APPLICATION OF HEAVY MINERAL ANALYSIS FOR CERAMIC PROVENANCE RESEARCH BY THE MICROMINERALOGICAL COLLECTION OF THE MINING AND GEOLOGICAL SURVEY OF HUNGARY – A CASE STUDY •

NEHÉZÁSVÁNY VIZSGÁLAT A KERÁMIÁK EREDETKUTATÁSÁNAK SZOLGÁLATÁBAN A MAGYAR BÁNYÁSZATI ÉS FÖLDTANI SZOLGÁLAT NEHÉZÁSVÁNY GYŰJTEMÉNYÉNEK SEGÍTSÉGÉVEL - ESETTANULMÁNY

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Abstract

This study introduces a possible archaeometric application of the micromineralogical collection belonging to the Mining and Geological Survey of Hungary. Micromineralogical (heavy mineral) assemblage of natural clastic sediments (clay, silt, sand) can characterize the plastic ceramic raw materials typical for a delimited region (i.e. a river catchment area or a geological subunit). Heavy mineral investigation is a useful method which can complete conventional ceramic provenance studies applying microscopic petrography and instrumental chemical analyses, especially in cases of very fine-grained pottery or mature, less characteristic ceramic compositions. Using the 10th c. pottery of Edelény-Borsod (NE Hungary) as an example, we present the application of the micromineralogical collection. The study points out the difficulties with the evaluation, i.e. different sample preparation and data collecting strategy for archaeological and geological samples. Finally, the benefits of the results are formulated as conclusions on the ceramic provenance.

Kivonat

Tanulmányunkban a Magyar Bányászati és Földtani Szolgálat nehézásvány gyűjteményének egy lehetséges archeometriai alkalmazását ismertetjük. A természetes üledékekből leválasztott nehézásvány frakciók jellemzőek egy adott régió (pl. folyó vízgyűjtő területe vagy kisebb földtani egység) törmelékes üledékes nyersanyagaira (agyag, kőzetliszt, homok), amelyek a kerámiakészítés alapanyagául szolgálhatnak. A természetes nyersanyagok és a régészeti kerámiák nehézásvány együtteseinek összevetésével a fazekasáru proveniencia vizsgálatában általánosan alkalmazott mikroszkópos petrográfiai és nagyműszeres kémiai módszerektől független adatokat nyerhetünk az eredet meghatározásához. A nehézásvány vizsgálat különösen hasznos a nagyon finomszemcsés vagy érett, túlságosan általános összetételű kerámiaanyagok esetében. A gyűjteményi anyag használatát Edelény-Borsod 10. századi település kerámia leletanyagán mutatjuk be. Tanulmányunk kitér a feldolgozást nehezítő körülményekre, mint például a régészeti és geológiai minták eltérő előkészítési és vizsgálati módja. Végeredményként az összehasonlító vizsgálattal nyert adatokat a régészeti kerámiák nyersanyag eredetének pontosítására használtuk.

KEYWORDS: HEAVY MINERAL, CERAMIC PROVENANCE, COMPARATIVE COLLECTION

KULCSSZAVAK: NEHÉZÁSVÁNY, KERÁMIA NYERSANYAGEREDET, ÖSSZEHASONLÍTÓ GYŰJTEMÉNY

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Introduction

Provenance of archaeological pottery means the sources of ceramic raw materials, and this approach helps to determine local, regional or long-distance material supply of pottery handicraft in a given ethnic group or culture. Ceramic provenance studies apply different methodologies to determine the sources of ceramic raw materials like chemical investigations (e.g. by XRF, INAA, PGAA, ICP-MS), or detailed textural and mineralogical characterization (e.g. by conventional petrography, SEM-EDS). Describing a ceramic matrix, i.e. the clastic (clay-silt-sand) raw material type may require detailed investigations in case of common mineralogical composition or fine-grained texture (e.g. Szilágyi et al. 2008). Such, less characteristic sediments are frequent in large sedimentary depositional areas, like the Carpathian Basin. In such cases, the exact determination of heavy mineral (HM) components in the clastic raw material type provides possibility to characterize its region of source, and a direct correlation with a ceramic matrix (Mange & Bezeczky 2007, Bong et al. 2010, Sauer 2013). Pottery provenance studies based on HM investigations were recently published by Hungarian researchers (e.g. Obbágy et al. 2014, Kürthy et al. 2018) and the method was described in details in this journal (Józsa et al. 2016).

Heavy minerals – being accessory constituents (usually below 1 wt%) in clastic to clayey sediments, i.e. the raw materials of pottery –are underestimated and considered as difficult to be investigated in material analysis in general. However, due to their resistivity to physical-chemical weathering those are preserved as characteristic components of the original eroded source rock. Hence these subsidiary components in the (natural or artificial) mineral mixture can be considered as 'fingerprint' of a given sediment. Most of the HM species differentiated in our study can be connected to specific parent rock lithology, e.g. metamorphic, igneous or sedimentary. There is different importance of each mineral species in different geological regions. For instance, for mature or redeposited sediments rounded zircon, tourmaline and rutile are typical minerals. However, less mature sediments can be characterized by several other minerals, e.g. metamorphic garnet, or igneous pyroxenes and amphiboles. This is the case in the here observed geological settings in NE Hungary.

The knowledge on the HM assemblages of potential raw material territories is the key to the successful provenance determination. The micromineralogical collection of the Mining and Geological Survey of Hungary (MBFSZ) provides a useful database for a direct comparison of mineral species detected in archaeological pottery to phases preserved in sediments by conventional petrography or SEM-EDS (Péterdi et al. 2020). The MBFSZ micromineralogical collection covers the surficial/near surface alluvial clastic sediments of Hungary with more than 700 localities. Due to the continuous evaluation, qualitative-quantitative information on the overall mineralogy is being accumulated. These data are appropriate for a more exact determining the potential raw material territories, and for the localization of paste or tempering material sources.

This paper presents the first attempt to apply the micromineralogical collection of the MBFSZ for pottery provenance investigations. Survey for sampling points in the observed region and availability of the HM data on sedimentary formations are presented. Comparability of the HM assemblage in archaeological pottery and that in the regional sediments is discussed, both on qualitative and quantitative levels.

Methodological aspect

It is a fundamental requirement in HM analysis to concentrate the HMs in a separatum thus reaching a grain abundance reasonable for investigations and statistical analyses. This enrichment is a complex process encumbered with the risk of losing important information about the subsidiary HM constituent in the natural grain mixture. A major difficulty of the methodology in the presented study – and any future works using the MBFSZ micromineralogical collection – is the different sampling and sample processing of the archaeological and geological materials. The initial 10 to 100 kgs of natural sediments (geological samples) finally resulted in a few grams of the separated material. The process involved wet sieving, preconcentration by spiral and separating funnel, further concentration by bromoform, and finally separation of magnetic and non-magnetic fractions of the 0.063–0.5 mm size range. Five categories were created by magnetic separator using different amperages (Gyuricza 1987; the detailed description will be provided by Péterdi et al. in an article submitted to this journal). In the case of archaeological pottery, such a huge amount of initial material usually is not available. With the exception of special cases (e.g. mass of Roman amphorae admissible to damage, Mange & Bezeczky 2007, Obbágy et al. 2014), the original amount of a ceramic vessel fragment is typically in the range of some tens of grams, so the sample is in the size range of a thin section in a randomly selected plane of the pottery, and the detection of HM species is accidental. In our study, one (30 µm thick) petrographic thin sections was prepared from each archaeological ceramic sample, while the comparative MBFSZ collection is in the form of grain separata.

This difference in the sample preparation method implies that the comparison (especially the quantitative one) is encumbered with significant uncertainties. Despite this limitation the method can be effective due to the nature of HMs. It means that HMs which are usually resistant to erosional processes remain tiny but characteristic constituents indicating the initial raw material even in a late end-product, i.e. in a lower section alluvial sediment far from the source area (e.g. Morton 1991, Mange & Wright 2007).

In case of the comparative materials selected from the micromineralogical collection of the MBFSZ, the large sample amount and the wide grain size range (0.063–0.5 mm) required to change the conventional microscopic method A heterogeneous investigation protocol was developed on more subsamples separated according to their magnetic susceptibility. This separation by the magnetic properties helped the determination of the mineral species. In addition, the shape and habit, color, luster, cleavage/fracture and transparency were the determinative parameters. Mineral abundances (in wt%) were estimated by fields of view in the binocular microscope (Swanson 1981), i.e. area estimations. Observations were done on significantly (approx. two order of magnitude) more grains (2000–6000 grains per sample) than by conventional methods where 200-500 grains of the non-opaque heavy mineral separatum are observed (e.g. Mange & Maurer 1992; von Eynatten & Gaupp 1999). Application of reflected light binocular microscopy instead of transmitted light microscopy provides a less adequate way of determination. Cross-checking of prepared separata by conventional petrographic microscope was necessary. This heterogeneous protocol resulted in individual area percentage values of more fractions per sample.

The original data provided by the MBFSZ is a table of minerals with abundances (see **Table 1.**). The table contains no information on the appearance of the mineral species, and it is not supported by photo documentation. This information must be gained by individual observations with the permission of the MBFSZ. As it can be seen from **Table 1.**, the basic classification of mineral phases contains 25 categories and the collective groups of 'light minerals', 'lithofragments' and 'undetermined altered grains'. Group of 'light minerals' gathers any crystals of non-HMs (<2.9 g/cm^3), e.g. quartz, feldspars, white mica) remaining in the lightest part of the preparatum after the sample treatment. 'Lithofragments' are complex grains containing more phases without further description. Any other weathered, encrusted grains or unidentified particles were classified into the last collective group. For a clearer presentation, original sub-categories (e.g. biogenic and crystalline pyrite, black and red rutile, green and brown and oxiamphibole) are not mentioned here.

The 25 raw categories contain both classical HMs (according e.g. to Lindholm 1987, Mange & Maurer 1992, Mange & Wright 2007, Garzanti & Andò 2019) and phases conventionally not classified as HMs (e.g. opaque (hematite, ilmenite, magnetite, limonite, other opaque), biotite, chlorite). Opaque minerals were separated and determined based on their magnetic properties (i.e. differentiation of magnetite, ilmenite and hematite). For practical reasons, the 25 mineral categories were merged into 17 technical categories (see 25 mineral names, plus 3 collective groups, and 17 separate white/grey groups in **Table 1.**). This process involved merging of the five original opaque mineral categories into three (hematite, ilmenite, other), uniting zircon and monazite categories, combining the Al_2SiO_5 varieties, staurolite and corundum into one class, and merging of titanite and leucoxene categories. The grouping the determined minerals helped the comparison with HM assemblages of the archaeological materials.

As a first step of the comparison, HM distribution patterns in the archaeological material and the two observed alluvial regions were described, and specific characteristics were identified. Second, HM assemblages of the archaeological ceramics were compared to the 'fingerprints' of the different possible source materials. The comparison did not follow the classical HM studies focusing exclusively on the allothigenic (deriving from the eroded source rock) HMs, but it also observed the authigenic and epigenic (syn- or post-diagenetic) HMs. In addition, another unconventional method was the joint considering of the transparent and opaque minerals in cases when opaque phases could be differentiated from each other. It might be useful when more and characteristic opaque minerals are present in the sediments.

Samples and selection criteria from the micromineralogical collection

The 10th c. settlement of Edelény-Borsod was situated at the bank of Bódva river in NE Hungary (**Fig. 1.**). The archaeological excavation (Wolf 2001, 2002, 2003a, 2003b, 2019) discovered an 11th c. earthen fortress which was established on a 10th c. settlement comprising a habitation area of wooden houses and a noble's house. Many household pottery (mainly cooking pots) were excavated from the 10th c. objects together with metal finds. Archaeometric study of pottery from the 10th c. settlement of Edelény-Borsod was described in detail elsewhere (Szilágyi et al. 2004, Szilágyi 2013, Szilágyi 2019 in Wolf 2019). The observed pottery assemblage (45 fragments) was

Table 1.: Results of quantitative heavy mineral analysis of the Sajó and Bódva river valley sediments of the MBFSZ micromineralogical collection (values are in the form of combined piece and weight percentage of several thousands grains per sample; background hue of columns indicate 'technical mineral groups' applied in this study). See the sample codes in Table 2.

1. táblázat: Az MBFSZ mikromineralógiai gyűjteményéből kiválasztott Sajó és Bódva üledékminták nehézásvány összetétele (az adatok a mintánként több ezer szemcse szemcseszámlálásából és térfogatméréséből származtatott, kombinált százalékos értékek; az oszlopok színezése az ásványfajok összevonásával képzett "technikai kategóriákra" utal). A mintajelek feloldását a 2. táblázat tartalmazza.

	Sajó valley sediments															Bódva valley sediments				
Inv. No.	**sz-101**	**sz-201**	**sz-601**	**sz-701**	**sz-801**	**b-2361**	**b-2371**	**sz-2701**	**sz-2801**	**b-2391**	**b-2392**	**sz-1101**	**b-2411**	**sz-1201**	**sz-2901**	**sz-301**	**sz-401**	**sz-501**	**sz-1001**	**sz-901**
garnet	31.75	44.53	50.55	16.96	60.07	54.4	32.36	32.21	43.72	27.87	16.5	28.47	5.06	5.88	10.25	2.12	1.87	5.98	12.96	12.05
hematite	1.01	4.17	3.09	0	1.38	0	6.41	0.31	0.61	3.39	4.06	1.83	6.39	0	1.58	19.07	22.4	18.29	7.14	13.14
ilmenite	9.14	8.83	7.9	6.01	7.42	0.16	3.73	5.16	2.81	10.77	13.89	7.45	14.47	6.8	10.76	20.57	8.83	17.42	9.51	7.5
magnetite	0.752	1.82	0.87	0.901	1.16	0.19	0.43	0.691	0.62	0.56	0.36	0.26	0.63	0.38	0.161	2.751	0.5	1.2	2.14	0.86
limonite	2.07	0.53	0.45	1.84	0.19	0.001	6.42	4.24	4.52	3.94	5.39	2.81	3.79	9.1	3.28	4.91	23.79	4.75	4.59	11.25
other opaque	0.02	0	0.03	0.32	0.02	0	0	1.16	0	0.02	0	0.21	0	0	0	0	0	0.3	0.04	0.69
rutile	0.84	0.81	0.78	0.6	0.78	1.52	0.65	0.61	0.88	1.36	1	0.95	0.81	0.63	0.7	0.93	0.94	1.75	1.84	1.17
zircon	0.06	0.23	0.25	0.34	0.27	0.42	0.2	0.34	0.19	0.19	0.04	0.32	0.12	0.15	0.16	0.27	0.59	0.47	0.52	0.36
monazite	0	0	0	0.02	0	0	0	0	0	0	0	0.21	0	0	0	0	0	0	0	0
tourmaline	0.34	0.12	0.42	0.71	0.17	4.94	4.26	0.09	0.13	1.16	0.49	0.33	0.32	0.14	0.17	0.39	0.28	3.19	6.22	4.56
corundum	0	0	0	0.001	0	0.08	0	0	0	0	0	0	0	0	0	0	0	0	0.13	0.04
andalusite	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0.13	0.07	0	0
kyanite	0.61	0.28	0.27	0.34	0.19	0.52	0.14	0.04	0.15	0.07	0.13	0.04	0	0.05	0.1	0.1	0	0.12	0.08	0.26
staurolite	0.61	0.03	0.001	1.33	0.14	1.69	0.66	0.25	0.17	1.01	0.37	0.03	1.13	0.04	0.17	0.26	0.06	0.36	0.05	0.01
sillimanite	0.1	0	0	0.06	0.07	0.01	0	0.06	0.03	0.3	0	0.24	0.1	0.04	0.32	0.01	0.06	0	0	0
biotite	0.001	0	0	0.2	0	0	0.83	0.25	0.02	0.09	0	0.03	0.12	0.42	0.04	0	1.37	0.61	0.43	0.05
chlorite	0.73	0.62	0.24	0.22	0.01	1.17	0.49	0.02	0.26	1.37	0	0.01	0.61	0.27	0.26	0.03	1.45	0.6	1.08	0.73
titanite	0.19	0.32	0.21	0.37	0.19	0.23	0.16	0.19	0.38	0.48	0.22	0.16	0.16	0.16	0.01	0.07	0.08	0.11	0.71	0.77
leucoxene	0.94	0.96	0.4	0.88	0.56	0.47	0.75	1.15	0.76	1.22	1.21	1.19	1.35	0.72	1.7	0.96	1.17	3.12	2.59	2.19
apatite	2.66	1.06	0.74	0.78	0.54	1.26	0.58	0.41	0.6	1.94	1.28	0.25	0.66	0.09	0.21	0	0	0.12	0.39	0.12
epidote/zoisite	3.41	1.45	1.94	2.94	0.47	0.181	1.74	2.2	2.59	5.18	3.42	1.45	3.19	1.85	3.65	0.73	0.42	1.61	2.7	3.741
opyroxene	4.23	11.13	10.66	19.38	12.17	2.11	16.89	34.03	24.55	7.13	15.48	38.71	31.02	45.51	34.74	0.271	0.01	0.61	10.75	6.05
cpyroxene	0.03	0.01	0.01	1.53	0.04	2.26	1.07	1.27	1.74	1.56	2.59	0.47	1.32	1.33	0.941	0.02	0.03	0.13	0.13	0.05
amphibole_ g-b-o	13.59	10.77	9.21	22.74	5.54	16.32	2.87	2.23	2.41	5.13	8.01	2.09	8.56	6.41	9.79	0.1	0.04	0.04	2.08	1.47
amphibole_alk-bl	0	0	0	0	0	0	0.04	0	0	0	0	0	0.01	0	0	10.19	4.56	13.42	7.72	5.54
light minerals	7.56	3	2.38	2.39	0.47	0.171	1.41	0.761	0.63	1.92	0.91	0.27	1.15	0.76	1.58	1.41	2.09	1.97	1.61	1.11
lithofragment	3.93	1.1	2.59	4.81	4.04	1.33	4.72	1.4	2.38	3.81	6.43	3.62	4.13	4.02	4.72	24.63	14.77	6.46	5.44	7.67
undetermined_altered	15.44	8.29	7.05	13.83	4.15	10.61	13.23	10.83	9.75	19.29	17.91	8.48	14.91	15.3	14.64	10.23	14.53	17.34	19.14	18.65

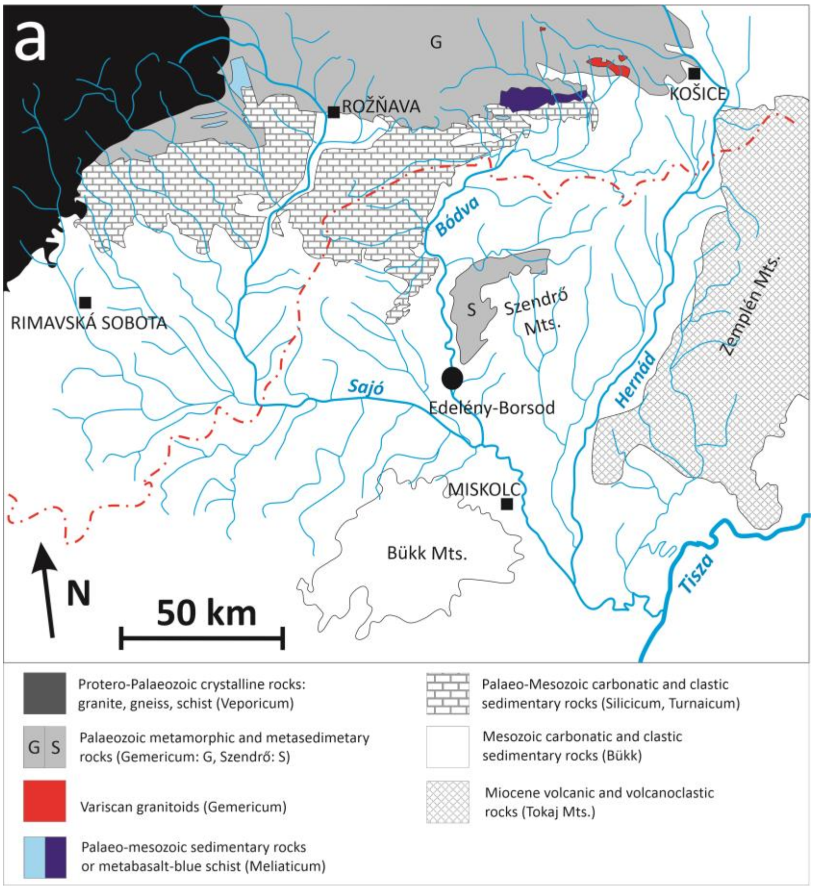

Fig. 1a: The studied area and the geological regions mentioned in the text.

(a) Simplified geological map about the catchment area of the Sajó and Bódva rivers (after Lexa et al. 2000, 2003, Hurai et al. 2010).

1a ábra: A vizsgált terület és a szövegben említett földtani egységek elhelyezkedése.

(a) A Sajó és a Bódva folyók vízgyűjtő területének egyszerűsített földtani térképe (Lexa et al. 2000, 2003, Hurai et al. 2010 nyomán)

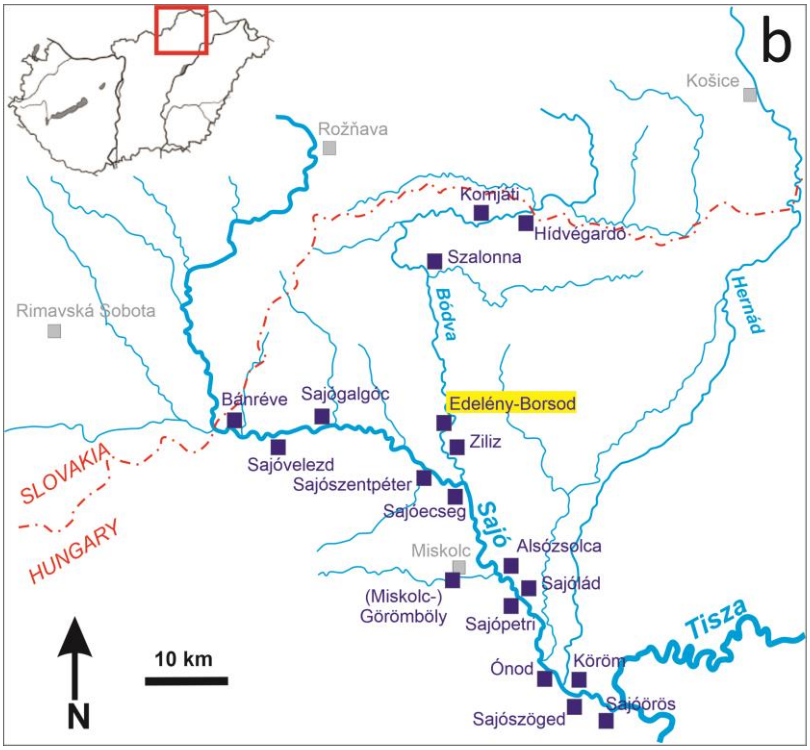

Fig. 1b: The studied area and the geological regions mentioned in the text.

(b) Geographic position of the archaeological site (Edelény-Borsod) in the Bódva river valley, and the distribution of geological localities (blue squares) providing comparative HM material from the micromineralogical collection of the MBFSZ.

1b ábra: A vizsgált terület és a szövegben említett földtani egységek elhelyezkedése.

(b) A régészeti lelőhely (Edelény-Borsod) elhelyezkedése a Bódva völgyében, és a nehézásvány adatokat szolgáltató, az MBFSZ mikromineralógiai gyűjteményéből kiválasztott, összehasonlító minták (kék négyzetek) földrajzi helyzete.

classified into three petrographic groups, and the most abundant group (85%, 38 samples) was subjected to detailed heavy mineral investigations.

Heavy mineral composition of pottery from Edelény-Borsod was compared with that of the surrounding Bódva and Sajó river sediments. The MBFSZ micromineralogical collection contained 20 samples from this region (see **Table 2.**, **Fig. 1.**).

The geological localities covered the middle-lower course of Bódva river (Hídvégardó, Komjáti, Szalonna, Edelény, Ziliz), the middle course of the Sajó river above the inflow of Bódva river (Bánréve, Sajóvelezd, Sajógalgóc, Sajószentpéter, Sajóecseg), the lower course of Sajó river between the inflow of Bódva and Hernád rivers (Miskolc-Görömböly, Alsózsolca, Sajólád, Sajópetri), and the lower course of Sajó river below the inflow of Hernád river (Ónod, Köröm, Sajószöged, Sajóörös). Samples were collected both from riverbeds (indicated with 'sz' in **Table 2.**) and open-air quarries (indicated with 'b' in **Table 2.**).

Heavy mineral composition of 10th century pottery from Edelény-Borsod and of comparative river sediments

The predominant pottery group of Edelény-Borsod is characterized by metamorphic rock-related aplastic inclusions (mono-polycrystalline quartz with undulatory extinction, fine-grained schistose and phyllitic lithofragments) and subordinate amount of weathered volcanic rock fragments (see details in Szilágyi et al. 2004, Szilágyi 2013, Szilágyi 2019 in Wolf 2019). This lithological composition is in agreement with the geology of the Bódva river valley (Fülöp 1994, Kovács 1998) and also the wider geological setting (neighboring river valleys, e.g. Sajó deriving from the N-Carpathian metamorphic crystalline units). HMs comprise part of the accessory minerals in the natural material mixture with 0.1-1.1 wt% (Szilágyi 2004). The HM assemblage of the ceramics is characterized by opaque minerals, tourmaline, garnet, zircon, brown and green amphibole, orthopyroxene and subordinate epidote. Opaque minerals (without detailed mineral determination) are small-sized (50—70 μm) grains, having irregular, isometric or subhedral columnar shapes. Anhedral tourmaline crystals are characterized with green pleochroism and pale zoning (**Fig. 2a,b**). Zircons have small, euhedral crystals (**Fig. 2c**). Garnets are colorless, isotropic, fragmented grains of variable sizes (**Fig. 2d**). Amphiboles with brown-yellow or green-yellowish green pleochroism (**Fig. 2e**) and rare orthopyroxenes (**Fig. 2f**) appear as larger crystals (80–150 μm). Rare epidote with pale yellow pleochroism is also present. In addition, a few biotite grains were present in the ceramics.

The HM assemblage (**Fig. 3.**) of sediments from the immediate surroundings of the archaeological site, i.e. the Bódva valley, is predominated by iron oxides/hydroxides and opaque minerals (23–55 wt%): hematite, ilmenite (and magnetite). Subordinate (4–13 wt%) but very characteristic constituent is the glaucophane (blue amphibole). In addition, garnet (2–13 wt%), tourmaline (0.3–6 wt%) and epidote-zoisite (0.4–4 wt%) are also important species. The most abundant hematite usually appears as flakes (platy habit). Garnets are colorless and fragmented. Tourmalines show bluish tint in their green pleochroism. Rare, rounded zircon grains are permanent components. Quantitative data on the HM assemblage is presented in **Table 1**. It is worth to mention that biotite and chlorite are tiny but characteristic sheeted silicate phases in these samples. Limonite – as an authigenic/epigenic phase – is also present.

Sediments of the Sajó valley provided another type of raw material. The middle course of the Sajó river (above the inflow of the Bódva river) has sediments of a HM spectrum (**Fig. 3.**) predominated by garnet (17–60 wt%). In addition, green-brown-oxyamphibole (5–23 wt%), orthopyroxene (4–19 wt%), ilmenite (6–9 wt%), epidote-zoisite (0.5–3 wt%) and hematite (0–4 wt%) are also important species. The section of the Sajó between the inflow of Bódva and Hernád is characterized by sediments with similar HM assemblage (**Fig. 3.**). The predominance of garnet (32–54 wt%), orthopyroxene (2–34 wt%), green-brown-oxyamphibole (2–16 wt%), ilmenite (0.2–5 wt%), subordinate epidote-zoisite (0.2–3 wt%) and tourmaline (0–5 wt%) are typical. The lowest section of the Sajó river (just above inflowing into Tisza river) provided sediments of a bit different HM composition (**Fig. 3.**). The predominance of orthopyroxene (7–46 wt%) and/or garnet (5–28 wt%) is accompanied by the moderate amount of ilmenite (7–14 wt%). In addition, green-brown-oxyamphibole (2–10 wt%), epidote-zoisite (1–5 wt%), tourmaline (0.1–1 wt%) and hematite (0–6 wt%) are present. Garnets are colorless (rarely pale rose) and fragmented, weakly rounded-angular. Orthopyroxenes are well preserved, eu-subhedral, columnar, pale green-yellow crystals. Tourmalines show green pleochroism. Quantitative data on the HM assemblage is presented in **Table 1**. Besides, biotite and chlorite are also present in the Sajó sediment samples. Authigenic/epigenic limonite is a relevant component (3–9 wt%) in the assemblage.

Table 2.: Localities selected from the Bódva and Sajó river catchment areas as comparative materials of the micromineralogical collection of the MBFSZ.

2. táblázat: A Bódva és Sajó vízgyűjtőterületén található mintavételi helyek az MBFSZ mikromineralógiai gyűjteményében.

Locality	Code/Inv. No.	Description of the sampling point
Hídvégardó	sz-301	1 km NW to Hídvégardó at the shallow, 40 m upstream from the pipe bridge, outcrop in the high bank of Bódva river
Komjáti	sz-401	500 m SW to Komjáti, 250 m downstream from the small bridge of Bódva river, gravelly sand exploited from the riverbed
Szalonna	sz-501	100-200 m upstream from the bridge at Szalonna, gravelly sand exploited from the riverbed
Edelény	sz-1001	N boundary of Edelény behind the Templom Hill at the shallow in a big meander of Bódva river, outcrop in the high bank of the high floodplain
Ziliz	sz-901	1.1 km W to Ziliz railway station, point bars in the riverbed of Bódva river
Bánréve – Serényfalva	sz-101	1.7 km SSE to Bánréve, 100 m upstream from the railway bridge, point bar at the left bank of Sajó river
Sajóvelezd	sz-201	1 km NE to the church of Sajóvelezd in the sharp meander of Sajó, point bar at the right bank of Sajó river
Sajógalgóc	sz-601	2.5 km SSE to Sajógalgóc, 1 km W to Vadna, in the sharp N directed meander of Sajó river, point bar at the left bank of Sajó river
Sajószentpéter	sz-701	800 m NE to the E boundary of Sajószentpéter, in the mild meander of Sajó river, riverbed sediment exploited at the right bank of Sajó river
Sajóecseg	sz-801	500 m NNE to the church of Sajóecseg, in the mild meander of Sajó river, gravel bar on the right bank
Miskolc (Görömböly)	b-2361	sand quarry (Bekecsi Hegyalja MGTSz) in the Tégla street at SW part of Görömböly
Alsózsolca	sz-2801	at the SW boundary of Alsózsolca, in the big meander of Sajó river, outcrop of a point bar in the left high bank
Sajólád	sz-2701	at the SW boundary of Sajólád, 400 m upstream from the road bridge between Sajólád and Sajópetri, point bar in the mild right meander of Sajó river
Sajópetri	b-2371	gravelly sand quarry (Sajópetri Egyetértés MGTSz) 1.5 km NNW to Sajópetri, NE to the road to Kistokaj, in the Bereznó-dűlő, above the ground water level
Ónod – gravel quarry – sorted	b-2391	gravelly sand quarry (Ónodi Rákóczi MGTSz II. "Muhi úti bánya") 1 km S to Ónod, along the road to Muhi, 750 m WSW to the confluence of Sajó and Hernád rivers, sorted sediment from 10-20 m depth
Ónod – gravel quarry – raw	b-2392	gravelly sand quarry (Ónodi Rákóczi MGTSz II. "Muhi úti bánya") 1 km S to Ónod, along the road to Muhi, 750 m WSW to the confluence of Sajó and Hernád rivers, raw dredged sediment
Ónod – shallow	sz-1101	800 m NE to Ónod, in the sharp meander of Sajó river, point bar on the right bank
Köröm	sz-1201	300 m W to Köröm, near the Muhi-Köröm ferry on Sajó river, point bar in the right high bank
Sajószöged	b-2411	abandoned gravelly sand quarry (Nógrádi Sándor MGTSz)on the NW boundary of Sajószöged, on a meadow along the road to the Girincs ferry
Sajóörös	sz-2901	gravelly sand quarry (Sajóörösi TSz) 1 km E to Sajóörös, in a mild meander of Sajó river, flat point bar along the right bank

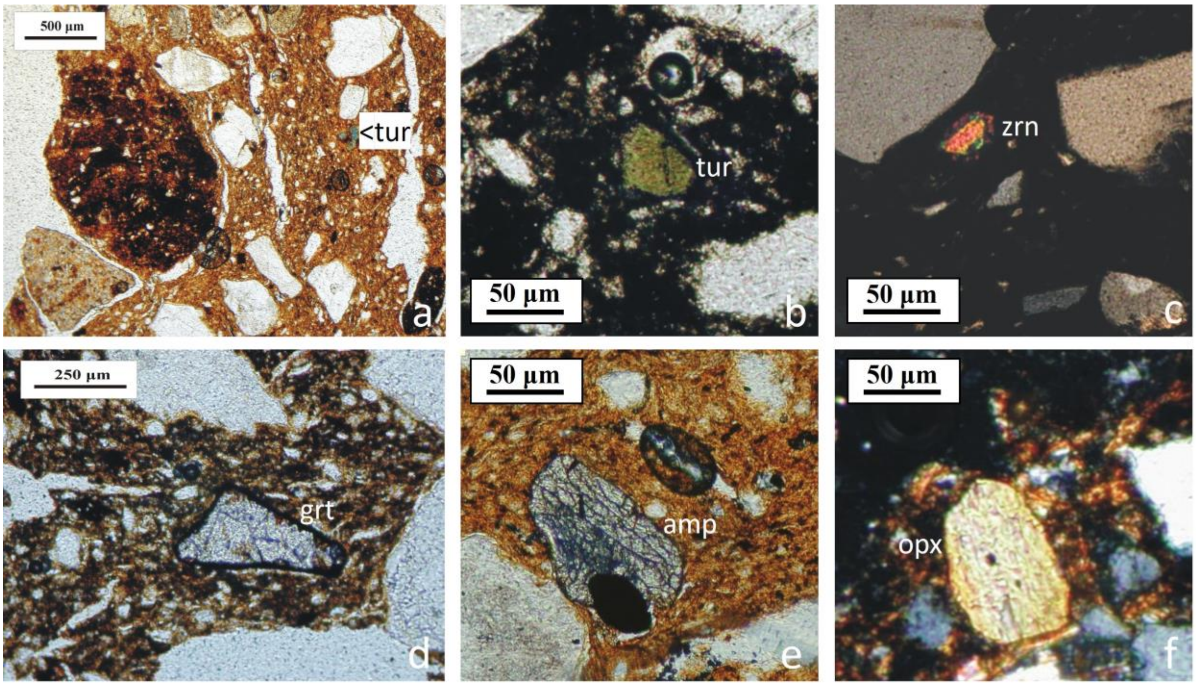

Fig. 2.: Characteristic heavy mineral species in ceramic thin sections (tur: tourmaline, zrn: zircon, grt: garnet, amp: amphibole, opx: orthopyroxene; abbreviations after Whitney & Evans 2010) in 10th c. ceramics from Edelény-Borsod (a, b, d, e: PPL microphotographs, c, f: XPL microphotographs)

2. ábra: Edelény-Borsod 10. századi kerámiáinak jellegzetes nehézásványai vékonycsiszolatban (rövidítések Whitney & Evans 2010 nyomán: tur: turmalin, zrn: cirkon, grt: gránát, amp: amfibol, opx: ortopiroxén) (a, b, d, e: PPL mikroszkópi kép, c, f: XPL mikroszkópi kép)

Fig. 4. demonstrates the anhedral zircon (**Fig. 4a**), bluish tinted pleochroic tourmaline (**Fig. 4b**), blue amphibole (**Fig. 4c**) and fragmented orthopyroxene (**Fig. 4d**) of Bódva sediments. On the contrary, Sajó sediments are characterized with euhedral zircon crystals (**Fig. 4e**), green-brown pleochroic, anhedral tourmaline crysts (**Fig. 4f**), green-brown pleochroic amphibole (**Fig. 4g**) and well preserved, subhedral orthopyroxenes (**Fig. 4h**).

Discussion

The first level of the comparison is the qualitative one. The main HM species in the observed 10th c. ceramics are the opaque minerals-tourmaline-garnet-zircon-brown and green amphibole-orthopyroxene. The Bódva sediments have hematite - limonite - ilmenite - glaucophane - garnet - tourmaline - epidote - zoisite HM assemblage (**Fig. 3.**). Sajó sediments are predominated by garnet-green and brown and oxyamphibole - orthopyroxene - ilmenite - epidote - zoisite - hematite HMs with varied ratios along the course (**Fig. 3.**). Being a comparative (and not a conventional geological) provenance study, not only the allothigenic transparent but also the authigenic/epigenic and opaque phases were considered in the interpretation. If we compare the most relevant HM species of the ceramics with the Bódva and Sajó sediments, we can conclude that garnet and zircon are permanent components in every sample and no difference among their appearance can be detected. Tourmaline is more similar in the ceramics and the Sajó sediments due to their green colour, while tourmaline of Bódva sediments has a more bluish tint. Blue tourmaline is characteristic for the granitoids of the Gemericum (Mahel 1986, Broska et al. 1998), which are present on the catchment area of Bódva river (see in **Fig. 1a**). Orthopyroxene is characteristic in all samples, but its eu-subhedral appearance and fresh optical behavior is more similar in the ceramics and the Sajó sediments (orthopyroxene of Bódva sediments has a more fragmented appearance). Amphibole varieties are present in all samples but the blue amphibole, namely glaucophane is exclusively connected to Bódva sediments, while it is missing from both the Sajó sediments and the ceramics. Glaucophane is a characteristic rock-forming mineral in the high-pressure metaophiolites of the Meliaticum (Faryad 1995a, 1995b, Mello et al. 1998, Dallmeyer et al. 2008), which have outcrops on the catchment area of Bódva river (see in **Fig. 1a**). Colored and higher-density sheeted silicates (biotite and chlorite) were present in sediments of both regions, while only biotite was detected in ceramics. Opaque phases were not further

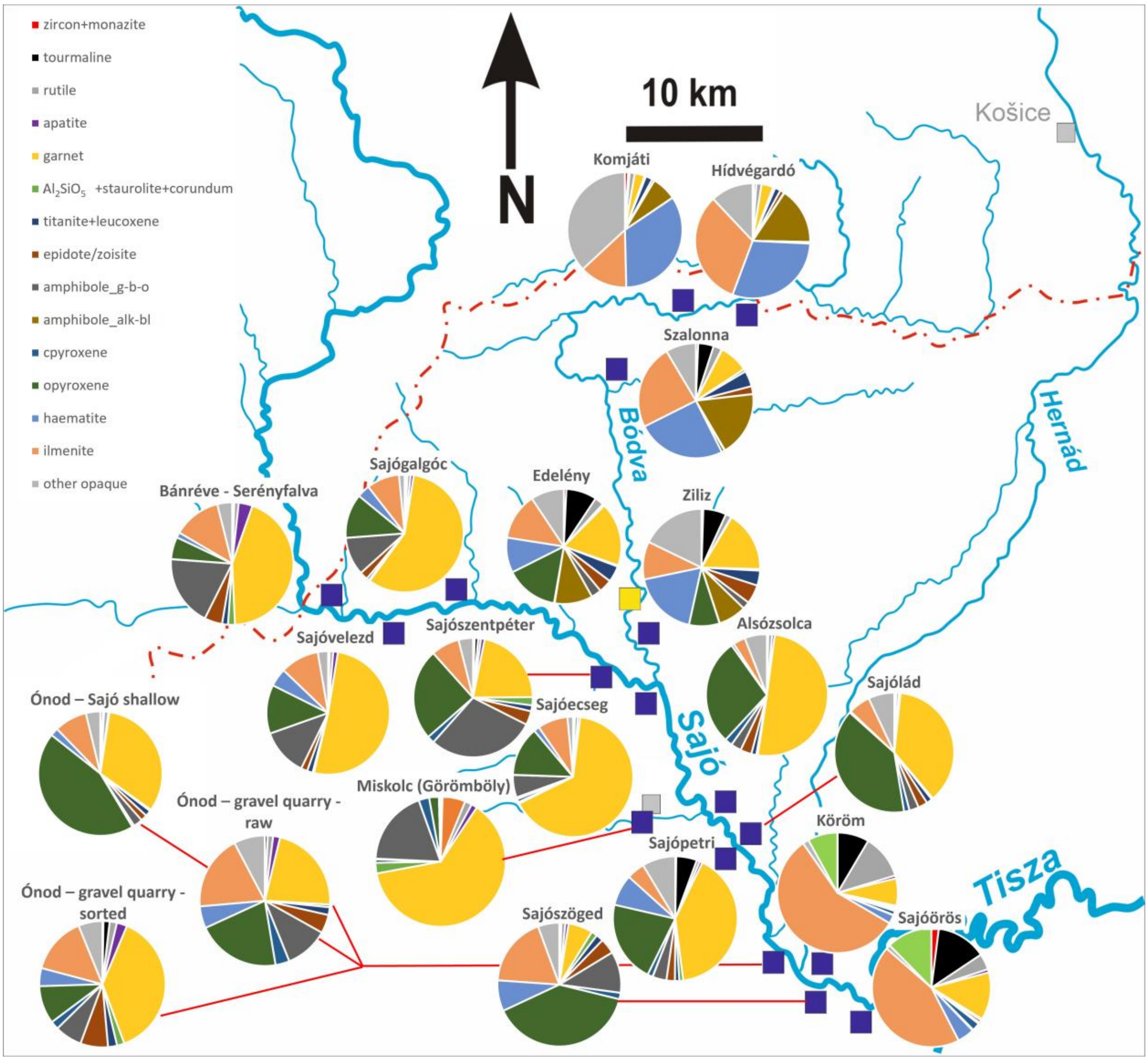

Fig. 3.: Heavy mineral distribution of sediments from the Bódva and Sajó valleys (the interest of our study, the archaeological site is indicated with yellow square). Note that values of the pie diagrams are not equivalent with the values in Table 1, but normalized to 100% without 'biotite', 'chlorite', the 'light minerals', 'lithofragments' and 'undetermined altered grains'. Abbreviations in the figure are pyroxene: clinopyroxene, opyroxene: orthopyroxene, amphibole_g-b-o: green-brown-oxyamphibole, amphibole_alk-bl: alkaline-blue amphibole.

3. ábra: A Bódva és Sajó üledékeinek nehézásvány eloszlása (a jelen tanulmány tárgyát képező régészeti lelőhelyet sárga négyzet jelöli). A tortadiagramokon ábrázolt értékek nem azonosak az1. táblázat adataival, hanem a 'biotit', 'klorit', 'könnyű ásványok', 'kőzettörmelékek' és 'meghatározatlan átalakult szemcsék' kategóriák levonását követő 100%-ra normált értékek kerültek ábrázolásra. A rövidítések feloldása cpyroxene: klinopiroxén, opyroxene: ortopiroxén, amphibole_g-b-o: zöld-barna-oxiamfibol, amphibole_alk-bl: alkáli-kék amfibol.

determined in ceramics but proved to be important components. Their detailed investigation is promising since the comparative geological samples show relevant differences (abundance of ilmenite/hematite/limonite).

To sum up, Sajó sediments are characterized by heavy minerals originating from the NW crystalline formations in the Gemericum (Grecula et al. 1997), while the Bódva sediments predominantly derived from crystalline rocks of the eastern region at the same geological unit (Mahel 1986). Based on our preliminary investigations, ceramics of Edelény-Borsod were manufactured from clayey sediments rather similar to the sediments of Sajó river.

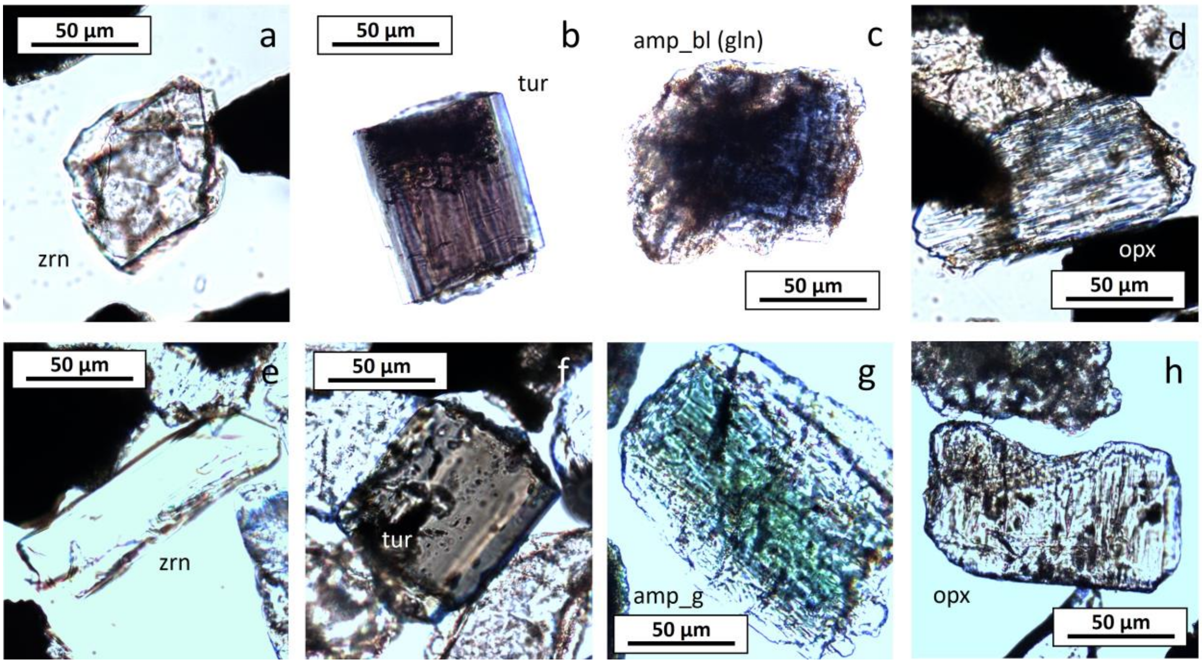

Fig. 4.: Heavy mineral species (PPL microphotographs) of (a-d) Bódva sediments and (e-h) Sajó sediments in HM separata (zrn: zircon, tur: tourmaline, amp_bl or _g: amphibole blue or green, gln: glaucophane, opx: orthopyroxene; abbreviations after Whitney & Evans 2010)

4. ábra: A Bódva (a-d) és a Sajó (e-h) üledékeinek jellegzetes nehézásványai szemcse szeparátumokban, PPL fotók (rövidítések Whitney & Evans 2010 nyomán; zrn: cirkon, tur: turmalin, amp_bl, illetve _g: kék- és zöldamfibol, gln: glaukofán, opx: ortopiroxén)

The second level of the comparison as another important fact would be the HM species ratios. However, it is not possible to gain representative information from the pottery material due to several reasons. As introduced in the 'methods' section, the most crucial part of the HM investigation is the sample processing. For sediments, grain separatum is used. For pottery, thin section is used. It makes the comparison difficult. The quantitative determination of aplastic minerals (e.g. opaques) by thin section petrography in ceramics is limited. These limitations in the quantification make the qualitative comparison even more important. This could be done by the determining the major and minor-trace element composition of HM mineral species (e.g. Józsa et al. 2016, Kürthy et al. 2018), especially garnet (Shimizu 1975; Smith et al. 2004; Ranjbar et al. 2016; Warren et al. 2018), zircon (Belousova et al. 2002; Claiborne et al. 2010), pyroxenes (Shimizu 1975; Smith et al. 2004) and amphiboles (Bong et al. 2010; Parker and Fleischer 1968; Li et al. 2017) applying SEM-EDS and LA-ICP-MS. In addition, Raman spectroscopic investigations could further refine the mineralogical characterization of HMs in thin sections. Determining the possible source rock types of detected heavy minerals can help to better characterize the geological composition of the source region of the ceramic raw materials.

As a result of the comparison, it can be concluded that the HM composition of Edelény ceramics is more similar to Sajó sediments (with garnet-(green, brown and oxy)amphibole-orthopyroxene-ilmenite-epidote-zoisite-hematite-tourmaline HM assemblage) than to the sediments of Bódva river. Both the dominance of iron oxides/hydroxides-hematite-limonite-ilmenite(-magnetite), the different appearance of tourmaline and orthopyroxene, and the presence of blue amphibole are typical for the Bódva sediments and are not characteristic neither for the Sajó sediments nor for the Edelény ceramics. Representative information on HM species ratios from the pottery material is not possible to gain due to the small sample amount (thin section size), the accidental sampling (plane of the thin section), and the limitations of thin section petrography in ceramics. So, much more attention must be dedicated to the qualitative comparison accompanied by mineral chemical investigations of HM mineral species.

Conclusions

To conclude, the existence of micromineralogical collections – such as that of the Mining and Geological Survey of Hungary – is a great opportunity for ceramics provenance studies. Although, adequate HM study of archaeological pottery requires as much amount of sample as possible, but it results in comparable and informative data on the raw material provenance. The comparison with the HM assemblages of sediment samples is not quantitative but qualitative. And it requires the deliberate synchronization of determination and categorization of HM species. In addition, receiving detailed knowledge on the mineral chemistry is highly recommended.

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