Long-distance mobility in the North-Western Mediterranean during the Neolithic transition using high resolution pottery sourcing

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Title

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Abstract

The Neolithisation of the North-Western Mediterranean is still an open issue. New data has recently enriched the chronological and cultural archaeological framework, providing more precise absolute dates and revealing a new and more complex process of expansion of farming in Southern Europe.

The Mediterranean route of colonization (6000-5600 BCE), is characterized by the so-called Impressed Wares (IW) or Impresso-Cardial Complex (ICC) which demonstrate huge internal diversity in material culture, notably in pottery style and technology. This polythetic imprint of the ICC is intimately linked to dynamics of raw material exploitation (such as obsidian) and interconnections within circulation and exchange networks of goods.

Through a comparative and multi-analytical approach to pottery characterization of entire assemblages from two distant sites in the North-Western Mediterranean, each characterized by predominantly local pottery production, we demonstrate long-distance mobility of non-local pottery vessels from the Tyrrhenian regions towards the Languedoc (up to 1000 km) during the Neolithic transition. Our study allows us to highlight this unexpected milestone in the first Neolithic migration in the North-Western Mediterranean.

Keywords

Pottery analysis, ceramic petrography, geochemistry, provenance study, early Neolithic, Impressa Ware

1 Introduction

1.1 Tracking farming pioneers in the North-Western Mediterranean

The spread of farming and Neolithic lifeways from the Eastern Mediterranean and the Aegean towards Western Europe is known to have followed two main routes (Childe, 1925). The continental route, which was at the origin of the Linearbandkeramik Complex (LBK), can be traced through the Central Balkans and the Danube valley, and reached Northern France after 5350 BCE (Whittle, 2018). The Mediterranean route, linked to the Impressed Wares or Impresso-Cardial complex (ICC), reached Southern France at least five centuries earlier, c. 5850 BCE (Binder et al., 2017). Many issues are related to the social dynamics at the origin of the erratic dispersal of the very first ICC farming communities in the Western Mediterranean, which highly contrasts with the LBK pioneer front.

In both cases, the role played by migrants within these processes has been demonstrated by genomics (Mathieson et al., 2018). Concerning the ICC, the modelling of a large set of audited radiocarbon dates currently places its formative stage in Southern Italy and Dalmatia during the very beginning of the 6th millennium BCE, mostly after 5950 BCE (Binder et al., 2017; McClure et al., 2014). Few genomic data are currently available for the earliest ICC aspects, i.e. between 6000 and 5750 BCE from Zemunica cave and between 5670 and 5560 BCE from Kargadur, both in Croatia. These data strengthen the idea of a genetic connection with the Balkans, Aegean and Anatolia, regarding both maternal and paternal lineages (Mathieson et al., 2018). This evidence raises new issues on the possible roots of the ICC in the second half of the 7th millennium BCE, and specifically in the Southern Balkans and Aegean regions in the context of the Monochrome or Proto-Sesklo Pottery which punctually reached the Ionian Sea (Berger et al., 2014).

North and westwards, in Italy and France, analyses of Neolithic DNA are very rare and mostly concern later periods (Lacan et al., 2011; Rivollat et al., 2017). In this area, peopling dynamics are mainly demonstrated by transfer of material culture and domestic taxa. For instance, it is now well known that domestic animals and crops were exogenous (mainly sheep, goat, wheat and barley) and originated from Southwest Asia (Rowley-Conwy et al., 2013). This enables us to study the spread of animal breeding and agriculture and to observe their rhythms and pathways. In this framework, systemic studies of material culture also offer the possibility to track the trajectories of the first farmers (Bernabeu Auban et al., 2017; Ibáñez-Estévez et al., 2017).

Peopling dynamics from each region of the Italian Apennine chain seem to have been diverse regarding cultural connections as well as diffusion tempo. On the Adriatic side, ICC settlements remained highly concentrated in Apulia, Basilicate and East Calabria during c. two centuries, crossing over the Tavoliere towards Central Italy at a rather late period: c. 5750 BCE in Abruzzo and c. 5600 BCE in Marche. In contrast, on the Tyrrhenian side, the meshing of the earliest settlements appears very sparse while the speed of diffusion appears to be very fast. In fact, early farmers reached the far Ligurian and French coasts as early as c. 5850 BCE (Binder et al., 2017). Similarly, the first data on pottery technology indicate that different communities of practice occurred in the Adriatic and Tyrrhenian sides of the Apennine range. In the Adriatic area, pottery forming methods using coils and long slabs were clearly related to the Balkan tradition, whereas a distinctive Spiralled patchwork technology (SPT) was in use in the Tyrrhenian. In the SPT ceramics were constructed by juxtaposing circular patches, each formed by spiral coil (Gomart et al., 2017).

Obsidian is well known for having played an important role during the earliest Eastern Mediterranean Neolithic (Dixon et al., 1968), and notably a symbolic one (Cauvin, 1998). Obsidian was totally ignored by the Late Hunter-Gatherers of the Western Mediterranean, and its use was transferred westward as part of a Neolithic package. Most of the attractive obsidian sources are located in the western Mediterranean islands (Pantelleria, Lipari, Palmarola and Sardinia) where this glass was exploited and distributed from the earliest stages of the ICC (Ammerman and Andrefsky, 1982; Muntoni, 2012; Tykot et al., 2013). Although there is currently no evidence of early ICC settlements located close to these obsidian sources, tools made of obsidian from Palmarola and Sardinia have been identified in the earliest North-Western Mediterranean ICC, especially at the sites of Arene-Candide in Liguria (Ammerman and Polglase, 1997), and Peiro Signado and Pont de Roque-Haute in the Mediterranean Languedoc (Briois et al., 2009; Binder et al., 2012).

Until now obsidian geochemical analysis has been the most effective and precise method for linking distant sites or people, and has provided the main evidence for voyaging and circulation throughout the Western Mediterranean compared to the simple analogies suggested by pottery styles.

These data shed light on a specific Tyrrhenian cultural landscape where the sea likely played a central role during part of the ICC. The range and the regime of maritime mobility is one of the key issues in this context. Research carried out in the last couple of decades has shown that the Mediterranean is a hot spot of cultural diversity (Rigaud et al., 2018). Furthermore, this maritime zone offered the possibility of multidirectional movements, but also different forms of mobility (pioneering, travelling, interaction and exchange) (Manen et al., 2018). Consequently it is still difficult to identify precise circulation routes, cultural filiations and origins of the incoming farmers. In this study we implement a multi analytical approach to pottery provenance through petrographic and geochemical analyses to provide additional insight into the crucial question of Neolithic dispersal routes. We demonstrate that pottery sourcing analysis is both complementary, and can be as equally precise and pertinent as obsidian sourcing, for tracking ICC networking dynamics in the Western Mediterranean.

1.2 Pottery pastes as a proxy for human trajectories

Pottery studies have been developed for and applied to Mediterranean Neolithic contexts since the early 1990s (Capelli et al., 2017, 2008; Convertini, 2010, 2007; Echallier, 1991; Ferraris and Ottomano, 1997; Gabriele, 2014, 2015; Gabriele and Boschian, 2009; Manen et al., 2010; Martini et al., 1996; Muntoni, 2003; Paolini-Saez, 2010; Spataro, 2002; Ucelli Gnesutta and Bertagnini, 1993). In most of these studies, pottery analyses have indicated local production of ICC pottery, while non-local pottery production remains exceptional within assemblages. The limited range of non-local ceramic circulation (10 to 100 km) generally suggests that the pottery trade was embedded in functional networks, illustrating the logistical mobility of the first ICC farmers (Binder, 1991a; Capelli et al., 2017; Manen and Convertini, 2012).

However, previous studies have already highlighted the possibility of long distance pottery circulation in the Mediterranean Languedoc (Convertini, 2010, 2007), the Liguro-Provençal arch and Tuscany (Capelli et al., 2017, 2008; Gabriele, 2014, 2015), especially with regard to the presence of volcanic components in certain pottery pastes (hereinafter referred to as volcanic pottery and paste). The latter offer specific petrographic markers and geochemical features of a very high resolution, as demonstrated by a large set of pottery studies from distinct regions (Comodi et al., 2006; Barone et al., 2010; Brunelli et al., 2013; Palumbi et al., 2014; Belfiore et al., 2014; Scarpelli et al., 2015; La Marca et al., 2017). Furthermore, recent applications of in situ geochemical methods on non-volcanic mineral inclusions allow us to enhance the accuracy and reliability of provenance analyses (Gehres and Querré, 2018).

Here, we provide a multi analytical comparative approach to pottery characterization and provenance through petrographic and geochemical analyses. Through high-resolution study focused on non-local volcanic pottery with similar petrographic composition from the two ICC sites of Portiragnes - Pont de Roque-Haute (Languedoc, France) (hereinafter referred to as PRH) (Guilaine et al., 2007) and Giglio - Le Secche (Tuscany, Tuscan Archipelago, Italy) (hereinafter referred to as GLS) (Brandaglia, 2002) (Fig. 1), we demonstrate that although most vessels were made locally, a few unique pottery vessels circulated at long distance between Central Italy and Languedoc, attaining distances exceeding 1000 km following the coast, or 600 km as the bird flies.

2 Materials and Methods

2.1 Sites and samples

The open-air site of PRH, which offered a set of pits dug into a fluvial terrace, was interpreted as a short duration settlement in a ria (Guilaine et al., 2007). The modelled age of this occupation is estimated between 5860-5710 and 5800-5680 BCE, i.e. one of the earliest ICC settlements currently known in the Western Mediterranean (Binder et al., 2017). Together with domestic remains (mammals, seashells and tools including obsidian from Palmarola) a series of ca. 603 sherds (pertaining to at least 55 individuals) (Manen and Guilaine, 2007), of which the totality was analyzed petrographically by the authors, indicates a dominant local pottery production exploiting reworked alluvial Pliocene deposits (Convertini, 2010, 2007). Few individual pots (ca. three at least) are characterized by volcanic aplastic components and among them one pot (ca. two sherds) is made of non-local raw materials and impressed with the umbo of a *Cardidae* shell (Fig. 2A).

The site of GLS is a shelter close to a north-western beach of Giglio Island. Rich deposits of well preserved pottery (Brandaglia, 1991) associated with a large set of Palmarola obsidian tools (Barone et al., 1996; Brandaglia, 1987) demonstrated its long occupation, starting during the earliest stage of ICC (5840-5540 BCE) and lasting at least until the second half of the 6th millennium BCE (Binder et al., 2017). Most of the earliest pottery (ca. 1091 sherds, pertaining to at least 60 individuals), of which the totality was analyzed petrographically by the authors, was made using local residual deposits of granite formation, with the exception of notable few vessels (ca. three sherds) shaped with a non-local volcanic paste and decorated with the ventral margin of a *Cardidae* shell (Fig. 2B, C) (Gabriele, 2014).

The remarkable presence of isolated non-local volcanic pottery within a homogeneous local production (ca. 99% of total sherds from both sites), has been demonstrated thanks to a systematic petrographic study of the entire pottery assemblage of both sites (Convertini, 2010, 2007; Gabriele, 2014). For the non-local pottery from both sites, the most likely sources of raw material are the volcanic provinces of central Italy. In order to verify this hypothesis and shed light on the earlier Mediterranean Neolithic scenario, three volcanic ceramic samples with similar petrographic composition from both sites (one from PRH and two from GLS), were further investigated using high performance geochemical methods in an integrated and comparative study perspective.

2.2 Analytical methods

Petrographic and chemical methods were performed on each specimen in its various prepared forms (prepared as powder, thin-section, etc.) using different scales of observations in order to have comparable and complementary data. As ceramic pastes are heterogeneous by definition, painstaking care is taken in microscopically discriminating those minerals which are most sourceable and mapping them using imagery to prepare the samples for successive analysis of multiple mineral grains from each sample. While the number of sherds, representing at least two pots from two sites, is small, the number of in-situ analyses conducted on each sherd was gargantuan.

First, petrographic analysis was obtained by stereomicroscopy directly on the three pottery fragments, and by standard optical microscopy on six thin sections (two for each sample) with the support of scanner images to characterize a-plastic inclusions and fabric textural features. Description of textures of inclusions, pores and matrix were performed following the guidelines of soil micromorphology (Stoops, 2003) and ceramic description (Quinn, 2013; Whitbread, 1989). Analyses were carried out at the CEPAM laboratory (CNRS, Université Cote d'Azur) in Nice, France.

Subsequently, to be able to verify the real compositional correspondence between ceramics from both sites, chemical analysis of major and trace elements were carried out to determine composition of the bulk pottery and of single mineral grains, such as clinopyroxene. Microchemical in-situ analysis on clinopyroxene is based on the assumption that its chemical composition represents the chemical composition of parental magma (Barone et al., 2010; Leterrier et al., 1982). Indeed, crystal-chemistry of clinopyroxene is related to different geochemical and petrological magma affinities (Cellai et al., 1994; Cundari and Salviulo, 1987; Gentili et al., 2014). Finally, to discern possible petrographic and geochemical sources, data available in scientific literature were used.

The bulk pottery compositions were obtained by Inductively Plasma Atomic Emission Spectrometry (ICP-AES) and Inductively Coupled Mass Spectrometry (ICP-MS) for major and trace elements respectively at the Geochemical and Petrographical Research Center in Nancy (SARM laboratory, CNRS-CRPG; Supplementary dataset) following the procedure described in Carignan et al. (2001).

Chemical analysis by environmental scanning electron microscope (FEI PHILIPS XL30 ESEM) equipped with an Energy Dispersive Spectroscopy (EDS) system for X-ray microanalysis (Quantax XFLASH6/30 silicon drift 10mm²) was applied on 74 clinopyroxene and 53 K-feldspar (sanidine) selected single crystal grain minerals found as inclusions in polished thin sections and using mapping of scanner images. The analyses were carried out at the laboratory of the Centre for Material Forming (CEMEF, Ecoles des Mines de Paris, CNRS, Sophia Antipolis, France).

Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) examinations for estimating major and trace elements were applied on clinopyroxene single crystals found as inclusions in the epoxy impregnated ceramic samples left from the processing of thin sections, by stereomicroscopy observations and using mapping of scanner images. LA-ICP-MS analysis were undertaken on 78 selected clinopyroxene grain minerals, other than those of the SEM-EDS investigations (Supplementary dataset). The largest clinopyroxenes were selected in order to avoid possible contamination by other mineral species or clay paste from the ceramic during the ablation process. LA-ICP-MS analysis was conducted at the IRAMAT laboratory, Centre Ernest-Babelon (Université d'Orléans, CNRS, France).

The analytical protocol developed for obsidian inclusion analysis (Palumbi et al., 2014) was adapted to the analysis of clinopyroxenes improving detection limits of elements such as rare earths. As encountered with the analysis of obsidian inclusions, one of the critical parameters of this type of analysis is the thickness of the analyzed clinopyroxene grains, specifically because they were inserted in a ceramic paste and thus may contain other mineral species in their structure.

Consequently, in order to avoid overshooting the inclusions and to maintain a high signal level, a 10 Hz laser pulse frequency was used and the analytical time was reduced from 55 to 25 seconds (8 seconds for pre-ablation and 17 seconds for analysis), that is 8 mass scans from lithium to uranium.

To ensure that the measured signal is not perturbed by the presence of other mineral species its evolution is systematically checked during the whole ablation. If other mineral phases are encountered, the calculation protocol developed to study concentration profiles in glass is applied to calculate the clinopyroxene composition and to identify the other mineral phase if it is possible (Gratuze, 2016).

However, the contribution or the modification brought by another mineral species to the signal measured for a perturbating mineral species in the whole signal is weak. It is thus only when the chemical contrast between both species is significant that the correction of the signal is possible, as illustrated by the presence of a zircon grain in one of the recorded spectra or by a transition between a clinopyroxene and a feldspar. For most of the other cases the presence of another mineral species may not be detected and will just increase the dispersion or the variability of the calculated compositions. To avoid clay contaminations, the analyses were carried out in the middle of the clinopyroxene grains. When possible the largest grains were selected for the analysis, however, analyses of very small grains were also carried out by adapting the laser beam diameter.

External calibration was performed using the National Institute of Standards and Technology Standard Reference Materials 610 (NIST SRM610), along with Corning reference glasses B and D. 28Si was used as an internal standard. Concentrations were calculated according to the protocol detailed in Gratuze (2016). Detection limits range from 0.01% to 0.1% for major elements, and from 20 to 500 ppb for minor and trace elements. Compatibility of data is monitored by the regular analysis of reference materials NIST SRM612 as unknown sample.

3 Results and discussion of the comparative study of the non-local volcanic pottery

3.1 Petrographic analysis of pottery pastes

At a stereo-microscopic scale, volcanic pottery pastes are significantly characterized by sub-rounded/rounded green and dark-green clinopyroxene and colourless or whitish feldspar inclusions (Fig. 3A, B), up to very coarse sand size. However, more heterometric and larger lithic inclusions are also observable. Pastes are friable and not homogeneous in colour (Fig. 3A, B).

At thin section optical-microscopic scale, porosity is characterized by meso- and macro planes and few macro vughs. The porosity distribution and orientation is well expressed in the GLS samples, where concentric features and parallel, inclined and bow-like bands of oriented planes were recognized. A-plastic inclusions are common, mostly sub-rounded and rounded, moderately sorted, with fine-medium sand size. Grain distribution and orientations are weakly-moderately expressed, up to single- and double-spaced relative distance. Clinopyroxene and K-feldspar (sanidine) are the most common minerals (Fig. 3C, D). Clinopyroxene is frequently rounded, coloured with green pleochroism and twinned (Fig. 3C-F). Sanidine is generally less rounded and larger (up to very coarse sand size) than clinopyroxene, fresh and Carlsbad twinned (Fig. 3C-F). Other mineral grains are identified in different proportions and size, within which there are oxides, quartz, plagioclase, and black and white micas. Lithic inclusions are generally rounded, heterometric, up to very coarse sand and very fine gravel size. Lithoclasts are identified as alkaline volcanic rocks (Fig. 3G, H), sandstone, siliceous sedimentary rocks, and quartz-metamorphic rocks. The matrix is optical active in GLS samples with stippled-speckled b-fabric and striated b-fabric. The colour is heterogeneous, linked to Fe reduction on the margins and Fe oxidation on the core of the fragments.

3.1.1 The importance of petrography for identifying potential volcanic source areas

On the basis of petrographic and archaeological considerations, the most likely source of raw materials are the Italian Miocene-Quaternary potassic and ultrapotassic volcanic rocks from the so-called Volcanic Provinces (hereinafter referred to as VP) part of the Magmatic Provinces of the Tyrrhenian region (Fig. 1) (Conticelli et al., 2004; Peccerillo, 2017). Furthermore, petrographic pottery data, namely characterized by the association of sanidine and green clinopyroxene minerals with minor amounts of volcanic, sedimentary and metamorphic lithoclasts, suggest considering volcanic formations that are hydrographically or geomorphologically linked with formations of different geological origins. In this perspective, more suitable volcanic centres are the Monte Amiata in the Tuscany VP (hereinafter referred as TVP) (Conticelli et al., 2015; Cristiani and Mazzuoli, 2003), and Vulsini (Barton et al., 1982; Holm, 1982; Palladino et al., 2014), Vico (Barbieri et al., 1988; Palladino et al., 2014; Perini et al., 2004; Perini and Conticelli, 2002) and Sabatini (Conticelli et al., 1997; Del Bello et al., 2014; Palladino et al., 2014) districts in the Roman VP (hereinafter referred to as RVP). We cannot a priori exclude Roccamonfina (Ghiara et al., 1979), Phlegrean Fields (Armienti et al., 1983; Belkin et al., 2016; Civetta et al., 1997; Fedele et al., 2009; Mollo et al., 2016) and Somma-Vesuvius (Bertagnini et al., 1998) districts in the Campania VP (hereinafter referred to as CVP) (in this paper Roccamonfina volcanic district is considered part of the CVP, Fig. 1; moreover for the CVP we haven't considered data on eruptions younger than 8 ka BP).

In addition, for comparison we can consider volcanic districts that can provide a similar K-feldspar-clinopyroxene mineralogical association as the archaeological pottery samples. For example, the Italian Miocene-Quaternary volcanic rocks of San Vincenzo (Feldstein et al., 1994; Ferrara et al., 1989; Poli and Perugini, 2003a) and Monte Cimino districts (Perugini and Poli, 2003; Conticelli et al., 2013) in the TVP, Monte Vulture Volcano (Bindi et al., 1999) in the Apulian VP (hereinafter referred as AVP); the Miocene-Quaternary Monte Arci (Dostal et al., 1982) district and the Oligo-Miocene Bosa-Alghero, Anglona and Logudoro districts (Guarino et al., 2011) of the Sardinia VP (hereinafter referred to as SVP) (in this paper the different Sardinian volcanic districts are considered in the same VP, Fig.1).

Conversely, because of their entirely volcanic origin, some Thyrrenian islands such as Capraia (Tuscan archipelago, Tuscany) (Chelazzi et al., 2006; Poli and Perugini, 2003b), Ponza (Pontine archipelago, Latium) (Conte and Dolfi, 2002; Paone, 2013) and Vulcano (Aeolian archipelago, Sicily) (Faraone et al., 1988) are unsuitable, even if they can bring a K-feldspar-clinopyroxene mineralogical association. At the same time, the basaltic volcanic formations near the site of PRH can be excluded, mainly due to the lack of K-feldspar phenocrysts in this rock type (Dautria et al., 2010). For the same reasons other French and Italian volcanic districts, such as Cap d'Ail, Alban hills (Boari et al., 2009) and Monti Ernici (Boari and Conticelli, 2007; Frezzotti et al., 2007), are not considered.

3.2 Major elements analysis of single mineral inclusions in pottery pastes

Data from the SEM-EDS analysis shows that alkali-feldspar minerals are compositionally homogenous with Or_{67} to Or_{85}, and in only one case (GLS02 sample) with Or_{50}. The alkali-feldspar classification is represented in a ternary diagram in supplementary Figure 1.

Clinopyroxenes are predominantly composed of diopside and Fe-rich diopside; augite to Mg-rich augite and CaFe-rich clinopyroxene are also present (Supplementary dataset). Also in the case of LA-ICP-MS analysis, clinopyroxenes are predominantly composed of diopside and Fe-rich diopside with Fs_{13} to Fs_{20}; augite ($Wo_{43}En_{54}Fs_4$) to Mg-rich augite ($Wo_{44}En_{33}Fs_{23}$) and CaFe-rich diopside ($Wo_{51}En_{38}Fs_{11}$ to $Wo_{52}En_{28}Fs_{20}$) are also present (Supplementary dataset). The clinopyroxene classification is represented in the QUAD diagram referring to Morimoto (1988) in supplementary Figure 2. The major-element chemical composition of clinopyroxene available in the scientific literature allows us to differentiate amongst previously indicated possible petrographic sources in the TVP (Aulinas et al., 2011; Conticelli et al., 2015, 2013; Feldstein et al., 1994), RVP (Barton et al., 1982; Comodi et al., 2006; Conticelli et al., 1997; Cundari, 1975; Dal Negro et al., 1985; Del Bello et al., 2014; Gentili et al., 2014; Holm, 1982; Kamenetsky et al., 1995; Palladino et al., 2014; Perini, 2000; Perini et al., 2004; Perini and Conticelli, 2002), CVP (Armienti et al., 1983; Aulinas et al., 2008; Belkin et al., 2016; Civetta et al., 1997; Fedele et al., 2009; Ghiara et al., 1979; Mollo et al., 2016; Pappalardo et al., 2008), AVP (Bindi et al., 1999; Caggianelli et al., 1990), and SVP (Dostal et al., 1982; Guarino et al., 2011). The Quad diagrams show substantial correspondence between Mg-rich augite and diopside composition of clinopyroxenes in pottery (Fig. 4A) and volcanic rocks of RVP, CVP and AVP (Fig. 4B, C, E). Instead, there is partial correspondence with rocks of TVP and SVP, especially due to the lack of clinopyroxene with augite composition in pottery pastes (Fig. 4D, F). Moreover, pottery clinopyroxenes are characterized by limited compositional variations in major elements, considered as cationic values. In Ti_{tot} vs Al_{tot} binary diagrams (Supplementary Figure 3), the cluster of pottery clinopyroxene composition fits in the field of clinopyroxenes of the RVP, TVP and CVP (Supplementary Figure 3B, C, D), but only partially fits in the clinopyroxene compositional fields of the AVP and SVP (Supplementary Figure 3E, F).

3.3 Trace element analysis of bulk pottery pastes

We conducted ICP-MS trace element analysis on two bulk ceramic samples from the two archaeological sites. A soil sample from the PRH site (Sedimentary Pliocene deposits) was also analyzed. Results are reported in the Supplementary Dataset. In the spider diagram (Fig. 5A) PRH and GLS pottery are geochemically indistinguishable. Their spectra display the same Large Ion Lithophile Elements (LILE) enrichment, the same high negative Ta and Ti anomalies, and the same slight Sr anomaly. Furthermore, trace element contents of rocks from the Languedoc Volcanic Province (Agde volcano and lava at the PRH site) do not display Ta, Sr and Ti anomalies (Fig. 5A), suggesting that volcanic minerals of these ceramics are not derived from southern France. Indeed, Languedoc Volcanic Province corresponds to homogeneous alkali basaltic geochemistry (Dautria et al., 2010), which is different from typical calc-alkaline geochemistry of the subduction zones (Italian Volcanic Provinces) (Peccerillo, 2017; Gasperini et al., 2002).

PRH soil shows the same pattern as the pottery except for Sr which shows a major negative anomaly. Furthermore, the PRH soil spectrum is different from the regional lavas (Fig. 5A). The PRH alluvial soil geochemistry can be interpreted as a mixing of sedimentary, metamorphic, plutonic and volcanic rocks. The absence of sanidine mineral grains suggests that it was not used for PRH and GLS pottery.

Trace element contents from rocks of RVP, TVP and CVP are also reported (Fig. 5B). Although PRH and GLS ceramic samples match Italian Volcanic Province spectra, differences remain apparent especially for Sr, High Rare Earth Elements (HREE, i.e. Tb, Dy, Ho, Tm, Yb) and High Field Strength Elements (HFSE, i.e. Ta, Zr, Hf). Significant negative Ta and Ti anomalies are present as well in Italian Magmatic Provinces and in bulk archaeological ceramics, supporting Italian volcanic rocks as potential sources for the archaeological materials. The CVP and TVP display a strong negative Sr anomaly unlike the RVP. Taking into account the Sr contents, ceramic samples are more in agreement with the RVP. Furthermore, archaeological samples display a depleted HREE content like the RVP and TVP, while the CVP provides slight HREE enrichment.

3.4 Trace element analysis of clinopyroxene inclusions in pottery pastes

LA-ICP-MS trace element analysis was performed on clinopyroxenes included in pottery paste from the PRH and GLS sites. Trace element contents are reported in the Supplementary Dataset. Our data were confronted with data available in the literature (i.e. trace element contents from RVP (Comodi et al., 2006; Gentili et al., 2014; Scarpelli et al., 2015) and CVP pyroxenes (Arienzo et al., 2009; Civetta et al., 1997; Fedele et al., 2009; Mollo et al., 2016; Pappalardo et al., 2008; Scarpelli et al., 2015). In the spider diagram, PRH and GLS ceramics display the same spectra pattern, with pronounced Ta, Sr, Zr and Ti negative anomalies (Fig. 6A). Although clinopyroxenes from RVP and CVP also show similar spectra, a small variance appears for Sr, Light Rare Earth Elements (LREE, La, Ce, Pr) and HREE contents (Fig. 6B). The RVP pyroxenes reach higher values for LREE, while the CVP pyroxenes can reach higher values for HREE and smaller values for Sr contents. However, spectra of archaeological pyroxene chemistry do not allow us to decipher the volcanic source accurately. We therefore investigated precise trace element contents which could be specific proxies for the sourcing. First, in the diagram Eu* vs Sm_N, we reported our data and those of the Italian Volcanic Provinces (Supplementary Figure 4). The pyroxenes of the PRH and GSL sites display similar variability and indistinguishable Eu* or Sm_N values, strengthening matches to an identical geological source for the ceramics. Although the ceramic pyroxenes fit better with the geochemical field of the RVP, we reliably cannot exclude the potential provenance of the archaeological pyroxenes from the CVP. Further tests were carried out in order to find geochemical discriminant parameters (Fig. 7; Supplementary Figures 5; 6). Finally, many content data on pyroxenes demonstrate the origin of the pottery pyroxenes to be the RVP, and confirm their equivalent composition. The Nd/Lu vs Ce/Lu, Sm/Yb vs La/Yb, Nd/Tm vs Ce/Tm and Zr/Y vs Ce/Y, diagrams allow us to discriminate the geochemical field of RVP and CVP pyroxenes (Supplementary Figures 5B-E; 6B). For our study, the most informative diagram is Y vs Ce where the pyroxenes from archaeological samples match the unique geochemical field of the RVP pyroxenes (Fig. 7B).

3.5 A unique source area for long distance exogenous pottery

Our study shows a clear correspondence between the three archaeological pottery samples at every level of each method of analysis. This petrographic and chemical evenness suggests the exact same provenance for the volcanic pottery from both PRH and GLS sites, confirming the non-local origin of the vessels. The basaltic volcanic formations near the site of PRH can be excluded, both through petrographic and geochemical analyses. Moreover, Giglio Island is not a suitable source due to the exclusive presence of granitic and metamorphic formations and the absence of volcanic formations (Capponi et al., 1997; Westerman et al., 2003). Petrographic investigations allow us to highlight the correspondence of mineralogical and roundness textural features of the a-plastic inclusions of pottery pastes of both sites. The diversity visible in the other textural features of the fabric elements (i.e. granulometry) may depend on the internal variability of the deposits used as raw material. The roundness of inclusions shows, indeed, that secondary sedimentary deposits were used for pottery production (Capelli et al., 2008; Convertini, 2007; Gabriele, 2014).

The correspondence between the elemental compositions of non-local volcanic pottery pastes from both sites is clearly demonstrated by the results of chemical analysis of bulk pottery and especially of a-plastic single mineral inclusions. In the ternary and binary diagrams, the clusters of pottery clinopyroxene composition in both major and trace elements match the same field and trend of evolution. LA-ICP-MS trace-element data of clinopyroxenes in pottery compared with literature data for clinopyroxenes in rocks of Roman and Campanian VPs allow us to distinguish the more likely source areas for pottery production. The correspondence between clinopyroxene compositions of archaeological and geological data is clearly demonstrated in Y vs Ce binary diagrams (Fig. 7), where trends of distribution concentration of trace elements match each other as well as the Roman VP. Conversely, there is no match with the cluster of Campanian VP.

These results effectively demonstrate the efficiency and reliability of our methodology which is based on a chain of successive and complementary stages of analysis. We have demonstrated that petrography (both macro and micro observations) is the first and essential step, and must be confirmed and detailed with subsequent chemical analysis, in order to circumscribe real source areas of raw materials.

4 Unravelling early farming dynamics in the Western Mediterranean

This comparative and multi-analytical pottery sourcing study provides the first evidence for interregional relationships at distances of more than 1000 km in the Western Mediterranean early Neolithic, through the circulation of pottery. We were moreover able to precisely circumscribe the source area for this pottery production, between the Fiora and the Tiber river basins in Southern Tuscany and Northern Latium, Italy.

These results show how pottery raw materials can act as a powerful proxy to grasp the strategies and dynamics of early farmers. Such long-distance pottery transfer is embedded in a wider framework during the very first stage of the Western Mediterranean Neolithic dispersal. Its rapid spread is interpreted as part of a pioneering colonization model based on the use of maritime routes, but whose social drivers are still misunderstood.

This model is suggested to be at the origin of the settlement of small Neolithic seafaring groups far from their place of origin. Through this process, Neolithic practices and know-how were progressively transferred to an extended region. The technical traditions newly implemented in the North-Western Mediterranean are therefore expected to be very similar to those of the origin area, a topic which remains controversial. However, PRH potters clearly belong to the community of practices developed west of the Apennine range in Italy and significantly differ from the Adriatic and Balkan tradition (Gomart et al., 2017). Similar connections between the North-Western and the Tyrrhenian sites are observed regarding cropping practices based on hulled wheats and barley, and animal husbandry, since PRH ewes exhibit the same morphology as most Tyrrhenian ewes (Guilaine et al., 2007).

Together with obsidian from Palmarola, the pottery originating from Latium can help to identify an unexpected milestone in the first Neolithic migration path from Southern Italy, towards the Central and High Tyrrhenian, and further west to the Mediterranean Languedoc.

Paradoxically, volcanic pastes and obsidian sources exploited during the earliest Impressa stages are situated in areas of Central Italy where dwelling sites are poorly identified; the closest and earliest sites are Settecannelle cave site in the Fiora Valley (Ucelli Gnesutta, 2002), and La Marmotta site on the banks of the Bracciano Lake (Fugazzola Delpino, 2002) in Latium region, and Panicarola site located on the banks of the Trasimene Lake in the Umbria region (De Angelis, 2003) (Fig. 8). A similar situation can be observed regarding Sardinian obsidian exploitation: despite the trade of Monte Arci glass towards Liguria (Arene Candide; Ammerman and Polglase, 1997; Maggi, 1997) and Languedoc (Pont-de-Roque-Haute and Peiro Signado; Briois et al., 2009; De Francesco and Crisci, 2007), from 5850-5750 BCE, only one early dwelling place has been identified on this island and is hesitantly suspected to belong to this first phase (Su Coloru; Lugliè, 2018; Sarti et al., 2012). Similarly, evidence for the earliest impressed wares is very rare in Corsica (Campu Stefanu, Cesari et al., 2014; Albertini rock-shelter, Binder and Nonza-Micaelli in press).

Considering this scarcity, one could suspect that the area where raw materials were collected was in some way *terra incognita* for Neolithic pioneer groups. But the same lack of data could also indicate that the territorial meshing of early farmers is severely underestimated today, due to various hazards such as littoral submersion, sedimentary filling, site destruction or research lacunae. Nonetheless, these pottery analyses reveal invisible parts of the original meshing of groups and territory, just as pollen has revealed very early cropping within areas where Neolithic sites are currently unknown (Branch et al., 2014; Guillon et al., 2010). This observation suggests a peopling discontinuity between Southern Italy and the Franco-Ligurian region and strongly encourages the reassessment of the leapfrog dispersal model (Zilhão, 2014).

These results bring up new issues, of which one of the more pressing concerns the nature and temporality of the processes for acquiring various raw materials and for transferring pots or other goods at long-distance. This questions both the mobility regimes and the social interactions at the beginning of the Neolithic transition in the Western Mediterranean.

The hypothesis of short-term voyaging episodes, connecting the Northern Latium, the Tuscan Archipelago and the Mediterranean Languedoc, is strongly supported by our data. Indeed, the chronological resolution of radiocarbon dating, as well as the vagueness of stylistic comparisons, cannot allow us to link those three regions solely to pioneer events. In fact, recent literature evokes a long duration of the production and trade of pottery from RVP, for instance in northern Latium (Settecannelle) (Ucelli Gnesutta and Bertagnini, 1993), Tuscan archipelago (Cala Giovanna Piano, Pianosa island) (Gabriele and Boschian, 2009), and Liguria (Pian del Ciliegio) (Capelli et al., 2017, 2008). At the same time, throughout the 6th millennium BCE, in the whole Tyrrhenian area and Liguria, several networks were developed at a smaller range as highlighted for example by movements of wares with low pressure ophiolitic components (Capelli et al., 2017; Gabriele and Boschian, 2009; Martini et al., 1996). In the Provencal area, the site of Nice - Caucade is a good example of regional multidirectional exploitation (early Impressa stage) (Convertini, 2010; Manen et al., 2006).

The multipolarity of the transfers observed for a large set of raw materials and goods have been considered as a strong argument for indirect acquisition and for the early setting of social networks (Binder and Perlès, 1990; Perlès, 2012). In the context of a pioneer colonization of the Western Mediterranean, this networking appears to be of great spatial extension, which could indicate a very high level of maritime mobility, the development of sailing skills and durable connections.

Surprisingly, during the following stage of the ICC, after 5500 BCE, this extended network seems to have collapsed. This is highlighted for instance by the general disappearance of the obsidian trade throughout Provence and Languedoc (Binder et al., 2012), by the increasing polymorphism of pottery styles (Manen, 2002), and by the diversification of economic patterns leaving a wider place to hunting activities (Binder, 1991b). This break could be the result of an increasing admixture between farmers and local Hunter-Gatherers or of an economic and social reorganization of communities facing new environments and a specific declension of the Neolithic Paradigm (Guilaine, 2018). The results provided here demonstrate that the development and comparison of both petrographic and mineral chemistry pottery sourcing methods are an indispensable contribution to understanding long-distance human mobility through time and space, as they complement and confirm obsidian sourcing data, while at the same time rendering visible unknown interactions and/or subtleties within known interactions. Furthering comparative approaches in ceramic sourcing are needed as they have great potential to expand our understanding of the complex dynamics of the neolithisation process, both in the Mediterrannean region and elsewhere.

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References

Ammerman, A.J., Andrefsky, Y., 1982. Reduction Sequences and the Exchange of Obsidian in Neolithic Calabria, in: Ericson, J.E., Earle, T.K. (Eds.), Contexts for Prehistoric Exchange. Academic Press, New York, pp. 149–172.

Ammerman, A.J., Polglase, C., 1997. Analyses and descriptions of the obsidian collections from Arene Candide, in: Maggi, R. (Ed.), Arene Candide: A Functional and Environmental Assessment of the Olocene Sequence (Excavations Bernabò Brea-Cardini 1940-50), Memorie Dell'Istituto Italiano Di Paleontologia Umana. Il Calamo, Roma, pp. 573–592.

Arienzo, I., Civetta, L., Heumann, A., Wörner, G., Orsi, G., 2009. Isotopic evidence for open system processes within the Campanian Ignimbrite (Campi Flegrei–Italy) magma chamber. Bull. Volcanol. 71, 285. https://doi.org/10.1007/s00445-008-0223-0

Armienti, P., Barberi, F., Bizojard, H., Clocchiatti, R., Innocenti, F., Metrich, N., Rosi, M., Sbrana, A., 1983. The Phlegraean Fields: magma evolution within a shallow chamber. J. Volcanol. Geotherm. Res. 17, 289–311.

Aulinas, M., Civetta, L., Di Vito, M.A., Orsi, G., Gimeno, D., Fernandez-Turiel, J.L., 2008. The “Pomici di mercato” Plinian eruption of Somma-Vesuvius: Magma chamber processes and eruption dynamics. Bull. Volcanol. 70, 825–840. https://doi.org/10.1007/s00445-007-0172-z

Aulinas, M., Gasperini, D., Gimeno, D., Macera, P., Fernandez-Turiel, J.L., Cimarelli, C., 2011. Coexistence of calc-alkaline and ultrapotassic alkaline magmas at Mounts Cimini: evidence for transition from the Tuscan to the Roman Magmatic Provinces (Central Italy). Geol. Acta 9, 103–125. https://doi.org/DOI: 10.1344/105.000001642

Barbieri, M., Peccerillo, A., Poli, G., Tolomeo, L., 1988. Major, trace element and Sr isotopic composition of lavas from Vico volcano (Central Italy) and their evolution in an open system. Contrib. Mineral. Petrol. 99, 485–497. https://doi.org/10.1007/BF00371939

Barone, G., Belfiore, C.M., Mazzoleni, P., Pezzino, A., Viccaro, M., 2010. A volcanic inclusions based approach for provenance studies of archaeological ceramics: Application to pottery from southern Italy. J. Archaeol. Sci. 37, 713–726.

Barone, G., Brandaglia, M., Pappalardo, L., Triscari, M., 1996. Caratterizzazione di ossidiane mediante spettrometria XRF con sorgenti radioattive. Plinius 16, 25–27.

Barton, M., Varekamp, J.C., Van Bergen, M.J., 1982. Complex zoning of clinopyroxenes in the lavas of Vulsini, Latium, Italy: Evidence for magma mixing. J. Volcanol. Geotherm. Res. 14, 361–388. https://doi.org/10.1016/0377-0273(82)90070-1

Belfiore, C.M., La Russa, M.F., Barca, D., Galli, G., Pezzino, A., Ruffolo, S.A., Viccaro, M., Fichera, G.V., 2014. A trace element study for the provenance attribution of ceramic artefacts: the case of Dressel 1 amphorae from a late-Republican ship. J. Archaeol. Sci. 43, 91–104. https://doi.org/10.1016/j.jas.2013.12.015

Belkin, H.E., Rolandi, G., Jackson, J.C., Cannatelli, C., Doherty, A.L., Petrosino, P., De Vivo, B., 2016. Mineralogy and geochemistry of the older (>40ka) ignimbrites on the Campanian Plain, southern Italy. J. Volcanol. Geotherm. Res. 323, 1–18. https://doi.org/10.1016/j.jvolgeores.2016.05.002

Berger, J.-F., Metallinou, G., Guilaine, J., 2014. Vers une révision de la transition méso-néolithique sur le site de Sidari (Corfou, Grèce). Nouvelles données géoarchéologiques et radiocarbone, évaluation des processus post-dépositionnels, in: Manen, C., Perrin, T., Guilaine, J. (Eds.), La Transition Néolithique En Méditerranée. Editions Errance & Archive d’Ecologie Préhistorique, Arles & Toulouse, pp. 213–232.

Bernabeu Auban, J., Manen, C., Pardo-Gordó, S., 2017. Spatial and Temporal Diversity During the Neolithic Spread in the Western Mediterranean: The First Pottery Productions, in: Garcia-Puchol, O., Salazar-Garcia, D.C. (Eds.), Times of Neolithic Transition along the Western Mediterranean, Fundamental Issues in Archaeology. Springer International Publishing, pp. 373–397. https://doi.org/10.1007/978-3-319-52939-4_14

Bertagnini, A., Landi, P., Rosi, M., Vigliargio, A., 1998. The Pomici di Base plinian eruption of Somma-Vesuvius. J. Volcanol. Geotherm. Res. 83, 219–239. https://doi.org/10.1016/S0377-0273(98)00025-0

Binder, D., 1991a. La céramique. Etude stylistique, in: Binder, D. (Ed.), Une Économie de Chasse Au Néolithique Ancien. La Grotte Lombard à Saint-Vallier-de-Thiey (Alpes-Maritimes), Monographie du CRA. CNRS, Paris, pp. 90–96.

Binder, D. (Ed.), 1991b. Une économie de chasse au Néolithique ancien. La grotte Lombard à Saint-Vallier-de-Thiey (Alpes-Maritimes), Monographie du CRA. Edition du CNRS, Paris.

Binder, D., Gratuze, B., Vaquer, J., 2012. La circulation de l’obsidienne dans le sud de la France au Néolithique. Rubricatum Rev. Mus. Gavà 5, 189–200.

Binder, D., Lanos, P., Angeli, L., Gomart, L., Guilaine, J., Manen, C., Maggi, R., Muntoni, I., Panelli, C., Radi, G., Tozzi, C., Arobba, D., Battentier, J., Brandaglia, M., Bouby, L., Briois, F., Carré, A., Delhon, C., Gourichon, L., Marinval, P., Nisbet, R., Rossi, S., Rowley-Conwy, P., Thiébault, S., 2017. Modelling the earliest north-western dispersal of Mediterranean Impressed Wares: new dates and Bayesian chronological model. Doc. Praehist. 44, 54–77. https://doi.org/10.4312/dp.44.4

Binder, D., Nonza-Micaelli, A. in press. Aspects de l’horizon impresso-cardial de l’abri Albertini – E Spilonche (Albertacce, Corse), in: Sicurani, J. (Ed.), L’Habitat Pré et protohistorique. Association de Recherches Préhistoriques et Protohistoriques Corses.

Binder, D., Perlès, C., 1990. Stratégies de gestion des outillages lithiques au Néolithique. Paléo 2, 257–283. https://doi.org/10.3406/pal.1990.1004

Bindi, L., Cellai, D., Melluso, L., Conticelli, S., Morra, V., Menchetti, S., 1999. Crystal chemistry of clinopyroxene from alkaline undersaturated rocks of the Monte Vulture Volcano, Italy. Lithos 46, 259–274. https://doi.org/10.1016/S0024-4937(98)00069-3

Boari, E., Avanzinelli, R., Melluso, L., Giordano, G., Mattei, M., De Benedetti, A.A., Morra, V., Conticelli, S., 2009. Isotope geochemistry (Sr–Nd–Pb) and petrogenesis of leucite-bearing volcanic rocks from “Colli Albani” volcano, Roman Magmatic Province, Central Italy: inferences on volcano evolution and magma genesis. Bull. Volcanol. 71, 977–1005. https://doi.org/10.1007/s00445-009-0278-6

Boari, E., Conticelli, S., 2007. Mineralogy and petrology of associated Mg-rich ultrapotassic, shoshonitic, and calc-alkaline rocks: the middle Latin valley monogenetic volcanos, Roman Magmatic Province, southern Italy. Can. Mineral. 45, 1443–1469. https://doi.org/10.3749/canmin.45.6.1443

Branch, N.P., Black, S., Maggi, R., Marini, N.A.F., 2014. The Neolithisation of Liguria (NW Italy): An environmental archaeological and palaeoenvironmental perspective. Environ. Archaeol. 19, 196–213.

Brandaglia, M., 2002. Isola del Giglio. Toscana, in: Fugazzola Delpino, M.A., Pessina, A., Tiné, V. (Eds.), Le Ceramiche Impresse Nel Neolitico Antico. Italia e Mediterraneo, Studi Di Paletnologia. Istituto Poligrafico e Zecca dello Stato, Roma, pp. 407–423.

Brandaglia, M., 1991. Il Neolitico a Ceramica impressa dell’Isola del Giglio. La ceramica. Studi L’Ecologia Quat. 13, 43–104.

Brandaglia, M., 1987. Il Neolitico a Ceramica impressa dell’Isola del Giglio. L’industria litica. II. Studi L’Ecologia Quat. 9, 51–61.

Briois, F., Manen, C., Gratuze, B., 2009. Nouveaux résultats sur l'origine des obsidiennes de Peiro Signado à Portiragnes (Hérault). Bull. Société Préhistorique Fr. 106, 809–811.

Brunelli, D., Levi, S.T., Fragnoli, P., Renzulli, A., Santi, P., Paganelli, E., Martinelli, M.C., 2013. Bronze Age pottery from the Aeolian Islands: Definition of Temper Compositional Reference Units by an integrated mineralogical and microchemical approach. Appl. Phys. Mater. Sci. Process. 113, 855–863.

Caggianelli, A., De Fino, M., La Volpe, L., Piccarreta, G., 1990. Mineral chemistry of Monte Vulture volcanics: petrological implications. Mineral. Petrol. 41, 215–227. https://doi.org/10.1007/BF01168496

Capelli, C., Cabella, R., Piazza, M., Starnini, E., 2008. Archaeometric analyses of Early and Middle Neolithic pottery from the Pian del Ciliegio rock shelter (Finale Ligure, NW Italy). ArchéoSciences 32, 115–124.

Capelli, C., Starnini, E., Cabella, R., Piazza, M., 2017. The circulation of Early Neolithic pottery in the Mediterranean: A synthesis of new archaeometric data from the Impressed Ware culture of Liguria (north-west Italy). J. Archaeol. Sci. Rep. 16, 532–541. https://doi.org/10.1016/j.jasrep.2017.03.022

Capponi, G., Cortesogno, L., Crispini, L., Gaggero, L., Giammarino, S., 1997. The Promontorio del Franco (Island of Giglio): a blueschist element in the Tuscan Archipelago (Central Italy). Atti Ticinensi Sci. Della Terra 39, 175–192.

Carignan, J., Hild, P., Morel, J., Yeghicheyan, D., 2001. Routine analyses of trace elements in geological samples using flow injection and low-pressure on-line liquid chromatography coupled to ICP-MS: a study of geochemical reference materials BR, DR-N, UB-N, AN-G and GH. Geostand. Geoanalytical Res. 46, 187–198.

Cauvin, J., 1998. La signification symbolique de l'obsidienne, in: Cauvin, M.-C., Gourgaud, A., Gratuze, B., Poidevin, J.-L., Poupeau, G., Chataigner, C. (Eds.), L'obsidienne Au Proche et Moyen Orient Ancien : Du Volcan à l'outil. British archaeological reports, Oxford, pp. 379–382.

Cellai, D., Conticelli, S., Menchetti, S., 1994. Crystal-chemistry of clinopyroxenes from potassic and ultrapotassic rocks in central Italy: implications on their genesis. Contrib. Mineral. Petrol. 116, 301–315. https://doi.org/10.1007/BF00306499

Cesari, J., Courtaud, P., Leandri, F., Perrin, T., Manen, C., 2014. Le site de Campu Stefanu (Sollacaro, Corse-du-Sud): une occupation du Mésolithique et du Néolithique ancien dans le contexte corso-sarde - Campu Stefanu (Sollacaro, Southern Corsica): a Mesolithic and Early Neolithic settlement in the Corso-sardinian context, in: Manen, C., Perrin, T., Guilaine, J. (Eds.), La Transition Néolithique En Méditerranée. Editions Errance & Archive d'Ecologie Préhistorique, Arles & Toulouse, pp. 283–303.

Chelazzi, L., Bindi, L., Olmi, F., Menchetti, S., Peccerillo, A., Conticelli, S., 2006. A lamproitic component in the high-K calc-alkaline volcanic rocks of the Capraia Island, Tuscan Magmatic Province: evidence from clinopyroxene crystal chemical data. Period. Mineral. 75, 75–94.

Childe, V.G., 1925. The Dawn of European Civilization, 6th ed. K. Paul, Trench, Trubner & Co, London.

Civetta, L., Orsi, G., Pappalardo, L., Fisher, R.V., Heiken, G., Ort, M., 1997. Geochemical zoning, mingling, eruptive dynamics and depositional processes — the Campanian Ignimbrite, Campi Flegrei caldera, Italy. J. Volcanol. Geotherm. Res. 75, 183–219. https://doi.org/10.1016/S0377-0273(96)00027-3

Comodi, P., Nazzareni, S., Perugini, D., Bergamini, M., 2006. Technology and Provenance of roman ceramics from Scoppieto, Italy: a mineralogical and petrological study. Period. Mineral. 75, 95–112.

Conte, A.M., Dolfi, D., 2002. Petrological and geochemical characteristics of Plio-Pleistocene volcanics from Ponza Island (Tyrrhenian Sea, Italy). Mineral. Petrol. 74, 75–94. https://doi.org/10.1007/s710-002-8216-6

Conticelli, S., Avanzinelli, R., Poli, G., Braschi, E., Giordano, G., 2013. Shift from lamproite-like to leucititic rocks: Sr–Nd–Pb isotope data from the Monte Cimino volcanic complex vs. the Vico stratovolcano, Central Italy. Chem. Geol. 353, 246–266. https://doi.org/10.1016/j.chemgeo.2012.10.018

Conticelli, S., Boari, E., Burlamacchi, L., Cifelli, F., Moscardi, F., Laurenzi, M.A., Ferrari Predaglio, L., Francalanci, L., Benvenuti, M.G., Braschi, E., Manetti, P., 2015. Geochemistry and Sr-Nd-Pb isotopes of Monte Amiata Volcano, Central Italy: Evidence for magma mixing between high-K calc-alkaline and leucititic mantle-derived magmas. Ital. J. Geosci. 134, 266–290. https://doi.org/10.3301/IJG.2015.12

Conticelli, S., Francalanci, L., Manetti, P., Cioni, R., Sbrana, A., 1997. Petrology and geochemistry of the ultrapotassic rocks from the Sabatini Volcanic District, central Italy: the role of evolutionary processes in the genesis of variably enriched alkaline magmas. J. Volcanol. Geotherm. Res. 75, 107–136. https://doi.org/10.1016/S0377-0273(96)00062-5

Conticelli, S., Melluso, L., Perini, G., Avanzinelli, R., Boari, E., 2004. Petrologic, geochemical and isotopic characteristics of potassic and ultrapotassic magmatism in central-southern Italy: inferences on its genesis and on the nature of mantle sources. Period. Mineral. 73, 135–164.

Convertini, F., 2010. Déplacements de terres ou de vases ? Le cas des matériaux d'origine volcanique, in: Manen, C., Convertini, F., Binder, D., Sénépart, I. (Eds.), Premières sociétés paysannes de Méditerranée occidentale: structures des productions céramiques, Mémoire de la Société préhistorique française. Société préhistorique française, Paris, pp. 105–113.

Convertini, F., 2007. Les matières premières argileuses, in: Guilaine, J., Manen, C., Vigne, J.-D. (Eds.), Pont de Roque-Haute. Nouveaux regards sur la Néolithisation de la France méditerranéenne. Archives d'Écologie Préhistorique, Toulouse, pp. 133–140.

Cristiani, C., Mazzuoli, R., 2003. Monte Amiata volcanic products and their inclusions. Period. Mineral. 72, pp. 169–181.

Cundari, A., 1975. Mineral chemistry and petrogenetic aspects of the Vico lavas, Roman volcanic region, Italy. Contrib. Mineral. Petrol. 53, 129–144. https://doi.org/10.1007/BF00373127

Cundari, A., Salviulo, G., 1987. Clinopyroxenes from Somma-Vesuvius: Implications of Crystal Chemistry and Site Configuration Parameters for Studies of Magma Genesis. J. Petrol. 28, 727–736. https://doi.org/10.1093/petrology/28.4.727

Dal Negro, A., Carbonin, S., Salviulo, G., Piccirillo, E.M., Cundari, A., 1985. Crystal Chemistry and Site Configuration of the Clinopyroxene from Leucite–bearing Rocks and Related Genetic Significance: the Sabatini Lavas, Roman Region, Italy. J. Petrol. 26, 1027–1040. https://doi.org/10.1093/petrology/26.4.1027

Dautria, J.-M., Liotard, J.-M., Bosch, D., Alard, O., 2010. 160Ma of sporadic basaltic activity on the Languedoc volcanic line (Southern France): A peculiar case of lithosphere–asthenosphere interplay. Lithos 120, 202–222. https://doi.org/10.1016/j.lithos.2010.04.009

De Angelis, M.C., 2003. Il Neolitico antico del lago Trasimeno (Umbria): il sito di Panicarola (La Lucciola). Rassegna Archeol. 20A, 117–140.

De Francesco, A.M., Crisci, G.M., 2007. Provenance de l'obsidienne, in: Guilaine, J., Manen, C., Vigne, J.-D. (Eds.), Pont de Roque-Haute. Nouveaux regards sur la Néolithisation de la France méditerranéenne. Archives d'Écologie Préhistorique, Toulouse, pp. 83–85.

Del Bello, E., Mollo, S., Scarlato, P., von Quadt, A., Forni, F., Bachmann, O., 2014. New petrological constraints on the last eruptive phase of the Sabatini Volcanic District (central Italy): Clues from mineralogy, geochemistry, and Sr–Nd isotopes. Lithos 205, 28–38. https://doi.org/10.1016/j.lithos.2014.06.015

Dixon, J.E., Cann, J.R., Renfrew, C., 1968. Obsidian and the origins of trade. Sci. Am. 218, 38–46.

Dostal, J., Dupuy, C., Venturelli, G., 1982. Geochemistry of volcanic rocks from the Monte Arci (west Sardinia, Italy). Chem. Geol. 35, 247–264. https://doi.org/10.1016/0009-2541(82)90004-3

Echallier, J.-C., 1991. La céramique. Les matières premières, in: Binder, D. (Ed.), Une Économie de Chasse Au Néolithique Ancien. La Grotte Lombard à Saint-Vallier-de-Thiey (Alpes-Maritimes), Monographie du CRA. CNRS, Paris, pp. 72–89.

Faraone, D., Molin, G., Zanazzi, P.F., 1988. Clinopyroxenes from Vulcano (Aeolian Islands, Italy): Crystal chemistry and cooling history. Lithos 22, 113–126. https://doi.org/10.1016/0024-4937(88)90020-5

Fedele, L., Zanetti, A., Morra, V., Lustrino, M., Melluso, L., Vannucci, R., 2009. Clinopyroxene/liquid trace element partitioning in natural trachyte–trachyphonolite systems: insights from Campi Flegrei (southern Italy). Contrib. Mineral. Petrol. 158, 337–356. https://doi.org/10.1007/s00410-009-0386-5

Feldstein, S., Halliday, A., Davies, G., Hall, C., 1994. Isotope and chemical microsampling: Constraints on the history of an S-type rhyolite, San Vincenzo, Tuscany, Italy. Geochim. Cosmochim. Acta 58, 943–958. https://doi.org/10.1016/0016-7037(94)90517-7

Ferrara, G., Petrini, R., Serri, G., Tonarini, S., 1989. Petrology and isotope-geochemistry of San Vincenzo rhyolites (Tuscany, Italy). Bull. Volcanol. 51, 379–388. https://doi.org/10.1007/BF01056898

Ferraris, M., Ottomano, C., 1997. Pottery Analyses, in: Arene Candide: A Functional and Environmental Assessment of the Olocene Sequence (Excavations Bernabò Brea-Cardini 1940-50), Memorie Dell'Istituto Italiano Di Paleontologia Umana. Il Calamo, Roma, pp. 339–348.

Frezzotti, M.L., De Astis, G., Dallai, L., Ghezzo, C., 2007. Coexisting calc-alkaline and ultrapotassic magmatism at Monti Ernici, Mid Latina Valley (Latium, central Italy). Eur. J. Mineral. 19, 479–497. https://doi.org/10.1127/0935-1221/2007/0019-1754

Fugazzola Delpino, M.A., 2002. La Marmotta. Lazio, in: Fugazzola Delpino, M.A., Pessina, A., Tiné, V. (Eds.), Le Ceramiche Impresse Nel Neolitico Antico. Italia e Mediterraneo, Studi Di Paletnologia. Istituto Poligrafico e Zecca dello Stato, Roma, pp. 373–395.

Gabriele, M., 2014. La circolazione delle ceramiche del Neolitico nel medio e alto Tirreno e nell'area ligure-provenzale. Studi di provenienza. Unpublished PhD Thesis, University of Pisa & University of Nice Sophia Antipolis.

Gabriele, M., 2015. La circolazione delle ceramiche del Neolitico nel medio e alto Tirreno e nell'area ligure-provenzale. Studi di provenienza. La circulation des céramiques néolithiques dans l'aire tyrrhénienne et dans l'aire liguro-provençale. Étude de provenance. Bull. Société Préhistorique Fr. 112, 567–568.

Gabriele, M., Boschian, G., 2009. Neolithic pottery from Pianosa Island (Tyrrhenian Sea), preliminary provenance data. Old Potter's Alm. 14, 8–14.

Gasperini, D., Blichert-Toft, J., Bosch, D., Del Moro, A., Macera, P., Albarède, F., 2002. Upwelling of deep mantle material through a plate window: Evidence from the geochemistry of Italian basaltic volcanics. J. Geophys. Res. Solid Earth 107, ECV 7-1. https://doi.org/10.1029/2001JB000418

Gehres, B., Querré, G., 2018. New applications of LA–ICP–MS for sourcing archaeological ceramics: microanalysis of inclusions as fingerprints of their origin. Archaeometry 60, 750–763. https://doi.org/10.1111/arcm.12338

Gentili, S., Comodi, P., Nazzareni, S., Zucchini, A., 2014. The Orvieto-Bagnoregio Ignimbrite: pyroxene crystal-chemistry and bulk phase composition of pyroclastic deposits, a tool to identify syn- and post-depositional processes. Eur. J. Mineral. 26, 743–756. https://doi.org/10.1127/ejm/2014/0026-2404

Ghiara, M.R., Lirer, L., Munno, R., 1979. Mineralogy and geochemistry of the "low-potassium series" of the Campania volcanics (south Italy). Chem. Geol. 26, 29–49. https://doi.org/10.1016/0009-2541(79)90028-7

Gomart, L., Weiner, A., Gabriele, M., Durrenmath, G., Sorin, S., Angeli, L., Colombo, M., Fabbri, C., Maggi, R., Panelli, C., Pisani, D., Radi, G., Tozzi, C., Binder, D., 2017. Spiralled patchwork in pottery manufacture and the introduction of farming to Southern Europe. Antiquity 91, 1501–1514. https://doi.org/10.15184/aqy.2017.187

Gratuze, B., 2016. Glass Characterization Using Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry Methods, in: Dussubieux, L., Golitko, M., Gratuze, B. (Eds.), Recent Advances in Laser Ablation ICP-MS for Archaeology. Springer-Verlag, Berlin, Heidelberg, pp. 179–196. https://doi.org/10.1007/978-3-662-49894-1_12

Guarino, V., Fedele, L., Franciosi, L., Lonis, R., Lustrino, M., Marrazzo, M., Melluso, L., Morra, V., Rocco, I., Ronga, F., 2011. Mineral compositions and magmatic evolution of the calcalkaline rocks of northwestern Sardinia, Italy. Period. Mineral. 80, 517–545.

Guilaine, J., 2018. A personal view of the neolithisation of the Western Mediterranean. Quat. Int. 470, 211–225. https://doi.org/10.1016/j.quaint.2017.06.019

Guilaine, J., Manen, C., Vigne, J.-D. (Eds.), 2007. Pont de Roque-Haute. Nouveaux regards sur la néolithisation de la France méditerranéenne. Archives d'Écologie Préhistorique, Toulouse.

Guillon, S., Berger, J.-F., Richard, H., Bouby, L., Binder, D., 2010. Analyse pollinique du bassin versant de la Cagne (Alpes-Maritimes, France) : dynamique de la végétation littorale au Néolithique., in: Delhon, C., Théry-Parisot, I., Thiébault, S. (Eds.), Des Hommes et Des Plantes. Exploitation Du Milieu et Des Ressources Végétales de La Préhistoire à Nos Jours. APDCA, Antibes, pp. 391–406.

Holm, P.M., 1982. Mineral chemistry of perpotassic lavas of the Vulsinian District, the Roman Province, Italy. Mineral. Mag. 46, 379–386. https://doi.org/10.1180/minmag.1982.046.340.14

Ibáñez-Estévez, J.J., Bao, J.F.G., Gassin, B., Mazzucco, N., 2017. Paths and Rhythms in the Spread of Agriculture in the Western Mediterranean: The Contribution of the Analysis of Harvesting Technology, in: García-Puchol, O., Salazar-García, D.C. (Eds.), Times of Neolithic Transition along the Western Mediterranean. Springer International Publishing, Cham, pp. 339–371. https://doi.org/10.1007/978-3-319-52939-4_13

Kamenetsky, V., Métrich, N., Cioni, R., 1995. Potassic primary melts of Vulsini (Roman Province): evidence from mineralogy and melt inclusions. Contrib. Mineral. Petrol. 120, 186–196. https://doi.org/10.1007/BF00287116

La Marca, C., Eramo, G., Muntoni, I.M., Conati Barbaro, C., 2017. Early Neolithic potters of the Italian Middle Adriatic region. Archeol. Rozhl. LXIX, 227–245.

Lacan, M., Keyser, C., Ricaut, F.-X., Brucato, N., Duranthon, F., Guilaine, J., Crubézy, E., Ludes, B., 2011. Ancient DNA reveals male diffusion through the Neolithic Mediterranean route. Proc. Natl. Acad. Sci. 108, 9788–9791. https://doi.org/10.1073/pnas.1100723108

Leterrier, J., Maury, R.C., Thonon, P., Girard, D., Marchal, M., 1982. Clinopyroxene composition as a method of identification of the magmatic affinities of paleo-volcanic series. Earth Planet. Sci. Lett. 59, 139–154. https://doi.org/10.1016/0012-821X(82)90122-4

Luglié, C., 2018. Your path led trough the sea … The emergence of Neolithic in Sardinia and Corsica. Quat. Int. 470, 285–300. https://doi.org/10.1016/j.quaint.2017.12.032

Maggi, R. (Ed.), 1997. Arene Candide: a functional and environmental assessment of the Olocene sequence (Excavations Bernabò Brea-Cardini 1940-50), Memorie dell'Istituto Italiano di Paleontologia Umana. Il Calamo, Roma.

Manen, C., 2002. Structure et identité des styles céramique du Néolithique ancien entre Rhône et Èbre. Gall. Préhistoire 44, 121–165.

Manen, C., Convertini, F., 2012. Neolithization of the Western Mediterranean: Pottery productions, circulation and recombination. Rubricatum Rev. Mus. Gavà 5, 363–368.

Manen, C., Convertini, F., Binder, D., Beeching, A., Briois, L., Bruxelles, L., Guilaine, J., Sénépart, I., 2006. Premiers résultats du projet ACR. «Productions céramiques des premières sociétés paysannes». L'exemple des faciès Impressa du Sud de la France, in: Fouere, P., Chevillot, C., Courtaud, P., Ferullo, O., Leroyer, C. (Eds.), Paysages et peuplement. Aspects culturels et chronologiques en France méridionale. ADRAHP & PSO, Périgueux, pp. 233–246.

Manen, C., Convertini, F., Binder, D., Sénépart, I. (Eds.), 2010. Premières sociétés paysannes de Méditerranée occidentale: structures des productions céramiques. Mémoire de la Société préhistorique française. Société préhistorique française, Paris.

Manen, C., Guilaine, J., 2007. La céramique: présentation du corpus, in: Guilaine, J., Manen, C., Vigne, J.-D. (Eds.), Pont de Roque-Haute. Nouveaux regards sur la néolithisation de la France méditerranéenne. Archives d'Écologie Préhistorique, Toulouse, pp. 47–49.

Manen, C., Perrin, T., Guilaine, J., Bouby, L., Bréhard, S., Briois, F., Durand, F., Marinval, P., Vigne, J.-D., 2018. The Neolithic transition in the western Mediterranean: a complex and non-linear diffusion process—The radiocarbon record revisited. Radiocarbon 1–41. https://doi.org/10.1017/RDC.2018.98

Martini, F., Pallecchi, P., Sarti, L. (Eds.), 1996. La ceramica preistorica in Toscana. Artigiani e materie prime dal Neolitico all'Età del Bronzo. Garlatti e Razzai Editori, Firenze.

Mathieson, I., Alpaslan-Roodenberg, S., Posth, C., Szécsényi-Nagy, A., Rohland, N., Mallick, S., Olalde, I., Broomandkhoshbacht, N., Candilio, F., Cheronet, O., Fernandes, D., Ferry, M., Gamarra, B., Fortes, G.G., Haak, W., Harney, E., Jones, E., Keating, D., Krause-Kyora, B., Kucukkalipci, I., Michel, M., Mittnik, A., Nägele, K., Novak, M., Oppenheimer, J., Patterson, N., Pfrengle, S., Sirak, K., Stewardson, K., Vai, S., Alexandrov, S., Alt, K.W., Andreescu, R., Antonović, D., Ash, A., Atanassova, N., Bacvarov, K., Gusztáv, M.B., Bocherens, H., Bolus, M., Boroneanţ, A., Boyadzhiev, Y., Budnik, A., Burmaz, J., Chohadzhiev, S., Conard, N.J., Cottiaux, R., Čuka, M., Cupillard, C., Drucker, D.G., Elenski, N., Francken, M., Galabova, B., Ganetsovski, G., Gély, B., Hajdu, T., Handzhyiska, V., Harvati, K., Higham, T., Iliev, S., Janković, I., Karavanić, I., Kennett, D.J., Komšo, D., Kozak, A., Labuda, D., Lari, M., Lazar, C., Leppek, M., Leshtakov, K., Vetro, D.L., Los, D., Lozanov, I., Malina, M., Martini, F., McSweeney, K., Meller, H., Menđušić, M., Mirea, P., Moiseyev, V., Petrova, V., Price, T.D., Simalcsik, A., Sineo, L., Šlaus, M., Slavchev, V., Stanev, P., Starović, A., Szeniczey, T., Talamo, S., Teschler-Nicola, M., Thevenet, C., Valchev, I., Valentin, F., Vasilyev, S., Veljanovska, F., Venelinova, S., Veselovskaya, E., Viola, B., Virag, C., Zaninović, J., Zäuner, S., Stockhammer, P.W., Catalano, G., Krauß, R., Caramelli, D., Zariņa, G., Gaydarska, B., Lillie, M., Nikitin, A.G., Potekhina, I., Papathanasiou, A., Borić, D., Bonsall, C., Krause, J., Pinhasi, R., Reich, D., 2018. The genomic history of southeastern Europe. Nature 555, 197–203.

McClure, S.B., Podrug, E., Moore, A.M.T., Culleton, B.J., Kennett, D.J., 2014. AMS 14C Chronology and Ceramic Sequences of Early Farmers in the Eastern Adriatic. Radiocarbon 56, 1009–1017.

McDonough, W.F., Sun, S.-S., 1995. The composition of the Earth. Chem. Geol. 120, 223–253. https://doi.org/10.1016/0009-2541(94)00140-4

Mollo, S., Forni, F., Bachmann, O., Blundy, J.D., De Astis, G., Scarlato, P., 2016. Trace element partitioning between clinopyroxene and trachy-phonolitic melts: A case study from the Campanian Ignimbrite (Campi Flegrei, Italy). Lithos 252–253, 160–172. https://doi.org/10.1016/j.lithos.2016.02.024

Morimoto, N., 1988. Nomenclature of Pyroxenes. Mineral. Petrol. 39, 55–76. https://doi.org/10.1007/BF01226262
Muntoni, I.M., 2012. Circulation of raw materials, final products or ideas in the Neolithic Communities of Southern Italy: The contribution of archaeometric analyses to the study of pottery, flint and obsidian. Rubricatum Rev. Mus. Gavà 5, 403–412.
Muntoni, I.M., 2003. Modellare l'argilla. Vasai del Neolitico antico e medio nelle Murge pugliesi, Origines. Istituto Italiano di Preistoria e Protostoria, Firenze.
Palladino, D.M., Gaeta, M., Giaccio, B., Sottili, G., 2014. On the anatomy of magma chamber and caldera collapse: The example of trachy-phonolitic explosive eruptions of the Roman Province (central Italy). J. Volcanol. Geotherm. Res. 281, 12–26. https://doi.org/10.1016/j.jvolgeores.2014.05.020
Palumbi, G., Gratuze, B., Harutyunyan, A., Chataigner, C., 2014. Obsidian-tempered pottery in the Southern Caucasus: a new approach to obsidian as a ceramic-temper. J. Archaeol. Sci. 44, 43–54. https://doi.org/10.1016/j.jas.2014.01.017
Paolini-Saez, H., 2010. Les productions céramiques du Néolithique ancien tyrrhénien, in: Manen, C., Convertini, F., Binder, D., Sénépart, I. (Eds.), Premières sociétés paysannes de Méditerranée occidentale: structures des productions céramiques, Mémoire de la Société préhistorique française. Société préhistorique française, Paris, pp. 89–104.
Paone, A., 2013. Petrogenesis of trachyte and rhyolite magmas on Ponza Island (Italy) and its relationship to the Campanian magmatism. J. Volcanol. Geotherm. Res. 267, 15–29. https://doi.org/10.1016/j.jvolgeores.2013.09.008
Pappalardo, L., Ottolini, L., Mastrolorenzo, G., 2008. The Campanian Ignimbrite (southern Italy) geochemical zoning: insight on the generation of a super-eruption from catastrophic differentiation and fast withdrawal. Contrib. Mineral. Petrol. 156, 1–26. https://doi.org/10.1007/s00410-007-0270-0
Peccerillo, A., 2017. Cenozoic Volcanism in the Tyrrhenian Sea Region, Advances in Volcanology. Springer International Publishing.
Perini, G., 2000. Sr-isotope and micro-isotope analyses of minerals: examples from some mafic alkaline potassic rocks. Period. Mineral. 69, 107–124.
Perini, G., Conticelli, S., 2002. Crystallization conditions of leucite-bearing magmas and their implications on the magmatological evolution of ultrapotassic magmas: the Vico Volcano, Central Italy. Mineral. Petrol. 74, 253–276. https://doi.org/10.1007/s007100200006
Perini, G., Francalanci, L., Davidson, J.P., Conticelli, S., 2004. Evolution and Genesis of Magmas from Vico Volcano, Central Italy: Multiple Differentiation Pathways and Variable Parental Magmas. J. Petrol. 45, 139–182. https://doi.org/10.1093/petrology/egg084
Perlès, C., 2012. Quand "diffusion" ne veut pas dire "interaction." Rubricatum Rev. Mus. Gavà 5, 585–590.
Perugini, D., Poli, G., 2003. The Monte Cimino volcano. Period. Mineral. 72, pp. 203–210.
Poli, G., Perugini, D., 2003a. San Vincenzo volcanites. Period. Mineral. 72, pp. 141–155.
Poli, G., Perugini, D., 2003b. The Island of Capraia. Period. Mineral. 72, pp. 195–201.
Quinn, P.S., 2013. Ceramic Petrography: The Interpretation of Archaeological Pottery and Related Artefacts in Thin Section, British Archaeological Reports Limited. Archaeopress, Oxford.
Rigaud, S., Manen, C., García-Martínez de Lagrán, I., 2018. Symbols in motion: Flexible cultural boundaries and the fast spread of the Neolithic in the western Mediterranean. PLOS ONE 13, e0196488. https://doi.org/10.1371/journal.pone.0196488
Rivollat, M., Rottier, S., Couture, C., Pemonge, M.-H., Mendisco, F., Thomas, M.G., Deguilloux, M.-F., Gerbault, P., 2017. Investigating mitochondrial DNA relationships in Neolithic Western Europe through serial coalescent simulations. Eur. J. Hum. Genet. 25, 388_392.
Rowley-Conwy, P., Gourichon, L., Helmer, D., Vigne, J.-D., 2013. Early domestic animals in Italy, Istria, the Tyrrhenian islands and Southern France, in: College, S., Conolly, J., Dobney, K., Manning, K., Shennan, S. (Eds.), The Origin of Spread of Domestic Animals in Southwest Asia and Europe. Left Coast Press, Walnut Creek, California, pp. 161–194.
Sarti, L., Fenu, P., Martini, F., Mazzucco, N., Pitzalis, G., Romagnoli, F., Rosini, M., 2012. Il Neolitico di Grotta Su Coloru (Laerru, Sassari): nuovi dati, in: La preistoria e la protostoria della Sardegna, Firenze, pp. 455–462.
Scarpelli, R., De Francesco, A.M., Gaeta, M., Cottica, D., Toniolo, L., 2015. The provenance of the Pompeii cooking wares: Insights from LA–ICP-MS trace element analyses. Microchem. J. 119, 93–101. https://doi.org/10.1016/j.microc.2014.11.003
Spataro, M., 2002. The first farming communities of the Adriatic: pottery production and circulation in the Early and Middle Neolithic, Quaderni della Società per la Preistoria e Protostoria della Regione Friuli-Venezia Giulia. Edizioni Svevo, Trieste.
Stoops, G., 2003. Guidelines for Analysis and Description of Soil and Regolith Thin Sections. Soil Science Society of America, Inc., Madison.
Tykot, R.H., Freund, K.P., Vianello, A., 2013. Source Analysis of Prehistoric Obsidian Artifacts in Sicily (Italy) Using pXRF, in: Armitage, R.A., Burton, J.H. (Eds.), Archaeological Chemistry VIII, ACS Symposium Series. American Chemical Society, pp. 195–210. https://doi.org/10.1021/bk-2013-1147.ch011
Ucelli Gnesutta, P., 2002. Grotta di Settecannelle. Lazio, in: Fugazzola Delpino, M.A., Pessina, A., Tiné, V. (Eds.), Le ceramiche impresse nel Neolitico Antico. Italia e Mediterraneo, Studi di Paletnologia. Istituto Poligrafico e Zecca dello Stato, Roma, pp. 341–349.
Ucelli Gnesutta, P., Bertagnini, A., 1993. Grotta delle Settecannelle (Ischia di Castro-Viterbo). Rassegna Archeol. 11, 67–112.
Westerman, D.S., Innocenti, F., Rocchi, S., 2003. Giglio Island: intrusive magmatism. Period. Mineral. 72, pp. 119–126.
Whitbread, I.K., 1989. A proposal for the systematic description of thin sections towards the study of ancient ceramic technology, in: Archaeometry: Proceedings of the 25th International Symposium, Athens 1986. Elsevier, Amsterdam, pp. 127–138.
Whittle, A., 2018. The times of their lives. Hunting history in the archaeology of Neolithic Europe. Oxbow Books, Oxford & Philadelphia.

Zilhão, J., 2014. Early prehistoric voyaging in the Western Mediterranean: Implications for the Neolithic transition in Iberia and the Maghreb. Eurasian Prehistory 11, 185–200.

Figure captions

Figure 1

Map of north western Mediterranean study area showing distribution of archaeological sites and geological formations of the Volcanic Provinces considered for this study.

Figure 2

Studied archaeological pottery from (A) Pont de Roque-Haute (drawn by J. Coularou in Manen and Guilaine 2007, fig. 49) and from (B-C) Le Secche (B macrophotography and C stereo-microphotography).

Figure 3

Microphotography comparison of pottery samples. Arrows point out the main mineral components of pottery pastes: rounded clinopyroxene (Cpx), K-feldspath (Kfs) and volcanic rock (VR). A, C, E and G from Le Secche (GLS); B, D, F, H from Pont de Roque-Haute (PRH). A-B stereomicroscopic observations; C-H thin section microscopic observations.

Figure 4

QUAD classification diagram of Wollastonite (Wo), Enstatite (En), Ferrosilite (Fs) for (A) clinopyroxenes from archaeological samples analysed by SEM-EDS and LA-ICP-MS and for (B-F) archaeological samples and selected Italian volcanic provinces (Armienti et al., 1983; Aulinas et al., 2008; Barton et al., 1982; Belkin et al., 2016; Bindi et al., 1999; Caggianelli et al., 1990; Civetta et al., 1997; Comodi et al., 2006; Conticelli et al., 2015, 2013, 1997; Del Bello et al., 2014; Dostal et al., 1982; Fedele et al., 2009; Feldstein et al., 1994; Ghiara et al., 1979; Guarino et al., 2011; Holm, 1982; Mollo et al., 2016; Palladino et al., 2014; Pappalardo et al., 2008; Perini et al., 2004; Perini and Conticelli, 2002). A to F diagrams correspond to the enlarged part of the QUAD diagram (grey coloured area).

Figure 5

Primitive mantle normalised trace-element spider diagram for (A) bulk archaeological samples, PRH soil and Languedoc volcanic formations (Dautria et al., 2010) and for (B) bulk archaeological samples and selected Italian volcanic formations (Gasperini et al., 2002; Peccerillo, 2017). Normalisation values from McDonough and Sun (1995).

Figure 6

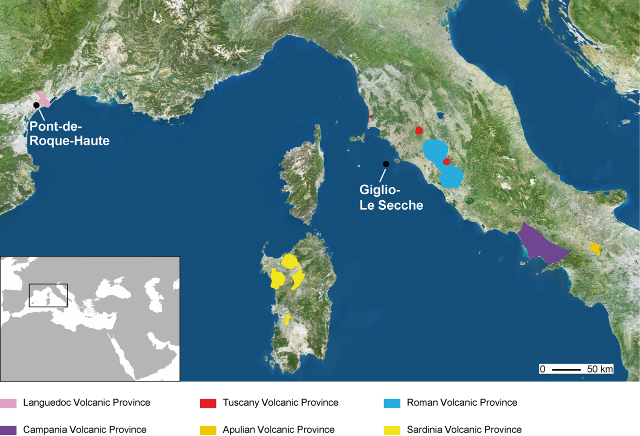
Primitive mantle normalised trace-element spider diagram for (A) clinopyroxenes from archaeological samples analysed by LA-ICP-MS and for (B) clinopyroxenes from archaeological samples and selected Italian volcanic provinces (Arienzo et al., 2009; Civetta et al., 1997; Comodi et al., 2006; Fedele et al., 2009; Gentili et al., 2014; Mollo et al., 2016; Pappalardo et al., 2008; Scarpelli et al., 2015). Normalisation values from McDonough and Sun (1995).

Figure 7

Binary diagram Y vs Ce where concentration in ppm is reported for (A) clinopyroxenes of archaeological samples and for (B) clinopyroxenes of archaeological samples and selected Italian volcanic provinces (Arienzo et al., 2009; Civetta et al., 1997; Comodi et al., 2006; Fedele et al., 2009; Gentili et al., 2014; Mollo et al., 2016; Pappalardo et al., 2008; Scarpelli et al., 2015).

Figure 8

Map of north western Mediterranean study area showing the identified volcanic source area for pottery provenance and location of Neolithic archaeological sites. Tyrrhenian geological obsidian outcrops are also reported.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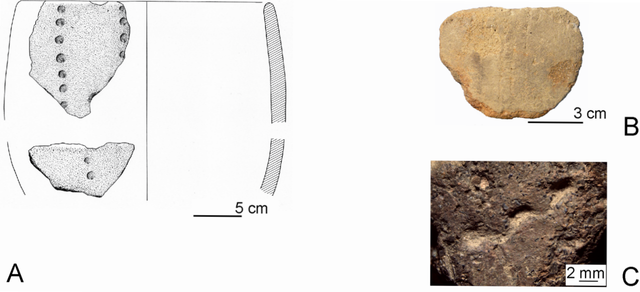
Tuscany Volcanic Province
Roman Volcanic Province
Campania Volcanic Province
Apulian Volcanic Province
Sardinia Volcanic Province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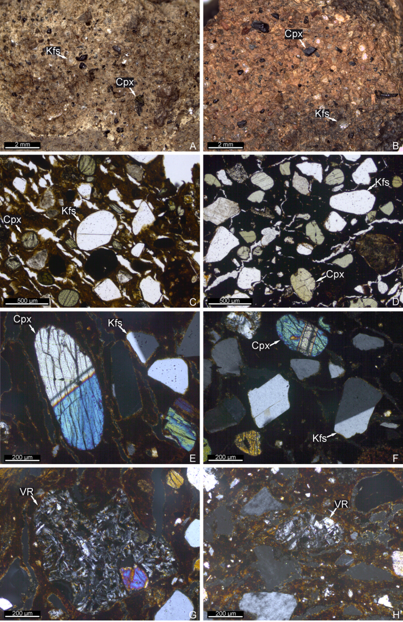
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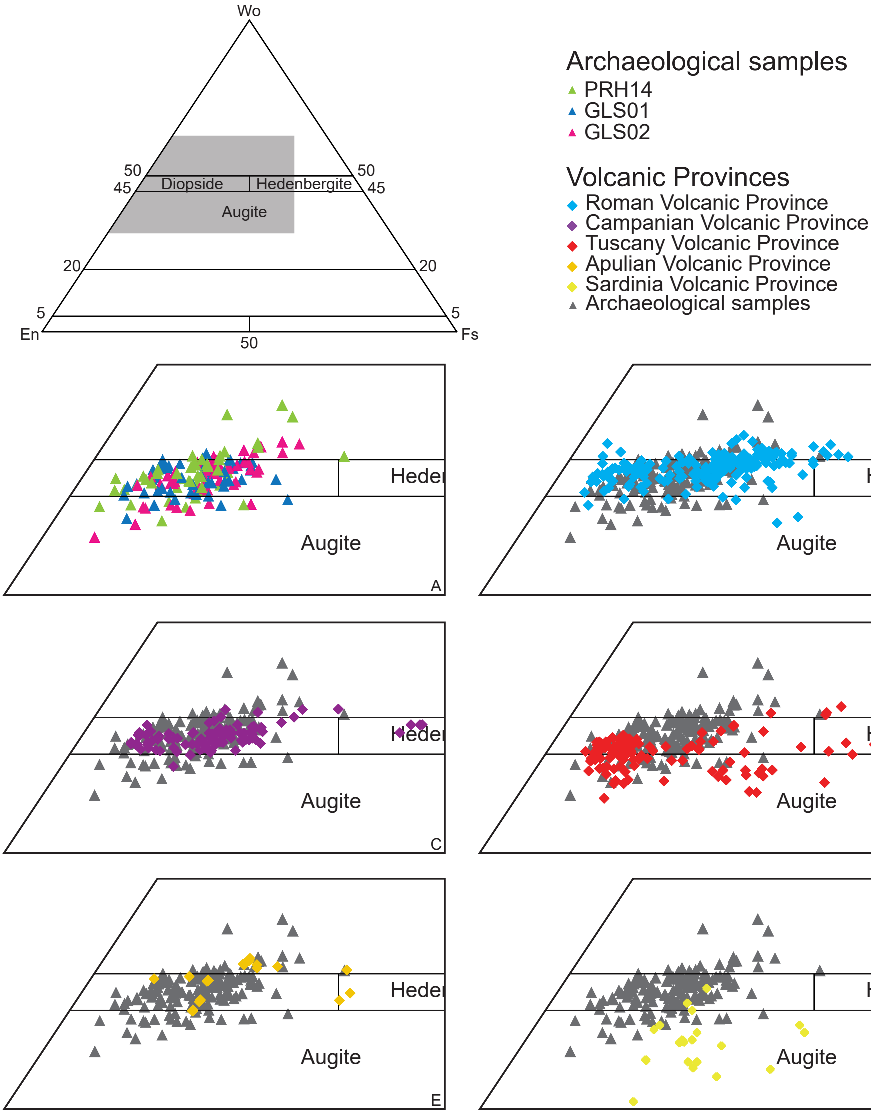
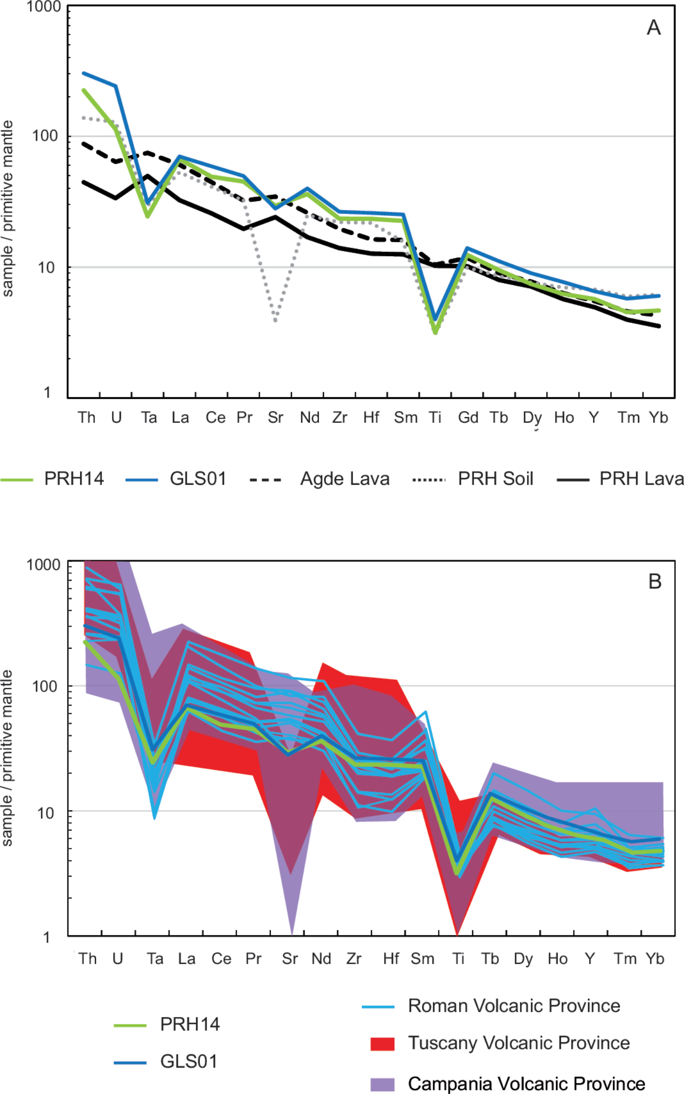
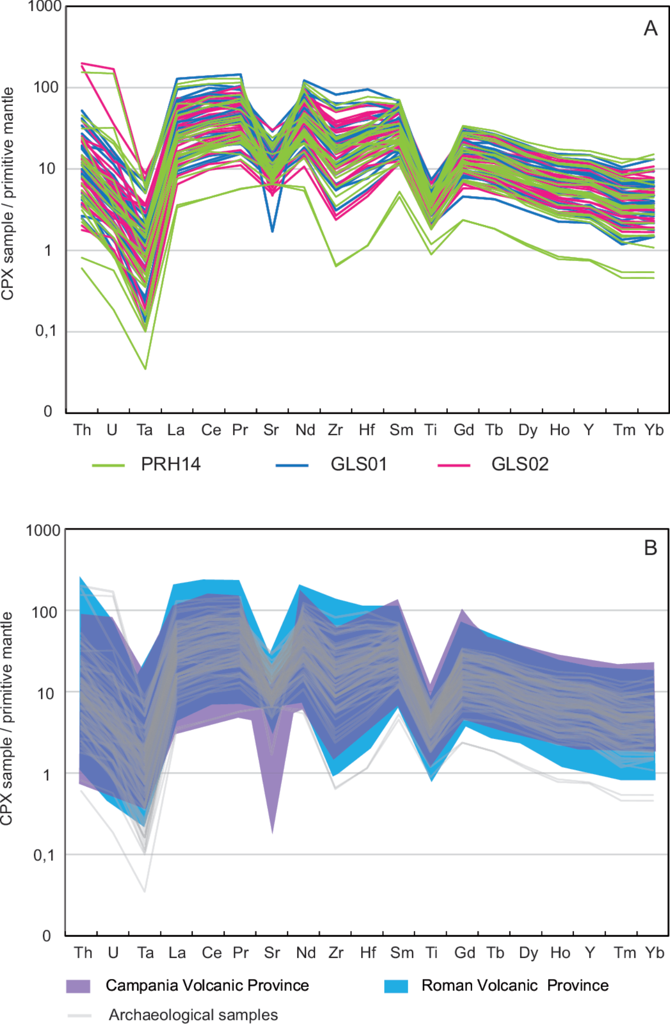
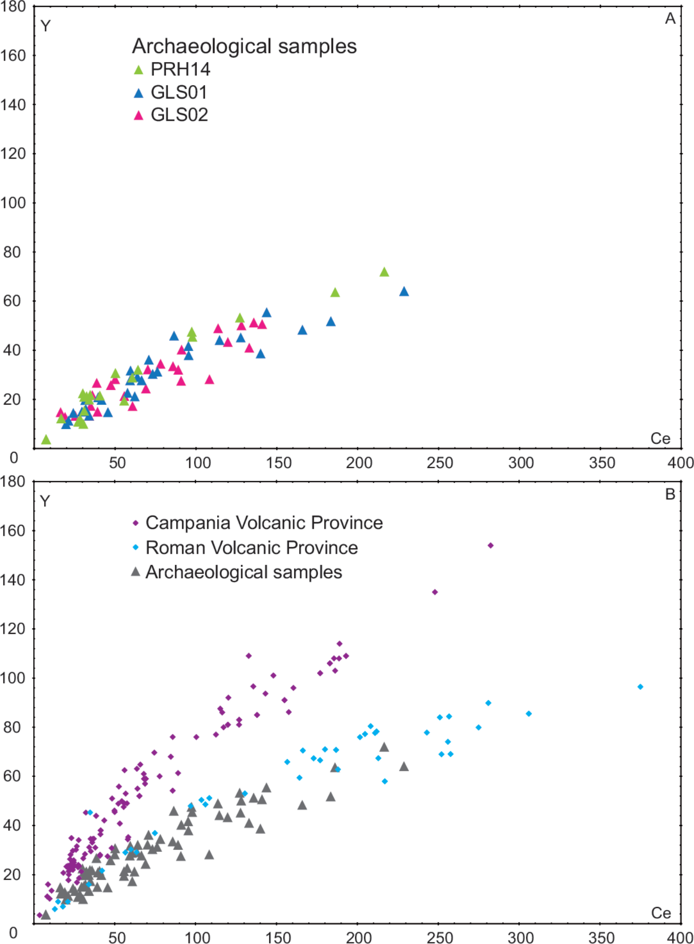
GLS PRH



Wo
50
45
Diopside
Hedenbergite
Augite
50
45
20
20
5
5
En
50
Fs
Archaeological samples
PRH14
GLS01
GLS02
Volcanic Provinces
Roman Volcanic Province
Campanian Volcanic Province
Tuscany Volcanic Province
Apulian Volcanic Province
Sardinia Volcanic Province
Archaeological samples
Heder
Augite
A
B
C
D
E
F


A
1000
100
10
1
sample / primitive mantle
Th U Ta La Ce Pr Sr Nd Zr Hf Sm Ti Gd Tb Dy Ho Y Tm Yb
PRH14
GLS01
Agde Lava
PRH Soil
PRH Lava
B
1000
100
10
1
sample / primitive mantle
Th U Ta La Ce Pr Sr Nd Zr Hf Sm Ti Tb Dy Ho Y Tm Yb
PRH14
GLS01
Roman Volcanic Province
Tuscany Volcanic Province
Campania Volcanic Province


A
1000
100
10
1
0,1
0
CPX sample / primitive mantle
Th U Ta La Ce Pr Sr Nd Zr Hf Sm Ti Gd Tb Dy Ho Y Tm Yb
PRH14
GLS01
GLS02
B
Campania Volcanic Province
Roman Volcanic Province
Archaeological samples



A
Y
Ce
Archaeological samples
PRH14
GLS01
GLS02
B
Campania Volcanic Province
Roman Volcanic Province
Archaeological samples
0
20
40
60
80
100
120
140
160
180
50
100
150
200
250
300
350
400

Roman Volcanic Province

Associated river basins

Neolithic archaeological sites

1 - Peiro-Signado 2 - Caucade 3 - Pendimoun 4 - Arene Candide 5 - Pian del Ciliegio 6 - Panicarola 7 - Settecannelle

8 - La Marmotta 9 - Pianosa - Cala Giovanna 10 - Albertini 11 - Campu Stefanu 12 - Su Coloru

Obsidian geological outcrops

13 - Monte Arci 14 - Palmarola