38 Archeologické rozhledy 76–2024–1 38–72

RESEARCH ARTICLE – VÝZKUMNÝ ČLÁNEK

Ceramic technology evolution at the beginning of the Roman Period: Case study of the Mlékojedy settlement site (Central Bohemia)

Vývoj technologie výroby keramiky na počátku doby římské: Případová studie ze sídliště v Mlékojedech (střední Čechy)

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This exploratory archaeometric study investigates pottery from a Großromstedt culture associated with a significant migratory wave from the north into the Bohemian Basin at the transition from the Late La Tène to the Roman periods. The analysis of ceramics from the Mlékojedy settlement reveals evidence of technological discontinuity in two key chronological transitions. The first and more significant transition between the Late La Tène period and the Early Roman period (LT D/R A) is characterised by a change in the pottery forming method, with a turn away from the use of the potter's wheel. New pottery shapes and a new range of ornamentation are also introduced in this period, potentially indicating cultural import or/and population migration. However, the technological changes in pottery production were not absolute, as certain processes persisted. The second technological discontinuity was found between phases R A and R B1 of the Roman period. It appears as a natural evolution of the ceramic technology, which was accelerated by the social changes. The findings suggest that the vast majority of pottery could have been produced from local sources.

Early Roman period – Late La Tène period – XRF – XRD – ceramic petrography

Tato průzkumná archeometrická studie zkoumá keramiku spojenou s významnou migrační vlnou ze severu do české kotliny na přelomu pozdní doby laténské a doby římské. Analýza keramiky ze sídliště Mlékojedy odhaluje doklady technologické diskontinuity ve dvou klíčových chronologických přechodech. K prvnímu a významnějšímu dochází mezi pozdní dobou laténskou a mladší dobou římskou (LT D/R A). Vyznačuje se změnou způsobu formování keramiky a odklonem od používání hrnčířského kruhu. V tomto období se také prosazují nové tvary keramiky a nová škála ornamentů, které mohou naznačovat kulturní import či/a migraci obyvatelstva. Technologické změny v hrnčířské výrobě však nebyly absolutní, neboť určité procesy přetrvávaly z předcházejícího období. Druhá technologická diskontinuita byla zjištěna mezi fázemi R A a R B1 doby římské. Vyznačuje se přirozeným vývojem keramické technologie, který byl pravděpodobně urychlen společenskými změnami ovlivněnými kontaktem s římsko-provinciální kulturou. Nálezy naznačují, že naprostá většina keramiky mohla být vyrobena z místních zdrojů.

mladší doba římská – pozdní doba laténská – XRF – XRD – keramická petrografie

Introduction

During the 1st century BC and at the beginning of the Christian era, Central Europe underwent significant changes. In Bohemia, they were manifested by the abandonment of the Celtic oppida and a distinctive modification of the cultural environment. This is traditionally explained by the arrival of a new population – the *Germani*, represented by the remnants of the Großromstedt culture. The study of this complex phenomenon, which affected

https://doi.org/10.35686/AR.2024.3

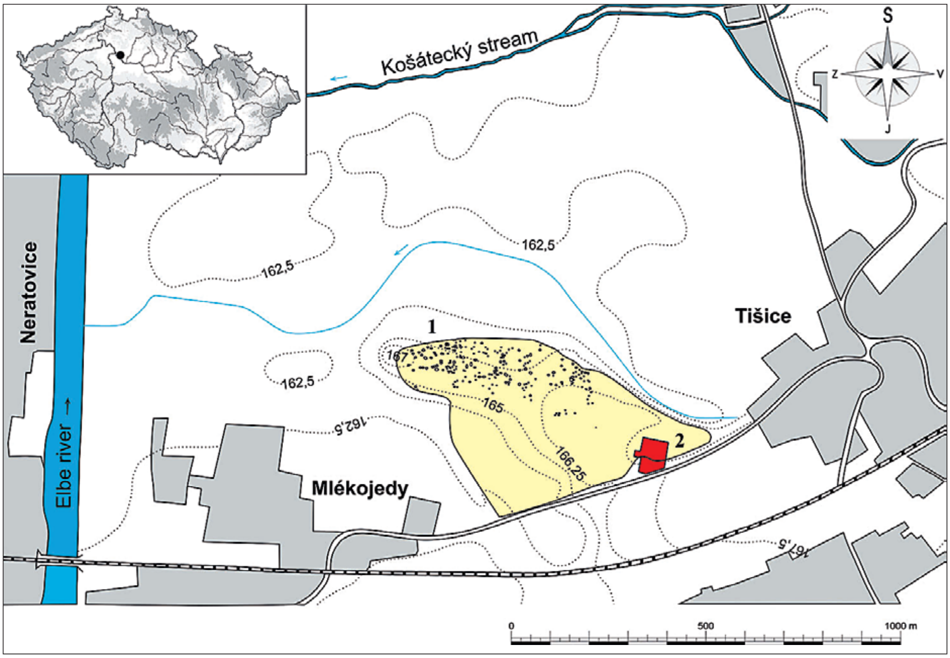

Fig. 1. Location of Mlékojedy site on the map of the Czech Republic and position of the settlement in Mlékojedy (no. 1) and burial ground in Tišice (no. 2). Yellow colouring indicates an area excavated by a sand pit.

ethnic changes, settlement structure, burial rites, and economy, has a long tradition and can be addressed in different ways. One possible approach is to follow a particular economic aspect in a given territory at a given period, such as agriculture (*Kreuz 2005*) or metallurgy of non-ferrous metals (*Bursák et al. 2022*). In this text, we will focus on pottery production.

Our source of information is the extensive material record of the Early Roman period settlement site at Mlékojedy, Central Bohemia (*Fig. 1*). It was excavated in the years 1972–1976 by K. Motyková and it was uncovered almost in the full extent due to a gradually expanding sand quarry at the site. Settlement size and dating from roughly the mid- 1st century BC (R A) to the mid-1st century AD (R B1) is a good illustration of the beginning of the culture of the Roman period (for the most recent information about the site, see *Beneš 2021*). The dating of the Mlékojedy settlement site is based on small metal finds, mainly brooches and pins, as well as on pottery (*Droberjar 2008*, 100–102; *Beneš 2021*, 15–21). However, small amount of the Late La Tène period pottery were found as intrusions in R A and R B1 features.

Just 150 m away from the settlement, burial ground of Tišice was excavated in 1953 and 1954. It was dated into the same time (*Motyková-Šneidrová 1963*) and apparently belonged to the settlement. Mlékojedy together with Tišice thus represent a unique situation where both settlement and burial ground belonging to the same community were explored.

This paper addresses socio-economic development in Bohemia at the beginning of the Roman Period using a case study of pottery from the Mlékojedy site and employing a combination of the traditional archaeological type-chronological and archaeometric analyses. At the beginning of the research, four specific questions were developed.

1) What was the typological and technological relationship between pottery fragments of the Late La Tène cultural tradition (wheel-made pottery fragments, graphite pottery, etc.) and pottery of the Großromstedt culture of the Roman Period?

2) Did domestic pottery from phases A and B1 of the Early Roman period undergo any technological development that is generally reflected in the typological development of pottery shapes and decoration?

3) Would it be possible to identify such pieces among the analysed pottery from the Early Roman Period which were not produced on the same site as the rest?

4) Can pottery shapes that seem to be typologically alien be designated as imports?

Archaeological and historical context

At the beginning of the 1st century BC, i.e. during the Late La Tène Period, specifically LT D1 relative chronological phase[1], the vast majority of Bohemia (except for its northernmost parts) was occupied by the people of the La Tène culture (*Danielisová 2020*, Fig. 18). At that time, the La Tène 'civilization' was already going through its final, so-called oppida phase. It was characterised by the emergence of large, fortified settlements that gradually took on the features of primitive urban agglomerations. The latest finds associated with the existence of oppida in Bohemia can be placed at the turn of the 3rd and 4th quarter of the 1st century BC (*Rybová – Drda 1994*, 130–132; *Militký 2015*, 168–169). The potential presence of individuals or groups of Germanic origin (i.e. those with a cultural background corresponding to the Jastorf, Przeworsk, and Oksywie cultures) in the Bohemian oppida environment in LT D1 phase has so far only been discussed in the case of northern peripheral regions (*Droberjar 2006a*, 16–22; *Beneš et al. 2017*, 41–45). However, from the growing evidence of contacts with the cultures in the northern half of Central Europe (e.g. *Vích 2017*, 658, Fig. 18), we can hypothesise that long-term contacts (commercial, political, even some sort of peripheral colonisation) between the bearers of these so-called 'Germanic' cultures and the population of La Tène Bohemia existed.

The cultural situation in Bohemia only changed significantly around the middle of the 1st BC with a new wave of settlers who represented the Elbe-Germanic Großromstedt culture. Its material record has already been sufficiently described (e.g. *Peschel 1978*, 72–118; *Droberjar 2006a*). Without any doubt, there was a strong cultural connection between Bohemia and the Main River region (*Steidl 2004*; *Frank 2009*). This Elbe-Germanic Großromstedt culture is assumed to have spread from the German Central Uplands and reached Bohemia during the late oppida phase at the earliest (*Droberjar 2006a*; *Danielisová 2020*, 142–144). The relationship between the Großromstedt culture and the Late La Tène population of Bohemia is attested by several pieces of evidence, including intrusions of La Tène pottery in later contexts, and even imitations of La Tène pottery with the 'new Großromstedt' technology, i.e. without the use of the potter's wheel or graphite (*Beneš et al. 2017*).

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[1] According to a concept of periodisation which was used by *Danielisová* (*2020*, Table 2, Fig. 2).

Bearers of the Großromstedt culture established unfortified flatland settlements in Bohemia, especially in the fertile northern half of the country in the traditionally settled regions (*Droberjar 2006a*, 28, 64–76). These ‘first Germanic people’ also brought a change in the burial rite by establishing necropolises consisting of cremation graves. The ashes were placed either in urns or pit graves. At several continuously investigated sites, such graves represent the initial phase of burials that lasted until the end of the 2nd century AD (e.g. *Droberjar 1999*). The incorporation of Bohemia into the large Elbe-Germanic circle of the Großromstedt culture created a new, large cultural block in the middle of Europe which was considered ‘Germanic’ by Roman authors writing at the turn of the Christian era (*Burmeister 2020*).

Shortly before the turn of the Christian era, the material culture of the entire Großromstedt area developed into the R B1 phase of the Roman Period, which is usually dated to ca. 10 BC to 50 AD (*Droberjar 2006b*). In spite of contemporary efforts to free archaeological analysis from the influence of written sources, these changes are traditionally interpreted as a consequence of historical events, which are well-documented in the works of authors such as Strabo (*Geografika* VII 1,3: *Radt ed. 2003*), Velleius Paterculus (*Historia Romana* II, 108–110: *Mouchová ed. 2013*), P. C. Tacitus (*Annalen* II, 26, 44–46, 62–63: *Minařík – Hartmann eds. 1975*). According to them, Bohemia can be considered the centre of the so-called Maroboduus Empire (e.g. *Salač 2021*). The rapid development of the social structure of the population inhabiting Bohemia during the first decades of the first century AD is proven by rich burials excavated in cemeteries established during the previous chronological phase R A (e.g. Stehelčeves, Tišice, Třebusice, Tvršice), the cemeteries newly founded in R B1 (Dobřichov-Pičhora), but also from isolated burials (*Droberjar 2006b*, 682–695). In addition to cremation graves, inhumations also began to appear in Bohemia (as well as in the Elbe-Germanic circle, see *Lichardus 1984*). Archaeological and historical sources show that this short period lasting roughly two to three decades marked a cultural and political upswing for the territory of Bohemia. It is archaeologically detectable thanks to an influx of cultural elements from various parts of Europe. The significant number of Roman objects, particularly Italian bronze and silver toreutics, imported in Bohemia mainly during the R B1a phase stands out compared to the rest of Central Europe where such imports are sparse (e.g. *Droberjar 2007*, 55–56). There is also evidence of a significant influx of antique brass, probably originating from the Massif Central in today’s France, demonstrating increased contact with the Roman Empire (*Bursák et al. 2022*). From a historical point of view, this is also supported by the attention paid to mutual Romano-barbarian relations by Roman written sources (e.g. *Kehne 2009*).

The settlement site of Mlékojedy (and the adjacent burial ground in Tišice), from which all the samples examined in this study originate, are a good representation of the beginning of the Roman period in Bohemia. Although few the Late La Tène potsherds have been found in some of the later features, no permanent component of this culture has been documented and excavated there. Two cultural reversals could be observed at the site and thus reflect the usual situation in Central Bohemia. At the time of its foundation in LT D2/R A (i.e. in ca. 50–30 BC), there was the first important reversal – the arrival of the Großromstedt culture. This change is supposed to have been caused by the collapse of the economy of the La Tène culture and the immigration of a new, technologically less advanced population. The second turning point is the social transition taking place between phases R A and R B1 (i.e. around ca. 10 BC). In Bohemia, this is mainly apparent in the funerary con-

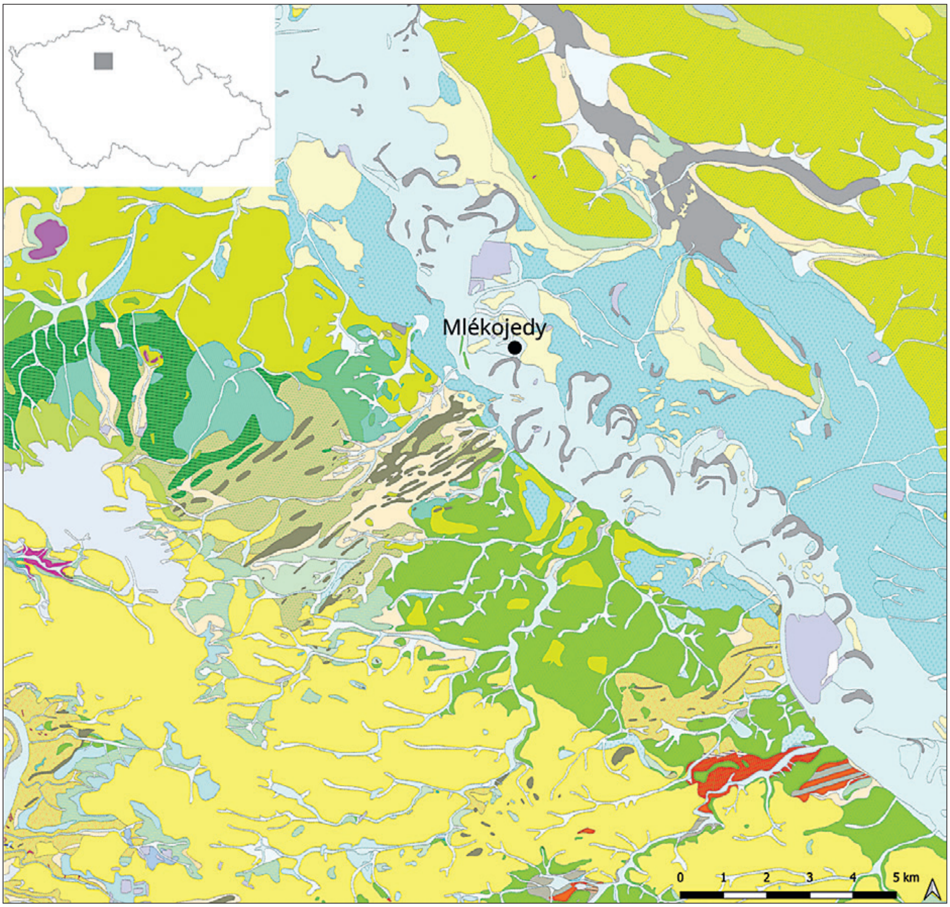

Fig. 2A. Location of Mlékojedy settlement on the geological map of the vicinity (after Czech geological survey 2023, modified).

text by the emergence of truly rich burials of both women and men equipped with a considerable number of Roman imports. It is usually explained by the arrival of a new group of settlers of the *Marcomanni* tribe under the leadership of Maroboduus from the west (*Droberjar 2006a*, 602–604). It remains a question to what extent this change was also manifested in the settlements of this culture, as topic has not been studied yet.

Geological setting

The geological setting of the study site was described in a geological report created by *Losert* (*1993*) as an annexe to the excavation report. The Mlékojedy settlement site is located on a former alluvial terrace of the Elbe River (*Fig. 2*) formed of sand and gravel. According to the pebbles analysis, the terrace consists dominantly of quartz with metamorphic, intrusive, and sedimentary rocks. The metamorphic rocks, principally gneiss,

Fig. 2B. Legend of geological map (after Czech geological survey 2023, modified).

orthogneiss, migmatite, and metabasite, come from the Krkonoše-Jizera and Kutná Hora crystalline complexes, and partly also from the region of the Iron Mountains. The intrusive rocks, namely granitised basalt, come from the nearby Neratovice complex, and the sedimentary rocks are siltstones, sandstones, and agglomerates of Permian and Mesozoic.

The bedrock of the Quaternary alluvium outcrops in the close vicinity of the settlement in several places; the closest outcrops are located in the riverbed of the Elbe River. They are formed of intermediate and basic igneous rocks, such as granodiorite, monzonite, diorite to gabbro, and granites. Igneous rocks are part of the Neratovice complex which outcrops in the town of Neratovice (located across the Elbe River from Mlékojedy) and further to the southwest.

However, the major part of the bedrock is formed by the Barrandian Proterozoic flinty shale, greywacke, and graphitic shales which outcrop up to seven kilometres to the southwest. Volcanic rocks are present in this series as spilites and veins of diorites. Coatings of iron-bearing minerals (hematite and limonite) are abundant on dislocations of disrupted

Proterozoic rocks. Ordovician shales and quartzites outcrop ca. 13 km to the south up the stream at Brandýs nad Labem or even little further to the west in the profile of the Vltava River where named sediments are accompanied with carboniferous clastic sedimentary rocks.

The largest part of the surroundings of the site of Mlékojedy is formed by Cretaceous sediments, which are covered by Quaternary alluvium of the Elbe River in the settlement's vicinity. The closest outcrops used to be located in the riverbed of the Elbe River right between Mlékojedy and Neratovice, but these have been removed along with the modern river flow regulation works. Given the fact that Mlékojedy is located in the Bohemian Cretaceous Platform, the Mesozoic sediments span tens of kilometres from the site. The sediments are represented by sandstone with a variable content of calcite, agglomerates, sandy limestones, shales, claystone, and marlite.

Tertiary rocks in the area are present only as small and isolated volcanic funnels, which are related to the Central Bohemian Uplands volcanic complex located ca. 40 km northwest. Local development of thermally altered rocks in contact with active volcanism is typical for Tertiary volcanic activity in the Bohemian Massif (forming hardened rocks such as porcelanite). Volcanic rocks are represented mostly by nephelinite and basaltoid.

Material and chronology

A total of 321 settlement features have been examined during the rescue excavations in Mlékojedy. Of these, 28 were dated to the Eneolithic, and one feature (a sunken hut) was dated to the Early La Tène period. The rest belongs to the Early Roman period. With approximately 20 thousand potsherds, it is among the largest settlement sites from the Roman period excavated in Bohemia. The burial ground in Tišice, which is believed to have served as the final resting place of the inhabitants, was key to the dating of the settlement in Mlékojedy. K. Motyková divided this burial ground into two chronological groups, primarily on the basis of brooches (*Motyková-Šneidrová 1963*, 429, Fig. 48). Later, other researchers succeeded in distinguishing a total of three phases (*Lichardus 1984*, Abb. 2–3; *Völling 2005*, 16–17), which are synchronous with general phases of Roman period: A, B1a, and B1b. A comparison of the settlement in Mlékojedy and the burial ground in Tišice will always be a comparison of two qualitatively different components. For chronological comparison, it was appropriate to use brooches at the beginning of processing. Compared to 51 specimens from Tišice, only six pieces were found in the settlement site Mlékojedy. If we were to arrange ourselves according to relative chronology, then two pieces come from phase A and the remaining four fibulae belong to phase B1 (*Beneš 2021*).

From the processed and evaluated sets of potsherds from the Mlékojedy settlement, 60 pottery samples were chosen (*Tab. 1*). They usually come from features rich in finds – usually sunken huts – which enable more reliable dating. The fragments were already visually described, analysed, and dated. Only the fragments dated indisputably were used in this study: 48 samples come from the early (R A) or later (R B1) phases of the Roman period, and 12 samples from the Late La Tène culture. The latter were visually identified by marks of rotational movement during vessel forming or typological attributes.

A subdivision was further made within the Roman period group. Two subgroups were defined, namely the tableware (fine) and cookware (coarse). The definition was based on the fineness of the ceramic matter visible in the fracture (the real or apparent absence of

Sample ID	Inv. no.	Feature	Chronology	Tech Group	XRF	Petrography	XRD
1	497.179	57	Late LT		+		
2	469.853	89	Late LT		+	+	+
3	469.854	89	Late LT		+	+	+
4	496.463	105	Late LT		+	+	
5	LT01	164	Late LT		+	+	+
6	LT02	167	Late LT		+		
7	ML63/6/1	I/63	Late LT		+		
8	LT03	200	Late LT		+		
9	469.874	102	Late LT		+		
10	469.832	50	Late LT		+	+	
11	LT05	174	Late LT		+	+	
12	LT04	170	Late LT		+		
13	497.181	57	R A	tableware	+		
14	466.668	76	R A	tableware	+	+	
15	466.683	76	R A	tableware	+		
16	467.684	84	R A	tableware	+	+	
17	497.825	141	R A	tableware	+		
18	497.901	141	R A	tableware	+	+	+
19	499.096	157	R A	tableware	+		
20	499.312	157	R A	tableware	+	+	+
21	500.427	172	R A	tableware	+	+	+
22	500.456	172	R A	tableware	+	+	
23	501.650	203	R A	tableware	+		
24	501.581	203	R A	tableware	+		
25	497.176	57	R A	cookware	+		
26	467.016	76	R A	cookware	+		
27	467.771	84	R A	cookware	+	+	
28	469.423	99	R A	cookware	+	+	+
29	497.816	141	R A	cookware	+	+	
30	498.172	141	R A	cookware	+		
31	499.217	152	R A	cookware	+		
32	499.227	152	R A	cookware	+	+	
33	499.132	157	R A	cookware	+	+	
34	500.473	172	R A	cookware	+		
35	501.569	203	R A	cookware	+	+	
36	501.599	203	R A	cookware	+		
37	63/1/1,11,12	I/63	R B1	tableware	+	+	
38	464.725	8	R B1	tableware	+		
39	465.097	32	R B1	tableware	+	+	
40	496.722	38	R B1	tableware	+	+	
41	465.716	43	R B1	tableware	+		
42	497.110	50	R A	tableware	+		
43	466.572	75	R B1	tableware	+	+	+
44	468.884a	87	R B1	tableware	+		
45	495.530	105	R B1	tableware	+	+	
46	496.195	117	R B1	tableware	+		
47	500.802	174	R B1	tableware	+		
48	501.339	200	R B1	tableware	+	+	
49	63/1/13	I/63	R B1	cookware	+	+	
50	464.932b	8	R B1	cookware	+	+	
51	465.098	32	R B1	cookware	+		
52	465.557	38	R B1	cookware	+		
53	465.597	43	R B1	cookware	+		
54	466.011	50	R B1	cookware	+	+	
55	467.072	75	R B1	cookware	+	+	
56	496.442	105	R B1	cookware	+		
57	496.140	117	R B1	cookware	+		
58	498.391	140	R B1	cookware	+		
59	500.506	171	R B1	cookware	+	+	+
60	500.758	174	R B1	cookware	+	+	+

Tab. 1. List of analysed samples including inventory number, feature number, cultural/chronological affiliation, typological determination of shape/decoration.

a temper), the surface treatment, and the sherd's thickness. Tableware is mostly distinguished from cookware by thorough surface treatment, which often includes polishing to achieve a metallic lustre and firing in a reducing atmosphere. Another attribute, although not primary and not always observed, is the use of finer temper or its (seeming?) absence. Tableware usually consists of more gracile thin-walled shapes. Some selected potsherds are relatively easy to date typologically, especially the characteristic tableware. On the contrary, dating of certain cookware shapes is limited. In such cases, a link to a well-dated feature was important.

Pottery fragments of La Tène tradition

La Tène fragments represent a cultural intrusion at the settlement site, since no Late La Tène features have been excavated at the site and it is not probable that there had been any. Fragments of the Late La Tène pottery occur relatively often at other sites dated to the R A phase. The main hypothesis explaining their presence in later assemblages is generally that the site might have been used for various (but mostly residential) purposes during earlier periods (not necessarily continuously). In the case of Mlékojedy, this can be ruled out. The area of the gentle hillside was thoroughly investigated, except for its eastern edge, and no Late La Tène settlement activity was detected (*Beneš 2021*, 21–27). The revision of the archaeological material from the site has not been completed yet, but 62 wheel-thrown or wheel-finished potsherds are already known from the site and seem to be scattered evenly throughout the entire settlement area. These sherds represent only 0.4% of the total number of recorded pottery fragments; such amount is considered negligible. Actually, similar percentages were observed at other Early Roman sites (e.g. Zwenkau-Nord: *Kretschmer 2019*, 104–105).

Not all such fragments from Mlékojedy can be reliably dated to the La Tène Period, as they are often small atypical pieces. A Late La Tène date and cultural affiliation can only be considered unquestionable in a few cases (*Fig. 3*). However, other atypical fragments can perhaps be dated to the same period, i.e. to LT C–D, based on the structure of the ceramic material and the characteristic firing pattern. Fragments of wheel-made pottery were found in features dated both to the earlier (R A) and later phase (R B1) of the Mlékojedy settlement. They thus represent either intrusions that got into the objects of the Roman period by accident (such as intrusions from the topsoil), or they were part of the material culture both in phase R A as well as in the later phase R B1. However, this would mean a serious rethinking of our perception of the so-called legacy of the Late La Tène culture in the Roman period (cf. *Salač 2011a*) meaning that at least in some regions and perhaps even individual settlements, the wheel-made pottery of the Late La Tène tradition could still be produced even in the R A phase.

Due to a high degree of fragmentation, only a few pieces from the Mlékojedy wheel-made pottery assemblage can be identified more closely. First, there is the remnant of a vase-shaped vessel from feature 57 (*Fig. 3*: 1). It is a type often encountered in major cemeteries of the Early Roman Period of phase R B1 (e.g. Großromstedt, Schkopau, Třebusice or Dobřichov-Pičhora), but also in graves of the South Bavarian group, which was strongly influenced by the Central German environment (*Droberjar 1999*, 3–40; *2006a*, 42–45, Fig. 17–18; *Salač 2011b*). Based on these wheel-made models, handmade imitations may have been produced in a purely 'Germanic' fashion (*Rieckhoff 1995*, 163; *Salač 2011b*,

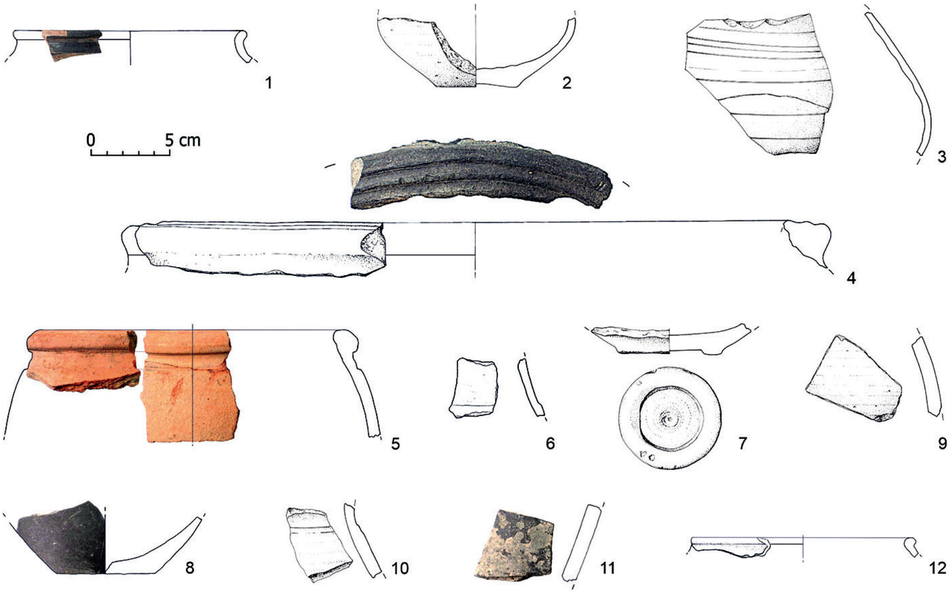

Fig. 3. Fragments of analysed La Tène vessels. Descriptive numbers match with the numbers in *Tab. 1*.

Abb. 1). A large fragment of shoulders and a bottom of a fine clay vessel is decorated with regularly spaced horizontal grooves (*Fig. 3*: 3). Coarse pottery is represented by the rim and shoulders of a barrel-shaped vessel with a finely roughened bulge from feature 164 (*Fig. 3*: 5), which can be dated to the LT C2–D1 horizon (*Venclová 1998*, 161–167). The rim of a storage vessel (ruff collar) with horizontal circumferential grooves on the outer side, which was excavated in the feature 105 (*Fig. 3*: 4), also differs from the common assortment of local pottery at Mlékojedy. It probably does not come from a wheel-thrown vessel, although it is not clear whether technological traces of wheel-throwing or wheel-finishing would be visible on a rim. However, analogous wheel-made finds are known from Bratislava-Devín hilltop and belong to the final phase of the Late La Tène occupation of the site, which was dated by a fragment of an A 18 type fibula (*Pieta 2008*, 182, Fig. 88: 9–11).

Pottery fragments from phase R A

Pottery fragments from vessels originate from features dating back to an earlier phase of the Mlékojedy settlement (n=25). Petrographic thin sections were made from six tableware and six cookware samples. XRD analysis was always carried out on a pair of samples from the first and second group.

Tableware

A typical vessel shape of the R A phase (Großromstedt culture) is the so-called Plaňany beaker (*scharfkantige Situle*; *Droberjar 2006a*, 25; *Peschel 2017*, 28–34; *Kretschmer 2019*, 68–75). According to preliminary typological observations, the occurrence of this vessel type can be mainly associated with the Saxon-Thuringian area, Bohemia, and the Main

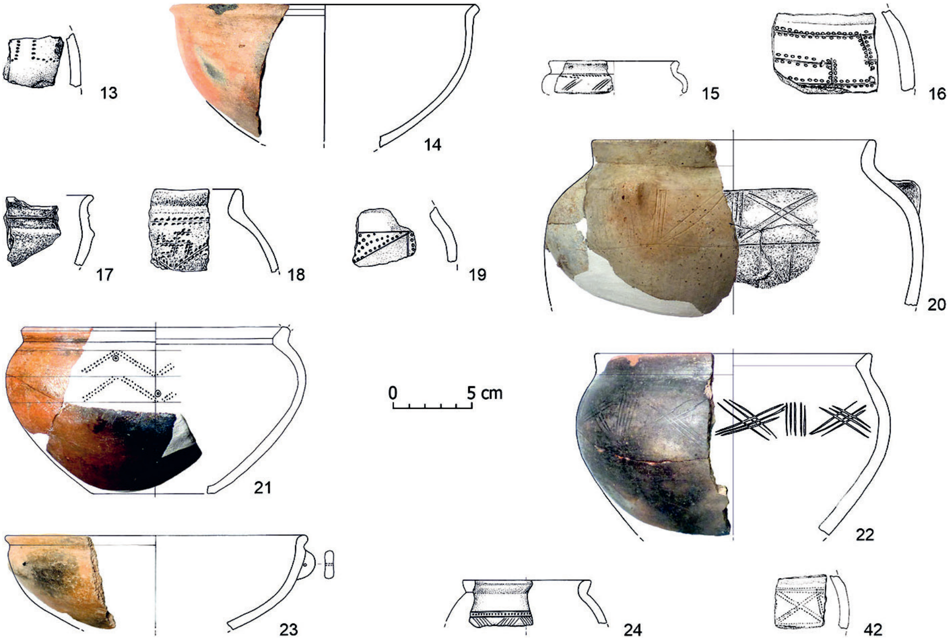

Fig. 4. Fragments of analysed R A tableware vessels. Descriptive numbers match with the numbers in *Tab. 1*.

River region (e.g. *Peschel 1978*, 74–77). A good example illustrating the representation of these beakers is the Schkopau burial ground, where they constitute up to 60% of all ceramic vessels (*Schmidt – Nitzschke 1989*, 23–25). A Plaňany beaker from Mlékojedy was decorated with a thin groove and oval puncture marks (*Fig. 4*: 15). Another shapes represented among the samples (*Fig. 4*: 21, 22) are the so-called unsegmented terrines, i.e. deep bowls with a short, sharply turned-out rim, which is often faceted (*Droberjar 2006b*, 617, Fig. 11). Chronologically speaking, this is a long-lasting shape used from phase R A to the 1st century AD (*Leube 1978*, 24–26; *Droberjar 1999*, 46–48; *Lenz-Bernhard 2002*, 65, Abb. 41–42; *Kretschmer 2019*, 86–87). A typical attribute, present both on tableware and, in a coarser form, also on cookware, is the faceting of rims (*Fig. 4:* 21, 22, 25, 26, 29, 33). Actually, pottery from this horizon of the Großromstedt culture is most easily recognisable on the basis of tableware decoration. These are simple geometric motifs which were often used during later stages and feature characteristic elements (e.g. *Jílek et al. 2015*, 49–51, Figs. 3–4; *Kretschmer 2019*, Abb. 54): fine grooves (*Fig. 4*: 15, 20, 22, 24), a band filled with puncture marks (*Fig. 4*: 24), lines of puncture marks along a fine groove (*Fig. 4*: 16, 18), fields filled with puncture marks (*Fig. 4*: 19), and also loosely executed lines of puncture marks (*Fig. 4*: 13, 21). As early as during this period, the first use of the so-called tracing wheels (cogged-wheel decoration) or stamps (*Fig. 4*: 42) is assumed (*Schmidt – Nitzschke 1989*, 23–25; *Droberjar 2008*, 104–106). The fact that this kind of decoration also occurred in features dated to the later phase (R B1) causes a problem. It cannot be distinguished whether it testifies to an intrusion (since such decoration on fine pottery is, generally speaking, quite rare even in features dating from phase R A) or a longer use of this element in the pottery production.

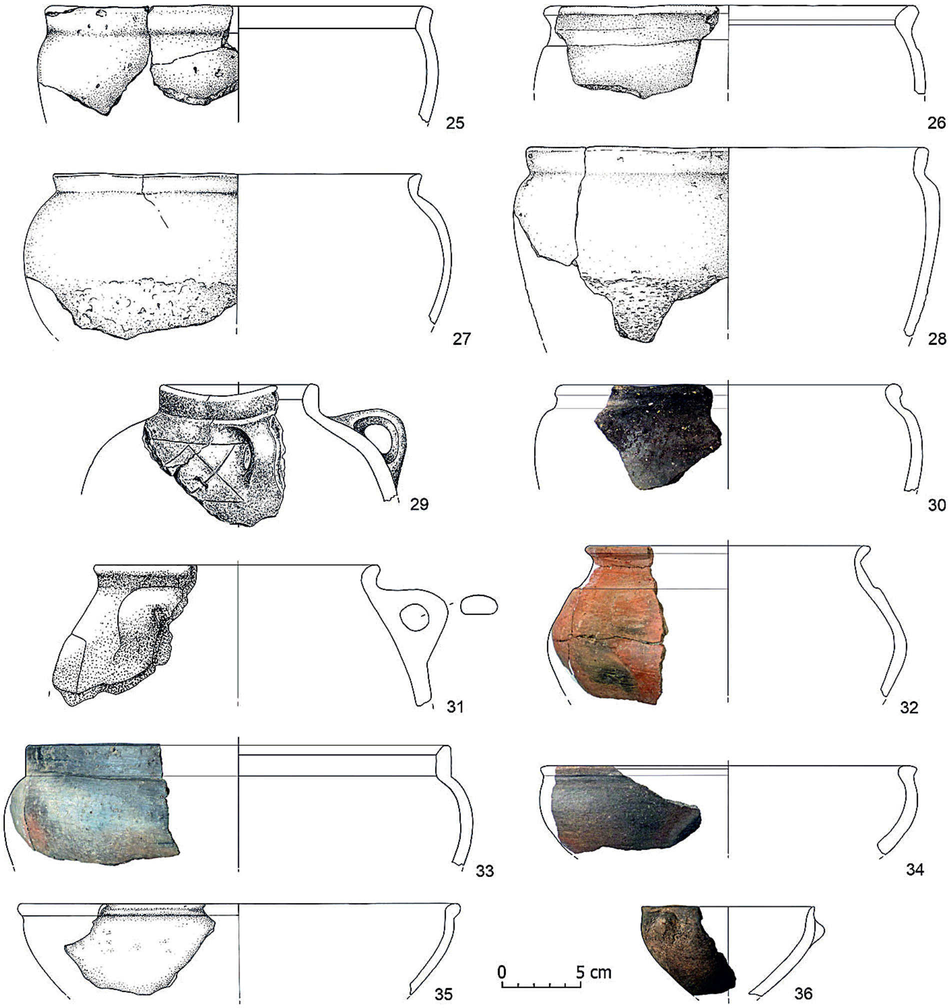

Fig. 5. Fragments of analysed R A cookware vessels. Descriptive numbers match with the numbers in *Tab. 1*.

Cookware

Coarse cookware from phase R A is mostly chronologically insensitive. It is rarely decorated (*Fig. 5*: 29), and the rims are sometimes faceted (*Fig. 5*: 25, 26, 29, 33). Pots and deeper bowls are often roughened in their lower parts (*Fig. 5*: 27, 28). There are also some exceptional shapes which are still reminiscent of the Late La Tène types, despite the fact that they are not wheel-made and their execution no longer corresponds to Late La Tène models (*Fig. 5*: 30). Similar evidence can also be found at other sites with finds of this horizon (e.g. Prague-Podbaba: *Kostka – Jiřík 2009*, Figs. 14–17; Horoměřice: *Šulová 2006*, Figs. 4: 1, 5, 13, 14; 5: 5; 6). The occurrence of coarse shapes with off-set shoulders is also quite remarkable. They may be indicative of development into the R B1 phase, of which this form is typical (*Fig. 5*: 26, 32).

Pottery fragments from phase R B1

Potsherds from vessels originate from features dating to the R B1 phase of the Mlékojedy settlement site (n=23). Petrographic thin sections were made from six samples of tableware, as well as from six samples of coarse cookware. XRD analysis was always carried out on a pair of samples from the first and second group.

Tableware

Fine pottery underwent rapid development during the R B1 phase. Perfectly polished thin-walled vessels were still fired in a reduction atmosphere, but the occurrence of faceted rims was noticeably declining. A characteristic vessel type representing tableware of the R B1 phase is the so-called segmented terrine with a conical (concave) neck (*Fig. 6*: 37, 40, 41, 46) and several derived shapes (vase-shaped terrines or low terrine-shaped bowls, e.g. *Fig. 6*: 45). These also included types 1, 6, 8 and 9 (so-called classic terrines) according to E. Droberjar (*Droberjar 1999*, 40–48, Abb. 12; *Lenz-Bernhard 2002*, 68–69, Abb. 48–52; *Droberjar 2006b*, 616–617, Fig. 10), or possibly certain types of vase-shaped terrines according to the same author (*Droberjar 2006b*, 610–616, Fig. 4–5). It is therefore a kind of ‘leitmotif’ of the later phase, although isolated occurrence of these types during the earlier period is not ruled out either, as demonstrated above. The segmented terrine with a conical neck also occurred in the adjacent burials ground of Tišice, where it was found in a total of four graves (no. 12, 34, 43, and 82), all of which are dated by fibulae to R B1, or more precisely to both of its subphases. Another group of vessels that almost exclusively belong to the settlement’s later phase are bowls with a rounded profile and a distinctly short, rounded, and sometimes even spherical rim (*Lenz-Bernhard 2002*, 53, Abb. 32; *Fig. 6*: 39, 43, 44). The technology of cogged-wheel decoration has come into prominence, although the decorative motifs seem to build on previous development (*Fig. 6*: 37, 40). Combing can also be noted on finer vessels (*Fig. 6*: 39). For the first time, we also encounter embossed horizontal bands and grooves on the shoulders (*Fig. 6*: 37, 43). They generally act as an element separating the vessel’s shoulder from the below-neck area, which is normally the function of an offset. An earlier theory argues that terrines with horizontal ribs might have been influenced by vase-shaped vessels made in the Late La Tène style on the potter’s wheel, as discussed above (*von Müller 1957*, 8; *Salač 2011b*, 57).

Cookware

Coarser cookware seems slightly more varied than during the previous phase. Terrine-shaped vessels with a turned-in neck and shoulders, which are divided either by an offset (*Fig. 7*: 51, 56, 59) or an embossed band (*Fig. 7*: 54) were popular. We also encounter deep bowls, formally corresponding to unsegmented terrines (*Fig. 7*: 50, 58, 60). Unusual shapes include sharply profiled vessels, which are formally reminiscent of the von Uslar I type typical of the Rhine-Weser area (*Schulterknickgefäße*, see *Meyer 2008*, 114–117, 221–225; *Fig. 7*: 49). Such indications of a relationship to the early Rhine-Weser cultural circle are supported by the observations made during the analysis of burial rite at the necropolis in Tišice (*Motyková-Šneidrová 1963*, 420–429). There are also other shapes in the Mlékojedy assemblage that make a slightly alien impression (*Fig. 6*: 45). Faceting of rims is relatively rare and occurs usually only in the form of a single edge (*Fig. 7*: 51, 52, 54).

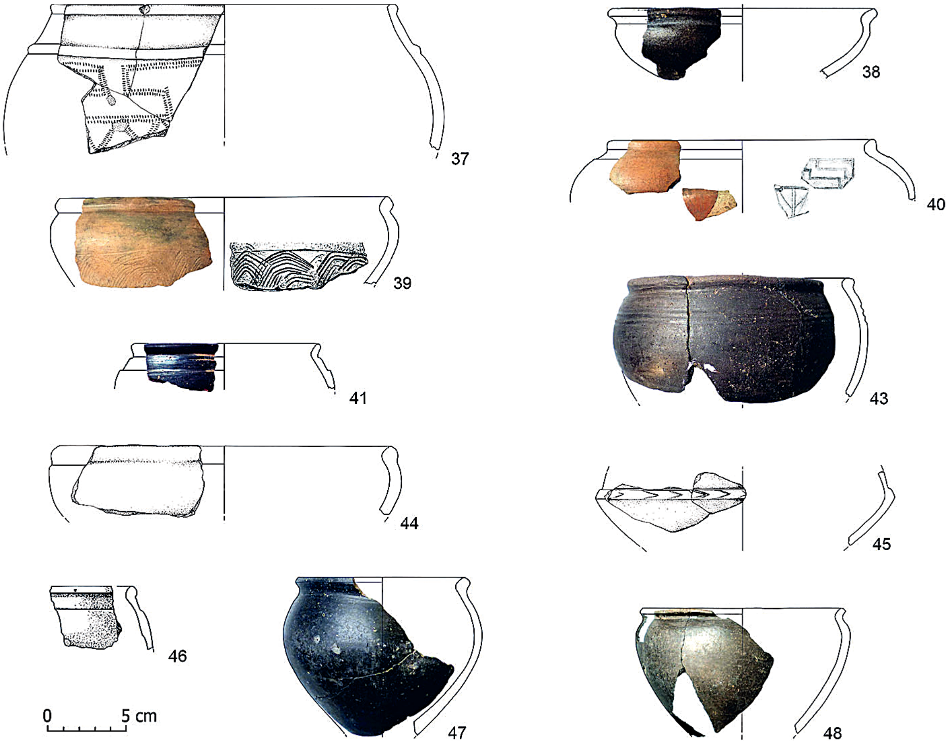

Fig. 6. Fragments of analysed R B1 tableware vessels. Descriptive numbers match with the numbers in *Tab. 1*.

Decoration also occurred on cookware in the form of a single embossed band on the shoulders (*Fig. 7*: 54). When it comes to engraved elements, disorderly spaced incisions were sometimes used (*Fig. 7*: 50). The technique of combing was, of course, also known during the earlier phase, but the termination in high arches did not appear before the phase B1 (*Fig. 7*: 55, 57). The lower parts of cookware vessels were often roughened, either in the form of so-called tangle-like (*Fig. 7*: 56) or fine roughening (*Fig. 7*: 54). It can be generally stated that combed decoration also fulfils the function of surface roughening, so that it can be considered partly as a decorative element, partly as a technological element. The same can probably be said of densely applied incisions (*Fig. 7*: 50).

Methodology

Samples for chemical composition analysis (60 pieces in total; *Tab. 1*) were prepared using a Retsch PM 100 agate planetary ball mill. The chemical composition was determined by a Rigaku NexCG energy-dispersive fluorescence (ED-XRF) spectrometer with a 50 W Pd tube and a silicon drift detector (SSD). The samples were analysed in the form of pressed powder pellets (1 g). Matrix-based error in element quantification was minimised by using a calibration library specialised for soils and ceramics.

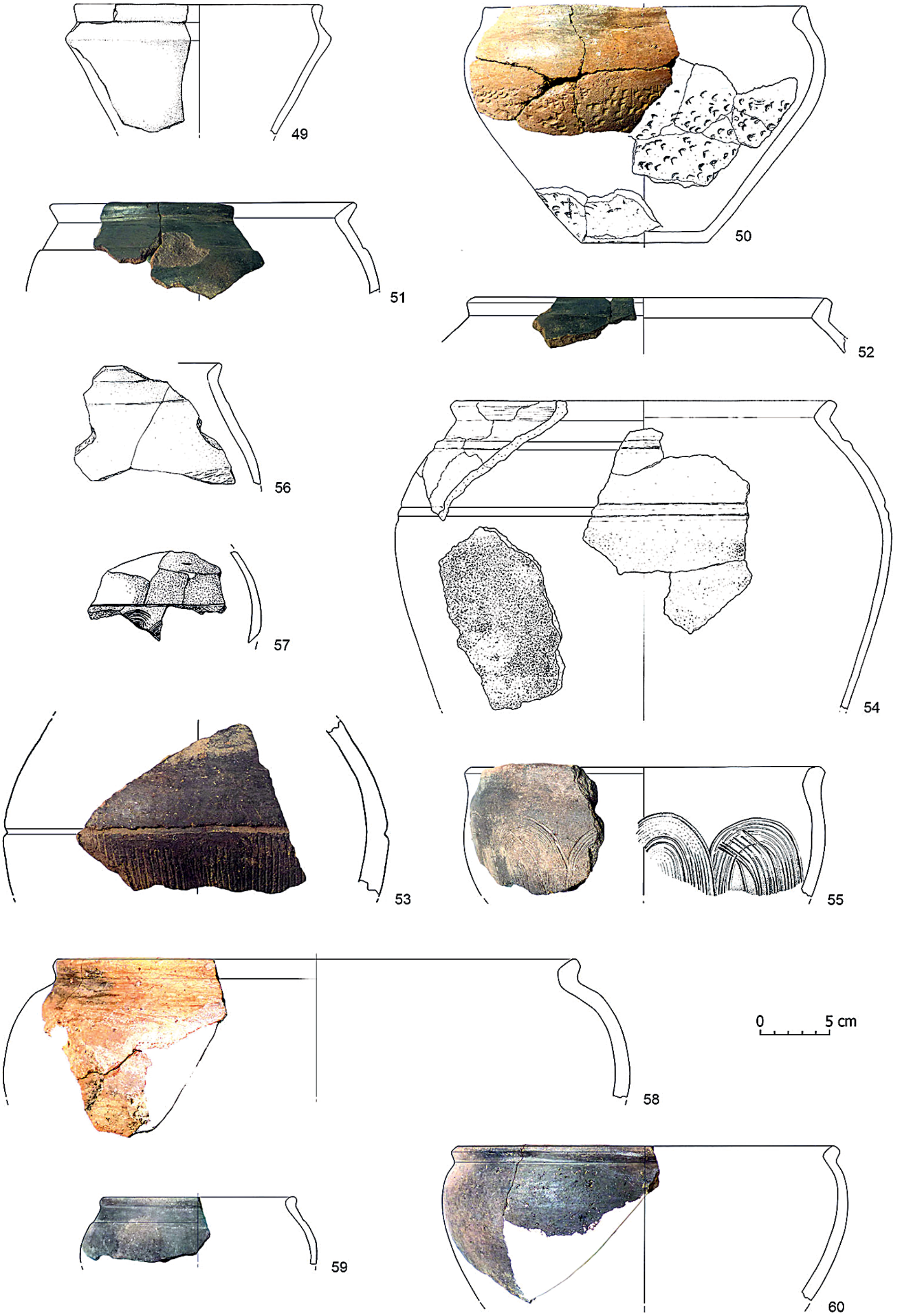

Fig. 7. Fragments of analysed R B1 cookware vessels. Descriptive numbers match with the numbers in *Tab. 1*.

Concentrations of Al, Si, K, Ca, Ti, V, Mn, Fe, Ni, Cu, As, Rb, Sr, Ba, and Pb were chosen for principal component analysis (PCA) using the FactoMiner package in R (*Lê et al. 2008*). The PCA results were further used for hierarchical clustering (*Husson et al. 2010*), which helped selecting samples for petrographic analysis.

Based on statistical evaluation of element concentration, 30 samples were chosen for petrographic analysis (*Tab. 1*). Standard thin sections (30 μm) were analysed by an Olympus BX 51 polarising optical microscope. This analysis focused on structure description (*Quinn 2013*), non-plastic inclusion identification, and quantification. The inclusion abundance was estimated using a semiquantitative scale similar to *Sauer* and *Waksman* (*2005*). Distinguishing between temper and natural inclusions was based on empirical assessment of grain size distribution. Larger-sized grains whose count was beyond natural distribution were classified as temper (similar to *Quinn 2013*, 103). Coarse/fine/void ratio (c/f/v) was estimated according to *Whitbread* (*1995*, 383) with the boundary between coarse and fine set to 10 μm.

Powder X-ray diffraction (XRD) analysis was used as a supplementary method on 10 samples in order to support mineralogical composition revealed by petrography and to determine the firing temperature (*Heimann 2017*). XRD was performed on a Panalytical X'Pert apparatus with a Co-anode and an RMTS detector (X'Celerator) in conventional Bragg-Brentano parafocusing $\Theta - \Theta$ reflection geometry (step: 0.033 °2Θ, time per step: 160 s, measured angular range: 4–100 °2Θ). The obtained data were processed using Bruker Diffrac plus EVA 2 and Topas 4 software. Quantitative phase analysis was performed using the Rietveld method. The degree of crystallinity of the samples was determined comparing the integral intensities of the diffraction lines of the crystalline phases and the diffuse background.

A similar combination of methods has been employed in earlier studies (e.g. *Nösler – Stilborg 2010*, 105–106) and can be considered a good practice to study the technology of prehistoric pottery.

Results

ED-XRF

The bulk chemical composition of all 60 samples (*Supplementary material 1*) made it possible to get an idea of the variability of the set. The former dataset was divided according to the chronology of samples, forming distinctive datasets of the Late La Tène, R A and R B1 phases. Each group was examined by statistical analysis using principal component analysis. Scree plots of PCA analysis of 12 La Tène samples, 25 R A, and 23 R B1 samples (*Supplementary material 2*) have shown that the first four components, for each chronological stage, expressed a sufficient amount of variance (86.1%, 76.7%, and 76% respectively) to be used for hierarchical clustering. The weight of each element for every component can be examined in scatter plots. The hierarchical clustering method has revealed clusters based on the first four components. Samples for petrographic analysis were chosen in order to represent each cluster sufficiently (*Tab. 1*). Based on the results, 30 samples for ceramic petrography were chosen in order to cover the maximum variability of the assemblage.

Ceramic petrography

Despite the sample selection was based on chemical clusters of each separate chronological stage, the classification, which is an outcome of petrographic analysis, was performed on all chosen samples regardless of their dating. Dependent on the character of the matrix and presence of mineral grains and rock fragments (*Supplementary material 3*, technological aspect of each sample was described individually in *Supplementary material 4*), samples were divided into four main petrofabrics groups labelled A–D. In order to avoid over-simplification and data loss, these groups were further divided into several subgroups. Samples that could not be merged based on the selected features were marked as loners and will be described individually. Petrofabrics and loners are described not only in terms of petrography (*Tab. 2*; *Tab. 3*), but also according to their distinct chemical composition (*Tab. 4*).

Petrofabric A (10 samples)

The group comprises pottery made from a very fine lenticular structure matrix with various amount of fine silt. Aplastic distribution is bimodal and the division into subgroups is based on the character of the largest fraction of sand-sized aplastics. Subgroup A1 (3 samples) is characterised by abundant subrounded to rounded equant psamitic quartz grains, as well as frequent polycrystalline quartz of similar fashion (*Fig. 8*: A). Other mineral or rock fragments are not so abundant. Alkali feldspars are common and plagioclases occasional. Biotite, muscovite, and amphiboles are rare. Rock fragments of various genetic types are present in very low volumes. Granitoid rocks, clastic sedimentary rocks, and even carbonatic rocks are rare. Few aplastic grains of anthropogenic nature (slag) were present in one sample (28). Subgroup A2 (3 samples) includes frequent angular and subangular granitoid rock fragments and plagioclases (*Fig. 8*: B). Quartz grains and alkali feldspars are common, as well as polycrystalline quartz. High amount of amphibole and biotite, which both occur commonly, are significant for this subgroup. Muscovite, on the other hand, is rare, similarly to tourmaline which was identified in two samples. Subgroup A3 (4 samples) differs in the presence of frequent grog and common slag (*Fig. 8*: C, D). Among the identified minerals, quartz is the most common. Alkali feldspars and plagioclase are occasional. Micas and accessory minerals, such as amphiboles and tourmalines are rare. Rock fragments are represented by rare fragments of granitoid and clastic sedimentary rocks.

Petrofabric B (5 samples)

The pottery has a matrix of unparallel structure. Non-plastic inclusions are of smaller grain size compared to petrofabric A. Yet, the size distribution of grains is also bimodal. The most abundant mineral is quartz, followed by polycrystalline quartz (*Fig. 8*: E). Alkali feldspars are common and outnumber occasional plagioclases. Micas, amphiboles, and tourmalines are rare. Among rock fragments, granitoid rocks are the most abundant as they occur occasionally. Clastic sedimentary rocks are rare, as well as metamorphic rocks. Some samples include slag (39) or remains of plant tissues (45, 59).

Petrofabric C (6 samples)

It represents variably grained pottery with a distinguishing unimodal distribution of plastics, an increased amount of micas, and the presence of sillimanite. Subgroup C1

Petrography/ Fabric subgroup	A1	A2	A3	B	C1	C2	D
Quartz	++++	++	++	++++	+++	+++	++++
Alkali feldspar	++	++	+	++	+/-	+	++
Plagioclase	+	+++	+	+	+	++	++
Biotite	+/-	++	+/-	+/-	+	+	+
Muscovite	+/-	+/-	+/-	+/-	++	+	++
Amphibole	+/-	++	+/-	+/-	+/-	+	+/-
Garnet	-	-	-	-	-	-	+/-
Sillimanite	-	-	-	-	+/-	+/-	-
Tourmaline	-	+/-	+/-	-	+/-	-	-
Calcite	-	-	-	-	-	-	+
Polycrystalline quartz	+++	++	++	+++	+++	+	++
Granitoid	+/-	+++	+/-	+	+/-	+/-	++++
Clastic sedimentary rock	+/-	-	+/-	+/-	-	-	-
Cabronatic clasts	+/-	-	-	-	-	-	+
Metamorphic rock	-	-	-	+/-	-	+/-	-
Grog	-	-	+++	-	-	-	-
Slag	+/-	-	++	+/-	-	-	++
Organics	-	-	-	+/-	-	-	-
c/f/v ratio	10/85/5–20/70/10	5/90/5–15/80/5	5/94/1–10/85/5	10/89/1–20/75/5	10/85/5	5/94/1–10/85/5	10/89/1–20/70/10

Tab. 2. Petrofabrics – summarisation of petrography.

Petrography/Sample	3	14	18	22	40	43	54
Quartz	+/-	++++	++	+++	+++	+++	++++
Alkali feldspar	+/-	+	+	+/-	+	++	+
Plagioclase	-	++	+	+	++	++	+
Biotite	+/-	++	+	+/-	+	+/-	+/-
Muscovite	+/-	++++	+/-	+/-	+	+/-	+++
Amphibole	+/-	-	-	+/-	+/-	++	-
Calcite	+/-	+	-	-	-	-	-
Tourmaline	-	-	-	-	-	-	+
Polycrystalline quartz	+/-	++	+	+	+++	++	++++
Granitoid	-	+++	+++	-	+/-	++	++
Clastic sedimentary rock	-	-	-	-	++++	++	+/-
Chert	-	-	-	+/-	+/-	-	-
Limestone	-	+	++++	-	-	++++	-
Metamorphic rock	-	-	-	-	-	-	+
Bone	-	-	+++++	-	-	-	-
Grog	-	-	+/-	-	-	-	-
Organics	-	-	+/-	-	-	-	-
Slag	-	-	-	-	-	-	+
Microfossils	-	++	-	-	-	-	-
Mollusc shell	-	-	-	-	-	-	+
c/f/v ratio	0/99/1	10/89/1	10/89/1	5/94/1	15/84/1	30/69/1	20/79/1

Tab. 3. Summarisation of petrography of loners.

Petrofabrics		Si*	Al*	Fe*	K*	Ca*	Ti*	V	Mn	Ni	Cu	As	Rb	Sr	Ba	Pb
A1	mean	32.7	7.0	3.7	1.6	1.3	0.4	100	482	35	34	12	132	214	1035	30
	sd	1.8	0.6	0.1	0.1	0.3	0.1	31	162	4	1	1	7	58	426	2
	min	31.2	6.4	3.6	1.5	1.0	0.3	77	305	30	34	11	125	149	545	28
	max	34.7	7.4	3.8	1.7	1.6	0.4	135	621	38	36	13	139	260	1320	32
A2	mean	31.1	8.2	3.1	2.0	1.4	0.4	122	351	35	37	9	160	230	814	23
	sd	0.4	0.3	0.1	0.3	0.1	0.0	14	19	2	2	1	24	42	113	1
	min	30.8	7.9	3.1	1.8	1.3	0.4	106	332	33	35	9	135	190	686	22
	max	31.5	8.4	3.3	2.4	1.4	0.4	130	369	36	39	10	182	274	900	24
A3	mean	31.1	7.5	3.5	1.9	1.2	0.4	115	376	36	38	11	161	218	904	27
	sd	1.9	0.8	0.3	0.1	0.1	0.0	19	62	1	7	1	13	44	214	3
	min	29.0	6.8	3.2	1.7	1.0	0.4	89	304	35	32	10	152	159	691	24
	max	33.1	8.5	4.0	2.0	1.3	0.5	136	433	37	46	12	180	263	1130	30
B	mean	40.2	8.9	2.3	1.6	1.0	0.3	82	262	32	35	10	134	180	738	24
	sd	8.3	3.2	0.4	0.2	0.1	0.0	19	47	2	6	1	7	22	102	2
	min	33.6	6.5	1.9	1.3	0.9	0.3	54	221	29	29	9	126	161	626	22
	max	53.9	14.5	3.0	1.8	1.2	0.4	102	322	35	46	11	140	214	867	27
C1	mean	32.2	7.4	3.5	1.8	1.1	0.5	131	432	36	34	11	132	198	1109	26
	sd	2.8	1.0	1.1	0.4	0.1	0.1	20	169	4	8	1	2	8	253	3
	min	30.3	6.3	2.3	1.4	1.0	0.4	110	247	31	27	9	130	191	846	23
	max	35.4	8.2	4.4	2.1	1.1	0.5	149	579	39	42	12	133	207	1350	29
C2	mean	30.6	8.1	4.0	1.9	1.1	0.5	158	789	40	40	12	131	175	1023	29
	sd	1.8	0.5	1.1	0.4	0.1	0.1	23	193	10	11	0	13	40	168	1
	min	29.0	7.7	3.1	1.5	1.0	0.5	140	651	31	33	12	118	142	883	28
	max	32.5	8.6	5.2	2.1	1.2	0.6	184	1010	50	53	12	144	219	1210	30
D	mean	30.4	8.9	4.0	2.3	1.1	0.5	152	498	33	26	10	234	166	918	25
	sd	0.5	0.6	0.0	0.2	0.2	0.1	14	186	3	2	1	60	18	399	2
	min	30.0	8.5	4.0	2.2	1.0	0.5	142	366	30	25	10	191	153	636	24
	max	30.7	9.3	4.0	2.5	1.2	0.6	162	629	35	28	11	276	178	1200	27
Loners	mean	29.5	7.0	2.8	2.1	3.4	0.3	73	372	35	29	9	151	271	739	22
	sd	4.0	1.3	0.5	0.4	2.4	0.0	18	71	9	3	1	51	99	259	2
	min	24.5	5.2	2.1	1.6	0.8	0.3	50	276	25	23	7	98	107	490	20
	max	35.2	9.1	3.6	2.5	6.9	0.4	105	505	53	33	10	238	377	1250	24

Tab. 4. Summarisation of general chemical composition of each petrofabric and loners (elements marked with * in wt %, other elements in ppm).

(3 samples) matrix is heterogeneous in the case of all three samples. Connecting attributes represent common muscovite and rarely occurring alkali feldspars (*Fig. 8*: F). Quartz and polycrystalline grains are frequent, while plagioclases and biotite are occasional and amphibole rare. The identification of sillimanite in sample 5 is significant. No metamorphic rock fragments were noticed. Granitoid rocks are rare. Subgroup C2 (3 samples) differs from the previous one by only occasional presence of polycrystalline quartz, lower abundance of muscovite, and higher volume of feldspars, both alkali and plagioclases (*Fig. 8*: G). Sillimanite is present in sample 21. Besides granitoid rocks, several rock fragments of metamorphic origin were identified.

Petrofabric D (2 samples)

This group includes pottery with a bimodal distribution of aplastics including abundant sand-sized grains. The distinguishing attributes are abundant quartz and granitoid rock fragments, common alkali feldspars and plagioclase, occasional biotite, and common muscovite and occasional calcite (*Fig. 8*: H). Accessory minerals are represented with rare amphibole and garnet. The abundance of slag in the matrix is also important for petrofabric D.

Loners (7 samples)

These samples were different from the main petrofabrics as well as one from another. Therefore, these seven samples were labelled loners and will be described individually.

Sample 3 was made of very fine calcareous raw material (loam or loess) which was very well sorted (*Fig. 9*: A). All aplastics were below fine sand fraction and the largest grains were scarce, which limited petrographic identification. Apart from quartz, alkali feldspar, calcite, amphibole, and micas were distinguished; all were present in very low amounts.

Sample 14 is distinctive, due to the presence of microfossils in the raw material and abundant muscovite (*Fig. 9*: B). The content of biotite is also increased compared to the rest of the assemblage. Sand-sized grains of temper are composed of abundant quartz and muscovite, which is present as stacked flakes. Frequent granitoids, common plagioclases, occasional alkali feldspars, calcite, and limestone were also observed.

Sample 18 is very special within the studied assemblage for it includes a plenty of bone fragments (*Fig. 9*: C). Besides bones, the aplastics are composed of abundant limestone fragments and frequent granitoid rocks (*Fig. 9*: D). Quartz is common, while feldspars and biotite are occasional, and muscovite is rare. The sample also includes rare plant tissue remains and grog.

Sample 22 stands out among the loners with the unimodality of the aplastics consisting mostly of silt and fine sand. This characteristic makes it comparable to petrofabric C, however, its petrography is very simple and straightforward when confronted with the named group (*Fig. 9*: E). Most aplastic particles are quartz, which is frequent. The rest belong to occasional plagioclase and rare alkali feldspar, micas, amphiboles, and chert.

For sample 40, the high amount of clastic sedimentary rock fragments, namely shale, is typical (*Fig. 9*: F). Among detected minerals, quartz is frequent and dominates the spectrum. Plagioclases are more abundant than alkali feldspars. Micas are occasional. Accessory minerals are represented by rare amphiboles. Granitoid rock fragments are also rare.

Significant for sample 43 is the abundance of limestone fragments of psamitic and aleuritic fraction, as well as the common occurrence of sandstone fragments (*Fig. 9*: G). The aplastics are further composed of frequent quartz, common alkali feldspars, plagioclase, and amphibole. Micas are rare. Granitoid rock fragments occur commonly.

Sample 54 is made of fine-grained homogeneous material. An important feature that distinguishes this loner is the presence of mollusc shales and slag (*Fig. 9*: H). The sample includes abundant sand-sized grains of quartz and polycrystalline quartz. The second most abundant mineral is muscovite, which was classified as occurring frequently; biotite, on the contrary, is rare. Feldspars of both types are occasional, as well as tourmaline. Among the distinguishable rock types, granitoid is common, metamorphic rock occasional, and sedimentary rock rare.

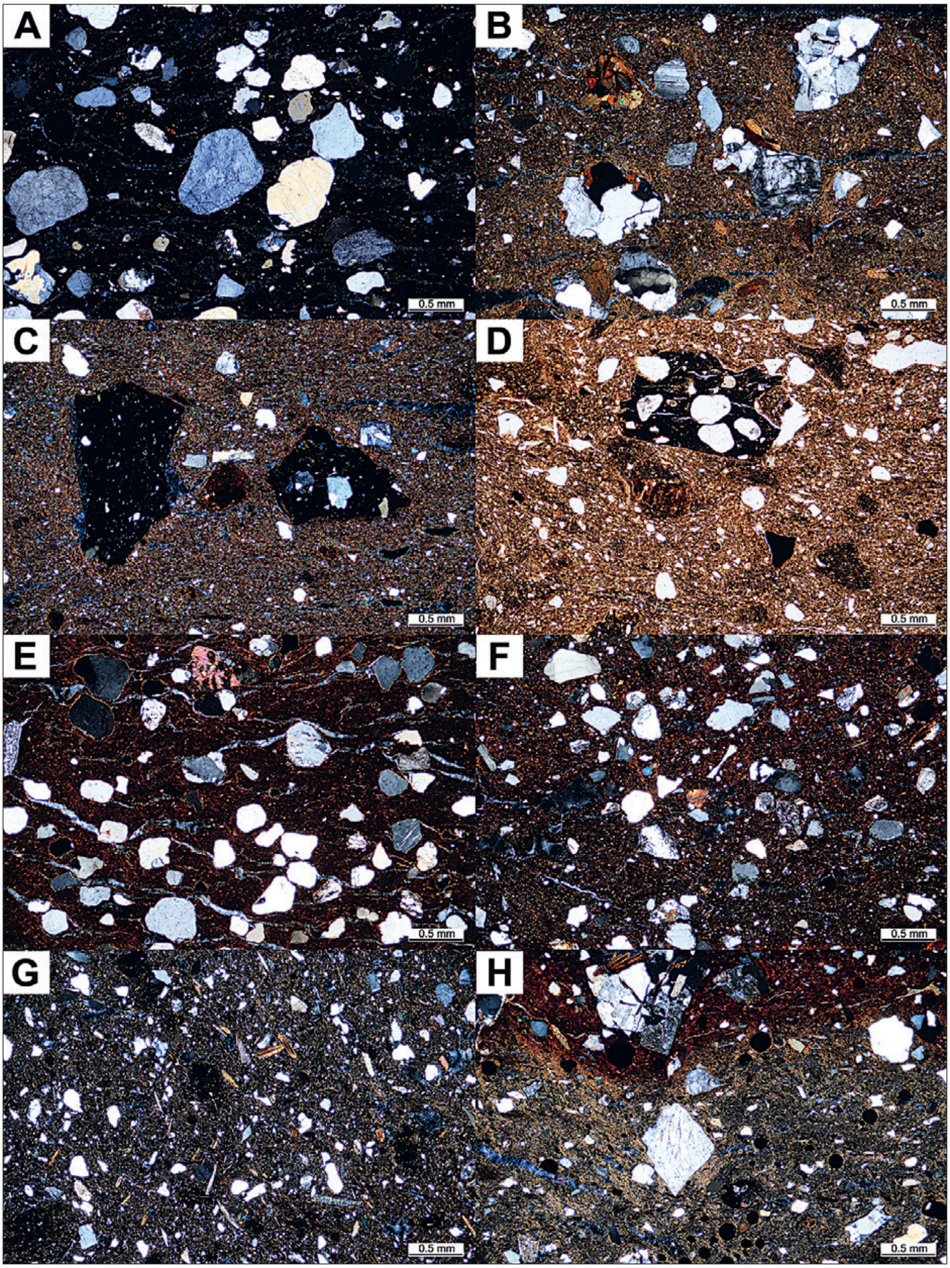

Fig. 8. Photomicrographs of samples representing petrofabrics: A – petrofabric A1: fine grained matrix tempered with rounded quartz sand (sample 55, XPL); B – petrofabric A2: dominant temper subangular fragments of granitoid rocks, high content of feldspars and amphiboles (sample 20, XPL); C – petrofabric A3: grog tempered (sample 33, XPL); D – petrofabric A3: grog tempered matrix containing particles of slag (sample 35, PPL); E – petrofabric B: quartz sand tempered, occasionally occurring granitoid rocks (sample 50, XPL); F – petrofabric C1: unimodal distributed aplastics of igneous, magmatic and sedimentary origin (sample 5, XPL); G – petrofabric C2: micaceous non tempered pottery (sample 2); H – petrofabric D: granitoid rock fragments used as temper, matrix rich in round particles – blacksmith slag (sample 60, XPL).

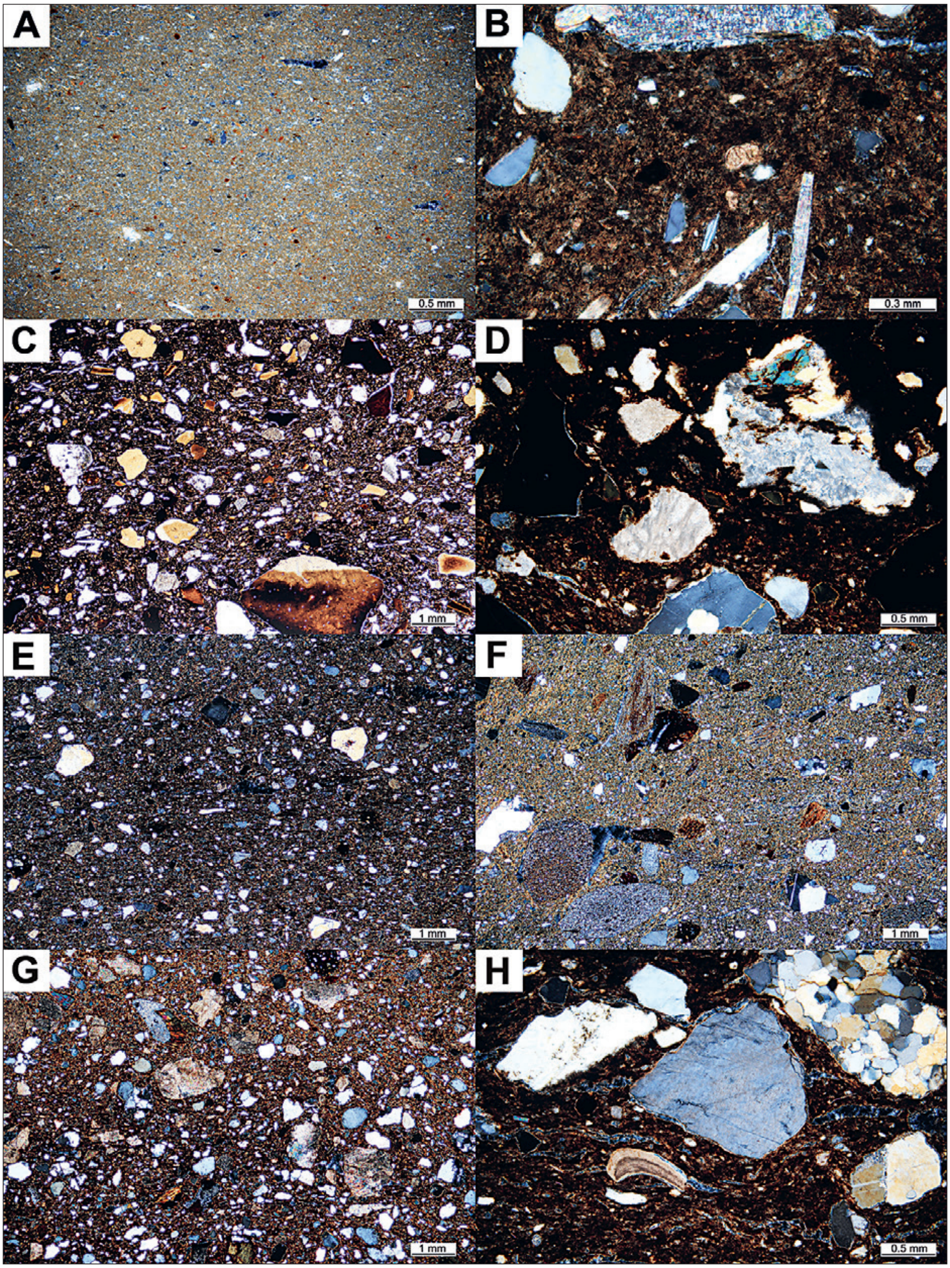

Fig. 9. Photomicrographs of loners: A – non-tempered calcareous matrix (sample 3, XPL); B – muscovite rich temper (sample 14, XPL); C – abundant bone fragments used as temper (sample 18, PPL); D – detail on a granitoid rock and limestone fragment (sample 18, XPL); E – fine-grained aleuritic matrix (sample 22, XPL); F – temper consisting of subrounded fine-grained clastic sedimentary rock fragments (sample 40, XPL); G – limestone rich temper (sample 43, XPL) ; H – detail on a mollusc shell (sample 54, XPL).

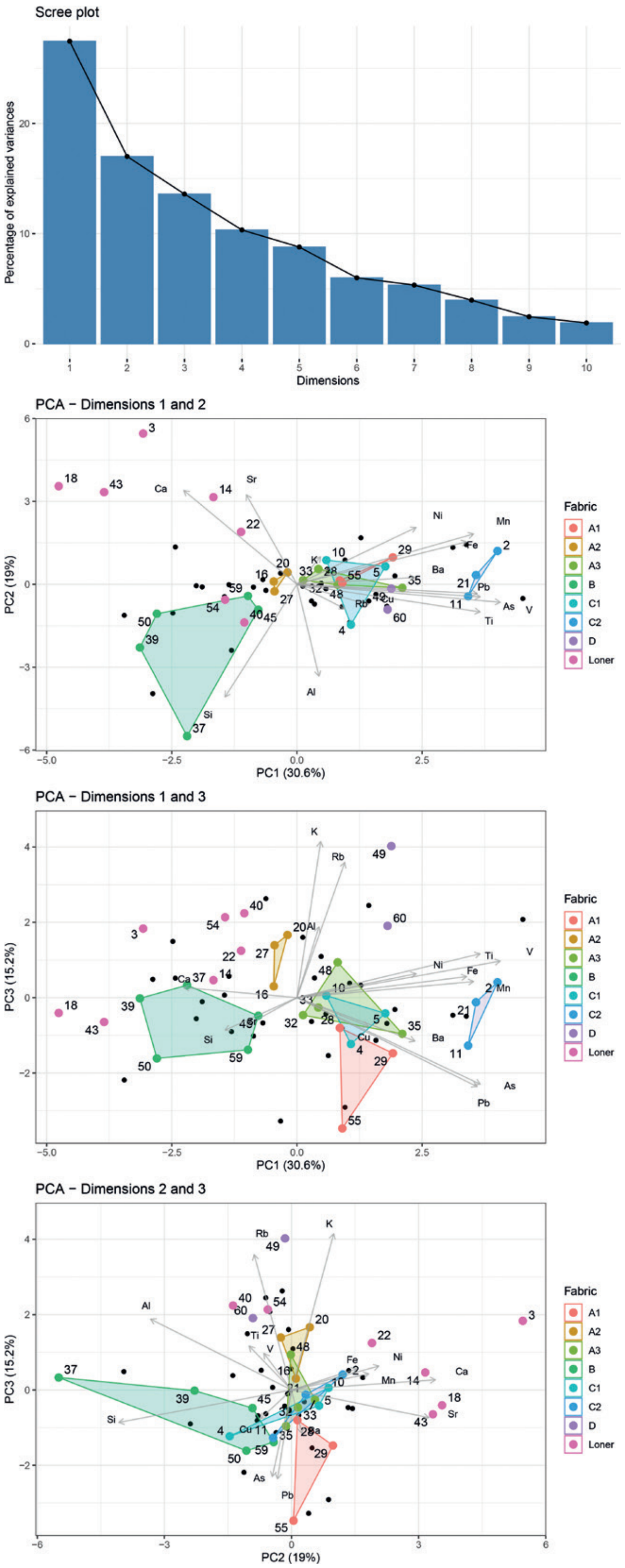

Fig. 10. Principal component analysis showing relations among petrofabrics based on their chemical composition.

Bulk chemical composition of petrofabrics

The principal component analysis was performed again on a whole dataset (*Fig. 10*). The same chemical elements were chosen as variables for the statistical analysis as in ED-XRF (Al, Si, K, Ca, Ti, V, Mn, Fe, Ni, Cu, As, Rb, Sr, Ba, Pb). The first component explains 31.2% of variance, which is the lowest value compared to the previous PCA analysis (see above in ED-XRF section). The reason may be that when comparing the more heterogeneous part of the assemblage (across all three chronological stages), the variance is caused by more factors unlike when comparing a limited dataset (e.g. assuming the pottery was made with one technological approach in the given chronological stage, the variance would be caused by provenance differences only, while the technology could have varied according to dating).

The first component is strongly defined by the presence of Ca and Sr with the lowest score and Mn, Fe, Pb, As, and Ba with the highest score. The first component allows to differentiate loners (*Fig. 10*), which have the highest concentrations of Ca and Sr, and also the petrofabric C2 with the highest values of Fe, Pb, As, Mn, and Ba. The second component shows the negative correlation of Si and Al against K and Ni. The scatter plot of the first two components reveals a distinct divergence of the petrofabric B having the highest concentration of Si. Petrofabrics A1, A2, A3, C1, and D seem to be close, and some of them are even overlapping in terms of their chemical composition. Distinction of A2 and D can be explored using the third component which shows high scores for increased concentrations of K, Rb, and Al, of which petrofabric D has the highest scores. The summary of bulk chemical composition underlines the result of PCA (*Tab. 4*).

XRD

Quartz was a predominant mineral in all analysed samples, followed by feldspars and mica minerals (*Tab. 5*). These constituents are common in the examined clays. Samples 3, 18, and 48 displayed relatively elevated concentrations of calcite, ranging from approximately 4 to 14%. Iron oxides, specifically magnetite and hematite, were observed as minor phases in all samples. Sample 20 was characterised by a high amphibole content (4%). Minor amounts of amphibole were detected in the remaining samples except for sample 3, where it was absent. Anatase, a common minor phase in clays, was identified in samples 43 and 60. Samples 18 and 43 contained smectite, while sample 18 also exhibited the presence of apatite (15.7%; *Fig. 11*).

The only unequivocally newly-formed crystalline phases, or ceramic phases, were gehlenite and pyroxene in sample 3, as well as a phase with a composition approximating $Al_{1.2}(Mg,Fe)_{0.6}Si_{1.8}O_6$ in samples 2 and 28 (quantified using ICSD pattern no. 31105). The content of X-ray amorphous phases ranged between approximately 7 and 31 mass percent. Gypsum in sample 21 and anhydrite in sample 43 were of secondary origin. A partially secondary origin cannot be ruled out for calcite, particularly in samples with lower concentrations (samples 28 and 60).

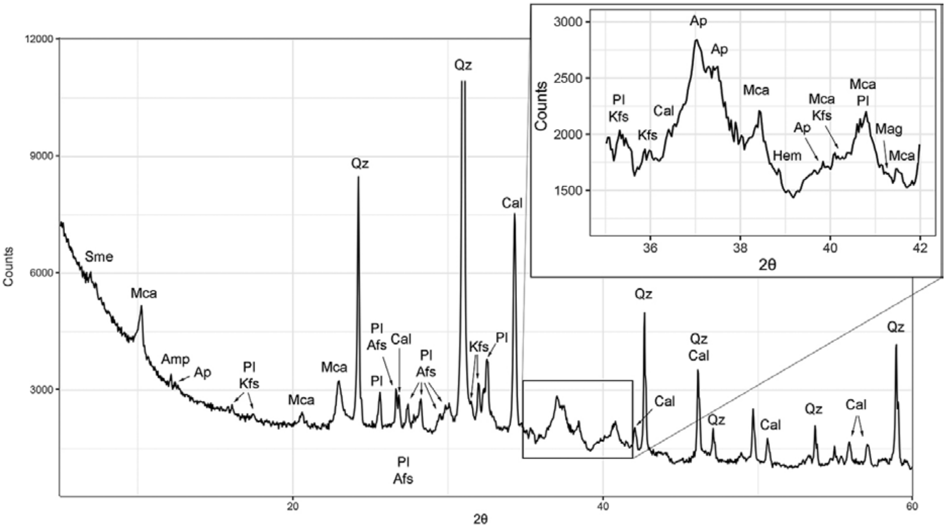

Fig. 11. Diffractogram of bone tempered pottery (sample 18). Sme – smectite, Mca – mica structure minerals, Amp – amphibole, Ap – apatite, Pl – plagioclase, Kfs – alkali feldspars, Qz – quartz, Cal – calcite, Hem – hematite, Mag – magnetite.

Discussion

The petrographic analysis of aplastics enabled to divide pottery into four main groups (petrofabrics). Some of them were further subdivided into subgroups. However, these are predominantly subgroups of petrofabrics A (3 subgroups) and C (2 subgroups). Positive results achieved by this method suggest that this division correlates with the cultural-chronological determination of the samples according to their archaeological contexts (*Tab. 6*). Petrofabrics also correlate with a formal division into tableware and cookware. In addition, the so-called isolated specimens (loners) yielded interesting results. In the following paragraphs, we discuss and interpret our results from a cultural-historical viewpoint.

Technological change between LT D and R A

Wheel-made pottery fragments of the Late La Tène tradition, numbering six samples, mainly belong to group C and its subgroups C1 and C2, where material is free of added temper. This correlates with the technology used for the production of pottery on a rapidly rotating potter's wheel since the rougher temper would significantly abrade the hands and damage the surface of the produced vessel. However, the thin sections of these samples did not show significant unified grain orientation, typical for wheel-thrown pottery (see *Thér – Toms 2021*). The fine-grained character of pottery was a limiting factor however not even the elongated grains of quartz evinced the orientation specific for tangential sections. It is therefore possible that this pottery could have been formed by hand and just finished on the potter's wheel. Only one Late La Tène sample (no. 3) stands out and can be designated as a 'loner'. It also shows signs typical for ceramics made on a fast potter's wheel. Clay without additional temper facilitated the formation of fine shapes on the potter's

Sample	2	3	5	18	20	21	28	43	59	60
Dating	**LT**	**Lt**	**LT**	**RA**	**RA**	**RA**	**RA**	**RB1**	**RB1**	**RB1**
Quartz	53.2	31.3	57.8	38.3	48.2	56.9	67.3	61.5	71.7	61.1
K – feldspar	10.5	7.2	12.3	7.5	15.0	11.7	9.5	4.9	7.3	15.2
Plagioclase + albite	13.2	9.9	10.6	8.0	18.6	12.5	6.7	2.9	6.1	4.7
Amphibole	0.8	0.0	0.7	0.8	4.0	1.4	0.4	1.0	0.5	0.4
Apatite	0.0	0.0	0.0	15.7	0.0	0.0	0.0	0.0	0.0	0.0
Anatase	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	1.3
Magnetite	1.4	2.3	2.2	0.8	1.4	2.2	1.2	1.1	0.6	3.0
Hematite	0.0	0.8	1.0	0.2	0.2	0.3	0.3	0.0	0.1	0.5
Gehlenite	0.0	13.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pyroxene with stucture close to diopside	0.0	20.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Calcite	0.0	3.9	0.0	11.1	0.0	0.0	0.8	13.8	0.0	0.4
Gypsum	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0
Anhydrite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
$Al_{1.2}(Mg,Fe)_{0.6}Si_{1.8}O_6$	7.1	0.0	1.8	0.0	0.0	0.0	7.0	0.0	0.0	0.0
Mica minerals (incl. illite)	13.8	10.8	13.7	15.5	12.8	14.3	6.9	9.9	13.6	13.4
Smectite	0.0	0.0	0.0	2.1	0.0	0.0	0.0	4.3	0.0	0.0
Total	100.0	100.0	100.1	100.0	100.2	100.0	100.1	100.1	99.9	100.0
Degree of crystallinity	77.6	76.6	77.5	74.9	73.3	62.8	76.0	92.3	81.0	69.5
Firing temperature [°C]	<650	<700	>850	<750	<700	<650	<800	<750	<650	<700

Tab. 5. Quantification of phase composition calculated by the Rietveld method.

Petrofabric	Subgroup/Samples	Datation			Total
		Late LT	**R A**	**R B1**	
A	A1		2	1	3
	A2		3		3
	A3		3	1	4
	Total		8	2	**10**
B				5	**5**
C	C1	3			3
	C2	2	1		3
	Total	5	1		**6**
D				2	**2**
Loners	Sample 3	1			1
	Sample 14		1		1
	Sample 18		1		1
	Sample 22		1		1
	Sample 40			1	1
	Sample 43			1	1
	Sample 54			1	1
	Total	1	3	3	**7**
Total		**6**	**12**	**12**	**30**

Tab. 6. Petrofabrics pivot table showing sample count belonging to each petrofabric.

wheel, as well as the final treatment of their surfaces (polishing). On the other hand, it also reduced the material's resistance to thermal shocks during firing. Firing of Late La Tène fine tableware is usually assumed to have been carried out in two-chamber kilns with a grate (*Thér et al. 2017*). However, statistically evaluated experimental firings in different types of firing devices (from open bonfires to clamp kilns to two-chamber kilns) show that similar technological properties of pottery can be achieved in open firings provided that craftsmen are skilled enough (*Thér 2014*). Regarding the firing temperatures, XRD findings demonstrated that the La Tène samples were exposed to higher temperatures than later pottery; it surpassed 850 °C. Sample 3, in particular, was subjected to the highest temperature, as indicated by the presence of newly-formed gehlenite and pyroxene.

A significant change is represented by the next chronological phase R A. Eight of the 12 samples can be assigned to the petrographic group A, which was tempered. The nature of the matrix is the unifying element of petrofabric A, which had to be divided into three subgroups. Subgroup A1 is represented by two samples, subgroups A2 and A3 are represented by three samples each. Subgroups A1 and A3 formally correspond to coarser cookware, but they both represent quite different manufacturing processes. While A1 was tempered with quartz sand, A3 was tempered with grog. Subgroup A2 contains two samples of fine tableware and a single sample of coarser pottery. The use of subangular granitoid rock as a temper is characteristic. Generally speaking, petrofabric A mainly corresponds to coarser cookware. One sample (no. 21) of finer tableware from chronological level R A belongs to subgroup C2, i.e. non-tempered material typical for samples of the Late La Tène period, and sample no. 22 is also very close, possibly representing a certain continuity between LT and R A phase in pottery technology. It is interesting that both samples come from the same archaeological feature.

An exception is the sample no. 18, which belongs to fine tableware. It has a black polished surface decorated with a swastika motif. This vessel was tempered with crushed bones (confirmed by XRD, the sample contains 15.7% apatite). Although the use of bone temper has been employed since the Neolithic, it has never been a widespread practice (*Mariotti Lippi – Pallecchi 2017*, 570–571; *Kowalski et al. 2020*). During the Iron Age in Northern Europe (500–300 BC and 180–400 AD), fine pottery with an admixture of bones was used. Despite the fact that bone temper may have had certain technological advantages, such as good incorporation of crushed bones into the clay or the vessel's increased resistance to thermal shocks, it is assumed that this tempering method had a more symbolic and perhaps even associative meaning (*Stilborg 2001*, 400–402). In some regions, it could have been a local tradition (e.g. *Taayke 2006*, 203–204).

The pottery of phase R A appears to be characterised by a variety of tempering. Similarly to the use of crushed bones, tempering with grinded pieces of older pottery (grog) is usually given a more symbolic significance, although it is actually very suitable for temper (*Holmquist 2021*). Tempering with grog has rarely been observed at other, similarly dated sites in Europe (e.g. *Daszkiewicz et al. 2017*; *Bajnok et al. 2022*). In this context, it is interesting to mention an archaeoceramological study summarising results from several sites in Central Germany dating from the pre-Roman Iron Age to the Roman Period (ca. 5th century BC to 3rd century AD) whose cultural background is comparable with Mlékojedy. The authors state that pieces of older pottery were used as temper mainly in the centuries before the beginning of the Christian era, whereas in the Roman Period itself, quartz grains and to a lesser extent also other types of rocks or organic particles were used

(*Daszkiewicz – Meyer 2008*, 317, Abb. 10). It still remains a question for further research, whether this finding, repeatedly observed especially on pottery of the earlier R A phase from Mlékojedy, is a generalisable phenomenon.[2]

Although the differences between the ceramics of the Late La Tène tradition and the R A phase of the Roman period are quite large, there are also certain connections. Interpreting this difference as proof of the migration of a new population is therefore not entirely without problems. Now let us put aside the option that all potsherds of Late La Tène character are mere intrusions having no relationship with settlement features from the Roman period – on the basis of constantly recurring cases not only from Bohemia but also from Central Germany, it can be judged that their presence is not a coincidence. We are left with two hypotheses then. First, they might got into the features of the Großromstedt culture (traditionally considered to be ‘Germanic’) because the pottery had some function in the living culture, for example it was traded with a still-surviving workshop in the vicinity, which produced pottery according to the old tradition, or as a kind of family heritage. The second hypothesis assumes the existence of a pottery workshop operating directly on the investigated site. After the initial production of pottery according to the old recipes, this workshop could very soon reorient itself to a new (possibly simpler) production technology. As a result of this shift, some procedures can still be observed in typologically younger vessels. However, the idea that specialised potters producing wheel-made pottery would switch to a completely different technological chain is unlikely. Such a chain is tied to a particular organisational form of craft that lost its grounding during the changes in the socio-economic structure at the beginning of the Roman Period. Therefore, it is far more likely that the technological phenomenon has a certain inertia and disappears with the last potters born into it. Moreover, discontinuous technological changes are usually linked to social changes (cf. *Thér – Mangel 2023*, 3–4). This change could take some time (one generation?), which offers a certain interpretation space enabling to explain the surviving fragments of the Late La Tène pottery on the settlement in Mlékojedy.

Technological change between phases R A and R B1

The analysed pottery of phase R B1 is mainly characterised by petrofabric B. Petrofabric A1 and B are very similar in terms of petrography; both are made of fine-grained loam tempered with sandy quartz. The difference is in the microstructure, which for A1 is slightly lenticular and for B mostly unparallel. A more important difference was observed in the chemical composition, with Si, Al, and Fe being the most dividing factors. Petrofabric B has significantly higher contents of Si (~ 8 percentage points) and Al (~2 pp), while Fe is lower (~1.5 pp). It is important to bear in mind that this is a comparison of bulk chemical composition. It does not necessarily mean that the pottery clay originated

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[2] *Holmquist* (*2021*, 10) commented on the significance of grog tempering in the Corded Ware culture, expressing the opinion that if vessels, which people took with them when migrating to new settlements, broke, they were symbolically used as a tempering agent to make new vessels. This is an interesting analogy for mobile communities, such as those who were the bearers of the Großromstedt culture during the LT D2/R A period. An analogous interpretation can also be found among indigenous populations of North America, who used grog tempering along with new technology of shell tempering during a time of cultural change after the advent of the Mississippian culture (*Weinstein – Dumas 2008*).

from a different source. The element concentrations could have been shifted by tempering meaning that petrofabric B was more tempered than petrofabric A, but it was not conclusively demonstrated by petrographic analysis. The reason for the discrepancy is probably a combination of both – differences in clays and tempering. The raw material for B included more alleuritic and pellitic quartz and it was slightly more tempered. Nonetheless, this similarity proves the continuation of pottery making tradition on the site between phases R A and R B1.

Petrofabric D (samples 49 and 60) differs from the other samples by the use of iron slag as a tempering agent. It is not clear to what extent this was the potter's intention and to what extent a result of 'contamination' of the raw material, for example due to the proximity of metallurgical facilities usually located at the settlement's edge. However, such cases are also known from northern Europe, and thus probably no coincidences (*Stilborg 2001*, 399–400). It should be mentioned in this context that sample 49 comes from a vessel close in shape to Uslar I type pottery from the Rhine-Weser cultural zone. The rest of the assemblage consists of three samples designated as 'loners'. Each was tempered with a specific material: sample 40 with shale fragments, sample 43 with pieces of limestone, and sample 54 with quartz, granitoids (including amphiboles) and mollusc shells. They do not stand out from the rest of the assemblage regarding their shape.

In terms of firing technology, which can be discussed based on mineral composition, there is no discernible difference between the R A and R B1 phases. All analysed samples suggest a lower firing temperature (less than 800 °C). For the majority of the samples, it is not possible to determine the firing temperature due to the absence of indicators, which are phases formed during firing at temperatures exceeding 850 °C. A certain indicator is the amount of detected X-ray amorphous phase, however in the case of the examined samples, this is not a result of melting, but rather the dehydroxylation of clay minerals. Two samples with distinct dating (sample 18 from R A and sample 43 from R B1) contain minerals that demonstrate very low temperatures, specifically smectite, and a relatively high content of calcite, which otherwise decompose at higher temperatures.

Provenance

The provenance of pottery will be discussed based on the ceramic petrography. It is necessary to bear in mind that each individual component of pottery – clay and temper – may be of separate origin. It is also necessary to take into account that imports may not be distinguishable if pottery was transported over short distances due to the similar petrographic and chemical composition of clays and tempers (*Daszkiewicz et al. 2019*, 38). All samples of petrofabric A have a very similar matrix, it is likely that the raw material came from a single source. The matrix was described as a very fine-grained material, most probably loam, which could have originated from alluvial sediment. The site is located in the alluvium of the Elbe River, therefore, it is feasible to place its origin in its close surroundings (see the 7 km radius around the site in *Fig. 2*) according to the hypothesis on the resource area by *Arnold* (*2005*, 17). Looking at the temper, which differs for each subgroup, it is necessary to interpret their provenance separately. Subgroup A1 was tempered with quartz sand. The site was built on a river terrace composed dominantly of quartz sand and gravel. It is therefore very likely that the sand originates either from the area of the settlement or from its close surroundings.

Subgroup A2 temper is dominantly sand of granitoid rocks. Even though the terrace is formed from this rock type as well, it is minor and mixed with other rock types, such as metamorphites. However, the igneous Neratovice complex forms the bedrock of the terrace on which the site was built. It used to outcrop in the riverbed, and the outcrops can still be found on the left riverbank in modern days. When comparing feldspar type volume in the granitoid temper, plagioclases are more abundant than alkali feldspars, which correlates well with local granodiorites. They could have been either collected in the form of sand, which was naturally formed by the erosion force of the river or picked up in bigger form and crushed before being added to pottery clay. The shape of grains (mostly equant, subangular to angular) testifies the formation by natural processes and thus supports the former interpretation.

Subgroup A3 shares similar mineralogy with A1, nevertheless the amount of quartz is significantly lower. Apart from quartz, only rare rock grains, namely granitoids and clastic sedimentary rocks, were identified, both of which commonly occur in the area. Since the pottery was tempered with grog, there is not a sufficient base for provenance discussion based on petrography only. However, the morphological, as well as decorative types, are common on the site and since the matrix is similar to the other subgroups, it can be concluded that A3 is also of local origin.

Petrography of petrofabric B is very similar to subgroup A1. The discussion on its provenance can, therefore, reach the same conclusion. It is very likely that it was made from local raw materials.

The matrix of both subgroups of petrofabric C differs from A and B. It is more silty and more abundant in micas. Still, the clay body resembles loam and could have originated from alluvium as well. The presence of sillimanite refers to metamorphic rocks which are not natural to the area. Nonetheless, such rocks are present, even though not abundant, among the alluvial sand of the Elbe River. The raw material was most probably taken from a different source than for A and B and this source was also likely located close to the site.

Petrography of group D is comparable to A2 with an even higher abundance of granitoid rocks and admixture of occasional calcite and carbonate clasts. The provenance discussion needs to be extended by finding the origin of carbonates. Calcareous claystone and marlite form a bedrock on both banks of the Elbe River. Biodetritic limestone is located on the left bank close to the site. It is very likely that these eroded rocks form part of the sand and alluvium around the site. Even though the petrofabric D is very probably of local origin, the raw materials could have been taken from a slightly different source than the petrofabrics described above.

The provenance of loners will be discussed individually. Sample 3 was made of very fine calcareous clay and does not include particles coarse enough, which could help interpret its provenance. The calcareous clay could have developed on a base of limestone or calcareous claystone forming the bedrock on the left riverbank close to the site. The raw material obviously comes from a source unsimilar to all the other studied samples. The potter most probably had to cross the river to obtain the clay. Sample 14 is unique in two attributes – the microfossils included in the ceramic matrix and the abundance of muscovite. Loam with microfossils could have developed on a limestone base, similarly as the calcareous clay of sample 3. Moreover, stacks of muscovite sheets are abundant. The presence of rounded equant sandy quartz indicates fluvial transport of the temper. One of the grains is a granitoid rock (more angular compared to quartz) with a high volume of muscovite.

It seems that the muscovite is derived from granitoid rocks, possibly from the Neratovice complex. According to the shape of granitoid rocks, no long-distance river transport was involved. The sand used as temper most probably originated from a river sediment close to the site.

Sample 18 with bone temper was also heavily tempered with sand, which includes quartz, subangular limestone, and granitoids. All the mentioned rock types are to be found on the left riverbank. Given the fact that they are not very rounded, they were not transported on a long distance. Therefore, we conclude that such sand could be of diluvial origin from the area around Neratovice. Sample 22 is quite fine grained, so petrography did not bring any specific information which could have been used for provenance discussion. The majority of aplastics are formed by fine subangular quartz sand. Sample 40 was tempered with elongated subrounded psamitic fragments of shales and equant rounded quartz sand. Shales outcrop ca. 13 km upstream on the left bank of the Elbe River near Brandýs nad Labem. The shape of shale fragments hints that water transport played a role in their abrasion. It is possible that the sand used as temper for the sample originates from the area between Brandýs nad Labem and Mlékojedy, because there are no traces of granitoids which are to be expected in the river sediment from Mlékojedy and Neratovice down the stream. Sample 43 shows a temper of sand formed by a combination of quartz, limestone, sandstone, granitoids, and amphibole fragments. All the above rocks occur locally. Petrography of the sample 54 temper is similar to sample 14 and so are the arguments for its provenance. The temper consists of granitoid rocks, an abundant muscovite and quartz. However, the sample 54 differs in having no microfossils in the ceramic body.

Conclusions

This study is the first step toward archaeometric investigation of the pottery associated with a significant migration wave from the north to the Bohemian Basin at the turn of the La Tène and Roman periods (cf. *Droberjar 2006a*). The analysis of pottery from the settlement of Mlékojedy shows signs of discontinuity in both major chronological transitional periods (LT D/R A and R A/B1), while the former change was more pronounced taking place between the Late La Tène period and the Early Roman period (LT D/R A). It manifests itself primarily in the way the vessels were shaped. The use of the potter's wheel was abandoned not only in the case of classic wheel-throwing but also as a finishing with the help of kinetic energy Another change consists in shaping the new pottery shapes of the Roman period, which can be explained as evidence of human migrations more than just a cultural imports. These new morphological vessel types bear a completely new range of decorative motifs. However, the similar absolute change cannot be observed in technology since not all aspects of pottery making changed. General adoption of new technology was accompanied by a few exceptions, which demonstrate that certain procedures (e.g. the selection and processing of pottery clay) may have continued to some extent. Some evidence of nostalgia for a bygone time or evidence of a transition phase of a certain kind may also be the reason why samples from the earliest phase of the Roman period (R A) were tempered with crushed bones or grog.

The second, less noticeable technological discontinuity was revealed at the transition between phases R A and R B1. It rather represents a natural development in the pottery making technology accelerated by social changes or internal development of technology. This change was reflected in the homogenisation of temper spectrum and the processes for manufacturing tableware and cookware probably also became unified. During phase R B1, finer clay was no longer strictly used for the production of tableware.

The achieved results show that the vast majority of the pottery could have been produced from local resources available either in the immediate vicinity of the settlement or not far from it (e.g. on the other side of the Elbe River). Only one of the analysed samples can be most probably interpreted as an import, as the deposits of materials which were used as temper are located at least 13 km away upstream of the Elbe River in the vicinity of Brandýs nad Labem. Also, the pottery shapes, which seem to be based on other cultural circles, were manufactured locally.

This research was financially supported by Charles University Grant Agency, project no. 160221 entitled 'The Ceramics Production in the Beginning of the Roman Period in Bohemia'. The research is part of the greater topic studied within the Ready for the future: understanding long-term resilience of the human culture project (CZ.02.01.01/00/22_008/0004593). Great thanks are due to Victory A. J. Jaques for the textual corrections. The authors would like to thank R. Thér for the discussion during the text review phase, the journal editorial team for the great effort in chiselling the text and the anonymous reviewers as well.

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