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?

Elena Leghissa\textsuperscript{a}, Zsolt Kasztovszky\textsuperscript{b}, Veronika Szilágyi\textsuperscript{b}, Ildikó Harsányi\textsuperscript{b}, Angelo De Min\textsuperscript{c}, Francesco Princivalle\textsuperscript{c}, Manuela Montagnari Kokel\textsuperscript{d}, Federico Bernardini\textsuperscript{e,f,g,h}

\textsuperscript{a}ZRC SAZU, Institute of Archaeology, Novi trg 1, 1000, Ljubljana, Slovenia
\textsuperscript{b}Nuclear Analysis and Radiography Department, Centre for Energy Research, Eötvös Thöge 26-33, Budapest, H-1121, Hungary
\textsuperscript{c}Department of Mathematics and Geosciences, University of Trieste, Via Weiss 8, 34127, Trieste, Italy
\textsuperscript{d}Department of Humanities, University of Trieste, Viale Lazzarino Vecchio 6-8, 34123, Trieste, Italy
\textsuperscript{e}Centro Fermi, Museo Storico Della Fisica e Centro di Studi e Ricerche "Enrico Fermi", Piazza del Viminale 1, 00184, Roma, Italy
\textsuperscript{f}Multidisciplinary Laboratory, The "Abdu Salam" International Centre for Theoretical Physics, Strada Costiera 11, 34151, Trieste, Italy

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\section*{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, K2O 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 mainly 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 K2O 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.

\section{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 Kokel, 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/Orefova pejca (Fig. 1: 1; Gilli and Montagnari Kokel (1993) - complete revision of findings; Cataricova/Catarjeka jama (Fig. 1: 3; Montagnari Kokel et al., 2002 -

\textsuperscript{*}Corresponding author. Centro Fermi, Museo Storico della Fisica e Centro di Studi e Ricerche "Enrico Fermi", Piazza del Viminale 1, 00184, Roma, Italy.
\textbf{E-mail address:} fbernard@ictp.it (F. Bernardini).

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complete revision of findings); Pettine/jama Pečinka (Fig. 1: 4; Marzolini, 1983 - original publication); Edera/Stenača (Fig. 1: 5; Marzolini, 1970 - complete revision of findings); Zingari/Cigansaška jama (Fig. 1: 2; Gilli and Montagnani Kokelj, 1996 - complete revision of findings); Pettiroso/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 (Demjanovski kolica 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; Fazinger, 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 re-defined 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 Montagnani 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 (Furchentich) 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 Coturiova 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
all obtained with impressions of twisted double cord, the same technique used on one of the bowls from the Ciclamí 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 Pettiroso cave between the end of the 19th century and the beginning of the 20th century (Moser, 1899, 64, Tab. II; Plego 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 (Lehgissa, 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-drág 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-drág 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 Lehgissa, 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 Lehgissa, 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 prokop (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

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**Table 1**

<table>
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<tr>
<th>Inventory number</th>
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<tr>
<td>3469</td>
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</tr>
<tr>
<td>201851</td>
<td>Ciclamí cave</td>
</tr>
<tr>
<td>201859</td>
<td>Cobrava cave</td>
</tr>
<tr>
<td>331461</td>
<td>Pettine cave</td>
</tr>
<tr>
<td>331462</td>
<td>Edera cave</td>
</tr>
<tr>
<td>331464</td>
<td>Deschmann’s pile dwellings</td>
</tr>
</tbody>
</table>

**Cultural-chronological attribution**

- Influence of Vučedol Culture?
- Petrographic analysis
- PGAA analysis
- MicroCT analysis

**Methods**

- µCT
- PGAA
- OM

**References**

- Gill and Montagnari Boldi (1990), Fig. 34:202
- Gill and Montagnari Boldi (1990), Fig. 51:497
- Maccari and Boldi et al. (2001), Pl. 27:245
- Montagnari Boldi et al. (2002), Pl. 27:245
- Montagnari Boldi et al. (2003), Pl. 21:25
- Maccari and Boldi (2006), Pl. 27:245

- Moser (1899), 64, Fig. 12, Lehen, 1967, Pl. 21:17, 18a.
- Leggissa (2007), Pl. 104:2
- Leggissa (2017), Pl. 104:3
- Leggissa (2017), Pl. 104:4
- Leggissa (2017), Pl. 104:5
- Leggissa (2017), Pl. 104:6
- Leggissa (2017), Pl. 104:7
- Leggissa (2017), Pl. 104:8
- Leggissa (2017), Pl. 104:9
- Leggissa (2017), Pl. 104:10
- Leggissa (2017), Pl. 104:11
- Leggissa (2017), Pl. 104:12
- Leggissa (2017), Pl. 104:13
- Leggissa (2017), Pl. 104:14
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 feet, 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.,
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 9.610^{18} 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 (Belgysa 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 cm³. 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 k₀ 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; Szlágyi 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 P₂O₅ (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 P₂O₅-rich samples, that is bowl B15939 (Bernardini et al., 2019b). Considering the K₂O and Al₂O₃ 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 K₂O 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) (K₂O content about 3 wt%). These high K₂O values are more probably due to a prevalence of the illicic 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.gkf. publ/foregasatlases) 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 K₂O content is 2.02% in subsoil and 1.92% in topsoil, with a range between <0.01 and 6.05% K₂O in subsoil and 0.026 and 6.13% K₂O in topsoil. High K₂O values are reported neither from the Karst area nor from central Slovenia, while they reach high concentrations in the Alp 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 (K₂O, TiO₂, CaO, MnO, Fe₂O₃, 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, Fe₂O₃ 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 K₂O, MnO and Fe₂O₃ 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 K₂O 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 TiO₂ 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$_2$O$_3$: total Fe content. Data recalculated on a volatile-free basis.

<table>
<thead>
<tr>
<th>Samples</th>
<th>3469</th>
<th>20591</th>
<th>20592</th>
<th>20419</th>
<th>139461</th>
<th>139462</th>
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<th>139464</th>
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<tr>
<td>SiO$_2$ (wt%)</td>
<td>45.84</td>
<td>61.85</td>
<td>44.27</td>
<td>56.59</td>
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<td>TiO$_2$</td>
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<td>0.71</td>
<td>0.67</td>
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<tr>
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<td>15.86</td>
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<td>5.78</td>
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<td>MnO</td>
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<td>0.11</td>
<td>0.06</td>
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<td>MgO</td>
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<td>2.87</td>
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<td>1.54</td>
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<td>CaO</td>
<td>23.60</td>
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<td>26.17</td>
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<td>2.97</td>
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<td>0.20</td>
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</table>

| B (ppm) | 43 | 68 | 42 | 64 | 49 | 63 | 47 | 61 |
| Ca | 304 | 38 | 186 | 51 | 28 | 76 | 45 | 82 |
| Mg | 0 | 3 | 0 | 0 | 1 | 0 | 1 | 0 |
| Na | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| K | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cl | 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 |

Note: The table continues on the next page.

Table 3
Major (wt%) and some trace (ppm) elements of the bowls from Deschmann's pile dwellings analysed by PGAA. Fe$_2$O$_3$: total Fe content. Data recalculated on a volatile-free basis.

<table>
<thead>
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Note: The table continues on the next page.

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

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<th>Samples</th>
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**Fig. 4.** K₂O vs. Al₂O₃ 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 Cliton 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(26,147),(976,965)

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 (Ciciliani 20591, Fig. 2: 1; Cotoriava 20419, Fig. 2: 3; Pettine 139462, Fig. 2: 8; Pettine 139463, Fig. 2: 7; 5C–D), but not from the area of Ljubljansko barje. Chemical data has revealed a similarity between bowl 20591 from Ciciliani cave (Fig. 2: 1) and vessel 20419 from Cotoriava 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 Cotoriava 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 Ciciliani cave – 20592, Fig. 2: 2 – and two bowls from the Cotoriava 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
few vessels of other types (see e.g. Leghissa, 2017, Pl. 65: 1). The cross-footed bowls from the Ljubljanisko 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. Bachvaldek, 1967; Furbolt, 2003).

Cross-footed bowls decorated with cord impressions represent a specific type of vessels of the 3rd millennium BC, which are known from
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; Brnič, 2011, Pl. 5: 7), Krňovany nad Duvšíhom (Fig. 7: 7; 8: 13; Točík, 1963, Fig. 9: 7a-c), Brně (Fig. 7: 8; 8: 12; Brnič, 2011, Pl. 5: 6) and Iža (Fig. 7: 9; 8: 11 a, b; Němejcová-Pavuková, 1968, Fig. 22; Brnič, 2011, Fig. 1) (all Slovakia) and Nagyalház-Királyhalom (Fig. 7: 12; 8: 15; Kalicz, 1968; Pl. 1: 18) (Hungary). The bowls from Nagyalház, Brně and Krňovany 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; Němejcová-Pavuková, 1968), to others it should be referred to the transitional period between the cultures of Kostolac and Vučedol (Burger, 1980; see also Kulcsár, 2009). Brnič in his doctoral thesis (2011) attributed the bowl from Iža to the post-Kostolac period (precisely to the late Vučedol period) (Brnič, 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; Šteková, 2010, Fig. 6: 2). The latter site is attributed to the Boška culture, dated at the turn of the 4th and the 3rd millennium BC (Šteková, 2010), but among the finds two “Slavonian” (i.e. Vučedol) bowls, known as Podolie type (see e.g. Kulcsár, 2009; Brnič, 2011), are reported too. In Slovakia at the site of Veľka 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 Pettirrosso cave (Fig. 2: 10 – num. Pettirrosso 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 Petrinec 139463 and 139462 (Fig. 2: 7b, 8b) and Pettirrosso cave (Fig. 2: 9a – num. Pettirrosso 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; Brnič, 2011, Pl. 3: 2) is decorated on
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 Krížovany (Fig. 7: 13). The best analogy for the bowl 20592 from Cíclami 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 Cíclami 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 Melč, Nagyhalász and Iza was interpreted as an indicator of influences of the steppe populations from the east to south 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. Kulesar, 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
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 Ljubljanjske barje finds and high K2O content in the vessels from Cimići and Kotarića caves. High K2O 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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