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ORIGINAL ARTICLE

Euganean trachytic grinding stones in the Caput Adriae from the Iron Age to the Roman period: Reassessment of the Protohistoric quarries

Federico Bernardini[1,2] | **Matteo Velicogna**[3] | **Angelo De Min**[4] | **Fabrizio Antonelli**[5] | **Giovanna Gambacurta**[1] | **Daniele Bressan**[4] | **Tomaz Fabec**[6]

[1]Dipartimento di Studi Umanistici, Università Cà Foscari Venezia, Venice, Italy

[2]Multidisciplinary Laboratory, The Abdus Salam International Centre for Theoretical Physics, Trieste, Italy

[3]Department of Land, Environment, Agriculture and Forestry, University of Padua, Legnaro, Italy

[4]Department of Mathematics and Geosciences, University of Trieste, Trieste, Italy

[5]LAMA—Laboratory for Analysing Materials of Ancient origin, University Iuav of Venice, Venice, Italy

[6]Centre for Preventive Archaeology, Institute for the Protection of Cultural Heritage of Slovenia, Ljubljana, Slovenia

Correspondence

Federico Bernardini, Multidisciplinary Laboratory, The Abdus Salam International Centre for Theoretical Physics, Strada Costiera 11, I-34151 Trieste. Italy.
Email: fbernard@ictp.it and federico.bernardini@unive.it

Abstract

A group of Euganean trachytic grinding stones from Slovenia and the available data about the same type of artefacts in the whole Caput Adriae are presented. The occurrence of Iron Age saddle querns in Karst and Istria is confirmed, but our study suggests a likely provenance from Mts Cero/Murale instead of Mts Altore/Rocca Pendice, as previously suggested. Este, an important Venetic centre, is just south of Mts Cero/Murale, suggesting its central role in the production and distribution of saddle querns. During the Roman period Euganean trachytes are still used for rotary millstones, but new quarries (Mt Rosso), relatively close to ancient Padua, are exploited. Such shift in the position of millstone quarries most probably reflects the changed geopolitical framework.

KEYWORDS

Caput Adriae, Euganean trachyte, grinding stones, Iron Age–Roman period, Protohistoric quarries

INTRODUCTION AND ARCHAEOLOGICAL BACKGROUND

Euganean trachyte can be considered the most important volcanic raw material used in northern Italy and neighbouring areas to produce grinding stones in both the Protohistoric and Roman periods (Antonelli et al., 2004; Antonelli & Lazzarini, 2012; Cattani et al., 1997; Crivellari, 1998; Zara, 2018).

The characterization and provenance of Protohistoric and Roman volcanic millstones from Caput Adriae (north-eastern Italy, western Slovenia and north-western Croatia) have been discussed in two contributions dedicated to selected samples from Aquileia (Antonelli & Lazzarini, 2012), the most important Roman city of the region, and to Iron Age and Roman grinding stones discovered in pre-Roman hillforts of Istria and Trieste Karst (Antonelli et al., 2004). Data about volcanic grinding stones from other Protohistoric and Roman archaeological sites located in the Slovenian Karst are a few (e.g., Horvat & Župančič, 1987) or not available. The review of the published data about the Euganean trachytic grinding stones from Caput Adriae, integrated with fresh evidence mainly from the Slovenian Karst (Figure 1a) (Fabec & Žerjal, 2013), is presented here in order to detail their distribution and, when possible, the raw material exploitation areas. This effort has also taken advantage of a new geochemical dataset of the Euganean Hills (Germinario, Hanchar, et al., 2018) in addition to that published by Capedri et al. (2000).

The Karst plateau and the Istrian peninsula on the north-eastern shore of the Adriatic Sea are marked by the presence of hundreds of Protohistoric settlements, generally located on hilltops. These sites, protected by dry-stone walls, locally called *castellieri*, *gradine* or *gradišča*, featured clear originality and cultural unity in pottery production, architectural models, defensive systems and funerary practices. They were settled for a very long time, spanning from the late Early Bronze Age, approximately between 1800 and 1650 BCE, to the advanced Iron Age (Borgna et al., 2018; Mihovilić, 2013; Teržan, 2021). The formation and rising of *castellieri* chronologically corresponds to the Early Bronze Age II in the Italian relative chronological system (Cardarelli, 2009) and to BZ A2 in the Central Europe Reinecke's system (Hänsel, 2009).

All the grinding stones known from Bronze Age hillforts are part of saddle querns made from sedimentary rocks. In general, Bronze Age saddle querns from hillforts of the Trieste area are made from local sandstones belonging to the Flysch succession (Bernardini, 2002) outcropping both north and south of the Karst anticline (Lenaz, 2000). Approximately during the same period, quartz arenitic sandstones collected from gravel deposits of the Isonzo River were used by the inhabitants of Karst hillforts for the production of whetstones (Bernardini, De Min, et al., 2015).

During the Iron Age, the large occurrence of saddle querns made from Euganean trachytes in many hillforts of Caput Adriae, from the Karst to central Istria, testifies to long-distance connections with the centre of Venetic cultural area in a period comprised mainly between the sixth and fifth centuries BCE (Antonelli et al., 2004; Bernardini, 2002, 2005a, 2005b). These cultural connections are confirmed by other traded or exchanged objects probably produced within the same Venetic territory and found in Karst and Istria too, such as, for example, fragments of red fired ceramic pedestal *situlae* with cordons and bands of black paint (Antonelli, 2004; Bernardini, 2002, 2005a, 2005b; Teržan & Turk, 2021), a typical Venetic pottery product (Capuis, 1993; Fogolari & Prosdocimi, 1988; Gambacurta, 2007; Peroni et al., 1975; Vitri, 2017). Saddle querns of the same type have been also found at various sites in Emilia and Veneto (Cattani et al., 1997; Crivellari, 1998). From the sixth century BCE onwards, millstones made from the Etnean volcanites (trachybasalts and basaltic trachyandesites) reached for the first time Puglia and neighbouring areas of southern Italy (Lorenzoni et al., 2000a, 2000b). Among the Protohistoric grinding stones from Caput Adriae, a few fragmented artefacts made from the same raw materials probably reflect the Magno-Greek, and in particular Syracusan, influence in the Adriatic region (Antonelli et al., 2004; Bernardini, 2005b) and culminated with the foundation of several colonies during the fourth century BCE (Braccesi, 1977).

After a first conflict between Rome and the inhabitants of the Istrian peninsula during the late third century BCE, Aquileia was founded in 181 BCE and the area entered under direct Roman influence in the first half of the second century BCE (Bandelli, 2004; Bernardini et al., 2013, 2021; Bernardini & Duiz, 2021; Bernardini, Vinci, et al., 2015). During the Roman period, Euganean trachytic rotary millstones and building material testify to the activation of new commercial routes and the exploitation of previously unexploited quarries (Antonelli et al., 2004; Antonelli & Lazzarini, 2010; Germinario, Hanchar, et al., 2018; Germinario, Zara, et al., 2018; Paltineri et al., 2020; Renzulli et al., 1999; Zara, 2018). Grinding stones of Imperial age from Aquileia (Antonelli & Lazzarini, 2012) indicate the presence in the territory of volcanic raw materials from multiple sources in addition to Euganean trachytes: leucite phonolite lavas from the Vulsini Volcanic District (Santi et al., 2004), trachybasalts and basaltic trachyandesites from Etna—already reported during late Protohistory—and Pantelleria basalts (Antonelli & Lazzarini, 2012).

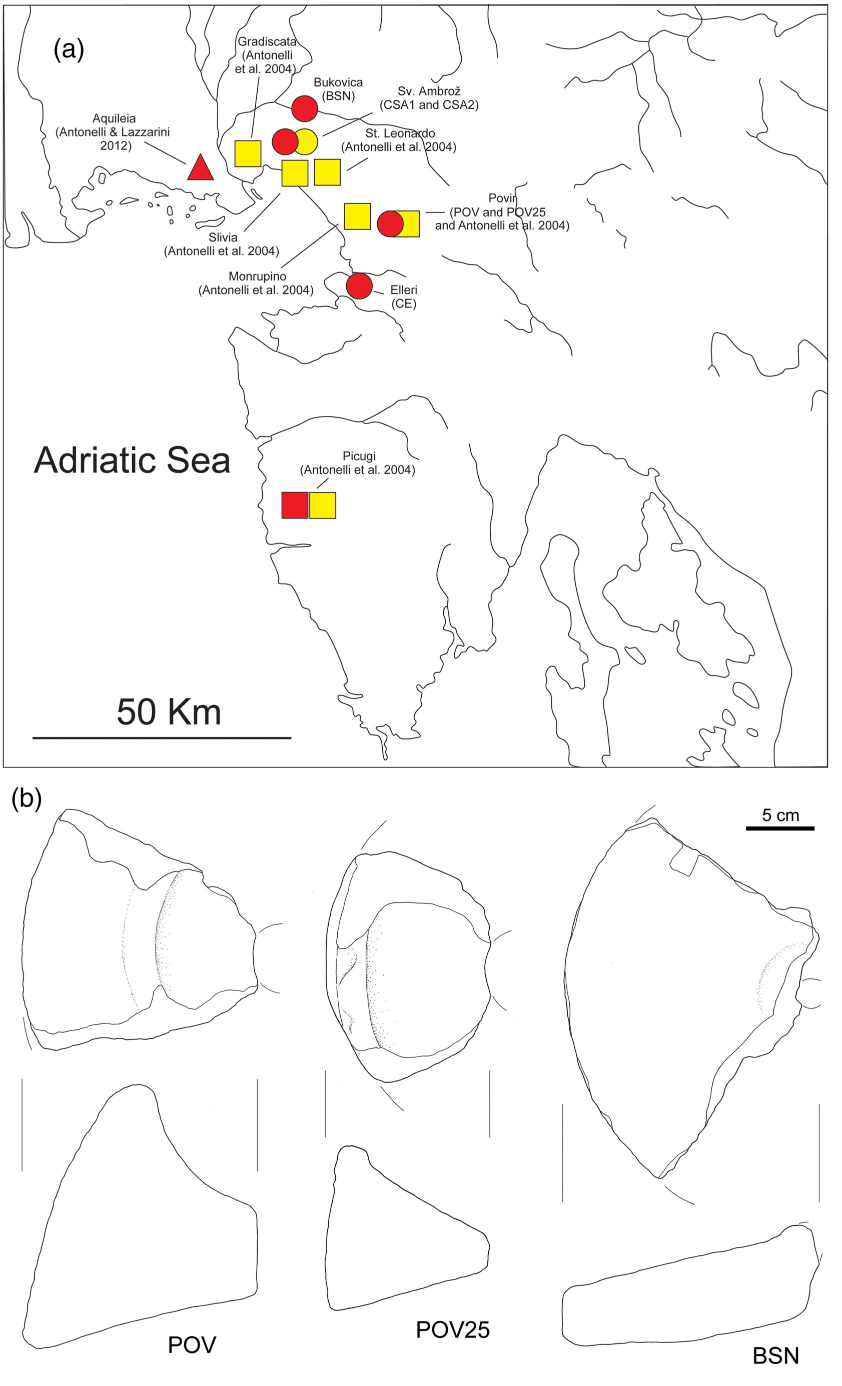

FIGURE 1 (a) Distribution of Protohistoric (yellow symbols) and Roman (red symbols) grinding stones made from Euganean trachyte in Caput Adriae. Squares correspond to literature data from Antonelli et al. (2004); triangles to literature data from Antonelli and Lazzarini (2012); and circles to newly analysed samples. (b) Fragmented upper (POV and POV25) and lower (BSN) stones of some of the investigated Roman rotary millstones. Drawings: Teja Gerbec.

MATERIALS AND METHODS

Six unpublished fragmented grinding stones have been analysed and compared with equivalent artefacts from the same region already described in the literature. Petrographic and geochemical features of about 30 Protohistoric and Roman grinding stones from Caput Adriae were then studied and compared with data available for the Euganean Hills (Capedri et al., 2000; Germinario, Hanchar, et al., 2018). Among the new samples, CSA2 is part of a Protohistoric saddle quern (Table 1). Five of them are part of small Roman rotary millstones (Table 1), but only three (corresponding to two upper stones and a lower stone) are big enough to reconstruct their original shape (Figure 1b). According to their typology, the millstones from Povir (POV and POV25), characterized by a considerable height (from about 15 to 25 cm) and a markedly oblique grinding surface, most probably date to the late Republican period. It is worth mentioning that some unpublished first century BCE militaria, such as shoe hobnails of Alesia type D (Bernardini et al., 2021, *passim*), are reported from Povir hillfort (Laharnar, personal communication). The larger and flatter lower stone from Bukovica dates to the Imperial period (Fabec & Žerjal, 2013).

TABLE 1 Resuming table of the finding site, chronology and typology of both the grinding stones investigated here and already described in the literature

Sample	Site	Chronology	Typology	Literature
CSA2	Sv. Ambrož (Slovenia)	Protohistoric	Saddle quern	Present study
CSA1	Sv. Ambrož (Slovenia)	Roman	Rotary quern	Present study
POV	Povir (Slovenia)	Roman	Rotary quern	Present study
POV25	Povir (Slovenia)	Roman	Rotary quern	Present study
BSN	Bukovica (Slovenia)	Roman	Rotary quern	Present study
CE	Elleri/Jelarji (Italy/Slovenia)	Roman	Rotary quern	Present study
CS1	Slivia (Italy)	Protohistoric	Saddle quern	Antonelli et al. (2004)
CS2	Slivia (Italy)	Protohistoric	Saddle quern	Antonelli et al. (2004)
CS3	Slivia (Italy)	Protohistoric	Saddle quern	Antonelli et al. (2004)
CS4	Slivia (Italy)	Protohistoric	Saddle quern	Antonelli et al. (2004)
CS7	Slivia (Italy)	Protohistoric	Undetermined	Antonelli et al. (2004)
CS8	Slivia (Italy)	Protohistoric	Undetermined	Antonelli et al. (2004)
CG1	Gradiscata (Italy)	Protohistoric	Saddle quern	Antonelli et al. (2004)
CG3	Gradiscata (Italy)	Protohistoric	Saddle quern	Antonelli et al. (2004)
CSL1	S. Leonardo (Italy)	Protohistoric	Saddle quern	Antonelli et al. (2004)
CSL3	S. Leonardo (Italy)	Protohistoric	Saddle quern	Antonelli et al. (2004)
CSL5	S. Leonardo (Italy)	Protohistoric	Undetermined	Antonelli et al. (2004)
CPO1	Povir (Slovenia)	Protohistoric	Saddle quern	Antonelli et al. (2004)
CM1	Monrupino (Italy)	Protohistoric	Saddle quern	Antonelli et al. (2004)
CP1	Picugi (Croatia)	Protohistoric	Saddle quern	Antonelli et al. (2004)
CP3	Picugi (Croatia)	Protohistoric	Saddle quern	Antonelli et al. (2004)
CP5	Picugi (Croatia)	Roman	Rotary quern	Antonelli et al. (2004)
CP6	Picugi (Croatia)	Roman	Rotary quern	Antonelli et al. (2004)
CP7	Picugi (Croatia)	Roman	Rotary quern	Antonelli et al. (2004)
AQ3	Aquileia (Italy)	Roman	Rotary quern	Antonelli and Lazzarini (2012)
AQ5	Aquileia (Italy)	Roman	Rotary quern	Antonelli and Lazzarini (2012)

Microscopic observations

All the samples were carefully observed under a stereomicroscope and chemically analysed. Since the main focus of the study is the reassessment of the Protohistoric exploitation areas, the thin sections of the 15 Protohistoric artefacts published by Antonelli et al. (2004) were reconsidered on the basis of the new petrographic criteria proposed by Germinario, Hanchar, et al. (2018). Antonelli et al. (2004) already provided a detailed description of the Euganean tools presented in their research, but they published the microphotographs of a single Protohistoric artefact and the petrographic criteria proposed by Germinario, Hanchar, et al. (2018) were not available.

An additional thin section of the Protohistoric sample (CSA2), published here for the first time, was produced and studied. All the thin sections were observed using a polarizing microscope at the Department of Mathematics and Geosciences, Trieste University, in order to define their mineralogical and petrographic features.

Geochemistry

Major and trace elements compositions of all samples (BSN, CSA1–2, POV, POV25 and CE) were carried out by inductively coupled plasma emission and mass spectrometry (ICP-ES and ICP-MS), respectively, at Acme Analytical Laboratories Ltd, Vancouver, Canada (Table 2). The analytical uncertainties are estimated to be between 5% and 10% (Govindaraju & Mevelle, 1987). The samples (about 20 g for each artefact) were previously powdered using an agate mill at a 150-mesh fraction in the laboratory of Department of Mathematics and Geosciences, Trieste University. Major elements and some minor ones were analysed following a Li borate fusion and a dilute acid digestion of 0.2 g samples pulp. Rare earth and refractory elements were analysed following a Li borate fusion. Additionally, a fraction of 0.5 g was removed for digestion in aqua regia (heated to 95°C) and analysed for base metals and precious metals. The loss on ignition was determined by measuring the weight lost during heating at 1000°C over a 3-h period.

Geochemical comparison with Euganean rocks

Geochemical features of the grinding stones from Caput Adriae were then compared with the two geochemical datasets available for the Euganean Hills. They include the X-ray fluorescence (XRF) data published by Capedri et al. (2000), used in previous studies on grinding stones from Caput Adriae, and those recently published by Germinario, Hanchar, et al. (2018). The last authors, following Maritan et al. (2013), suggest that some discrepancies between the concentrations of some elements (e.g., Ti, Th, Sr and Zr) could be related to the preparation of the pellets for XRF analysis by Capedri et al. (2000). According to these authors, the grain size of the powder was probably not fine enough (Germinario, Hanchar, et al., 2018: 18–19). To show such a mismatch, Germinario et al. (2018, Figure 12) modified the Sr versus Th scatterplot, the main discriminant diagram by Capedri et al. (2000), also including their new XRF geochemical data. However, the compositional mismatch showed by Zr (up to about 200 ppm) and Sr (up to about 250 ppm) seems too high to have been caused by a wrong sample preparation. This is even more unlikely in the case of Sr, which is not much affected by matrix effects. As Sr is a large ion lithophile element (LILE), its concentration can be quite variable, even within the same quarry locality. In addition, the new chemical data generally show a lower Th concentration for many localities, but this does not apply to all of them, such as the Zovon area, Rocca Pendice, Mt Rusta. Alternative or concurrent hypotheses, such as compositional heterogeneities within the same quarry areas, cannot therefore be definitely ruled out. For these reasons, we have decided to use both datasets as a comparison for the investigated grinding stones.

TABLE 2 Major and trace elements' composition of the investigated samples

	CSA2	POV	POV 25	CSA1	BSN	CE
SiO_2 (wt%)	64.94	62.68	63.26	64.00	64.21	63.62
TiO_2	0.67	1.04	0.75	1.06	1.02	1.07
Al_2O_3	17.58	17.14	19.49	16.40	16.37	16.36
Fe_2O_3	3.12	5.16	2.86	4.70	4.82	4.87
MgO	0.56	1.41	1.30	1.18	1.06	1.38
MnO	0.05	0.05	0.03	0.06	0.06	0.07
CaO	1.39	2.93	3.36	2.81	2.88	3.37
Na_2O	5.60	4.48	3.82	4.35	4.42	4.34
K_2O	5.68	4.69	4.74	4.99	4.74	4.39
P_2O_5	0.33	0.42	0.39	0.45	0.42	0.53
Ni (ppm)	< 20.00	< 20.00	< 20.00	< 20.00	< 20.00	< 20.00
V	17.00	64.00	73.00	56.00	63.00	58.00
Cr	–	–	34.15	–	–	8.53
Rb	115.10	112.60	230.20	124.80	127.90	119.40
Ba	701.00	812.00	1017.00	729.00	715.00	668.00
Th	15.40	14.90	35.50	14.40	13.20	14.20
U	4.30	4.20	12.90	4.10	4.00	3.90
Pb	25.00	5.20	5.10	12.40	4.70	7.50
Sr	243.40	453.80	384.70	424.00	470.90	438.50
Nb	86.80	57.50	31.60	63.30	60.90	58.20
Ta	5.30	3.50	2.40	4.10	3.60	3.70
Zr	732.30	428.60	326.40	459.10	452.80	410.10
Hf	15.20	9.90	8.70	9.70	9.70	9.50
Y	23.80	27.00	23.20	27.00	27.30	26.70
La	106.60	59.70	38.20	60.80	59.70	54.40
Ce	111.20	105.90	72.80	106.10	105.90	105.60
Pr	18.87	11.88	8.74	11.8	12.18	11.97
Nd	62.60	46.40	31.60	43.4	46.60	43.00
Sm	9.73	8.12	5.76	7.9	8.39	8.33
Eu	2.60	2.20	1.15	2.14	2.19	2.30
Gd	7.30	7.16	4.86	7.03	7.33	6.96
Tb	1.02	1.03	0.76	0.99	1.03	1.02
Dy	4.80	5.21	4.18	4.77	5.42	5.46
Ho	0.85	0.99	0.83	0.96	0.97	0.97
Er	2.43	2.70	2.52	2.49	2.85	2.52
Tm	0.34	0.36	0.37	0.37	0.39	0.38
Yb	2.02	2.37	2.56	2.36	2.31	2.26
Lu	0.28	0.34	0.36	0.33	0.36	0.34

Major elements are expressed as anhydrous analyses in wt%, while the trace elements are expressed in ppm.

RESULTS AND DISCUSSION

The Roman artefacts are grey-greenish in colour, while the Protohistoric ones are characterized by a reddish-brown surface. They show macroscopic aspect and minero-petrographic features typically coherent with those of the classical Euganean trachyte lavas.

Optical description of Protohistoric samples and comparison with the Euganean Hills

All the Protohistoric trachytic grinding tools analysed by Antonelli et al. (2004) share similar petrographic features and a hiatal grain-size distribution (Figure 2). They are fine-grained (with phenocrysts generally no larger than 5–8 mm^2), grey-brown to brown-reddish, mildly vesiculated and little porphyritic (porphyritic index (PI) = 5–20, usually 6–10; where PI is defined as the area of phenocrysts and macro-phenocrysts, if present, over the total area of the thin section × 100) with phenocrysts of

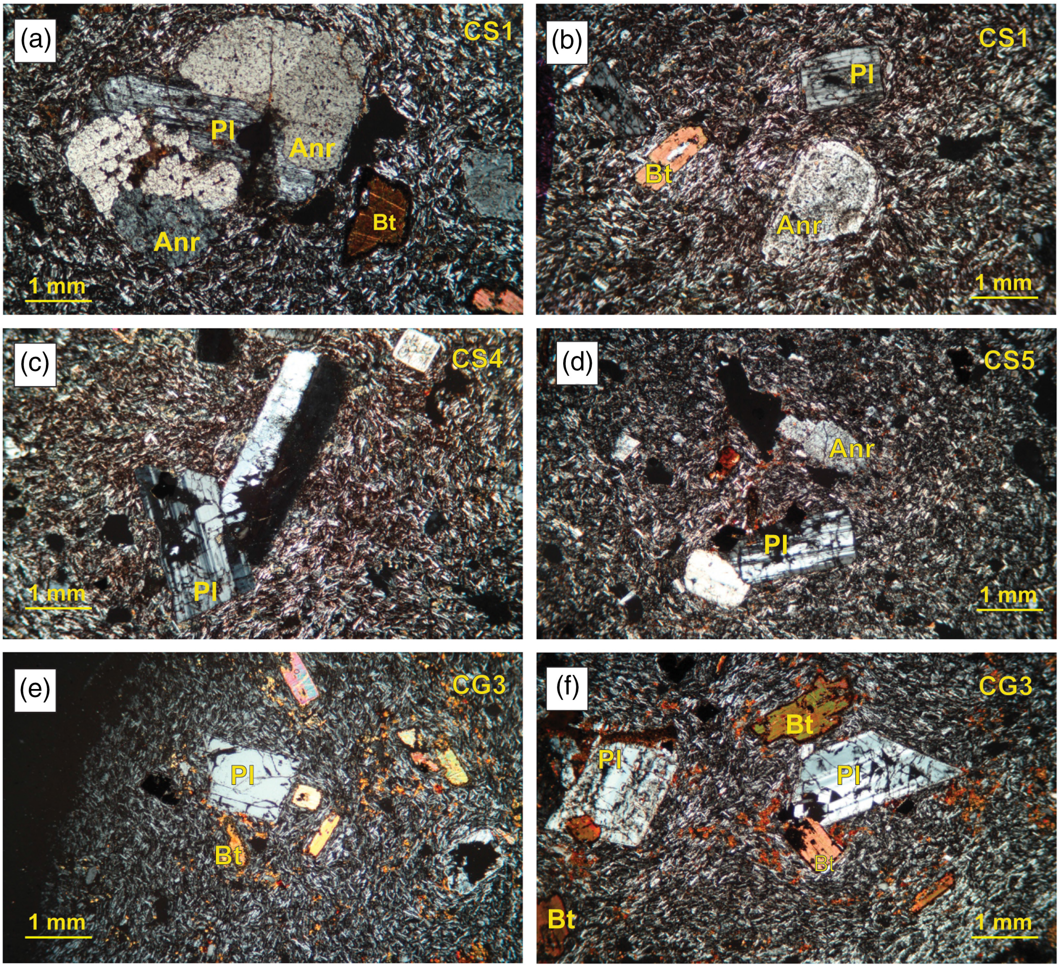

FIGURE 2 Thin-section photomicrographs (crossed polarized light) of selected Protohistoric grinding stones from Caput Adriae. They show anorthoclase (Anr), plagioclase (Pl) and biotite (Bt) phenocrysts in a microcrystalline(-trachytic) groundmass mainly composed by microlites of sanidine–plagioclase–opaques.

euhedral plagioclase, anhedral to subhedral anorthoclase and biotite. Zircon and apatite appear as accessories and generally can be mainly found in biotite and plagioclase phenocrysts. The matrix is composed of microlites of sanidine–plagioclase–opaques ± interstitial quartz that show subparallel dominant crystallization direction in a minute interstitial brownish glass (in order of decreasing abundance), suggesting a trachytic or a hyalopilitic matrix. In most of the samples the amount of anorthoclase crystals is generally similar to the plagioclase one (anorthoclase/plagioclase ratio generally approaches 1, rarely it higher).

Sample CSA2, here presented for the first time, is a mildly vesiculated and porphyritic (PI = 10) trachyte with phenocrysts of anorthoclase, biotite and zoned plagioclase (optically labradorite–oligoclase), often surrounded by a rim of anorthoclase, besides zircon and apatite as accessories. The groundmass is mainly trachytic to hyalopilitic and mainly composed by microlites of anorthoclase–sanidine–plagioclase, scarce biotite and very rare interstitial quartz.

The low values of PI in the Protohistoric grinding stones (PI = 5–20, usually 6–10) can be compared only with the trachytic rocks from Mt Cero, Mt Murale and Mt Trevisan, together with some samples from Mt Oliveto and Mt Alto, which show the lowest values in the whole magmatic complex (Germinario, Hanchar, et al., 2018). Fine-grained trachytes, such as the raw material of the grinding stones, are known from Mt Murale, Mt Cero, San Daniele, Mt Oliveto and Mt Alto (Germinario, Hanchar, et al., 2018). Finally, the hiatal grain-size distribution and the anorthoclase/plagioclase ratio of most of the samples fit well the features reported for Mt Cero and Mt Murale (Germinario, Hanchar, et al., 2018).

Chemical characterization

Results of the geochemical analyses are summarized in Table 2. In the total alkali silica (TAS) (Le Bas et al., 1992; Le Maitre et al., 1989) classification diagram and in the bivariate K_2O versus Na_2O plot (Figure 3a,b) the new trachytic grinding stones here studied are considered together with all those known from Caput Adriae (Antonelli et al., 2004; Antonelli & Lazzarini, 2012).

All the samples plot in two separate fields where chemical differences well correspond to different chronology and general typology (i.e. Protohistoric saddle querns versus Roman rotary millstones). Most Protohistoric samples are clustered and show an alkali content higher than the Roman artefacts for comparable silica values. In facts, the Roman grinding stones are characterized by a more transitional behaviour plotting in correspondence of the alkaline–subalkaline border of Miyashiro (1978). Nevertheless, all the Euganean samples published here for the first time are quartz (Q) and hypersthene (Hy) normative, although the Roman ones show higher Q (11–13 versus 7) and Hy (2.61–3.43 versus 1.36) values than the Protohistoric one. It is interesting to note that most Roman artefacts fall within the field of Mt Rosso trachytes, while the Iron Age artefacts plot in an area where the fields of Mts Cero/Murale, Mt Merlo, Mt Altore and Rocca Pendice overlap.

In the K_2O versus Na_2O diagram (Figure 3b), most Protohistoric and Roman artefacts fall in two well-separated clusters, too. A few samples are an exception. They include two Protohistoric saddle querns (samples CS3–4 from Antonelli et al., 2004) that show a depletion of K_2O for comparable Na_2O values with respect to other Protohistoric samples, the Roman millstone POV25 displaying the lowest Na_2O content, and the Roman millstone AQ5 (Antonelli & Lazzarini, 2012), characterized by the lowest K_2O and highest Na_2O values of the Roman artefacts (Figure 3b). Samples CS3–4 and AQ5 have been compared with the Euganean alkaline trachyandesites (Milani et al., 1999) by Antonelli et al. (2004) and Antonelli and Lazzarini (2012), respectively. Samples CS3 and CS4 are not shown in the next diagrams since they show a peculiar chemical behaviour already discussed by Antonelli et al. (2004).

In the Zr versus V diagram (Figure 3c), sometimes used for the identification of the main sources of Italian millstone (Antonelli & Lazzarini, 2012; Williams-Thorpe, 1988), we have plotted

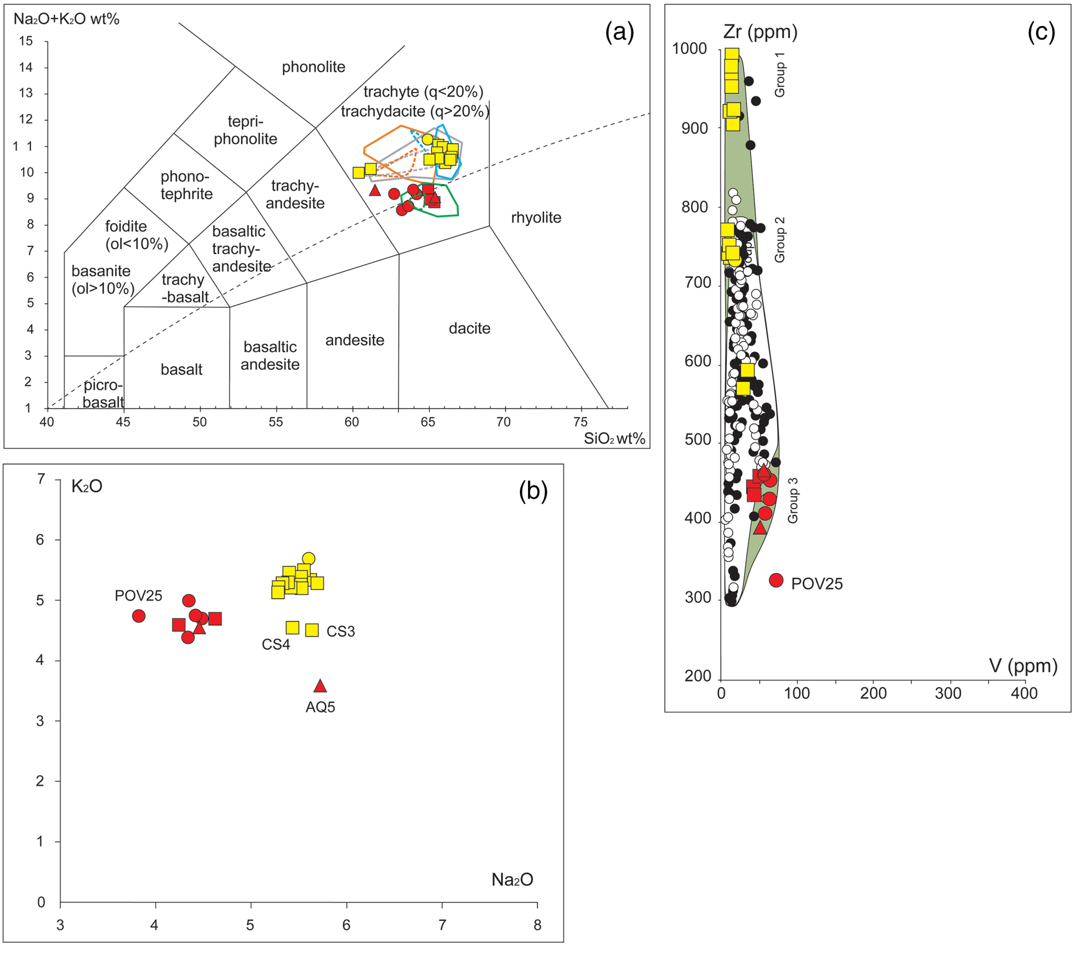

FIGURE 3 (a) Total alkali versus silica classification diagram (Le Bas et al., 1992) for the analysed samples. Fields of the possible provenance areas are plotted for comparison. Green field, Mt Rosso; orange field, Mt Merlo; grey field, Mt Cero and Mt Murale; and light blue, Mt Altore and Mt Pendice. Fields from Capedri et al. (2000) are shown within solid lines, while those from Germinario, Hanchar, et al. (2018) are within dotted lines. The dashed line divides the diagram into alkaline and subalkaline fields (Miyashiro, 1978). (b) K_2O versus Na_2O diagram of the investigated samples. (c) Zr versus V discrimination diagram (after Williams-Thorpe, 1988, modified by Antonelli & Lazzarini, 2012) for the investigated samples. The white field corresponds to the Euganean Hills according to Antonelli and Lazzarini (2012), while the green field represents the composition of the Caput Adriae grinding stones produced with the Euganean trachytes. Black and white circles correspond to all Euganean Hills samples from Capedri et al. (2000) and Germinario, Hanchar, et al. (2018), respectively. Symbols and colours as in Figure 1.

the Euganean Hills data by Capedri et al. (2000; black circles) and Germinario et al. (2018; white circles) and the field of the Euganean Hills according to Antonelli and Lazzarini (2012). The latter was drawn by using data from Capedri et al. (2000); however, a few samples very rich in Zr were not included.

The trachyte grinding stones are distributed in three separate groups, characterized by different Zr contents. More precisely, the high Zr (> 800 ppm) group 1 (Figure 3c) includes only Protohistoric samples and plots outside the Euganean field proposed by Antonelli and Lazzarini (2012). The group shows V values comparable with those suggested by Antonelli and Lazzarini (2012), but higher Zr concentration (up to about 100 ppm). Similarly, the intermediate group 2 includes only Protohistoric samples and plots at the edge of the Euganean field by Antonelli and Lazzarini (2012), while the

Roman artefacts (group 3) show the lowest Zr content and V values higher than Protohistoric grinding stones, probably reflecting a slightly different source and magmatic history (Figure 3c). Finally, the sample POV25 plots not far from the Roman ones.

In addition, it is worth stressing that there are no significant differences in the Zr and V concentrations between the whole datasets of Capedri et al. (2000) and Germinario, Hanchar, et al. (2018), with exception of the few samples of Capedri et al. (2000) with high Zr concentrations comparable to those of Group 1.

When the samples are plotted in the Sr versus Th diagram proposed by Capedri et al. (2000) for discriminating the quarries of Euganean Hills, here integrated with the data from Germinario, Hanchar, et al. (2018), Roman and Protohistoric artefacts are well clustered in (or close to) field 4 (Mt Oliveto 1, Mt Bello, Mt Cero, Mt Lonzina, Mt Lozzo, Mt Merlo, Mt Murale, Mt Rosso) and field 3 (Mt Altore and Mt Pendice) of Capedri et al. (2000), respectively (Figure 4a). Sample POV25 makes exception: it falls between the fields 1 (Monselice) and 2 (Mt Trevisan).

However, according to the new geochemical data (Germinario, Hanchar, et al., 2018), fields 3 and 4 partially overlap, leaving open the question if the Protohistoric artefacts really belong to field 3 (Mt Altore and Mt Pendice) of Capedri et al. (2000) or if they could originate from one of the other areas included within field 4. For this reason, we have modified TiO_2 versus Zr diagram (Figure 4b) proposed by Capedri et al. (2000) to detail the quarries of field 4. It is worth noting that Protohistoric samples (mainly those belonging to group 1 of Figure 3c), which should have originated from Mt Altore and Mt Pendice according to Antonelli et al. (2004) (field 3 of Figure 4a), fall in or close to areas corresponding to Mt Murale and Mt Cero based on Capedri et al. (2000) and Germinario, Hanchar, et al. (2018) datasets (field 4 of Figure 4a). Most samples of Protohistoric group 2 plot between Mt Cero plus Mt Murale and Mt Merlo, Mt Pendice and Mt Altore according to Germinario, Hanchar, et al. (2018) and close or within Mt Merlo and Mt Altore according to Capedri et al. (2000).

The Roman samples fall near the Mt Rosso area, in agreement with Sr versus Th diagram (Antonelli et al., 2004; Antonelli & Lazzarini, 2012), with the exception of POV25 and AQ5 that plot outside the diagram because of the low content of Zr and the high content in TiO_2, respectively.

To limit possible weathering effects, that could have affected LILE such as Sr, we propose a discrimination diagram based on less mobile high field strength elements (HFSE), and in particular Zr versus Nb, that can help discriminating among the most probable quarries of Euganean Hills for both Roman and Protohistoric grinding stones (Figure 4c). These elements indicate that the Protohistoric samples probably belong to rock types included in field 4 of Figure 4(a), and in particular to those outcropping in the Mts Murale/Cero areas (Figure 4). Protohistoric group 1 falls within Mts Murale/Cero areas according to the data of Capedri et al. (2000). Protohistoric group 2 falls very close to Mts Murale/Cero and well separated from Mt Merlo according to Germinario, Hanchar, et al. (2018), while it falls between Mts Murale/Cero and Mt Merlo according to Capedri et al. (2000).

In the same diagram the Roman sample POV25 plots far from Mt Rosso, Monselice and Mt Trevisan, showing the lowest Zr and Nb contents. The Nb content of POV25 is so far not reported for the Euganean Hills, making its provenance definition uncertain.

According to Germinario, Hanchar, et al. (2018), the most informative binary plots to discriminate Euganean quarries are V versus Nb (especially useful for Monselice, Mt Rosso, Mt Trevisan and Mt Merlo areas) and TiO_2 versus Zr, TiO_2 versus K_2O, Na_2O versus Zr, Rb versus Zr, Al_2O_3 versus Zr, and Ce versus Nd. We have then followed such recommendation, selecting the V versus Nb, TiO_2 and Na_2O versus Zr plots to test the indications given by previous diagrams. In these plots we have also added the data of Capedri et al. (2000) only for the relevant possible quarrying sites under discussion (always represented by solid lines and with the same colour as the one of the corresponding fields of Germinario, Hanchar, et al., 2018).

In the V versus Nb plot (Figure 5a) most Roman millstones fall close to or within the field of Mt Rosso, with the exception of two samples falling within Mt Bello plus Mt Lonzina field (CP6 and CP7), POV25 and AQ5. However, in the TiO_2 versus Zr plot (Figure 5b), all the samples, with the exception of POV25 and AQ5, plot within or very close to Mt Rosso field and well separated from Mt Bello plus Mt Lonzina field.

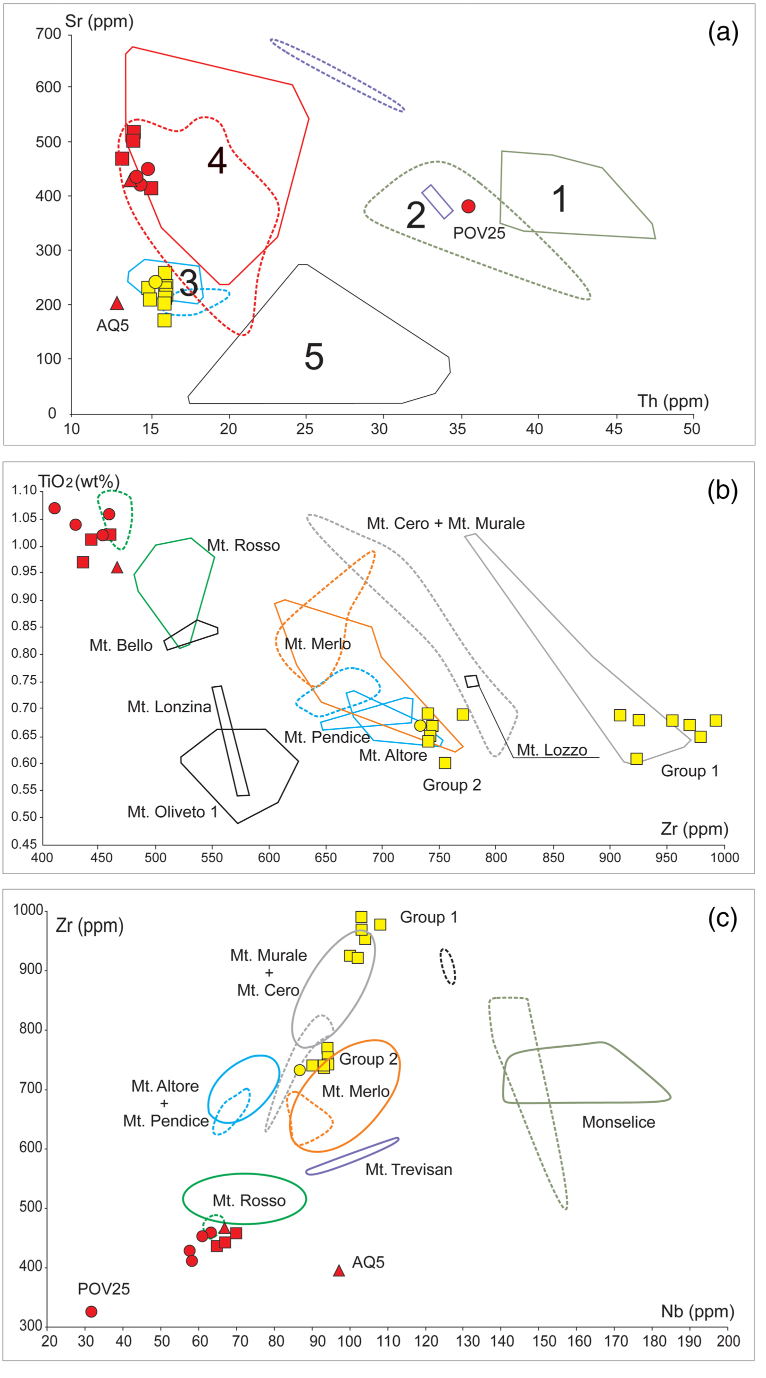

FIGURE 4 Legend on the next page

FIGURE 4 (a) Th versus Sr (ppm) diagram after Capedri et al. (2000) (fields enclosed by solid lines) modified including data from Germinario, Hanchar, et al. (2018) (fields enclosed by dotted lines). Fields: 1 (Monselice), 2 (Mt Trevisan), 3 (Mt Altore and Mt Pendice), 4 (Mt Oliveto 1, Mt Bello, Mt Cero, Mt Lonzina, Mt Lozzo, Mt Merlo, Mt Murale, Mt Rosso), 5 (Mt Alto, Mt Grande, Mt Lispida, Mt Oliveto 2, Mt Rustà, Mt S. Daniele). (b) Zr (ppm) versus TiO_2 (%) diagram after Capedri et al. (2000) modified adding the fields of Mt Altore and Mt Pendice (Capedri et al., 2000) and the fields of Mt Merlo, Mt Altore plus Mt Pendice and Mt Cero plus Mt Murale of Germinario, Hanchar, et al. (2018) (fields within dotted lines). POV25 and AQ15 fall outside the diagram. (c) Nb versus Zr (ppm) diagram. The fields of Mt Rosso, Mt Merlo, Mt Cero plus Mt Murale and Mt Altore plus Mt Pendice, Mt Monselice and Mt Trevisan have been drawn based on the literature data by Capedri et al. (2000) (fields within solid lines) and Germinario, Hanchar, et al. (2018) (fields within dotted lines). Symbols and colours as in Figure 1.

In the V versus Nb plot all Protohistoric grinding stones fall very close to Mt Cero and Mt Murale and well separated from Mt Merlo according to both the datasets by Capedri et al. (2000) and Germinario, Hanchar, et al. (2018). Similarly, in the TiO_2 versus Zr and Na_2O versus Zr diagrams the same samples fall within or very close to the field of Mt Cero and Mt Murale and well separated from Mt Merlo, Mt Altore and Mt Pendice (Figure 5b,c).

Rare earth elements

Although all the Euganean grinding stones investigated in this paper for the first time show similar patterns (Figure 6a, 1), the Protohistoric sample CSA2 is characterized by slightly different La/Yb, La/Ce and La/Sm chondrite-normalized ratios with respect to the Roman millstones (35.58 versus 10.06–17.42, 2.49 versus 01.34–1.49, and 6.89 versus 4.11–4.84, respectively). These geochemical features are not related to weathering effects and imply slight genetic differences, which likely exclude the exploitation of the same quarrying area in the Euganean Hills, as already suggested by Antonelli et al. (2004). Among the Roman samples, POV25 shows a lower La/Yb_{CN} ratio (10.06), an evident Eu negative anomaly (Eu/Eu* = 0.65) and a quite flatter Dy/Yb_{CN} (1.06 versus 1.31–1.57).

A few rare earth elements (La, Ce and Nd) of the Euganean quarry areas are available from Germinario, Hanchar, et al. (2018). Despite the few available elements, the La/Ce_{CN} ratio (0.82 and 1.03, respectively) of two selected samples from Mt Cero (MUR-05) and Mt Murale (MUR-03) is quite similar to the values of the Protohistoric grinding stones (1.51–2.67) (Figure 6a, 3).

Incompatible elements

In general, all the Euganean samples show similar behaviours, characterized by slight Ba, Nb and more pronounced Sr, P and Ti negative anomalies (Figure 6a, 2). However, the Sr and P negative anomalies are more pronounced in the Protohistoric sample CSA2 than in the Roman ones CSA1, BSN and POV (Ce/Sr_{PM} = 5.43 versus 2.67–2.97; Zr/P_{PM} = 4.50 versus 2.05–2.17). Similar geochemical features are reported also for the outcrops of Mts Cero (Zr/P_{PM} = 4.43–6.57), Murale (Zr/P_{PM} = 2.78–6.99) and Merlo (Zr/P_{PM} = 5.17) in the Euganean Hills (Capedri et al., 2000). The patterns of two selected samples from Mt Cero (MUR-05) and Mt Murale (MUR-03) from Germinario, Hanchar, et al. (2018) confirm such similarity fitting quite well (Ce/Sr_{PM} = 6.35 and 7.67, respectively; Zr/P_{PM} = 7.50 and 37.95, respectively) the field of Protohistoric grinding stones (Ce/Sr_{PM} = 2.59–9.19, respectively; Zr/P_{PM}: 1.88–6.87; Figure 6a, 4).

The Roman sample POV25 differs; it shows the lowest values in several incompatible elements an a more pronounced negative Nb anomaly (K/Nb: 3.5 versus 1.8–1.9).

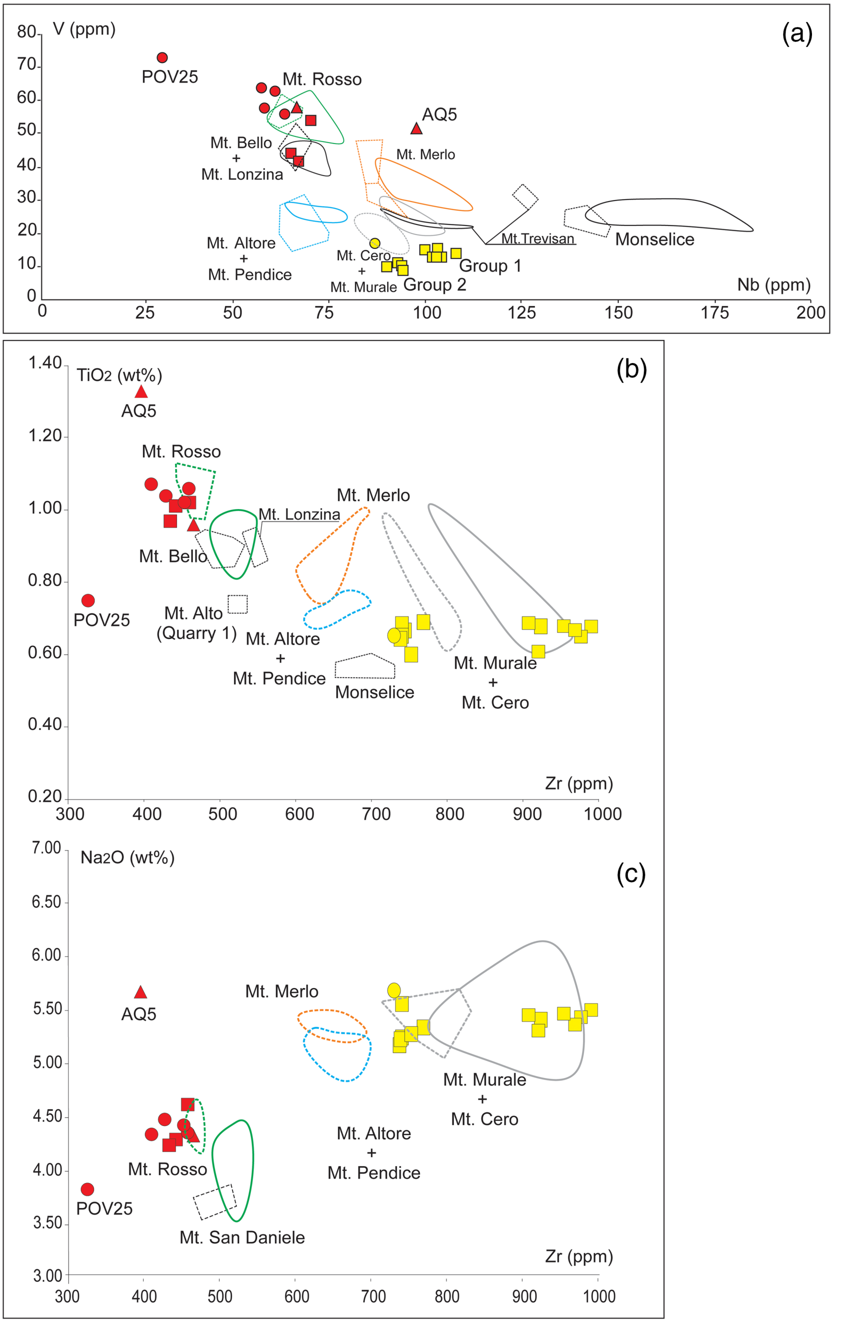

FIGURE 5 (a) V versus Zr (ppm) diagram after Germinario, Zara, et al. (2018) (fields within dotted lines) modified adding the fields of the same localities based on Capedri et al. (2000) (fields within solid lines with the same colour as the one of the corresponding fields of Germinario et al. 2018). (b, c) TiO_2 versus Zr and Na_2O versus Zr plots after Germinario, Zara, et al. (2018) (fields within dotted lines) modified adding the fields of Mt Rosso and Mt Cero plus Mt Murale based on Capedri et al. (2000) (fields within solid lines with the same colour as the one of the corresponding fields of Germinario et al., 2018). Symbols and colours as in Figure 1.

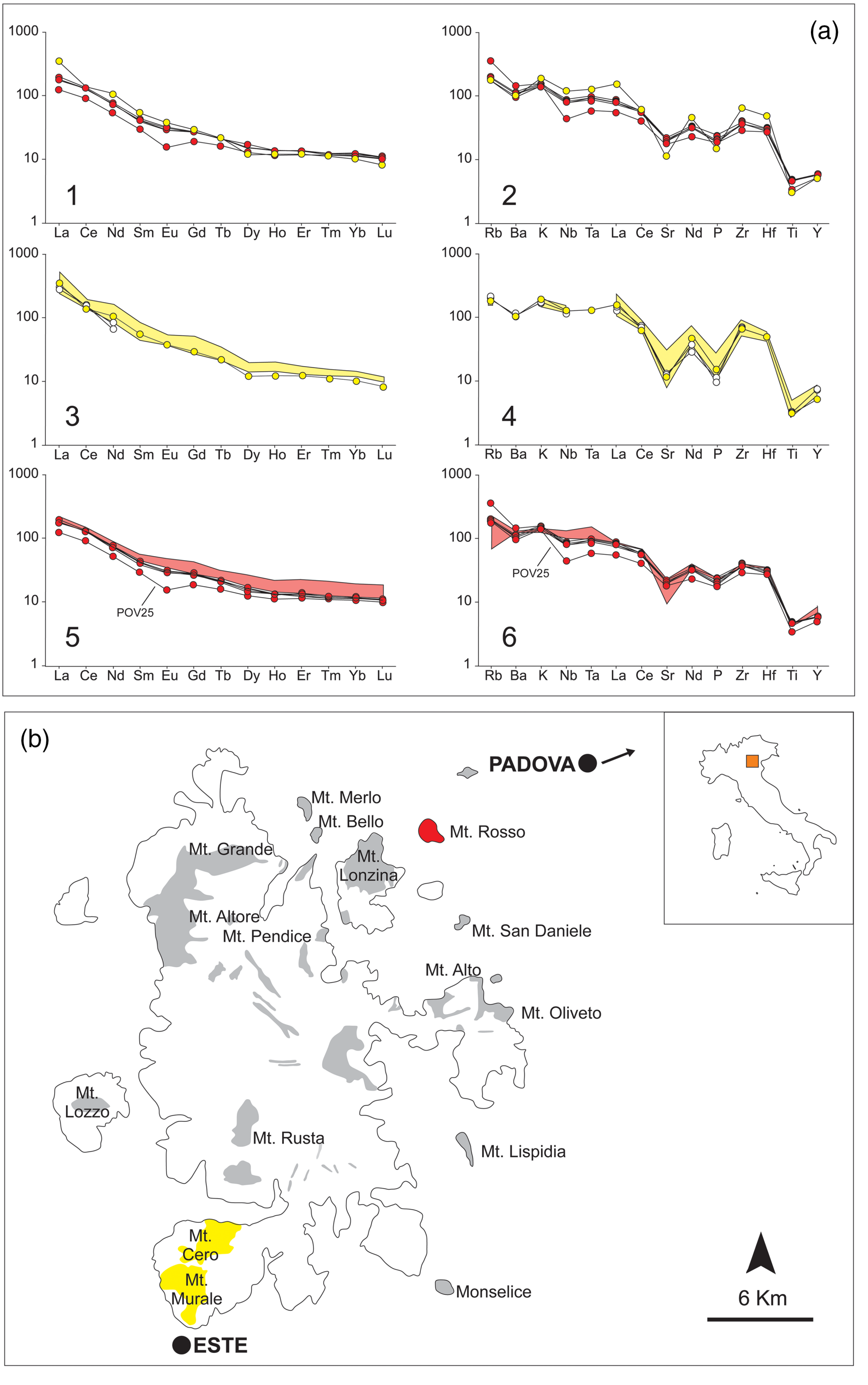

FIGURE 6 Legend on the next page

FIGURE 6 (a) Rare earth and incompatible elements of the artefacts analysed in the present paper (1 and 2, respectively) and a comparison with the literature data on Protohistoric (3 and 4; Antonelli et al., 2004) and Roman grinding stones (5 and 6; Antonelli & Lazzarini, 2012). Selected samples from Mt Cero (MUR-05) and Mt Murale (MUR-03) from Germinario, Hanchar, et al. (2018) (white circles) are plotted in diagrams 3 and 4 for comparison. The chondrite values used for the normalization of the rare earth element patterns are after Boynton (1984), while the PM (primitive mantle) values of McDonough and Sun (1995) have been used for the normalization of the incompatible elements. (b) Trachyte outcrops of Euganean Hills with the indications of probable Protohistoric (in yellow) and Roman (in red) sources of the grinding stones found in Caput Adriae.

DISCUSSION AND CONCLUSIONS

The relatively large occurrence of saddle querns made from Euganean trachytes in the coastal regions of Caput Adriae has been already reported by previous studies and it has been considered as evidence of the Venetic cultural influence in the area during the advanced Iron Age (Antonelli et al., 2004; Bernardini, 2002). During the Iron Age, Este, located on the southern slope of Euganean Hills and very close to Mts Cero and Murale, becomes one of the main centres of the Venetic area (Bianchin Citton et al., 1998; Capuis & Gambacurta, 2015; Ruta Serafini, 2002) and it probably plays a crucial role in both the exploitation of trachytic rocks and production of saddle querns; the latter have been found in a wide area at least from Emilia to the Istrian peninsula (Antonelli et al., 2004; Cattani et al., 1997). The revision and integration of petrographic and geochemical data concerning Protohistoric grinding stones from Caput Adriae make this hypothesis stronger, showing that the most probable sources of Iron Age trachytic saddle querns precisely correspond to Mts Cero/Murale (Figure 6b) and not to the Mt Altore and Rocca Pendice quarries, as previously suggested (Antonelli et al., 2004). This conclusion agrees with the results of the chemical and petrographic characterization of Protohistoric saddle querns from Emilia and Veneto, whose provenance was mainly attributed to Mt Cero and/or Murale (Cattani et al., 1997; Crivellari, 1998; Zara, 2018). The trachytic saddle querns were most probably exported taking advantage of the different paleoenvironmental conditions. From about 3 ka cal. BCE to Roman times, the Adige River run through Montagnana, Este and Conselve, reaching the southern Venetian lagoon (Piovan et al., 2010, 2012). The grinding stones could have been transported (as cargo or as ballast) by the Adige to the Venice Lagoon and then, by sea, to the coasts of the Karst and Istria, reaching sites placed at most about 20 km from the sea.

During the Roman period, Euganean trachytes were still used for the production of rotary millstones, but the available data confirm the exploitation of new quarries (Mt Rosso for most of the artefacts) and the abandonment of the Protohistoric exploitation areas close to Este. The Roman Mt Rosso source, probably active from the late Republican period, is located along the northern margin of the Euganean Hills and relatively close to ancient Padua. Such a shift in the position of quarries most probably reflects the changed geopolitical framework (Paltineri et al., 2020). Beside the use of Mt Rosso trachyte for the production of millstones, a growing need for building material explains the exploitation of multiple trachytic sources by the Romans (Germinario, Hanchar, et al., 2018; Paltineri et al., 2020; Previato et al., 2014; Zara, 2018). The exclusive use of the Mt Rosso trachyte for the production of rotary millstones can perhaps be explained by assuming the particularly good abrasive properties of the raw material or specialized workshops in the area.

However, among the materials here discussed for the first time, some uncertainties about the origin of Roman sample POV25 still remain; in fact, it shows a general geochemistry in agreement with that of the Euganean magmatic complex, including the behaviour of the vicariant HFSE elements (i.e. Zr versus Hf and Nb versus Ta), but quite peculiar chemical features related to a slightly different genesis are also evident. This suggests the sample could have been collected from a quarry completely exhausted in ancient times or from an area not yet identified.

Finally, the present paper allows to make some considerations about the geochemical datasets available for the Euganean Hills and their use in provenance studies (Capedri et al., 2000; Germinario, Hanchar, et al., 2018), especially in relation to the hypothesis that the data of Capedri et al. (2000) are not reliable due to possible wrong sample preparation (Germinario, Hanchar, et al., 2018; Maritan et al., 2013). (1) Considering Mt Cero plus Mt Murale, it is very likely that Capedri et al. (2000) and Germinario, Hanchar, et al. (2018) sampled different areas. The composition of Protohistoric group 1 fits well the composition of the Mt Cero plus Mt Murale by Capedri et al. (2000), but has no comparison in the dataset by Germinario, Hanchar, et al. (2018). (2) The differences in the Sr and Zr contents between the two datasets are so high for some localities (up to 200 and 250 ppm, respectively) that it cannot be due to matrix effects, which are generally very limited for Sr. (3) Capedri et al.'s (2000) dataset cannot be dismissed and can be still useful for archaeometric purposes, even if the main discrimination diagram Sr versus Th is not reliable for most quarry localities, as well shown by Germinario, Hanchar, et al. (2018).

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon request.

ORCID

Matteo Velicogna https://orcid.org/0000-0001-9303-9315

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