Neolithic pottery from the Trieste Karst (northeastern Italy): A multi-analytical study☆

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ABSTRACT

A group of Neolithic potsherds from caves of the Trieste Karst (northeastern Italy) belonging to the Vlaška Group has been studied through a multi-analytical approach mainly based on non-destructive X-ray computed microtomography (μCT) and portable X-ray fluorescence (XRF), combined with X-ray diffraction (XRD) and optical microscopy (OM) to investigate both manufacture technology and provenance of the vases. Most samples, probably produced using a modelling technique, were made using clay-silt size paste containing quartz inclusions, tempered with the addition of abundant calcite and some limestone fragments. Calcite minerals, very common in the karstic environment, were probably obtained by grinding speleothems. This peculiar paste seems to be typical of the Karst area since prehistoric times. One single sample (5880), characterized by an unusual shape recalling those of the Fiorano culture (present in Emilia-Romagna and Veneto), shows a fine-grained fabric with numerous grog fragments, quartz, minor feldspar but without calcite. The 2D and 3D μCT-derived fabric parameters, reflecting the manufacture technology, are also quite different from those of the local vases. These features suggest that sample 5880 was manufactured elsewhere and later reached the Karst, directly or indirectly. The combined use of conventional techniques and non-destructive XRF and μCT, which allows the quantification of clay material, lithic inclusions and porosity, has proved to be an effective approach to investigate both technology and provenance of ceramic materials.

1. Introduction

The physical–chemical study of prehistoric pottery can provide information on provenance (local vs. non-local raw materials and manufacturing) and forming technology of the artefacts. Different analytical techniques, including non-destructive methods such as portable X-ray fluorescence (XRF), neutron activation analysis (NAA) and prompt gamma activation analysis (PGAA), provide chemical composition of ancient pottery [1–5], while thin section optical microscopy (OM) and X-ray diffraction (XRD) give information on paste fabric, mineral components and manufacturing techniques. Recent studies have shown that X-ray computed microtomography (μCT) can provide useful textural and technological information in the study of archaeological pottery [6].

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In this work we have adopted a multi-analytical approach mainly based on non-destructive methods (XRF and μCT) combined with traditional XRD and OM to investigate both technology and provenance of a group of vases from the Trieste Karst (northeastern Italy, Table 1), found in layers attributed to the Neolithic Vlaška Group [7].

Scientific studies of Neolithic pottery from the northeastern Adriatic regions are still limited [8–12]: the present work aims to understand if differences recognized through traditional typological analysis reflect also differences in paste composition, ceramic forming process and area of production, i.e. local vs. non-local manufacturing processes and thus connections with more or less distant areas.

2. Archaeological background

Evidence on the human presence in the Italian part of the Karst (northeastern Italy) throughout prehistory comes almost exclusively from caves and rock shelters – approx. 180 out of more than 3000 natural cavities – investigated by both speleologists and professional archaeologists since the last decades of the 19th century [13]. The

Table 1
List of the Neolithic analysed samples with the indication of the chronology, archaeological site, typology, analytical methods, voxel size of μCT data-sets and references. XRD: X-ray diffraction; OM: optical microscopy; XRF: non-destructive X-ray fluorescence; μCT: X-ray computed microtomography.

Number	Chronology	Cave	Typology	Analytical Methods	μCT voxel size	References
3523	Neolithic, Vlaška Group	Zingari	*vaso a coppa*	XRD; OM; XRF; μCT	37.61	Gilli, Montagnari Kokelj 1996, n. 112 [21]
3533	Neolithic, Vlaška Group	Zingari	*vaso a coppa*	XRD; OM; XRF; μCT	39.71	Gilli, Montagnari Kokelj 1996, n. 47 [21]
3534	Neolithic, Vlaška Group	Zingari	*vaso a coppa*	XRD; μCT	37.61	Gilli, Montagnari Kokelj 1996, n. 45 [21]
3540	Neolithic, Vlaška Group	Zingari	*vaso a coppa*	XRD; OM; XRF; μCT	39.71	Gilli, Montagnari Kokelj 1996, n.67 [21]
3541	Neolithic, Vlaška Group	Zingari	*vaso a coppa*	XRD; OM; XRF; μCT	30.95	Gilli, Montagnari Kokelj 1996, n. 46 [21]
3543	Neolithic, Vlaška Group	Zingari	*vaso a coppa*	XRD; OM; XRF; μCT	39.71	Gilli, Montagnari Kokelj 1996, n. 73 [21]
3545	Neolithic, Vlaška Group	Zingari	*vaso a coppa*	XRD; OM; XRF; μCT	37.61	Gilli, Montagnari Kokelj 1996, n. 72 [21]
3546	Neolithic, Vlaška Group	Zingari	*vaso a coppa*	XRD; OM; XRF; μCT	30.95	Gilli, Montagnari Kokelj 1996, n. 74 [21]
3548	Neolithic, Vlaška Group	Zingari	*vaso a coppa*	XRD; OM; XRF; μCT	37.61	Gilli, Montagnari Kokelj 1996, n. 48 [21]
3556	Neolithic, Vlaška Group	Zingari	*vaso a coppa*	XRD; OM; XRF; μCT	39.71	Gilli, Montagnari Kokelj 1996, n. 2 [21]
NP	Neolithic, Vlaška Group	Zingari	*vaso a coppa*	OM; μCT	37.61	Gilli, Montagnari Kokelj 1996, n. 75 [21]
2697	Neolithic, Vlaška Group	Tartaruga	*vaso a coppa*	XRD; OM; XRF; μCT	37.61	Cannarella and Redivo 1983 [22]
5880	Neolithic, Vlaška Group	Ciclami	mug	XRD; OM; XRF; μCT	11.98	Gilli, Montagnari Kokelj 1993, n. 102 [23]

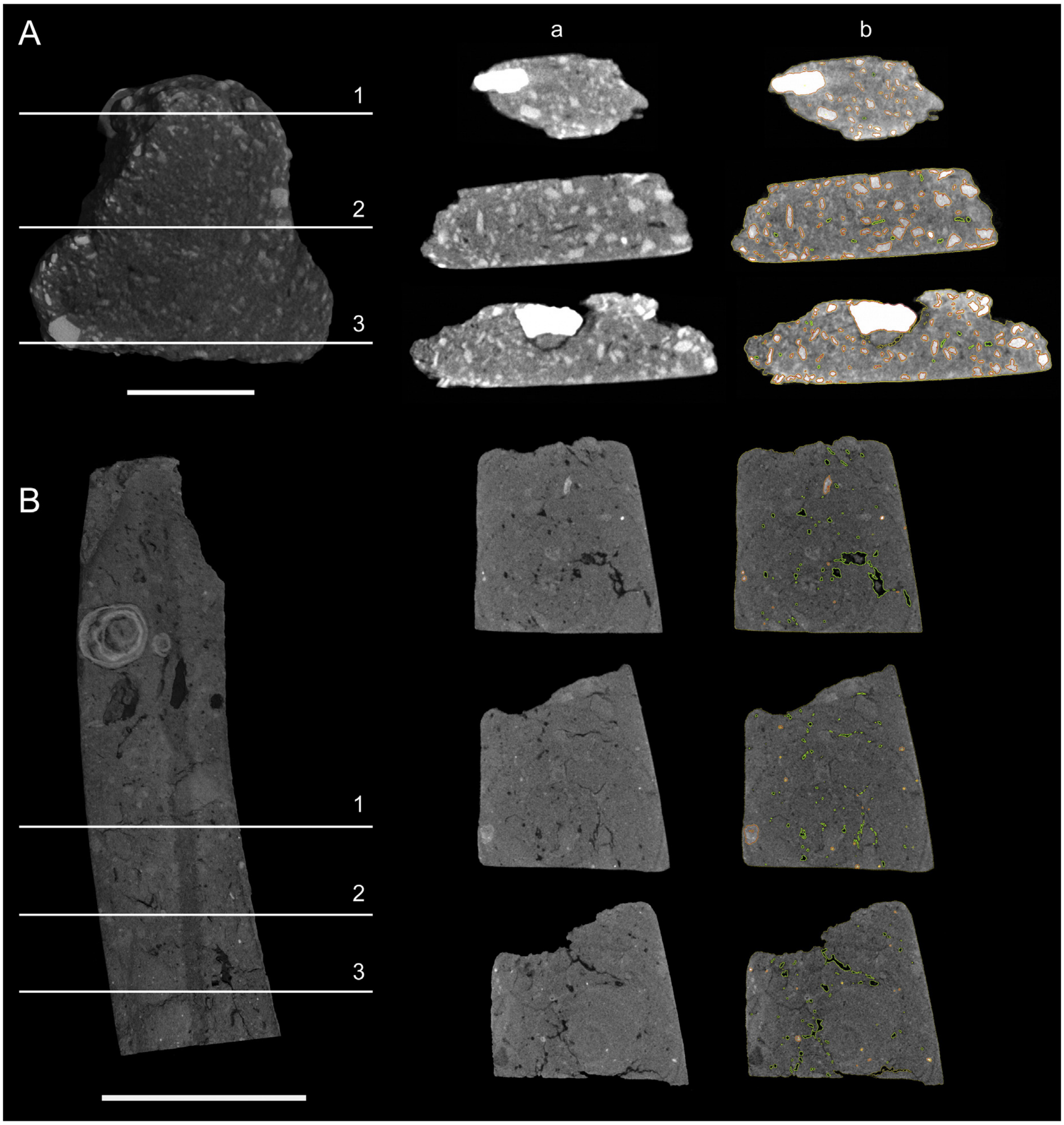

Fig. 1. μCT volume renderings and virtual cross-sections of the *vaso a coppa* 2697 (A) and the sample 5880 (B). Numbers 1 to 3 show the position of the cross-sections. Letter a indicates the plain cross-sections while letter b shows the same segmented cross-sections where the clay material (yellow), the inclusions (red) and the pores (green) have been separated. Scale bar: 1 cm. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

high number of findings during the period of most intensive field research (approx. 1950s–early 1980s) brought about the definition of a local Neolithic *facies*, known as Vlaška Group [7] or *Cultura dei vasi a coppa* [14], approximately dated to the second half of the 6th millennium BC. These interpretations are partially divergent in the identification of the main components and of the nature of the relationship (influence/derivation) with the Danilo culture in Dalmatia (eastern Adriatic coast) [15]. Later on, the theoretical debate has been reopened by: 1) new excavations in the Karst (Edera cave), in Istria and western Slovenia [15]; 2) by geo-archaeological studies that demonstrated the use of Karst caves made for millennia by shepherds with their flocks of sheep and goats [16,17]; and 3) by systematic revisions of materials from old investigations, still partially or completely unpublished in the early 1990s [18,19]. These revisions allowed specifically to distinguish between stable and occasional ceramic components and to assess the relative incidence and the characteristics of the most typical vases, *vasi a coppa* , i.e. bowls that are basically variants of a hemisphere, showing differences in the restriction of the upper part, the depth of the body and the decoration. Vessel types that are seldom present, often once and with one single piece, and *vasi a coppa* with rare or unique decorative motifs have raised the question of their provenance, in terms of raw materials and place of production. Answering this question could shed light on the problem of stronger or looser connections of the Vlaška Group with Danilo, and also on the possible role of the Karst as intermediary between the Adriatic regions and central Friuli [20].

Consequently, samples of both categories (occasional components and peculiar *vasi a coppa*) have been selected for a first set of scientific analyses aimed at checking the hypotheses based on typological studies.

3. Materials and methods

In this work we have investigated 13 pottery samples. Most of them are fragments of *vasi a coppa*, discovered in the Zingari [21] and Tartaruga [22] caves. Sample 5880, found in the level 8 of Ciclami cave [23], shows a different typology, which partially recalls the style of contemporaneous pottery materials belonging to the Fiorano culture [23]. However, differences between this sample and the Fiorano productions have been observed [23], leaving open the question on its typological attribution and origin.

Small powdered samples taken from the vases (generally less than 0.5 g) have been analysed by XRD at the Department of Mathematics and Geosciences of Trieste University using a STOE D 500 X-ray diffractometer at room temperature (Table 1). CuKα radiation was used through a flat graphite crystal monochromator. The current used was 20 mA and the voltage was set at 40 kV. The 2θ scanning angle ranged from 2 to 60°, with 0.01° steps and a counting time of 2 s/step. Approximate percentages of identified mineral phases have been determined according to the relative intensities of the highest peaks of the two minerals.

After impregnation by epoxy resin, 12 samples have been cut, perpendicularly to the vase walls, and thin sections have been prepared at the Department of Geosciences of Padua University. The thin sections have been examined under a polarizing microscope at the Department of Mathematics and Geosciences of Trieste University in order to define their mineralogical and textural features (Table 1).

All samples have been characterized by μCT at the Multidisciplinary Laboratory (MLAB) of the “Abdus Salam” International Centre for Theoretical Physics of Trieste (ICTP), Italy [24], using the following parameters: 110–120 kV voltage and 80–90 μA current; 1440/1800 projections over 360°. μCT slices have been then reconstructed with the commercial software DigiXCT, obtaining an isotropic voxel size from 11.98 to 39.71 μm (Table 1).

Using Amira v.5.3 (Visualization Sciences Group Inc.) and with the limitations given by the voxel size, a semi-automatic threshold-based segmentation has been carried out in order to separate the lithic inclusions (including both temper material and lithic grains included in the paste), the porous system and the clay matrix in three selected virtual cross-sections for each sample, taken approximately at the centre and the edges of the datasets (Fig. 1), and in cubical subvolumes virtually extracted from the samples (Fig. 2). The subvolumes side length has been set to half the thickness of the shards. VGStudio Max 2.0 has been used to produce the virtual renderings of Fig. 1. To separate the pores inside the pottery samples the half-maximum height protocol (HMH) has been adopted [25,26]. This method, developed mainly for bone materials, calculates the threshold value as the mean of the minimum and maximum grey scale values along a row of pixels crossing the pores-

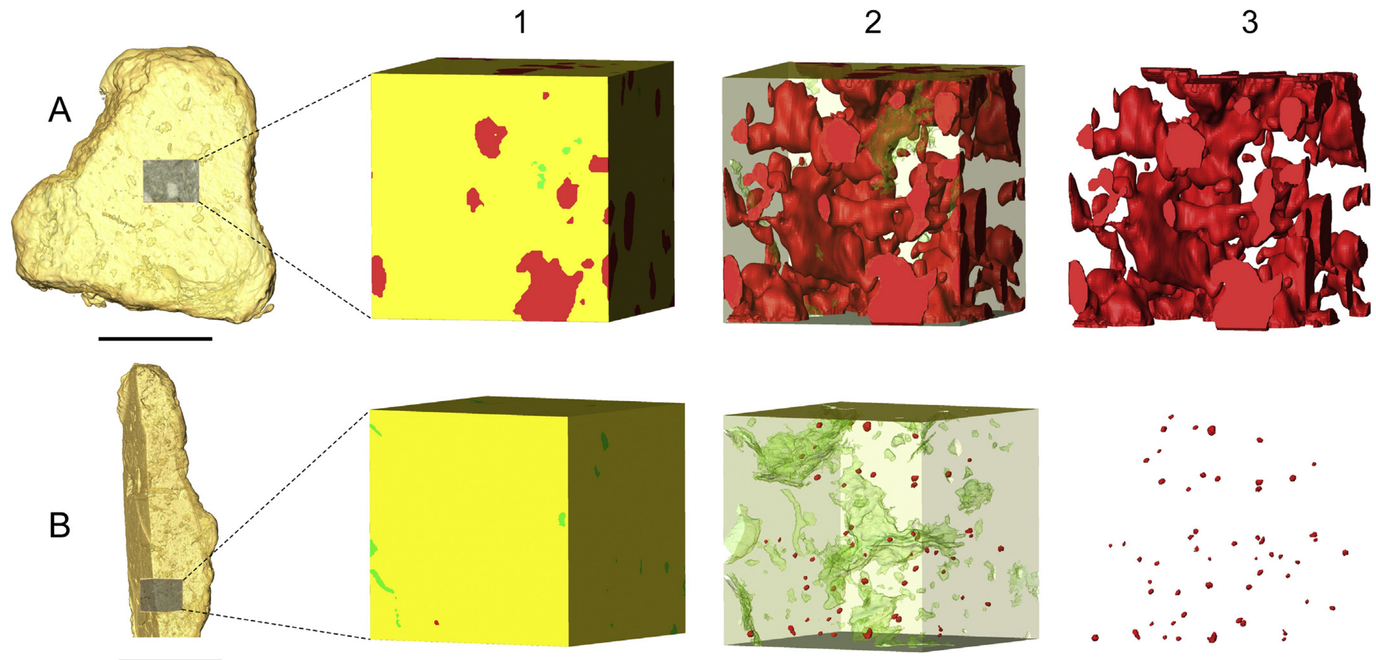

Fig. 2. μCT volume renderings of the *vaso a coppa* 2697 (A) and the sample 5880 (B) in transparency showing the position of the extracted subvolumes where the clay material (yellow), the inclusions (red) and the pores (green) have been segmented. Scale bar: 1 cm. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

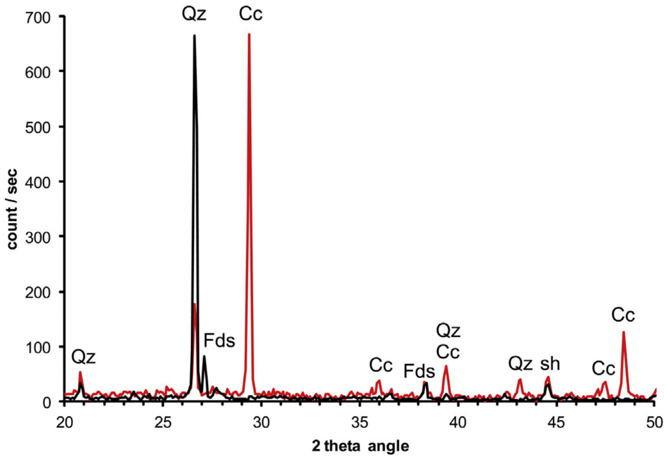

Fig. 3. Selected XRD spectra of the calcite-rich *vaso a coppa* 3533 (red spectrum) and the sample 5880 (black spectrum). Qz: quartz; Fds: feldspar; Cc: calcite, sh: sample holder. Even if the XRD have been performed in the range 2–60°2θ we decided to show only the range (20–50°) where peaks are effectively present.

to-clay matrix transition. In the case of 3D subvolumes, the mean value of 10 HMH values, calculated for the same number of slices randomly selected, has been taken as threshold for the complete datasets. Unfortunately, the HMH protocol is inadequate for separation between clay matrix and lithic inclusions due to the variable density of the latter. In this case the threshold values have been visually adjusted until threshold limits corresponded to lithic inclusions boundaries. This operation has been repeated many times applying different thresholds until all lithic temper material and grains have been separated.

All the artefacts (Table 1) have been analysed by means of a portable X-ray fluorescence spectrometer (XRF), recently built at the MLAB of the ICTP [27]. The system is based on light, compact and relatively low-cost components, including a mini X-ray tube (air cooled with fans, Ag anode, voltage: 10–40 kV, max. current: 200 μA) and a silicon drift detector (energy resolution: 125 eV at 5.9 keV). They are assembled on a goniometer to change independently both the X-ray tube and detector angles. Distances from the sample can be changed with micrometre accuracy to optimize the alignment (with about 0.01 mm resolution). Two laser pointers, which can be fixed in the required position, identify the point of analysis on the object surface. This system has already been used for archaeometric studies [27,28]. The samples have

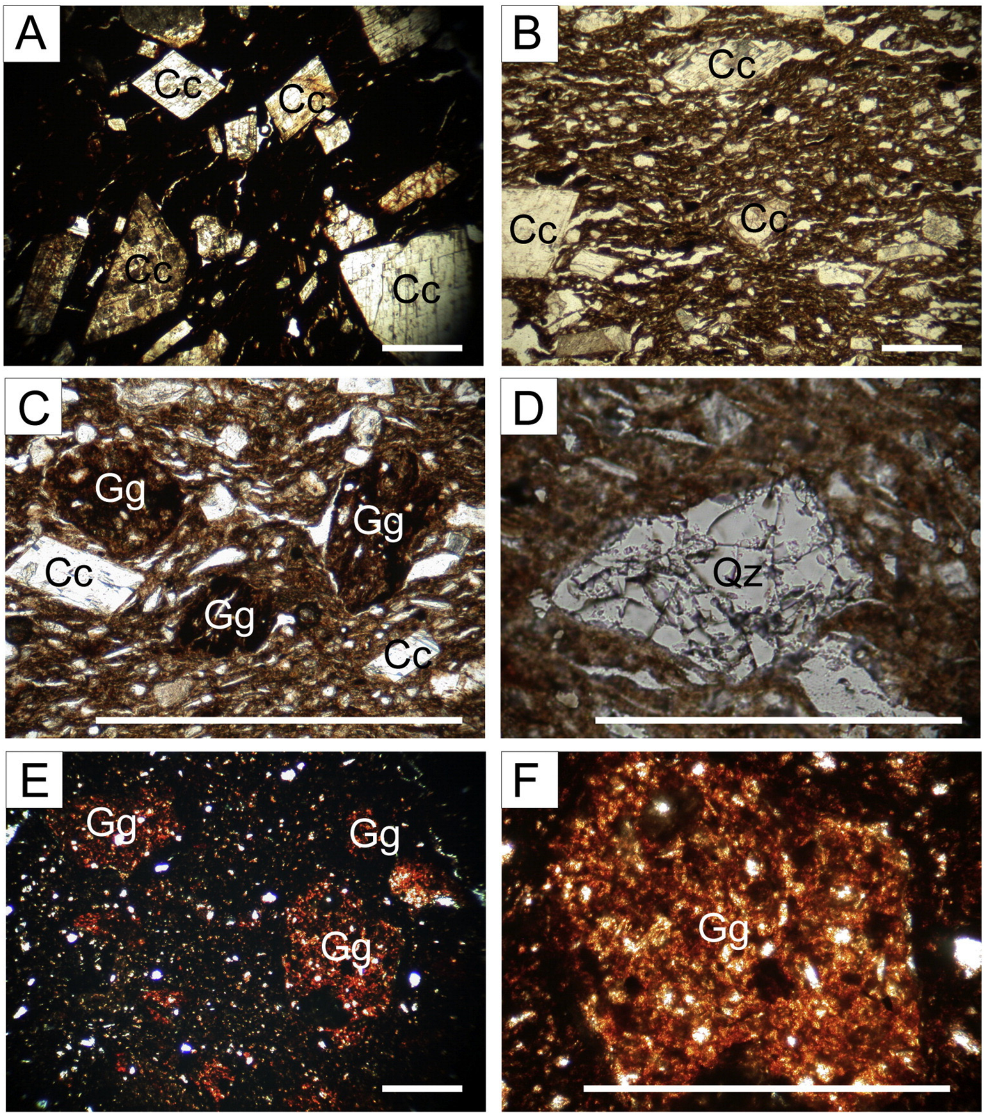

Fig. 4. Thin-section microphotographs of the calcite-rich *vasi a coppa* 3533 (A) and 3534 (B–D) and of the vase 5880 (E–F). In the first two samples abundant angular calcite fragments are visible (A–B); fine grained quartz (D) and rare grog temper (C) are also present. Sample 5880 shows a fine-grained fabric with abundant grog fragments (E–F). All the pictures are taken using plane polarised light. Cc: calcite crystals, Gg: grog, Qz: quartz. Scale bars: 1 mm.

been irradiated with a collimated X-ray beam (30 kV, 132 μA) and the analysed spot size diameter was set at about 10 mm. The resulting scattered beam has been measured using a silicon drift detector and the corresponding spectra have been acquired by means of a multichannel analyzer (MCA).

On the one hand, precise quantification of elemental concentration [29,30] is particularly useful when the analysed artefacts have to be compared with geochemical results obtained by different studies. On the other hand, to determine differences, similarities and correlation within a group of analysed samples, direct multivariate analysis of peaks area or complete XRF spectral data profiles allows reliable and fast results [31–33]. In the present study, the last approach, and in particular the principal component analysis (PCA) of the complete spectra, has been adopted.

4. Results

XRD patterns of the 13 analysed artefacts indicate that the minerals identified in all the *vasi a coppa* are prevalent calcite (70–95%) with some quartz (5–30%; Fig. 3). Vase 5880 contains mainly quartz (>90%), with a minor fraction of feldspar (<10%) and no calcite (Fig. 3).

According to thin section observations made using a polarised light microscope, all the *vasi a coppa* show very similar pastes. Their fabric is characterized by angular quartz grains with silt to very fine sand-size, numerous clay pellets, and abundant unsorted euhedral calcite (up to 40%) with size up to very fine gravel (Fig. 4A–B). The calcite was probably obtained by grinding speleothems, which are very common in the Karst environment where the archaeological sites are located. In some samples, a few grog temper (3534; Fig. 4C) and rare sub-rounded limestone fragments (NP, 3548, 3533) have been also detected. The clay-silt size paste containing quartz inclusions (Fig. 4D) has been tempered with the addition of abundant calcite and rare limestone fragments.

From a technological view point, the orientation of the pores, often recognizable, is parallel to the wall surfaces. According to several authors [34–36], this structure can be mainly produced using a modelling and not a coiling technique.

Sample 5880 shows a completely different fine-grained paste (Fig. 4E–F), with small sub-angular quartz and minor feldspar grains (optically plagioclase) with silt to very fine sand-size. Calcite is completely absent. Moreover it contains abundant grog fragments (0.5–2 mm size), which resemble, in terms of fabric and mineral content, the other parts of the potsherd (Fig. 4E–F). Unfortunately, the orientation of the pores is not easily recognizable due to the small size of the sample and the abundance of grog.

Direct multivariate treatment of XRF spectral data profiles by means of principal component analysis (PCA) has allowed a quite good separation between most of the calcite-rich *vasi a coppa* and sample 5880 (Fig. 5). The principal component 2 isolates the Ca-rich *vasi a coppa* from sample 5880 with a low Ca composition.

The segmentation of 3 virtual μCT cross-sections for each sample has allowed the separation between clay material (Cl), lithic inclusions (Li) and pores (Po) as well as their quantification (Fig. 1, Table 2). Moreover the Cl + Po/Li and Cl/Li ratios have been calculated (Table 2), showing a clear difference between sample 5880 and *vasi a coppa* characterized by a very homogeneous coarse carbonate-tempered paste. On the one hand, *vasi a coppa* contain abundant lithic temper material (Cl + Po/Li ratio: 4.26–12.20; Cl/Li ratio: 4.23–12.15) corresponding to the angular euhedral calcite fragments observed in the thin sections and detected by XRF as a relatively high Ca content. On the other hand, the sample 5880 (Cl + Po/Li ratio: 212.26; Cl/Li ratio: 206.88) shows only a few small sub-circular lithic grains, probably corresponding to silicate minerals already present in the raw material.

In order to validate the 2D analysis of selected cross-sections, the same segmentation process has been applied to the subvolumes virtually extracted from the samples (Fig. 2, Table 3). The results of this 3D analysis are comparable to those obtained with the segmentation of the cross-sections (Figs. 6–7) with some minor differences probably related to the distribution of lithic inclusions in the pastes.

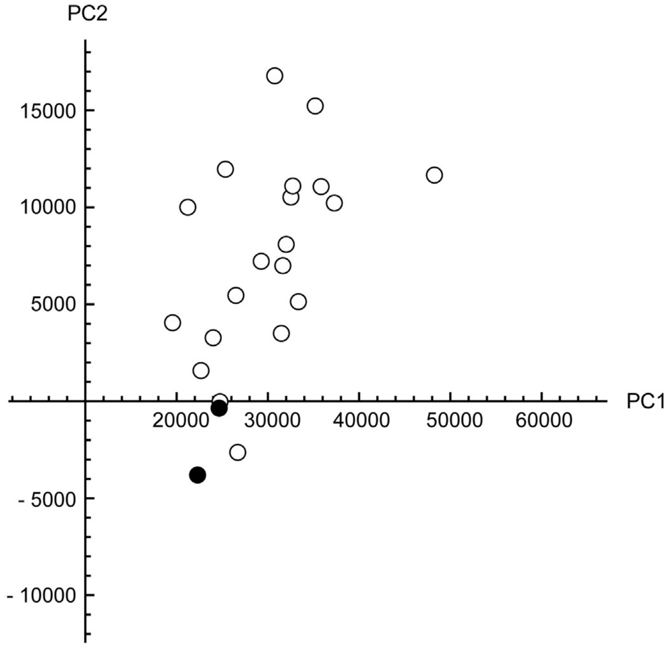

Fig. 5. PCA12 plot showing the scores for the *vasi a coppa* (white circles) in comparison to the sample 5880 (black circles).

5. Discussion and conclusions

Soil samples from the Karst area are characterized by the presence of quartz as main mineral, with subordinated feldspars and clay minerals (illite, chlorite and kaolinite) [8,37]. Calcite is usually absent due to weathering effects. Most of the pottery samples – all the Vlaška *vasi a coppa*, independently from differences in shape and decoration – are made from clay mixed with abundant euhedral calcite fragments of variable size probably obtained by grinding speleothems. Such mineral was intentionally added as temper material to the fabric, too plastic for pottery manufacture. The small angular quartz grains are very likely natural components present in the local soil used as raw material. These data confirm the results of the archaeometric study of the pottery assemblage of another archaeological site of the Trieste Karst, the Edera cave, where almost all the local pottery production, from the Neolithic Vlaška period to historic time, shows abundant use of vein calcite temper mixed to local raw material [8].

It is interesting to notice that Tenconi et al. [38] have recently suggested that a peculiar type of protohistoric pottery (already studied by Boschian and Floreano [39]) found in nowadays Veneto could originate from the Friuli Venezia Giulia area because of the vein calcite fragments in the ceramic paste.

Among the analysed pottery samples from the Neolithic site of Sammardenchia in the Friuli plain, west of the Karst area, fabric group 2 shows numerous polygonal holes probably derived from the secondary dissolution of euhedral calcite temper due to the environment conditions [12]. The original paste was probably very similar to the fabric of the *vasi a coppa* of the Vlaška culture discussed in the present paper. This is also suggested by the low Cl/Li ratio (about 3–6) of the fabric 2 samples (SAM24, SAM26, SAM41 and SAM43). This ratio has been calculated separating the polygonal holes and the other lithic inclusion from the paste in high-resolution pictures of the thin sections (taken from Carbonetto [40]) using the same procedure followed for the μCT cross-sections. Although an accurate selection and exploitation of calcite temper from sources located relatively close to the

Table 2
Fabric data of the investigated cross-sections: with the exception of vase 5880, all the *vasi a coppa* show very similar fabric features. The areas of lithic inclusions, clay material and pores are expressed in mm^2.

Sample	Cross-section number	Lithic inclusions	Clay material	Pores	Total area	Clay + pores/lithic i.	Clay/lithic i.
3523	260	61.98	460.19	3.75	525.91	7.49	7.43
	277	34.50	196.58	0.77	231.84	5.72	5.70
	282	22.27	134.86	2.07	159.19	6.15	6.06
	Average	39.58	263.87	2.19	305.65	6.45	6.39
3533	2323	183.50	2003.77	15.68	2202.95	11.00	10.92
	2346	206.07	1633.14	21.90	1861.11	8.03	7.93
	2365	169.93	1207.84	14.21	1391.99	7.19	7.11
	Average	186.50	1614.92	17.26	1818.68	8.74	8.65
3534	936	13.69	122.78	0.09	136.55	8.98	8.97
	1039	48.28	483.62	0.34	532.24	10.02	10.02
	1071	45.04	451.65	3.95	500.64	10.12	10.03
	Average	35.67	352.68	1.46	389.81	9.71	9.67
3540	307	68.33	347.09	1.87	417.30	5.11	5.08
	309	73.17	346.42	2.53	422.12	4.77	4.73
	322	58.70	482.56	1.60	542.86	8.25	8.22
	Average	66.74	392.02	2.00	460.76	6.04	6.01
3541	1390	21.08	184.03	2.85	207.96	8.86	8.73
	1770	49.75	251.04	4.70	305.49	5.14	5.05
	1810	58.10	323.51	2.17	383.78	5.61	5.57
	Average	42.98	252.86	3.24	299.08	6.54	6.45
3543	1800	197.67	2524.87	11.63	2734.17	12.83	12.77
	1933	93.36	1259.73	4.77	1357.85	13.54	13.49
	1954	42.73	435.72	0.63	479.08	10.21	10.20
	Average	111.25	1406.77	5.68	1523.70	12.20	12.15
3545	498	36.22	254.29	1.72	292.24	7.07	7.02
	581	29.07	240.04	269.11	538.22	17.51	8.26
	689	12.72	66.89	1.27	80.88	5.36	5.26
	Average	26.01	187.07	90.70	303.78	9.98	6.84
3546	1143	46.28	266.18	0.93	313.39	5.77	5.75
	1175	73.43	620.36	1.98	695.77	8.48	8.45
	1306	119.62	1113.48	5.86	1238.95	9.36	9.31
	Average	79.78	666.67	2.92	749.37	7.87	7.84
3548	804	31.54	204.70	0.86	237.10	6.52	6.49
	840	38.09	242.74	2.02	282.86	6.43	6.37
	952	33.64	182.59	0.55	216.78	5.44	5.43
	Average	34.43	210.01	1.14	245.58	6.13	6.10
3556	850	115.15	642.57	16.99	774.71	5.73	5.58
	910	164.80	952.16	10.46	1127.42	5.84	5.78
	1000	165.37	1117.59	24.26	1307.22	6.90	6.76
	Average	148.44	904.10	17.24	1069.78	6.16	6.04
NP	936	77.41	1137.34	10.91	1225.66	14.83	14.69
	1039	37.37	413.96	3.07	454.40	11.16	11.08
	1174	23.47	129.60	0.00	153.07	5.52	5.52
	Average	46.08	560.30	4.66	611.04	10.51	10.43
2697	1281	105.19	477.61	5.65	588.44	4.59	4.54
	1393	121.34	529.57	2.30	653.21	4.38	4.36
	1416	93.68	355.34	1.49	450.51	3.81	3.79
	Average	106.73	454.18	3.14	564.05	4.26	4.23
5880	400	0.23	73.95	1.91	76.09	335.41	326.95
	700	0.85	84.88	1.00	86.73	101.45	100.27
	1000	0.45	86.31	2.90	89.66	199.92	193.42
	Average	0.51	81.71	1.94	84.16	212.26	206.88

Sammardenchia site cannot be excluded, the hypothesis of the import of these materials from the Karst or Dalmatia (directly or mediated by the Karst Neolithic groups) looks more likely due to the large use of local calcite temper in the coeval Vlaška and Danilo productions [8,10]. Since the original lithic temper of the Sammardenchia group 2 has been seriously weathered, and this alteration has affected also the geochemical composition, the non-destructive µCT analysis of these samples could provide 3D fabric information (i.e. quantification of different paste components) useful to confirm or not a similarity with the calcite-rich Karst productions: a possible similarity that in any case

Table 3
Fabric data of the investigated subvolumes: with the exception of sample 5880, all the *vasi a coppa* show very similar fabric features. The volumes of lithic inclusions, clay material, pores are expressed in mm^3.

Samples	3523	3533	3534	3540	3541	3543	3545	3546	3548	3556	NP	2697	5880
Lithic inclusions	2.08	1.73	1.98	2.96	3.75	2.54	4.81	6.29	8.49	4.14	1.25	5.92	0.10
Clay material	24.25	29.34	24.31	41.45	38.02	28.10	56.23	112.95	42.57	26.95	25.14	45.76	25.90
Pores	0.10	0.03	0.14	0.02	0.10	0.05	0.89	0.38	0.87	0.02	0.03	0.18	0.61
Total volume	26.43	31.10	26.43	44.44	41.88	30.68	61.94	119.61	51.93	31.11	26.43	51.87	26.61
Clay + pores/lithic i.	11.74	16.96	12.32	13.99	10.15	11.09	11.87	18.02	5.12	6.51	20.10	7.76	259.66
Clay/lithic i.	11.69	16.94	12.25	13.98	10.13	11.07	11.69	17.96	5.01	6.51	20.07	7.73	259.00

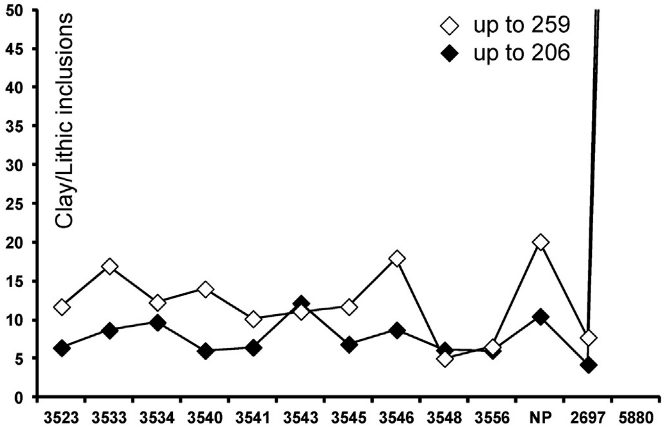

Fig. 6. Diagrams showing the clay/lithic inclusions ratio in the analysed samples. The black diamonds correspond to 2D data based on cross-sections segmentation while white diamonds to 3D data deriving from subvolumes segmentation.

must be checked also through a closer examination of the formal characteristic of the vases.

Concerning the production technology of the Vlaška *vasi a coppa*, the presence of well preserved calcite in the pottery samples indicate the firing temperature was lower than 700–750 °C [8,10], while the porous structures parallel to the pottery walls, detected by both OM and μCT, suggest that a modelling technique was used [34–36].

Sample 5880, showing a typology partially recalling the Fiorano culture shapes of central-northern Italy [23], is characterized by a fine-grained fabric with numerous grog fragments, quartz, minor feldspar and absence of calcite. Also the 2D and 3D μCT-derived textural parameters, reflecting the production technology, are quite different from those of Vlaška *vasi a coppa*. These features suggest that sample 5880 was imported from elsewhere, probably from the area of the Fiorano culture. Among the pottery samples of Sammardenchia analysed by Carbonetto et al. [12], the fabric group 5, including a few likely imported Fiorano-type vases, shows a fine-grained fabric with silt to very fine sand-size silicate minerals and grog fragments. All these features recall those of sample 5880, but additional data about sure Fiorano culture pottery would be necessary for a more detailed comparison, as well as for some speculations about direct or indirect contacts among these areas.

Other classes of Neolithic artefacts from the northeastern Adriatic regions, such as the so-called Alpine or Lessini flint and the polished stone axes made from high pressure metaophiolites (mainly jades and eclogites), originating respectively from the Southern Alpine Jurassic-Cretaceous formations and northwestern Italy, provide (though with different degree of reliability) additional evidence of the connections

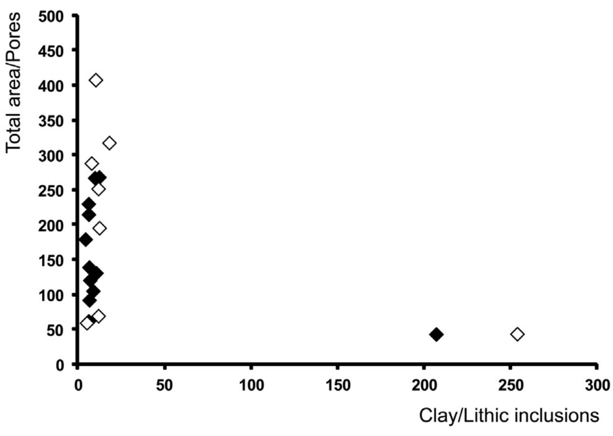

Fig. 7. Total area/pores vs. clay/lithic inclusions diagram. Symbols as in Fig. 6.

between the Vlaška Group and the coeval cultures of northern Italy [41]. Sample 5880 could be related to the same exchange systems responsible for the distribution of the imported stone artefacts.

The combined use of conventional petrographic and mineralogical techniques and non-destructive analytical methods (XRF and μCT) has proved to be an effective approach to investigate both forming techniques and provenance of the ceramic materials. The application of μCT allows the fabric characterization of pottery, thanks to the quantification of clay material, inclusions (including both temper material and lithic components contained in the raw material) and porosity. In the study of some archaeological materials, such as the Ca-rich vases of the Karst area, this technique can provide preliminary evidence of local vs. non-local pottery productions. Contrary to thin sections observations, μCT allows the non-destructive 3D quantification of pottery components, thus giving access to information not always provided by 2D examination alone. The morphology of inclusions and pores, including the empty spaces derived from plant remains burnt during the firing process, can be observed, segmented and measured [6]. For these reasons, μCT is especially useful to identify pottery manufacturing techniques. Using large area detectors, big portions of pottery vases can be imaged with high resolution (20–40 μ). The produced datasets are therefore representative of the whole samples and can be effectively used to define possible sampling positions as well as to target both conventional and non-destructive analysis.

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