Ceramic production in the *Ager Calenus* from the 3rd century BCE to early Imperial period

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INTRODUCTION AND AIM

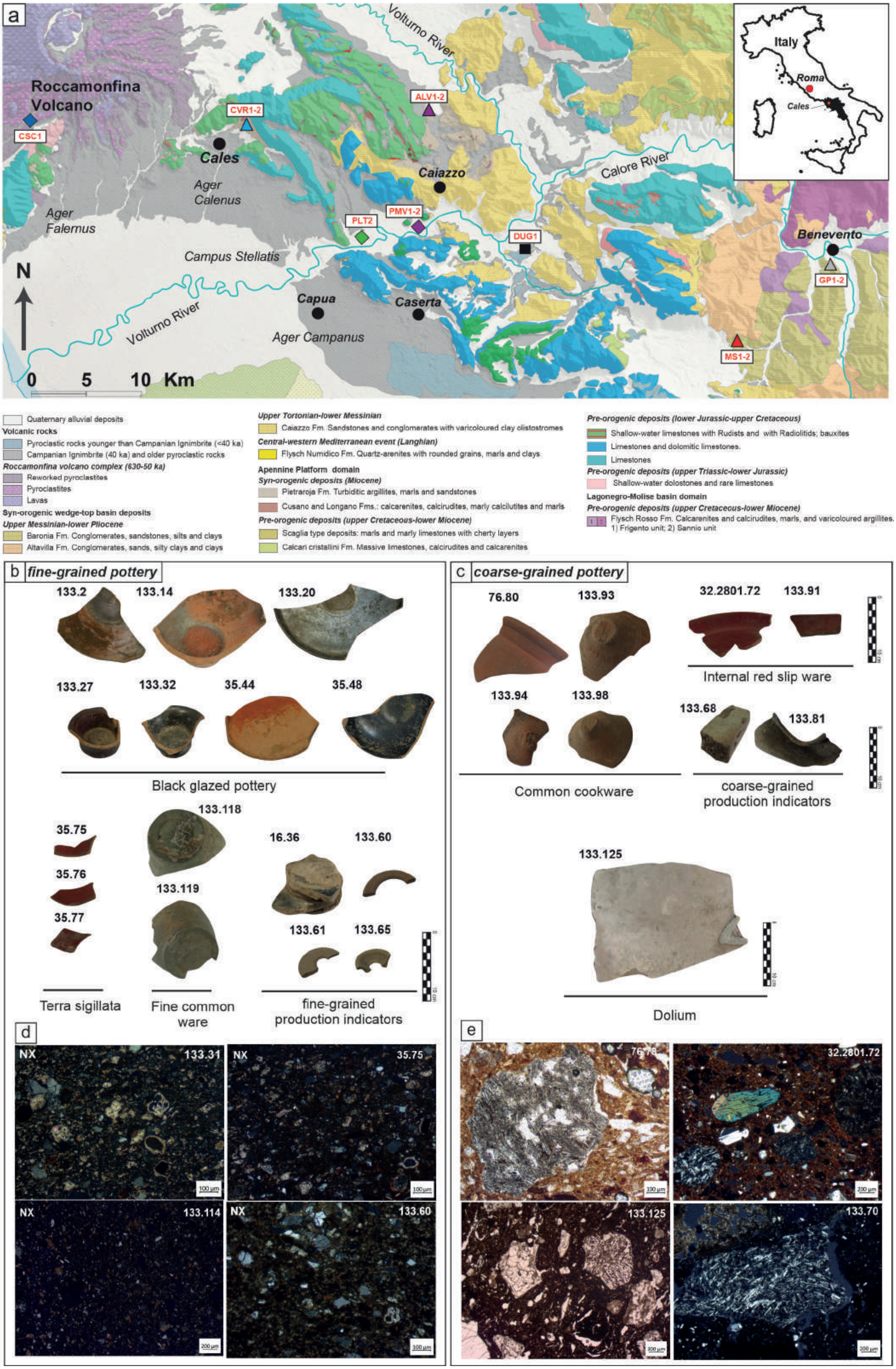
The ancient city of Cales (modern Calvi Risorta) is located in the northern sector of the Campania region of Italy. Thanks to its geographical position Cales had an important strategic function for the Roman control of the *Ager Falernus*, the *Campus Stellatis* and the *Ager Campanus* (Pedroni, 1993; Ruffo, 2010), also known as Campania Felix thanks to the fertile soil of the *Volturnum* river that runs through the plain.

The territory of Cales is considered one of the most important production centers of fine-grained pottery, oriented towards the export of tableware. Cales was particularly renowned for its production and distribution of black glazed ware, a type of fine pottery first made in Greece in the 5th century BCE (Pedroni & Soricelli, 1996), and later in the western Mediterranean from the end of the 4th century BCE to the middle of the 1st century BCE. Following the foundation of the Roman colony in the port of *Volturnum* in 194 BCE (Pedroni, 2001), it is presumed to be connected with the long-distance export of Calenian ceramics. For centuries the black glazed pottery has been considered the hallmark of Calenian production, in particular thanks to the availability of raw materials close to the city (De Bonis et al., 2013). As a matter of fact, in such an important manufacturing center of ceramics, it is not surprising that the workshops also produced common ware, documented over a wide time span from the 3rd century BCE to the 2nd-3rd century CE. The collected data allow us to shed new light on the production activities of the Calenian workshops and document their remarkable continuity over time. The end of the production of black glazed pottery in the early imperial period does not determine the end of production activities. On the contrary, there is an adjustment to new market demands with the manufacture of Sigillata pottery and a vast production of common ware. The continuity and liveliness of production testify to the role of an important craft center that Cales continued to play in the height of the imperial period, when the different senatorial families, linked to the imperial court, continued to boost the local economy, fitting into a market logic that managed to survive the strong economic changes that occurred during this period. The production of most of these important ceramic classes, fine-grained pottery in particular, took advantage of the presence of large outcrops of clay next to the city of Cales (De Bonis et al., 2013), which represented important sources of raw materials.

The study aims to define the local production of fine and coarse-grained pottery from the 3rd century BCE to the 2nd century CE through a minero-petrographic characterization of 125 samples. The samples include black glazed pottery, Terra sigillata, fine common ware, common cookware, internal red slip ware, thin-walled pottery imitation, and objects related to the production process. The study benefits from the comparison of important production indicators, such as wastes of black glazed pottery and common cookware, along with spacers and supports, these represent significant materials for defining with certainty the compositional features of local potteries. The study also aims to expand previous knowledge on these important ceramic classes, through comparison with other fine ceramics found in the same context. Indeed, for the first time, three isotopic systematics were used to perform provenance studies, Sr-Nd and Pb respectively. This pioneering approach allowed us to understand the existing relationships between raw material and finished products. In the light of this, some Campanian clay raw materials Ca-rich and Ca-poor, well known in the literature, were selected and compared to the ceramics under study. This approach highlights the importance of combining geochemical data to identify sources of raw materials and gave us back encouraging results that strengthening the previously experimental study, providing further confirmation of the validity of the method.

GEOLOGICAL SETTING

Cales is located on the northern edge of the Campanian plain, right between the Roccamonfina volcano and the Trebulani mountains belonging to the carbonate pla-


a
Roccamonfina Volcano
CSC1
CVR1-2
ALV1-2
Volturno River
Italy
Roma
Cales
Cales
Ager Calenus
Ager Falernus
Caiazzo
Calore River
PLT2
PMV1-2
DUG1
Benevento
GP1-2
Campus Stellatis
N
Capua
Caserta
Volturno River
Ager Campanus
MS1-2
0 5 10 Km
Quaternary alluvial deposits
Volcanic rocks
Pyroclastic rocks younger than Campanian Ignimbrite (<40 ka)
Campanian Ignimbrite (40 ka) and older pyroclastic rocks
Roccamonfina volcano complex (630-50 ka)
Reworked pyroclastites
Pyroclastites
Lavas
Syn-orogenic wedge-top basin deposits
Upper Messinian-lower Pliocene
Baronia Fm. Conglomerates, sandstones, silts and clays
Altavilla Fm. Conglomerates, sands, silty clays and clays
Upper Tortonian-lower Messinian
Caiazzo Fm. Sandstones and conglomerates with varicoloured clay olistostromes
Central-western Mediterranean event (Langhian)
Flysch Numidico Fm. Quartz-arenites with rounded grains, marls and clays
Apennine Platform domain
Syn-orogenic deposits (Miocene)
Pietraroja Fm. Turbiditic argillites, marls and sandstones
Cusano and Longano Fms.: calcarenites, calcirudites, marly calcilutites and marls
Pre-orogenic deposits (upper Cretaceous-lower Miocene)
Scaglia type deposits: marls and marly limestones with cherty layers
Calcari cristallini Fm. Massive limestones, calcirudites and calcarenites
Pre-orogenic deposits (lower Jurassic-upper Cretaceous)
Shallow-water limestones with Rudists and with Radiolitids; bauxites
Limestones and dolomitic limestones.
Limestones
Pre-orogenic deposits (upper Triassic-lower Jurassic)
Shallow-water dolostones and rare limestones
Lagonegro-Molise basin domain
Pre-orogenic deposits (upper Cretaceous-lower Miocene)
Flysch Rosso Fm. Calcarenites and calcirudites, marls, and varicoloured argillites. 1) Frigento unit; 2) Sannio unit
b fine-grained pottery
133.2
133.14
133.20
133.27
133.32
35.44
35.48
Black glazed pottery
35.75
35.76
35.77
133.118
133.119
16.36
133.60
133.61
133.65
Terra sigillata
Fine common ware
fine-grained production indicators
c coarse-grained pottery
76.80
133.93
32.2801.72
133.91
Internal red slip ware
133.94
133.98
133.68
133.81
Common cookware
coarse-grained production indicators
133.125
Dolium
d
NX 133.31
NX 35.75
NX 133.114
NX 133.60
e
76.78
32.2801.72
133.125
133.70
100 µm
200 µm

(◄ previous page) ***Figure 1 a)*** *geological sketch map of the investigated area;* ***b)*** *macroscopic fragments of fine-grained pottery;* ***c)*** *macroscopic fragments of coarse-grained pottery;* ***d)*** *Thin-sections of fine-grained pottery;* ***e)*** *thin-sections of coarse-grained pottery. crossed polars; NII=parallel polars*

tform succession that forms the Matese, Maggiore, and Camposauro mountain ridges (Fig. 1a; Bonardi et al., 2009). Just north of Cales, extensive clay deposits crop out on the Trebulani muntains slopes. These clay sediments belong to the Pietraroja foredeep succession of the Middle-Upper Tortonian (Fig. 1a) and were utilized until recently to make bricks (Guarino et al., 2011).

Just west of Cales there is the Roccamonfina volcano, which is a stratovolcano characterized by pyroclastic rocks and lavas erupted during three periods of activity that led to the formation of an apical central caldera and sector collapses (Rouchon et al., 2008). The pre-caldera stage is characterized by ultrapotassic leucite-bearing rocks with geochemical characteristics akin to those of the Roman volcanic province (Peccerillo, 2017). Products following the major sector collapse (ca. 400 ka) are mostly shoshonitic rocks erupted from cinder cones and domes located within the caldera and on the pre-caldera outer flanks of the volcano (Conticelli et al., 2009).

In a vast territory around Cales, volcanic deposits also belong to the two high-magnitude eruptions of the Phlegraean fields, which mostly produced trachytes ascribed to the potassium series (KS) of shoshonitic affinity (Conticelli et al., 2004). The most intense and older eruption is that of the Campanian Ignimbrite, which occurred ca. 40 ka before the present (Giaccio et al., 2017). This eruption emplaced huge pyroclastic flows that reached the territory of Cales and a large part of the inner Campania region. The second eruption is that of the Neapolitan Yellow Tuff (ca. 15 ka; Galli et al., 2017) which is represented in the area of Cales only by incoherent deposits.

MATERIAL AND METHODS

The study has focused on 125 samples of different ceramic classes (Fig. 1b,c) discovered during the excavations carried out at the so-called Arx of Cales by the Soprintendenza in 2007. The wide variety of selected material can be divided into two major groups based on inclusions grain size: fine (Fig. 1b) and coarse-grained pottery (Fig. 1c).

On all samples a minero-petrographic characterization via a multi-analytical approach was carried out.

The color of the ceramic bodies was evaluated visually using the Munsell Soil Colour Chart. Hardness was assessed using the Williams hardness test (Williams, 1990).

Polarized light microscopy (PLM) in thin section was used to investigate the textural and petrographic features of ceramic pastes with an OPTIKA V-600 POL microscope and a ZEISS Axiocam 105 color camera (ZEN 2.3 Lite software) for capturing the images.

The mineralogical composition was determined via X-ray powder diffraction (XRPD) on random powder samples with a PANalytical X'Pert PRO 3040/60 PW diffractometer (CuKα generator operating at 40 kV, 40 mA, at a scanning interval from 4 to 50° 2θ, step interval of 0.017°2θ, a step counting time 66 s).

Microstructural observations of fresh fracture surfaces were conducted using a Zeiss Merlin VP Compact FE-SEM (Field Emission Scanning Electron Microscopy).

Quantitative Microchemical Analyses were performed on Polished thin sections of the ceramic bodies, coated with carbon, using FESEM equipped with an energy-dispersive X-ray spectrometer (EDS) and Oxford Instruments Microanalysis Unit (X Max 50 EDS detector). Data were processed with the INCA Xstream pulse processor. Mineral standards and the precision/accuracy of the EDS analyses were described in previous publications (Rispoli et al., 2019).

The chemical composition of the samples was analyzed using XRF (X-ray fluorescence) on pressed powder pellets. An AXIOS PANalytical Instrument was used for this analysis. The concentration of 10 major oxides (SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O, P_2O_5 in wt%) and 10 trace elements (Rb, Sr, Y, Zr, Nb, Ba, Cr, Ni, Sc, V in ppm) were determined. The analytical uncertainty for major elements was 1–2%, and for trace elements was 5–10% (Cucciniello et al., 2017).

The routine analytical techniques described above were completed implementing a new geochemical approach using TIMS (Thermal Ionization Mass Spectrometry) and MC-ICP-MS (Multi Collector - Inductively Coupled Plasma - Mass Spectrometer), which includes for the first time three isotopic systematics: Sr, Nd and Pb. This method provided stronger feedback both in terms of provenance and clay-temper processing.

RESULTS AND DISCUSSION

Fine-grained pottery

Thin section analyses showed that almost all the samples had an optically inactive matrix; in some cases a diffuse birefringence was visible in the matrix due to secondary calcite.

From a textural point of view, the 79 ceramic samples analyzed are extremely fine. The size of the inclusions is generally less than 200 μm and the type of phases present is consistent in all samples. The presence of feldspars, extremely abundant calcite, very small quartz crystals, sporadic mica, lithic fragments of both sedimentary (carbonatic fragments) and volcanic nature (fragments of trachyte >200 μm, and sometimes even fossil fragments) were recognized (Fig. 1d).

Mineralogical analysis shows that quartz is the most abundant phase in all the samples analyzed, along with

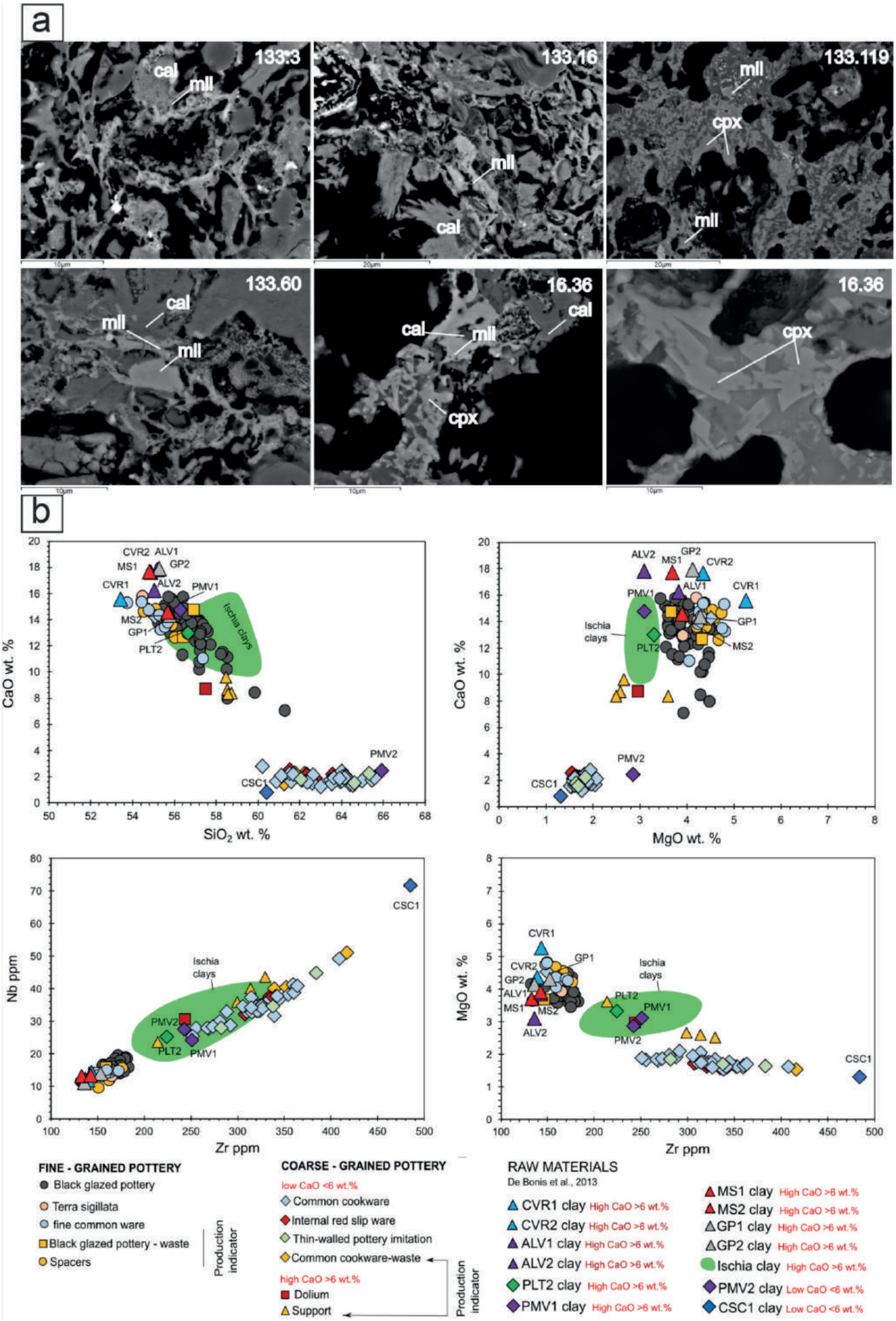


*Figure 2 a) Backscattered electron images of polished surfaces. Abbreviation according to Whitney & Evans, 2010: cal = calcite; mll = melilite; cpx = clinopyroxene. **b)** XRF binary diagrams with major oxides (wt%) and trace elements (ppm) for fine- and coarse-grained pottery, compared with Ca-rich and Ca-poor clay raw material from the Campania region* frequent feldspar, calcite, and traces of mica. Neofromed pyroxene and gehlenite (Fig. 2a) were detected in all samples. These Ca-silicates formed over firing at specific temperatures are used to estimate the EFTs (Equivalent Firing Temperatures). These ranges from 850 and 1050°C, with some exceptions. In particular, sample 35.44 has lower firing temperatures (< 850) due to the presence of phyllosilicates and the absence of newly formed Ca-silicates.

The chemical analisis shows that all the samples are characterized by a calcareous composition of the ceramic body along with a very homogeneous chemical composition (Fig. 2b). The production indicator (16.36) is in line with the chemical composition of the other samples analyzed. In the chemical binary diagrams the ceramic samples were also compared to some Ca-rich clay raw materials from the deposits most likely exploited in the past in the surroundings of Cales (data from De Bonis et al., 2013). From this comparison, the 79 samples of fine-grained pottery show a greater affinity with the Mio-Pliocene marine clay sediments of the Apennine chain sector, among which the local clay samples (CVR) also fall.

The efficiency of Pb isotopes for determining different sources of raw materials was already tested by several authors (e.g., Carter et al.,2011; Makarona et al., 2014; Renson et al., 2013), by comparing different geological materials (from bedrocks to their weathered products) to pottery sherds. The results show a good geochemical affinity with the Mio-Pliocene basin clays of the Apennine chain sector.

For Sr and Nd isotope ratios the local clay (CVR) and a volcanic temper from the area were considered for comparison. All the ceramic samples of glazed pottery, Terra sigillata, fine common ware and the production indicators (wasters of black glazed pottery and spacers) are very close to the local clay raw material. This is an interesting point, in fact the considered ceramic classes are fine-grained and the use of sporadic volcanic temper does not induce any meaningful changes in the isotopic signature as already demonstrated in experimental study by De Bonis et al. (2018). In the same way, the isotopes ratio of the production indicators follow the same behavior of the ceramics. The isotopic fingerprint allows us to define with great approximation the validity of the method as a support of the usual analytical routine used for the archaeometric characterization and the definition of the origin of the possible sources of supply of raw material used for these artifacts.

Coarse-grained pottery

Samples belonging to the investigated classes show very homogeneous macroscopic and petrographic features. The arrangement of aplastic inclusions is characterized by a bimodal distribution, where a fine (generally < 50 μm) and a coarse (generally > 200 μm) fraction are recognizable (Fig. 1e). The coarse fraction is mainly formed of feldspar, clinopyroxene, prevailing volcanic lithics, juvenile fragments represented by pumices and glass shards, with a composition consistent with products of the Roccamonfina volcano and other Plio-Quaternary volcanic complexes (i.e., Phlegraean fields) of the Tyrrhenian border. The fine fraction mainly contains quartz and mica. This led us to hypothesize that a coarse volcanic-bearing temper was added to a clay body containing a tiny siliciclastic natural skeleton to improve the physical properties of the ceramic body, especially for cookwares that had to stand thermal shocks during their use (De Bonis et al., 2014 and reference therein)

The chemical composition of the investigated samples shows a narrow variability among samples of common cookware, internal red slip ware, thin-walled pottery imitation, and wastes of common cookware, thus reasonably suggesting that the same raw material was employed for their manufacture. On the contrary, the high concentration of calcium oxides in the supports and the dolium suggests that a different clay raw material was employed.

To establish their local origin, the pottery samples were compared with raw materials Ca-poor and Ca-rich (Fig. 2b; data from De Bonis et al., 2013). Taking into account all the results of this comparison, the Ca-poor wares represented by common cookware, internal red slip ware, thin-walled pottery imitation show a greater affinity with the alluvial clays from the Volturnum river plain in the locality of Piana di Monte Verna (PMV2). This confirms the use of alluvial raw materials from the Volturnun river plain, as already verified in the production of Alife (Grifa et al., 2015), an ancient town not so far from Cales. On the other hand, samples of supports and the dolium have a Ca-rich character and show a greater affinity with the alluvial clays from the Volturnum river plain from Piana di Monte Verna (PMV1) and Pontelatone (PLT2). This result highlights that alluvial clays from the surrounding area (i.e., Volturnum river plain) could represent the raw material used for coarse-grained ceramic objects.

These sources also differ from those used for the fine ware production at Cales (3rd and the 1st century BCE), for which the local marine clay from the Calvi Risorta outcrop was preferred (Guarino et al., 2011), likely for its better technological performances (natural refined material and sintering attitude) for manufacturing fine pottery (De Bonis et al., 2013). The difference between the considered alluvial and marine clays is provided by the presence of planktonic foraminifers in marine clays, which also occur in fine ware (Verde et al., 2023).

As already shown for the fine-grained pottery, in order to define the origin of ancient ceramics, the determination of Sr, Nd and Pb isotopes ratio was applied.

As far as the Pb isotope ratios are concerned, they confirm the geochemical affinity with the alluvial clays from the Volturnum river plain from Piana di Monte Verna (PMV1-2) and Pontelatone (PLT2).

For Sr-Nd isotopes we taken into account as comparison materials the Alluvial clays from the Volturnum river plain in the locality of Piana di Monte Verna (PMV1-2) and a local volcanic temper (DUG1). The results are very encouraging because, as already observed for fine-grained pottery, valuable information on the origin of the raw material was obtained. In fact, the analyzed pottery have a composition that indicates the use of Ca-rich PMV1, PLT2) and Ca-poor (PMV2) from the Volturno floodplain. In addition, the influence of the volcanic inclusions on the isotopic fingerprint is well detectable and can be used to predict the temper-clay ratio.

CONCLUSION

The archaeometric characterization of the fine-grained pottery revealed a remarkable homogeneity within the different ceramic classes, including black glazed pottery, Terra sigillata, fine common wares, and production indicators. The production indicators, such as spacers and welded pieces of black glazed pottery, played a significant role in identifying local ceramic production due to their historical importance.

The petrographic analysis showed an extreme compositional homogeneity of all the finds belonging to the different ceramic classes along with same mineralogical assemblage.

The chemical analysis indicates that all samples are characterized by high concentrations of CaO which is compatible with the use of a local clay raw material from the Apennine chain sector. This conclusion was further supported by geochemical analysis using three different isotopic systems: Sr, Nd, and Pb. These isotopic analyses helped distinguish different ceramic productions and identify the specific sources of the raw materials. The isotopic "fingerprint" of the fine-grained pottery aligned closely with the clay raw material used, indicating a negligible manipulation of the starting clay.

From a technological point of view, the samples exhibit an extreme variability of the EFTs (from 750 to 1050°C). The presence of hematite suggested that an oxidizing atmosphere predominated during firing, with a brief reducing phase potentially employed for blackening the coating of the black glazed pottery.

As far as the coarse-grained pottery is concerned, the set of techniques used for the archaeometric characterization showed the compositional homogeneity between the common cookware, internal red slip ware, thin-walled pottery imitation, including the production indicators. The latter are represented by wastes of common cookware that provided a great contribution to the definition of a local production of coarse pottery.

The chemical analysis highlights that common cookwares, internal red slip ware, thin-walled pottery imitation and wastes of common cookware are characterized by Ca-poor character, compatible with the use of an Alluvial clay raw material from the Volturnum river plain with similar features with the alluvial clay of Piana di Monte Verna (PMV2). On the other hand, the supports and the dolium are characterized by Ca-rich character, compatible with the use of an Alluvial clay raw material from the Volturnum river plain with similar features with the alluvial clay of Piana di Monte Verna but collected in a level with higher CaO values (PMV1) and Pontelatone (PLT2). These affinities were closely confirmed by isotopic analysis of Sr, Nd and Pb isotopes.

As observed for fine-grained pottery, the use of three different isotope systems is a valuable tool for investigating the provenance of ceramics, even when considering and expecting the addition of temper to reduce plasticity, in particular for the coarse-grained pottery production. In this regard, the method allowed us not only to discriminate the origin of the raw material, but also to be able to define its mix design (temper-clay ratio).

This pioneering approach is not intended to replace traditional methods for characterizing archaeological ceramics, but rather to provide more support to the normal analytical routine used for provenance studies.

From a technological point of view, the samples of coarse-grained pottery fired at temperatures varying from 750 to 950°C in a prevailing oxidizing atmosphere. Production indicators clearly show higher temperatures than those of other investigated ceramic classes, occasionally exceeding 1000°C.

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