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GEOSCIENCES AND CULTURAL HERITAGE

Petrographic and chemical characterization of Bronze Age pottery from the settlement of Mount San Paolillo (Catania, Italy)

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Abstract The excavations at Mount San Paolillo (Catania, Italy) led to the discovery of a Prehistoric site that still represents the most important evidence of Middle and Late Bronze Age settlement in this area. During the excavations, archeologists located a hut, a store for ceramic storage vessels, and a pottery workshop, all of which provided a large quantity of heterogeneous ceramics with apparent typological parallels in other areas of Sicily, such as Syracuse, Augusta, and Messina. A large number of specimens were selected in order to cover all the macroscopic types and the main classes. The results identified four petrographic fabrics. Most of the ceramics are characterized by abundant tempers consisting of volcanic rock fragments and occasionally of grog. Only a few samples contained common fine-grained quartz. The groundmass ranges from non-micaceous to very micaceous. In some cases, there is evidence of mixed clays. Analysis of the chemical composition of the ceramics revealed the existence of two groups with low and high CaO contents. The high Fe_2O_3 content (more than 8.7 wt%) is probably due to the use of temper from altered pyroclastic rocks which are of local provenance as SEM-EDX data suggest, even if petrographic and chemical results suggest that different raw materials may have been used. The data provided by these archeometric analyses have made a significant contribution to the study of Middle and Late Bronze Age pottery from the Catania area, by offering insights into the methods, production processes, and high technical level of the prehistoric craftsmen.

Keywords Prehistoric pottery · Sicily · Petrographic analysis · Chemical analysis

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1 Introduction

The Thapsos facies was probably the most important cultural expression of the Middle Bronze Age (fifteenth–thirteenth century BC) in Sicily. In terms of pottery production, it was characterized initially by a certain degree of experimentation followed by a period of clear technical evolution, in which a firm set of standards were established in every phase of the production chain, from clay selection to manufacture, from decoration to firing (Alberti 2004). The arrival in Sicily of Late Helladic IIIA/IIIB Mycenaean and Cypriot fine wares had enormous influence on the work of local craftsmen, inspiring them to greater achievements (La Rosa 2004). Mycenaean pottery was technically superior to the local Sicilian wares and was highly valued by those who traded with the Mycenaeans (Van Wijngaarden 2002). This encouraged local production of Mycenaean style pottery creating what became known as the Sicano-Mycenaean style (Levi and Jones 2005; Tanasi 2005). This encounter with a more developed technical tradition proved to be a watershed in local pottery manufacturing, as new findings about improvements in firing technology have recently shown (Barone et al. 2011a). The variety and the particular features of Thapsos pottery are known above all because of the excavations of several burial sites in the Syracuse area, while less is known about the Catania area where, except for a few exceptions (Procelli 2007), little archeological exploration has taken place.

Due to this lack of data, it was therefore impossible to undertake any interpretative analysis about Thapsos pottery production in this area.

In view of this scenario, in 2010, a research project aiming to conduct typological, stylistic, technical, and archeometric analyses of Thapsos pottery from the Catania area was launched by scholars from the University of Catania and from Arcadia University. The settlements at Grotte di Marineo (Licodia Eubea) and Mount San Paolillo were chosen as key sites for the research. The initial studies of the pottery from Grotte di Marineo (Barone et al. 2011a, 2012) added significant new data to the investigation. The petrographic and geochemical analysis conducted on this material showed, for the first time, that visual analysis, on which many hypotheses about Middle Bronze Age pottery are based, can be misleading. The archeometric tests also provided sufficient information to enable us to speculate on the relationship between fabric, shape, and chronological phase.

As a natural development of this research, this paper presents the preliminary data from the pottery found at the other key site at Mount San Paolillo.

2 Context and materials

The Mount San Paolillo archeological site is located on the top of a 220 m hill in a north-eastern suburb of Catania. From 1994 to 1996, the Superintendence for Cultural Heritage of Catania explored a small terrace on the southern side of the hill, discovering parts of a Middle Bronze Age village (Patanè 1997–1998) (Fig. 1).

The site is located on the southern flank of Mount Etna and is characterized by the outcropping of lava flows and volcaniclastic successions overlaid to Lower–Middle Pleistocene clays (Argille grigio azzurre Formation). In particular, Mount San Paolillo vulcanite is represented by thin lava flows, scoria deposits, and volcaniclastic succession with clay and silt layers from the Timpa Formation (Upper Pleistocene) at the top.

The investigated area comprised a circular hut, referred to as Hut 1 and an open space used as a store for storage jars (Tanasi 2010). A large quantity of ceramics was found inside Hut 1 and its surrounding area, including two LH IIIA2 Mycenaean sherds, which enabled us to date Hut 1 to the middle of the Thapsos period (1400/1380–1310/1300 BC). At the end of the 14th century BC, the village was entirely destroyed by a fire, which caused the collapse of Hut 1 and the firing of the clay used in the traditional roof, which was also made out of straw and other perishable materials (McConnell 1992). After the fire, the ruins of Hut 1 were leveled creating an open area in which a small temporary storage area for large *pithoi* was established. Mount San Paolillo was later totally abandoned until the Iron Age (Tanasi 2010). A wide range of finds were made including fine and coarse table wares, cooking wares, and storage jars (Fig. 2a) along with other objects such as spindle whorls and portions of the baking plate from Hut 1. Numerous misfired vessels and kiln spacers were discovered spread around outside the hut (Fig. 2b), suggesting that there was a pottery production center nearby.

On initial visual examination, these ceramics appeared to be quite heterogeneous in terms of fabric composition, manufacture, and technical features. In the absence of references about ceramic production in the Catania area, we decided to carry out archeometric analyses to investigate the provenance of these pieces.

The excavation produced a significant amount of diagnostic ceramics (462). We began by examining the pieces visually in an attempt to distinguish and classify them. In this initial macroscopic examination, we identified 15 different types, as summarized in Table 1. Of these 15 types, three were classified as “fine ware”, types I, II, and III. They each showed features comparable with other already known classes from different parts of eastern Sicily: type I corresponds to yellow slipped burnished fine ware, a type of

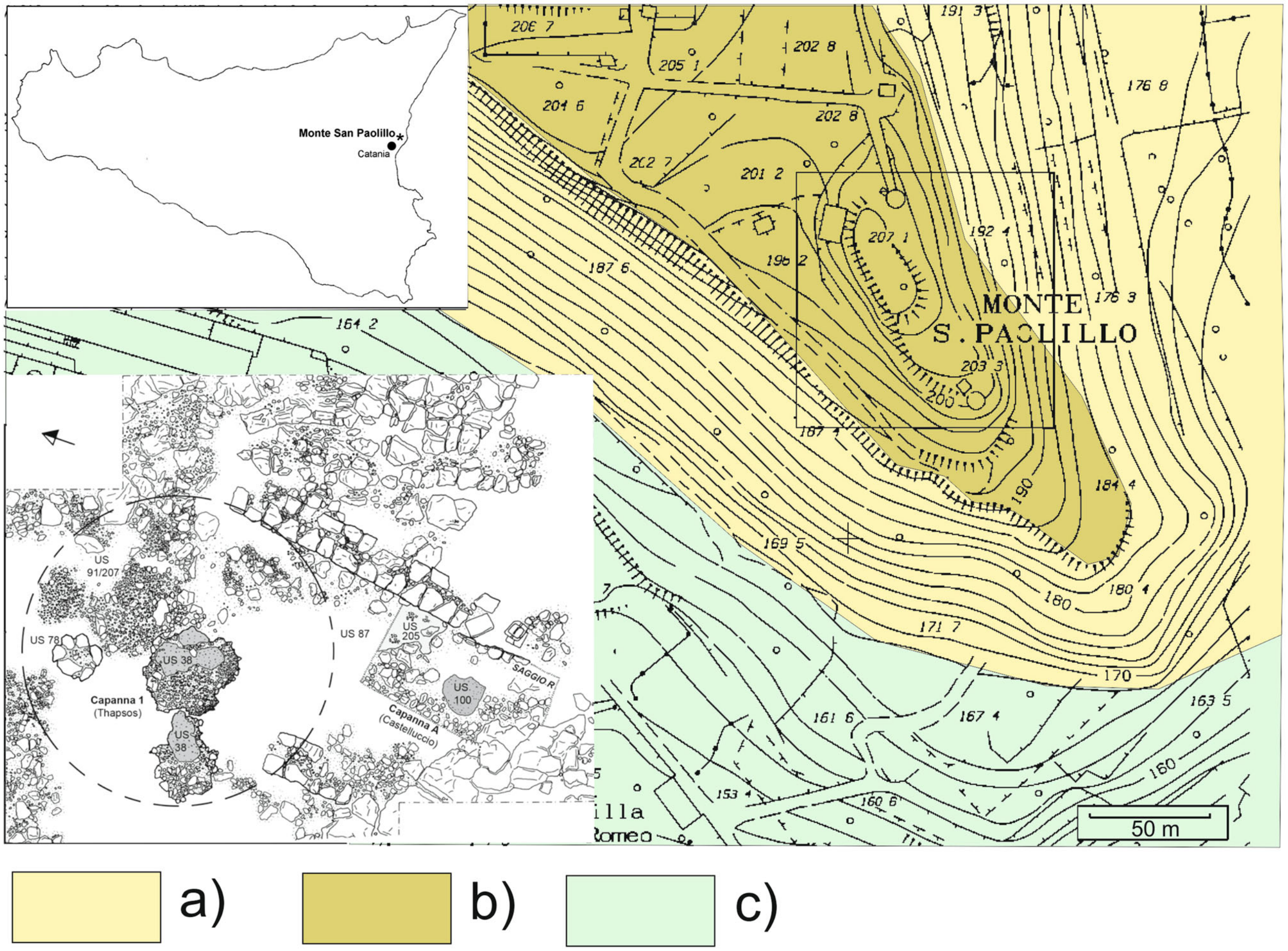

Fig. 1 Geological sketch Map of Mount San Paolillo and detailed plan of the explored portion of the settlement. **a** Talus formed by irregularly sized heterolithologic clasts; **b** thin lava flows and scoria deposits (Timpa formation Paternò Member) and volcaniclastic succession with clay and silt layers at the top (Timpa Formation, Leucatia Member); **c** Lower–Middle Pleistocene clays (Argille grigio azzurre Formation). Data from Branca et al. (2011), modified

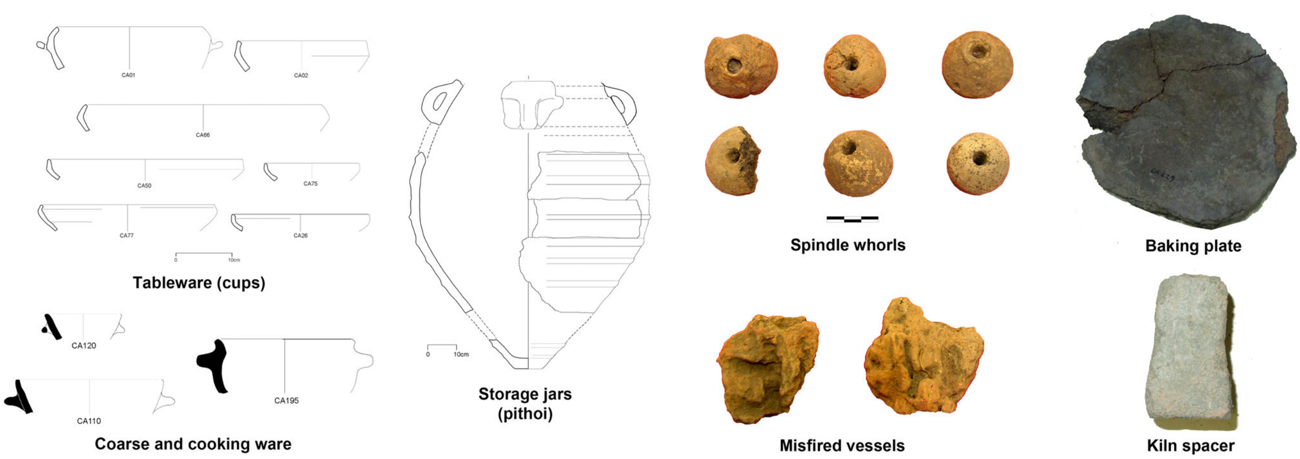

Fig. 2 *Left* main pottery classes identified at Mount San Paolillo. *Right* other classes of artifacts identified at Mount San Paolillo

ceramic typically found in the Syracuse area (Hyblean district), and very rarely found in Catania (Barone et al. 2012; Privitera 2010); type II corresponds to a ceramic ware with unslipped surfaces that was decorated by painting with black or dark-brown geometric patterns and directly resembles other wares produced in various different

Table 1 Types of fabrics indentified through direct observation

Type	Fabrics visually identified
Type I	Very fine hard fabric with volcanic grits (fine 25 %); smoothed, slipped, and burnished surfaces; body color 10 YR 6/3 light yellowish red, slip color from 10 YR 8/1 white to 10 YR 6/6 brownish yellow
Type II	Fine hard fabric with volcanic grits (very fine 50 %); poor traces of mica; smoother surfaces; dark-brown paint applied directly over the body, more rarely over a yellowish-gray slip; body color 10 YR 5/1 gray, paint color 7.5 YR 4/2 brown, slip color 10 YR 6/6 brownish yellow
Type III	Fine hard fabric with volcanic grits (very fine 50 %); traces of mica and chamotte; smoothed undecorated and slipped surfaces; overfired; body color 10 YR 6/3 10 YR 7/6 yellow
Type IV	Coarse soft fabric with lithic, volcanic grits, and chamotte (medium-fine 10–20 %); rough surfaces, rarely slipped; body color 5 YR 6/8 reddish yellow, slip color 10 YR 7/4 very pale brown
Type V	Medium soft fabric with lithic (fine 10 %) and volcanic grits (medium 10 %); traces of mica; rough unslipped and undecorated surfaces; body color 5 YR 7/6 reddish yellow
Type VI	Very fine hard fabric with crack, voids, and chamotte (fine 10 %); body color 5 YR 6/6 reddish yellow
Type VII	Very hard fine fabric with volcanic grits (fine 5 %); overfired; body color 7.5 YR 6/6 reddish yellow
Type VIII	fine hard fabric with lithic (fine 2 %), volcanic (fine 25 %), micaceous (fine 20 %) grits; smoothed, slipped surfaces; body color 5 YR 7/8 reddish yellow, slip color, 7.5 YR 7/4 pink
Type IX	Very hard medium fabric with volcanic grits (fine 10 %); overfired; body color 2.5 YR 6/6 light red
Type X	Hard fabric with lithic, volcanic, and chamotte (fine 10 %); cracks and voids; smoothed surfaces, slipped inside and out; body color from 2.5 YR 6/6 light red to 2.5 YR 5/4 reddish brown, inner slip color from 10 YR 7/3–7/4 very pale brown to 10 YR 6/2 light brownish gray, outer slip color from 2.5 Y 7/2 light gray to 10 YR 7/4 very pale brown
Type XI	Hard fabric with volcanic grits and quartz and chamotte (fine 25 %); cracks and voids; smoothed and slipped surfaces; body color from 2.5 YR 5/6 red to 5 GY 8/1 light greenish gray; slip color from 7.5 YR 7/6 reddish yellow to 10 YR 7/3 very pale brown
Type XII	Hard fabric with lithic, volcanic, and quartz grits (fine 25 %) and isolated pebbles; cracks and voids; smoothed, slipped, and rarely painted surfaces; body color from 2.5 YR 8/2 pinkish white to 2.5 YR 8/3 pink, slip color 10 YR 8/2–10 YR 7/4 very pale brown, paint color 10 Y 8/1 white
Type XIII	Hard fabric with volcanic and quartz grits (fine 25 %) and isolated pebbles; smoothed unslipped surfaces; body color 2.5 YR 8/2 pinkish white, inner slip color
Type XIV	Hard fabric with volcanic grits (fine 10 %); cracks and voids; smoothed unslipped surfaces; body color from 5 GY 8/1 light greenish gray to 5 YR 7/4 pink
Type XV	Soft fabric with volcanic grits (fine 10 %); cracks and voids; smoothed unslipped surfaces; body color 7.5 YR 8/3 pink

geographic areas such as north-east Sicily and the Aeolian Islands (Aeolian district) (Alberti 2008); and type III corresponds to gray burnished undecorated fine ware that is comparable to the undecorated Thapsos pottery found in the Aetnean or Peloritan district, which was recently defined by Barone et al. (2011a, b, 2012) and Tanasi (2010).

Having completed our initial survey of the ceramics, we moved on to the petrographic and chemical analyses for which we established three main objectives:

1. The discovery of numerous misfired vessels and kiln spacers in the area around Hut 1 could indicate the presence of a nearby pottery factory. This hypothesis would be reinforced if our petrographic and chemical analyses of these items showed that they had a similar composition to other local pottery.
2. Recent research has shown that classification of pottery. The identification of 15 types on the basis of purely visual observation may prove unreliable. Petrochemical analysis would allow us to correct any mistakes in the initial classification of the pieces into 15 types.
3. We identified three different typologies of fine pottery traditionally related with different production districts (Hyblaean, Aeolian, Peloritan/Etnean). Our analysis should seek to establish whether ceramic products circulated or were traded between the different districts, a possibility that has yet to be investigated for the Middle Bronze Age in Sicily.

In short, the aim of this work is to ascertain whether there were petrographic similarities between the high numbers of fabrics identified by archeologists and to verify the hypotheses about the circulation of fine pottery between different cultural districts. To this end, a statistically representative selection of 32 samples was selected from all the types that had been subjected to archeometric analyses (Table 2). The most important criteria applied when selecting these 32 samples (from a total of 462) were their condition and size. We selected the best-preserved and most typologically significant examples of each of the 15 types that we had visually identified.

Table 2 Description of studied samples and analyses performed

Sample code/inv. no.	Provenance	Shape	Fabric	Macroscopic description	XRF	OM	SEM
MSP1A (CA257)	US 39, Trench G/96	Cup	Type I	Yellow slipped burnished fine ware	X	X	
MSP1B (CA258)	US 79, Trench L/96	Juglet	Type I	Yellow slipped burnished fine ware	X	X	
MSP1C (CA264)	US 41, Trench G/96	Jar	Type I	Yellow slipped burnished fine ware	X	X	
MSP1D (–)	US 79, Trench L/96	Juglet	Type I	Yellow slipped burnished fine ware	X	X	
MSP2A (CA259)	US 52, Trench B	Jar	Type II	Black painted geometric patterns ware	X	X	
MSP2B (CA260)	US 52, Trench B	Jar	Type II	Black painted geometric patterns fine ware	X	X	
MSP2C (CA265)	US 52, Trench B	Jar	Type II	Black painted geometric patterns fine ware	X	X	
MSP3F (CA134)	US 52, Trench B	Jar	Type II	Black painted geometric patterns fine ware	X	X	
MSP5D (CA167)	US 16, Trench G/96	Jar	Type II	Black painted geometric patterns fine ware	X	X	X
MSP3A (CA01)	US 19, Trench G/96	Carinated cup	Type III	Gray burnished undecorated fine ware	X	X	X
MSP3B (CA04)	US 19, Trench G/96	Conical pedestal	Type III	Gray burnished undecorated fine ware	X	X	X
MSP3C (CA13)	US 19, Trench G/96	Dipper cup	Type III	Gray burnished undecorated fine ware	X	X	
MSP3D (CA51)	US 19, Trench G/96	Conical pedestal	Type III	Gray burnished undecorated fine ware	X	X	
MSP3E (CA117)	US 16, Trench G/96	Conical pedestal	Type III	Gray burnished undecorated fine ware	X	X	
MSP3G (CA261)	US 123, Trench N/96	Pedestal cup	Type III	Gray burnished undecorated fine ware	X	X	
MSP4A (CA227)	US 42, Trench G/96	Tray	Type IV	Thapsos medium ware	X	X	
MSP4B (CA262)	US 79, Trench L/96	Cooking jar	Type IV	Thapsos medium ware	X	X	
MSP5A (CA03)	US 19, Trench G/96	Conical pedestal	Type V	Thapsos coarse ware	X	X	
MSP5B (CA12)	US 19, Trench G/96	Tray	Type V	Thapsos coarse ware	X	X	
MSP5C (CA67)	US 19, Trench G/96	Basin	Type V	Thapsos coarse ware	X	X	
MSP7 (–)	Trench G/96, Hut 1	Clay render	Type VI	–	X	X	X
MSP8 (CA196)	US 16, Trench G/96	Pyramidal kiln spacer	Type VII	–	X	X	
MSP9 (CA113)	US 16, Trench G/96	Painted jar	Type VIII	Cassibile ware	X	X	X
MSP10 (CA229)	US 16, Trench G/96, Hut 1	Baking plate	Type IX	–	X	X	
MSP14 (MSP96/14)	US 19, Trench G/96,	Rope banded pithos	Type X	Thapsos coarse ware		X	
MSP4C (CA263)	US 41, Trench G/96	Rope banded pithos	Type XI	Thapsos coarse ware	X	X	
MSP11 (MSP96/11)	US 19, Trench G/96	Rope banded Pithos	Type XI	Thapsos coarse ware	X	X	
MSP12 (CA177–MSP96/12)	US 16, Trench G/96,	Rope banded Pithos	Type XII	Thapsos coarse ware	X	X	X
MSP4D (CA270)	US 41, Trench G/96	Rope banded Pithos	Type XIII	Thapsos coarse ware	X		
MSP6 (CA144–MSP96/6)	US 16, Trench G/96	Rope banded Pithos	Type XIII	Thapsos coarse ware	X	X	
MSP15 (MSP96/15)	US 19, Trench G/96	Rope banded Pithos	Type XIV	Thapsos coarse ware		X	
MSP16 (MSP96/16)	US 19, Trench G/96,	Grid banded Pithos	Type XV	Thapsos coarse ware		X	

3 Analytical methods

The texture and mineralogical composition of the ceramics were determined by optical microscopy (OM) using a polarized Leica DM microscope.

For X-ray fluorescence (XRF) analyses, a Philips PW 2404/00 spectrometer was used to determine the concentrations of major and minor elements. Loss on ignition (L.O.I.) was gravimetrically estimated after heating overnight at 950 °C [more details of this technique are reported in Barone et al. (2014)].

Finally, semiquantitative analyses of inclusions in the ceramics were carried out by field emission scanning electron microscope (FESEM, Leo Gemini 1530) coupled with a Oxford Inca 200 microanalysis which uses ten standards, including natural minerals (albite, MAD-10 feldspar, wollastonite), pure elements (Ti, Cr, Mn, Fe), and simple compounds (MgO, Al_2O_3, SiO_2). This technique provides useful analytical results in terms of identifying the different elements although they are not always very accurate (Newbury and Ritchie 2013). EDX analyses were acquired on polished carbon-coated thin sections. Inclusions were observed in backscattered electron (BSE) mode using an accelerating voltage of 20 kV and a working distance of 8–10 mm.

4 Results and discussion

4.1 Petrographic analysis

The petrographic description and classification of the MSP samples revealed differences in the dimension and nature of the fragments, as well as in the groundmass features and the microstructure (Whitbread 1986). Many ceramic wares are characterized by abundant volcanic temper formed by euhedral plagioclases, pyroxenes, and rare olivines (partially altered by iddingsite), and by volcanic rock fragments with glomeroporphyritic and holocrystalline textures resembling volcanites from Mount Etna. A few samples are different in that they contain grog or finer inclusions formed by plagioclases. As regards the groundmass, the most distinctive feature is the mica content which ranges from scarce to very abundant.

This approach enabled us to identify four fabrics:

1. Petrofabric with dominant plagioclase, quartz, volcanic fragments, and scarcely or non-micaceous groundmass (Fig. 3a): (medium-coarse grained) MSP1B, MSP3E, MSP5A, MSP3F, MSP2A, MSP2B, MSP2C, MSP3A, MSP3B, MSP4A, MSP4C, MSP4D, MSP5C, MSP6, MSP8, MSP14, MSP15, MSP16; (medium fine grained) MSP3G.
   I microstructure (a) Vughy microstructure: vesicles and vughs (10–30 %); (b) spatial distribution: double or open space; (c) preferential orientation: due to the vesicles, absent in MSP3G.
   II Groundmass (a) heterogeneous except in MSP5A, MSP2C; (b) micromass optical activity: low, medium–high (MSP3F, MSP3B, MSP4C, MSP3G); (c) color: (pp) blackish; (d) c:f 40:60.
   III Inclusion (a) grain size distribution: polymodal, bimodal in MSP3G; (b) coarse fraction–dominant: plagioclase, monocrystalline, and polycrystalline quartz; common scarce: pyroxene, volcanic rocks

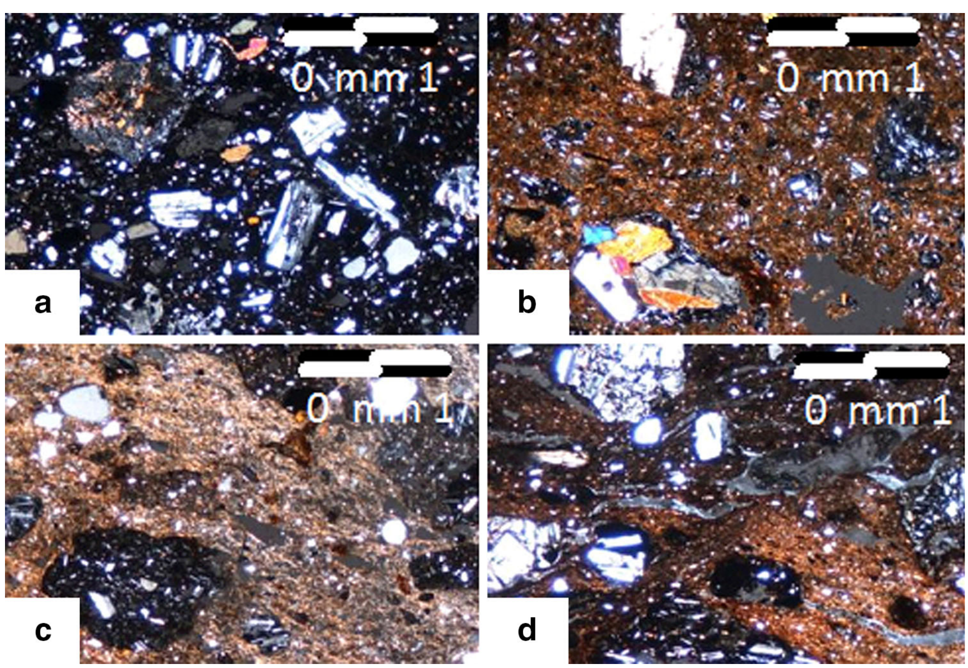

Fig. 3 Microphotographs (cross polarized light): **a** sample MSP3E petrofabric 1; **b** sample MSP3C petrofabric 2; **c** sample MSP5D petrofabric 3; **d** sample MSP10 petrofabric 4

fragments; rare: olivine with alteration in iddingsite, amphibole in MSP2A, MSP5C; volcanic glass in MSP3F and MSP2A; fine fraction–dominant: quartz, sub-rounded in MSP3G, common: plagioclase, scarce: micas, pyroxene; very scarce: microcline in MSP2C.

IV ACF mainly reddish but sometimes there are blackish ACF.

2. Petrofabric with common volcanic rock fragments and very rare quartz with micaceous groundmass (Fig. 3b): MSP1A, MSP3C, MSP3D, MSP11.

   I microstructure: (a) Vughy microstructure: vesicles and vughs (10–15 %); (b) spatial distribution: double and open space; (c) preferential orientation: absent.

   II Groundmass (a) homogeneous, in MSP1A heterogeneous; (b) micromass optical activity: high; (c) color: (pp) yellowish, brownish; (d) c:f 35:65.

   III Inclusion (a) grain size distribution: bi-polymodal; (b) coarse fraction–dominant: volcanic rock fragments (sub-rounded), predominant in MSP1A; scarce: plagioclase, quartz, pyroxene; rare: olivine; in MSP11 rare metamorphic rock fragment; fine fraction–common: micas, plagioclase, quartz; very scarce: pyroxene.

3. Petrofabric with common grog, rare volcanic rock fragments, and scarcely micaceous or micaceous groundmass (Fig. 3c): MSP5D, MSP9, MSP5B, MSP4B, MSP1C.

   I microstructure (a) Vughy microstructure: vesicles and vughs (15–20 %); (b) spatial distribution: double or open space; c) preferential orientation: absent.

   II Groundmass (a) heterogeneous; (b) micromass optical activity: high; (c) color: (pp) yellowish; (d) c:f 20:80.

   III Inclusion (a) grain size distribution: polymodal; (b) coarse fraction–common grog; common scarce: volcanic rock fragments, pyroxene; rare: olivine, absent in MSP9; fine fraction–dominant: quartz; common: plagioclase, abundant: micas.

4. Petrofabric with common plagioclase and heterogeneous groundmass(fine grained; Fig. 3d): MSP7; MSP 1D; MSP 10; coarse-grained MSP12.

   I microstructure (a) Vughy microstructure: vughs (20 %); (b) spatial distribution: open space; (c) preferential orientation: absent.

   II Groundmass (a) very heterogeneous probably due to a mixing of two clays with high and low mica abundances; (b) micromass optical activity: high; (c) color: (pp) reddish–brownish; (d) c:f 5:95.

   III Inclusion (a) grain size distribution: bimodal; (b) coarse fraction–common plagioclase, rare: pyroxene, quartz, volcanic rock fragments; in MSP12 rare metamorphic fragments.

4.2 Chemical (XRF) analysis

The chemical compositions of the samples we studied are reported in Table 3. The data showed a large compositional variability and the presence of Low CaO ceramic (LCa) and High CaO ceramic (HCa) samples as can be seen in Fig. 4.

Major and trace elements data were used for multivariate statistical analysis. The Aitchinson (1986) approach was used (details are described in Barone et al. 2014) in order to highlight the chemical differences among samples of the four petrographic fabrics. The HCa and LCa samples are clearly separated in the biplot of the first two principal components (Fig. 5). The ceramics made of petrofabrics 1 and 2 plot in the HCa field, while all those made of petrofabric 3 are in the LCa area. Finally, the samples made of petrofabric 4 plot in both fields probably due to the fact that the potters mixed calcareous and non-calcareous clays, as suggested by petrographic analysis. Table 3 summarizes the petrographic and chemical correlations highlighting the absence of a relationship between Ca contents and micaceous/non-micaceous groundmass.

It is important to note that in each group, there is one product that is almost certainly local. Kiln firing spacers in the HCa area suggest that the pottery with this composition is locally produced. Furthermore, the clay render and hearth element samples from the LCa field strongly support the presence of raw materials with CaO <6 % in the same area.

The raw materials are Plio-Pleistocene clay sediments used from the Greek period onward in the Catania area (Barone et al. 2005) and characterized by high levels of CaO from 7.49 to 9.48 wt%. The composition of these clays, which also outcrop in large quantities in the vicinity of Mount San Paolillo, is comparable with those of the ceramics we studied with higher CaO.

The presence in the Mount San Paolillo area of clay sediments with low CaO levels (<6 %) is attested by the hearth element from the hut, which was clearly produced using local clays. These sediments should be represented by sedimentary and volcaniclastic clays and silts deposited in a lake environment (Timpa Fm.—Leucatia Member; Branca et al. 2011), although they do not outcrop due to the fact that the area has been widely urbanized.

4.3 FESEM analysis

Petrographic observations showed that almost all the samples contain pyroxene, whereas volcanic glass is quite rare. Pyroxenes from selected ceramics were analyzed to determine the provenance of the volcanic fragments used and in this way the provenance of the ceramics.

Table 3 XRF chemical compositions of the pottery and clay raw materials (major oxides are expressed in wt%, trace elements in ppm)

Samples	Petrofabric	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Sr	V	Cr	Co	Ni	Rb	Y	Zr	Nb	Ba	La	Ce
MSP1B	1	58.22	1.39	17.20	9.11	0.13	2.11	5.93	1.56	1.85	0.41	2.10	627	106	86	41	41	58	30	201	33	566	45	91
MSP2A	1	55.64	1.22	17.49	9.00	0.13	2.66	8.24	1.87	2.22	0.40	1.15	708	98	72	39	38	69	32	226	38	500	52	123
MSP2B	1	55.79	1.18	17.60	8.73	0.12	2.61	8.25	1.88	2.17	0.44	1.23	699	101	73	37	36	71	30	225	38	517	55	115
MSP2C	1	56.80	1.37	17.99	9.09	0.11	2.15	6.62	1.63	2.15	0.51	1.59	616	103	83	39	43	70	31	223	37	567	51	95
MSP3A	1	55.10	1.35	17.09	9.02	0.14	2.34	6.67	1.80	1.70	0.58	4.24	703	101	75	42	41	51	28	186	38	654	49	93
MSP3B	1	56.69	1.38	16.87	8.99	0.15	2.06	6.15	1.60	1.68	0.55	3.89	552	106	86	41	43	43	22	149	21	650	41	99
MSP3E	1	56.71	1.38	16.55	8.93	0.15	1.59	5.53	1.47	1.24	0.47	5.98	650	109	74	39	37	37	29	205	31	731	45	101
MSP3F	1	56.72	1.20	17.44	9.25	0.13	2.66	6.60	1.73	2.16	0.56	1.56	655	99	85	39	41	70	30	213	36	544	56	101
MSP3G	1	57.59	1.30	16.06	9.45	0.13	2.03	5.80	1.91	2.03	0.74	2.98	642	89	74	37	39	59	32	262	43	685	53	104
MSP4A	1	54.94	1.33	17.20	9.87	0.14	2.79	6.97	1.91	2.26	0.62	1.98	616	107	88	43	42	79	33	232	45	606	59	134
MSP4C	1	55.80	1.53	17.36	9.67	0.19	2.11	6.60	2.05	1.83	0.61	2.25	819	111	70	46	35	53	28	205	42	804	47	114
MSP4D	1	53.78	1.29	17.37	9.77	0.14	3.08	8.42	1.82	2.26	0.47	1.60	682	120	84	45	41	68	30	216	40	567	48	107
MSP5A	1	56.32	1.33	16.89	9.11	0.14	2.13	6.18	1.59	1.91	0.64	3.76	666	103	83	40	41	60	28	197	35	664	51	112
MSP5C	1	55.58	1.21	17.62	8.65	0.13	2.03	5.54	2.03	2.18	0.65	4.38	795	84	59	36	35	66	30	272	58	740	60	119
MSP6	1	54.39	1.37	17.43	9.84	0.13	2.80	7.21	2.22	2.36	0.51	1.74	683	108	77	43	39	74	33	233	46	621	58	129
MSP8	1	54.89	1.33	16.72	9.40	0.12	2.46	5.95	1.66	1.83	0.58	5.06	510	111	81	42	45	53	24	191	31	680	60	106
MSP11	2	55.43	1.39	16.73	8.72	0.13	1.72	5.39	1.70	1.43	0.69	6.66	708	99	70	38	34	40	28	174	32	795	46	113
MSP1A	2	51.00	1.27	14.61	9.64	0.19	6.14	6.13	1.77	2.47	0.88	5.90	646	104	91	44	46	54	22	151	27	994	60	121
MSP3C	2	55.08	1.19	16.48	8.87	0.13	1.91	5.62	1.81	2.29	0.79	5.83	626	92	67	34	37	71	32	209	39	823	62	100
MSP3D	2	55.87	1.17	16.47	8.93	0.12	3.44	7.52	1.31	1.75	0.43	2.98	411	95	174	44	79	60	27	166	26	495	39	81
MSP1C	3	58.57	1.13	17.66	8.85	0.11	2.23	5.94	1.03	2.40	0.44	1.64	412	99	101	34	44	91	33	225	28	461	44	91
MSP4B	3	56.06	1.30	17.48	9.13	0.11	1.98	3.68	1.23	1.87	0.45	6.73	500	110	80	36	41	75	31	218	37	610	49	115
MSP5B	3	59.37	1.09	17.77	8.64	0.07	2.12	4.56	0.92	2.55	0.35	2.56	259	104	109	33	51	93	25	172	18	461	46	85
MSP5D	3	56.21	1.10	16.89	8.07	0.10	1.87	5.06	1.13	1.88	0.46	7.23	498	86	89	33	43	73	29	199	31	772	46	85
MSP9	3	56.42	1.10	16.27	7.97	0.10	1.83	3.07	0.83	1.64	0.58	10.19	356	88	83	37	51	59	22	183	19	632	42	75
MSP10	4	56.40	1.30	17.27	9.65	0.13	2.00	4.39	1.85	2.87	1.00	3.14	486	114	76	35	41	72	24	161	25	593	52	117
MSP12	4	55.85	1.11	16.38	8.30	0.11	2.56	6.88	1.46	2.02	0.42	4.92	460	103	87	36	42	65	24	173	21	416	50	111
MSP1D	4	56.94	1.19	17.72	8.83	0.12	2.18	5.75	2.00	2.17	0.65	2.45	565	92	57	35	35	48	16	166	21	575	55	105
MSP7	4	57.47	1.07	16.33	8.35	0.08	1.47	3.52	0.66	2.00	0.63	8.43	360	87	98	31	41	82	30	207	25	766	37	87
MB1	Pleistocene clays	50.79	0.77	15.66	6.08	0.08	2.53	7.20	1.45	1.97	0.14	13.34	274	127	99	15	39	92	25	217	20	286	23	88
MB2	Pleistocene clays	50.25	0.84	16.05	7.04	0.09	2.55	6.49	1.14	2.07	0.14	13.35	258	133	101	16	42	97	26	210	21	267	31	84
MB4	Pleistocene clays	50.20	0.78	15.11	7.22	0.10	2.57	7.63	0.87	2.02	0.14	13.36	292	130	98	11	40	92	26	202	19	233	30	77
MB5	Pleistocene clays	52.45	0.74	14.50	6.50	0.09	2.43	7.78	0.89	1.87	0.14	12.61	280	121	96	13	36	85	27	263	19	235	30	95
MB6	Pleistocene clays	49.37	0.83	16.34	6.82	0.09	2.59	7.06	0.95	2.06	0.14	13.75	293	140	109	15	45	97	26	190	22	285	34	90
MB7	Pleistocene clays	50.48	0.80	15.55	6.82	0.10	2.60	6.87	1.08	2.11	0.13	13.48	262	129	99	15	40	93	25	205	21	282	21	68

Table 3 continued

Samples	Petrofabric	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Sr	V	Cr	Co	Ni	Rb	Y	Zr	Nb	Ba	La	Ce
MB8	Pleistocene clays	50.18	0.82	15.84	7.02	0.08	2.84	7.42	1.09	2.17	0.14	12.41	310	139	109	12	40	101	27	189	21	264	27	80
GU 1S	Pleistocene clays	49.86	0.73	15.12	5.95	0.09	2.72	8.12	1.01	1.98	0.13	14.28	310	122	98	11	38	93	26	225	20	268	31	92
AT 1	Pleistocene clays	47.81	0.80	16.16	6.81	0.09	2.87	6.63	0.68	2.11	0.13	15.93	292	143	109	13	40	104	26	183	23	215	30	81
GRAV 1	Hydrothermally altered pyroclastic rocks	49.95	1.58	20.19	11.28	0.17	2.7	7.87	3.49	1.63	0.54	0.60	1426	197	29	28	15	59	16	173	52	972	99	173
GRAV 2	Hydrothermally altered pyroclastic rocks	49.15	1.56	20.63	11.34	0.16	2.81	8.17	3.52	1.52	0.53	0.61	1512	188	25	26	16	57	15	163	52	925	87	155
GRAV 3	Hydrothermally altered pyroclastic rocks	49.22	1.57	20.16	11.67	0.16	2.82	8.26	3.53	1.56	0.56	0.49	1398	197	28	27	17	60	16	153	53	908	100	161
GRAV 4	Hydrothermally altered pyroclastic rocks	49.59	1.53	20.67	11.19	0.15	2.67	8.13	3.6	1.50	0.54	0.43	1513	188	22	27	12	53	15	154	52	956	100	148
GRAV 5	Hydrothermally altered pyroclastic rocks	49.75	1.46	21.00	10.90	0.15	2.60	8.12	3.56	1.53	0.54	0.39	1463	186	22	26	12	54	8	126	47	923	100	155
GRAV 6	Hydrothermally altered pyroclastic rocks	49.43	1.56	20.07	11.60	0.16	2.84	8.25	3.48	1.52	0.56	0.53	1500	201	28	27	14	55	16	172	56	971	100	168
RAP 1	Hydrothermally altered pyroclastic rocks	51.25	1.59	20.76	12.07	0.18	2.46	6.88	2.54	1.68	0.51	0.08	1100	190	61	30	25	97	16	179	52	931	94	164
RAP 2	Hydrothermally altered pyroclastic rocks	50.33	1.53	20.56	11.29	0.16	2.49	7.26	3.10	1.43	0.49	1.36	1351	190	34	29	18	65	13	167	53	951	93	176
RAP 3	Hydrothermally altered pyroclastic rocks	50.37	1.74	19.95	12.64	0.18	2.18	5.42	3.00	1.65	0.36	2.51	961	201	56	33	21	54	32	244	70	1021	105	199
RAP 4	Hydrothermally altered pyroclastic rocks	49.93	1.63	21.15	12.27	0.18	2.36	6.45	2.82	1.39	0.41	1.41	1180	204	39	27	20	72	15	178	55	990	116	192
SPCL 1	Hydrothermally altered pyroclastic rocks	51.12	1.46	18.61	11.24	0.16	2.67	8.27	2.96	1.74	0.97	0.80	1098	187	42	27	21	76	0	120	0	974	92	148
SPCL 2	Hydrothermally altered pyroclastic rocks	50.98	1.44	18.47	11.23	0.17	2.78	8.40	3.04	1.82	0.97	0.70	1273	180	42	28	20	75	8	166	50	959	88	142
SPCL 3	Hydrothermally altered pyroclastic rocks	51.00	1.48	18.06	11.47	0.16	2.82	8.27	3.34	2.04	0.95	0.41	1088	183	49	28	24	87	1	139	43	924	88	155
SPCL 4	Hydrothermally altered pyroclastic rocks	51.50	1.40	18.32	11.04	0.16	2.83	8.29	2.98	1.74	0.96	0.78	1062	185	45	27	21	74	0	116	6	942	88	142
SPCL 5	Hydrothermally altered pyroclastic rocks	51.01	1.48	18.74	11.31	0.17	2.68	8.43	3.16	1.73	1.02	0.27	1284	187	38	27	18	76	11	176	54	974	88	136
PLB 2	Hydrothermally altered pyroclastic rocks	51.73	1.49	18.48	11.14	0.15	2.61	7.36	3.29	1.61	0.50	1.64	1175	197	34	29	20	61	13	170	53	904	90	145

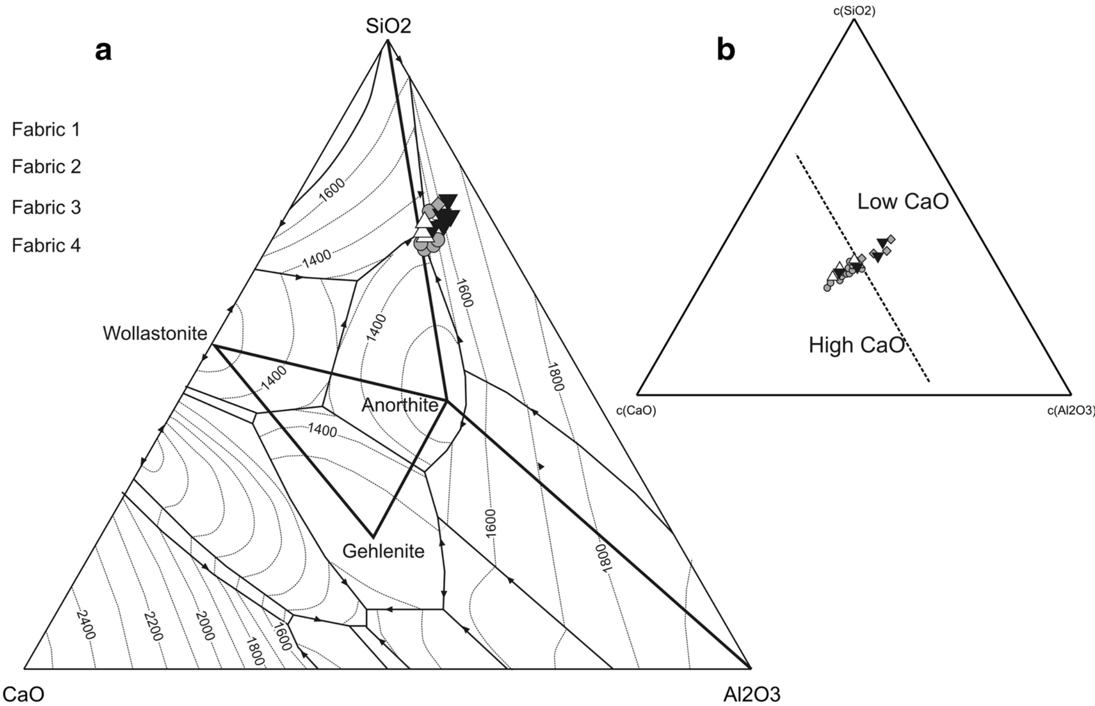

Fig. 4 **a** The SiO_2–CaO–Al_2O_3 ternary diagram. **b** The centered SiO_2–CaO–Al_2O_3 ternary diagram obtained by perturbation in order to rescale the original diagram by moving compositions into the center of the ternary diagram

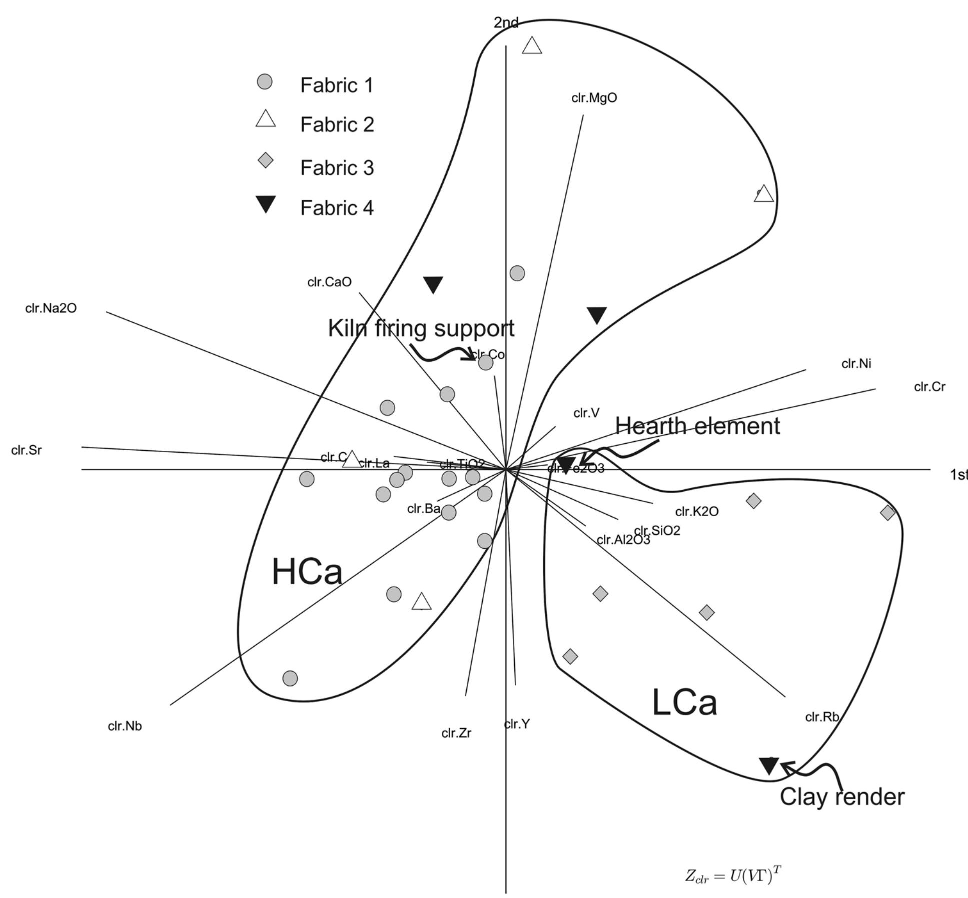

Fig. 5 Biplot representation of principal component 1 versus principal component 2 of the *clr* transformed data for major and trace elements

Table 4 Statistical parameters of chemical compositions of pyroxene included in six representative pottery samples

	MSP3A (n = 22)		MSP3B (n = 13)		MSP5D (n = 8)	
	Mean	SD	Mean	SD	Mean	SD
Na_2O	0.53	0.09	0.50	0.18	0.54	0.16
MgO	12.68	0.83	13.02	0.94	12.89	0.73
Al_2O_3	4.46	1.10	4.80	1.06	3.36	1.02
SiO_2	50.00	1.98	50.55	1.31	50.75	1.47
K_2O	0.00	0.00	0.00	0.00	0.00	0.00
CaO	22.32	1.51	21.99	0.68	22.40	1.06
TiO_2	1.67	0.61	1.55	0.63	1.46	0.32
Cr_2O_3	0.04	0.11	0.07	0.17	0.00	0.00
MnO	0.11	0.13	0.08	0.14	0.16	0.17
FeO	8.20	0.81	7.43	1.24	8.45	0.83

	MSP7 (n = 19)		MSP9 (n = 18)		MSP12 (n = 18)	
	Mean	SD	Mean	SD	Mean	SD
Na_2O	0.46	0.16	0.51	0.08	0.51	0.11
MgO	13.38	1.22	12.64	0.54	12.79	0.97
Al_2O_3	4.09	1.32	4.61	1.00	4.72	1.79
SiO_2	50.90	1.62	49.79	0.86	50.06	1.81
K_2O	0.00	0.00	0.00	0.00	0.00	0.00
CaO	22.07	0.81	22.55	0.81	22.29	1.03
TiO_2	1.43	0.48	1.76	0.52	1.53	0.59
Cr_2O_3	0.10	0.29	0.00	0.00	0.03	0.09
MnO	0.11	0.16	0.05	0.12	0.08	0.12
FeO	7.45	1.09	8.09	1.04	7.98	0.96

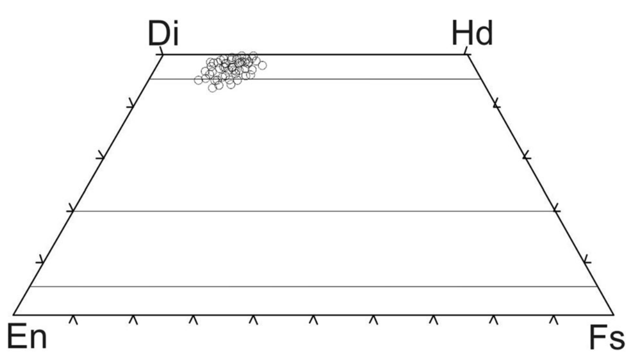

Fig. 6 Classification diagrams (Morimoto et al. 1988) of the analyzed ceramic pyroxenes

Starting from the archeological hypothesis that some of the studied ceramics were produced in the Aeolian Islands, we compared the chemical composition of clinopyroxenes with those of volcanic rocks from the different magmatic provinces of southern Italy as classified by Barone et al. (2010).

In particular, six samples, representative of petrographic groups 1, 2, and 4, were selected for the analysis of 78 pyroxenes of which average compositions and standard deviations are reported in Table 4. All the analyzed pyroxenes have homogeneous diopsidic composition (Fig. 6) suggesting that no or minimal, chemical variations occurred during the firing process.

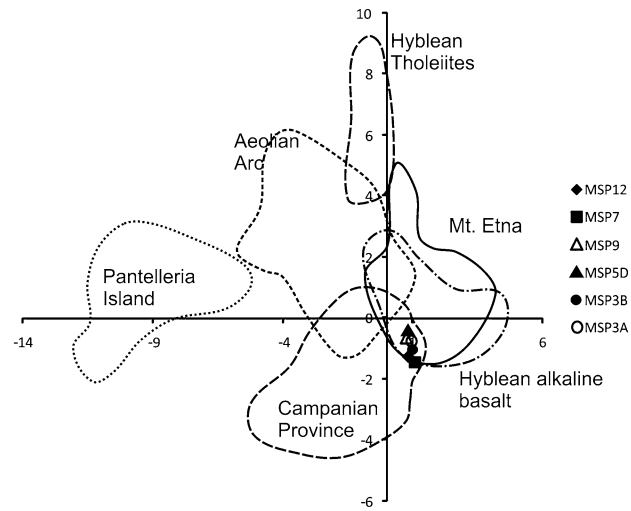

Fig. 7 Discriminant function 1 versus discriminant function 2 diagram showing the correspondence between clinopyroxenes from volcanic rocks and those from pottery samples

Furthermore, discriminant analysis (Fig. 7) performed with a database of pyroxenes from the volcanic rocks from the magmatic provinces of southern Italy suggests the use of Etnean volcanic inclusions, while the absence of pyroxenes with Aeolian composition rules out the possibility of imported pottery from this archipelago (Levi and Jones 2005). The fact that the six samples in Fig. 7 fall into three different areas, labeled as "Campanian province," "Hyblean alkaline basalt," and "Mount Etna," does not have significant archeological implications. In fact, in terms of typology, our samples are quite different from those produced in the Campania region and have little in common with those from Hyblaea. This reinforces the hypothesis that the samples from Mount San Paolillo are closely related with those from the Mount Etna area.

Further information regarding the inclusions may be deduced from the ceramic's high Fe_2O_3 content (>8.7 wt%), which cannot be obtained by adding Etnean volcanic rock fragments (Fig. 8). However, this feature was probably the result of the presence of hydrothermally altered pyroclastic rocks outcropping near the archeological site which had a higher iron oxide content compared to the lava.

5 Conclusions

Archeometric analyses proved very useful for refining the initial visual classification of the pottery found at Mount San Paolillo. Petrographic analysis revealed that rather than 15

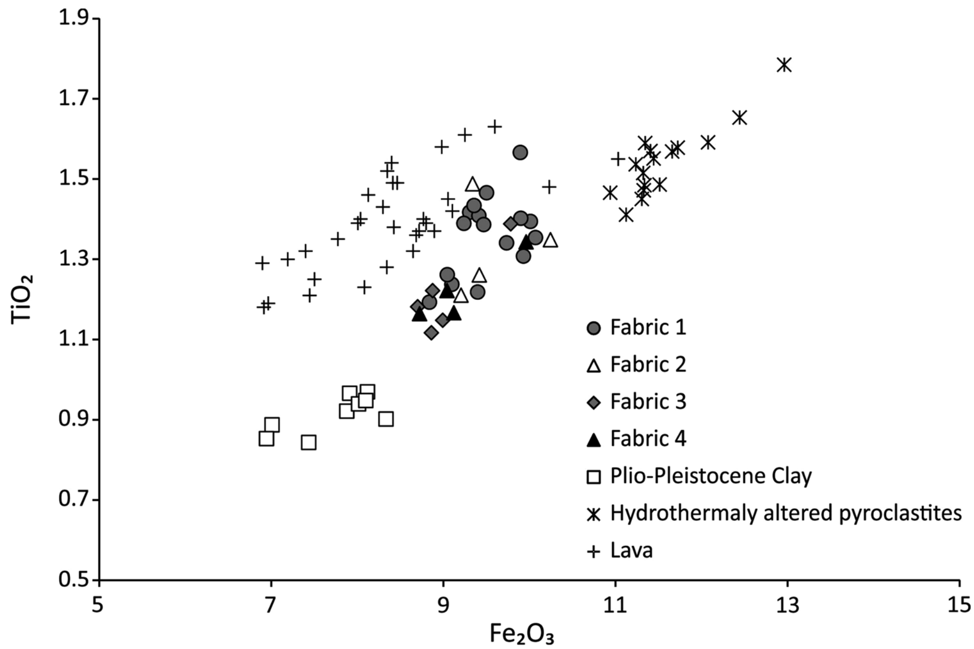

Fig. 8 TiO_2 versus Fe_2O_3 diagram. Chemical data for plotted Mount Etna lavas are from Corsaro and Cristofolini (1993)

groups of ceramics, there were in fact just four. It also confirmed the presence of petrofabrics with predominantly volcanic inclusions and micaceous or non-micaceous groundmass. The chemical data we obtained pointed to a high variability of the material composition of the pottery from Monte San Paolillo, and the samples with LCa and HCa in particular indicated the use of different clay sediments.

This evidence suggests that some of the pieces were produced locally and that at least two different clay sources were quarried in this area. However, other factors must also be considered: (1) the composition of the pyroxenes from certain ceramics was homogeneous and compatible with those of Mount Etna; (2) a mixture of clayey sediments with different compositions (i.e., with and without carbonates) may have been used as the raw material, as in the case of petrofabric 4; (3) the samples which judging by their typological features (i.e., the hearth element and kiln spacers) were produced in the Catania area clearly reflect the chemical and petrographic variability of the sample group.

These additional factors suggest that the entire group of 32 samples was locally produced. This hypothesis is compatible with the particular geology of the Mount San Paolillo area in which there are outcrops with an alternation of sedimentary and volcaniclastic clays and silts deposited in a lake environment (Timpa Fm.—Leucatia Member; Branca et al. 2011).

To sum up, the data from the archeometric analysis tests demonstrate that the hypothesis that the yellow slipped burnished ware was an exclusive product of the Hyblaea area is wrong, as is the assumption that the ware with black painted geometric patterns is a typical product of the Aeolian Islands. The mineralogical data and the analysis of textures suggest different manufacturing processes for the specimens we studied, probably due to the simultaneous activity of different pottery workshops or due to the presence of potters with different skills working in the same workshop. Grog was used as inclusion in some of the samples from Mount San Paolillo (MSP12 and MSP 16), as occurred in other sites in the Catania area, such as Ramacca (Agodi et al. 2000) and Grotte di Marineo (Barone et al. 2012), perhaps identifying a technological trend for this area.

Finally, we discovered that the ancient potters used a mixture of clays (petrofabric 4) in the production of certain artifacts that required special properties. This suggests that the Thapsos craftsmen had a high level of technical skill and an expert knowledge of the natural resources at their disposal.

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