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Provenance of late Republican Roman pottery from Caput Adriae revealed by non-invasive mineral chemistry of melanitic garnets and other igneous minerals

Federico Bernardini [1,2], Davide Lenaz [3,*], Jana Horvat [4], Alma Bavdek [5], Paola Ventura [6], Angelo De Min [3]

[1] Department of Humanities, Università Ca' Foscari Venezia, Dorsoduro, 3484/D, 30123 Venezia, Italy
[2] Multidisciplinary Laboratory, The "Abdus Salam" International Centre for Theoretical Physics (ICTP), Strada Costiera, 11 - 34151 Trieste, Italy
[3] Department of Mathematics and Geosciences, University of Trieste, Via Weiss 8, - 34128 Trieste, Italy
[4] ZRC SAZU, Inštitut za arheologijo, Novi trg 2 - 1000 Ljubljana, Slovenia
[5] Notranjski muzej Postojna, Kolodvorska cesta 3 - 6230 Postojna, Slovenia
[6] Soprintendenza Archeologia, Belle Arti e Paesaggio del Friuli Venezia Giulia, Piazza della Libertà, 7 - 34135 Trieste, Italy

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* Corresponding author:
lenaz@units.it

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ABSTRACT

Quite rare pottery shards showing a paste rich in black sand particles, possibly igneous minerals, have been discovered in late Republican Roman sites of Trieste area (north-eastern Italy) and south-western Slovenia in the Caput Adriae. Most of them belong to late Greco-Italic and Dressel 1 amphora types, in use from the end of the 3rd and the beginning of 1st centuries BC. Following a methodological procedure based on the analysis of igneous temper, proved to be particularly effective by several scholars, numerous minerals have been extracted from the surface of 16 pottery shards, without causing any visible damage to them. Microprobe analysis has allowed the identification of igneous minerals (olivine, clinopyroxene, feldspar and garnet), most likely originating from the Roman or Campanian magmatic provinces. The chemistry of garnets, indicated in the past as a possible tracer of ancient commerce but no longer used in the last decades to study Italian late Republican pottery, has proved to be a promising tool to distinguish among the two magmatic provinces. According to our study, most of the investigated garnets-bearing samples would originate from Somma-Vesuvius while some of them from Latium.

Keywords: Republican Roman pottery; Caput Adriae; melanitic garnets; igneous minerals; mineral chemistry; provenance.

INTRODUCTION

Remains of a large late Republican Roman military fortification, occupied in the 2nd-1st century BC, has been recently identified on the San Rocco hill, close to Trieste, (north-eastern Italy; Bernardini et al., 2015), in the *Caput Adriae* area (north-eastern Italy, south-western Slovenia and north-western Croatia; Figure 1). Several amphora shards, including a rim belonging to late Greco-Italic type, handles and wall fragments showing a pink-orange paste rich in black sand particles, have been discovered during field surveys (Figures 1-3). According to macroscopic observations, the black and shiny particles have been identified as possible igneous mineral grains. A group of amphora shards from San Rocco, including most of the

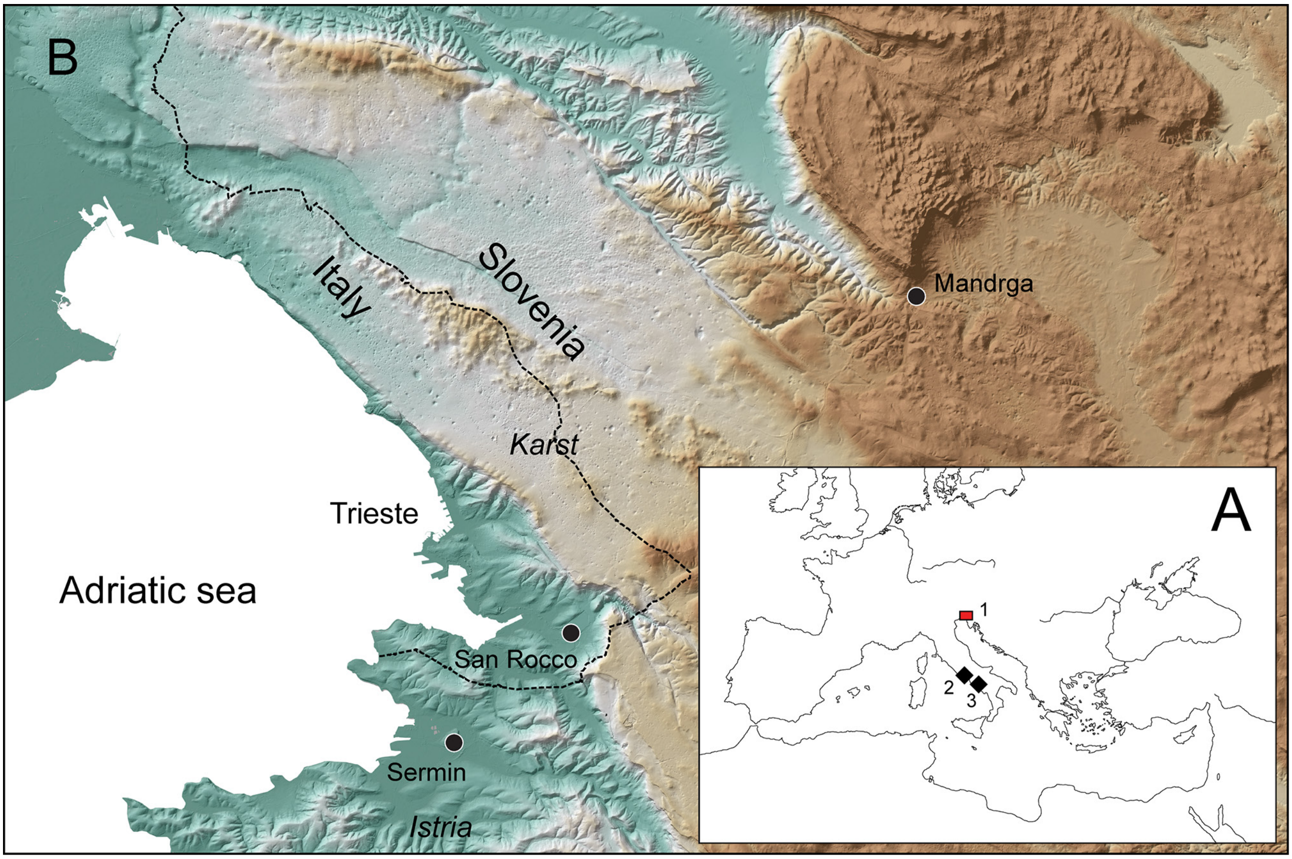

Figure 1. A: schematic position of north-eastern Adriatic region (1) and of Roman (2) and Campanian (3) magmatic provinces. B: elevation model of north-eastern Adriatic area showing the location of the sites discussed in the paper.

findings containing black shiny grit, and selected Roman pottery fragments from nowadays western Slovenia, showing a similar ceramic paste, have been studied to investigate their most probable origin (Figures 1-3; Table 1). In detail, Slovenian samples have been taken from a Greco-Italic and a Dressel 1a amphora rims form Sermin (Horvat, 1997), a coastal archaeological site north of Koper with a chronology similar to San Rocco, and from two baking dishes found at Mandrga site close to Razdrto pass (Horvat and Bavdek, 2009), occupied between the end of the 2nd century BC and the beginning of the 1st century BC.

The typological classification of Greco-Italic amphorae, and especially that one of late types, has been discussed by several authors and is still controversial (Lyding Will, 1982; Manacorda, 1986, 1989; Vandermersch, 1994, 2001; Panella, 2011; Cibecchini and Capelli, 2013). This group generically includes amphorae with a morphology derived from Greek models, spread mainly in Sicily, Magna Grecia and along the Italian and western Mediterranean coast from the beginning of 3rd century BC up to the advanced 2nd century BC, when late Greco-Italic amphorae gradually develop into Dressel 1 and Lamboglia 2 types in the Tyrrhenian and Adriatic areas, respectively. Archaeological data have revealed or suggested the existence of numerous production centres in the Tyrrhenian regions, in Sicily and in the Adriatic area too, in the territory of Adria-Spina (Toniolo, 2000; Olcese, 2004, 2007, 2010, 2012; Cibecchini and Capelli, 2013).

Along the north-eastern Adriatic regions, remains of indisputable late Greco-Italic amphorae have been mainly discovered along the coast (Horvat, 1997 and references therein; Tortorici, 2000; Donat, 2009) and are related to the first Roman expansion in the region. They are rather rare in sites of Trieste province and most of them, according to their macroscopic fabric descriptions, are not imported from the Tyrrhenian area. Among late Greco-Italic amphorae from Sermin only two rims (1.2% of all rims) show a ceramic paste compatible with a provenance from the Tyrrhenian coast. The presumed origin of the majority is from the Adriatic area (Horvat, 1997; Župančič and Bole, 1997). Interestingly enough, a preliminary study of amphorae kept in the Archaeological Museum of Aquileia reported a low percentage of Dressel 1 containers, typical

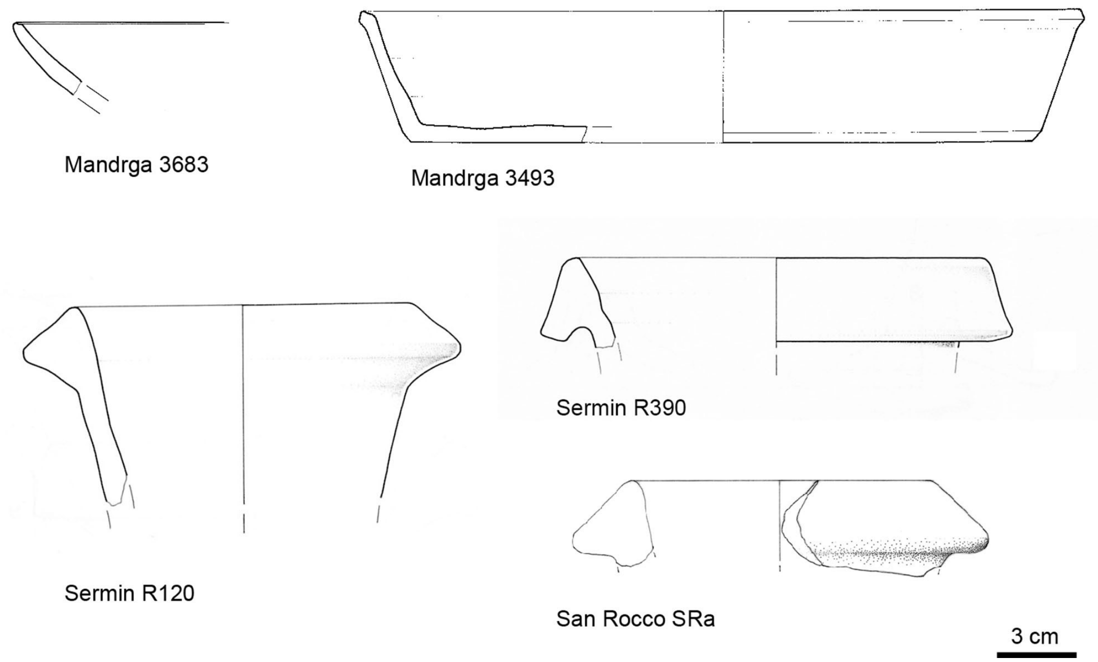

Figure 2. Drawings of typologically significant analysed shards.

production of Tyrrhenian area developed from Greco-Italic types (Cipriano and Carre, 1987).

In recent years remarkable progress has been made in the characterization of Greco-Italic and other Republican amphorae (e.g. Olcese, 2004, 2007, 2010, 2012; Barone et al., 2010, 2011; Cibecchini et al., 2012; Cibecchini and Capelli, 2013; Belfiore et al., 2014; Carratoni et al., 2016). Petrographic and bulk chemical analyses are the most common techniques applied in the study of such archaeological materials. However, several authors have highlighted the advantages of a different analytical approach to provenance ceramic materials, based on the punctual chemical study of single igneous minerals included within the ceramic paste (Velde and Courtois, 1983; Dorais and Shriner, 2002; Dorais et al., 2004; Barone et al., 2010; Belfiore et al., 2014).

As already observed (Barone et al., 2010), the chemistry of single igneous minerals is generally not affected by firing processes, keeping its original signature, which can be easily compared with the abundant literature about mineral chemistry of igneous rocks. In addition, bulk chemical analyses of a ceramic paste, which is an artificial mixture of clay plus mineral and organic temper modified during firing, can provide data not easily comparable with possible sources of clayey raw materials and mineral temper. It is to notice that the use of heavy minerals for provenance purposes is widely used in geology because they are considered as indicators of provenance given the fact that their chemistry is very specific for particular geological environments. Among them, there are pyroxenes (Nechaev and Isphording, 1993; Ernst and Shirahata, 1996; Acquafredda et al., 1997; Krawinkel et al., 1999; Lenaz, 2008), garnets (Morton, 1985, Mange and Morton, 2007; von Eynatten and Dunkl, 2012; Lenaz et al., 2018) and spinels (Pober and Faupl, 1988; Cookenboo et al., 1997; Lenaz et al., 2000; Bonova et al., 2018).

However, the analysis of single minerals within ceramic materials is particularly suitable to investigate ceramic assemblage rich in igneous minerals of relatively large dimensions, such as in our case, especially if mineral chemistry is applied on crystals extracted from the surface of the vessels and not on thin sections. In other cases, a multi-analytical approach including mineralogical, petrographic and geochemical analysis of both pottery and possible raw material sources is generally necessary to fully characterize the investigated archaeological samples and define their origin.

According to the review of Borgwartd and Wells (2017) of the term non-destructive in archeology, including those by Jakes (2002; "a procedure that leaves no visible effect and allow additional tests to be performed"), Ciliberto and Spoto (2000; "allow analytical information to be obtained with no damage whatsoever to the sample or in some cases, the object in question. All visible alterations are avoided,

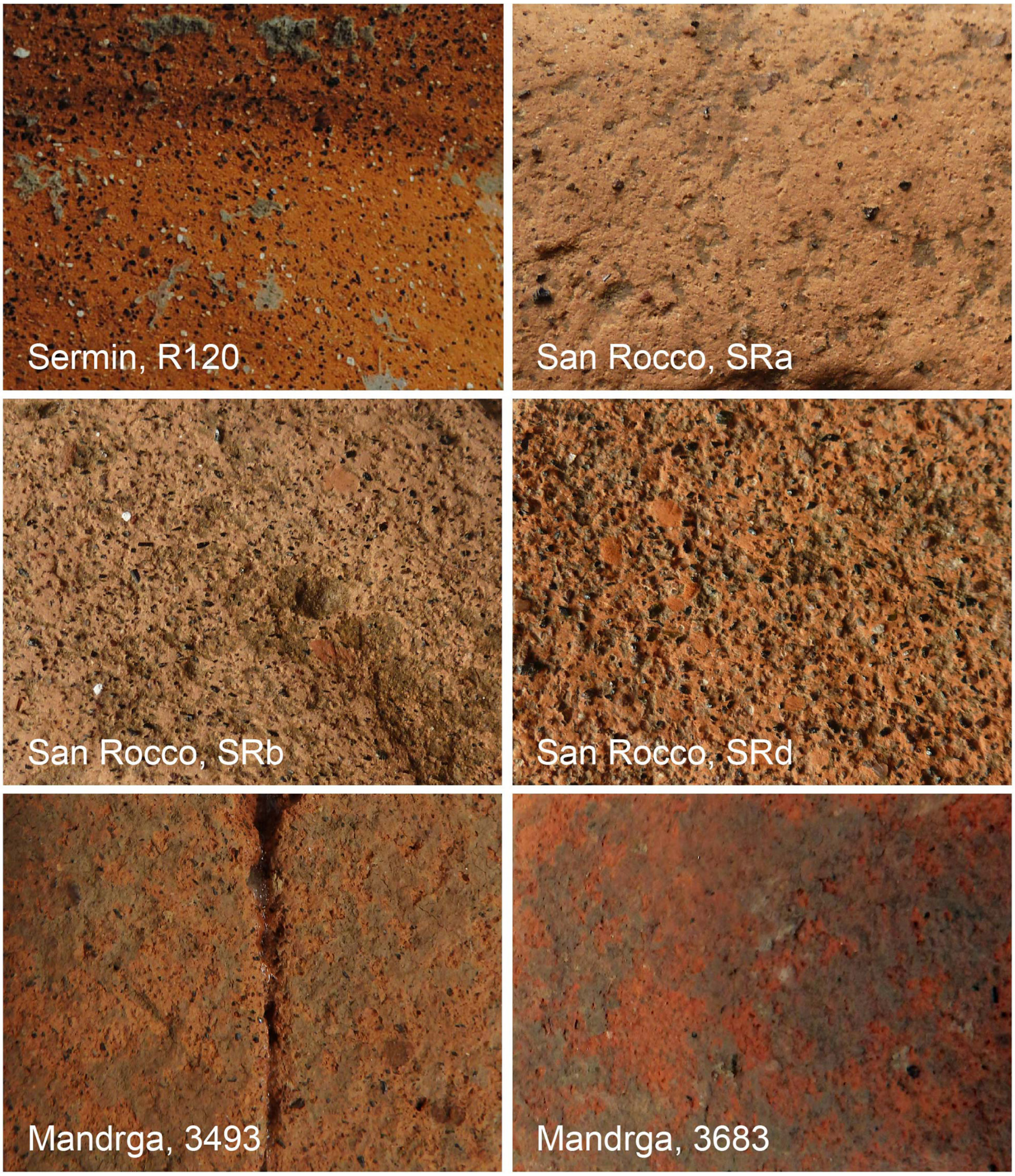

Figure 3. Photographs of the surfaces of selected samples: all of them show black shiny grit in different proportions. The width of single pictures corresponds to about 2 cm.

and the object remains aesthetically unimpaired”), and Goffer (2007; “neither require sampling nor physically damage or impair the integrity of the object studied”), we define non-destructive our technique consisting of hand-picking of single crystals from the surface to investigate the possible origin(s) of the investigated artefacts. These handpicking leaves small “holes” that cannot be distinguished from those already present on the surface caused by the natural wear of time.

MATERIALS AND METHODS

As we were not allowed to take larger samples, we decided to use the following almost non-invasive procedure, producing minimal damages to the artefacts. Several minerals, up to 2-3 mm long, have been extracted from the surface of 11 amphora walls and a late Greco-Italic amphora rim (SRa) from San Rocco (all the available shards rich in black shiny grit from the site and whole Trieste area), picking them under a microscope by using

Table 1. List of the analysed samples. Drawings and description of artefacts 3683, 3493, R120, R390 and SRa were already published (without any archaeometric data) by Horvat and Bavdek (2009, Pl. 29: 5), Horvat and Bavdek (2009, Pl. 6: 3), Horvat (1997, Pl. 15: 5), Horvat (1997, Pl. 58: 5) and Bernardini et al. (2015, Fig. 3: 4), respectively.

Inv. number	Archaeological site	Typology	Chronology
3683	Mandrga, western Slovenia	baking dish	end 2nd- beginning 1st century BC
3493	Mandrga, western Slovenia	Albintimilium 115/116 baking dish	end 2nd- beginning 1st century BC
R120	Sermin, western Slovenia	late Greco-Italic amphora rim	end 3rd century BC-mid 2nd century BC
R390	Sermin, western Slovenia	Dressel 1a amphora rim	mid 2nd century BC-beginning 1st century BC
SRa	San Rocco, north-eastern Italy	late Greco-Italic amphora rim	end of 3rd century BC-mid 2nd century BC
SRb	San Rocco, north-eastern Italy	amphora wall	2nd-1st century BC
SRc	San Rocco, north-eastern Italy	amphora wall	2nd-1st century BC
SRd	San Rocco, north-eastern Italy	amphora wall	2nd-1st century BC
SR11	San Rocco, north-eastern Italy	amphora wall	2nd-1st century BC
SR12	San Rocco, north-eastern Italy	amphora wall	2nd-1st century BC
SR13	San Rocco, north-eastern Italy	amphora wall	2nd-1st century BC
SR14	San Rocco, north-eastern Italy	amphora wall	2nd-1st century BC
SR15	San Rocco, north-eastern Italy	amphora wall	2nd-1st century BC
SR16	San Rocco, north-eastern Italy	amphora wall	2nd-1st century BC
SR18	San Rocco, north-eastern Italy	amphora wall	2nd-1st century BC
SR35	San Rocco, north-eastern Italy	amphora handle	2nd-1st century BC

a common needle, embedded in epoxy resin, polished and analyzed by means of electron microprobe (Figures 1-3; Table 1). For comparison other crystals have been extracted from a late Greco-Italic (R120) and a Dressel 1a (R390) amphora rims found at Sermin (Horvat, 1997) and from two baking dishes (3683 and 3493) found at Mandrga close to Razdrto pass (Horvat and Bavdek, 2009) in Slovenia (Figures 1-3; Table 1) and then analysed using the same analytical method. Most of the shards from San Rocco are very similar showing a reddish or pinkish paste with abundant black shiny grit and rare whitish, possibly carbonate, particles only in some of them. The paste of the late Greco-Italic rim SRa from the same site is similar but it contains a lower amount of black grains (Figure 3). The samples R120 and R390 from Sermin can be compared to those from San Rocco showing a reddish colour and abundant black shiny grit but sample R120 contains quite abundant white particles too (Figure 3). Finally, the paste of the baking dishes from Mandrga shows a reddish colour and a lower amount of black shiny grains, especially in the sample 3493 (Figure 3). In the pottery shards from San Rocco the size of the black inclusions can reach 2-3 mm, while they are generally smaller in the other samples (Figure 3).

Microprobe analyses of all the igneous minerals extracted from the archaeological artefacts were carried out using a Cameca-Camebax operating at 15 kV and 15 nA, at the CNR of Padova (Italy). The PAP Cameca program has been used to convert X-ray counts into weight percentages of the corresponding oxides. The results are considered accurate within to 2-3% for major elements and 9% for minor elements. The Fe^{2+} and Fe^{3+} contents have been calculated according to Papike et al. (1974).

RESULTS

The microprobe analysis has confirmed that the investigated grains correspond to igneous minerals. Among them, pyroxenes, feldspars, olivines and garnets have been found.

Clinopyroxene (hereafter cpx) is the most abundant phase which has been identified. Most of them can be classified as diopsides (Table 2, Figure 4; Supplementary Table 1). Regardless of their chronology and finding site, they share a similar geochemical composition (San Rocco: $Wo_{45-50}En_{18-49}Fs_{5-32}$; Sermin: $Wo_{45-52}En_{31-48}Fs_{4-20}$;

Mandrga: $Wo_{45-50}En_{26-49}Fs_{5-23}$).

Feldspars, identified among the minerals from San Rocco, Sermin and Mandrga, are mainly orthoclase (Table 3). In the San Rocco samples they show orthoclase content in the range 54-85, while in the Sermin samples they are Ort_{75-97}. The only feldspar from Mandrga shows an orthoclase content of 81.

We have found a few olivine minerals in four San Rocco amphorae, showing a similar fosterite content ranging from 87 to 88, and a single olivine from Mandrga sample 3683 with a fosterite content of 82 (Table 4).

The analyzed garnets are brown/black in color and have been found in both San Rocco and Sermin amphorae. The pyrope-almandine-spessartine component is very limited showing, on the contrary grossular content in the range 25-46 and andradite content spanning from 51 to 67 (Table 5). It is to notice the high content of the schorlomite component related to the TiO_2 amount. In the analyzed crystals it ranges between about 3 and 7 mol%.

Table 2. Representative analyses of clinopyroxenes (Cpx) from the investigated artefacts. Cpx 1, 3 and 5 are those with the highest Wo content. Cpx 2, 4 and 6 are those with the lowest Wo content. Cpx 5, 8 and 10 are those with the lowest En content.

	San Rocco	San Rocco	Sermin	Sermin	Mandrga	Mandrga	San Rocco	San Rocco	Sermin	Sermin	Mandrga
	1	2	3	4	5	6	7	8	9	10	11
Sample	SR14	SRc	R120	R390	3683	3683	SRc	SR16	R120	R390	3683
Na_2O	0.27	0.29	0.17	0.32	0.54	0.28	0.12	0.80	0.14	0.57	0.10
MgO	7.77	14.16	10.64	14.56	8.60	13.77	17.98	5.52	17.47	10.23	17.92
Al_2O_3	13.91	3.99	9.10	4.26	7.63	4.89	1.50	9.19	1.69	6.85	1.46
SiO_2	40.60	48.13	43.98	50.01	43.70	47.73	53.00	41.17	53.15	46.15	52.97
K_2O	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.01
CaO	23.96	21.17	24.27	21.57	23.21	21.74	22.76	22.06	23.61	23.01	23.46
TiO_2	1.21	0.87	1.42	1.01	1.52	1.46	0.23	1.63	0.20	1.17	0.27
Cr_2O_3	0.00	0.11	0.01	0.04			0.66	0.00	0.71	0.00	
Mno	0.12	0.20	0.11	0.22	0.34	0.24	0.09	0.80	0.06	0.32	0.09
FeO	11.10	8.52	9.92	7.99	13.46	8.61	3.18	17.20	2.81	11.46	3.12
Sum	98.96	97.46	99.62	99.98	99.00	98.72	99.52	98.37	99.86	99.77	99.40
FeO	3.71	4.41	2.91	5.41	5.71	4.45	1.84	8.08	1.62	5.55	1.32
Fe_2O_3	8.21	4.58	7.79	2.86	8.62	4.63	1.49	10.13	1.32	6.57	2.00
Sum	99.78	97.91	100.40	100.27	99.86	99.18	99.67	99.38	99.99	100.43	99.60
Si	1.55	1.83	1.65	1.85	1.68	1.80	1.93	1.62	1.93	1.74	1.93
Ti	0.03	0.02	0.04	0.03	0.04	0.04	0.01	0.05	0.01	0.03	0.01
Al	0.62	0.18	0.40	0.19	0.35	0.22	0.06	0.43	0.07	0.30	0.06
Cr	0.00	0.00	0.00	0.00			0.02	0.00	0.02		
Fe^{3+}	0.24	0.13	0.22	0.08	0.25	0.13	0.04	0.30	0.04	0.19	0.06
Fe^{2+}	0.12	0.14	0.09	0.17	0.18	0.14	0.06	0.27	0.05	0.18	0.04
Mn	0.00	0.01	0.00	0.01	0.01	0.01	0.00	0.03	0.00	0.01	0.00
Mg	0.44	0.80	0.60	0.80	0.49	0.77	0.98	0.32	0.95	0.58	0.98
Ca	0.98	0.86	0.98	0.85	0.96	0.88	0.89	0.93	0.92	0.93	0.92
Na	0.02	0.02	0.01	0.02	0.04	0.02	0.01	0.06	0.01	0.04	0.01
K	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Wo	55.04	44.39	51.74	44.71	50.51	45.47	45.23	50.37	47.07	49.55	46.09
En	24.84	41.32	31.56	42.00	26.04	40.07	49.70	17.53	48.46	30.65	48.99
Fs	20.12	14.29	16.69	13.29	23.45	14.45	5.07	32.09	4.47	19.81	4.92

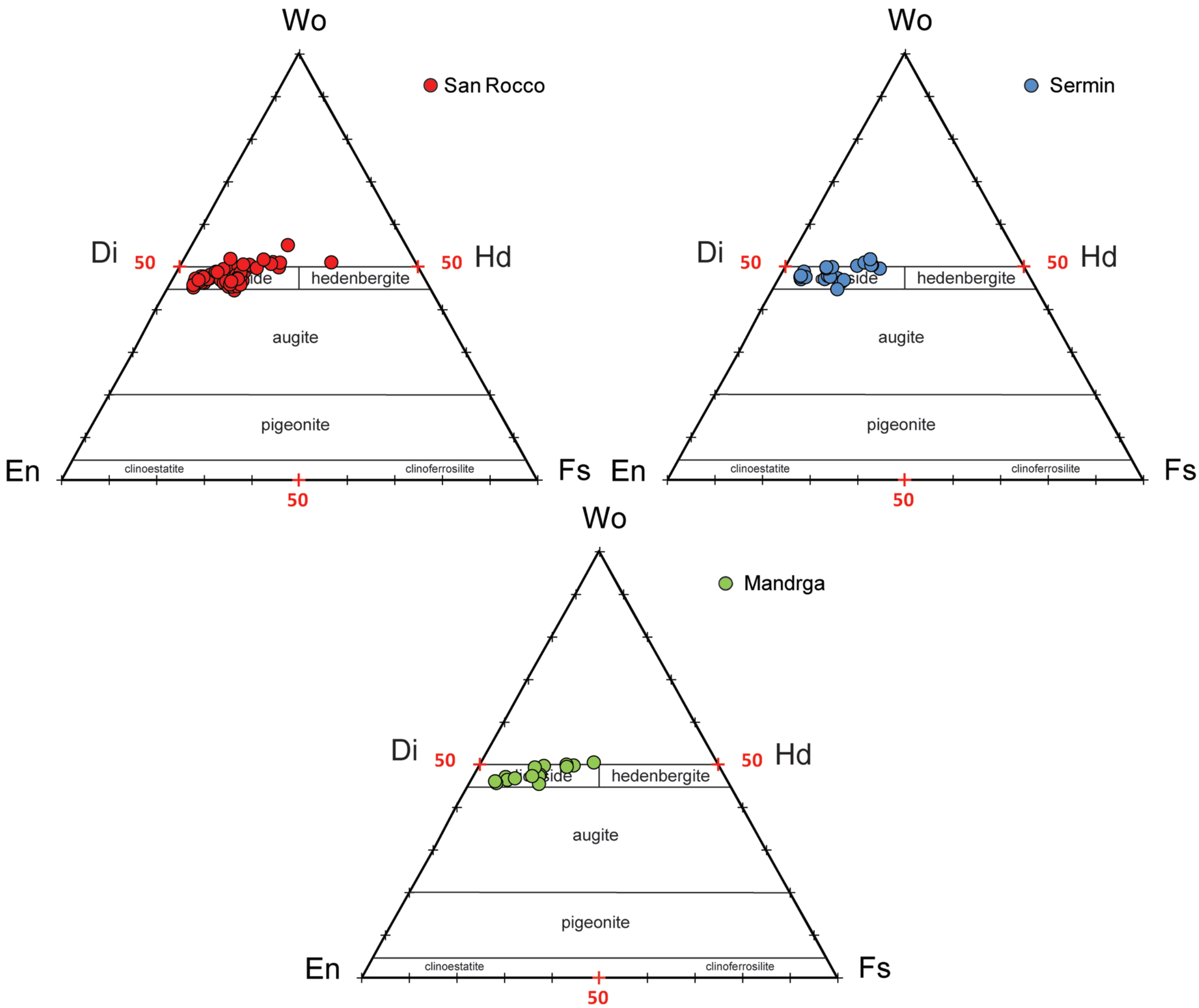

Figure 4. Classification diagrams of pyroxene crystals from the investigated amphorae from San Rocco, Sermin and Mandrga.

DISCUSSION

Comparisons with soil mineralogy and amphorae from NE Adriatic area

In order to verify if the studied amphorae are of local production or imported from elsewhere, first we have considered the mineralogy of the soils of the north-eastern Adriatic area (mainly terra rossa) and the surrounding siliciclastic rocks paying attention to their heavy mineral paragenesis. In the terra rossa soils, accessory minerals in sandy fraction are rutile, tourmaline, garnet, Cr-spinel, corundum, hematite and limonite (Šinkovec, 1974; Lenaz et al., 1996). It is to remember that terra rossa, as a poligenetic soil (Durn et al., 1999, 2007), is highly heterogeneous and variations in mineral proportions are common. Unfortunately, no chemical analyses of these phases are available. Anyway, it has been established that these soils are the results of the weathering of the siliciclastic rocks belonging to the flysch sequences surroundings this area (Lenaz et al., 1996). These rocks can be classified as lithic greywackes, mainly constituted by quartz and calcite with minor feldspar, clay minerals and dolomite. Micas are rare. Among the lithic fragments, clasts of limestones, dolostones, radiolarites, cherts, sandstones, quartzites, gneisses and low-grade schists have been observed in thin sections (Orehek, 1972; Venturini and Tunis, 1992). Heavy mineral association is composed by Cr-spinel, garnet, staurolite, tourmaline, zircon, pyrite, amphibole, pyroxene and opaque minerals (Orehek, 1972; Lenaz et al., 2000, 2001, 2003; Lenaz and Princivalle, 2002). Even in this case the size of the heavy minerals is below 250 μm.

Lenaz et al. (2001; 2018) noticed that the garnets are mainly of pyralspite composition being Alm-Py rich

Table 3. Analyses of feldspars from the investigated artefacts.

	San Rocco										Sermin			Mandrga
Sample	SRa	SRb	SRb	SRc	SRc	SRd	SRd	SR13	SR13	SR12	R390	R120	R120	3493
Na_2O	2.05	2.33	2.41	1.46	1.99	4.47	4.59	2.96	3.07	3.09	0.38	1.76	2.43	1.96
Al_2O_3	19.04	19.02	19.05	18.85	18.96	19.46	19.38	19.15	19.08	18.65	22.68	19.38	19.09	18.45
SiO_2	63.41	63.31	63.97	63.68	63.15	63.73	64.13	64.18	63.59	63.13	56.32	62.82	64.77	63.65
K_2O	12.90	12.45	12.69	14.08	12.95	9.13	9.18	12.23	12.10	12.03	19.07	12.80	12.43	13.72
CaO	0.55	0.55	0.57	0.32	0.54	0.98	0.94	0.21	0.19	0.16	0.00	0.35	0.41	0.27
TiO_2	0.06	0.08	0.05	0.02	0.05	0.10	0.11	0.00	0.04	0.01	0.07	0.06	0.03	0.00
FeO	0.19	0.20	0.16	0.13	0.19	0.24	0.26	0.06	0.12	0.09	0.35	0.20	0.15	0.14
Sum	98.20	97.94	98.90	98.54	97.83	98.11	98.59	98.84	98.19	97.16	98.88	97.41	99.33	98.18
Si	2.957	2.956	2.960	2.969	2.957	2.940	2.945	2.964	2.958	2.968	2.720	2.948	2.974	2.978
Ti	0.002	0.003	0.002	0.001	0.002	0.003	0.004	0.000	0.001	0.000	0.003	0.002	0.001	0.000
Al	1.047	1.047	1.039	1.036	1.047	1.058	1.049	1.042	1.046	1.033	1.291	1.072	1.033	1.018
Fe^{2+}	0.007	0.008	0.006	0.005	0.007	0.009	0.010	0.002	0.005	0.004	0.014	0.008	0.006	0.005
Fe^{3+}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ca	0.027	0.028	0.028	0.016	0.027	0.048	0.046	0.010	0.009	0.008	0.000	0.018	0.020	0.013
Na	0.185	0.211	0.216	0.132	0.181	0.400	0.409	0.265	0.277	0.282	0.036	0.160	0.216	0.178
K	0.768	0.742	0.749	0.838	0.774	0.537	0.538	0.721	0.718	0.722	1.175	0.766	0.728	0.819
Sum	4.994	4.994	5.001	4.997	4.995	4.996	5.000	5.005	5.015	5.017	5.237	4.975	4.979	5.011
Ab	18.91	21.52	21.76	13.39	18.41	40.57	41.17	26.61	27.57	27.85	2.94	16.96	22.43	17.60
An	2.80	2.81	2.84	1.62	2.76	4.91	4.66	1.04	0.94	0.80	0.00	1.86	2.09	1.32
Or	78.29	75.67	75.39	84.98	78.83	54.52	54.17	72.35	71.49	71.35	97.06	81.17	75.48	81.08

(Alm_{65-77}; Py_{7-30}). The schorlomite component is lower than 0.26. The pyroxenes found in the flysch rocks from Istria are augitic and pigeonitic (Lenaz, 2008) while the few recovered from the flysch of the Julian Basin are omphacitic (Lenaz and Princivalle, 2002). The most abundant heavy mineral is Cr-spinel that have been studied in detail by Lenaz and Princivalle (1996, 2005) and Lenaz et al., (2000, 2003).

Considering the mineralogy of amphorae produced in Istria, Dr. 6B vessels manufactured in the Laecanius workshop between the end of 1st century BC and the 1st century AD have been studied in detail by Mange and Bezeczky (2006, 2007), Bezeczky and Mange (2009) and Józsa et al., (2016).

Mange and Bezeczky (2007) found diverse detrital heavy minerals with generally high epidote and garnet quantities. Occasionally zircon is important. Apatite, biotite, blue-green and brown hornblende, staurolite, garnet, kyanite, rutile are accessory heavy minerals. Considering this association, the authors suggested that the heavy mineral composition of Istrian terra rossa and the Laecanius amphora shards show appreciable similarities.

According to Józsa et al. (2016), siliciclastic and carbonatic components are present in variable proportions in the amphorae. Mono- and polycrystalline quartz dominate, feldspars, microquartz rock fragments are rare, micas are variable. Sedimentary rock fragments (sandstone, siltstone, claystone, limestone) appear rarely. The finding of abundant and characteristic Cr-spinels in the amphora suggested the use of altered flysch in the making of the paste and temper.

According to these findings the main raw material of the Laecanius workshop was the Cenozoic flysch outcropping in central and northern Istria, mixed to few recent sea shore sediments and terra rossa (Mange and Bezeczky, 2007; Józsa et al., 2016).

A chemical and mineralogical study of late Greco-Italic and Lamboglia 2 amphorae from Sermin has been performed by Župančič and Bole (1997). Only samples of a large group of probable Adriatic origin were analysed. The authors found a heavy mineral association including diopside, hematite/maghemite, muscovite, Fe-hydroxides, ackermanite, gehlenite, hedenbergite, actinolite. Other minerals apart from quartz and calcites are zeolites, micas and dolomite/ankerite. It is important to notice that these authors considered the presence of pyroxene (diopside)

Table 4. Analyses of olivines from the investigated artefacts.

	San Rocco					Mandrga
Sample	SRb-11	SRb-12	SR11	SR12	SR16	3683
SiO_2	40.2	40.4	39.9	38	39.7	39.3
FeO	11.3	11.9	13.1	10.9	11.4	17
MnO	0.2	0.21	0.22	0.23	0.22	0.3
MgO	48.5	47.9	46.5	47.6	48.1	44.1
CaO	0.26	0.23	0.22	0.25	0.23	0.35
Sum	100.46	100.64	99.94	96.98	99.65	101.05
Si	0.989	0.994	0.994	0.971	0.985	0.988
Fe^{2+}	0.232	0.244	0.273	0.232	0.237	0.356
Mn	0.004	0.004	0.005	0.005	0.005	0.007
Mg	1.779	1.757	1.727	1.813	1.78	1.65
Ca	0.007	0.006	0.006	0.007	0.006	0.009
Sum	3.011	3.005	3.005	3.028	3.013	3.010
Fo	88.26	87.6	86.15	88.44	88.03	81.98

and gehlenite as new formation minerals resulting from an high carbonate content in the source clay and a firing temperature of over 950 °C. According to their chemical and mineralogical analyses of the pottery, the amphorae from Sermin were probably made from a clay formed from carbonate marl rocks.

Olivines are not present in the amphorae from Istria, nor in Istria and Trieste soils and siliciclastic rocks.

Nisbet and Pearce (1977) and Leterrier et al. (1982) suggested that the chemistry of pyroxenes can be used in magmatic petrology as an indicator of the affinity of volcanic rocks. In particular, elements as Ti, Ca, Na and Al can be used to discriminate between alkaline, tholeiitic and calc-alkaline basalts. In the Ti vs. Al the amphorae cpx slightly differ from those of the flysch being depleted in Ti at the same Al contents (Figure 5A). In the simplified plot of eigenvector-based discriminant functions F1 versus F2 considering all the major oxides present in the pyroxenes (Nisbet and Pearce, 1977) they fall in the within-plate basalt field, well separated from flysch ones (Figure 5B).

The size of the here studied minerals (garnets, diopsides, olivines) is rather similar each other so that it is difficult to think that diopsides can be a product of firing techniques. Moreover, all of these minerals are very large crystals (up to 3 mm) so that they cannot be compared to the thin minerals present in the local soils or in the flysch sequences of the area. Moreover, the composition of garnets in the here studied amphorae is different from garnets in flysch. Giving all of these, it sounds clear that the local soils and siliciclastic rocks cannot be the raw material of these amphorae.

Comparisons with Italian magmatic provinces and amphorae produced in the Tyrrhenian regions

Comparing the WoEnFs composition of our pyroxenes with those of different Italian magmatic provinces, as Mt. Etna, Hyblean Plateau, Aeolian arc, Campanian Province, Roman Province, Pantelleria Island (Barone et al., 2010; Belfiore et al., 2014), they overlap with the fields of those from the Roman and Campanian provinces.

Feldspars, with an orthoclase content ranging between 54 and 97, are similar to those found in central Italy volcanic province (Melluso et al., 1996; Stoppa et al., 2005). Olivines from San Rocco amphorae present a forsterite content of about 86-88 similar to the Fo_{87-88} shown by Melluso et al. (1996) in Mt. Vulture, while the only olivine analyzed in Mandrga shows a Fo_{82}.

Ti-bearing andradite (often called by the varietal name “melanite”, Grew et al., 2013) have been already found in several amphorae of different period from Yemen, Cyprus, Italy and France, including Greco-Italic and Dressel I forms (e.g. Velde and Courtois, 1983; Cibecchini and Capelli, 2013). Velde and Courtois (1983) found out, according to the MnO and TiO_2 contents of garnets, two distinct compositional groups. According to their observations, they supposed the origin of the garnets being related to the volcanic rocks of the Roman province and Vesuvius area where they possibly concentrated in stream beds or beach sands not far from primary outcrops. According to them, minerals showing a low Mn content could be identified with multiple origins in the Roman area, while those with a higher Mn concentration were tentatively assigned to Vesuvius area.

Melanitic garnets are found in Vesuvian tuffs and volcanic rocks of Roman comagmatic area, while they are rare elsewhere. In the comparison between composition of amphora garnets and garnets found in lavas of the Campanian and Roman magmatic provinces, proposed by Velde and Courtois (1983), they report the composition of two garnets from tuffs along Via Appia (no raw data published in Velde and Courtois,1983), 1 garnet from Frascati (Alban Hills; Huggins et al., 1977), one garnet from Tavolato close to Rome (Baldridge et al., 1981), two garnets from Pompeian eruption (younger then our amphorae) and one garnet from the Avellino prehistoric eruption of Vesuvius. In order to investigate the most probable origin of the investigated amphorae, we included in the same bivariate plot (Figure 6) five additional garnets from the Alban Hills (Schwartz et al., 1980; Schingaro et al., 2004) and 13 garnets from the Mt. Somma-Vesuvius (Scheibner et al., 2007) of which 9 from the Mercato eruption (dated to about 8000 BP) and 4 from the Avellino eruption (dated to about 3550 BP). Both new and old data confirm that the garnets from Alban Hills show a MnO content lower than that of garnets from Mt.

Table 5. Analyses of garnets from the investigated artefacts.

	San Rocco						Sermin		
Sample	SRa-5	SRa-11	SRb-6	SRc-6	R390	R390	R120	R120	R120
SiO_2	34.95	35.33	35.16	34.89	35.58	35.66	36.87	35.33	34.87
TiO_2	2.08	2.14	2.01	2.69	2.15	2.03	1.16	2.05	3.08
Al_2O_3	8.40	8.96	8.47	8.23	8.53	8.58	10.33	6.83	6.91
Fe_2O_3	18.50	17.82	18.74	18.67	18.48	18.33	16.57	21.17	20.92
FeO	1.41	1.54	1.11	1.09	1.47	1.72	0.00	0.00	0.00
MnO	1.92	1.99	1.88	1.40	1.81	1.86	0.31	0.67	0.63
MgO	0.09	0.10	0.08	0.24	0.13	0.10	0.36	0.38	0.44
CaO	30.90	31.01	31.46	31.44	31.27	31.01	34.58	33.06	32.89
Sum	98.25	98.89	98.91	98.65	99.42	99.29	100.18	99.49	99.74
Si	2.896	2.900	2.894	2.876	2.908	2.919	2.943	2.898	2.854
Ti	0.130	0.132	0.124	0.167	0.132	0.125	0.070	0.126	0.190
Al	0.820	0.867	0.822	0.799	0.822	0.828	0.972	0.660	0.666
Fe^{3+}	1.153	1.101	1.161	1.158	1.137	1.129	0.995	1.307	1.288
Fe^{2+}	0.097	0.106	0.076	0.075	0.100	0.118	0.000	0.000	0.000
Mn	0.135	0.138	0.131	0.098	0.016	0.129	0.021	0.047	0.044
Mg	0.011	0.012	0.010	0.029	0.016	0.012	0.043	0.046	0.054
Ca	2.744	2.727	2.774	2.776	2.738	2.719	2.957	2.905	2.884
Sum	7.986	7.983	7.992	7.978	7.869	7.979	8.001	7.989	7.980
Py	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67
Alm	2.79	2.91	2.29	2.11	2.58	2.94	0.00	0.00	0.00
Sp	4.55	4.69	4.41	3.33	4.26	4.39	0.00	1.58	0.00
Gro	28.98	31.38	29.38	29.05	30.39	30.81	46.46	26.77	24.93
And	58.44	55.95	58.55	59.16	58.01	57.69	50.55	66.39	65.88
Sch	5.25	5.07	5.37	6.35	4.69	4.16	2.89	5.18	7.49

Somma-Vesuvius. The single garnet from Tavolato shows at its centre a TiO_2/MnO ratio similar to some garnets from the Avellino eruption but a higher TiO_2 content in correspondence of the rim. Thanks to the available data of Mt. Somma-Vesuvius garnets, we are able to distinguish among minerals from the Avellino eruption, characterized by an increase of MnO content accompanied by a decrease in TiO_2, from those of the Mercato eruption, showing a less variable composition and high MnO content.

The garnets from the San Rocco amphorae (SRa, SRb and SRd), including the Greco-Italic amphora SRa, and from the Sermin Dressel 1a (R390) show TiO_2/MnO ratios comparable with minerals of the Avellino eruption of Mt. Somma-Vesuvius, while the garnets from Greco-Italic amphora R120 from Sermin are characterized by a lower MnO content comparable with that of Alban Hills garnets (Figure 6).

If we consider the Greco-Italic and Dressel 1a amphorae analysed by Velde and Courtois (1983), it is interesting to note that one of them, from Conglue (most probably corresponding to Grand Congloué 1; see e.g. Cibecchini and Capelli, 2013), falls in the low-MnO group of Alban Hills garnets, such as the Greco-Italic amphora from Sermin R120. The Greco-italic amphorae from Grand Congloué 1 shipwrek have been classified as Gr.-Ita VIb type by Cibecchini and Capelli (2013), partially corresponding to Lyding Will 1c type (Lyding Will, 1982), dated to the first decades of 2nd century BC. This chronology could well correspond to that of the amphora R120 from Sermin. The Greco-italic amphorae from Cala Rossa (with graffito L. AURE) and Tour d'Agnello studied by Velde and Courtois (1983) contain garnets with a composition well comparable to that of garnets from the Mercato eruption, while the SRa sample here investigated fall very close to the Avellino eruption garnets. This difference could be related to the different chronology of San Rocco Greco-Italic amphora SRa and those from Cala Rossa and Tour d'Agnello shipwrecks. The amphorae from the last localities have

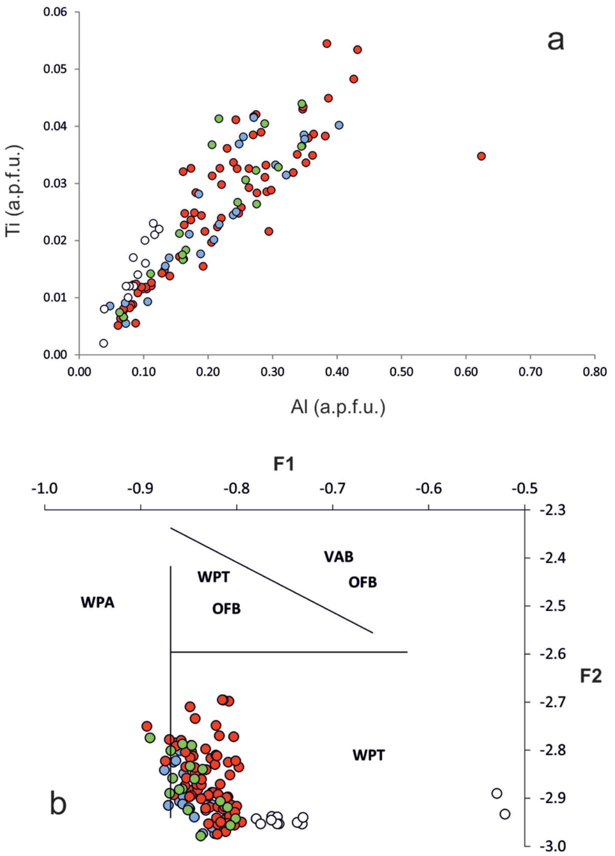

Figure 5. Ti (a.p.f.u.; atoms per formula units) vs. Al (a.p.f.u.) for the studied cpx (a). Simplified plot of eigenvector-based discriminant functions F1 versus F2 (b; after Nisbet and Pearce 1977). VAB: volcanic arc basalts, OFB: ocean floor basalts, WPT: within-plate basalts; WPA: within-plate alkali basalts. F1: -0.012 x SiO_2 - 0.0807 x TiO_2 + 0.0026 x Al_2O_3 - 0.0012 x FeO - 0.0026 x MnO + 0.0087 x MgO - 0.0128 x CaO - 0.0419 x Na_2O; F2: -0.0496 x SiO_2 - 0.0818 x TiO_2 - 0.0212 x Al_2O_3 - 0.0041 x FeO - 0.1435 x MnO - 0.0029 x MgO - 0.0085 x CaO + 0.0160 x Na_2O. Red circles: San Rocco cpx; blue circles: Sermin cpx; green circles: Mandrga cpx; open circles: cpx from flysch (Lenaz, 2008).

been assigned by Gr.-Ita Vc type (Cibecchini and Capelli, 2013), partially corresponding to MGS/RMR VI type of Vandermersch (1994, 2001) and Lyding Will 1b (Lyding Will, 1982), dated to the last quarter of 3rd century BC. San Rocco Roman site has been probably occupied not before the beginning of the 2nd century BC (Bernardini et al., 2015).

Excluding the low-MnO specimens, all the Dressel 1a and most of the Dressel 1b amphorae analysed by Velde and Courtois (1983) fall close to the Mercato eruption garnets, while the Sermin R390 Dressel 1a amphora falls close to the Avellino eruption ones (Figure 6).

CONCLUDING REMARKS

Considering the extension of the Roman Republic at that time and the geology of the areas, the composition of pyroxenes, feldspars and olivines suggest that all the investigated samples, including both amphorae and baking dishes, are imported and most likely originate from the Roman or Campanian magmatic provinces. Only later, between the 1st century BC and the 1st century AD, local clays will be used as shown by Mange and Bezeczky (2006, 2007), Bezeczky and Mange (2009) and Józsa et al. (2016).

Our study, adopting a non-invasive approach, confirms that the chemistry of garnets can be considered as a tracer of ancient commerce, useful to discriminate among multiple sources within the two above mentioned magmatic provinces. Of course, a reliable definition of its efficacy and limits would require a much larger number of archaeological and comparative geological materials.

Nevertheless, according to our preliminary results, most of the samples bearing garnets, including the San Rocco SRa Greco-Italic amphora and the Sermin R390 Dressel 1a amphora, would originate from Mt. Somma-Vesuvius area, more precisely from the Avellino eruption deposits, while the R120 Sermin Greco-Italic amphora from Latium and in particular from Alban Hills area.

Our results demonstrate that during the early Romanization of *Caput Adriae*, relatively rare Republican amphorae produced in Campania or Latium were imported to the region. Their presence at San Rocco, a large military fortification probably established in connection with the Roman conquest of Istria (178-177 BC), could be related to the presence of the Roman army.

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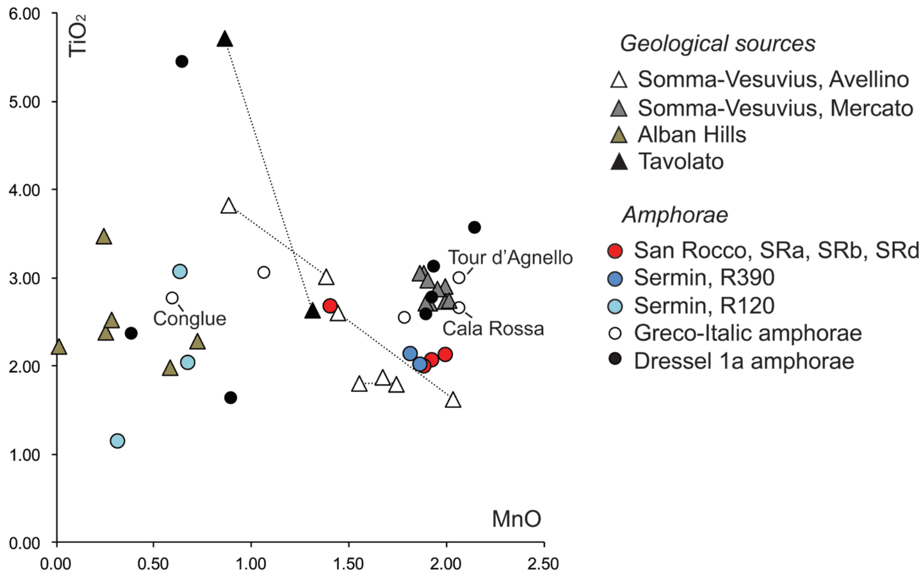

Figure 6. Percentage weight plot of TiO_2 vs. MnO in garnets from amphorae and geological outcrops (geological data from Huggins et al., 1977; Schwartz et al., 1980; Baldridge et al., 1981; Schingaro et al., 2004; Scheibner et al., 2007) . White and black circles correspond to Greco-Italic and Dressel 1a amphorae studied by Velde and Courtois (1983). Symbols linked by dotted lines refer to analyses performed in different areas of the same zoned crystal.

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