SPRAWOZDANIA ARCHEOLOGICZNE 76/2, 2024
PL ISSN 0081-3834
DOI: 10.23858/SA76.2024.2.3840

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TECHNOLOGY AND RAW MATERIAL ANALYSIS OF LINEAR POTTERY CULTURE CERAMICS FROM THE EASTERN CARPATHIANS, ROMANIA

ABSTRACT

Rauba-Bukowska A., Diaconu V. and Bukowski K. 2024. Technology and raw material analysis of Linear Pottery culture ceramics from the Eastern Carpathians, Romania. *Sprawozdania Archeologiczne* 76/2, 37-66.

Only a few Neolithic settlements attributed to the Linear Pottery culture 5100-4850 cal. BC) are known from the Sub-Carpathian area of Eastern Romania. From the Neamţ Depression, settlements were known from Târpeşti and recently from Topoliţa. The aim of the presented analyses was to determine data regarding ceramic technology at the Topoliţa site and to compare it with LBK ceramic technology in neighbouring areas. It was found that ceramic production patterns at Topoliţa were similar to those at nearby LBK sites in Romania and even to pottery from southeastern Poland. However, the selection of raw materials varied. At Topoliţa, only one type of raw material was used, while the nearest site at Târpeşti employed several different raw materials. These differences underscore the importance of local environmental factors in understanding ceramic production practices. The technological similarities between Topoliţa and Poland suggest that knowledge and practices were transmitted through cultural interactions and long-distance exchange networks.

Keywords: Northeastern Romania, Neolithic, Linear Pottery culture, ceramic petrography, XRD analysis
Received: 20.05.2024; Revised: 14.06.2024; Accepted: 09.09.2024

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INTRODUCTION

In the Sub-Carpathian area of Eastern Romania, only a few Neolithic settlements are known (Fig. 1), those being attributed to the Starčevo-Criş culture (Ursulescu 1984) and the Linear Pottery culture (hereafter LBK) (Cucoş 1992). The existence of salt resources represents an important factor that led those communities to the sub-mountainous area, some of which were exploited by human groups from the Early Neolithic (Dumitroaia 1994; Ursulescu 1996; Weller *et al.* 2007; Preoteasa and Diaconu 2018). Although several dozen sites attributed to the Linear Pottery culture are known in eastern Romania, we currently have very few absolute dates. We may mention here, for the Târpeşti settlement, two dates, but which are uncalibrated and too late for the Neolithic: 4220±100 and 4295±100 B.C. (Marinescu-Bîlcu 1981, 18; Ursulescu 2000, 274). According to the current relative chronology, east of the Carpathians the Linear Pottery culture can still be placed between 5100-4850 cal. BC (Garvăn *et al.* 2009, 8; Garvăn and Frînculeasa 2021, 431-435).

Although there are some conclusive data for Starčevo-Criş culture about the settlements and the relation between humans and the surrounding environment (Marinescu-Bîlcu 1975; Ursulescu 1985; Dumitroaia 1987; Marinescu-Bîlcu and Beldiman 2000; Diaconu 2022), the information on the Linear Pottery culture is still rather sparse. Significantly, over the past six decades, there has been a notable absence of research conducted within settlements of this cultural context. This has led to significant gaps in our understanding of LBK settlement patterns in these areas.

The only artefacts attributed to the Linear Pottery culture from the Neamţ Depression (in Neamţ county there are only six LBK sites) were known from the excavations at Târpeşti (realised in the 1960s; Marinescu Bîlcu 1981). Recently, during the systematic research from the multi-layered settlement of Topoliţa – *La nord-vest de sat* (Neamţ County), artefacts of the Linear Pottery culture have also been discovered (Diaconu *et al.* 2023).

The archaeological site of Topoliţa is in the Subcarpathian region of Moldavia, situated in eastern Romania. Specifically, it lies within the northeastern part of Neamţ County, positioned centrally within the depression bearing the same name (Fig. 1). The settlement is located approximately 6 km south of Târgu Neamţ city. It occupies a part of the low terrace to the right of the Valea Seacă stream, an affluent of the Topoliţa River (Diaconu 2007, 101, 103).

Since the site is multi-layered, in 2017, a geophysical scan was carried out by a German team from the University of Erlangen-Nürnberg. On that occasion, the traces of several residential structures (25), somewhat unevenly arranged over an area of approximately 2 ha, were identified (Preoteasa *et al.* 2018). The results of the non-invasive investigations were very promising. In 2019, systematic archaeological research began (Diaconu *et al.* 2020). Several stages of use of the site were documented: Neolithic (Linear Pottery culture, Fig. 2), Eneolithic (Precucuteni culture, middle and late phases), Late Bronze Age (Noua culture), Iron Age (Poieneşti-Lucaşeuka culture) and activity in Late Antiquity (IV century AD, Sântana

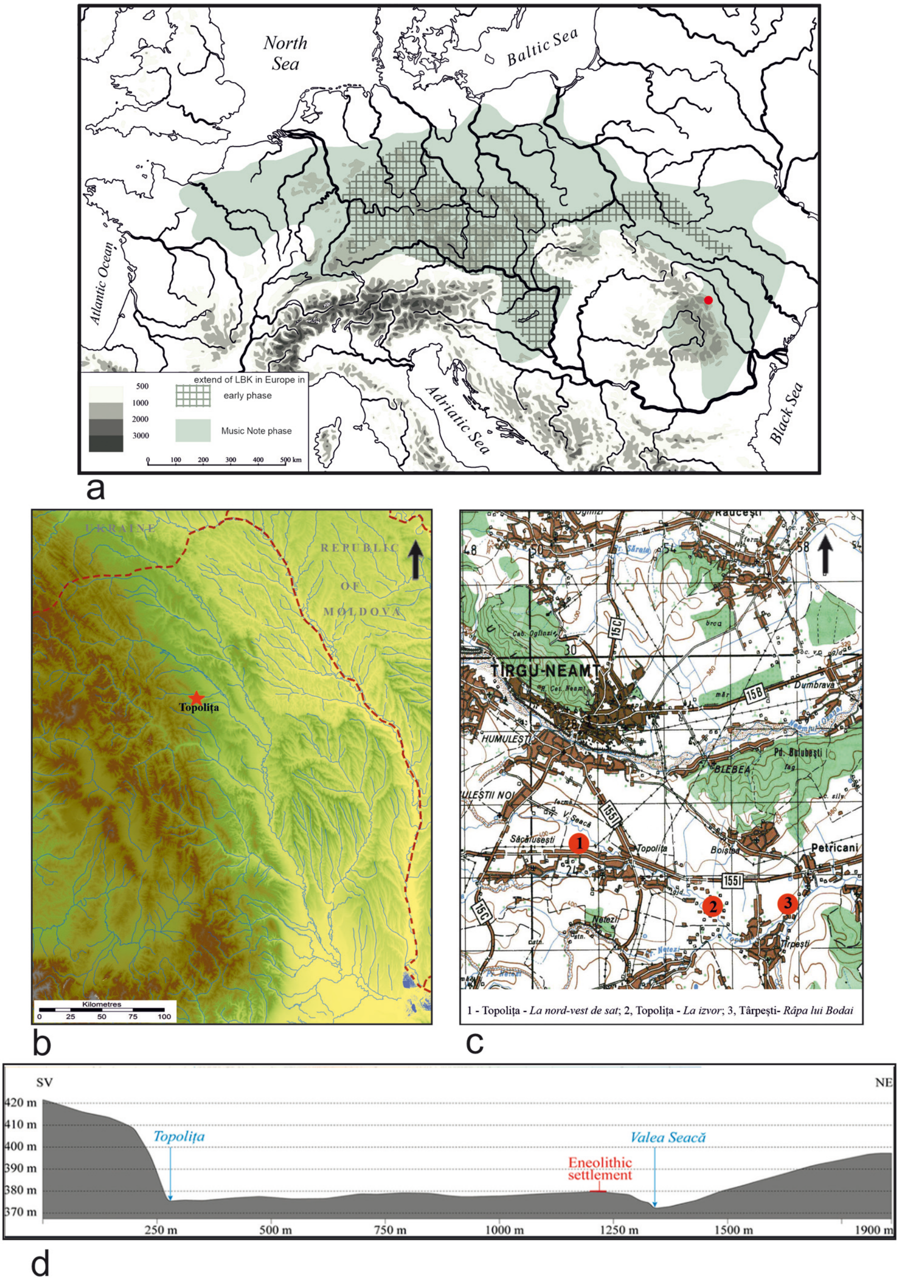

Fig. 1. Topolița, Neamț County; location of the site (red dot) against the background of the extent of the Linear Pottery culture in Europe (a) (after Czekaj-Zastawny 2008); site location in the north-western part of Romania (b); LBK settlements in the Neamț Depression (c); location of the site on the topographic profile (d) (according to Pîrnău *et al*. 2022)

Fig. 2. Topolița, Neamț County; aerial view of the site (a); the area where LBK pottery was discovered (b); pedological profile (c); a, b – photo V. Diaconu; c – soil horizons (according to Pirnau et al. 2022, 7); A – surface mineral horizon; B – subsurface horizon; C- horizon that is little affected by pedogenetic processes; h – accumulation of organic matter; t – illuvial accumulation of silicate clay; b – buried genetic horizon; w – development of colour or structure; k – accumulation of pedogenetic carbonates

de Mureş culture). The most consistent vestiges belong to the Early Eneolithic (second half of the 5^{th} millennium BC).

In the 2022 archaeological campaign, the first artefacts specific to the Linear Pottery culture were discovered, but without a clear cultural context. The research from the summer of 2023 facilitated the discovery of a more consistent batch. A pit attributed to the Linear Pottery culture, in which numerous pieces of burnt clay were found, as well as pottery fragments and animal bones was excavated. The finds, however still sparse, demonstrates that those Neolithic communities also frequented the Sub-Carpathians area.

The aim of the conducted analyses was to determine fundamental data regarding LBK ceramic technology at the Topoliţa site and to compare it with LBK ceramic technology in neighbouring areas. We employed petrographic analysis of thin sections to characterize the compositions of ceramic vessels, along with XRD analysis. The mineral composition, any deliberate additives, clay mixing, and the atmosphere, as well as the approximate firing temperature, were determined. The analyses enabled the determination of the vessel ceramic technology at the Topoliţa site. Gathering data allowed for comparison with LBK ceramics from the Târpeşti site, where five LBK vessel fragments had been sampled for analysis (Kadrow *et al.* 2018). In further steps, we were able to technologically embed ceramics from Topoliţa within the context of other examined fragments from the further regions in Romania: Isaiia, jud.Iaşi; Olteni, jud. Covasna; Mihoveni, jud. Suceava; Preuteşti-Ciritei, jud. Suceava, Traian-Dealul Fântânilor, jud. Neamţ, Târpeşti, jud. Neamţ (Kadrow *et al.* 2018) and compare the results in this regard to ceramics from areas north of the Carpathians in southeastern Poland (Rauba-Bukowska 2014; Rauba-Bukowska 2021; Rauba-Bukowska and Czekaj-Zastawny 2020; Czekaj-Zastawny *et al.* 2017).

MATERIALS, AND METHODS

Eleven samples of LBK ceramics were selected for petrographic studies, guided by technological characteristics of the ceramic mass, form, and decoration (Table 1). The investigations were conducted using a Nikon Eclipse LV100N POL polarizing microscope for transmitted light at the Institute of Archaeology and Ethnology of the Polish Academy of Science in Kraków. The ceramics intended for specialized research consist of thin-walled forms, approximately 0.3-0.5 cm thick (five pieces), and thick-walled forms, approximately 0.6-0.8 cm thick (six pieces). These vessels were discovered in Surface B/2022 at Topoliţa and belong to the Linear Pottery culture, exhibiting the typical ornamentation of this culture (Fig. 3). The sampled fragments were marked with the label RumTop and differentiated by consecutive ordinal numbers 1-11 (RumTop1, RumTop2, *etc.*).

Thin sections were prepared from pottery fragments for microscopic examination in transmitted polarized light. Point-counting quantitative microscopic analysis was employed to determine the percentage composition of various components, including clay

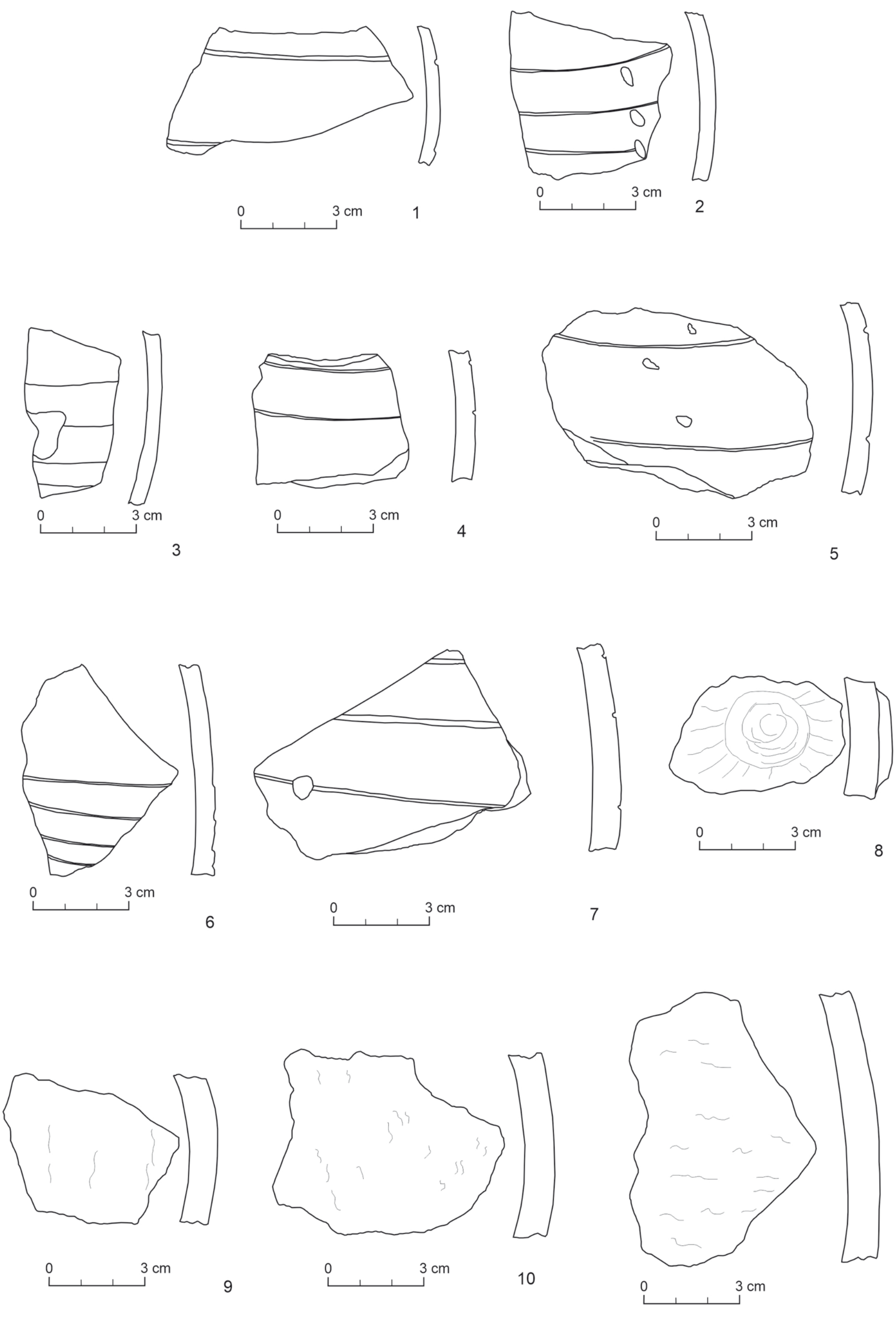

Fig. 3. Topolița, Neamț County. Drawings of vessel fragments (1-11) selected for petrographic analysis. Drawing by V. Diaconu, I. Ściana

Table 1. Topolița, Neamț County. List of the samples

Symbol of the sample	Site	Atmosphere of firing	Approx. Firing temperature in °C	Morphology	Fabric types	Petrographic group
RumTop1	Topolița, Neamț County	oxidizing	700-750	thin-walled	IIa	1a
RumTop2	Topolița, Neamț County	reducing	700-750	thin-walled	IIa	1a
RumTop3	Topolița, Neamț County	reducing	700-750, 750-800	thin-walled	IIa	1a
RumTop4	Topolița, Neamț County	oxidizing	850	thin-walled	IIa	1b
RumTop5	Topolița, Neamț County	oxidizing	700-750	thin-walled	IIa	1b
RumTop6	Topolița, Neamț County	redox	700-750	thick-walled	Ia	2a
RumTop7	Topolița, Neamț County	redox	700-750	thin-walled	IIa	1b
RumTop8	Topolița, Neamț County	redox	700-750	thick-walled	Ia	2a
RumTop9	Topolița, Neamț County	redox	700-750	thick-walled	Ia	2a
RumTop10	Topolița, Neamț County	redox	700-750	thick-walled	Ia	2b
RumTop11	Topolița, Neamț County	redox	700-750	thick-walled	Ia	2b

minerals, quartz, potassium feldspar, plagioclase, muscovite, biotite, carbonates, grains of sedimentary, igneous, and metamorphic rocks, fragments of secondarily used ceramics, as well as organic material. Petrographic descriptions of the ceramic sections were conducted, considering the degree of consolidation of the masses, firing conditions, and temperature (Whitbread 2016; Reedy 2008, 109-210). The collected data were utilized for comparative studies and to determine petrographic and fabric groups. The approximate firing temperature was inferred from the thermal transformations of clay minerals, as well as minerals such as biotite, hornblende, and glauconite (Stoch 1974, 484; Bolewski and Żabiński 1988; Quinn 2013, 190-203; Daszkiewicz and Maritan 2016). Grain size measurements were conducted using a micrometric scale under a polarizing microscope, following the guidelines of the Polish Soil Science Society (Polskie Towarzystwo Gleboznawcze 2009).

The mineral composition of two samples (RumTop7 and RumTop11) was determined by an X-ray diffractometer (XRD) on an ADP-2.0 diffractometer (Fe radiation, filtered Mn, 30 kV, 12 mA). The scanning rate of the powder preparations was 2°/min, and the step was 0.025°. Quantitative mineral content was determined using Profex-8.4 software, which simulates the calculated diffractogram profile as close to the experimental one (Döbelin and Kleeberg 2015).

Table 2. Topolița, Neamț County. Mineral composition; value in percentages

Symbol of the sample	Site	Clay minerals	grains <0.05 mm	Quartz	Chalcedony / flint	Potassium feldspars	Plagioclases	Fragments of sedimentary rocks	Fragments of igneous rocks	Fragments of matamorphic rocks	Muscovite	Biotite	Opaque minerals	Iron oxides and hydroxides	Grog	Clay pellet	Organic fragments	Heavy minerals	Others	Voids
RumTop1	Topolița, Neamț County	66.3	19.4	0.6	0.0	0.0	0.0	0.6	0.0	0.0	6.8	1.6	1.3	2.6	0.0	0.0	0.0	0.0	0.0	0.6
RumTop2	Topolița, Neamț County	63.8	17.5	1.3	0.0	0.5	0.0	4.8	0.0	0.0	4.8	0.8	2.8	1.8	0.0	0.0	0.0	0.0	0.3	2.0
RumTop3	Topolița, Neamț County	74.8	12.3	2.7	0.0	0.3	0.0	0.0	0.0	0.0	4.3	1.0	0.3	1.7	0.0	0.0	0.0	0.3	0.3	2.0
RumTop4	Topolița, Neamț County	76.0	12.8	2.5	0.0	1.2	0.0	0.6	0.0	0.0	2.2	0.3	0.0	3.4	0.0	0.0	0.0	0.0	0.0	0.9
RumTop5	Topolița, Neamț County	73.1	12.1	1.2	0.0	0.0	0.0	1.5	0.0	0.0	3.0	0.3	0.9	4.2	0.0	0.0	0.3	0.0	0.0	3.3
RumTop6	Topolița, Neamț County	64.1	16.0	6.6	0.0	1.5	1.1	0.0	0.0	0.3	3.8	0.5	0.5	2.5	0.0	0.0	0.0	0.0	0.0	3.1
RumTop7	Topolița, Neamț County	78.4	15.1	1.5	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.9	1.5	0.0	0.0	0.3	0.3	0.0	0.3
RumTop8	Topolița, Neamț County	49.5	20.1	3.5	0.0	0.6	0.9	0.0	0.0	1.9	4.0	0.5	0.0	2.6	0.0	0.0	5.1	0.0	0.0	11.2
RumTop9	Topolița, Neamț County	61.3	17.2	6.0	0.0	0.5	1.8	0.0	0.0	0.7	2.0	0.2	0.5	1.2	0.0	0.5	1.2	0.0	0.0	6.7
RumTop10	Topolița, Neamț County	48.9	17.6	14.6	0.5	2.5	1.2	0.2	0.0	1.2	4.0	0.5	0.7	1.0	0.0	0.0	1.7	0.0	0.0	5.2
RumTop11	Topolița, Neamț County	50.5	14.1	14.1	0.3	3.8	2.2	0.0	0.0	1.8	5.0	0.5	0.3	0.5	0.0	0.0	1.0	0.0	0.5	5.5

RESULTS

Thin section petrographic analysis

The mineral composition of the ceramic fabrics consists of clay minerals (49.3-79.7%), grains of silty fraction (5.1-35.6%), fine mica flakes (max. 9.4% in sample RumTop1), iron oxides and hydroxides (Table 2). Additionally, the ceramic fabrics contain a small number of opaque and heavy minerals. The coarser fraction (>0.05 mm) is represented by quartz grains (up to 19.3%), occasionally feldspars. Moreover, fragments of sedimentary rocks – mudstone and claystone are identified (more abundant in RumTop1, RumTop5, RumTop6, and RumTop7). Samples RumTop3, RumTop6, RumTop7, RumTop8, RumTop9, RumTop10, RumTop11 contain fragments of metamorphic rocks (mostly quartz-mica schist or quartz schists, *e.g.*, in sample RumTop7). Additionally, optically isotropic clay clasts, which were difficult to identify precisely, were noted in the samples RumTop2, RumTop3, and RumTop7.

The coarser grains are medium and well-rounded. Fine-grained quartz grains are moderately to well-rounded. Rock fragments are well-rounded.

XRD analysis

XRD analysis was performed for two ceramic samples representing two petrographically distinct groups: fine-grained raw materials (RumTop7) and coarse-grained raw materials (RumTop11). For these samples, the type and contents of minerals were interpreted based on the intensity of specific XRD peaks using Profex-8.4 software.

In the RumTop7 sample, the XRD analysis revealed the presence of quartz, plagioclases, and microcline. Similar to the situation in the microscopic observations, a significant presence of clay minerals was observed, including minerals from the smectite group (*e.g.*, nontronite), illite, and montmorillonite. Additionally, a substantial proportion of mica was observed, including muscovite and biotite, with glauconite and a small content of iron hydroxides and chlorites (Fig. 4).

In the RumTop11 sample representing coarse-grained raw materials, there is a high proportion of quartz, with feldspar grains, mainly plagioclases, and potassium feldspars – microcline. The background mass of the sample comprises clay minerals, in which XRD determined the high presence of illite. Small mica flakes, primarily muscovite and biotite, were also observed. Furthermore, glauconite and a small proportion of iron hydroxides (lepidocrocite) were also noted (Fig. 4).

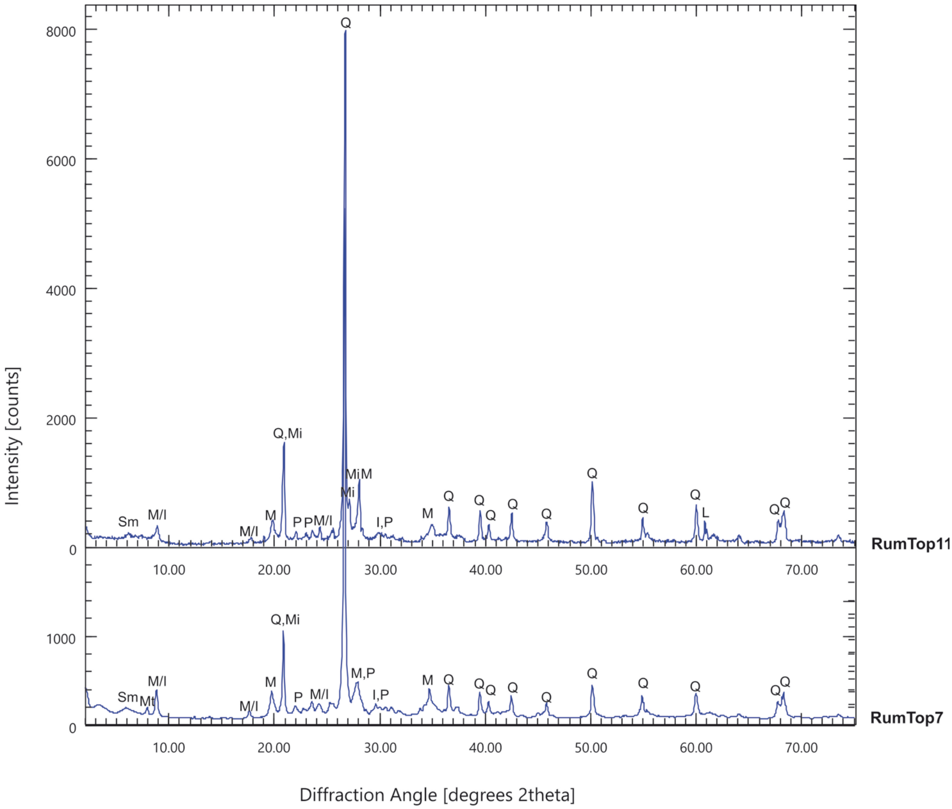

Fig. 4. X-ray diffractograms of the pottery samples RumTop7 and RumTop11 selected from Topolița. Main minerals: Q – quartz, P – plagioclases, Mi – microcline, M/I – muscovite/illite, Sm – smectite, Mt – montomorillonite, L – lepidocrocite

INTERPRETATION OF THE ANALYSIS

Source of the raw materials

Geologically, the research area is located within the Subcarpathian (Pericarpathian) nappes of the Eastern Carpathians (Matenco and Bertotti 2000). The Subcarpathian nappes, which were partially overlaid by the Carpathian thin-skinned nappes and exhumed by erosion, were formed by Oligocene and Miocene molasse (Grasu *et al.* 1999). Molasse sediments of the Oligocene-Miocene age are generally poorly consolidated sediments represented by rudites, sandstones, and arkoses without clear stratification (Grasu *et al.* 1999). Near the study area, molasse sediments mainly comprise the Middle Miocene (Badenian) deposits consisting of alternating layers of marl and fine sandstone and gypsum (Gypsum

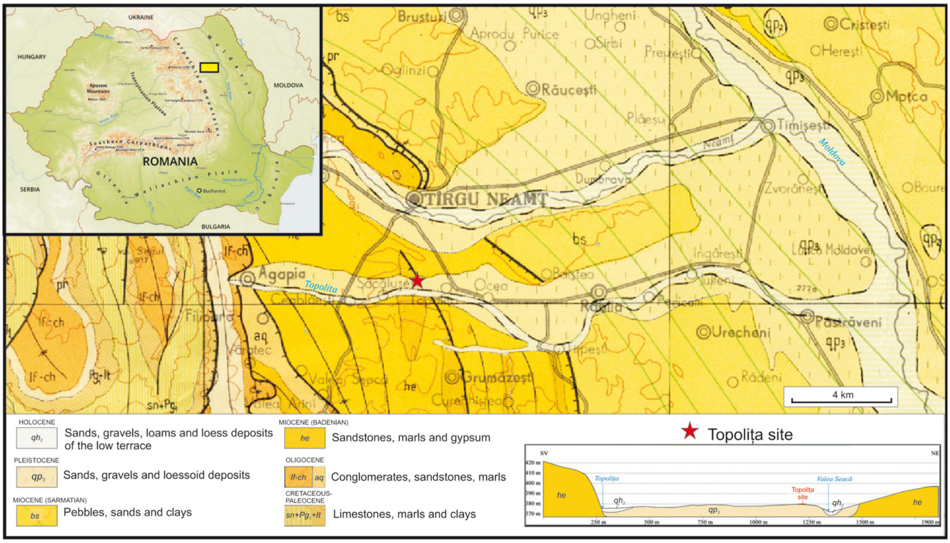

Fig. 5. Geological map of the area around Topolița (Joja *et al.* 1968); geological cross-section after topographic profile (Pîrnău *et al.* 2022)

de Parchiu) (Săndulescu *et al.* 1995). The archaeological site is located on the alluvial deposits of the Topoliţa River and its tributary, the Valea Seacă stream, represented by sands, gravels, and clays of Pleistocene and Holocene age. Eolian sediments (loess or loessoid sediments) are also observed (Măţău *et al.* 2021) (Fig. 5).

Based on the quartz-feldspar mineral composition, a large share of mica, the characteristic presence of glauconite found in several samples, and the sorting and rounding of quartz and feldspar grains, it can be assumed that the source material could have been sandy clays formed as alluvial river deposits. This material, resulting mainly from the erosion of older formations, was deposited in the Topoliţa River Pleistocene/Holocene terrace sediments. This is confirmed by the presence of individual fragments of sandstones and mudstones, and even lithoclasts of metamorphic rocks (quartz-mica schists) that could have been preserved from the source rocks that eroded to prosuce the Oligocene-Miocene molasse sediments (Sylvester and Lowe 2004).

The mineral composition shows no significant differences between the two sample groups (coarse-grained and fine-grained), suggesting a common or similar raw material source.

Petrographic groups

Due to their mineral-petrographic composition and granulation, the samples can be divided into two main groups (Table 3). The first group pertains to fine-grained raw materials. It is characterized by the presence of quartz and mica, as well as iron oxides and hy-

Table 3. Petrographic groups

Symbol of the petrographic group	Petrographic group description	Sample
1	fine-grained	
1a	fine-grained, micaceous clay with a higher number of silty grains	RumTop1, RumTop2, RumTop3
1b	fine-grained, micaceous clay	RumTop4, RumTop5
2	coarse-grained	
2a	coarse grained clay with quartz and fragments of Quartz-mica schists	RumTop7, RumTop8, RumTop9
2b	coarse grained clay with quartz, feldspars, glauconite and fragments of Quartz-mica schists	RumTop10, RumTop11

droxides, a small number of opaque and heavy minerals, and rounded fragments of sedimentary rocks such as mudstone and siltstone (Figs 6-11). Within this group, materials with a higher number of very fine-grained particles can be distinguished (Raw Material 1a, samples: RumTop1, RumTop2, RumTop3) and those with a lower number of very fine-grained particles (Raw Material 1b, samples: RumTop4, RumTop5, RumTop7).

The second group relates to coarse-grained raw materials (Raw Material 2; Figs 12-16). In this group, quartz grains are more abundant, along with moderately well-rounded fragments of metamorphic rocks such as quartz-mica schists (Raw Material 2a, samples: RumTop6, RumTop8, RumTop9). Within this group, two samples (RumTop10 and RumTop11) stand out due to their glauconite content in the clayey mass and a higher number of feldspars (Raw Material 2b, Figs 15, 16).

This conclusion, drawn from a comprehensive analysis, highlights the main difference in grain size distribution, particularly the larger portion of the sandy fraction. This variation could be attributed to the processing method, where raw coarse grain material was removed, and some vessels were made from such fine-grained clays. The low degree of grain sorting and rounding in some samples (*e.g.*, RumTop11) could indicate a relatively short transport of the detrital material, which could have significant implications for our understanding of material transport processes.

Admixtures

In the examined ceramics, two main types of admixtures can be distinguished – organic and mineral. The organic material consists of plant fragments. They are visible in the form of brown, opaque, lattice-like or cellular structures. These fragments are almost completely burnt out in areas where more air reached during firing. They leave behind charac-

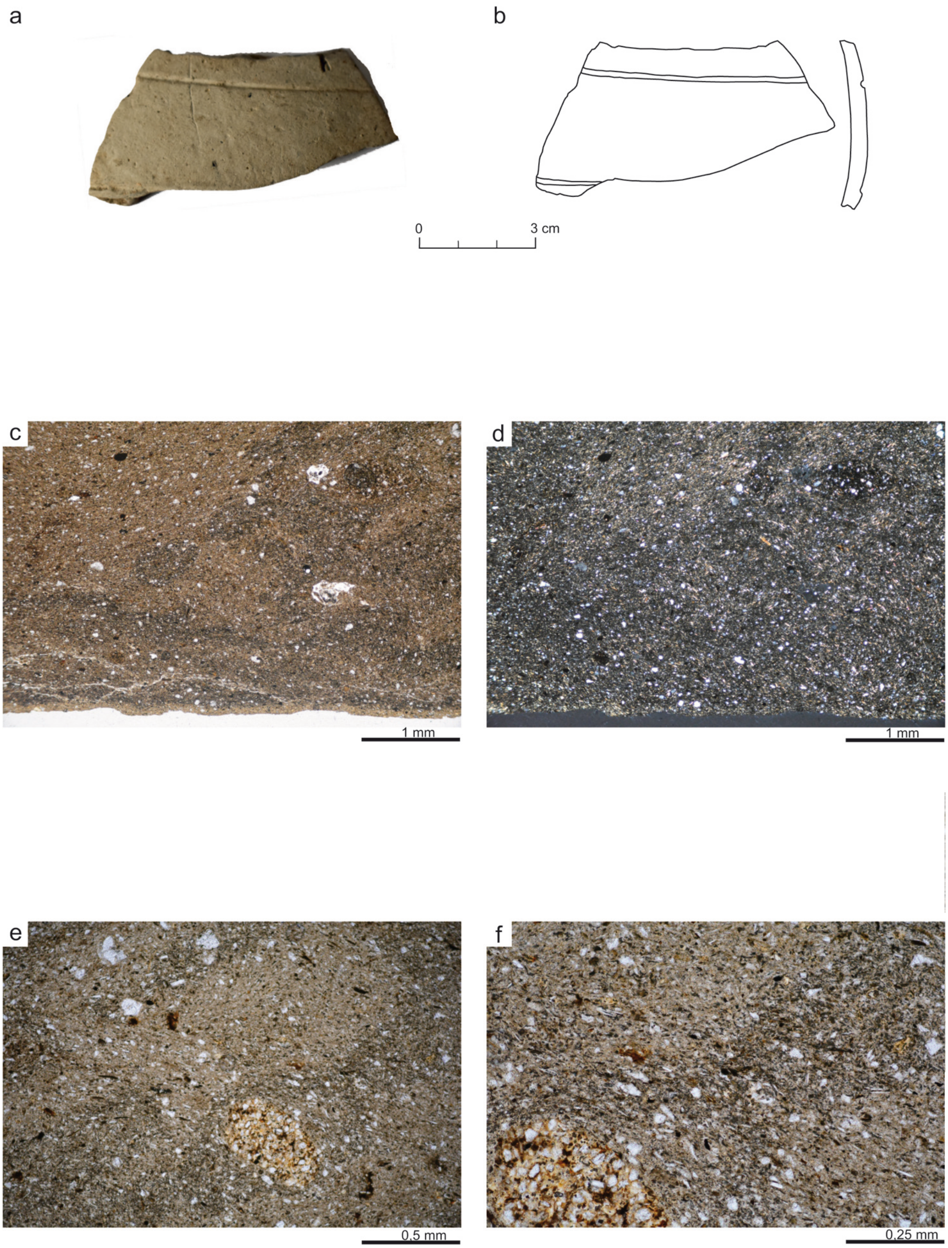

Fig. 6. Topolița, Neamț County, sample RumTop1, technological Type IIa; photography (a) and drawing (b) of the fragment; microphotographs of thin section (c-f); fine grained, homogeneous fabric (c, d); uneven coloration of the body matrix (e); rounded fragment of clay pellet – bottom left (f); plane polarized light (c, e, f); crossed polarized light (d)

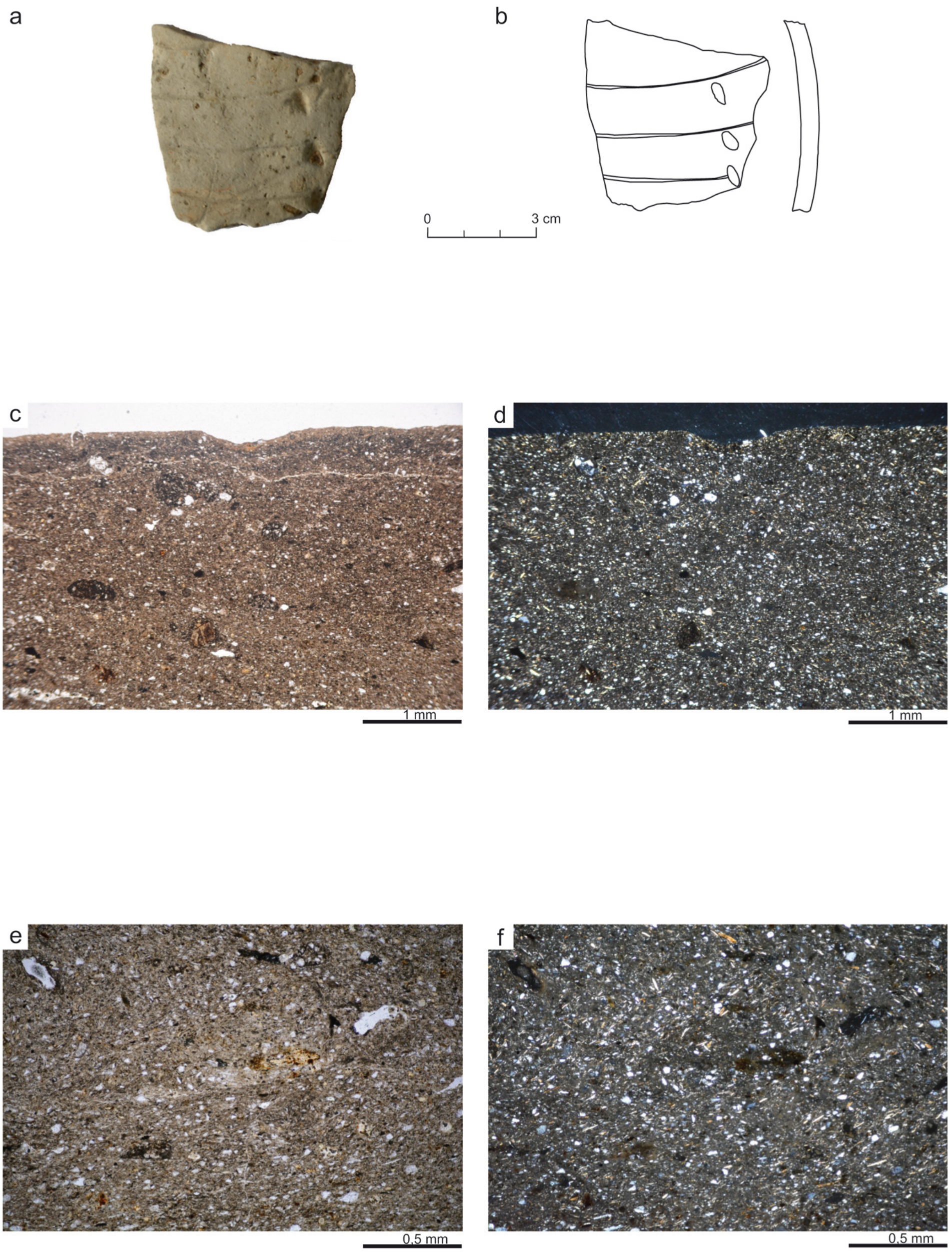

Fig. 7. Topolița, Neamț County, sample RumTop2, technological Type IIa; photography (a) and drawing (b) of the fragment; microphotographs of thin section (c-f); fine grained, homogeneous fabric, a small micro-crack parallel to the surface is visible (c, d); body matrix with small voids (e, f); plane polarized light (c, e); crossed polarized light (d, f)

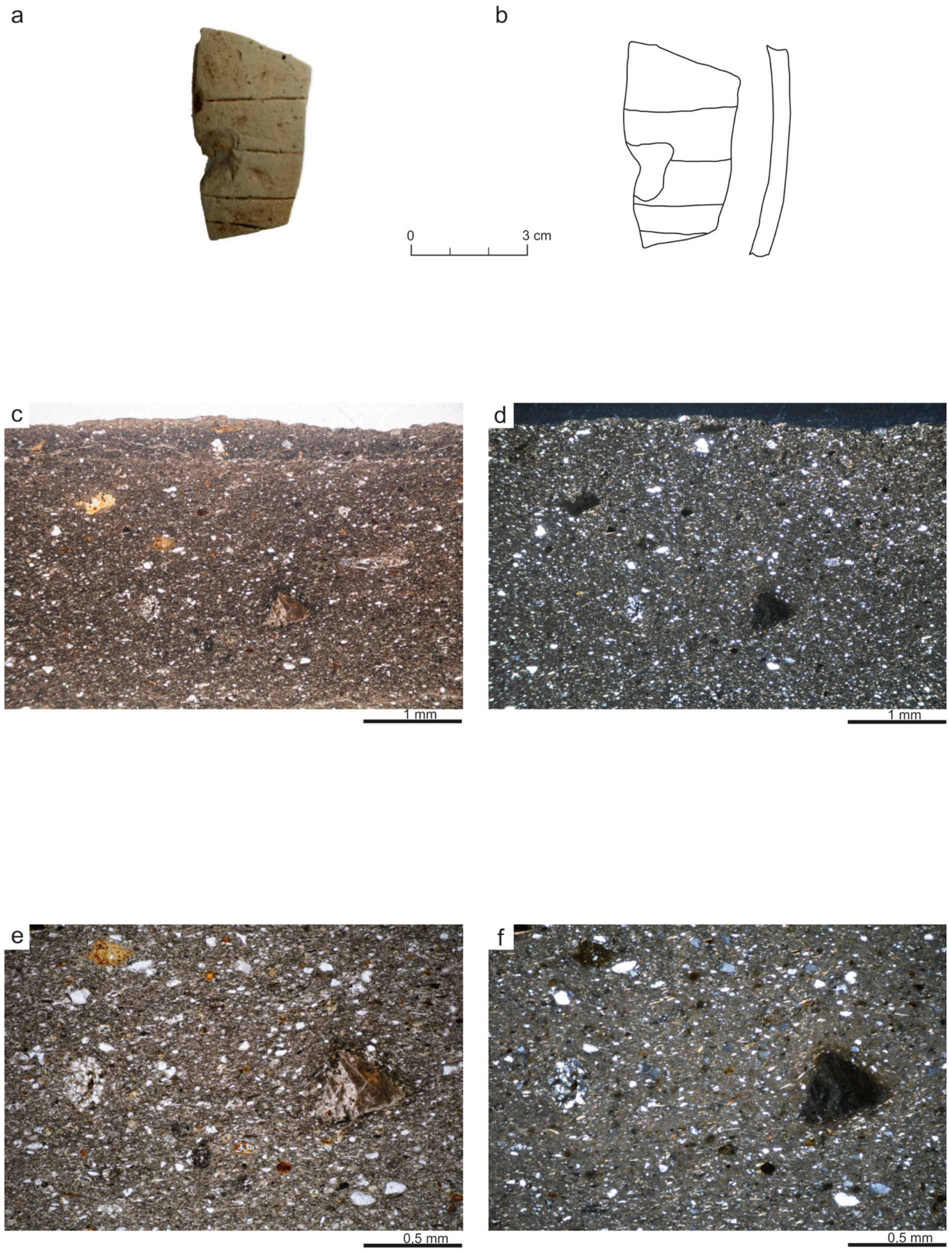

Fig. 8. Topolița, Neamț County, sample RumTop3, technological Type IIa; photography (a) and drawing (b) of the fragment; microphotographs of thin section (c-f); small inclusions within fine grained fabric are visible (c, d); chalcedony (right), rounded rock fragment (left) in ceramic body (e, f); plane polarized light (c, e); crossed polarized light (d, f)

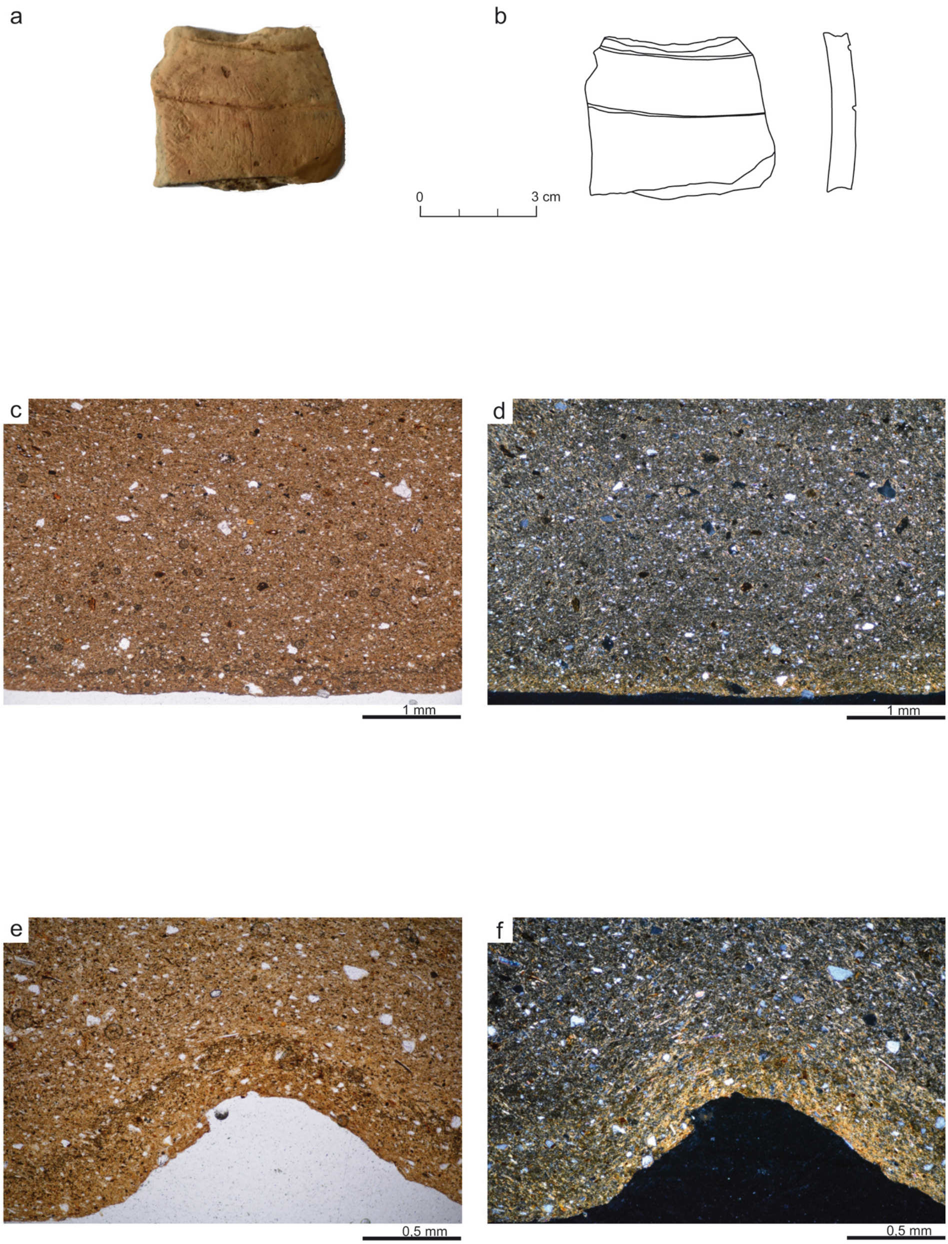

Fig. 9. Topolița, Neamț County, sample RumTop4, technological Type IIa; photography (a) and drawing (b) of the fragment; microphotographs of thin section (c-f); oxidized, fine grained, homogeneous fabric (c, d); detail of engraved line (e, f); plane polarized light (c, e); crossed polarized light (d, f)

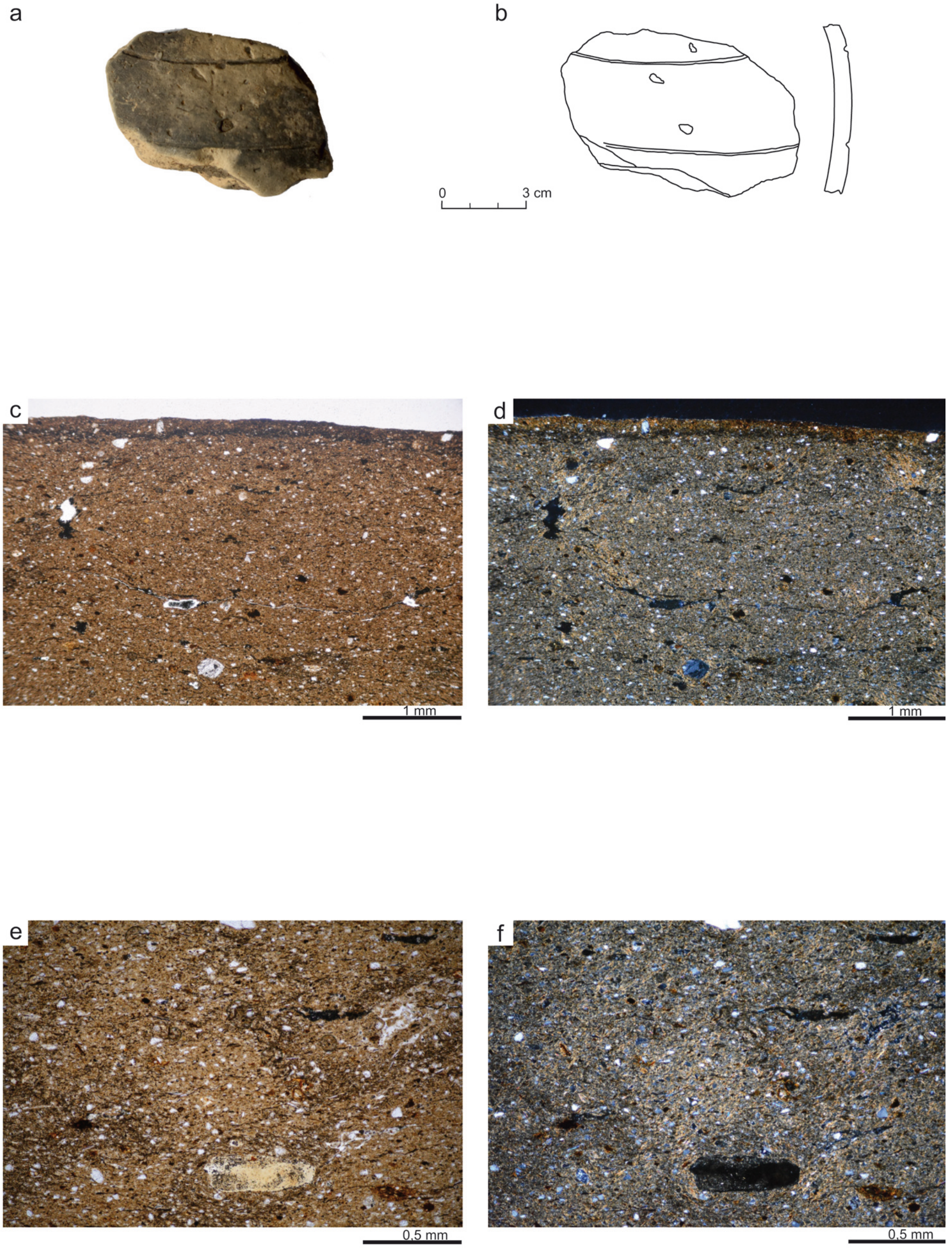

Fig. 10. Topolița, Neamț County, sample RumTop5, technological Type IIa; photography (a) and drawing (b) of the fragment; microphotographs of thin section (c-f); fine grained, homogeneous fabric, a thin layer of coloration parallel to the outer surface is visible (c, d); isotropic inclusion in ceramic matrix – in the bottom (e, f); plane polarized light (c, e); crossed polarized light (d, f)

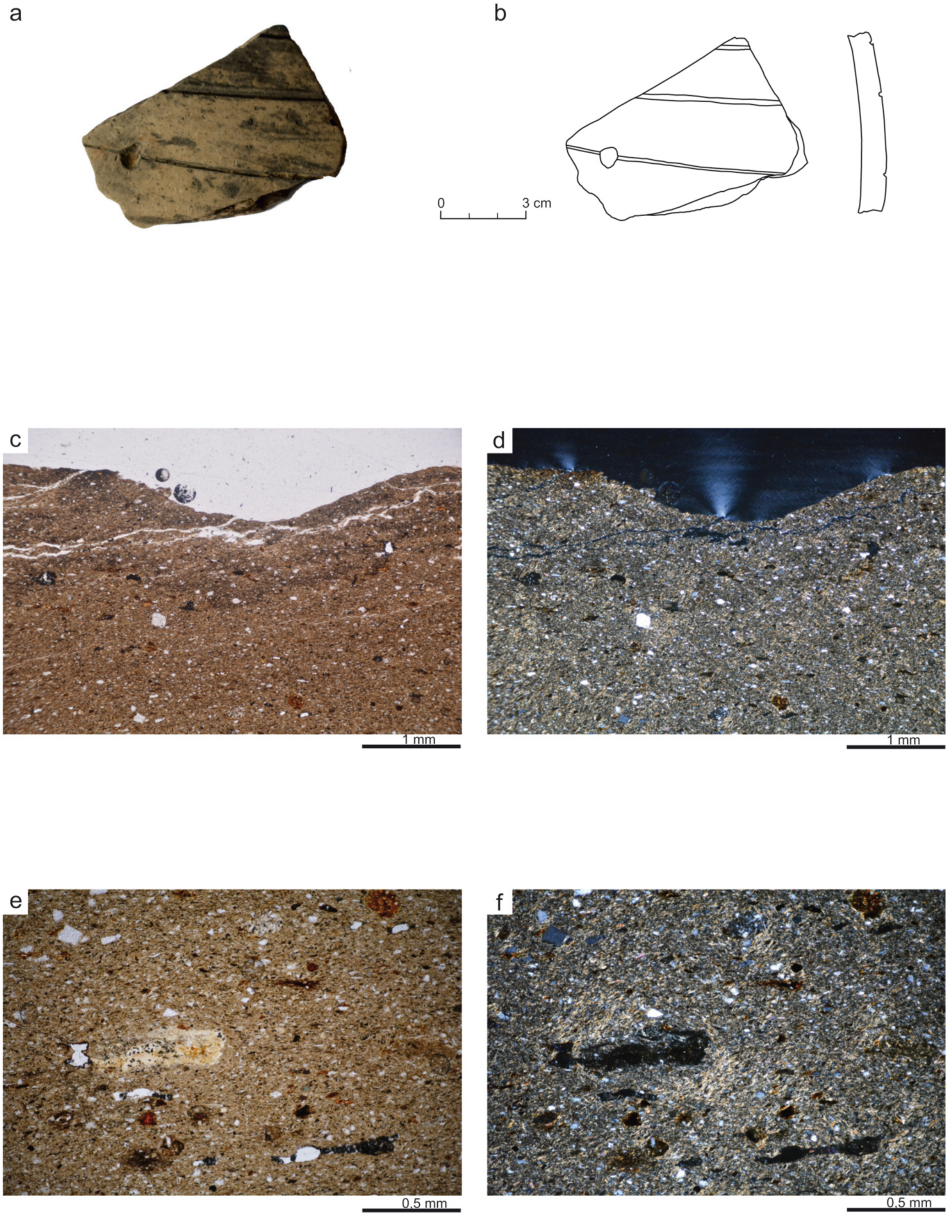

Fig. 11. Topolița, Neamț County, sample RumTop7, technological Type IIa; photography (a) and drawing (b) of the fragment; microphotographs of thin section (c-f); fine grained, homogeneous fabric, a small microcracks parallel to the surface are visible (c, d); isotropic inclusion in ceramic matrix – left (e, f); plane polarized light (c, e); crossed polarized light (d, f)

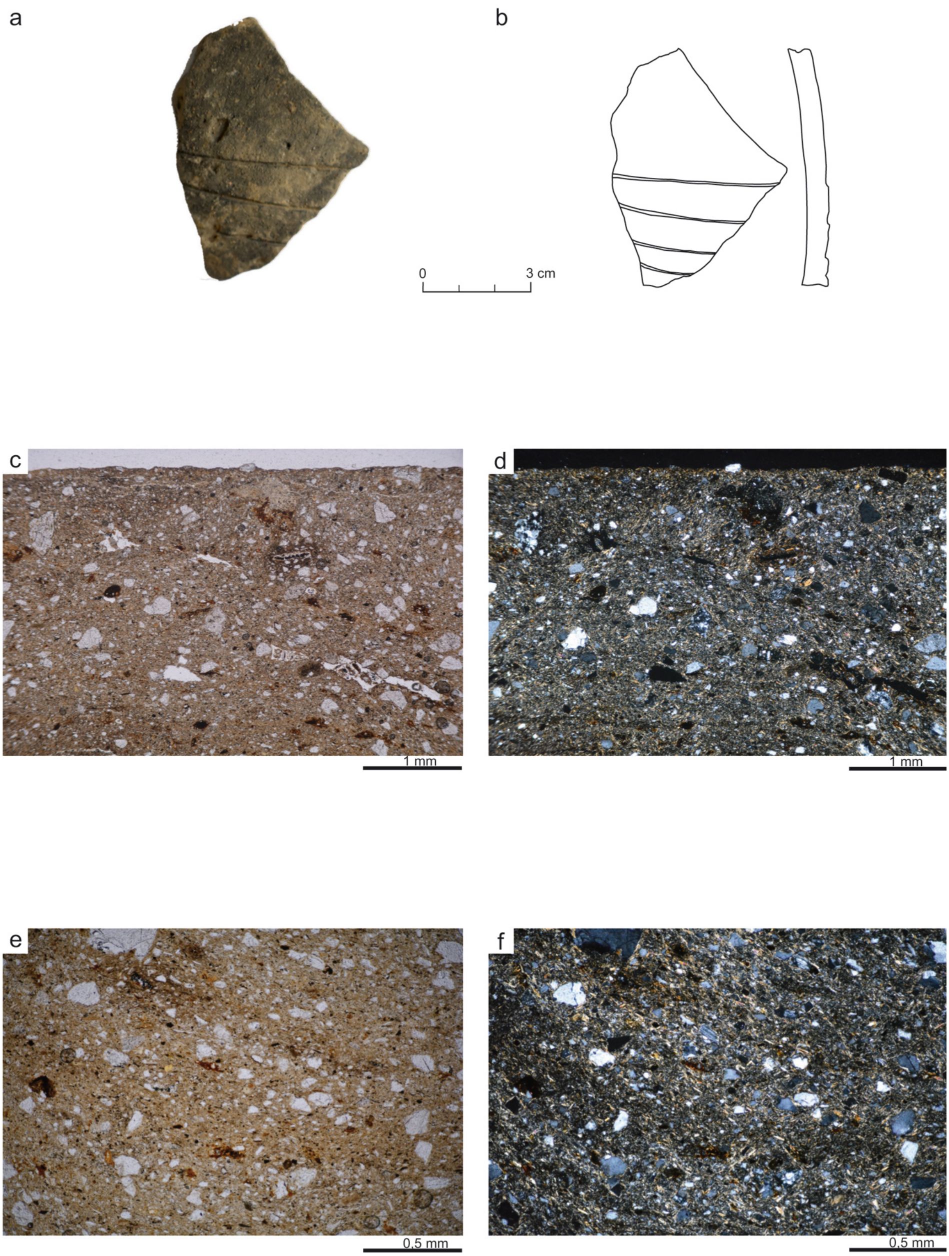

Fig. 12. Topolița, Neamț County, sample RumTop6, technological Type Ia; photography (a) and drawing (b) of the fragment; microphotographs of thin section (c-f); sand grains evenly distributed in the ceramic fabric (c, d, e, f); plane polarized light (c, e); crossed polarized light (d, f)

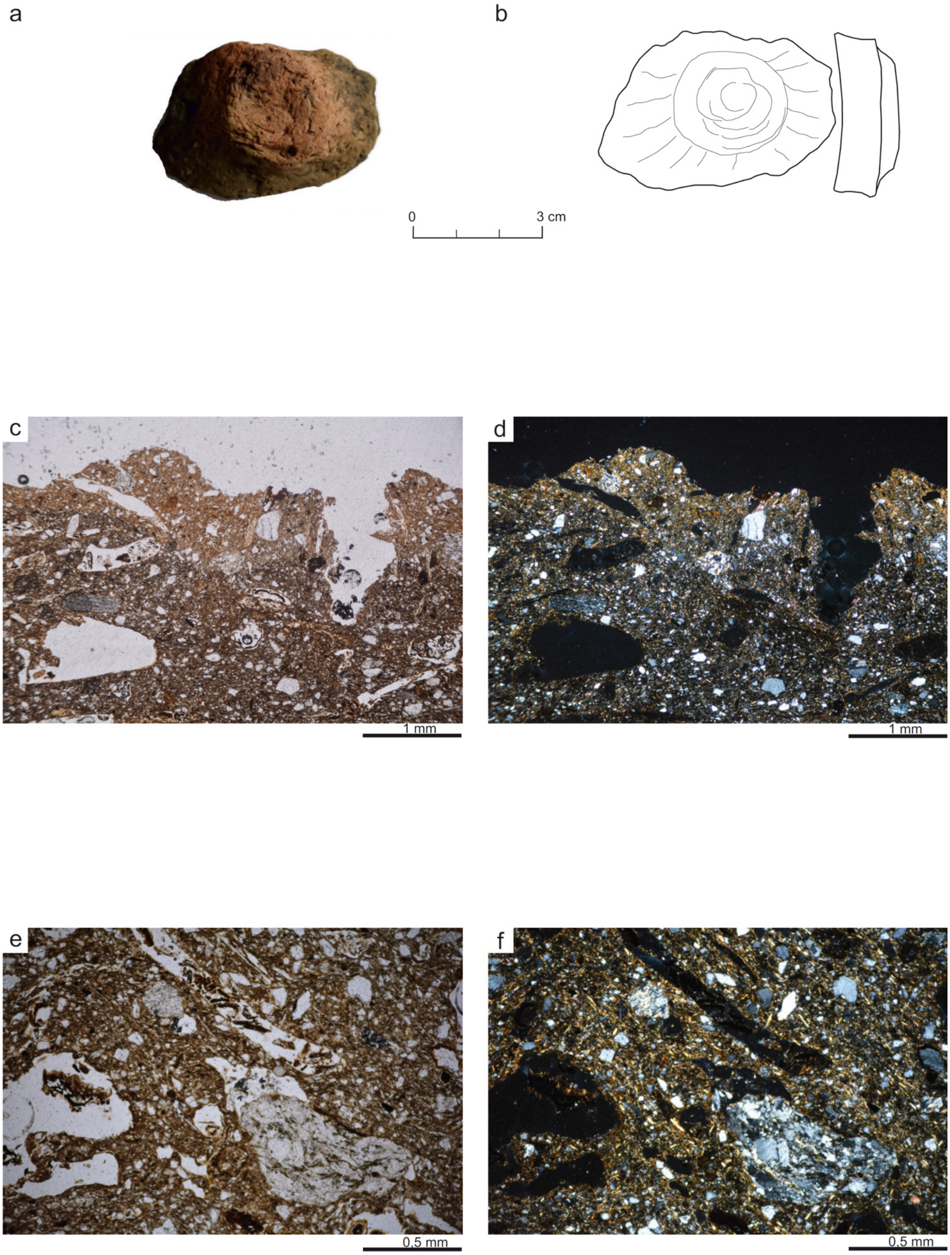

Fig. 13. Topolița, Neamț County, sample RumTop8, technological Type Ia; photography (a) and drawing (b) of the fragment; microphotographs of thin section (c-f); heterogeneous fabric, grains of quartz and feldspars and numerus voids after plant fragments are visible (c, d); fragment of rounded rock – left bottom, residues of plant fragments are visible (e, f); plane polarized light (c, e); crossed polarized light (d, f)

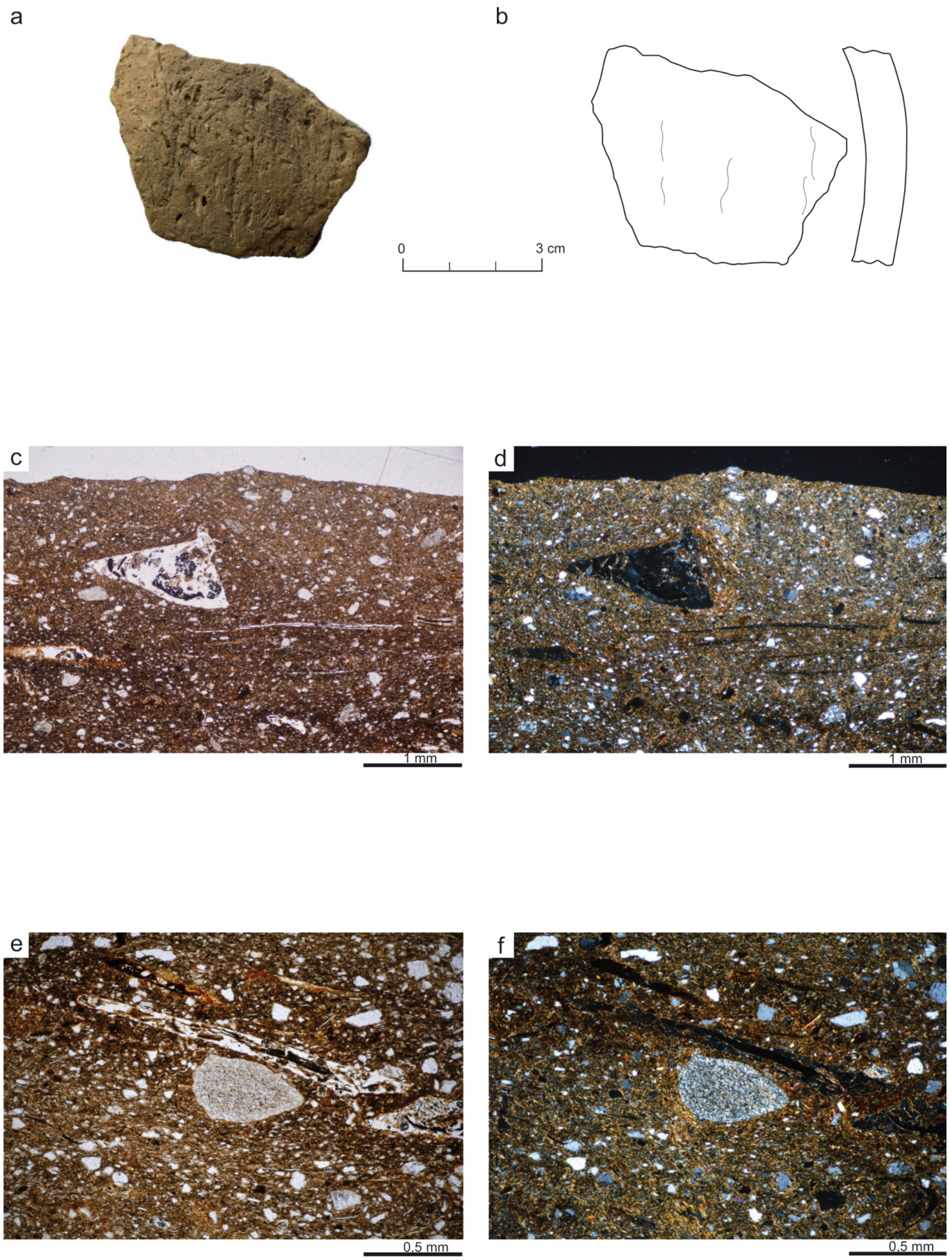

Fig. 14. Topolița, Neamț County, sample RumTop9, technological Type Ia; photography (a) and drawing (b) of the fragment; microphotographs of thin section (c-f); residues of plant fragments are visible in a well-mixed fabric (c, d); fragment of rounded rock – centre, and residues of plant fragments are visible (e, f); plane polarized light (c, e); crossed polarized light (d, f)

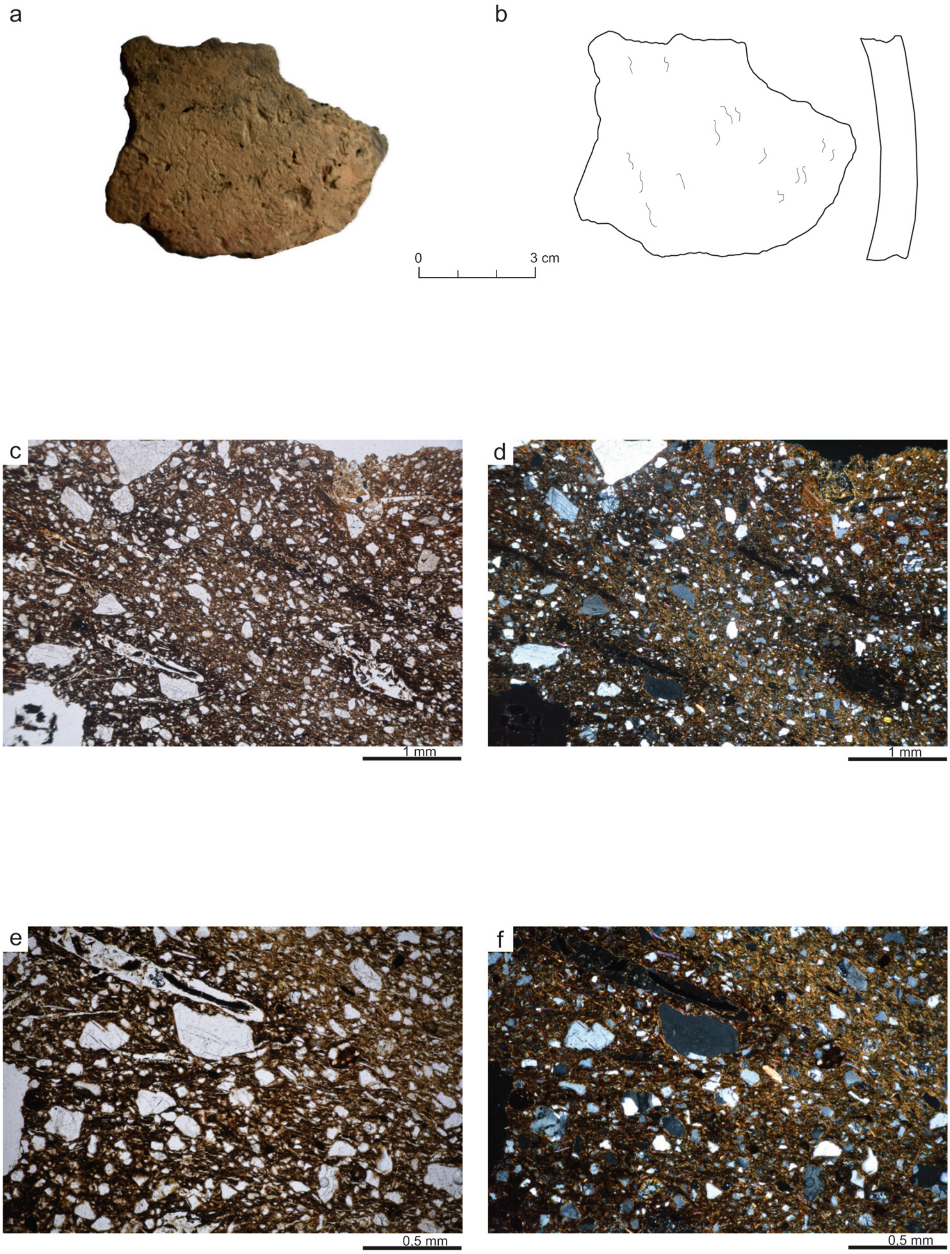

Fig. 15. Topolița, Neamț County, sample RumTop10, technological Type Ia; photography (a) and drawing (b) of the fragment; microphotographs of thin section (c-f); numerous sand grains and residues of plant fragments are visible in a well-mixed fabric (c, d, e, f); plane polarized light (c, e); crossed polarized light (d, f)

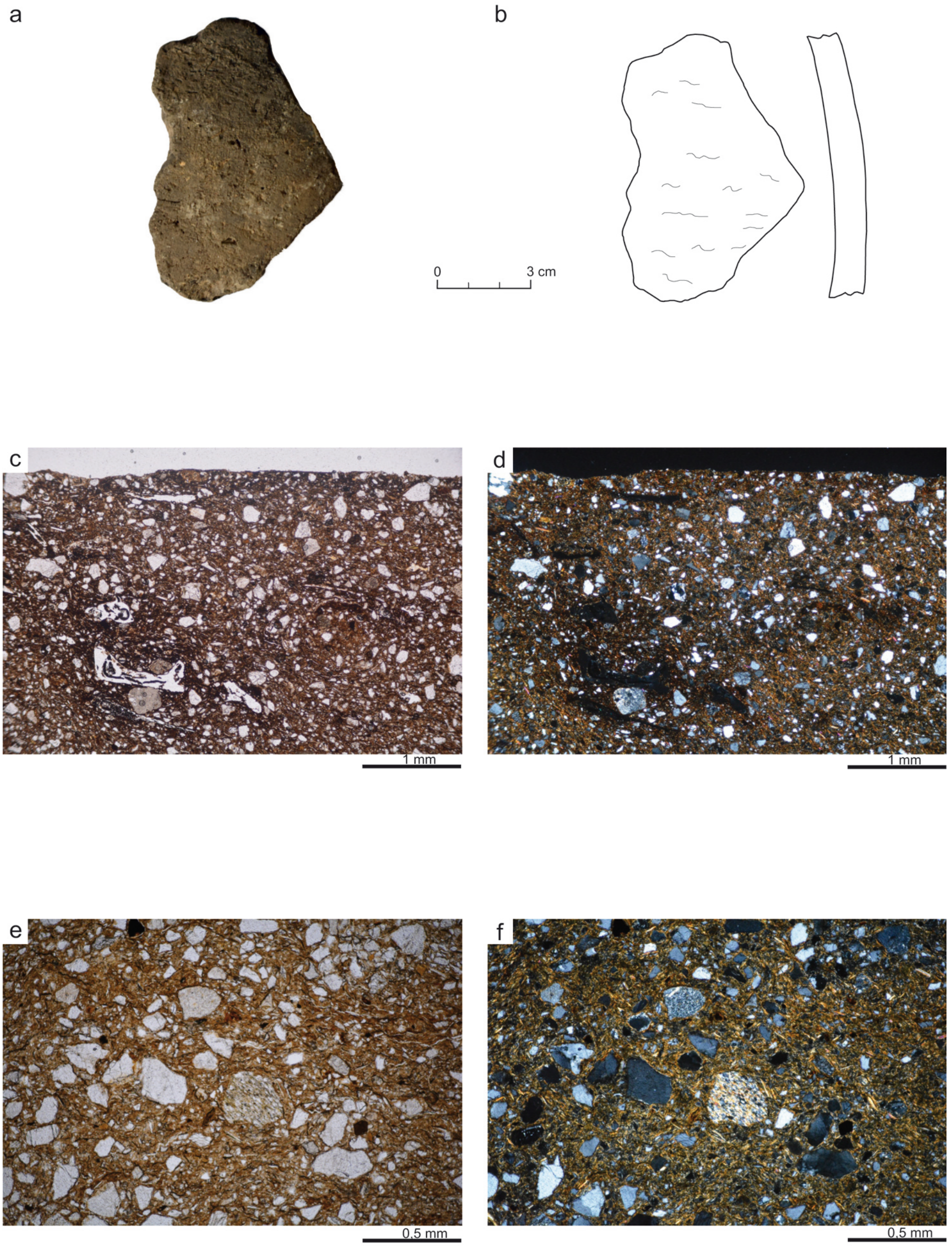

Fig. 16. Topolița, Neamț County, sample RumTop11, technological Type Ia; photography (a) and drawing (b) of the fragment; microphotographs of thin section (c-f); numerous sand grains and residues of plant fragments are visible in a well-mixed fabric (c, d); rounded fragment of rock in the centre (e, f); plane polarized light (c, e); crossed polarized light (d, f)

teristic voids, resulting in greater porosity of the pots walls. Plants fragments were intentional added to the clay.

The mineral inclusions primarily comprise sand and are identified in coarse ceramics. Sand consists of quartz grains, less frequently feldspars, and rounded fragments of metamorphic rocks. The latter were also sporadically noted in fine-grained ceramics (samples RumTop3 and RumTop7).

A significant correlation was noted between the presence of organic material and an increased number of mineral components (sand). It is difficult to determine conclusively whether the sand was deliberately added or if it was a natural component of the clay used. It is possible that coarse-grained clay was intentionally selected for making pots with thicker walls, while for thin-walled vessels, clay was purified from coarse grains.

Firing

The examined ceramic fragments exhibit various firing characteristics. The approximate firing temperature was determined based on the degree of alteration of clay minerals, observing their optical properties. Most fragments show signs of reduction firing or firing with the influx of air towards the end or during cooling. Only one fragment (TopRum1) displays features of oxidizing firing. Seven fragments show firing at temperatures around 700-750°C, while three fragments (TopRum4, RumTop10, RumTop11) were fired at temperatures around 800-850°C. The fracture of one fragment (sample RumTop3) is optically heterogeneous. Presumably, the wall's core reached a temperature of about 750-800°C, while the outer parts reached around 700-750°C.

Ceramic fabrics

Two main groups can we distinguished for analysed pottery from Topolița (Table 4).

Vessels RumTop1, RumTop2, RumTop3, RumTop4, RumTop5, and RumTop7 were made of very fine-grained ceramic fabrics, Type IIa according to the classification adopted for ceramics from Romania (Kadrow *et al.* 2018, table 4). They are characterized by good sorting, the absence of coarser mineral grains, and the lack of intentional admixtures. Neither organic nor mineral inclusions were observed. The clays were well mixed; all components are evenly distributed in the clay. There are no clear correlations regarding firing preferences. The vessels were fired in different atmospheres: oxidizing, reducing, and mixed. Firing temperatures ranged from 700°C to 850°C. Vessels with smoothed surfaces and engraved ornamentation and wall thicknesses ranging from approximately 0.3 to 0.7 cm were made from the described ceramic fabrics.

Vessels labelled RumTop6, RumTop8, RumTop9, RumTop10, and RumTop11 were made from poorly sorted, coarse-grained clays (Type Ia according to the classification adopted for ceramics from Romania; Kadrow *et al.* 2018, 11). Plant fragments and numer-

Table 4. Descriptions of fabric Types (after Kadrow *et al.* 2018)

Symbol of the fabric types	Fabric description	Sample from this study
I a	thicker grains in the ceramic body, organic admixture	RumTop6, RumTop8, RumTop9, RumTop10, RumTop11
I b	thicker grains in the ceramic body, presence of unmixed clay clasts (poorly mixed), organic admixture	
I c	thicker grains in the ceramic body, poorly mixed, without organic admixture	
II a	fine grained, homogeneous, compact, without organic admixture	RumTop1, RumTop2, RumTop3, RumTop4, RumTop5, RumTop7
II b	heavy clay, fine grained, with clay clasts and fragments of sedimentary rocks, without organic admixture	
II c	fine grained, homogeneous, compact, with organic admixture	
II d	fine grained, heterogeneous, with grog admixture	

ous sand grains were noted in these ceramic fabrics. Sand consists of quartz, feldspars (plagioclases, microcline), chalcedony, and fragments of metamorphic rocks. Clayey clasts and iron hydroxides (lepidocrocite) were observed. The fabrics are characterized by poor workmanship and greater porosity. Vessels made from these masses were more frequently fired under reducing and mixed atmospheres. The approximate firing temperature rangeed from 700°C to 850°C. The wall thickness of vessels varies from 0.5 to 0.8 cm. With one exception, these vessels have rough surfaces and lack engraved ornamentation. Sample RumTop6 originates from a vessel with smoothed walls and engraved ornamentation.

DISCUSSION

As part of earlier research, 23 fragments of ceramic vessels of the Linear Pottery culture from sites in northeastern Romania were examined (Kadrow *et al.* 2018). The sites closest to the Topolița site are Târpești, Traian, Preutești, and Mihoveni (n = 14); further southwest – Olteni (n = 4); and to the east – Isaiia (n = 5). Based on microscopic analyses, several ceramic types were distinguished. Generally, they can be divided into fine-grained and coarse-grained with various impurities and different clay preparation methods (Kadrow *et al.* 2018, table 4). Most thin-walled ceramics were made from fine-grained, homogeneous, compact fabrics (Type IIa). Two vessels were made from fabrics with organic admixture (Type IIc). Such fine-grained pastes with organic admixture were not found in Topolița.

The characteristic features of coarse-grained ceramics from Olteni, Târpeşti, Traian, Preuteşti, Mihoveni, and Isaiia are coarser-grained fabrics with sand and organic material admixture. The raw materials used for making vessels varied and had their characteristics depending on the site. Among others, heavy clays, sandy clays, and carbonate mud were identified.

The closest site to Topoliţa is Târpeşti, where (similarly to Topoliţa) no organic admixture was found in fine-grained fabrics. However, coarse-grained ceramics were made similarly at both sites – with sand and organic material admixture (Table 4). Significant differences can be observed in the raw materials used. In Târpeşti, several raw materials were identified, with a predominance of material rich in carbonates, primarily carbonate mud (three fragments), as well as pure heavy clay (one frag.) and clay with fragments of metamorphic rocks (one frag.). On the basis of the examined samples, only one type of clay was likely used in Topoliţa, which was prepared in various ways depending on the desired effect. This raw material is characterized by the presence of fine mica flakes and, within the coarser fraction, fragments of sedimentary and metamorphic rocks, mainly mudstone, quartz-mica schists, and quartz schists.

Several characteristic and consistent features exist for all examined fragments from Romania (n = 34). Thin-walled vessels were made from fine-grained, homogeneous, and compact fabrics (Type IIa or IIc). In contrast, vessels with thicker walls were made from poorly sorted fabrics with mineral admixture and with or without organic admixture (Type Ia, Ib, and Ic). This pattern is also characteristic of ceramics from southern and southeastern Poland (Rauba-Bukowska 2014; Rauba-Bukowska 2021; Rauba-Bukowska and Czekaj-Zastawny 2020; Czekaj-Zastawny *et al.* 2017).

Comparisons with the late Starčevo-Criş pottery from Tăşnad-Sere, Călineşti-Oaş, and Homorodul in eastern Romania did not reveal such a clear division into fine-grained and coarse-grained fabrics. Both thin-walled and thick-walled ceramics were made from fabrics with organic and mineral admixture (Kadrow and Rauba-Bukowska 2017). M. Spataro's (2019) research on Starčevo-Criş pottery from Romania (Banat, Transylvania), Serbia, and Slavonia revealed that both thin-walled and thick-walled vessels were made from clay fabrics with organic temper and, to a lesser extent, with a combination of organic temper and sand (Spataro 2019, 340–359). In this regard, there is a subtle resemblance to the earliest phases of LBK pottery from Poland (the Zofipolska phase, phase Ib of LBK in Poland) when organic admixture was predominant in the clay fabrics (*e.g.*, Moskal-del Hoyo et al. 2017; Rauba-Bukowska and Czekaj-Zastawny 2020).

By tracing the technology of LBK ceramic production in Małopolska, we know that it underwent continuous evolution. An important shift was observed in LBK pottery production in southern Poland between the Music-Note and Želiezovce phases. This was primarily associated with the introduction of grog admixture into the coarse ceramic fabrics at the expense of organic additives. It was also noted that during the Želiezovce phase, more homogeneous, compact, and often organic-free pottery fabrics were used for producing thin-walled vessels. Observing similar changes in LBK ceramic production from Romania is not currently possible. We only have material from one phase – the Music-Note phase. Comparisons of Romanian ceramic technology to ceramics from Małopolska suggest the Romanian ceramics might be assigned to a late stage of the Music-Note phase, when organic additives were used less frequently.

CONCLUSION

Similar ceramic production patterns were identified at the Topolița site and nearby LBK sites in Romania (Kadrow *et al.* 2018). Fine-grained, homogeneous, and compact ceramic fabrics without organic admixture were used to produce thin-walled vessels, while fabrics containing more sand and plant fragments were employed for vessels with thicker walls. This suggests a common technological tradition.

The raw materials used in Topolița were relatively uniform. Both microscopic and XRD diffraction analyses confirm that clay was locally sourced. The clay body is composed by illite/smectite and very fine mica flakes, mainly muscovite and biotite. Quartz and feldspars are the main inclusion in the clays. Microcline was distinguished within the potassium feldspar group, while albite and oligoclase were identified among the plagioclases. It can be assumed that the source material could have been sandy clays formed as alluvial river deposits. This material, resulting mainly from the erosion of older formations, was deposited in the Topolița River terrace sediment. A similar composition was obtained during the analysis of Bronze Age ceramics from the Topolița site (Mățău *et al.* 2021). This may indicate prolonged use of local raw materials. The reliance on locally sourced raw materials indicates self-sufficiency in ceramic production**.**

The raw material selection pattern was not similar everywhere. Contrast can be seen, for instance, with the nearest site in Târpeşti, where several different raw materials were identified (Kadrow *et al.* 2018, table 5, 34, 35). This disparity may reflect variations in geological formations and accessibility to different clay deposits between the two regions. Such differences highlight the importance of considering local environmental factors in understanding ceramic production practices.

The study of the technological aspects of pottery at Topolița (which is a new site on the settlement map of LBK), Târpeşti and other nearby sites provides valuable insights into the ceramic production practices in LBK in northeastern Romania. The similarities and differences observed shed light on regional variations in LBK ceramic technology and raw material procurement strategies. Furthermore, **similar technological patterns in Topolița and southeastern Poland**, especially during the Music-Note phase, suggest the transmission of knowledge and practices through cultural interactions and exchange networks.

Aknowledgements

The studies were made possible with financial support from the Institute of Archaeology and Ethnology PAS, Departments of Mountain and Highland Archaeology. This work was supported by research grant no 16.16.140.315 from AGH University.

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