Late-Copper-Age decorated bowls from the Trieste Karst (north-eastern Italy): What can typology, technology and non-destructive chemical analyses tell us on local *vs.* foreign production, exchange systems and human mobility patterns?

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ABSTRACT

Twenty-two Late-Copper-Age decorated cross-footed bowls from the Trieste Karst (north-eastern Italy) and the Deschmann's pile dwellings (Ljubljansko barje, Slovenia), recently investigated using X-ray computed microtomography (microCT), have been studied and chemically analysed using non-destructive prompt gamma activation analysis (PGAA). The main aim of our research was to determine whether the cross-footed bowls found in the Trieste Karst were locally produced or if they might have been imported from central Slovenia or even from more distant regions. The PGAA results, combined with the microCT ones, have shown that only 1 bowl from the Karst might have been imported from Ljubljansko barje, while other 4 Karst vessels were most probably imported but not from central Slovenia. In more detail, K_2O contents, higher than values reported from local Karst and Slovenian soils, have been recorded in two of these Italian bowls. The Karst bowls represent, according to their morphology and rich ornamentation manly consisting of cord impressions, a special variant of cross-footed bowls with relevant typological comparisons in the Carpathian basin (Hungary, Slovakia and the Czech Republic). A possible central European origin of some Karst bowls would be in agreement with high K_2O soil contents in some areas of the Czech Republic. Cross-footed bowls from the Trieste Karst might be considered as evidence of long distance connections, movements of ideas, artefacts and/or even movements of people, triggered by large-scale migrations from the north Pontic steppe region to central Europe, revealed by recent genetic studies.

1. Introduction

Numerous caves and rock shelters of the Trieste Karst (north-eastern Italy) had been used by man since prehistoric times onwards. Many sites were discovered and excavated already at the end of the 19th century, while others in the last century, mainly from the late 1950s to the 1980s (Montagnari Kokelj, 2015). All these investigations produced a large quantity of data, revealing that human groups lived in this territory, more or less discontinuously, from the Lower Palaeolithic to the Iron Age (historical periods are out of scope in this paper). However, the quality of these data is variable due to the combination of different factors, from the state of preservation of the deposits to the expertise of the researchers, and this situation applies also to the caves with materials datable to the Copper Age that are discussed here.

In the Karst there are c. twenty caves with findings assigned to the Copper Age: richly decorated bowls on foot in different state of preservation – from intact or almost intact vessels to small fragments – have been found in six of them: Ciclami/Orehova pejca (Fig. 1: 1; Gilli and Montagnari Kokelj (1993) - complete revision of findings; Cotariova/Čotarjeva jama (Fig. 1: 3; Montagnari Kokelj et al., 2002 -

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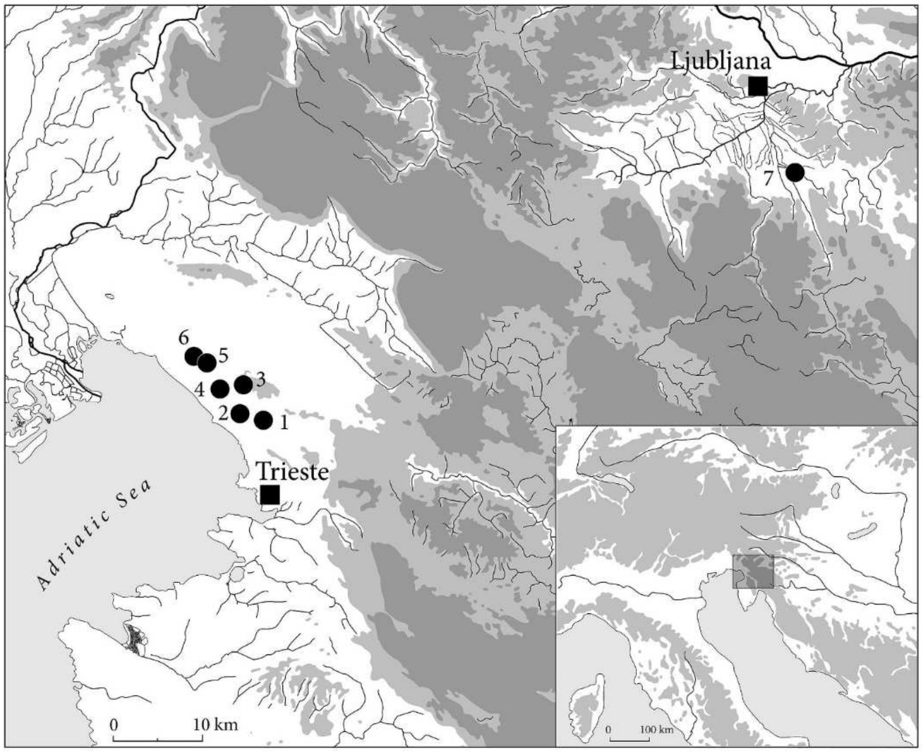

Fig. 1. Position of the archaeological sites where the investigated bowls have been discovered. 1: Ciclami cave; 2: Zingari cave; 3: Cotariova cave; 4: Pettine cave; 5: Edera cave; 6: Pettirosso cave; 7: Deschmann's pile dwellings. All the cave sites are located in the Trieste Karst (map prepared by M. Belak, ZRC SAZU).

complete revision of findings); Pettine/jama Pečinka (Fig. 1: 4; Marzolini, 1983- original publication); Edera/Stenašca (Fig. 1: 5; Marzolini, 1970 - complete revision of findings); Zingari/Ciganska jama (Fig. 1: 2; Gilli and Montagnari Kokelj, 1996 - complete revision of findings); Pettirosso/Vlaška jama (Fig. 1: 6; Moser, 1899; Flego and Župančič, 2012 - complete revision of literature). Unfortunately the stratigraphic data, when available, just allow a broad chronological attribution within the 3rd millennium BC but their typology suggests a chronology within the first half of the same millennium. In fact, already in the 1950s P. Korošec (1956) – as well as other scholars afterwards (e.g. Dimitrijević, 1967; Govedarica, 1989a, 1989b) – indicated the possible connections between these few bowls and other scarce findings from Karst caves and similar vessels found in much greater number in the Deschmann's pile-dwellings near Ig (*Dežmanova kolišča pri Igu*) in the Ljubljansko barje, close to Ljubljana, the most famous site of the 3rd millennium BC in south-eastern Alpine region (Fig. 1: 7). Numerous scholars identified two main phases in the life of the Ig pile-dwellings (e.g. Korošec, 1959; Dimitrijević, 1961, 1979a; Parzinger, 1984). According to the latest study (Leghissa, 2017), the older phase (28th – 26th century BC) is characterised by pottery of the so-called *Ljubljansko barje variant of the Vučedol Culture* (redefinition of *Phase Ig I* after Korošec, 1959 and of *Late Vučedol period-Vučedol C* after Dimitrijević, 1979a), while the younger one (26th century BC to 25th century BC) has been named *Ljubljana Culture* (redefinition of Phase *Ig II* of Korošec, 1959 and of *Alpine variant of the Ljubljana Culture* of Dimitrijević, 1979a and of *Classical Ljubljana Culture* of Govedarica, 1989a). The recently redefined *Ljubljana Culture* includes fine-grained vessels decorated with impressions of cord wrapped around a plate (see Leghissa, 2015) and mostly non-decorated fine and coarse wares, sharing numerous similarities with the pottery of Somogyvár-Vinkovci and Makó-Kosihy-Čaka cultures (last Leghissa, 2017, pp. 278–286).

In the light of the recent revision of the 3rd millennium cultural evolution in the *Ljubljansko barje*, and thanks to the possibility of carrying out non-destructive analyses – X-ray computed microtomography (microCT) and prompt gamma activation analysis (PGAA) –, in our study we have combined typological, technological and chemical approaches to determine whether the cross-footed bowls from the Trieste Karst were locally produced, or, if not, they might have been imported from the Deschmann's pile dwelling or even from more distant regions.

2. Materials

2.1. *Cross-footed bowls*

In this research we have studied 10 bowls from the Trieste Karst and 14 from the Deschmann's pile dwellings (Table 1). Most of them show rich decorations, sometimes filled with a whitish material.

Eight of the ten bowls recovered in the Karst were found in the 1970s–1980s; they have been studied with a traditional, typological and comparative approach as well as with analytical techniques.

Two cross-footed bowls come from the Ciclami cave (Gilli and Montagnari Kokelj, 1993, Fig. 37: 355; 51: 497). One of them, from layer 4 (Fig. 2: 1), is completely preserved and shows a low, solid cross-shaped foot; its surface is light brown and almost without visible lithic grains. Impressions of twisted double cords create different designs over the whole surface, including the foot: the decoration of the exterior, consisting of hatched triangles and star motifs, is nearly unique (Fig. 2: 1a, c). The other cross-footed bowl from the Ciclami cave, found in layer 5, is almost complete but composed of several glued fragments (Fig. 2: 2); its solid foot is peculiar, as it resembles a star with seven points (Fig. 2: 2c): it is richly decorated with stab-and-drag technique (*Furchenstich*) and incisions on the rim, interior and exterior.

A large fragment including a solid cross-like foot and the lower part of the body is reported from the Cotariova cave (Fig. 2: 3). Incised geometric decoration covers all the surfaces, while a motif resembling flower petals on the standing part of the foot is obtained with impressions of twisted double cord. A small rim fragment decorated with incised hatched triangles, possibly belonging to a footed bowl, was also found in the same cave (Fig. 2: 4).

The other bowls from the Karst show different designs, but these are

Table 1
List of the studied Copper Age bowls from Trieste Karst (north-eastern Italy) and central Slovenia. µCT: X-ray computed microtomography; PGAA: prompt gamma activation analysis; OM: optical microscopy.

Inventory number	Site	Cultural/chronological attribution	Methods	Voxel size	References
3469	Zingari cave	influences of Vučedol Culture ?	µCT; PGAA	30.95	Gilli and Montagnari Kokelj (1996), Fig. 34: 202
20591	Ciclami cave	influences of Vučedol Culture ?	µCT; PGAA	21.42; 42.19	Gilli and Montagnari Kokelj (1993), Fig. 51: 497
20592	Ciclami cave	influences of Vučedol Culture ?	µCT; PGAA	21.42; 38.99	Gilli and Montagnari Kokelj (1993), Fig. 37: 355
20419	Cotariova cave	influences of Vučedol Culture ?	µCT; PGAA	21.42; 43.33	Montagnari Kokelj et al., 2002, Pl. 27: 244
139461	Cotariova cave	influences of Vučedol Culture ?	µCT; PGAA	21.42	Montagnari Kokelj et al., 2002, Pl. 27: 245
139462	Pettine cave	influences of Vučedol Culture ?	µCT; PGAA; OM	21.42	Marzolini (1983), Fig. 1: 22, 25
139463	Pettine cave	influences of Vučedol Culture ?	µCT; PGAA; OM	21.42	Marzolini (1983), Fig. 1: 11
139464	Edera cave	influences of Vučedol Culture ?	µCT; PGAA	21.42	Marzolini (1970), Fig. 2/1
/	Pettirosso cave	influences of Vučedol Culture ?	/	/	Moser (1899), 64, Fig. 12; Leben, 1967, Pl. 21: 18, 18a.
/	Pettirosso cave	influences of Vučedol Culture ?	/	/	Leben, 1967, Pl. 21: 17, 17a.
B1482	Deschmann's. pile dwellings	Ljubljansko barje variant of Vučedol Culture	µCT; PGAA	41.01; 81.42	Leghissa (2017), Pl. 91: 1
B1963	Deschmann's. pile dwellings	Ljubljansko barje variant of Vučedol Culture	µCT; PGAA	21.42; 43.15	Leghissa (2017), Pl. 107: 2
B1984	Deschmann's. pile dwellings	Ljubljansko barje variant of Vučedol Culture	µCT; PGAA	39.71	Leghissa (2017), Pl. 95: 1
B1965	Deschmann's. pile dwellings	Ljubljansko barje variant of Vučedol Culture	µCT; PGAA	21.42; 39.71	Leghissa (2017), Pl. 102: 2
B1939	Deschmann's. pile dwellings	Ljubljansko barje variant of Vučedol Culture	µCT; PGAA	21.42; 39.71	Leghissa (2017), Pl. 93: 2
B1994	Deschmann's. pile dwellings	Ljubljansko barje variant of Vučedol Culture	µCT; PGAA	21.42; 39.71	Leghissa (2017), Pl. 95: 5
B1505	Deschmann's. pile dwellings	Ljubljansko barje variant of Vučedol Culture	µCT; PGAA	21.42; 39.71	Leghissa (2017), Pl. 96: 2
B5009	Deschmann's. pile dwellings	Ljubljansko barje variant of Vučedol Culture	µCT; PGAA	21.42; 44.68	Leghissa (2017), Pl. 97: 3
NI19	Deschmann's. pile dwellings	Ljubljansko barje variant of Vučedol Culture	µCT; PGAA	21.42; 39.71	Leghissa (2017), Pl. 97: 4
B1479	Deschmann's. pile dwellings	Ljubljansko barje variant of Vučedol Culture	µCT; PGAA	21.42; 39.71	Leghissa (2017), Pl. 103: 4
B1972	Deschmann's. pile dwellings	Ljubljana Culture	µCT; PGAA	21.42; 39.71	Leghissa (2017), Pl. 104: 3
B1973	Deschmann's. pile dwellings	Ljubljana Culture	µCT; PGAA	39.71	Leghissa (2017), Pl. 99: 2
B1490	Deschmann's. pile dwellings	Ljubljana Culture	µCT; PGAA	21.42; 39.71	Leghissa (2017), Pl. 41: 7 a, b
B1497	Deschmann's. pile dwellings	Ljubljana Culture	µCT; PGAA	39.71	Leghissa (2017), Pl. 109: 3

all obtained with impressions of twisted double cord, the same technique used on one of the bowls from the Ciclami cave. Two rather big fragments – that might belong to one single bowl (see below) – are reported from the Pettine cave (Fig. 2: 7a-c; 8a-c), while two smaller ones come respectively from the Edera (Fig. 2: 5) and the Zingari caves (Fig. 2: 6).

Two more bowls (Fig. 2: 9, 10) were found in the Pettirosso cave between the end of the 19th century and the beginning of the 20th century (Moser, 1899, 64, Tab. II; Flego and Župančič, 2012, pp. 147–149). They were not available for direct observation and for microCT and PGAA analyses, consequently our considerations are based on the literature. One stands on a cross-shaped foot similar to that of one of the bowl fragments from the Pettine cave: also the decoration with hatched triangular and lines of ladder motifs is comparable (Fig. 2: 9 *vs* Fig. 2: 8). The second apparently shows a decoration simpler than that of all the other bowls, but it is peculiar for its base, on four small separated foots, and the presence of two (maybe four?) coupled perforated lugs (Fig. 2: 10).

The bowls discovered in the 1870s in the Deschmann's pile dwellings are very numerous, although their precise number is currently difficult to determine, since the findings are kept in several museums: the National Museum of Slovenia, for example, holds about 100 fragments of bowls with a cross-shaped or round foot. Most of the cross-footed bowls are dated to the earlier phase of the Deschmann's pile dwellings and are attributed to the *Ljubljansko barje variant of the Vučedol Culture*. This type of vessels persists also during the second phase of the pile-dwellings, where it is considered a traditional element developed from the previous Vučedol Culture (Leghissa, 2017).

Some bowls are almost complete but many others are fragmented; altogether, they show variable shape and decoration. The best-preserved one has a solid low cross-shaped foot, slightly curved inwards at the bottom, and a broken small handle. It is decorated with stab-and-drag technique and incisions on the rim, interior – where four lozenges create a unique cross-like motif –, exterior and on the standing surface of the foot too (Fig. 3: 1).

Most of the other chosen fragments are also decorated with stab-and-drag technique and/or incisions. In five cases the syntax of the decoration, inside and outside, is very similar, in spite of minor differences (Fig. 3: 2, 3, 4, 6, 7, 8). Two pieces are decorated only inside: one shows motifs similar to those described above, but the quality of the engravings is poorer (Fig. 3: 9), while the second is particularly interesting as its style is very similar to that typical of the Ljubljana Culture pottery (Fig. 3: 10; see Leghissa, 2017, p. 169).

Three bowls are non-decorated: one is almost entirely preserved and has a conical shape and a small low solid cross-shaped foot (Fig. 3: 5); the other two are fragments of cross-shaped foots with a small hollow in the middle of the lower part (Fig. 3: 12, 13).

The last two examined bowls (Fig. 3: 11, 14) are differentiated by the decorative technique, i.e. impressions of cord wrapped around a thin plate, as well as by the syntax, which – like in one of the bowls above (Fig. 3: 10) – is that typical of the *Ljubljana Culture* pottery (see Leghissa, 2015).

2.2. Natural clay samples

Four natural clay samples have been collected from cores or archaeological trenches of the Ljubljansko barje area, quite close to the Deschmann's pile dwellings, and have been analysed by PGAA (see below). Two of them are from the area of the Neolithic site of Resnikov prekop (Velušček, 2006) and come from a depth of 240–250 and 250–260 cm respectively. Other two are from the site of Bevke and were taken from a depth of 540–550 and 680–690 cm.

3. Methods

Almost all the archaeological samples selected for our study are

Fig. 2. Drawings of Copper age bowls from Trieste Karst. 1a–c: Ciclami cave 20591; 2a–c: Ciclami cave 20592; 3a–c: Cotariova cave 20419; 4: Cotariova cave 139461; 5: Edera cave 139464; 6a–b: Zingari cave 3469; 7a–c: Pettine cave 139463; 8a–c: Pettine cave 139462; 9a–b: Pettirosso cave 1; 10: Pettirosso cave 2.1–8, 10 – scale 1:4; 9 – approximate scale 1:4. For the references see Table 1 (num. 10: new drawings by T. Korošec).

valuable artefacts, which cannot be sampled for destructive analysis. For this reason we have decided to combine mainly non-destructive methods, in particular X-ray computed microtomography (microCT), whose results have been recently published (Bernardini et al., 2019b), and prompt gamma activation analysis (PGAA). These techniques have been applied to 22 bowls with cross-shaped foots, 8 from the Trieste Karst and 14 from the Deschmann's pile dwellings (Table 1).

3.1. X-ray computed microtomography

The microCT analyses had been carried out at the Multidisciplinary Laboratory of the “Abdus Salam” International Centre for Theoretical Physics (Trieste, Italy), using a system (Tuniz et al., 2013) specifically designed to study archaeological and paleoanthropological materials (e.g. Bernardini et al., 2012, 2016, 2018, 2019a, 2019b; Tuniz et al.,

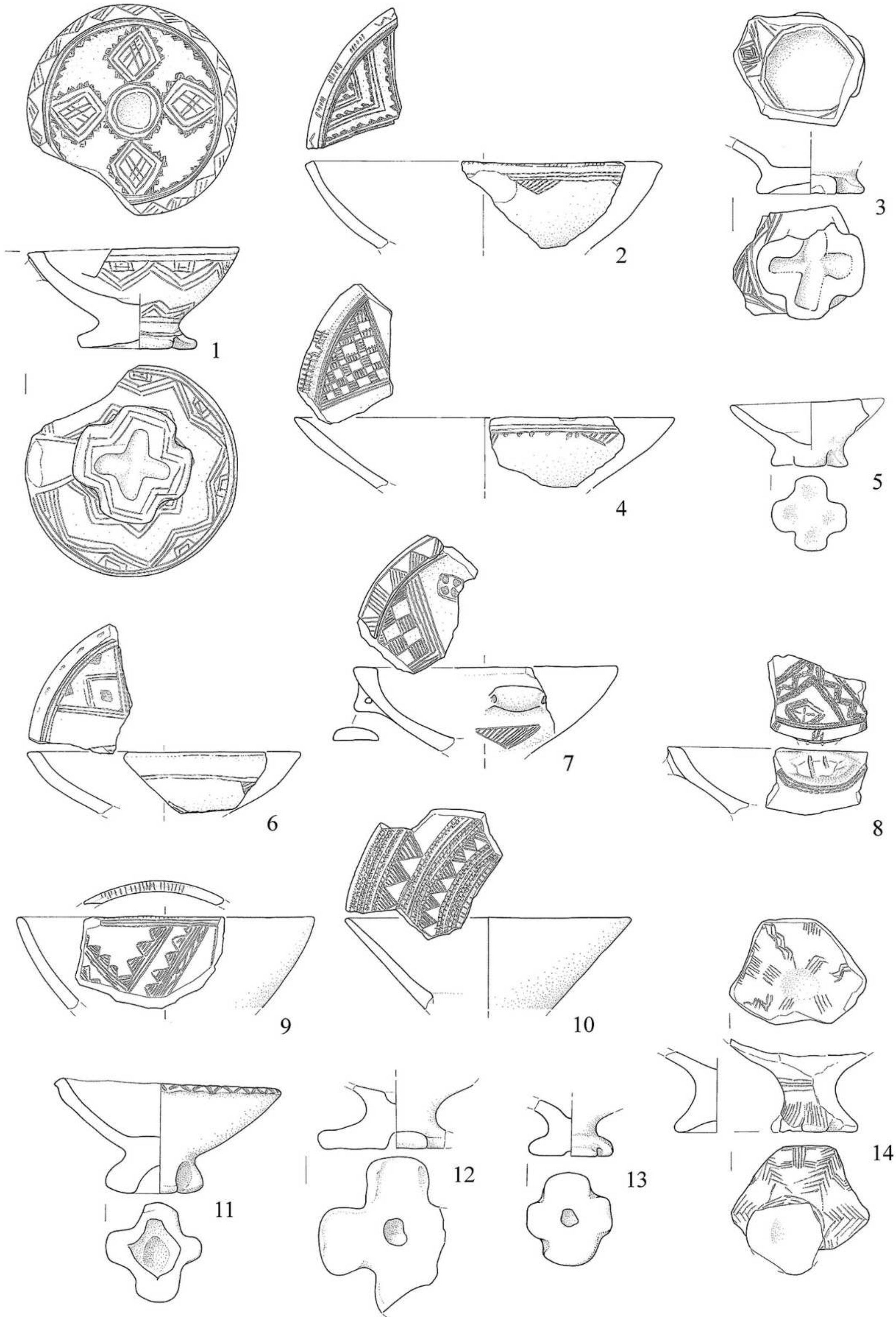

Fig. 3. Drawings of Copper age examined bowls from Deschmann's pile dwelling: 1 – B1482; 2 – B1963; 3 – B1505; 4 – B1965; 5 – B1479; 6 – B1984; 7 – B1939; 8 – B1994; 9 – B1972; 10 – B1973; 11 – B1490, 12 – B5009, 13 – N19, 14 – B1497. Scale 1:4. For the references see Table 1.

2013; Duches et al., 2018). Since the results of microCT analysis have been already published (Bernardini et al., 2019b), in the present paper they have mainly been used to interpret the PGAA results.

Many techniques, including non-destructive ones, can reveal the chemical composition of pottery, which often provides useful information for provenance studies. However, the pottery forming techniques are generally studied by destructive optical microscopy (e.g. Lindahl and Pikirayi, 2010; Ther, 2015) or 2D radiography. Contrary to optical microscopy, microCT can provide information about provenance and production technology of the artefacts, in terms of local *vs* non-local raw materials and manufacturing (Kahl and Ramminger, 2012; Bernardini et al., 2016, 2019a, 2019b), without damaging the samples. MicroCT allows the 3D fabric characterization of pottery thanks to the quantification of clay material, lithic inclusions and voids, which can be the result of either the loss of organic temper mixed to the paste or pottery forming techniques. The mineralogical classification of lithic temper is often difficult, since different minerals can show small density variations, but their *habitus* and morphology can give some clues for their identification. Despite the inability to provide a direct mineralogical and chemical classification of pottery components, microCT can be useful to target chemical analysis, so as to avoid selecting or sampling paste areas unrepresentative of the whole specimen. Even if the recent microCT analyses have given a good indirect fabric and technological characterization of the investigated vessels (Bernardini et al., 2019b), PGAA geochemical data have been considered necessary to obtain an average bulk geochemical composition of the samples useful to detail, confirm and/or correct the microCT results. The microCT data have been used to target the PGAA analysis, selecting paste areas representative of the whole specimen and avoiding any large-sized inhomogeneity.

3.2. Prompt gamma activation analysis

The quantitative analysis of major elements and a few trace ones of all archaeological pottery and natural clay samples have been carried out by PGAA at the Budapest Neutron Centre. The PGAA instrument operates at the $9.6{\cdot}10^{8}$ cm^{-2} s^{-1} intensity horizontal cold neutron beam (for the detailed description, see Szentmiklósi et al., 2010). PGAA is a non-destructive nuclear analytical method for quantitative determination of all major and some trace elements in samples of various physical and chemical forms. The method is based on the detection of characteristic gamma photons, emitted by atomic nuclei following neutron capture (Belgya and Révay, 2004). Since neutrons can penetrate deep into the sample material, PGAA provides an average bulk composition for the irradiated volume of a few cm^3. The prompt gamma spectra were collected by a Compton-suppressed HPGe detector, which has been accurately calibrated. The acquisition times have been set between 1900 s and 5400 s, in order to achieve the statistically sufficient counts in the characteristic spectrum peaks for the determined elements. The gamma-ray spectra were evaluated using the Hypermet-PC program (Révay et al., 2005). The quantitative analysis is based on the k_0 principle (for a detailed description see Révay, 2009), using the spectroscopic data libraries developed at the Budapest laboratory (Choi et al., 2007). Both the self-absorption of prompt-gamma photons due to the 20–30 cm thickness of the samples and the background from the blank measurement have been taken into account. The accuracy of the results is lower than 3 and 10% for major and trace elements respectively (Révay, 2009).

PGAA has been applied successfully to the characterization of various archaeological objects, including stone artefacts (Bernardini et al., 2014a, 2014b; 2018, 2019a; Kasztovszky et al., 2008, 2018; Szakmány et al., 2011) and pottery (Kasztovszky et al., 2004; Kasztovszky, 2007; Szilágyi et al., 2012).

4. Results

The results of PGAA analysis, recalculated on a volatile-free basis, are reported in Tables 2–4 for the Italian and Slovenian bowls and natural clay samples, while the data including LOI are reported in Supplementary Tab. 1. Some of the Slovenian samples show relatively high percentages of P_2O_5 (from about 2 to 7 wt%), probably due to the presence of bone material within the paste. However, microCT data have revealed macroscopic bone remains in just one of the P_2O_5-rich samples, that is bowl B1939 (Bernardini et al., 2019b).

Considering the K_2O and Al_2O_3 contents in the investigated vessels, which can be mainly correlated to the chemistry of the clay raw materials (Fig. 4), the Italian and most of the Slovenian samples fall in different areas of the diagram. The relatively high K_2O content (about 3.5 wt%) of the Karst sample 20591 (from Ciclami) distinguishes it from all the other bowls, with the exception of another Karst vessel, 20419 (from Cotariova) (K_2O content about 3 wt%). These high K_2O values are more probably due to a prevalence of the illitic component in the clay raw materials and/or the occurrence of K-rich minerals, such as muscovite. Such mineral phase, probably originated by the weathering of metamorphic rocks, is abundant in the paste of bowl 20591 (Bernardini et al., 2019b).

According to the Geochemical Atlas of Europe (http://weppi.gtk.fi/publ/foregsatlas/) and the Radioactivity Environmental Monitoring group of the Joint Research Centre of the European Commission (https://remap.jrc.ec.europa.eu/Atlas.aspx?layerId=9), in Europe the median K_2O content is 2.02% in subsoil and 1.92% in topsoil, with a range between < 0.01 and 6.05% K_2O in subsoil and 0.026 and 6.13% K_2O in topsoil. High K_2O values are reported neither from the Karst area nor from central Slovenia, while they reach high concentrations in the Alps at the Austrian-Italian border, central Germany, the Czech Republic and elsewhere.

In order to compare the bowls' chemical composition among each other and between Slovenian and Italian groups, we have selected some of the most significant major and trace elements (K_2O, TiO_2, CaO, MnO, Fe_2O_3, Sm and Gd) to produce spider diagrams (Figs. 5 and 6). Such elements have been normalised using the Upper Continental Crust composition (Rudnick and Gao, 2004), in order to enhance their possible different geochemical features; additionally, the contents of trace elements have been multiplied by 10^4 to better visualize the data in the diagrams.

As to the Karst bowls, chemical analysis confirms their considerable heterogeneity, already indicated by both typology and microCT data. One group (3469, 20592, 139464 – from Zingari, Ciclami and Edera respectively), perfectly corresponding to the samples with the highest lithic inclusion/clay ratio based on microCT results (Bernardini et al., 2019b, Fig. 2), have Ca-rich pastes (CaO from about 12 to 26 wt%) mainly due to the presence of abundant calcite, well visible in microCT images. Their patterns are not identical but they share a quite high CaO concentration followed by a decrease in MnO, Fe_2O_3 and Sm in all samples (Fig. 5A). Bowl 139461 has a Ca-rich paste too, but its pattern is slightly different mainly due to lower K_2O, MnO and Fe_2O_3 contents (Fig. 5B).

Other 2 groups from Trieste Karst are characterised by flatter patterns with a lower amount of CaO (Fig. 5C–D). The first group includes samples 20591 (from Ciclami cave) and 20419 (from Cotariova cave) (Fig. 5C). Macroscopic observation and microCT results showed that bowl 20591 is different from all the investigated Slovenian and Italian samples for its very dense and fine-grained paste with abundant white mica and almost absent lithic inclusions, and its chemical composition confirms its peculiarity. In fact, its pattern is well different from all the others, with the exception of bowl 20419. Both of these Karst vessels are characterised by a high K_2O values and a quite flat pattern, but one of them (20419) shows a higher CaO content (Fig. 5C), as expected from the probable presence of calcite well shown by microCT data (Bernardini et al., 2019b).

The second group includes samples 139462 and 139463 from Pettine cave, which show a very similar pattern with small differences in the TiO_2 and CaO contents (Fig. 5D). As such a strong similarity was already highlighted by optical microscopy, microCT data and their statistical analysis (PCA), the new results would further support the hypothesis that the two fragments originally belonged to one single bowl. The microCT data and petrographic features of the Pettine vessels indicated a similarity also with the fine-grained vessels from the Deschmann's pile dwellings (Bernardini et al., 2019b, Figs. 2, 8, 13), in spite of differences in the decoration technique (Bernardini et al., 2019b).

When the Slovenian bowls are considered, the first important observation is that their patterns are different from those of the Italian ones (Fig. 6) with the only exception of sample 139461 from Cotariova

Table 2
Major (wt%) and some trace (ppm) elements of the bowls from the Trieste Karst analysed by PGAA. Fe_2O_3: total Fe content. Data recalculated on a volatile-free basis.

Samples	3469	20591	20592	20419	139461	139462	139463	139464
SiO_2 (wt%)	45,84	61,85	44,27	56,59	60,47	66,44	67,75	55,99
TiO_2	0,95	0,71	0,67	0,91	1,08	0,97	0,00	1,06
Al_2O_3	18,96	21,63	17,40	22,38	15,86	17,68	16,86	19,70
Fe_2O_3	8,03	6,26	5,78	8,55	3,39	7,68	7,71	7,24
MnO	0,39	0,05	0,11	0,06	0,08	0,11	0,12	0,19
MgO	0,00	3,60	2,87	3,37	0,99	1,54	1,53	1,00
CaO	23,60	1,82	26,17	4,81	16,61	2,97	3,90	12,56
Na_2O	0,00	0,53	0,20	0,29	0,12	0,43	0,30	0,00
K_2O	2,23	3,56	2,52	3,05	1,41	2,19	1,83	2,25
P_2O_5	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Sum	100	100	100	100	100	100	100	100
B (ppm)	43	68	42	64	49	63	47	61
Cl	304	38	186	51	28	76	45	82
Sc	10	0	0	0	10	23	13	28
Cr	0	0	0	0	279	0	0	356
Ni	0	0	0	0	0	0	0	253
Nd	33	48	0	0	36	0	0	46
Sm	4	3	3	6	5	4	3	5
Gd	5	4	3	5	6	5	4	6

cave (see below).

One group including bowls B1482, B5009 and B1497 (Fig. 6A) shows the highest CaO contents (from about 14 to 30 wt%), and corresponds well to the Slovenian samples with the highest lithic inclusion/clay ratio as indicated by the microCT analysis (Bernardini et al., 2019b, Fig. 2). As it can be seen in Fig. 6A, their pattern is different from that of the CaO-rich Karst samples (Fig. 5A), with the exception of sample 139461 (Fig. 5B) that, however, shows a bit higher MnO content. According to the available chemical data, this Italian vessel is the only one that might have been imported from the Deschmann's pile dwellings to north-eastern Italy.

Other two groups with a moderate CaO content have been recognised. Both differ from the Karst bowls too, and include samples with very similar patterns that suggest the use of almost undistinguishable raw materials as well as similar technological processes (Fig. 6B–C). This is confirmed by the microCT data, and in particular by the lithic inclusions/clay ratio and PCA of the same microCT data, considering length, width and area of lithic inclusions and lithic inclusions/clay ratio as variables (Bernardini et al., 2019b, Fig. 13). The lithic inclusions/clay ratios of the group 2 samples are very similar, ranging from about 0.02 to 0.04 (Bernardini et al., 2019b, Fig. 2), and they all fall very close in the bottom right quadrant of the PCA plot (Bernardini et al., 2019b, Fig. 13).

The last group of Slovenian bowls includes samples showing low CaO values. Their patterns are quite similar to the CaO-rich group, and in particular to sample B5009, but with a much lower concentration of CaO. The CaO-rich and the CaO-poor groups have been probably produced by using the same or similar clay raw materials, but abundant calcite temper was added to the vessels of the first group causing a considerable increase in their CaO concentration.

The composition of the natural clay samples from the Ljubljansko barje area (Table 4; Supplementary Tab. 1), particularly rich in CaO (values from 47 to 79 wt%), is different from that of the 4 main groups that have been identified on chemical basis (Fig. 6). Further sampling of local clay deposits is necessary to understand where the prehistoric potters collected the raw materials for pottery production.

5. Discussion and conclusions

Cross-footed bowls, also known as “bowls on cross-shaped foots” or

Table 3
Major (wt%) and some trace (ppm) elements of the bowls from Deschmann's pile dwellings analysed by PGAA. Fe_2O_3: total Fe content. Data recalculated on a volatile-free basis.

Samples	B1482	B1963	B1984	B1965	B1939	B1994	B1505	B5009	NI19	B1479	B1972	B1973	B1490	B1497
SiO_2 (wt%)	53,19	43,65	59,89	59,29	58,03	54,85	58,52	41,03	69,14	63,04	55,99	57,85	56,41	53,18
TiO_2	0,90	1,36	1,45	1,05	1,30	1,16	1,10	0,92	0,76	1,09	1,17	1,19	1,18	1,23
Al_2O_3	25,90	31,88	21,42	24,55	24,08	27,66	20,23	19,90	17,95	21,79	20,57	22,88	25,28	19,86
Fe_2O_3	2,22	5,16	8,69	8,00	4,48	8,46	6,06	5,65	3,10	3,06	5,24	4,19	4,97	5,10
MnO	0,03	0,10	0,02	0,04	0,05	0,02	0,06	0,02	0,07	0,04	0,06	0,05	0,10	0,05
MgO	1,79	0,00	0,00	1,93	0,00	1,12	3,38	1,57	0,00	1,46	2,50	2,14	0,00	2,79
CaO	14,24	9,58	2,66	2,03	6,47	1,54	4,57	29,88	7,20	6,88	7,95	8,86	10,18	16,80
Na_2O	0,44	0,00	0,69	0,51	0,66	0,57	0,87	0,13	0,27	0,52	0,72	0,87	0,00	0,46
K_2O	1,29	1,59	1,14	2,58	2,36	2,38	2,39	0,90	1,52	2,12	2,22	1,95	1,87	1,29
P_2O_5	0,00	6,68	4,05	0,00	2,58	2,25	2,80	0,00	0,00	0,00	3,57	0,00	0,00	0,00
Sum	100	100	100	100	100	100	100	100	100	100	100	100	100	100
B (ppm)	49	44	51	51	67	50	65	28	43	58	62	51	56	41
Cl	48	43	535	46	95	73	39	15	39	34	144	118	55	0
Sc	0	0	22	26	24	29	0	11	27	0	0	24	0	0
Cr	0	0	497	814	0	218	1076	0	0	0	704	0	0	0
Ni	0	0	2037	0	0	126	0	0	564	0	389	264	0	0
Nd	62	0	52	67	51	0	58	42	78	41	59	54	0	44
Sm	7	27	6	6	8	4	7	4	10	4	7	5	13	6
Gd	7	42	7	7	8	4	7	4	11	5	8	6	16	6

Table 4
Major (wt%) and some trace (ppm) elements of clay samples from the Ljubljansko barje area. Data recalculated on a volatile-free basis.

Samples	Resnikov p.	Resnikov p.	Bevke	Bevke
depth	240–250	250–260	540–550	680–696
SiO_2 (wt%)	13,16	11,00	14,25	30,42
TiO_2	0,19	0,16	0,20	0,51
Al_2O_3	5,20	4,73	6,06	12,07
Fe_2O_3	2,27	1,72	2,31	4,61
MnO	0,06	0,05	0,06	0,08
MgO	1,79	2,07	1,81	2,76
CaO	76,33	79,41	74,21	47,08
Na_2O	0,13	0,12	0,10	0,40
K_2O	0,87	0,74	1,00	2,07
P_2O_5	0,00	0,00	0,00	0,00
Sum	100	100	100	100
B (ppm)	13	11	17	38
Cl	11	11	15	17
Sc	0		0	0
Cr	0	0	0	0
Ni	0	0	0	0
Nd	8	0	8	10
Sm	1	1	1	3
Gd	1	1	1	3

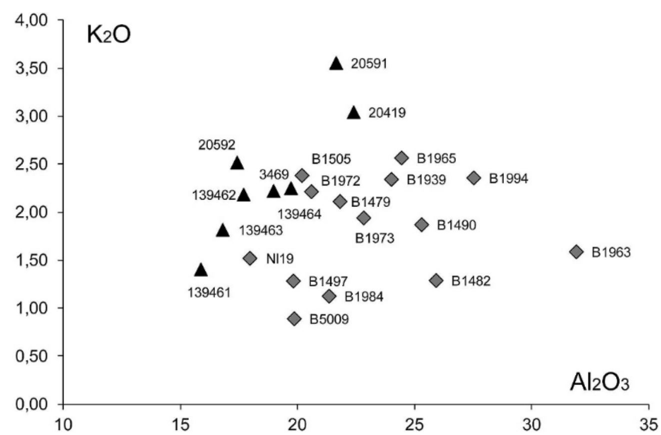

Fig. 4. K_2O *vs.* Al_2O_3 bivariate diagram of the Italian (black triangles) and Slovenian (grey diamond) bowls.

"interior decorated footed bowls", represent one of the most characteristic vessels of the 3rd millennium BC (Kulcsár, 2009; Kaiser, 2013; Leghissa, 2017). They are particularly abundant in Vučedol sites of south-eastern Europe, dating back to the first half and the middle of the 3rd millennium BC. The Vučedol Culture formed in the southern Carpathian basin (Slavonia, Croatia). According to Dimitrijević (1979a), it spread to the northern Carpathian basin (Czech Republic, Slovakia, Hungary), to the south-western Balkan peninsula (Serbia and Montenegro) and to north-eastern Italy (e.g. Bianchin Citton et al., 2015).

Cross-footed bowls appear also in other closely related contemporary or partly contemporary cultures, such as the Jevišovice one in southern and central Europe, Makó-Kosihy-Čaka and Somogyvár-Vinkovci in the Carpathian Basin. Similar vessels are also known in the Yamnaya (or "Pit Grave") and Catacomb Culture in the southern Ukraine and southern Russia, where they are defined as censers (Kulcsár, 2009; Kaiser, 2013).

The bowls from the Trieste Karst represent, according to their morphology and ornamentation, a special variant of cross-footed bowls. The exact chronological definition of these bowls is problematic, since they have been found in layers containing finds assignable to the Copper/Early Bronze Age on typological grounds only, as no C14 dates are available. They are mostly associated with Vučedol Culture but often referred to as an individual type (e.g. Burger, 1980; Kulcsár, 2009). The influence of the Vučedol Culture should have reached the Trieste Karst through central Slovenia, precisely through Ljubljansko barje, where the Vučedol Culture is well represented by abundant pottery attributed to the recently re-defined *Ljubljansko barje variant* (Leghissa, 2017). As already mentioned, cross-footed bowls are very numerous and stylistically various at the Deschmann's pile dwellings, mostly during the first phase. They are still present during the second phase probably as a heritage of the Vučedol Culture, but in a smaller number and with a simpler decoration (Leghissa, 2017, pp. 166–173). Despite their abundance at the Deschmann's pile dwellings, apparently they do not offer precise analogies for the bowls of the Trieste Karst, but only generic similarities in some of the decorative compositions, such as the hatched triangles on the rim (e.g. see Leghissa, 2017, Pl. 93: 1, 2; 94: 1–4), triangular motifs trimmed with hatched triangles (e.g. see Leghissa, 2017, Pl. 105: 1; 106: 1–4) or hatched triangles on the exterior of the vessel (e.g. see Leghissa, 2017, Pl. 92: 1; 107: 4, 5; 108: 3). Similarly, in Hungarian sites of Vučedol culture, where numerous cross-footed bowls were discovered, bowls well comparable to those from the Karst have not been identified (e.g. see Patay, 1940, Pl. I: 5; Ecsedy, 1982, Pl. II, III).

According to the chemical composition of the analysed artefacts, we can distinguish four different groups of bowls from the Deschmann's pile-dwellings, that are a CaO-rich one (Fig. 3: 1, 12, 14; Fig. 6A), two with a moderate CaO content (group 1, Fig. 3: 5, 7, 9, 10, Fig. 6B; group 2, Fig. 3: 2, 11, 13, Fig. 6C) and a last group including samples with a pattern similar to the CaO-rich group 1 but showing low CaO values (Fig. 3: 4, 6, 8, Fig. 6D). The vessels of the two groups with a moderate CaO content include samples with very similar patterns, suggesting the use of almost undistinguishable raw materials for each group and similar technological processes. In addition, it is worth noting that some bowls of different chronological and cultural attribution have been modelled using similar recipes and clay raw materials. For example the CaO-rich group (Fig. 6A) includes bowls B1482 (Fig. 3: 1) and B5009 (Fig. 3: 12), dated to the first phase of the pile-dwellings and attributed to the Vučedol Culture, and bowl B1497 (Fig. 3: 14) attributed to the later Ljubljana Culture. Furthermore, we can see that similar recipes and raw materials have been used for both decorated and undecorated bowls. From this, it follows that the potters from the Deschmann's pile-dwellings probably used in both periods a few clay raw materials sources, most probably located close to the settlement, and similar recipes, adding in some cases crushed calcite and/or limestone as inorganic temper.

In the case of the bowls from Trieste Karst the PGAA results have been important to show that four of the eight analysed bowls are most probably imported to the Trieste Karst (Ciclami 20591, Fig. 2: 1; Cotariova 20419, Fig. 2: 3; Pettine 139462, Fig. 2: 8; Pettine 139463, Fig. 2: 7; Fig. 5C–D), but not from the area of Ljubljansko barje. Chemical data has revealed a similarity between bowl 20591 from Ciclami cave (Fig. 2: 1) and vessel 20419 from Cotariova cave (Fig. 2: 3), not recognised on the basis of microCT data. Additionally, the two bowl fragments from Pettine cave (139462 and 139463, Fig. 2: 7, 8) do not find a good chemical comparison with the Slovenian analysed vessels, even if microCT data showed a strong technological similarity (Bernardini et al., 2019b).

One Karst bowl could have been imported from Ljubljansko barje (139461 from Cotariova cave, Fig. 2: 4, Figs. 5B and 6A) and other three have Ca-rich pastes that could have been locally produced but this cannot be demonstrated without a chemical comparison with local soil and clay deposits.

The main characteristic of the Trieste Karst bowls is above all the decoration technique: with the exception of three cases (one bowl from the Ciclami cave – 20592, Fig. 2: 2 – and two bowls from the Cotariova cave – 20419 and 139461, Fig. 2: 3, 4 –) they are all decorated with impressions of a twisted double cord (the so-called cord impressed ornamentation). In Ljubljansko barje such decoration is known only on

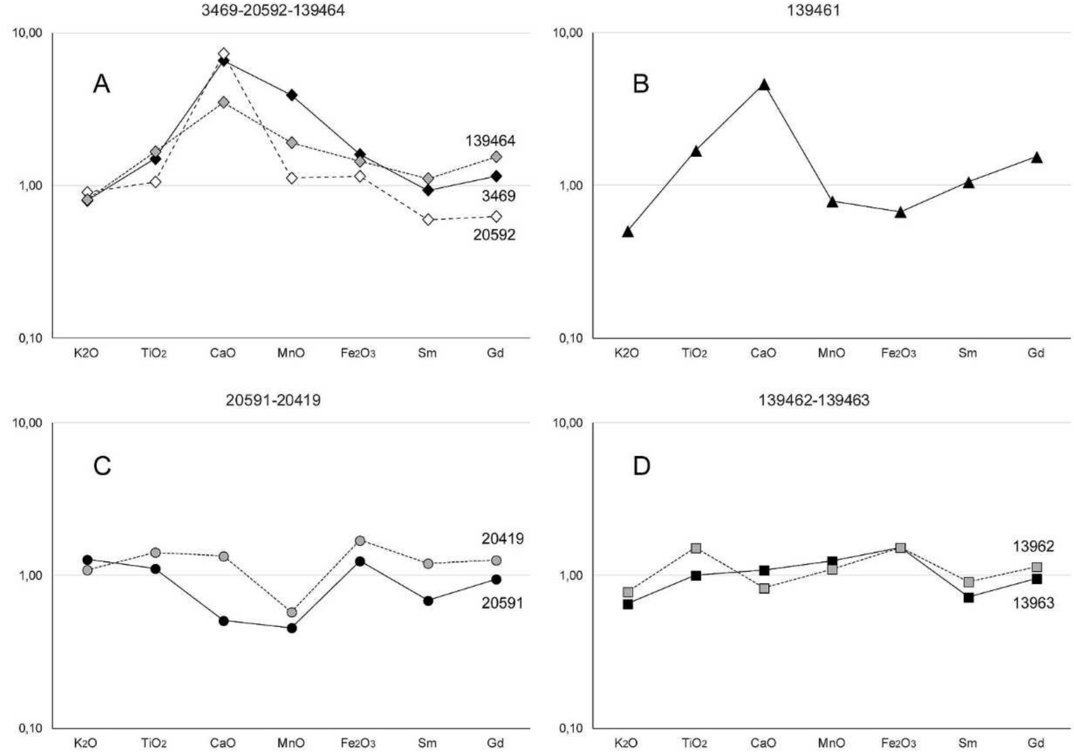

Fig. 5. The Upper Continental Crust (UCC)-normalised spider diagrams of selected major and trace elements of Karst bowls divided in 4 main groups. Trace elements content has been multiplied by 10^4.

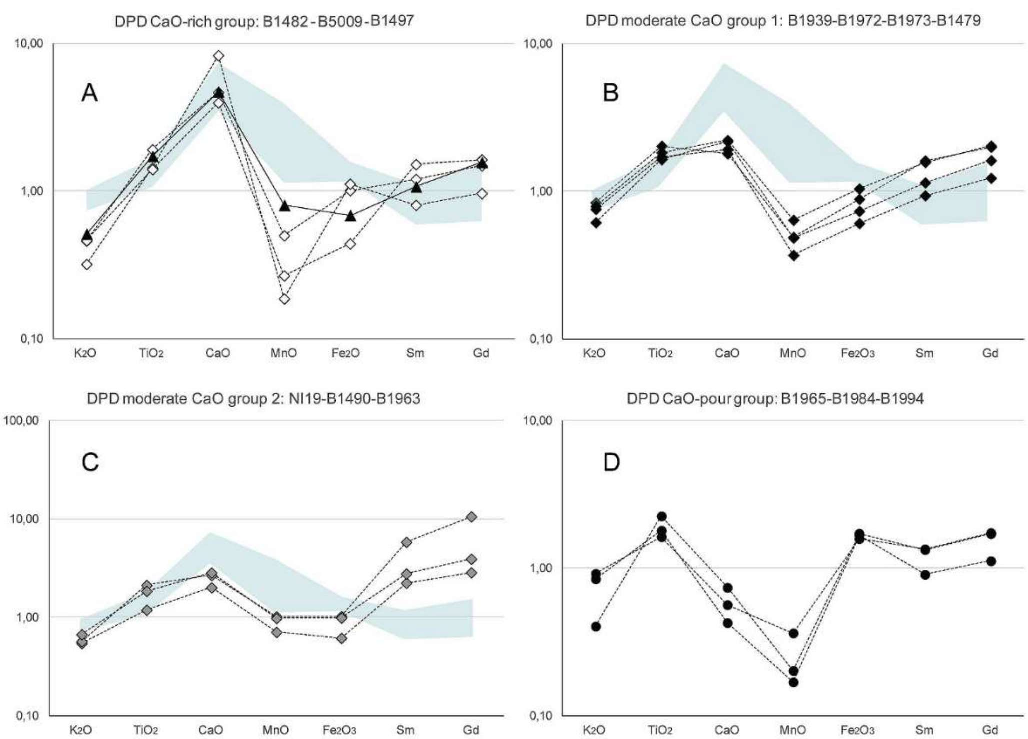

Fig. 6. The Upper Continental Crust (UCC)-normalised spider diagrams of selected major and trace elements of Deschmann's pile dwellings bowls. DPD: Deschmann's pile dwellings. The bluish area corresponds to the patterns of the CaO-rich Karst samples of Fig. 5A. The black triangles in the A diagram correspond to the Karst sample 139461 of Fig. 5B. Sample B1505 is not shown but its pattern is very similar to those of the moderate CaO group 1. Trace elements content has been multiplied by 10^4.

few vessels of other types (see e.g. Leghissa, 2017, Pl. 65: 1). The cross-footed bowls from the Ljubljansko barje and from Vučedol sites are decorated mostly with "stab and drag" technique and/or incisions: decorations with impressions of a twisted double cord are almost unknown in the context of the Vučedol Culture.

So, where would the Trieste bowls, especially those without chemical comparisons in central Slovenia, have been imported from?

Ceramic finds decorated with impressions of double twisted cord are known in other contemporary cultures in central Europe, for example in the Corded Ware Culture (*Schnurkeramische Kultur*), where, however, there are no cross-footed bowls (see e.g. Buchvaldek, 1967; Furholt, 2003).

Cross-footed bowls decorated with cord impressions represent a specific type of vessels of the 3rd millennium BC, which are known from

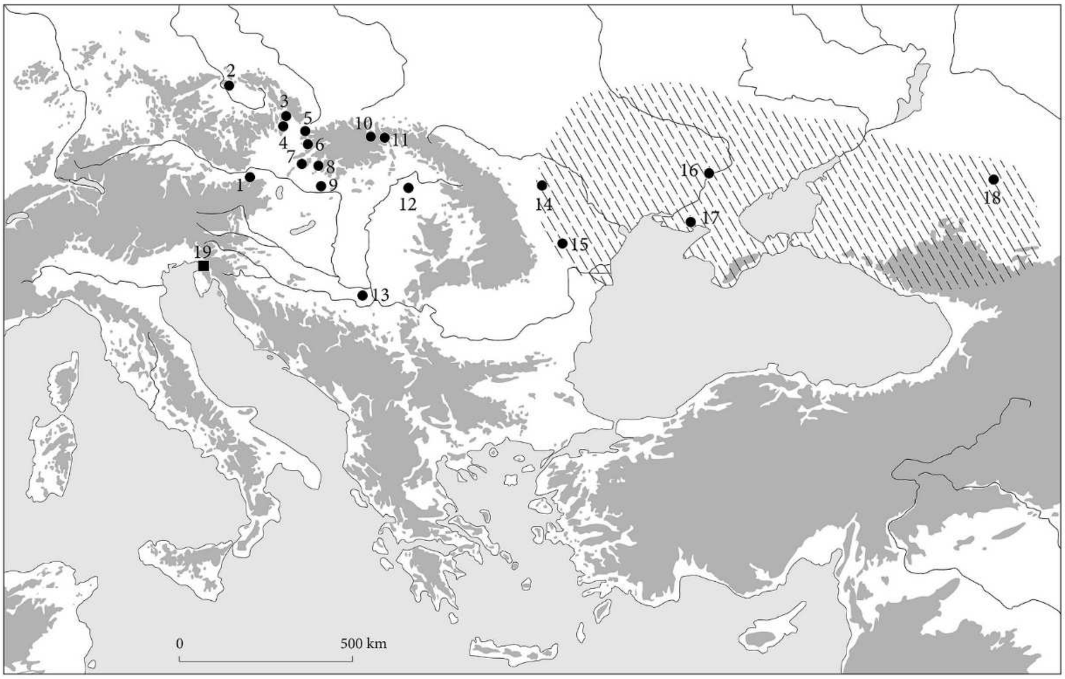

Fig. 7. Positions of sites with bowls and censers, decorated with impressions of double twisted cord, mentioned in the article. The distribution of the censers of the Early Catacomb culture and the censers of the Yamnaya culture (after Kaiser, 2013, Fig. 6) is marked with hatched pattern (map prepared by M. Belak, ZRC SAZU). 1 – Melk-Pielachmündung (Austria), 2 – Praha VIII Bohnice (Czech Republic); 3 – Vysočany (Czech Republic); 4 – Brno-Líšeň (Czech Republic); 5 – Havřice (Czech Republic); 6 – Podolie (Slovakia); 7 – Krížovany nad Dudváhom (Slovakia); 8 – Branč (Slovakia); 9 – Iža (Slovakia); 10 – Vel'ka Lomnica (Slovakia); 11 – Žehra-Dreveník (Slovakia); 12 – Nagyhalász-Királyhalom (Hungary); 13 – Ruma (Serbia); 14 – Corlăteni (Romania); 15 – Valea Gerului (Romania); 16 - Mihajlivka (Ukraine); 17 - Skadovsk, Region of Kherson (Ukraine); 18 - Zunda-Tolga, Kalmykia (Russia); 19– Trieste Karst (Italy).

several different sites in a very wide area in central and south east Europe (Fig. 7). Among them, completely preserved vessels but also fragmented ones, only hypothetically attributed to cross-footed decorated bowls, are reported. Some of them were found without context, which makes their exact chronological and cultural definition still an open question. Each of these bowls represents a unique product. Despite this, according to their morphological characteristics and type and syntax of decorations three groups of bowls decorated with cord impressions have been recognised.

In the first group, bowls decorated on the interior with concentric circles or lines are included. Such bowls have been discovered at Havřice (Czech Republic) (Fig. 7: 5; 8: 8; Brnić, 2011, Pl. 5: 7), Krížovany nad Dudváhom (Fig. 7: 7; 8: 13; Točík, 1963, Fig. 9: 7a-c), Branč (Fig. 7: 8; 8: 12; Brnić, 2011, Pl. 5: 6) and Iža (Fig. 7: 9; 8: 11 a, b; Němejcová-Pavúková, 1968, Fig. 22; Brnić, 2011, Fig. 1) (all Slovakia) and Nagyhalász-Királyhalom (Fig. 7: 12; 8: 15; Kalicz, 1968; Pl. 1: 18) (Hungary). The bowls from Nagyhalász, Branč and Krížovany are decorated also on the rim with zig-zag lines, the last has semi-circular garland motifs on the exterior. The bowl from Iža has on the rim incised lines, while on the foot is decorated with cord impressed parallel straight lines. The chronological attribution of the bowl from Iža (and the others here mentioned bowls with similar decorations) varies from author to author. According to some of them it is attributed to the Kostolac period (e.g. Točík, 1963; Nêmejcová-Pavúková, 1968), to others it should be referred to the transitional period between the cultures of Kostolac and Vučedol (Burger, 1980; see also Kulcsár, 2009). Brnić in his doctoral thesis (2011) attributed the bowl from Iža to the post-Kostolac period (precisely to the late Vučedol period) (Brnić, 2011, pp. 36–40) and defined it as an indicator of the influences and/or migrations of the Yamnaya group into the Carpathian basin (as it has already been mentioned by various authors; see Kulcsár, 2009, pp. 123–124 and the literature quoted there).

The second group comprises bowls decorated with cord impressions with more elaborated concentric motifs on the interior, for example in combinations with hatched triangular motifs or clepsydra motifs, and hatched triangular motifs on the exterior. Bowls with this kind of ornamentation are known from Melk-Pielachmündung in Upper Austria (Fig. 7: 1; 8: 1 a, b; Pittioni, 1954, p. 238, Fig. 160, Praha-VIII Bohnice (Fig. 7: 2; 8: 2 a-c; Novotný, 1955, Pl. II: 2a-c) and another unknown site in the Czech Republic (Fig. 8: 7 a, b; Novotný, 1955, Fig. 2: 2a, b), Žehra-Dreveník (Slovakia) (Fig. 7: 11; 8: 14; Novotný, 1955, Fig. 8: 2) and Podolie (Slovakia) (Fig. 7: 6; 8: 9 a-c; Šuteková, 2010, Fig. 6: 2). The latter site is attributed to the Bošáca culture, dated at the turn of the 4th and the 3rd millennium BC (Šuteková, 2010), but among the finds two "Slavonian" (i.e. Vučedol) bowls, knowns as Podolie type (see e.g. Kulcsár, 2009; Brnić, 2011), are reported too. In Slovakia at the site of Vel'ka Lomnica (Fig. 7: 10), a bowl with four small unconnected feet was found too (Novotná, Štefanovičova, 1958, 270, Pl. I: 9). It is comparable to one of the bowls from Pettirosso cave (Fig. 2: 10 – num. Petirosso cave 2).

The third group consists of bowls with a cord impressed decoration on the interior arranged in a cross (or star) motif, similar to the typical ornamentation on the bowls of the Vučedol Culture. Four bowls with this kind of decoration were found in the Czech Republic, at the site of Brno-Líšeň (Fig. 7: 4) and Vysočany (Fig. 7: 3). Another one is known at the site of Podolie in Slovakia (Fig. 7: 6) and Ruma in Serbia (Fig. 7: 13). The bowls from Brno-Líšeň and Vysočany are attributed to the Jevišovice Culture, dated to the first half of the 3rd millennium BC. The first one from the site Brno-Líšeň, a small fragment (Fig. 8: 4 a, b; Brnič, 2011, Pl. 3: 1), is decorated on the interior with triangular motifs and hatched bands, comparable to the decorations on the bowls from Pettine 139463 and 139462 (Fig. 2: 7b, 8b) and Pettirosso cave (Fig. 2: 9a – num. Pettirosso cave 1), while two zig-zag hatched bands cover the exterior, such as in the bowl from Zingari cave 3469 (Fig. 2: 6b). Another bowl from Brno-Líšeň, also fragmentarily preserved (Fig. 7: 6; Novotný, 1955, Fig. 1: 6) shows transverse lines on the rim and part of hatched triangular motifs and lines on the interior. The last bowl from the same site (Fig. 7: 5 a, b; Brnić, 2011, Pl. 3: 2) is decorated on

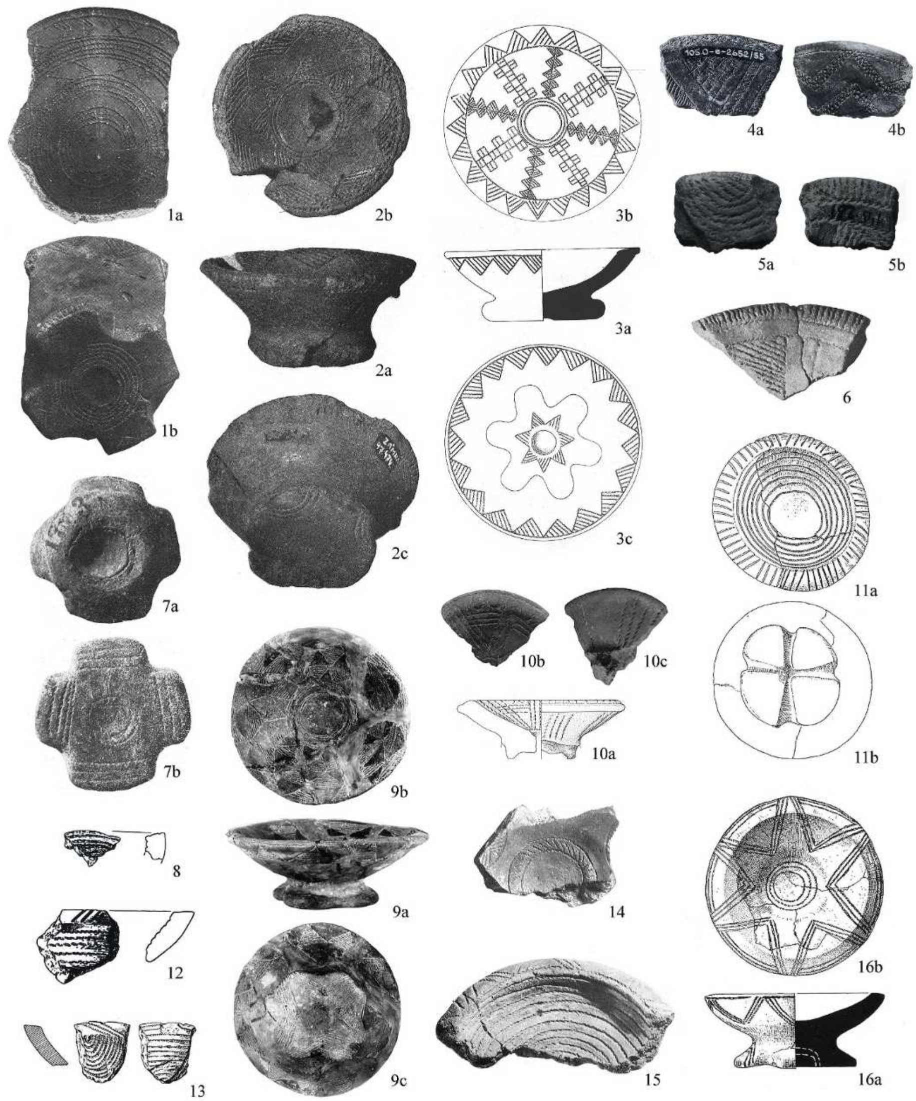

Fig. 8. Drawings of selected bowls from central and south-eastern Europe. 1 a, b – Melk-Pielachmündung (Austria), 2 a-c – Praha VIII Bohnice (Czech Republic); 3 a-c – Vysočany (Czech Republic); 4 a, b, 5 a, b, 6 – Brno-Líšeň (Czech Republic); 7 a, b – unknown site (Czech Republic); 8 – Havřice (Czech Republic); 9 a-c, 10 a-c – Podolie (Slovakia); 11 a, b – Iža (Slovakia); 12 – Branč (Slovakia); 13 – Krížovany nad Dudváhom (Slovakia); 14 – Žehra-Dreveník (Slovakia); 15 – Nagyhalász-Királyhalom (Hungary); 16 a, b – Ruma (Serbia). (after Brnič, 2011, 36, Fig. 1; Pl. 3: 1a-c, 2a, b; 5: 6, 7; Dimitrijević, 1979b, Pl. 17: 6; Kalicz, 1968, Pl. 1: 18; Medunová-Benešová, 1977, Pl. 48; Novotný, 1955, Fig. 1: 6; 2: 2a, b; 8: 2; Pl. II: 2a-c; Pittioni, 1954, 238, Fig. 160; Šuteková, 2010, Fig. 6: 1, 2; Točík, 1963, Fig. 9: 7a-c). Not in scale.

exterior with semi-circular garland motif and on the interior with horizontal and vertical lines, similar to the decoration on the already mentioned bowl from Križovany (Fig. 7: 13). The best analogy for the bowl 20592 from Ciclami cave (Fig. 2: 2) comes from the site Vysočany, where was discovered a bowl with a foot resembling a star with six points (Fig. 8: 3 a-c; Medunová-Benešová, 1977; Pl. 48). Hatched triangles cover the rim and the upper part of the exterior, while on the interior hatched triangles and rectangles form a star motif (Fig. 8: 3a). The bowl from Vysočany is not the only analogy for the specific shape of the foot of Ciclami bowl 20592. In fact, in the Czech Republic, especially nearby Praha, a few bowls with a similar foot have been found, but decorated with "stab and drag" technique and/or incisions (e.g. Novotný, 1955, Fig. 6: 9, 10; 8: 4; Turek, 2012, Fig. 10 attributed by Dimitrijević (1979b, pp.45-46) to the oldest period of the Vučedol Culture and together with the bowls from Melk, Nagyhalász and Iža was interpreted as an indicator of influences of the steppe populations from the east to south east Europe.

As we already mentioned in the introduction, bowls on a cross-shaped foot or on several small round feet, known as censers, are also found in the sites of the Yamnaya and Eastern Catacomb Culture in the Pontic-Caspian steppe region, dated to the 3rd millennium BC (e.g. Kaiser, 2013) (Fig. 9). Since the 1960s, several authors have extensively treated cross-footed bowls as potential indicators of connections between the areas of the Eurasian steppe (Ukraine and southern Russia) and south-eastern Europe, i.e. the Carpathian basin and the Balkan Peninsula (a general overview of the various theses on cross-footed bowls is provided by G. Kulcsár, 2009, pp. 121–124, 308–314). Like the cross-footed bowls, censers are very heterogeneous as to their shape and decoration. Among the similarities between the censers and cross-footed bowls it is worth mentioning the decorative technique, including cord impressions, comparable ornamentations motifs, such as for example concentric circles on the interior, and even the shape of the foot or of the small feet (Fig. 9).

If the question whether the bowls of the Eurasian steppe area influenced the emergence and the development of similar bowls in the Carpathian basin and western Balkan or *vice versa* (see among the last Kaiser, 2013) remains open, it is undeniable that strong interactions between the two areas occurred. In the last decade several publications have presented scientific data, including very recent genetic results, proving large-scale migrations from the north Pontic steppe region to central and south east Europe during the 3rd millennium BC (see e.g. Harrison, Heyd, 2007; Allentoft et al., 2015; Haak et al., 2015; Kristiansen et al., 2017; Heyd, 2017; etc.).

Cross-footed bowls, decorated with cord impressions, can be probably considered as evidence of these interactions, movements of ideas, artefacts and/or even migrations of people, in agreement with recent genetic studies. Unfortunately, detailed chemical and technological data are not yet available for most of the cross-footed bowls from the

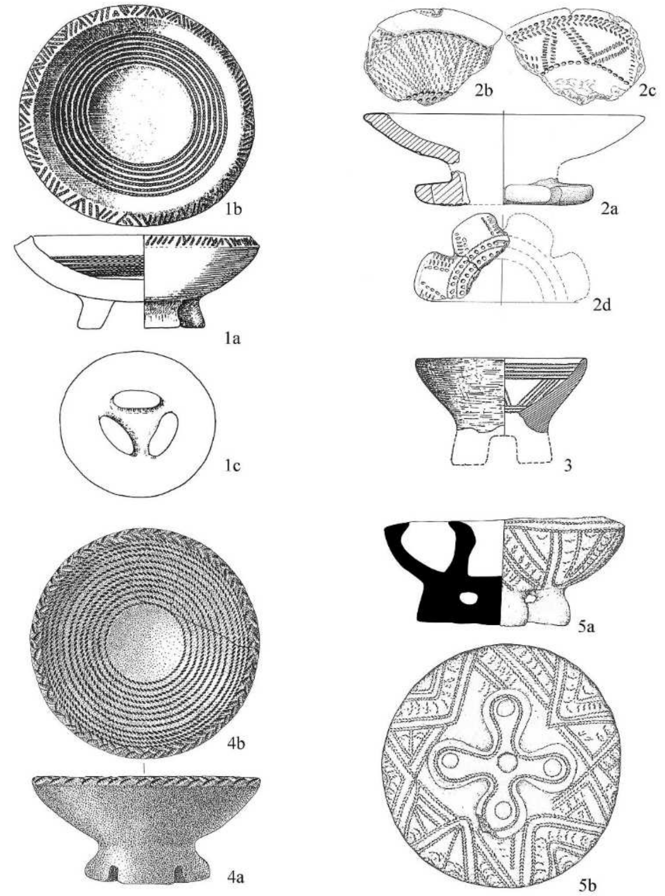

Fig. 9. Drawings of selected censers attributed to Yamnaya (1a-c - Valea Gerului, Romania; 2 a-c – Corlăteni, Romania); 3 – Mihajlivka, Ukraine; 4 a, b - Skadovsk, Region of Kherson, Ukraine) and Eastern Catacomb cultures (5 a, b - Zunda-Tolga, Kalmykia (Russia) (after Roman et al., 1992, Pl. 59.12a–d; Brnić, 2011, Pl. 4: 9; 5: 1 a-c; Kaiser, 2013, Fig. 1; 8). Not in scale.

large area where they have been found (Fig. 7). However, the analytical results presented here are an exception and show that at least four Karst bowls (20591, 20419, 139462 and 139463) were probably imported to the Karst from a distant area, as indicated by the difference with Ljubljansko barje finds and high K_2O content in the vessels from Ciclami and Cotariova caves. High K_2O concentrations in soils, as mentioned above, can be found in the Czech Republic, where the best typological comparisons have been identified. The possibility that these connections are due to movements of people triggered by migrations from the north Pontic steppe region to central Europe is certainly appealing, but only future dedicated analyses and studies might confirm it.

Declaration of competing interest

There are no conflict of interest.

Acknowledgments

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References

Allentoft, M.E., Sikora, M., Sjögren, K.-G., Rasmussen, S., Rasmussen, M., Stenderup, J., Damgaard, P.B., Schroeder, H., Ahlström, T., Vinner, L., Malaspinas, A.-S., Margaryan, A., Higham, T., Chivall, D., Lynnerup, N., Harvig, L., Baron, J., Della Casa, P., Dąbrowski, P., Duffy, P.R., Ebel, A.V., Epimakhov, A., Frei, K., Furmanek, M., Gralak, T., Gromov, A., Gronkiewicz, S., Grupe, G., Hajdu, T., Jarysz, R., Khartanovich, V., Khokhlov, A., Kiss, V., Kolář, J., Kriiska, A., Lasak, I., Longhi, C., McGlynn, G., Merkevicius, A., Merkyte, I., Metspalu, M., Mkrtchyan, R., Moiseyev, V., Paja, L., Pálfi, G., Pokutta, D., Pospieszny, Ł., Price, T.D., Saag, L., Sablin, M., Shishlina, N., Smrčka, V., Soenov, V.I., Szeverényi, V., Tóth, G., Trifanova, S.V., Varul, L., Vicze, M., Yepiskoposyan, L., Zhitenev, V., Orlando, L., Sicheritz-Pontén, T., Brunak, S., Nielsen, R., Kristiansen, K., Willerslev, E., 2015. Population genomics of bronze age Eurasia. Nature 522, 167–172. https://doi/.org/10.1038/nature14507.

Belgya, T., Révay, Zs, 2004. Gamma-ray spectrometry. In: Molnár, G.L. (Ed.), Handbook of Prompt Gamma Activation Analysis with Neutron Beams. Kluwer Academic Publishers, Dordrecht/Boston/New York, pp. 71–111.

Bernardini, F., Tuniz, C., Coppa, A., Mancini, L., Dreossi, D., Eichert, D., Turco, G., Biasotto, M., Terrasi, F., De Cesare, N., Hua, Q., Levchenko, V., 2012. Beeswax as dental filling on a neolithic human tooth. PloS One 7 (9), e44904. https://doi:10.1371/journal.pone.0044904.

Bernardini, F., De Min, A., Lenaz, D., Kasztovszky, Z., Turk, P., Velušček, A., Szilágyi, V., Tuniz, C., Montagnari Kokelj, E., 2014a. Mineralogical and chemical constraints about the provenance of Copper Age polished stone axes of Ljubljana type from Caput Adriae. Archaeometry 56 (2), 175–202.

Bernardini, F., De Min, A., Lenaz, D., Kasztovszky, Z., Turk, P., Velušček, A., Tuniz, C., Montagnari Kokelj, E., 2014b. Petrographic and geochemical comparison between the Copper Age Ljubljana type axes and similar lithotypes from Eisenkappler Diabaszug complex (southern Austria). J. Archaeol. Sci. 41, 511–522.

Bernardini, F., Vecchiet, A., De Min, A., Lenaz, D., Mendoza Cuevas, A., Gianoncelli, A., Dreossi, D., Tuniz, C., 2016. Neolithic pottery from the Trieste Karst (northeastern Italy): a multi-analytical study. Microchem. J. 124, 600–607.

Bernardini, F., Sibilia, E., Kasztovszky, Z., Boscutti, F., De Min, A., Lenaz, D., Turco, G., Micheli, R., Tuniz, C., Montagnari Kokelj, M., 2018. Evidence of open-air late prehistoric occupation in the Trieste area (North-Eastern Italy): dating, 3D clay plaster characterization and obsidian provenancing. Archaeol. Anthropol. Sci. 10, 1933–1943. https://doi.org/10.1007/s12520-017-0504-7.

Bernardini, F., De Min, A., Lenaz, D., Kasztovszky, Zs, Lughi, V., Modesti, V., Tuniz, C., Tecchiati, U., 2019a. Polished stone axes from varna/nössingbühel and castelrotto/grondlboden, south tyrol (Italy). Archaeol. Anthropol. Sci. 11 (4), 1519–1531. https://doi.org/10.1007/s12520-018-0612-z.

Bernardini, F., Leghissa, E., Prokop, D., Velušček, A., De Min, A., Dreossi, D., Donato, S., Tuniz, C., Princivalle, F., Montagnari Kokelj, M., 2019b. X-ray computed microtomography of Late Copper Age decorated bowls with cross-shaped foots from central Slovenia and the Trieste Karst (North-Eastern Italy): technology and paste characterisation. Archaeol. Anthropol. Sci. https://doi.org/10.1007/s12520-019-00811-w.

Bianchin Citton, E., Balista, C., Fontana, A., Martinelli, N., Mondini, C., Tecchiati, U., 2015. Il sito del Col del Buson (Belluno) nella Valle dell'Ardo: aspetti geomorfologici, strutturali, culturali e paleoeconomici delle stratificazioni dell'Età del rame. In: Leonardi, G., Tiné, V. (Eds.), Preistoria e Protostoria del Veneto, Studi di Preisotria e Protostoria 2, Firenze 2015, pp. 157–167.

Brnić, Ž., 2011. Prodori Stranih Kultura U Kasnom Eneolitu Karpatske Kotline. Ph.D. Thesis. University of Zagreb, Faculty of Humanities and Social Sciences, Zagreb.

Buchvaldek, M., 1967. Die Schnurkeramik in Böhmen. Acta Universitatis Carolinae Philosophica et Historica monographia XIX. (Prag).

Burger, I., 1980. Die chronologische Stellung der Fußschalen in den endneolithischen Kulturgruppen Mittel- und Südosteuropas. In: Spindler, K. (Ed.), Vorzeit zwischen Main und Donau. Neue archäologische Forschungen und Funde aus Franken und Altbayern. Erlanger Forschungen Reihe A 26, Erlangen, pp. 11–45.

Choi, H.D., Firestone, R.B., Lindstrom, R.M., Molnár, G.L., Mughabghab, S.F., Paviotti-Corcuera, R., Révay, Zs, Trkov, A., Zerkin, V., Chunmei, Z., 2007. Database of Prompt Gamma Rays from Slow Neutron Capture for Elemental Analysis. International Atomic Energy Agency, Vienna.

Dimitrijević, S., 1961. Problem neolita i eneolita u sjeverozapadnoj Jugoslaviji/Problem des Neolithikums und Aeneolithikums in Nordwestjugoslawien. Opusc. Archaeol. 5, 5–78.

Dimitrijević, S., 1967. Die Ljubljana Kultur. Problem des Substrats, der Genese und der regionalen Typologie. Archaeologia Iugoslavica, vol. 8, 1–27.

Dimitrijević, S., 1979a. Vučedolska kultura i vučedolski kulturni kompleks. In: Benac, A. (Ed.), Praistorija Jugoslovanskih Zemalja III – Eneolit. Sarajevo, pp. 267–341.

Dimitrijević, S., 1979b. Zur Frage der Genese und der Gliederung der Vučedoler Kultur in dem Zwischenstromlade Donau-Drau-Sawe (O pitanju geneze i podjele Vučedolske kulture u međuriječju Dunava, Drave i Save). Vjesnik arheološkog muzeja u Zagrebu 10–11, 1–96 Zagreb.

Duches, R., Nannini, N., Fontana, A., Boschin, F., Crezzini, J., Bernardini, F., Tuniz, C., Dalmeri, G., 2018. Archeological bone injuries by lithic backed projectiles: new evidence on bear hunting from the Late Epigravettian site of Cornafessa rock shelter (Italy). Archaeol. Anthropol. Sci. 11 (5), 2249–2270. https://doi.org/10.1007/

s12520-018-0674-y.
Ecsedy, I., 1982. Ásatások zók-várhegyen (1977-1982) (előzetes jelentés) (excavations at zók-várhegy (1977-1982) preliminary report). Janus Pannonius Múzeum Évkönyve 27, 59–105 Pécs 1983.
Flego, S., Župančič, M., 2012. K arheološki dejavnosti L. K. Moserja v jamah Tržaškega krasa. In: Flego, S., Rupel, L. (Eds.), 20012, Ludwig Karl Moser (1845–1918) med Dunajem in Trstom: zbornik Mednarodnega študijskega dne, Trst, 21. novembra 2008/Ludwig Karl Moser (1845–1918) tra Vienna e Trieste: Atti della Giornata internazionale di Studi Trieste, 21 novembre 2008, Ljubljana, pp. 127–190.
Furholt, M., 2003. Die absolutchronologische Datierung der schnurkeramik in Mitteleuropa und Südskaninavien. Universitätsforschungen zur Prähistorischen Archäologie 101 (Bonn).
Gilli, E., Montagnari Kokelj, E., 1993. La grotta dei Ciclami nel Carso Triestino (Materiali degli scavi 1959-1961). Atti della Società per la Preistoria e Protostoria della Regione Friuli-Venezia Giulia 7, 65–162.
Gilli, E., Montagnari Kokelj, E., 1996. La grotta degli Zingari nel carso triestino (materiali degli scavi 1961-1965). Atti della Società per la Preistoria e Protostoria della Regione Friuli-Venezia Giulia 9, 63–126.
Govedarica, B., 1989a. O kulturnom i hronološkom položaju nalaza ljubljanske kulture na Jadranskom području (Einiges über die kulturelle und zeitliche Stellung der Funde der Ljubljana-Kultur aus dem adriatischen Gebiet). Arheol. Vestn. 39–40, 401–412.
Govedarica, B., 1989b. Rano bronzano doba na području istočnog Jadrana (L'age du bronze ancien dans la region de l'Adriatique de l'est). Djela ANUBiH 67/7 (Sarajevo).
Haak, W., Lazaridis, I., Patterson, N., Rohland, N., Mallick, S., Llamas, B., Brandt, G., Nordenfelt, S., Harney, E., Stewardson, K., Fu, Q., Mittnik, A., Bánffy, E., Economou, C., Francken, M., Friederich, S., Garrido Pena, R., Hallgren, F., Khartanovich, V., Khokhlov, A., Kunst, M., Kuznetsov, P., Meller, H., Mochalov, O., Moiseyev, V., Nicklisch, N., Pichler, S.L., Risch, R., Rojo Guerra, M.A., Roth, C., Szécsényi-Nagy, A., Wahl, J., Meyer, M., Krause, J., Brown, D., Anthony, D., Cooper, A., Alt, K.W., Reich, D., 2015. Massive migration from the steppe was a source for Indo-European languages in Europe. Nature 522, 207–211. https://doi.org/10.1038/nature14317.
Harrison, R., Heyd, V., 2007. The transformation of Europe in the third millennium BC: the example of 'le petit chasseur I + III' (sion, valais, Switzerland). Praehistorische Z. 82, 129–214. https://doi.org/10.1515/PZ.2007.010.
Heyd, V., 2017. Kossinna's smile. Antiquity 91 (356), 348–359. https://doi.org/10.15184/aqy.2017.21.
Kristiansen, K., Allentoft, M.E., Frei, K.M., Iversen, R., Johannsen, N.N., Kroonen, G., Pospieszny, Ł., Price, T.D., Rasmussen, S., Sjögren, K.-G., Sikora, M., Willerslev, E., 2017. Re-theorising mobility and the formation of culture and language among the Corded Ware Culture in Europe. Antiquity 91 (356), 334–347. https://doi.org/10.15184/aqy.2017.17.
Kahl, W.-A., Ramminger, B., 2012. Non-destructive fabric analysis of prehistoric pottery using high-resolution X-ray microtomography: a pilot study on the late Mesolithic to Neolithic site Hamburg- Boberg. J. Archaeol. Sci. 39, 2206–2219.
Kaiser, E., 2013. Import, imitation and interaction: a critical review of the chronology and significance of cross footed bowls of the third millennium BC in southeastern and eastern Europe. In: Heyd, V., Kulcsár, G., Szeverényi, V. (Eds.), Transitions to the Bronze Age Interregional Interaction and Socio-Cultural Change in the Third Millennium BC Carpathian Basin and Neighbouring Regions. Archaeolingua 49, pp. 139–152.
Kasztovszky, Zs, 2007. Application of prompt gamma activation analysis to investigate archaeological ceramics. Archeometria Műhely IV/2, 49–54. elektronic journal. http://www.ace.hu/am/.
Kasztovszky, Zs, Antczak, M.M., Antczak, A., Millan, B., Bermúdez, J., Sajo-Bohus, L., 2004. Provenance study of Amerindian pottery figurines with prompt gamma activation analysis. Nukleonika 49 (3), 107–113.
Kasztovszky, Zs, Biró, K.T., Markó, A., Dobosi, V., 2008. Cold neutron prompt gamma activation analysis – a non-destructive method for characterisation of high silica content chipped stone tools and raw materials. Archaeometry 50 (1), 12–29.
Korošec, P., 1956. Nekaj novih podatkov o slavonski kulturi na področju Jadranske obale (Einige neue Angaben betreffend die slawonische Kultur im Bereiche der Adriaküste). Arheol. Vestn. 7, 369–383.
Korošec, P., 1959. Kulturna opredelitev materialne kulture na koliščih pri Igu (Kultureinreihung der materiellen Kultur in den Pfahlbauten bei lg). Arheol. Vestn. 9–10, 94–107.
Kulcsár, G., 2009. The beginnings of the bronze age in the Carpathian basin. The makó–kosihy–caka and the somogyvár–vinkovci cultures in Hungary. Varia archaeologica Hungarica 23 (Budapest).
Leghissa, E., 2015. Način okraševanja keramike ljubljanske kulture in pramenaste keramike – eksperimentalna arheologija (Decorating the pottery of the Ljubljana culture and the Litzen pottery—an experimental archaeology case study). Arheol. Vestn. 66, 275–292.
Leghissa, E., 2017. Dežmanova Kolišča Pri Igu in Njihovo Mesto V Pozni Bakreni in Zgodnji Bronasti Dobi (The Dežman (Deschmann) Pile Dwellings Near Ig in the Late Copper and Early Bronze Ages). Ph.D. Thesis. University of Ljubljana, Faculty of Arts, Department of archaeology, Ljubljana.
Lindahl, A., Pikirayi, I., 2010. Ceramics and change: an overview of pottery production techniques in northern South Africa and eastern Zimbabwe during the first and second millennium AD. Archaeol. Anthropol. Sci. 2, 133–149.
Marzolini, G., 1970. La grotta dell'Edera, Annali del Gruppo Grotte dell'Associazione XXX Ottobre 4. pp. 19–35.
Marzolini, G., 1983. La Grotta del Pettine di Gabrovizza (Carso Triestino). In: Atti del Convegno "Preistoria del Friuli-Venezia Giulia" (Trieste, aprile 1981). Atti della Società per la Preistoria e Protostoria della regione Friuli-Venezia Giulia 4, pp. 33–43.
Montagnari Kokelj, E., 2015. Carso fra Italia e Slovenia dal 1950 a oggi: scavi, revisioni, banche dati e problematiche rivisitate. In: 150 anni di preistoria e protostoria in Italia. Atti della 46 Riunione Scientifica dell'Istituto Italiano di Preistoria e Protostoria, Roma, 23-26 novembre 2011. Studi di Preistoria e Protostoria 1, pp. 551–558.
Montagnari Kokelj, E., Greif, T., Presello, E., 2002. La Grotta Cotariova Nel Carso Triestino (Italia Nord-Orinetale). Materiali Ceramici Degli Scavi 1950-70/the Grotta Cotoriova in the Trieste Karst (North-Eastern Italy). The Pottery of the 1950-70 Excavations. Aquileia Nostra LXXIII, pp. 37–190.
Moser, K., 1899. Der Karst und seine Höhlen. (Triest.).
Nemejcova-Pavukova, V., 1968. Aneolithische Siedlung und Stratigraphie in Iža. Slovenska archeologia 16-2. pp. 353–433.
Novotná, M., Štefanovičová, T., 1958. Výšinné sídlisko vo Vel'kej Lomnici a osídlenie kanelovanou kultúrou na Spiši. Sborník Filozofickej fakulty Univerzity Komenského Musaica 9, 267–290.
Novotný, B., 1955. Slavónska kultúra v Československu. Slov. Archeol. 3, 5–69.
Parzinger, H., 1984. Die Stellung der Uferrandsiedlungen bei Ljubljana im äneolitischen und frühbronzezeitlichen Kultursystem der mittleren Donauländer (Mesto kolišč Ljubljanskega barja v eneolitiku in zgodnji bronasti dobi srednjega Podonavja). Arheol. Vestn. 35, 13–75.
Patay, P., 1940. Vučedoli-stílusú talpas tálak elterjedése Magyarországon (La répartition des plats à pied du type de Vučedol en Hongrie). Archaeol. Értesito 3/1, 1–12.
Révay, Zs, 2009. Determining elemental composition using prompt gamma activation analysis. Anal. Chem. 81, 6851–6859.
Révay, Zs, Belgya, T., Molnár, G.L., 2005. Application of hypermet-PC in PGAA. J. Radioanal. Nucl. Chem. 265, 261–265.
Roman, P., Dodd-Opriţescu, A., János, P., 1992. Beiträge zur Problematik der schnurverzierten Keramik Südosteuropas. Heidelberger Akademie der Wissenschaften, Internationale Interakademische Kommission für die Erforschung der Vorgeschichte des Balkans, Monographien 3. Mainz am Rhein 1992.
Rudnick, R.L., Gao, S., 2004. Composition of the continental crust. Treatise on Geochemistry 3, 1–65.
Šuteková, J., 2010. Ein Einblick in die post-Badener Epoche in der Westslowakei. In: Šuteková, J., Pavúk, P., Kalábková, P., Kovár, B. (Eds.), Panta Rhei. Studies on the Chronology and Cultural Development of South-Eastern and Central Europe in Earlier Prehistory Presented to Juraj Pavúk on the Occasion of his 5. Birthday. Studia Archaeologica et Mediaevalia XI. Bratislava, pp. 469–489.
Szakmány, G., Kasztovszky, Z., Szilágyi, V., Starnini, E., Friedel, O., Biró, K.T., 2011. Discrimination of prehistoric polished stone tools from Hungary with non-destructive chemical Prompt Gamma Activation Analyses (PGAA). Eur. J. Mineral 23, 883–893.
Szentmiklósi, L., Belgya, T., Révay, Zs, Kis, Z., 2010. Upgrade of the prompt gamma activation analysis and the neutron-induced prompt gamma spectroscopy facilities at the Budapest Research Reactor. J. Radioanal. Nucl. Chem. 286, 501–505.
Szilágyi, V., Gyarmati, J., Tóth, M., Taubald, H., Balla, M., Kasztovszky, Zs, Szakmány, Gy, 2012. Petro-mineralogy and geochemistry as tools of provenance analysis on archaeological pottery: study of Inka Period ceramics from Paria, Bolivia. J. S. Am. Earth Sci. 36.
Thér, R., 2015. Identification of pottery-forming techniques using quantitative analysis of the orientation of inclusions and voids in thin sections. Archaeometry 58, 222–238.
Točík, A., 1963. K otázke mladého eneolitu na juhozápadnom Slovensku (Zur Frage des späten Äneolithikums in der Südwestslowakei). Študijné Zvesti Archeologického Ústavu Slovenskej akadémie Vied 11, 5–22 Nitra.
Tuniz, C., Bernardini, F., Cicuttin, A., Crespo, M.L., Dreossi, D., Gianoncelli, A., Mancini, L., Mendoza Cuevas, A., Sodini, N., Tromba, G., Zanini, F., Zanolli, C., 2013. The ICTP-Elettra X-ray laboratory for cultural heritage and archaeology. Nucl. Instrum. Phys. Res. A 711, 106–110.
Turek, J., 2012. The neolithic enclosures in transition. Tradition and change in the cosmology of early farmers in central Europe. In: In: Gibson, A. (Ed.), Enclosing the Neolithic Recent Studies in Britain and Europe, vol. 2440. BAR International Series, pp. 185–201.
Resnikov prekop: najstarejša koliščarska naselbina na Ljubljanskem barju (Resnikov prekop: the oldest pile-dwelling settlement in the Ljubljansko barje). In: Velušček, A. (Ed.), Opera Instituti Archaeologici Sloveniae 10, Ljubljana. Inštitut za arheologijo ZRC SAZU, Založba ZRC.