, Site 2 in Modlniczka and Site 62 in Mogiła, presented here for the first time.

Geology and geomorphology of the research area

The analysed sites lie within the Carpathian Foredeep. Their geological structure consists of Palaeozoic and Mesozoic deposits forming the substratum of the foredeep, Miocene deposits filling the basin, and a Quaternary cover which has developed since the Pleistocene.

The Miocene sediments are situated discordantly on the Upper Cretaceous planation surface. They are known from drilling and isolated surface exposures e.g. in the brickyard in Zesławice near Nowa Huta, or from isolated outcrops in the vicinity of the site in Brzezie. They are sediments of marine origin: clays and marly claystones interbedded with sand with interlayers of sandstones and locally with characteristic levels of tuffites. The outcrops of the Miocene sediments are located in places where the Quaternary cover has been cut through by erosion.

The Quaternary deposits consist mainly of alluvial sediments, including fluvioglacial sands and gravels filling the glacial valley of Vistula, loesses covering the high terrace of the Vistula and elevations, as well as Holocene muds, sands and gravels deposited within the flood plain of the Vistula and in the valleys of its tributaries.

The archaeological sites north of the Vistula lie within deposits of the high terrace (6–25 m high) built of sands, calcareous gravels and sandy loams covered with a loess layer 10–15 m deep.

The sites south of the Vistula (Brzezie) are located on loess. Site 17 in Brzezie lies in the seepage spring area of the Tusznica, a left-bank tributary of the Raba, on flat terrain between a steep scarped slope to the west and a gentle slope descending towards the bottom of the river valley to the east. Loesses are the immediate substratum of the soil.

When the Neolithic cultures evolved, the Vistula was an aggrading river in the low-lying areas (the Grobla Forest near Niepołomice being one of the vestiges). The aggradation, related to high humidity at the beginning of the Atlantic period (Kalicki and Starkel 1989), has left its traces in the avulsion of the channel in the Vistula valley. At the beginning of the Subboreal (ca. 3300 BC) the river started to cut into the rocks of the substratum. This probably resulted from climatic changes and anthropogenic transformations of the Vistula catchment area, which grew stronger with the developing settlement in the Carpathians at the turn of the Bronze Age (Valde-Nowak 1988).

Materials and methods

Specialist analysis, including microscopic examination of ceramics, is widely used in archaeology, and the material for comparison is steadily growing. Analysed ceramic fragments from the Krakow region mostly represent the Linear Pottery culture (abbreviated as LBK from German: Linearbandkeramik): approx. 400 thin plate sections (e.g. Rauba-Bukowska *et al.* 2007; Rauba-Bukowska 2014; Rauba-Bukowska 2016). The study has also covered vessels produced by the Malice culture (MC): 45 thin sections (Rauba-Bukowska *et al.* 2007; Rauba-Bukowska 2011), the Funnel Beaker culture (FBC): 20 thin sections (Rauba-Bukowska 2011), and the Corded Ware culture (CWC): 7 thin sections (Rauba-Bukowska 2011). Moreover, samples of local clay raw materials have been collected as reference material (Fig. 1).

Thin sections of the pottery sherds and the clay samples were examined under a polarizing microscope in transmitted light. The quantitative petrographic method (point counting) was used to identify the percentage of individual components, such as clay minerals, quartz, potassium feldspars, plagioclases, muscovite, biotite, carbonates, heavy minerals, and grains of sedimentary, metamorphic or igneous rocks. The analysis also involved the schematic description of each thin section, as well as photographic documentation of the results. Moreover, micrometric measurement of the grain size was taken under a microscope. Thermally induced changes in the clay matrix and temperature-sensitive minerals (e.g. glauconite, biotite) helped to establish the approximate temperature at which the vessels had been fired. Small bricks, 5 × 7 cm, were formed from the sampled raw material, dried at 100°C for 24 hours and then fired at 700°C in an electric kiln for 12 hours. The resulting product was well fired and hard, and thin sections were made for microscopic examination.

Results

Characteristics of raw materials sampled in the vicinity of the sites

Five samples were taken in the vicinity of Site 5 in Modlnica. After macroscopic overview, three of them were selected for further analysis: sample Sur14, taken from the depth of approx. 60 cm in a flat terrace of the Wedonka River in a boggy area near an old brickyard (Fig. 2:a); sample Sur15, a piece of a brick from the brickyard (Fig. 2:b); and sample Sur16, coming directly from the Wedonka river bed (Fig. 2:c). The analysis has shown that all three samples are loess-like sediments with a significant amount (>50%) of medium-rounded grains of silty fraction. Main components of the sampled materials are: clay minerals (approx. 30–40%), grains of quartz (40–60%), feldspars (approx. 1–3%), mica flakes (approx. 1%) and heavy minerals (approx. 0.1%). The clay mass is saturated with iron compounds, which makes the samples intensely orange after firing. Most grains are 0.02–0.05 mm in diameter. In this

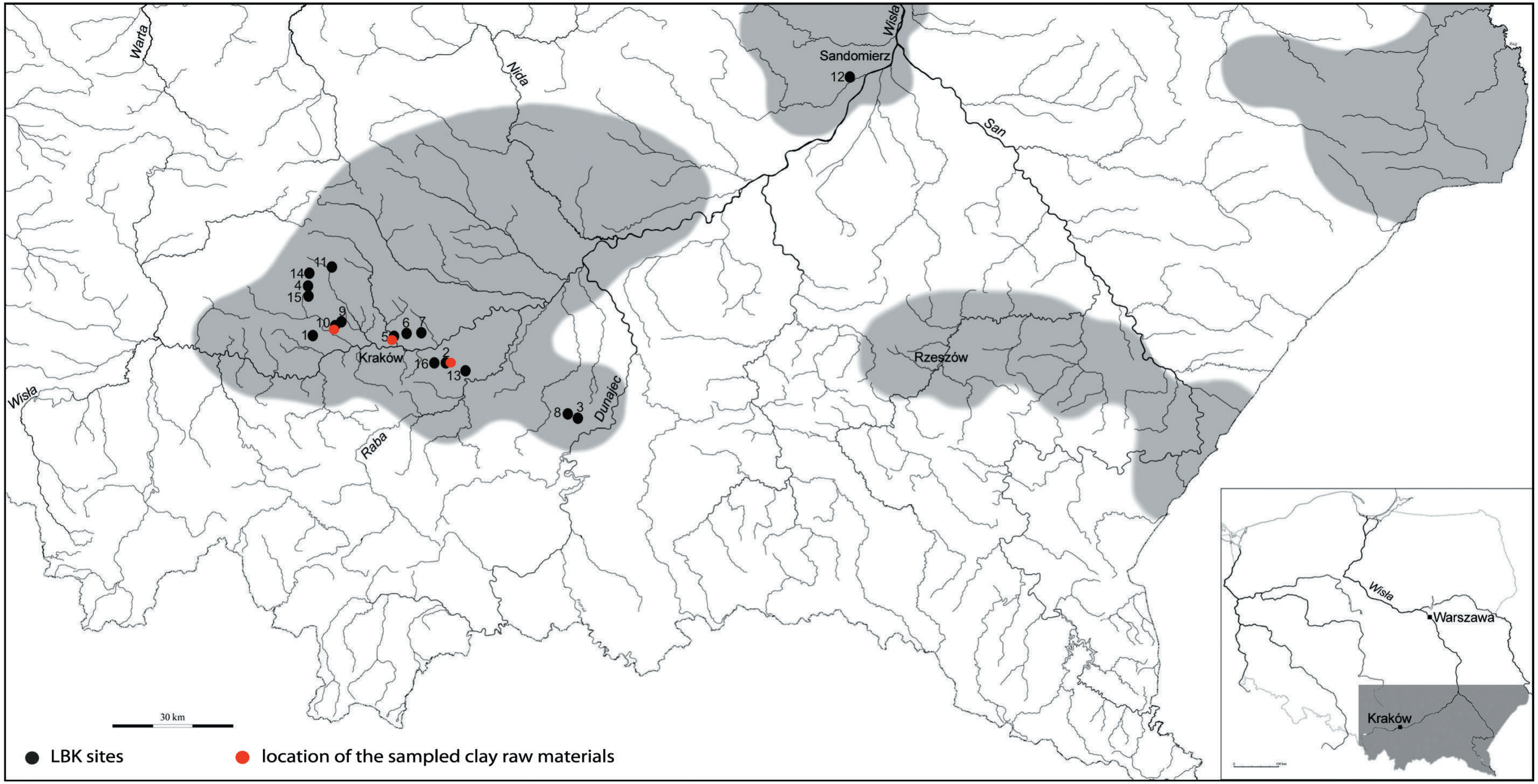

Fig. 1. A map of the Linear Pottery culture in south-eastern Poland with the sites which have provided ceramics and samples of raw material for analysis. 1 – Aleksandrowice 2, Zabierzów commune; 2 – Brzezie 17, Kłaj commune; 3 – Gwoździec 2, Zakliczyn commune; 4 – Kobylany 1 (Pod Słupami Cave), Zabierzów commune; 5 – Krakow-Nowa Huta-Mogiła, Site 62; 6 – Krakow-Nowa Huta-Pleszów, Site 17–20; 7 – Krakow-Nowa Huta-Wyciąże, Site 5; 8 – Łoniowa 18, Dębno commune; 9 – Modlnica 5, Krakow commune; 10 – Modlniczka 2, Krakow commune; 11 – Ojców 3 (Okopy Wielka Dolna Cave), Skała commune; 12 – Samborzec 1, Samborzec commune; 13 – Targowisko 11, Kłaj commune; 14 – Wierzchowie (Wierzchowska Górna Cave), Wielka Wieś commune; 15 – Więckowice 4, Zabierzów commune; 16 – Zagórze 2, Niepołomice commune.

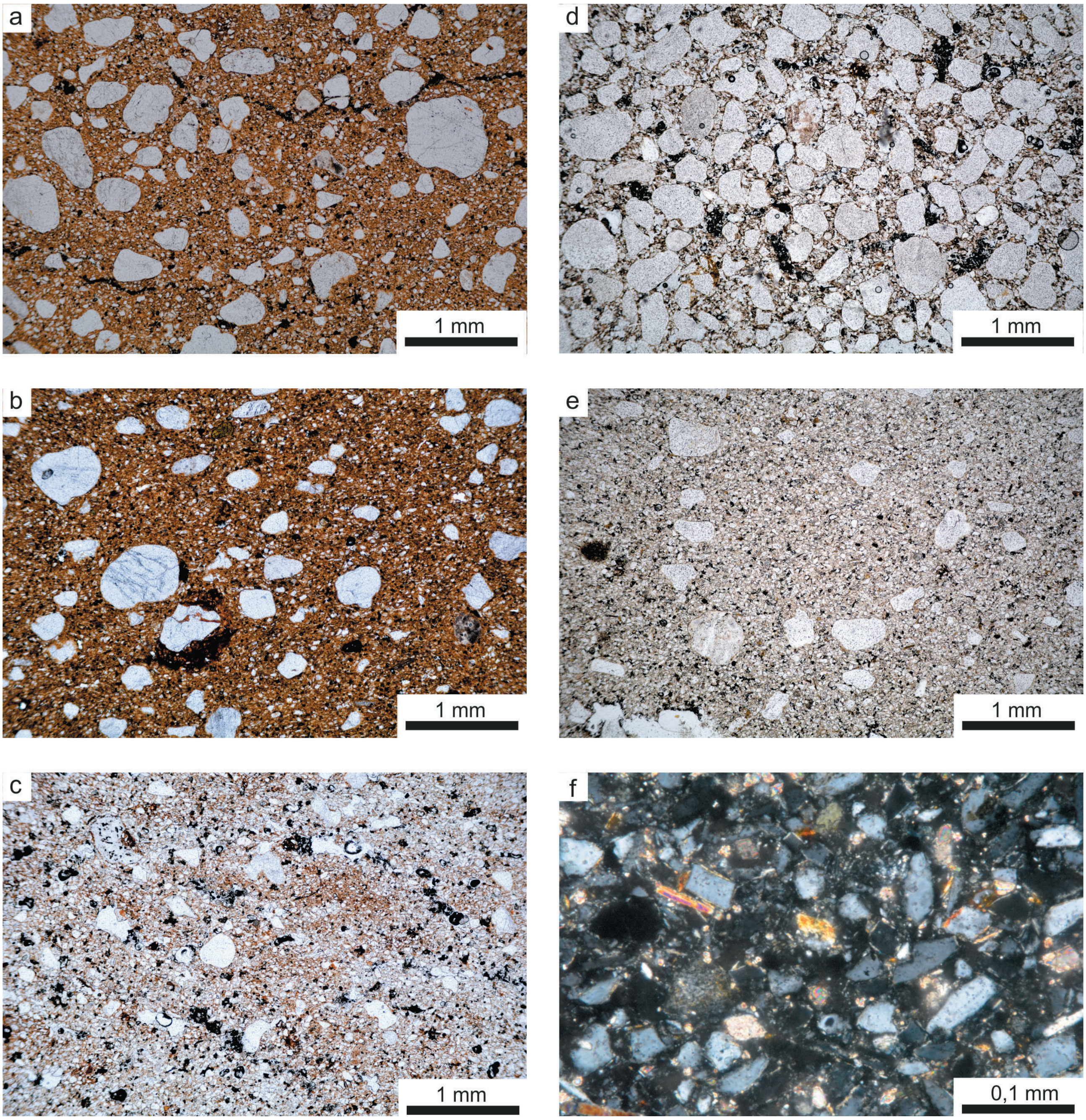

Fig. 2. Microscopic photographs of sampled raw materials: a – sample Sur14: numerous rounded grains of quartz in a fine-grained matrix, 1N; b – sample Sur15: numerous rounded grains of quartz in a fine-grained matrix, 1N; c – sample Sur16: fine-grained matrix coloured with iron compounds in some places, small content of clay minerals, 1N; d – sample Sur6: sandy clay with a significant amount of well-rounded grains of sandy fraction of quartz and feldspars, 1N; e – sample Sur9: loess consisting mainly of grains of silty fraction, a small amount of clay minerals, and rounded grains of sandy fraction, 1N; f – sample Sur9: carbonate components (micrite and fine grains of calcite) visible in voids, NX.

fraction, rounded grains of monocrystalline or (more rarely) polycrystalline quartz, usually with a diameter of 0.2–1 mm, make up approx. 5–10%. The smallest amount of grains of silty fraction has been identified in the sample taken from the brick in the old brickyard (Fig. 2: b).

During the excavation carried out at Site 62 in Mogiła in 2010–2011, which uncovered artefacts of the LBK, samples of sediments: sandy clay (Sur6; Fig. 2: d) and loess (Sur9; Fig. 2: c) were taken directly from the site. The analysis has shown that apart from grains of silty fraction, the loess sample contains medium- and well-rounded grains of quartz (approx. 0.15–0.3 mm), as well as clay and carbonate clay in voids (Fig. 2: f). The sample of sandy clay consists of grains of silty fraction and a significant amount (>50%) of grains of sandy fraction, mainly 0.2–0.5 mm, with clay substance without carbonates as the matrix.

During field survey at Site 17 in Brzezie, six samples were taken from the immediate vicinity of the site: loess, river sediments, soil and three samples of Miocene clay (Rauba-Bukowska 2007, 2014). The samples of loess, alluvial sediments and soil include over 50% of quartz, approx. 40% of clay minerals, as well as feldspars, grains of sedimentary, igneous or metamorphic rocks, mica (Fig. 3: a, b), and a small amount of heavy minerals. The grains are poorly rounded (Rauba-Bukowska 2014). Measurement of the grain size confirmed granulometry typical of loess deposits (e.g. Książkiewicz 1979: 238–241). The samples of Miocene deposits consist of clay minerals (60–70%), quartz (20–30%) and such non-plastic inclusions (5–15%) as feldspars, rock fragments, muscovite and biotite flakes and grains of glauconite (Fig. 3: c, d). As the analysis has shown, two clay samples taken from the depth of 10 and 20 cm are more contaminated, e.g. with organic matter and sedimentary rock fragments. Sample BVI collected at the depth of over 30 cm is the most plastic and with no contamination (Rauba-Bukowska 2014). The samples from the top part of the substratum have definitely coarser grains than the clay from the depth of 30 cm. The degree of the roundness of silty grains is again low.

In 2006, deep test pits near Site 17 in Brzezie revealed a continuous level of clays at 267 m a.s.l. The deposits had formed in a Miocene sea over the vast area between Krakow and Tarnów ca. 13–13.5 million years ago (the Upper Badenian). In their facies, they turn locally into the Bogucice sands, identified e.g. in the vicinity of Wieliczka (Porębski, Oszczypko 1999). The continuous level of those clays was documented several dozen metres from Site 17 in Brzezie.

The sample of clay with the least contamination (sample BVI) has additionally been examined under a scanning electron microscope. Moreover, the porosity and density of the material have been analysed, and the phosphorus content has been determined by absorption spectrophotometry and X-ray fluorescence spectrometry (XRF).

The examination of sample BVI under the scanning electron microscope has shown that the fired

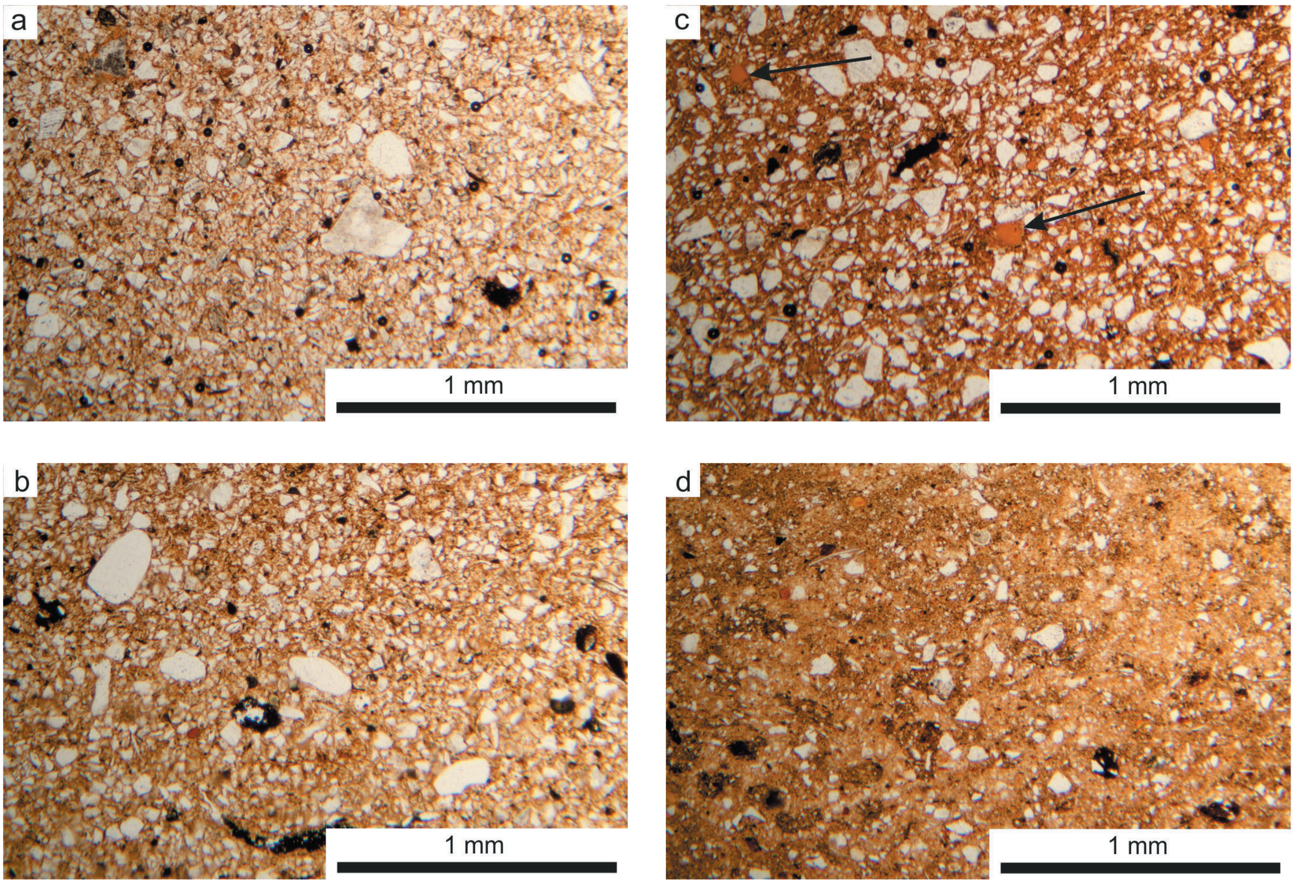

Fig. 3. Microscopic photographs of sampled raw materials: a – sample BI: loess with grains of silty fraction, 1N; b – sample BII: alluvial clay with grains of silty fraction and some organic remains, 1N; c – sample BIV: Miocene clay (10 cm) with grains of thermally altered glauconite (arrows) visible in sorted coarser clastic material, 1N; d – sample BVI: Miocene clay (30 cm), heavy clay with a small admixture of clastic material, 1N.

sherd is compact and fine-grained with no organic matter. Energy dispersive spectroscopy and chemical analysis have not detected a phosphorus content in the clay matrix. The content of P_2O_5 is 0.024% – over a hundred times lower than in the ceramic bodies of vessels (Rauba-Bukowska *et al.* 2007: 85). As the analysis of the physical properties of the sample has shown, the actual density of the material resembles that of earthenware and the porosity is low (Rauba-Bukowska 2014).

In order to determine the usefulness of the material for the production of ceramics, an attempt was made to form vessels from the sampled loess and alluvial sediment. The former material turned out to be unsuitable for the task, whereas the latter was successfully used to make a vessel, which was later polished with a piece of bone to obtain a smooth and slightly glossy surface (Rauba-Bukowska 2014).

The results show that heavy clay is a very good material in pottery. Its technological properties may be improved, however, by mixing loam with an appropriate amount (ca. 20–30%) of fine-grained sand (e.g. Kordek 1986; Bolewski, Budkiewicz and Wyszomirski 1991).

Characteristics of Neolithic ceramics in terms of raw materials used

Analysis of samples of pottery fragments recovered from Site 5 in Modlnica has shown that vessels of the LBK, the MC, the FBC, a Modlnica type assemblage with furchenstich and the CWC were made of two kinds of raw material at least (Rauba-Bukowska 2011: 311–383). One of the kinds, commonly used, was heavy clay with remains of marine microfauna, e.g. siliceous frustules of diatoms, and with sherds of volcanic glass (Fig. 4: a, b). This suggests that the material was Miocene age clay deposited in that area under of the Quaternary cover. Volcanic glass typical of those deposits reflects increased volcanic activity in the Carpathians during the Miocene time. The other popular raw material was fine-grained alluvium clay with fine mica flakes and fragments of rocks (e.g. flint) (Fig. 4: c). Sherds of the CWC, which have also been examined, do not contain any elements characteristic of Miocene clay, such as marine microfauna or volcanic glass. The ceramic bodies of those vessels include fragments of calcareous rock and grains of flint. Their raw material seems to have been alluvial sediment of rivers which carried clastic matter from the Krakow–Częstochowa Upland.

As microscopic examination has shown, ceramics of the LBK at Site 62 in Mogiła are made of diverse raw materials (Czekaj-Zastawny A. and Rauba Bukowska A. 2013), Miocene clay and alluvium being the most common (Fig. 4: d). Two kinds of remains of marine plankton have been identified within the Miocene clay: some samples contain skeletons built of calcium carbonate (*Foraminifera*), while other samples contain skeletons built of silica (*Diatoms* or *Radiolaria*). The alluvium usually includes grains of flint, chalcedony and the rocks of the Carpathian flysch (Fig. 4: c).

Several vessels were made most probably of material unavailable locally, with a significant amount of well-sorted medium-rounded grains of fine sand fraction. The samples also contain many thermally altered grains of glauconite (Fig. 4: f). The properties are reminiscent of Cretaceous deposits in the Miechów Basin (Panow 1934; Tarkowski, Liszka 1982).

Analysis of Linear Pottery ceramics from Site 17 in Brzezie has helped to identify several types of raw material which differ in their mineral composition, especially in the percentage of clastic material in the ceramic body. The first type: heavy clay with a small natural admixture of grains of silty fraction, contains small amount of mica flakes and heavy minerals, e.g. zircon, as well as bigger rounded grains of sedimentary rock, e.g. ferruginous slate, mudstone or, more rarely, sandstone (Fig. 5: a). The second type has a small amount of grains of silty fraction, too, but it contains a larger amount of clastic material, which consists mainly of grains of quartz, feldspars, fine mica flakes and heavy minerals. It also shows sporadic fragments of igneous rock. The grains are poorly or medium-rounded (Fig. 5: b). The third type has a significant amount of grains of silty fraction, of very fine or fine sand (ca. 15–30%), which are mostly grains of quartz or, more rarely, feldspars. There are small (approx. 0.05 mm) inclusions of yellowish isotropic clay substance and some thermally changed glauconite. The material contains more mica flakes (muscovite and biotite) than the preceding types. Heavy minerals, such as zircon, and clasts of sedimentary rock, mainly mudstone, are present as well (Fig. 5: c). The fourth type consists of clay mass (approx. 50–70%) and almost exclusively of grains of fine silt (<0.02 mm) and fine mica flakes, though heavy minerals have also been identified (Fig. 5: d). The analysed samples do not include relics of marine plankton or grains of volcanic glass, which are characteristic of Miocene clay on the left bank of the Vistula.

Conclusions

The Neolithic settlements were situated near genetically diversified ceramic raw materials including alluvial clay, loess-like material, Miocene clay and older marly deposits, mainly from the Cretaceous period.

Ceramics from the sites on the left bank of the Vistula include vessels made of Miocene clay which con-

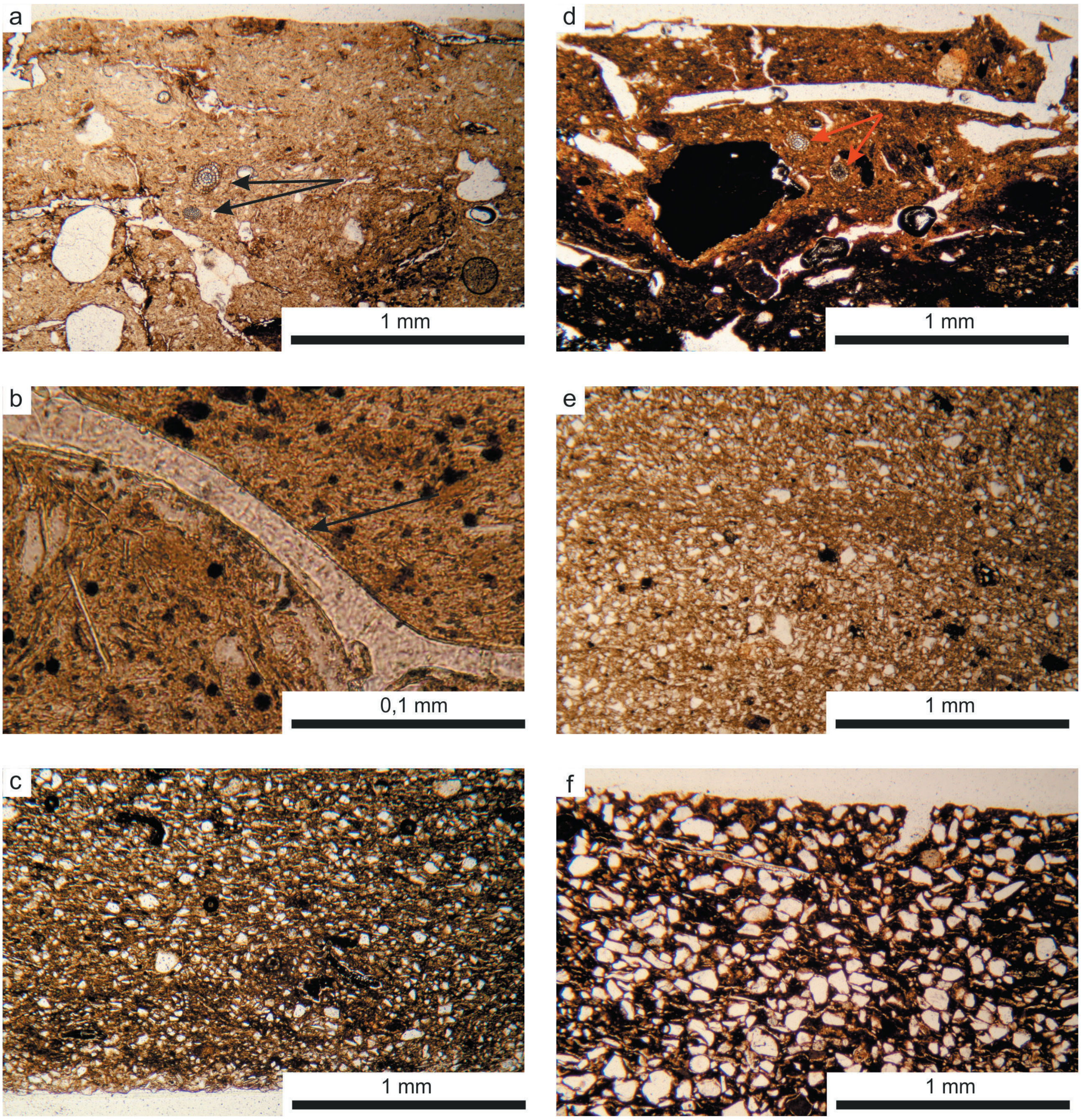

Fig. 4. Microscopic photographs of the ceramic bodies of Neolithic vessels: a – sample Modl69: ceramic body with relics of siliceous skeletons of plankton (arrows), 1N; b – sample Modl64: fragment of volcanic glass (arrow), 1N; c – sample Mod152: fine-grained matrix with some plant remains, 1N; d – sample Mog23: ceramic body with clasts of ferruginous rock (the dark clast in the centre) and relics of siliceous skeletons of plankton (arrows), 1N; e – sample Mog41: homogenous fine-grained ceramic body, 1N; f – sample Mog26: ceramic body with well-sorted grains of sandy fraction and thermally altered grains of glauconite (dark brown), 1N.

tains siliceous skeletons of *Diatoms* or *Radiolaria*. At Site 62 in Mogiła, calcium carbonate shells of *Foraminifera* have been recorded as well. Site 5 in Modlnica has yielded pottery with grains of volcanic glass. All these traits indicate the local diversity of deposits of a similar origin. The presence of volcanic glass and well-preserved relics of marine plankton in the ceramic bodies show clearly that the clay was formed in the Miocene.

Ceramics from the right bank of the Vistula are also made of older clay and loess-like material. Identification of raw materials has proven more difficult there than in the case of vessels from the left bank, because the examined thin sections do not have such characteristic components such as microfauna, volcanic glass or clasts of limestone. The clay sampled near Site 17 in Brzezie is more contaminated with clastic material, mostly quartz

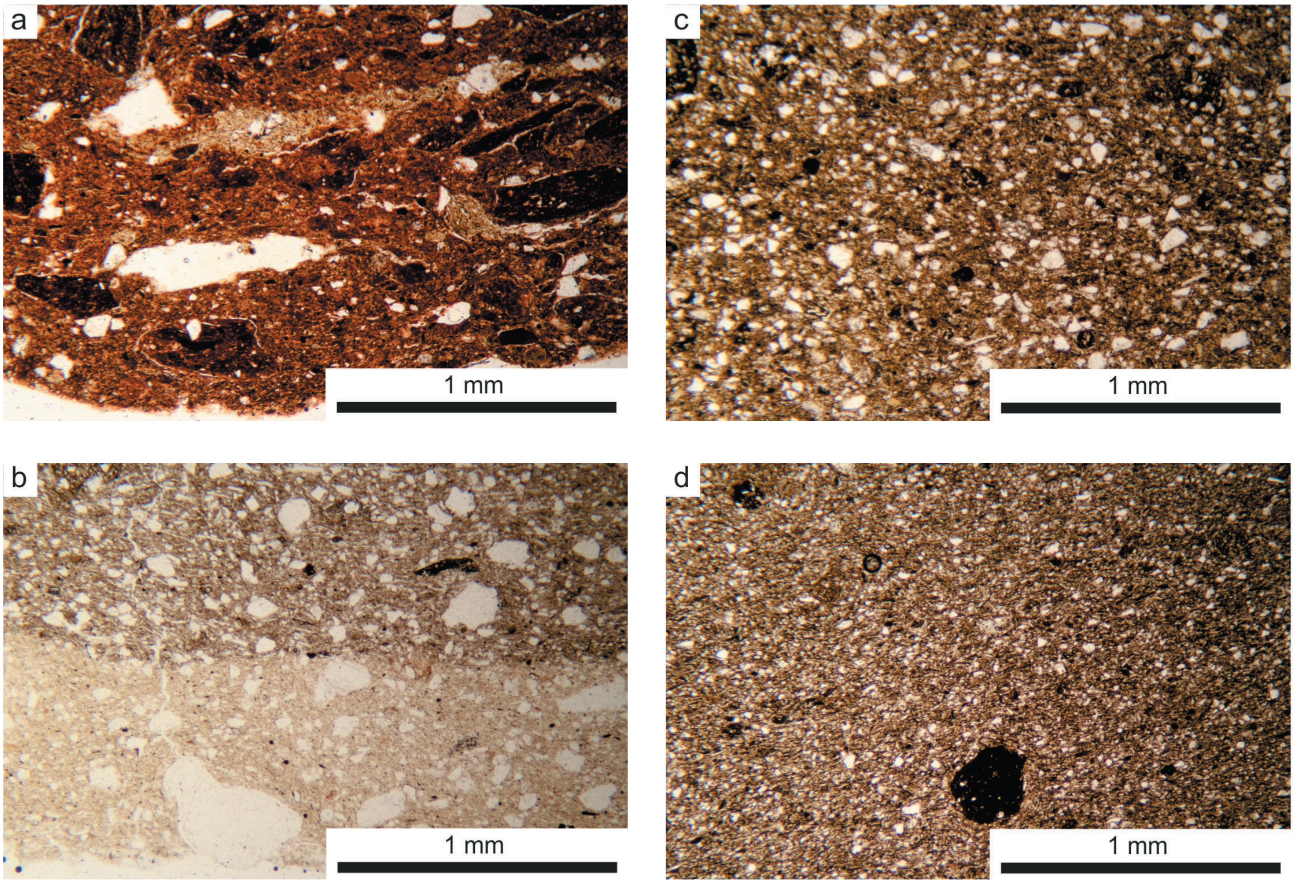

Fig. 5. Microscopic photographs of the ceramic bodies of Neolithic vessels: a – sample Br2: ceramic body with numerous clasts of ferruginous sedimentary rock (slate), 1N; b – sample Br1: coarser clastic material visible in a fine-grained ceramic body, 1N; c – sample Br3: homogenous fine-grained ceramic body, 1N; d – sample Br9: very fine-grained ceramic body containing almost exclusively grains of fine silt (0.002<d<0.02 mm), 1N.

and feldspars. There are also grains of eroded flint and clasts of sandstone. The percentage of mica is low. Both the Neolithic ceramics and the samples of Miocene clay contain thermally changed grains of glauconite, a mineral with the structure of mica, common in various marine deposits which abound in fine clastic material. In terrestrial formations, it is found only on secondary deposits (Borkowska, Smulikowski 1973: 352 ff.). A pit dug in the vicinity of Site 17 in Brzezie in 2006 revealed a locally exposed deposit of Miocene clay (Rutkowski 1989). This finding and the similarities in the mineral and petrographic composition suggest that the Linear Pottery communities in Brzezie used older (marine) clay for the production of their ceramics.

Fine-grained alluvium was commonly used, while pure loess was not suitable for vessel production, because it contained too little clay matrix and was not viscous enough, as the experiments have shown (Rauba-Bukowska 2007, 2014). Loess may also have served as an admixture to heavy clay, as suggested by some ceramic bodies with poorly mixed areas and silty spots visible under a microscope.

The SEM-EDS analysis of the pottery samples from the left-bank and right-bank sites has shown diversity in their content of calcium (Kozłowski *et al.* 2014: 63). This has recently been confirmed by examination under a polarising microscope which has recorded carbonate elements: micrite and fine grains of calcite, in loess deposits near Site 62 in Mogiła, while loess and loess-like deposits sampled near Site 17 in Brzezie do not have such components (Rauba-Bukowska 2014).

The identified characteristic traits of various raw materials, e.g. the presence of relics of marine plankton, volcanic glass and carbonates, suggest "migration" of some ceramic products.

During the field survey, it was not always possible to collect samples which matched the material of the recovered ceramics. This probably resulted from deforestation and intensive farming which had led to gradual accumulation of loess-like sediment in river valleys (Rutkowski 1984: 80–81; Rutkowski 1993: 25–26). In this way, natural exposures of Miocene deposits in the Wedonka valley had been covered with the accumulated material. The borehole (no. 28) in the vicinity of Site 5 in Modlnica revealed Miocene series at approx. 262 m above sea level, i.e. at the depth of approx. 6–10 m below Quaternary deposits (Rutkowski 1989; Rauba--Bukowska and Zastawny 2011(2013): 199). There are no outcrops of Miocene deposits in that area at present, as proven by raw material exploration.

Similarities in the ceramic bodies used by the archaeological cultures at the site indicate that access to raw materials changed to a relatively small degree in the period between the LBK and the FBC (over a thousand years). The outcrops of Miocene clay presumably still existed in the Wedonka valley at that time. By contrast, ceramics of the CWC at Site 5 in Modlnica do not contain Miocene clay. This can be accounted for in two ways: either the CWC vessels were produced far from that site or Miocene clay was no longer available to this communities (Rauba-Bukowska, Zastawny 2011).

The analysis of the ceramics has also shown that the various morphological types of vessels were made of different raw materials. In the LBK, thick-walled vessels were more often formed from heavy clay, whereas thin-walled vessels, especially those from the Želiezovce phase, were shaped from fine-grained loess-like material (Czekaj-Zastawny *et al.* 2017). This suggests that the potters observed certain rules for making the ceramic paste, despite the local diversity of raw material.

The materials sampled in the vicinity of Site 2 in Modlniczka have a bimodal distribution of the grain size, which can sometimes be considered as evidence of an admixture of sand added deliberately to the ceramic body. The data presented here indicate that interpretation of such results should be based on careful analysis both of the recovered ceramics and of the local raw material.

The specialist analysis of the Neolithic ceramics from the upper Vistula basin has shown that the vessels were shaped from clay with various origins. The field survey has also revealed that the raw materials were obtained locally in the vicinity of the settlements. The differences resulted both from the location of the sites and from the chronology of the vessels (Kozłowski *et al.* 2014; Czekaj-Zastawny *et al.* 2017). The chemical composition is not the same in the raw materials on the left and the right banks of the Vistula near Krakow. The ceramic bodies from the sites on the left bank have a higher content of calcium oxides (Kozłowski *et al.* 2014: 63), which is related to calcareous rocks, e.g. marl and limestone, situated near the surface and to alluvia of the Prądnik River. The tendency to use local material has also been confirmed at sites located in caves north of Krakow (the Pod Słupami Cave in Kobylany, the Okopy Wielka Dolna Cave in Ojców), where some LBK ceramics were made of carbonate clay available there (Czekaj--Zastawny, Rauba-Bukowska 2013).

Raw material analysis gives a lot of new information. Consequently, a database of clay raw materials is compiled to serve as reference material.

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