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When the potter has a choice: New insights into Neolithic pottery production in the Adige Valley (northeastern Italy)

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ABSTRACT

During the 5th millennium BCE the Neolithic way of life was gradually established in the Adige Valley (northeastern Italy). This process was also linked to the appearance of pottery production. While ceramic assemblages from this region have traditionally been investigated through a stylistic approach, their technological aspects have not been addressed. This study tackles this gap by focusing on two key sites located in the Adige Valley, Riparo Gaban and La Vela. These sites provide a diachronic perspective on ceramic production from the early to the middle Neolithic. Petrographic analysis was conducted on 46 sherds to investigate technological choices, particularly the selection of raw materials. The aim is to reconstruct the relationship between Neolithic communities and the natural resources available in their environment and to understand how this changed during the considered timespan. The results highlight a significant variability in raw materials choices, reflecting a knowledge of the different resources available in the area. They also reveal continuity and change in the selection and processing of raw materials across the two considered phases. These findings contribute to a better understanding of the exploitation of geological resources in the Adige Valley during the Neolithic period and provide a basis for future comparative studies in the region and beyond.

1. Introduction

Archaeometric analyses of ceramic assemblages have become a crucial tool for investigating ancient technological choices and raw material procurement strategies. These approaches allow us to address questions that go beyond stylistic classification, offering insights into pottery provenance, human mobility, environmental interaction, and technological traditions. The selection of clay sources, for instance, reflects an engagement with the local landscape and is often connected with other daily activities (Michelaki et al., 2015). Technological practices in pottery-making are not only dictated by functional needs but are also shaped by tradition, identity, and social organisation (Michelaki et al., 2015; Roux, 2019; Quinn, 2022; Amicone, 2025).

In Italian prehistoric studies, ceramic assemblages have traditionally been interpreted through stylistic analysis, with a focus on vessel shapes and decorations. While this approach has provided a robust framework for constructing chrono-cultural sequences, it has limitations when it comes to understanding production technologies and the socio-environmental contexts of pottery manufacture. In recent years, several archaeometric studies across northern Italy have begun to address this gap, revealing detailed patterns of raw material selection, technological skills, and cultural transmission (e.g., Spataro, 1999; Fabbri et al., 2006; Capelli et al., 2008; Bernardini et al., 2016, 2024a,b; Gabriele et al., 2022; Tiezzi et al., 2024). Despite these advances, the Adige Valley—a key corridor in northeastern Italy—remains poorly understood in terms of Neolithic ceramic technology. This region is characterised by complex geology and a diverse range of sedimentary deposits and provides an ideal setting to explore how potters engaged with their environment over time.

This study addresses this gap by applying petrographic analysis to ceramic assemblages from two significant sites: Riparo Gaban and La Vela. These sites span the early to middle Neolithic and offer a rare

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opportunity to trace technological developments diachronically. The aim is to reconstruct patterns of raw material selection, technological choices, and their relationship to shifting cultural contexts by examining 46 ceramic samples and comparing them with geological materials collected both in the vicinity of the sites and in the Adige Valley. Specifically, the research investigates how Neolithic human groups engaged with their environment in an area of complex and diverse geology, and how this relationship evolved from the early to the middle Neolithic, as the Neolithic way of life gradually became established. It also explores how technological continuity or change can be correlated with the chrono-cultural sequences established by traditional studies. In doing so, this study not only deepens our understanding of Neolithic pottery production in the Adige Valley but also lays the groundwork for comparative analyses across northern Italy, helping to shed new light on the processes of neolithisation and the formation of the complex cultural mosaic that characterised the Italian Peninsula during the 5th millennium BCE.

2. Archaeological background

The Neolithic appears in the Adige Valley (northeastern Italy) towards the end of the 6th millennium BCE (Bagolini and Biagi, 1990; Mottes, 2021), and the neolithisation process of the region is traditionally attributed to acculturation dynamics of local Mesolithic groups. However, this process remains a topic of debate (Bagolini, 1980a, 1986, 1987, 1990b, 1992, 1990a, 1992; Bagolini and Broglio, 1985; Kruta, 1993; Guilaine, 1994; Bazzanella, 2000; Pessina and Tinè, 2022; Pedrotti, 2009; Perrin et al., 2009; Mottes, 2013, 2021; Gibaja et al., 2025). The first attested Neolithic material culture is the "Gaban group" that characterises the area between 5000 and 4700 cal BCE (Bagolini and Biagi, 1977; Pedrotti, 1998; Pearce, 2013). It is marked by the presence of pottery associated with stone tools and an economy that still shows Mesolithic features (Bagolini and Biagi, 1977; Bagolini and Pedrotti, 1998; Pedrotti, 2001). Around 4800–4700 cal BCE, there is evidence in the Adige Valley of some contacts with the Square Mouthed Pottery (SMP) Culture, which was present in the north of Italy from the beginning of the 5th millennium BCE (Pedrotti, 2001; Mottes et al., 2009). The SMP Culture is named after its characteristic square-mouthed vessels, and it is divided into three phases based on the stylistic features of pottery decorations (Bagolini et al., 1979). All three are attested in the Adige Valley. The emergence of the SMP Culture marks an economic shift: hunting starts to lose its predominance while evidence of animal farming becomes increasingly consistent (Pedrotti, 2001; Mottes, 2021).

2.1. Riparo Gaban

Riparo Gaban (46°05′36″N 11°07′21″E) is a rock shelter, situated 3 km to the north-east of the city of Trento (Italy) at 270 m a.s.l. (Fig. 1). The site is located in a small hanging valley, which runs parallel to the left bank of the Adige River about 80 m above the current valley floor (Bagolini, 1972, 1974, 1980b; Bagolini et al., 1976; Bagolini and Pedrotti, 1998; Kozlowski and Dalmeri, 2000; Pedrotti, 2001).

The investigated area is 60 m^2 wide, and it is divided into six sectors (I-VI) (Pedrotti, 2009). A 6 m thick archaeological deposit is present: the site was frequented from the Mesolithic to the middle Bronze Age, with some interruptions (Bagolini, 1980b). The archaeological sequence includes early and late Mesolithic layers (Kozlowski and Dalmeri, 2000), early Neolithic layers, Copper Age layers, and early to middle Bronze Age layers (Bagolini and Pedrotti, 1996).

During the excavation, the Neolithic layer (layer D) was divided into 5–10 cm spits (D0-D10). In the following text, the phase corresponding to spits D10-D6 will be called early Neolithic – A, and the phase corresponding to spits D5-D0 will be called early Neolithic – B.

The Neolithic frequentation is attributed to the Gaban group, but the more recent Neolithic spits (early Neolithic – B) show influences from the archaic SMP Culture. A gap between the middle Neolithic and the middle Copper Age (2700/2600 cal BC) is attested (Bagolini, 1980b; Bagolini and Pedrotti, 1996).

The first stylistic analysis on pottery documented a change in decorations across the Neolithic sequence of Riparo Gaban: in spits D10-D6, pottery decoration is mostly impressed (similar to the Adriatic tradition) and incised. However, in spits D5-D0, the impressed decoration is absent, and the scratched decoration becomes more frequent (Bagolini and Biagi, 1977; Pedrotti, 1998, 2001). Furthermore, archaeozoological studies (Cristelli, 2012/2013) showed that hunting dominates in spits

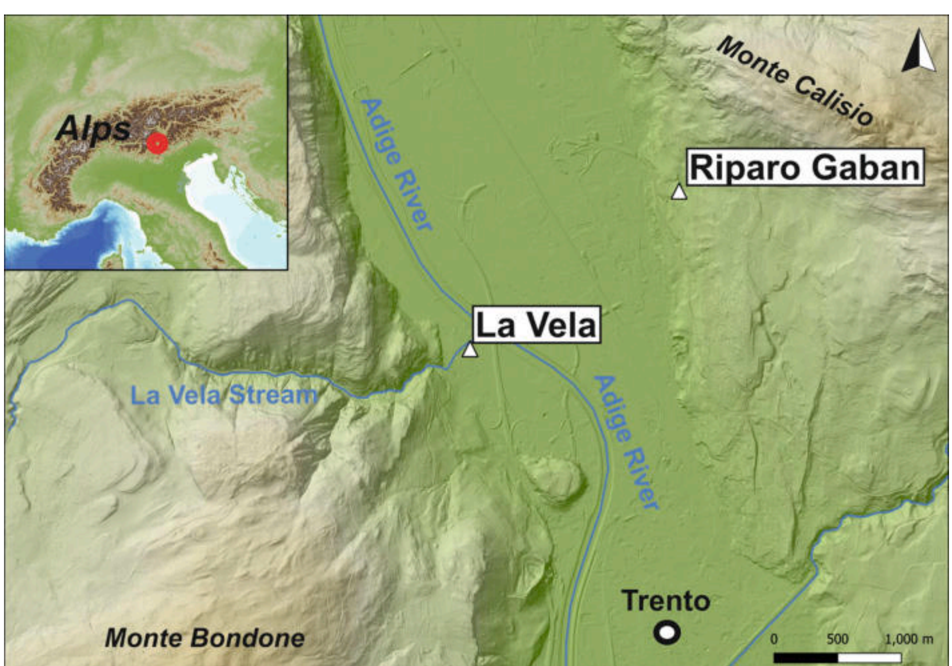

Fig. 1. Localisation of the sites of Riparo Gaban and La Vela, note the proximity of the sites (created by J. Armellini, topographic data from European Space Agency, 2024).

D10-D6, with significant evidence of fishing, bird hunting, mollusc, and turtle collection. In contrast, spits D5-D2 show clear evidence of animal husbandry on site, including sheep, goats, and possibly cattle (Bagolini, 1980b). From the spit D5, sheep/goats and cattle dung was discovered: geoarchaeological analyses displayed the presence of *fumiers*, typically associated with animal husbandry, particularly with stabling and stock keeping (Angelucci et al., 2009). Finally, many art objects from both the Mesolithic and Neolithic layers have been found in Riparo Gaban. This led to the hypothesis that the site may have had a ritual purpose (Bagolini, 1972; Graziosi, 1975; Pedrotti, 1998, 2001, 2009).

2.2. La Vela

La Vela (46°04′52″N 11°06′05″E) is an open-air site situated to the north-west of Trento (Fig. 1). It is located on an alluvial fan created by the Vela Stream, on the right bank of the Adige River. The site was discovered in 1960 and investigated in 12 sectors (I-XII) (Degasperi et al., 2006; Mottes, 2021). This paper focuses on sector VII, which was excavated by CORA archaeological cooperative under the direction of Bernardino Bagolini (University of Trento), on behalf of the Ufficio dei Beni Archeologici della Soprintendenza della Provincia Autonoma di Trento.

The stratigraphic sequence of sector VII is the most complete of the site. It shows early and recent Mesolithic layers, early Neolithic layers, and middle Neolithic layers. It also displays the presence of a ditch, whose creation can be dated to the early Neolithic. The middle Neolithic layers are characterised by the presence of Square Mouthed Pottery Culture burials (Degasperi and Pedrotti, 1997a, 1997b; Bazzanella et al., 2001; Mottes, 2007).

Stylistic analysis of the ceramic production reveals that the early Neolithic layers are characterised by the presence of Gaban group pottery and by the appearance of typical SMP elements. The middle Neolithic layers can be divided into two distinct phases based on pottery style: the SMP I phase (geometric-linear style) and the SMP II phase (meander-spiral style) (Degasperi and Pedrotti, 1997b; Pedrotti et al., 1997, 2002; Pedrotti, 2001). Archaeozoological studies show that in the early Neolithic period, the presence of domestic animals contributed to a shift, with hunting becoming a secondary activity. This trend persisted during the middle Neolithic (Bazzanella, 1997).

3. Geological and geomorphological background

The Adige Valley is located within the Southern Alps, in the north-eastern part of the Italian Peninsula. It stands out as the main valley in the region, serving as the primary linkage between the northern and southern sectors of the Eastern Alps. Running in a NS direction, the Adige River gives rise to a broad alluvial plain on the valley bottom (Avanzini et al., 2010). The geological and structural configuration of the region is quite complex, reflecting the complicated formational history of the Alps (Borsellini et al., 1999; Angelucci and Bassetti, 2009).

The current morphological characteristics of the region stem from the Pleistocene's glacial-interglacial cycles, which shaped most of the landforms within the valley. The Quaternary deposits are represented by glacial sediments deposited by Alpine glaciers (moraines), fluvioglacial deposits associated with the withdrawal of the alpine glaciers in the Last Deglaciation, and Holocene alluvial and slope deposits (Fig. 2). Namely, the "*Sintema del Garda*" (SDG) encompasses the glacial (till), fluvioglacial, glacial-lacustrine, and aeolian deposits formed during the expansion, acme, and retreat of the Alpine Glaciers in the Trentino region. The "*Sintema Postglaciale Alpino*" (PTG) comprises the deposits formed following the retreat of glaciers during the final phases of the Pleistocene and throughout the Holocene period. During the Holocene, the Adige Valley experienced overall geomorphological stability, characterised by vegetal colonisation and soil development. The valley floor constituted a large alluvial plain shaped by the activity of the Adige River, with scattered swampy areas and alluvial fans formed by the tributaries of the river. Additionally, alluvial deposits formed in proximity to the Adige River (Avanzini et al., 2010).

For the purpose of this study, it is particularly important to highlight the textural and compositional characteristics of Pleistocene deposits, as these aspects play a significant role in the selection of raw materials. The sediment's granulometry can range from fine sediments (clay, silt, and sand), as seen in glacial, glaciolacustrine, fluvioglacial, and aeolian sediments, to coarser materials found in fluvioglacial and glacial sediments. Additionally, the lithotypes observed in these deposits exhibit considerable diversity, including most, if not all, of the lithotypes found upstream in the area under study.

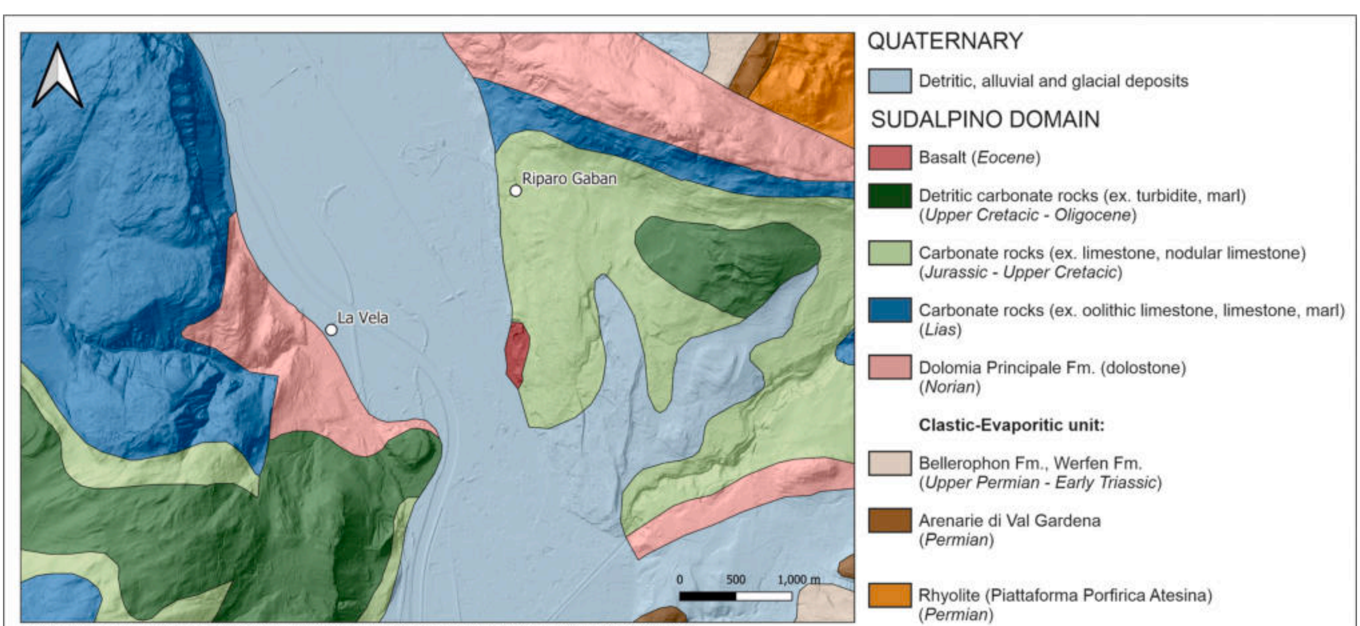

Fig. 2. Lithographic map of the surroundings of the La Vela and Riparo Gaban archaeological sites. Note the extent of Quaternary deposits and carbonate lithotypes (created by J. Armellini, modified from Borsellini et al., 1999).

4. Materials and methods

Macroscopic analysis was conducted on 53 sherds from Riparo Gaban and 350 sherds from La Vela – VII (Table 1). The analysis focused exclusively on sherds bearing decorative patterns or morphological elements, through the observation by naked eye and the use of an optical stereomicroscope (LEICA MZ 12.5) at the LABAAF (University of Trento). For Riparo Gaban, most of the sherds were retrieved from sector IV. For both sites, only findings with a clear indication of the stratigraphic unit and square were considered. Macrofabrics were mainly defined based on observations of texture (coarseness) and colour of inclusions. When relevant, characteristics of the matrix and porosity were taken into consideration. To gain an understanding of the firing atmosphere, the colours of the surfaces and the cross-sections of the sherds were evaluated using the Munsell Soil Colour Chart. In addition, some information about surface treatments was recorded (Roux, 2019; Forte, 2020). Details about the samples are provided in the Supplementary material 1.

Ceramic petrography was applied to identify raw materials, reconstruct technological processes, and contribute to the interpretation of potential production areas in conjunction with comparative geological data (Whitbread, 1986; Rice, 1987; Quinn, 2022). Sixteen samples from the Riparo Gaban assemblage were selected for petrographic analysis (Table 2). The samples were chosen mainly based on the stratigraphic position, the macrofabrics (Fig. 4), and, when possible, on the vessel decoration style (Fig. 3). At least two samples for each macrofabric were selected to represent the variability of the assemblage clay pastes (Supplementary material 1). The samples were mainly retrieved from spits D10-D6 (early Neolithic - A), since spits D5-D0 (early Neolithic - B) yielded few ceramic fragments (Table 1).

A total of 30 samples from the La Vela assemblage were selected for petrographic analysis (Table 3) based on the variability of the macrofabrics (Fig. 5), the stratigraphic position and, when possible, the style and shape of the vessels (Fig. 3). At least one sample for each macrofabric was selected, to represent the variability of the assemblage clay pastes, with more samples chosen for the most common macroscopic groups (Supplementary Material 1). This study focuses on pottery retrieved from the early Neolithic layers (7 samples) and the middle Neolithic – SMP II layers (17 samples). The middle Neolithic – SMP I layers show a small quantity of ceramic findings and a complex attribution of stratigraphic units to this chronological phase. 6 samples were also chosen from the stratigraphic unit 71. This unit displays the presence of elements characteristic of the Gaban group, in addition to vessels exhibiting a squared mouth.

The thin sections were studied using a LEICA DM2500P polarising microscope at the Archaeometry Research Group (University of Tübingen) and an OPTIKA B-1000 POL polarising microscope at the LABAAF (University of Trento). The samples were grouped into petrographic fabrics and described using a visual descriptive approach (Whitbread, 1989; Quinn, 2022).

A prospection for raw materials was conducted to investigate the availability of raw materials in the surrounding areas of the sites. Published geological literature available for the region was taken into consideration (Bassetti and Borsato, 2005; Angelucci and Bassetti, 2009; Avanzini et al., 2010; Tomasoni et al., 2012; Angelucci, 2016). Only outcrops and sediments located within a 7 km radius of the sites were considered, following the "resource area model", which is based on ethnographic data (Arnold et al., 1991; Arnold, 2000). It is important to note that the area may need to be adjusted based on the local geomorphology, as accessing mountainous zones may require more time and energy. However, due to strong urbanisation, the morphogenesis of the Adige Valley (Angelucci, 2016), and the anthropic transformations of the Adige River course over time (Scorpio et al., 2017), it is extremely difficult to find clayey outcrops comparable to those available during the Neolithic period. Eleven geological samples, including clay, sands and rock fragments, were collected and prepared as thin sections (Supplementary material 2).

Table 1
Number of sherds considered for the macroscopic analyses for each phase of frequentation of the sites.

Spits D10-D6 (early Neolithic - A)	42
Spits D5-D0 (early Neolithic - B)	11
Total sherds from Riparo Gaban	**53**
Early Neolithic layers	59
Middle Neolithic – SMP I layers	15
Middle Neolithic – SMP II layers	276
Total sherds from La Vela	**350**

5. Results

5.1. Riparo Gaban

Petrographic analysis on 16 samples from Riparo Gaban archaeological pottery revealed 3 different petrographic fabrics and 3 outliers (Table 2). A detailed description of each petrographic fabric is provided as Supplementary material 3.

Fabric RGB – 1 (Carbonate fabric). This fabric is characterised by a moderately homogeneous non-calcareous matrix and the presence of predominant angular and subangular inclusions of calcite, dolomite, as well as carbonate rocks (for the presence of dolomite, see also Supplementary material 4 with XRPD analysis on sample RGBC08). The fabric was divided into two variants due to differences in grain size and sorting of the carbonate inclusions. Variant A (Fig. 6a) (RGBC01, RGBC08, RGBC15, RGBC16) is characterised by inclusions with a maximum size of 1.0 mm, a mode of 0.3 mm, and a weakly bimodal grain size distribution. In addition to carbonate minerals and rocks, other inclusions are rare bones, muscovite, and iron-rich features. Variant B (Fig. 6b) (RGBC02, RGBC03) is characterised by inclusions with a maximum size of 1.4 mm, a mode of 0.7 mm, and a strongly bimodal grain size distribution. In addition to carbonate minerals and rocks, other inclusions are few monocrystalline quartz and very rare acidic volcanic rocks.

Fabric RGB – 2 (Plutonic fabric). This fabric (Fig. 6c) (RGBC04, RGBC05, RGBC14) is characterised by a moderately homogeneous non-calcareous matrix and the predominant presence of intermediate plutonic rocks. Other inclusions are very rare acidic volcanic rocks and foliated metamorphic rocks. This fabric features inclusions with a maximum size of 3.5 mm and a strongly bimodal grain size distribution.

Fabric RGB – 3 (Argillaceous inclusions fabric). This fabric is characterised by a non-homogeneous non-calcareous matrix rich in organic material and opaque minerals, and the presence of dominant to common argillaceous inclusions. It has been divided into two variants due to differences in grain size and the nature of certain inclusions. Variant A (Fig. 6d; Fig. 6e) (RGBC06, RGBC13) shows the presence of argillaceous inclusions with a maximum size of 0.8 mm and a unimodal grain size distribution. Other inclusions are few monocrystalline and polycrystalline quartz and muscovite, and rare bones, foliated metamorphic rocks, chert, and calcite. Variant B (Fig. 6f) (RGBC09, RGBC10) shows the presence of coarser argillaceous inclusions with a maximum size of 1.6 mm and a polymodal grain size distribution. Other inclusions are frequent monocrystalline and polycrystalline quartz, common metamorphic rocks (comparison with sample TN012, Supplementary material 2), muscovite, few bones, and rare altered limestone.

Outlier RGB – 4 (Carbonate and volcanic fabric). The RGBC07 sample (Fig. 6g) is characterised by a homogeneous non-calcareous matrix and the presence of frequent monocrystalline quartz and acidic or intermediate volcanic rocks. Other inclusions are common muscovite, few carbonate rocks, and rare polycrystalline quartz. This sample features inclusions with a maximum size of 2.7 mm and a polymodal grain size distribution.

Outlier RGB – 5 (Calcite and chert). The RGBC11 sample (Fig. 6h) is characterised by a slightly homogeneous non-calcareous matrix and the

Table 2
Pottery samples from Riparo Gaban analysed in this study with the stratigraphic, stylistic, and petrographic information.

Sample	Spit	Frequentation phase	Petrographic fabric	Variant	Stylistic description
RGBC01	D5-6 + D8	Early Neolithic A	RGB – 1	A	Undecorated wall sherd
RGBC02	D5-D3	Early Neolithic B	RGB – 1	B	Undecorated wall sherd
RGBC03	D7	Early Neolithic A	RGB – 1	B	Undecorated wall sherd
RGBC04	D5-D6	Early Neolithic B	RGB – 2	/	Undecorated wall sherd
RGBC05	I5 (=D4-D5)	Early Neolithic B	RGB – 2	/	Undecorated wall sherd
RGBC06	D9	Early Neolithic A	RGB – 3	A	Undecorated wall sherd
RGBC07	D5-D7	Early Neolithic B	RGB – 4	/	Undecorated wall sherd
RGBC08	D9	Early Neolithic A	RGB – 1	A	Wall sherd decorated with nail impressions
RGBC09	D8	Early Neolithic A	RGB – 3	B	Wall sherd decorated with nail impressions
RGBC10	D8-D9	Early Neolithic A	RGB – 3	B	Wall sherd decorated with nail impressions
RGBC11	D8	Early Neolithic A	RGB – 5	/	Carinated wall (probably of a mug)
RGBC12	D1	Early Neolithic B	RGB – 6	/	Rim of a square mouthed vessel
RGBC13	D9	Early Neolithic A	RGB – 3	A	Wall sherd decorated with incised parallel lines
RGBC14	D5-D6	Early Neolithic B	RGB – 2	/	Wall sherd decorated with incised parallel lines
RGBC15	D8	Early Neolithic A	RGB – 1	A	Wall sherd with incised decoration
RGBC16	D7	Early Neolithic A	RGB – 1	A	Olla with incised, scratched and polished decoration. Stylistically it has been interpreted as an import.

common presence of sparitic calcite and chert. Other inclusions are very few monocrystalline quartz, rare polycrystalline quartz, and argillaceous inclusions. This sample features inclusions with a maximum size of 1.1 mm and a weakly bimodal grain size distribution.

Outlier RGB – 6 (Volcanic fabric). The RGBC12 sample (Fig. 6i) is characterised by a slightly homogeneous non-calcareous matrix and by the presence of common very altered basic volcanic rocks, monocrystalline quartz, and feldspars. Other inclusions are very few polycrystalline quartz (of metamorphic origin), rare acidic/intermediate plutonic rocks, and very rare chlorite and muscovite. This sample features inclusions with a maximum grain size of 2.5 mm and a polymodal grain size distribution.

5.2. La Vela

Petrographic analysis on 30 samples from La Vela archaeological pottery revealed 5 petrographic fabrics and 3 outliers. Due to the strong heterogeneity of the identified ceramic pastes, variants were defined. A detailed description of each petrographic fabric is provided as Supplementary material 3.

Fabric LV – 1 (Carbonate fabric). This fabric is characterised by a homogeneous non-calcareous matrix and the presence of predominant angular and subangular inclusions of sparitic calcite, dolomite, as well as fragments of carbonate rocks (for the presence of dolomite, see also Supplementary material 4 with XRPD analysis on samples LVC01 and LVC13). The fabric displays a strongly bimodal grain size distribution. It was divided into two variants due to differences in grain size and sorting of inclusions. Variant A (Fig. 7a) (LVC01, LVC02, LVC04, LVC27) is characterised by inclusions with a maximum size of 1.9 mm, a mode of 0.2 mm, and a high degree of sorting. In addition to carbonate minerals and rocks, rare iron-rich inclusions and very rare volcanic rocks are present. Variant B (Fig. 7b) (LVC08, LVC10, LVC12, LVC13, LVC24, LVC30, LVC31, LVC32) is characterised by inclusions with a maximum size of 2.3 mm and a mode between 0.7 mm and 0.4 mm. In addition to carbonate minerals and rocks, other inclusions are rare polycrystalline quartz and very rare feldspars, volcanic rocks, and metamorphic rocks. This variant is heterogeneous in terms of the clay processing and sorting of carbonate inclusions.

Fabric LV – 2 (Plutonic fabric). This fabric is characterised by a homogeneous non-calcareous matrix and the presence of intermediate plutonic rocks. The fabric was divided into two variants due to differences in the grain size distribution of inclusions. Variant A (Fig. 7c) (LVC15, LVC17, LVC18, LVC19) is characterised by inclusions with a maximum size of 3.0 mm and a strongly bimodal grain size distribution. Other inclusions in this variant are few monocrystalline quartz, feldspars, biotite, rare opaque minerals, and very rare metamorphic rocks, acidic volcanic rocks, and argillaceous inclusions. Variant B (Fig. 7d) (LVC14) is characterised by inclusions with a maximum size of 2.9 mm and a polymodal grain size distribution. Other inclusions in this variant are frequent monocrystalline quartz, feldspars, muscovite, and few biotite.

Fabric LV – 3 (Metamorphic fabric). This fabric (Fig. 7e) (LVC05, LVC07, LVC29) is characterised by a slightly homogeneous non-calcareous matrix and the frequent presence of metamorphic rocks. Other inclusions are rare monocrystalline quartz, biotite, acidic volcanic rocks, and acidic/intermediate plutonic rocks. This fabric features inclusions with a maximum size of 1.7 mm and a polymodal grain size distribution.

Fabric LV – 4 (Volcanic fabric). This fabric is characterised by a slightly homogeneous non-calcareous matrix and the presence of acidic/intermediate volcanic rocks (that match with geological sample TN007; see Supplementary material 2). It was divided into two variants due to differences in the grain size distribution of inclusions. Variant A (Fig. 7f) (LVC20, LVC21) features inclusions with a maximum grain size of 4.2 mm and a strongly bimodal grain size distribution. Other inclusions in this variant are very few monocrystalline quartz, rare polycrystalline quartz, and very rare plutonic rocks. Variant B (Fig. 7g) (LVC03, LVC23) features inclusions with a maximum grain size of 1.5 mm and a polymodal grain size distribution. Other inclusions in this variant are common muscovite, monocrystalline quartz, feldspars, altered limestone, few opaque minerals, and very rare metamorphic rocks.

Outlier LV – 5 (Depurated fabric). Sample LVC25 (Fig. 7h) is characterised by a non-homogeneous non-calcareous matrix and very fine inclusions. It contains predominant monocrystalline quartz, frequent muscovite, opaque minerals, and polycrystalline quartz. The fabric features inclusions with a maximum size of 0.5 mm and a unimodal grain size distribution. This fabric is attested in only one sample. From a macroscopic point of view, it rarely occurs within the assemblage.

Fabric LV – 6 (Polymictic fabric). Variant A (Fig. 7i) (LVC26) is characterised by a slightly homogeneous non-calcareous matrix and inclusions representing an association of different lithologies. It contains common acidic volcanic rocks, rare metamorphic rocks, and rare acidic/intermediate plutonic rocks. Other inclusions are common monocrystalline quartz, very few plagioclases and opaque minerals, rare amphibole and carbonate rocks, and very rare argillaceous inclusions. This variant features inclusions with a maximum grain size of 3.7 mm and a polymodal grain size distribution. Variant B (Fig. 7j) (LVC11, LVC28) is characterised by a slightly homogeneous non-calcareous matrix and the common presence of acidic/intermediate plutonic rocks and intermediate/basic volcanic rocks. Other inclusions are

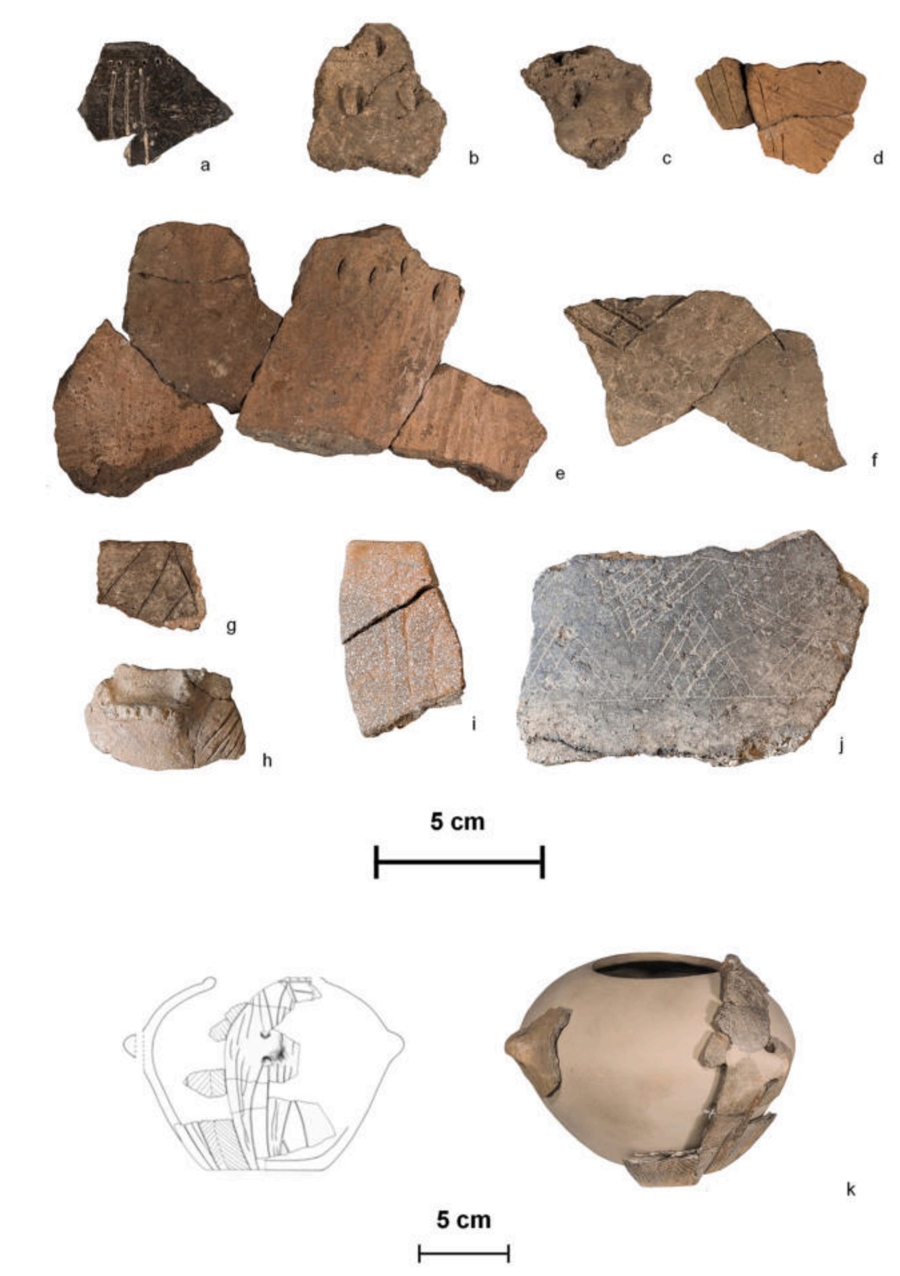

Fig. 3. Decorated pottery from Riparo Gaban and La Vela: a) RGBC01, b) RGBC09, c) RGBC10, d) RGBC13, e) RGBC08, f) RGBC15, g) RGBC14, h) LVC28, i) LVC27, j) LVC32, k) RGBC16. Photos of the Riparo Gaban sherds by P. Chistè; photos of the La Vela sherds by G. Deimichei. Drawing from Bagolini and Pedrotti, 1996.

common monocrystalline quartz, few feldspars and mica minerals, and rare acidic volcanic and metamorphic rocks. This variant features inclusions with a maximum grain size of 3.9 mm and a polymodal grain size distribution.

Outlier LV – 7 (Polycrystalline quartz and muscovite fabric). Sample LVC06 (Fig. 7k) is characterised by a homogeneous non-calcareous matrix and by dominant monocrystalline quartz, as well as common polycrystalline quartz and muscovite. Other inclusions are very few biotite and plagioclase, and rare sparitic calcite, and acidic volcanic rocks. This sample features inclusions with a maximum size of 0.8 mm and a unimodal grain size distribution.

Outlier LV – 8 (Sand fabric). Sample LVC22 (Fig. 7l) is characterised by a slightly homogeneous non-calcareous matrix and frequent monocrystalline quartz and common sparitic calcite, acidic volcanic rocks, and metamorphic rocks. Other inclusions are rare feldspars and very rare basic volcanic rocks. This sample features inclusions with a maximum grain size of 1.2 mm and a weakly bimodal grain size distribution.

6. Discussion

6.1. Raw materials for ceramic production at Riparo Gaban

The analysis of the Riparo Gaban samples revealed a wide variety of choices in raw materials acquisition and processing. Three ceramic pastes were identified in the early Neolithic – A phase.

Fabric RGB – 1A and *Fabric RGB – 5* contain sparitic calcite and dolomite, which were added as a temper after being crushed. *Fabric RGB – 5* is slightly different due to the presence of chert. Carbonate outcrops are strongly present around the site and, more generally, throughout the

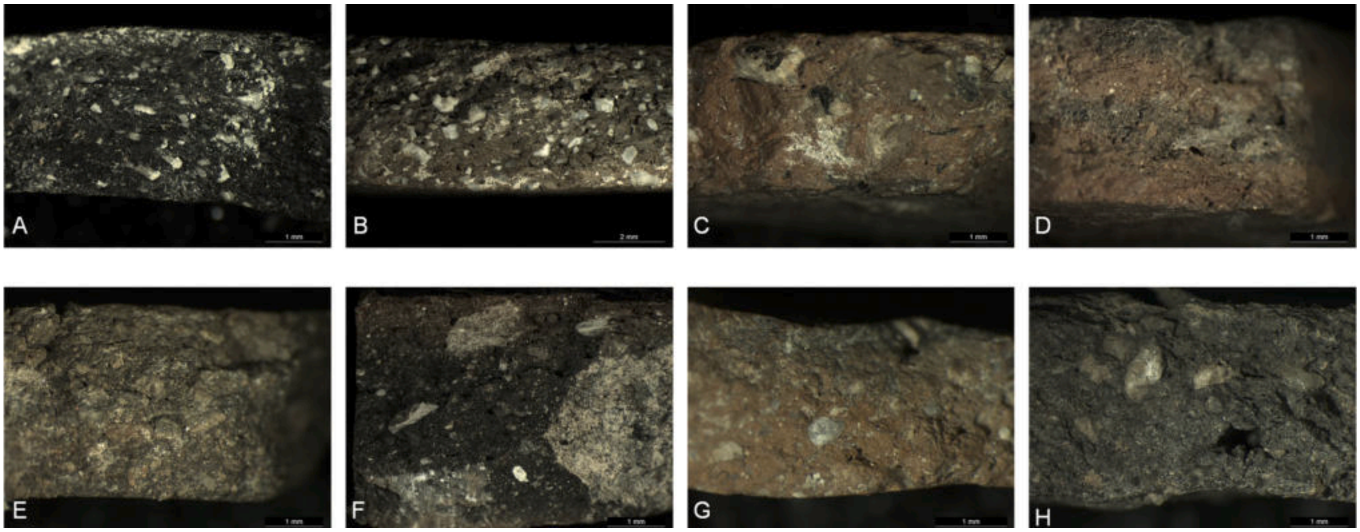

Fig. 4. Selected sherds from Riparo Gaban seen in fresh fracture: A) RGBC05 (Fabric 1a), B) RGBC03 (Fabric 1b), C) RGBC14 (Fabric 2), D) RGBC06 (Fabric 3a), E) RGBC09 (Fabric 3b), F) RGBC07 (Fabric 4), G) RGBC11 (Fabric 5), H) RGBC12 (Fabric 6).

Table 3
Pottery samples from La Vela analysed in this study with the stratigraphic, stylistic, and petrographic information.

Sample	Layer	Frequentation phase	Petrographic fabric	Variant	Stylistic description
LVC01	110	SMP II	LV – 1	A	Undecorated wall sherd
LVC02	18	SMP II	LV – 1	A	Undecorated wall sherd
LVC03	4	SMP II	LV – 4	B	Undecorated wall sherd
LVC04	4	SMP II	LV – 1	A	Undecorated wall sherd
LVC05	2 + 4	SMP II	LV – 3	/	Rim of a square mouthed vessel
LVC06	166	Early Neolithic?	LV – 7	/	Undecorated wall sherd
LVC07	2	SMP II	LV – 3	/	Undecorated wall sherd
LVC08	71	Early Neo-SMP I	LV – 1	B	Carinated wall
LVC10	28	Early Neolithic	LV – 1	B	Undecorated wall sherd
LVC11	19	Archaic SMP II?	LV – 6	B	Undecorated wall sherd
LVC12	166	Early Neolithic?	LV – 1	B	Undecorated wall sherd
LVC13	71	Early Neolithic-SMP I	LV – 1	B	Undecorated wall sherd
LVC14	45	SMP II	LV – 2	B	Undecorated wall sherd
LVC15	28	Early Neolithic	LV – 2	A	Undecorated wall sherd
LVC17	2	SMP II	LV – 2	A	Undecorated wall sherd
LVC18	2	SMP II	LV – 2	A	Undecorated wall sherd
LVC19	4	SMP II	LV – 2	A	Undecorated wall sherd
LVC20	4	SMP II	LV – 4	A	Undecorated wall sherd
LVC21	4	SMP II	LV – 4	A	Undecorated wall sherd
LVC22	166	Early Neolithic?	LV – 8	/	Bottom of a bowl
LVC23	108	SMP II	LV – 4	B	Rim
LVC24	71	Early Neo-SMP I	LV – 1	B	Vessel on a small foot
LVC25	71	Early Neo-SMP I	LV – 5	/	Rim
LVC26	60	Early Neolithic	LV – 6	A	Undecorated wall sherd
LVC27	2	SMP II	LV – 1	A	Fragment of a bowl decorated with scratched meander-spiralic motif
LVC28	89	Archaic SMP II?	LV – 6	B	Wall decorated with scratched linear geometric pattern
LVC29	4	SMP II	LV – 3	/	Rim of a square mouthed vessel
LVC30	71	Early Neo-SMP I	LV – 1	B	Rim of square mouthed vessel decorated with scratching
LVC31	71	Early Neo-SMP I	LV – 1	B	Bowl
LVC32	28	Early Neolithic	LV – 1	B	Small olla with incised and plastic decoration (cordon bearing impressions)

Adige Valley. Additionally, these rocks are a significant component of the Quaternary deposits of the area (Avanzini et al., 2010).

Fabric RGB – 3 is characterised by the presence of argillaceous inclusions whose origin is still unclear. We cannot exclude that these inclusions could be grog fragments, but a broad definition has been used because the identification of grog is not always straightforward (Whitbread, 1986; Cuomo di Caprio and Vaughan, 1993).

Two ceramic pastes and two outliers were identified in the early Neolithic – B phase.

Fabric RGB – 1B and *Fabric RGB – 2* display a tempering action, with carbonate rocks and plutonic rocks, respectively. Plutonic rock outcrops are present both on the right and left side of the Adige Valley: in the Valsugana Valley (*"Gruppo di Cima d'Asta"*) and in the Adamello area (*"Batolite dell'Adamello"*) (Braga et al., 1971; Castellarin et al., 2005; Avanzini et al., 2010). As both outcrops are remote from the sites (more than 50 km), it is reasonable to suggest that the Neolithic potters gathered these rocks from Quaternary deposits ("*Sintema del Garda*" and "*Sintema Postglaciale Alpino*") present in the Adige Valley (Tomasoni et al., 2009; Avanzini et al., 2010).

Outlier RGB – 4 contains both carbonate and acidic volcanic rocks, which have a shape and grain size distribution consistent with a natural presence in the clay. The association of these rocks is consistent with

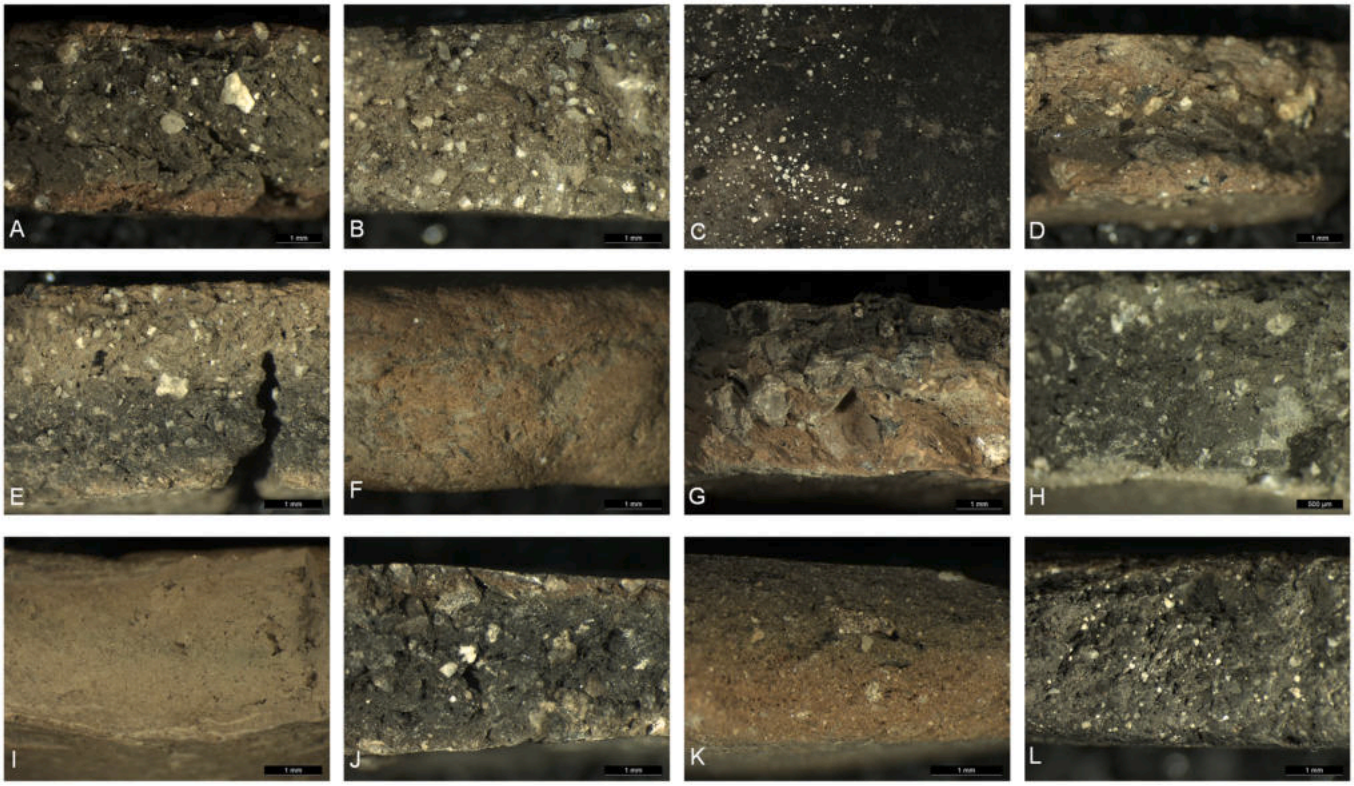

Fig. 5. Selected sherds from La Vela seen in fresh fracture: A) LVC27 (Fabric 1a), B) LVC10 (Fabric 1b), D) LVC15 (Fabric 2a), E) LVC14 (Fabric 2b), F) LVC05 (Fabric 3), G) LVC21 (Fabric 4a), H) LVC03 (Fabric 4b), I) LVC25 (Fabric 5), J) LVC26 (Fabric 6), K) LVC06 (Fabric 7), L) LVC22 (Fabric 8). C) Surface of a sherd belonging to Fabric 1b.

geological sample TN001 (Supplementary material 2), which was retrieved from a fluvio-glacial deposit in the surroundings of the site. Since fluvio-glacial deposits can also bear clay-rich material, it cannot be excluded that this kind of geological source was used to produce pottery, although it was not possible to identify it at the present day. However, the use of fluvial deposits cannot currently be excluded.

Outlier RGB – 6 is distinguished from the other samples by the presence of basic volcanic rocks. The fact that these lithologies are present both in the fine and coarse fractions suggests the use of a sediment formed through the alteration of volcanic rocks. Outcrops of these lithologies are present at 1.5 km from the site ("*Basalto della Vallagarina*"). The presence of other lithologies (plutonic, metamorphic) in the coarse fraction suggests a possible use of fluvio-glacial sediments as temper.

6.2. Raw materials for ceramic production at La Vela

La Vela pottery assemblage shows a high variety of raw material choices and paste preparation processes. Two fabrics and three outliers were identified in the early Neolithic phase.

Fabric LV – 1B (Carbonate fabric) and *Fabric LV – 2A* (*Plutonic fabric*) display a tempering action with carbonate and plutonic rocks, respectively. These fabrics are strongly similar to those previously discussed for Riparo Gaban (*RGB – 1* and *RGB – 2*), and the origin of the raw materials is likely to be the same.

Outlier LV – 5 shows peculiar characteristics, also from a macroscopic point of view (Fig. 5I). In this case, the clay was refined but not tempered. The low presence of muscovite in the fine fraction distinguishes this sample from the other samples in this assemblage.

Outlier LV-7 (Polycrystalline quartz and muscovite fabric) is characterised by inclusions that can be linked with the use of a secondary clay, whose composition is consistent with the Adige River sediments (geological sample TN003; Supplementary material 2).

The compositions of both *Fabric LV – 6 (Polymictic fabric)* and *Outlier – 8 (Sand fabric)* are compatible with the composition of the Quaternary deposits present in the surroundings of the site and spread throughout the Adige Valley.

These data show that during the final phase of the Gaban material culture and the first appearance of the SMP material culture in the region, the most widespread ceramic paste was characterized by the addition of carbonate inclusions as temper. The other fabrics are only represented by one sample each, making it difficult to understand their significance. However, they do demonstrate a wide range of choices in raw materials and processing techniques.

In the middle Neolithic – SMP II phase, five fabrics were identified.

Fabric 1A displays a tempering action with carbonate minerals and rocks. When compared to *Fabric LV – 1B* (present in the early Neolithic), the inclusions are more finely ground and possibly sieved before their addition to the clay.

Fabric LV – 2 is characterised by the tempering with plutonic rocks.

The compositions of *Fabric LV – 3* (*Metamorphic fabric*), *Fabric LV – 4 (Volcanic fabric),* and *Fabric LV – 6 (Polymictic fabric)* are consistent with the composition of Quaternary deposits (*Sintema del Garda* and *Sintema Postglaciale Alpino*) present in the Adige Valley. Variations in lithological composition of these fabrics are linked with the compositional heterogeneity of such deposits.

6.3. Ceramic technology in the Adige Valley between the early and middle Neolithic

All the lithologies present in the pottery were recognised in the Quaternary deposits of the Adige Valley during raw materials prospections (Supplementary material 2). Therefore, it can be inferred that pottery found in the two sites was produced within the Adige Valley

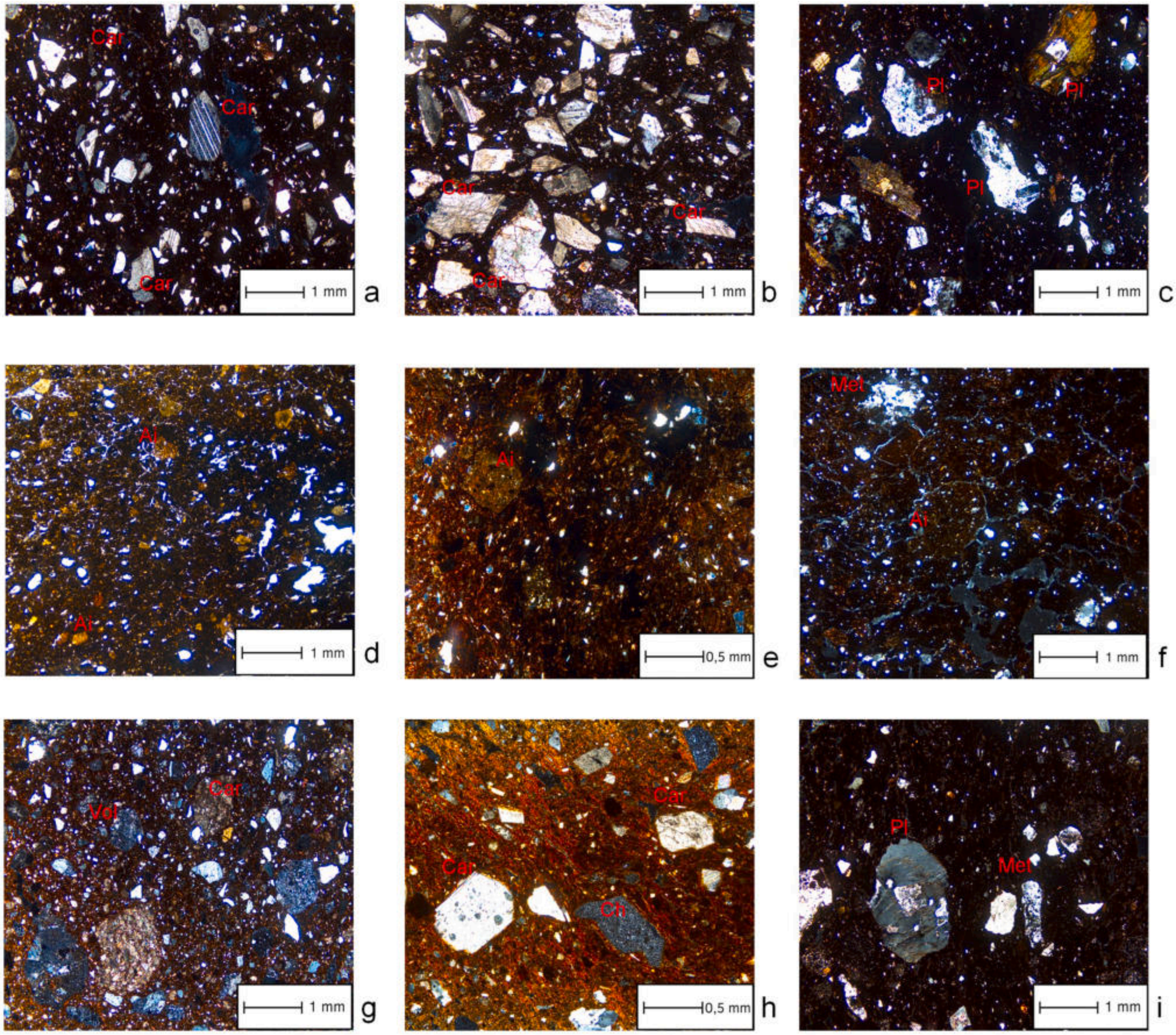

Fig. 6. Thin section photomicrographs of selected samples representative of the different fabrics and outliers identified at Riparo Gaban. Fabric RGB – 1 (Carbonate fabric), variant A, sample RGBC08, XPL (a); Fabric RGB – 1 (Carbonate fabric), variant B, sample RGBC02, XPL (b); Fabric RGB – 2 (Plutonic fabric), sample RGBC04, XPL (c); Fabric RGB – 3 (Argillaceous inclusions fabric), variant A, sample RGBC06, PPL (d); Fabric RGB – 3 (Argillaceous inclusions fabric), variant A, sample RGBC13, XPL (e); Fabric 3 (Argillaceous inclusions fabric), variant B, sample RGBC10 (f); Outlier RGB – 4 (Carbonate and volcanic fabric), sample RGBC07, XPL (g); Outlier RGB – 5 (Carbonate and chert fabric), sample RGBC11, XPL (h); Outlier RGB – 6 (Volcanic fabric), sample RGBC12, XPL (i). Abbreviations: Car: carbonate inclusions; Pl: plutonic rocks; Ai: argillaceous inclusions; Vol: volcanic rocks; Met: metamorphic rocks; Ch: chert.

framework. However, the widespread distribution of Quaternary deposits throughout the valley makes it extremely challenging to determine the exact area where the raw materials were acquired. Therefore, it cannot be ruled out that some of the identified fabrics were imported from other sites present in the Adige Valley. Regardless of the presence of possible imports, the dataset enables us to discuss, for the first time, important aspects of ceramic technology at the sites of Riparo Gaban and La Vela. The Neolithic stratigraphic sequences of the two sites allow us to consider the pottery production in the area diachronically from the early to the middle Neolithic (SMP II phase).

A significant technological change can be detected between the early Neolithic – A and the early Neolithic – B of Riparo Gaban, marked by the disappearance of the fabric characterised by the organic-rich clay bearing argillaceous inclusions. This was replaced by an increased use of mineral tempers. The change detected in the paste preparation appears to correspond with a stylistic change in the decoration of the vessels and with a shift in the economy of the site (from hunting to animal farming) (Bagolini and Biagi, 1977; Bagolini, 1980b; Pedrotti, 1998, 2001, 2009; Angelucci et al., 2009). This supports the idea of two distinct phases of the Gaban material culture, as previously suggested by Bagolini and Biagi (1977). Macroscopic analysis suggests that the *Argillaceous inclusions fabric* is mainly associated with pottery bearing impressed decoration. The disappearance of this type of decoration at the site seems to correspond with the disappearance of the aforementioned fabric. However, there is no complete gap between the two phases, as a continuity in the use of carbonate material as temper can be identified. At this stage, we cannot rule out the possibility that the identified continuity is linked to an environmental factor, such as the widespread presence of carbonate rocks in the region. Nevertheless, the typological study also identified continuity in pottery style (Pedrotti, 2001), which

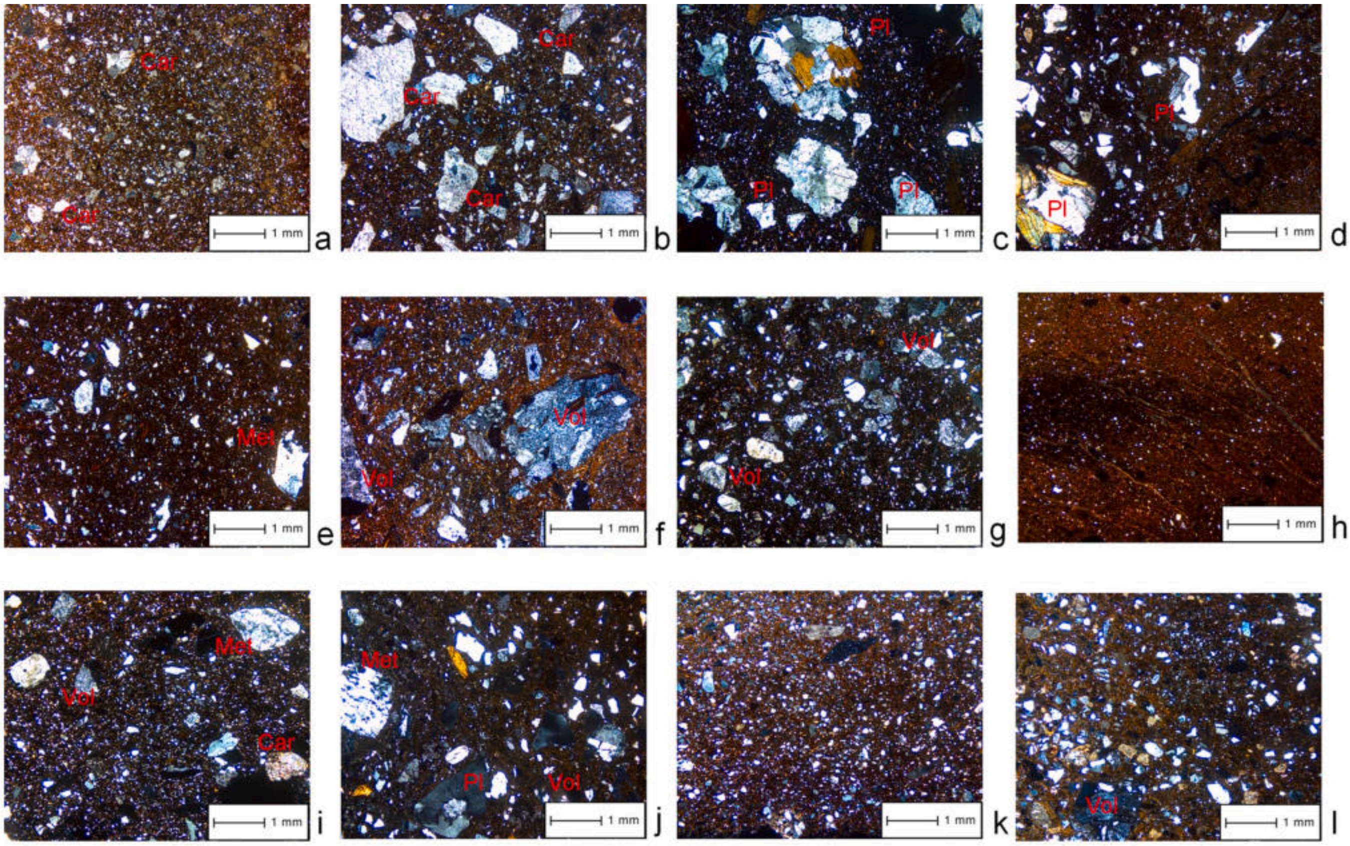

Fig. 7. Thin section photomicrographs of selected samples representative of the different fabrics identified at La Vela. Fabric LV – 1 (Carbonate fabric), variant A, sample LVC01, XPL (a); Fabric LV – 1 (Carbonate fabric), variant B, sample LVC13, XPL (b); Fabric LV – 2 (Plutonic fabric), variant A, sample LVC17, XPL (c); Fabric LV – 2 (Plutonic fabric), variant B, sample LVC14, XPL (d); Fabric LV – 3 (Metamorphic fabric), sample LVC05, XPL (e); Fabric LV – 4 (Volcanic fabric), variant A, sample LVC21, XPL (f); Fabric LV – 4 (Volcanic fabric), variant B, sample LVC03, XPL (g); Outlier LV – 5 (Depurated fabric), sample LVC25, XPL (h); Fabric LV – 6 (Polymictic fabric), variant A, sample LVC26, XPL (i); Fabric LV – 6 (Polymictic fabric), variant B, sample LVC28, XPL (j); Outlier LV – 7 (Polycristalline quartz and muscovite fabric), sample LVC06, XPL (k); Outlier 8 (Sand fabric), sample LVC22, XPL (l). Abbreviations: Car: carbonate inclusions; Pl: plutonic rocks; Met: metamorphic rocks; Vol: volcanic rocks.

suggests a continuous change (Roux and Courty, 2013) between the Early Neolithic – A and Early Neolithic – B of Riparo Gaban.

While the cause of the identified technological shift remains uncertain, we can propose some ideas. The technological change may be linked to the appearance of stylistic features related to the SMP culture in the Adige Valley. Indeed, from the early Neolithic – B onwards, elements that can be interpreted as influences from this material culture can be found at the site, and more generally in the Adige Valley (Pedrotti, 2001; Mottes, 2021). Moreover, macroscopic analyses of pottery from other areas of northern Italy have revealed that the SMP material culture is characterised exclusively by pottery containing mineral inclusions (e.g., Dal Santo and Mazzieri, 2014; Tinè et al., 2015). It is also possible that the shift in raw material choices and paste preparation reflects changes in how human groups interacted with their environment. In the early Neolithic – B, changes in the economy have been observed. Ethnographic studies indicate that the procurement of raw materials for pottery production is often linked to other daily activities (Gosselain, 2008; Michelaki et al., 2015). Therefore, the new economy, more breeding-oriented, may have prompted the Neolithic groups to explore new areas and to acquire new raw materials for ceramic production. Additionally, this economic shift may have influenced the lifestyle of the communities, affecting learning networks related to pottery production. Furthermore, the limited amount of pottery found in phase D5-D0 also suggests a potential shift in the patterns of site occupation. We cannot rule out the possibility that all of these different hypotheses are simultaneously valid and connected.

Based on radiocarbon dating (Bagolini and Biagi, 1990; Pedrotti, 2001; Kapper et al., 2014), the early Neolithic – B layers of Riparo Gaban were active simultaneously with the early Neolithic layers of La Vela – VII. Through petrographic analyses, a match was found in the ceramic pastes identified at both sites: there is a correspondence in the use of carbonate rocks (*Fabric RGB – 1* and *Fabric LV – 1, variant B)* and plutonic rocks (*Fabric RGB – 2* and *Fabric LV – 2)* as tempers.

The use of carbonate materials can be related to the geographic proximity of the outcrops to the sites or to technological or functional reasons (Hoard et al., 1995; Eramo, 2020). Concerning the plutonic rocks, there are many possible reasons for using them as tempers. Firstly, the use of plutonic rocks can be linked to the exploitation of the Quaternary deposits, particularly the fluvio-glacial ones, which are widespread around the sites. Therefore, procuring these types of rock may have been easy for the Neolithic groups. Moreover, these rocks can be easily broken when heated (Maggetti, 2009), and they are known to improve the physical properties of the vessels (Quinn, 2022). Furthermore, aesthetic purposes cannot be ruled out as a possible reason for the addition of plutonic rocks. The surfaces of fabrics containing plutonic rocks exhibit large biotite inclusions, giving the vessel a shining appearance.

The procurement of raw materials from Quaternary deposits appears to be present at both sites, from a late phase of the early Neolithic onwards. The exploitation of glacial deposits for ceramic raw materials was common in the Alpine area during Prehistory, as shown by examples in Switzerland (Maggetti, 2009; Stapfer et al., 2019; Carloni et al., 2021). These deposits are rich in sediments of varying grain size and composition, potentially providing Neolithic communities with a wide range of options to choose from when selecting the most appropriate raw materials for ceramic production. It appears that the human groups in the Adige valley were able to identify suitable clay outcrops and to exploit the diversity of geological resources offered by the territory.

The similarity in technological choices between the two sites during the late early Neolithic period could suggest that they were part of the same community of practice (Lave and Wenger 1991; Wenger 1998), exploiting the same raw materials on opposite sides of the Adige Valley. The proximity of the two sites may have prompted the sharing of knowledge regarding pottery making. However, due to the limited number of samples analysed, we are currently not able to provide more information about the relationship that exists between the people who frequented the two sites. Further studies focusing on a higher amount of pottery sherds and on other aspects of the material culture will provide additional insights into this relationship.

The petrographic results of the middle Neolithic (SMP II) layers of La Vela indicate a continuity in the use of carbonate and plutonic rocks as tempering agents and in the exploitation of Quaternary deposits between the early and middle Neolithic, suggesting a similarity in the choice of raw materials and a continuity in ceramic production traditions. However, a new way of treating carbonate inclusions appears in the middle Neolithic – phase SMP II. Macroscopic observations allowed a correlation of the presence of very fine carbonate tempers with a specific sequence of firing, probably oxidising followed by a reducing cooling phase (Fig. 5C). Indeed, a high percentage of sherds, that can be macroscopically linked to Fabric 1A, show dark and smoothed surfaces. The macroscopic paste is frequently associated with vessels with a squared mouth and typical SMP decorations. Previous macroscopic studies on SMP pottery from the north of Italy highlighted the presence of very fine calcite inclusions, coupled with firing in reducing conditions, starting from the SMP I (Dal Santo and Mazzieri, 2014). In order to gain a better understanding of the timing and meaning of this technological change in the Adige Valley, it will be necessary to analyse nearby SMP I and SMP II contexts. Indeed, the lack of other technological studies on pottery from the region prevents us from offering broader cultural interpretations.

7. Conclusions

Our study applies a technological approach to the analysis of early and middle Neolithic ceramic samples retrieved from two key-sites of the Adige Valley, Riparo Gaban and La Vela. It demonstrates the potential of petrographic analyses, a new approach in the study of Neolithic pottery from the Adige Valley, to yield new insights into the technological behaviour of prehistoric communities.

The diversity and complexity of the geology of the region are well reflected in the choices of raw materials used to produce pottery. The ceramic production of both sites can be located within the framework of the Adige Valley. Overall, it can be observed that Neolithic human groups of the Adige Valley showed an ability to successfully exploit a diverse range of raw materials, taking advantage of the geological heterogeneity of the region.

In addition, the results show continuities and changes between the early and middle Neolithic. A significant technological change has been detected in the choice of raw materials and paste preparation between the two frequentation phases of Riparo Gaban (early Neolithic – A and early Neolithic – B), which have been traditionally identified through a stylistic approach. The change can probably be linked to the appearance of SMP stylistic elements, to a new way to exploit the resources available in the territory, and to a possible change in pottery production learning networks. The greatest change occurs at this stage, while the choice of raw materials appears to have remained stable between the early Neolithic – B of Riparo Gaban, and the early and middle Neolithic layers of La Vela. Nevertheless, the introduction of a new method for treating carbonate inclusions has been identified at La Vela site, which appears to be characteristic of the Square Mouthed Pottery phase. Additionally, the comparison between Riparo Gaban (early Neolithic – B) and the early Neolithic layers of La Vela revealed correspondence in some of the ceramic pastes, suggesting the belonging of both sites to the same community of practice.

As this is the first technological study of pottery from the region, it provides valuable insights into the technological choices of the Neolithic communities in the Adige Valley. However, it is currently not possible to compare our findings with other sites in the region, which would provide a more complete picture of pottery production, resource exploitation, and exchange networks. Further studies of early and middle Neolithic sites in the Adige Valley could reveal potential exchanges between sites and offer a deeper understanding of the pottery production within the context of the Gaban and the SMP material cultures. The comparison of these data with those from other Neolithic sites in the region and northern Italy will help to acquire a broader knowledge regarding the dynamics of human occupation of the Adige Valley and the entire North of Italy.

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CRediT authorship contribution statement

Giulia Deimichei: Conceptualization, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Silvia Amicone:** Conceptualization, Methodology, Resources, Writing – review & editing, Supervision. **Jacopo Armellini:** Investigation (raw materials prospection), Visualization, Writing – review & editing. **Annaluisa Pedrotti:** Conceptualization, Resources, Funding acquisition, Writing – review & editing, Supervision, Project Administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.

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Data availability

The data that supports the findings of this study are available in the supplementary material of this article.

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