

Petrography and Provenance of Laecanius Amphorae from Istria, Northern Adriatic Region, Croatia

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Amphorae sherds from the Laecanius workshop of Roman Istria (10–5 B.C. and 78 A.D.), Croatia, were studied by integrating archaeological and geological techniques including fabric analysis, thin-section petrography, X-ray diffractometry (XRD), and heavy mineral analysis. The fabric of the sherds showed distinctive characteristics, permitting their classification and allocation into nine fabric groups. Petrography revealed that quartz is the dominant clastic component, whereas carbonate is common as temper; XRD provided information on firing temperatures that ranged between 750 and 900°C. The sherds contain diverse heavy mineral suites with generally high epidote and garnet proportions; zircon is occasionally important. Garnet/epidote ratios and the presence of diagnostic species (pyroxene, hornblende) showed systematic variations that coincided with similar variations in fabric characteristics. Heavy mineral signatures of amphorae produced in other workshops proved essential in differentiating them from Laecanius sherds. A comparative heavy mineral analysis of terra rossa samples from the vicinity of the workshop indicated that terra rossa was the major source for the paste. Differences observed in the heavy mineral composition of the sherds and terra rossa were interpreted by the spatial heterogeneity of the latter and the mixing of the paste with sandy temper. Fresh Adriatic sponge spicules in the majority of Laecanius sherds and the temper-derived, generally immature heavy mineral assemblages suggest that sandy deposits from the Adriatic were used for the clastic temper.

INTRODUCTION

Archaeology and geology have long benefited from collaboration because archaeological raw materials are predominantly geological. Geological laboratory techniques are, therefore, important in the analysis of artifacts made of stone or clay, the principal inorganic raw material of ancient times. Pottery is one of the most abundant artifacts at any Roman-period archaeological site, and the study of amphorae occupies a distinguished place in Roman ceramics research. Amphorae were the large two-handled pottery containers of the Greek and Roman world, used for the storage and transportation of liquids, especially wine, olive oil, and other foodstuffs.

We conducted an interdisciplinary study on Roman amphorae manufactured during the first century A.D. at a prominent workshop on the western coast of the Istrian Peninsula in the northern Adriatic region. The aims of this study were (a) to use heavy mineral analysis, thin-section petrography, and X-ray diffractometry (XRD) to complement archaeological methods in the characterization and grouping of the amphorae, and (b) to determine the provenance of the material used for the paste and temper. Knowledge of the source and composition of raw material can provide insight into ancient transport, trade routes, and manufacturing practices, and reveal improvements or decline in technology. Output variation is controlled principally by the strength of the economy; therefore, any new knowledge on the production, distribution, and dating of amphorae from any Roman period will advance understanding of contemporary economy. The prolonged existence of pottery workshops in Istria, supported by the high output of agricultural products, has long been the focus

of archaeological research (Manacorda, 1994; Mazzocchin and Pastore, 1996–1997; Bezeczky, 1998; Cipriano and Mazzocchin, 1998; Martin-Kilcher, 2000; Pesavento et al., 2000; Tassaux, 2001), and in our integrated study, we concentrate on a so-far unexplored field of ceramics research in Istria.

Key words: Dressel 6B amphorae, fabric analysis, heavy mineral analysis, temper, provenance

THE ISTRIAN PENINSULA, PHYSIOGRAPHY, AND GEOLOGY

The Istrian Peninsula in westernmost Croatia occupies an area of 2.820 km² (Figure 1, inset), rising from sea level to about 1400 m in the Cicarija Mountains to the northeast. The southwestern part of the Peninsula is a 300-m-high karst plateau with a typical karstic landscape, characterized by 5–10-m-deep dolines (sinkholes) and karren (limestone pavements). The soil here is the conspicuous terra rossa, a red clay to silty-clay soil widespread throughout the Mediterranean. Terra rossa is intimately linked to carbonate rocks and is thus typically associated with karstic features, filling in cracks and sinkholes (Durn et al., 1999; Miko et al., 1999). This area is commonly referred to as “Red Istria” because of the intense red color of the soil. The Trieste-Pazin belt in central and northwestern Istria, with its grayish marly or sandy soil, is called the “Gray Istria.” The Cicarija Mountains to the north, with their bare white cliffs (“White Istria”), form a prominent background to the whole region. The geology of the Istrian Peninsula is relatively simple (Figure 1). As part of the northwestern region of the Adriatic Carbonate Platform (Velic et al., 1995), it comprises three principal units: (a) the Upper Jurassic to Cretaceous carbonate plain of southern and western Istria, (b) Cretaceous-Paleogene carbonate-clastic sequences occupying the eastern and northeastern part of Istria, and (c) a Paleogene flysch basin in central Istria. Upper Pleistocene loess occurs only in the southern and northeastern regions (Durn et al., 1999).

Historical Background

After the end of the Roman Republic and the chaos of civil war from which Augustus emerged victoriously in 31 B.C., the Roman Empire entered into a phase of peace and security that spread throughout the Empire and influenced, for a long time, the life and economy of the provinces. Political stability created economic well-being with thriving trade and cultural vitality throughout the Mediterranean. In the late Republican period,

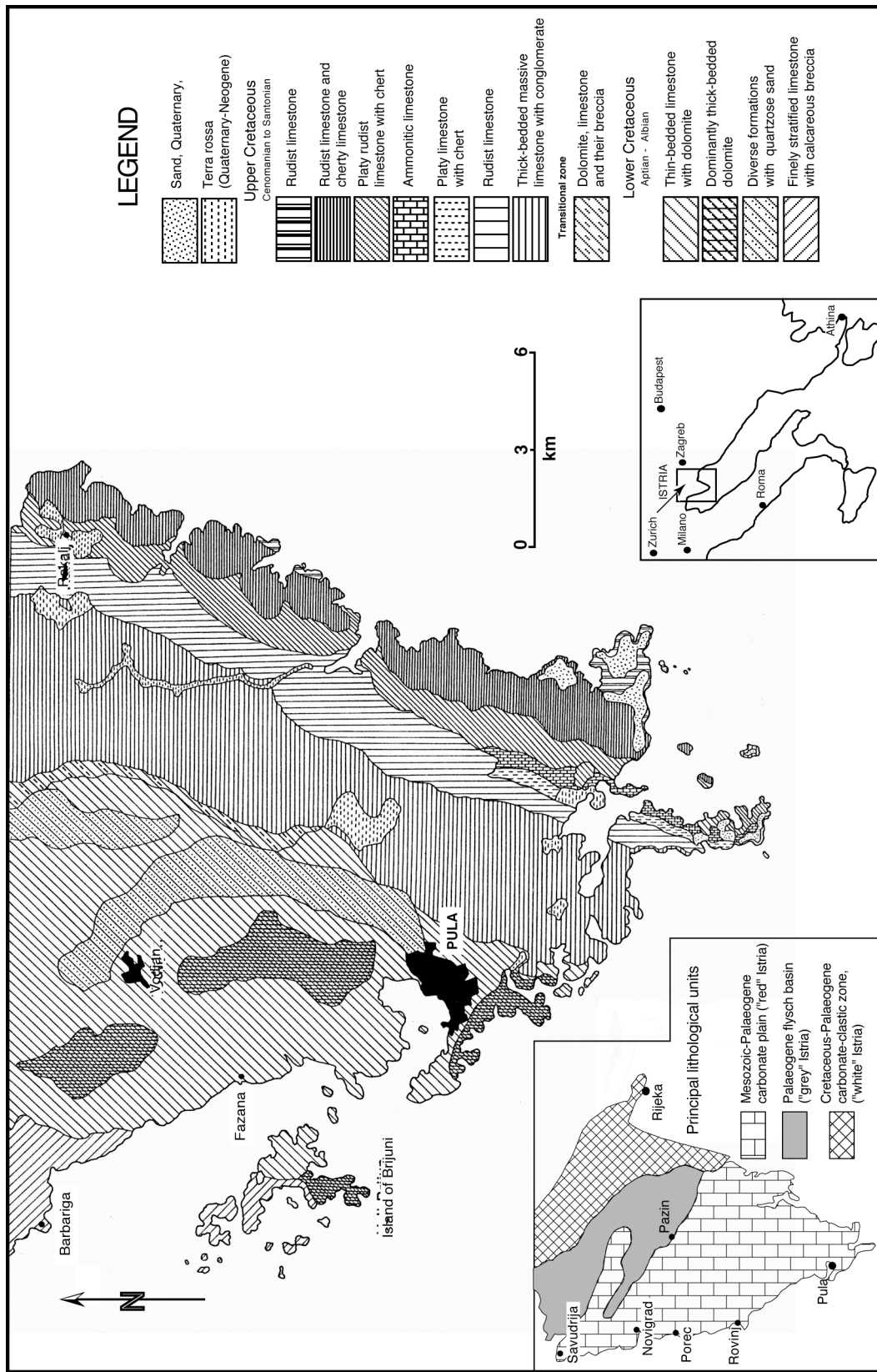


Figure 1. Simplified geological map of the southern part of Istria (after Poliak, 1964). Inset shows the three principal geological regions of Istria.

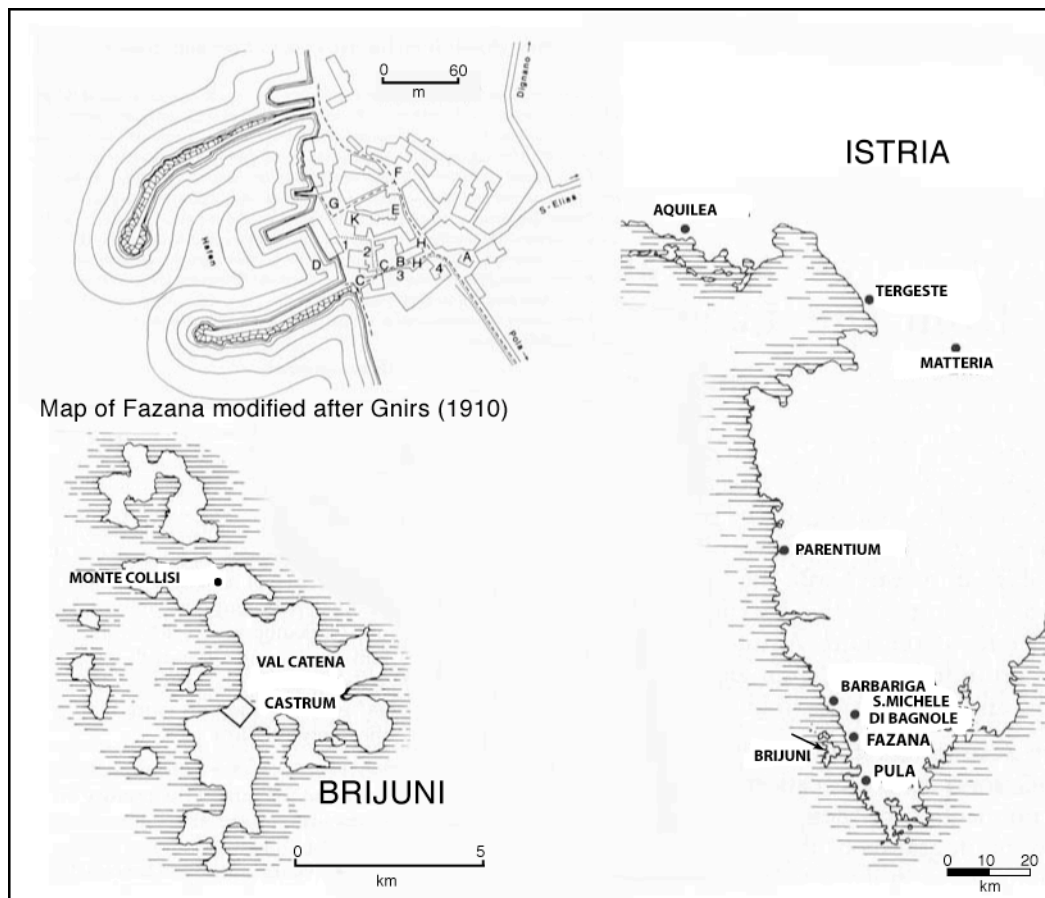


Figure 2. Historical map of Istria and detailed map of Brijuni and Fazana.

new settlements were established on Istria and their development continued in the early phase of the Empire (Figure 2). Augustus showed a continued interest in the region since the beginning of the war against Iapodes (35–33 B.C.). Two friends of his inner circle, Statilius Taurus and Maecenas, also owned properties in Istria. The Istrian wine reached the emperor’s table. Pliny (NH 2.127; 16.60; 17.31) tells us that Empress Livia liked the wine produced in Pucinum, near Tergeste.

In the Mediterranean climate, a thriving agriculture developed and produced large quantities of wine and olives. The ancient sources (Pliny the Elder NH 15.9) regarded Istrian olive oil as one of the best on the market. The Roman proprietors of the villas on the Peninsula cultivated, harvested, and processed the olives; they also had their own oil presses, storage cellars, and ceramic workshops. The amount of olive oil produced by the Istrian agricultural estates (villas) was sufficient to fulfill the need of all the northern Roman provinces (Raetia, Noricum, and Pannonia) and those in northern Italy for more than a century. Excavations in these regions have brought to light large quantities of amphorae, both in civil settlements and in military camps. The production of olive oil in Istria, from the end of the first century B.C. to the beginning of the second century A.D., is well documented. Towards the end of the reign of emperor Hadrian (A.D. 117–138), the Istrian olive oil suddenly disappeared from the market, and from that time, the villas satisfied only the local demand (Bezeczky, 1998).

The Istrian Villas

From Pula to Tergeste, traces of several villas with olive-producing facilities (Matijasic, 1993) have been discovered (Figure 2). The owners of the properties were mainly senators and members of the Roman elite (Tassaux, 2001). One of the best-known owners was the Laecanius family. They owned a villa at Fazana, 9 km north of Pula, a well-known amphora workshop in Istria (Figure 2). Gnirs (1910) who also found the amphora kiln of the workshop, excavated the villa at the turn of the last century. Between 10–5 B.C. and 78 A.D., the amphorae produced in this workshop were shipped to northern Italy and provinces beyond the Alps. Amphorae from this workshop have been found in 53 ancient sites in Italy, Austria, Croatia, Slovenia, Switzerland, Hungary, and Yugoslavia (Mazzocchin and Pastore, 1996–1997; Bezczky, 1998; Cipriano and Mazzocchin, 1998; Pesavento et al., 2000).

The Villas and Workshops

Besides the villa and workshop (*figlina*) in Fazana, the remains of three other villas were discovered on the Island of Brijuni where amphorae, marked with Laecanius stamps, were identified. No other owner's stamps were found, so these villas were also interpreted as being the property of the Laecanius family (Bezczky, 1998, Tassaux, 2001). The Val Catena villa in Brijuni (Verige Bay) was a luxurious maritime villa with elegant peristyles and colonnades, developed atria, bathrooms, and an industrial area. Gnirs found another *villa rustica* on Monte Collisi (Kolci hill), on the northwestern part of the island (Gnirs, 1908; Bezczky, 1998). There is another villa in Dobrika Bay, in the western part of the Island of Brijuni (Girardi Jurkic, 1985; Matijasic, 1993; Bezczky, 1998). This villa was surrounded by a late Roman/Byzantine fortress (*Castrum*). In the three villas, the storage capacity of the cellars was 10,000–12,000 amphorae annually. The products of the *figlina* include amphorae, stoppers, *dolia*, tiles, clay lamps, *spicae*, and heating pipes.

The Laecanius amphorae are regarded traditionally as belonging to the Dressel 6B type (Figure 3), which is a typical product of the Istrian peninsula (Baldacci, 1967–1968; Carré, 1985). This form is characteristic for all the Laecanian amphorae, although there may be some variations among the individual pieces. There are differences even among amphorae with the same stamp. The most important feature of the Dressel 6B amphora is the chalice-shaped rim, which meets the neck at a sharp angle. The outer contours are continuous along the body and the handles, and the upper ends of the handles are attached below the rim and onto the neck. The body is oval with a short stub base. Unfortunately, very few complete amphorae have been found; the overwhelming majority are fragmentary. Each amphora had two stamps on the rim with the stamp of Laecanius at the center and the second stamp, the *vilicus's* (estate manager) stamp, above the handle (Figure 4). The names of more than 40 successive *vilici* are preserved in these stamps, providing a relative chronology for the workshop. Furthermore, these names also allow dating of the various phases in its history (Bezczky, 1998).

There are three known phases of the *figlina* at Fazana. From the end of the first century B.C. to A.D. 78, it belonged to the Laecanius family. During the reign of

Emperor Vespasian (A.D. 69–79), the last Laecanius died without an heir and the ownership was taken over by the ruler of the Empire. Around the last third of the second century A.D., it is presumed that M. Aurelius Iustus rented the workshop, but from this period, only small amphorae without stamps were found. The figlina's whole history can be read from the stamps, from the stone inscriptions, and from ancient sources (Bezeczky, 1998; Tassaux, 2001).

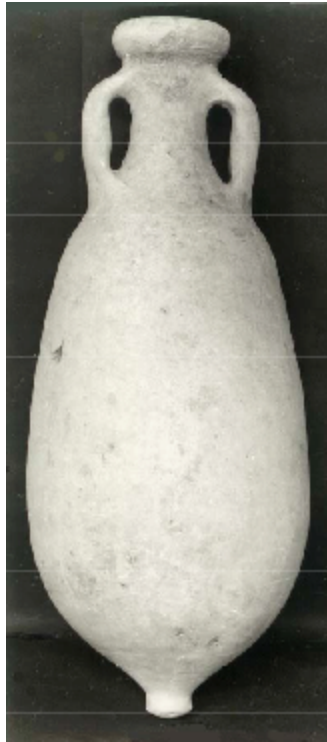


Figure 3. Dressel 6B type amphora, a typical product of Istria.

METHODS

Archaeological Methods

Fabric analysis is an important first step in the characterization of ceramic raw material and for providing an insight into processes used in the manufacture of pottery. Characteristics utilized are color, physical properties, texture, and inclusions. These properties vary between sherds; therefore, it is essential to allocate those with similar characteristics into discrete fabric groups. Sherds with corresponding fabrics indicate similar raw material and production technology.



Figure 4. Amphora stamps showing the stamp of Laecanius (left) and that of the vilicus (right).

Geological Methods

Because ceramics are anthropogenically prepared and high-temperature-fired products of naturally occurring, predominantly “soft” rocks, geological laboratory techniques developed for the analysis of their source counterparts are equally suitable for ceramic analysis. In this study, we employed X-ray diffraction and thin-section petrography to determine the framework components, and, for the first time on Laecanius amphorae, heavy mineral analysis.

Three hundred seventy-four thin sections were made from the available sherds. Because of the minute size of some sherds, many thin sections were of poor quality, and

only 174 were suitable for both qualitative and quantitative analyses. Microscopic components were identified under the polarizing microscope, their abundance was quantified, and their size was recorded. These analyses, conducted by Józsa and Szakmány (1987) and Józsa et al. (1994) were carried out for an earlier project and subsequently published, but for completeness, their results are included in the current study.

Heavy Mineral Analysis

Heavy mineral analysis (minerals with densities > 2.89) is a versatile technique used in the geosciences. It is one of the most sensitive approaches for the reconstruction of sediment provenance (Morton, 1985; Mange and Maurer, 1992). Used alone or integrated with thin-section petrography, heavy mineral data provide important clues to the lithology of source regions. This, in turn, permits grouping and identification of sediments derived from a common source and their differentiation from those of different provenance.

Peacock (1967, 1970) was one of the first to recommend heavy mineral analysis as an archaeometric tool, especially for ceramics. He emphasized its potential in sourcing raw material and promoting accuracy in classification and grouping. Identification of the temper added to the paste is important for the reconstruction of methods used by different workshops. Heavy mineral analysis is a valuable and efficient tool for temper characterization. Over the years, numerous researchers have proved the potential of heavy mineral analysis in the study of ceramics, especially amphorae (Williams, 1977; Peacock and Williams, 1986). In addition to pinpointing geological source areas, heavy mineral signatures have helped to differentiate between pottery made from two known sources (Williams, 1982). In recent years, the heavy mineral technique for ceramic analysis was used in Austria (Sauer, 1989–1991; 1997; Zabehtlicky-Scheffenegger et al., 1996) to obtain new information for provenance evaluation and for comparative purposes.

We performed heavy mineral analysis on Laecanius amphorae sherds manufactured in the Fazana workshop in Istria and found either in Fazana, other locations on the island, or in more distant places, such as Magdalensberg (Austria) and Aquincum (Hungary). Our objectives were (a) to trace the sources of raw material that were poorly understood until now and (b) to compare and differentiate the products of various coeval workshops in the region. Study material included 50 amphora sherds, one spica sample, five sherds from other workshops in the region, and six surface samples collected from quarries near Pula and Rovinj (Figure 1).

Sample preparation and heavy mineral separation was carried out using the technique described by Mange and Maurer (1992). Neck, rim, or handle fragments proved to be most suitable for the analyses because of their larger size (though rarely larger than 2x2 cm), which is required to obtain sufficient heavy mineral residues. They were gently crushed using a mortar and pestle and sieved frequently through a 300- μm -diameter sieve to prevent overgrinding and breakage of the grains. The fine substances were removed by wet sieving, using a sieve of 40 μm in diameter. The dry material was sieved, retaining the finer than 210 μm fraction for the heavy mineral separation. This relatively “coarse” size was chosen for the upper grain-size limit to

avoid overlooking any informative species that might occur in the coarser grades. Separation was performed in bromoform (density 2.89), using the centrifuge and partial freezing method. Heavy mineral residues were mounted in liquid Canada balsam on microscope slides, identified, and point-counted under the polarizing microscope. All non-opaque grains were counted, including micas. The latter were counted separately and used for general information or comparison. Of the 50 sherds prepared and separated, only 31 yielded sufficient amounts of heavy residue for counting 150–200 grains per sample, excluding micas.

RESULTS

Fabric Analysis

Fabric analysis was carried out under the stereo microscope at 20 magnification, focusing on physical properties and microscopic content. Detailed examination and variations of these properties permitted the separation of the Laecanius amphorae sherds into discrete fabric groups labeled A–I (Table I). Their characteristics are summarized in the Appendix. Within groups A–I, four main groups, A, B, E, and H were defined. Some sherds have the characteristics of types A and B, but because they were fired at higher temperatures, as discussed below, separate groups, C and D, were created for them. Some enigmatic pieces were allocated into groups G and I. As seen from Table I, about 80% of the amphorae belong to fabric groups A–D.

The Munsell-Soil color of the fresh breaks and surfaces was recorded. The amphorae generally are light red (2.5YR 6/6–6/8), red (2.5YR 5/6–5/8), or reddish-yellow (5YR 7/6–6/8). These are typical colors of the Istrian amphorae (Figure 5). By contrast, the color of group E is pink with a porcelaneous groundmass. Sherds in groups G and H are light red and pink (2.5 YR 6/6 and 5YR 7/4) and they contain not only pieces of carbonate rocks but also fine calcareous matter dispersed in the fabric.

The hardness, feel, and fracture of the clay, as well as the frequency, sorting, size, rounding, and composition of the inclusions in the clay matrix, were described (Peacock, 1977, 1984). Hardness was described as soft, hard, or very hard. Ceramics in the “hard” and “very hard” categories can be scratched with a knife. This applied to all categories, except fabric A in which pieces were soft and could be scratched with a fingernail. Feel included harsh, rough, smooth, soapy, or powdery. The feel of all studied amphorae was smooth, a result of the small size range of the sand inclusions. Fracture was described as conchoidal, smooth, hackly, or laminated. The fracture of Fazana amphorae is “hackly” showing a jagged, irregular surface with sharp edges.

Inclusions are embedded particles that can be a natural component of the clay raw material or that have been intentionally added by the potter as temper to improve cohesion of the clay during working and firing and to increase durability. Description and categorization of the inclusions followed the criteria defined by Peacock (1977, 1984). (a) Approximate frequency values: sparse < 5%, moderate 5–10%, common 10–30%, abundant > 30%. (b) Sorting: well sorted and poorly sorted. In the majority of the Fazana amphorae, the inclusions are poorly sorted, with a moderate alignment

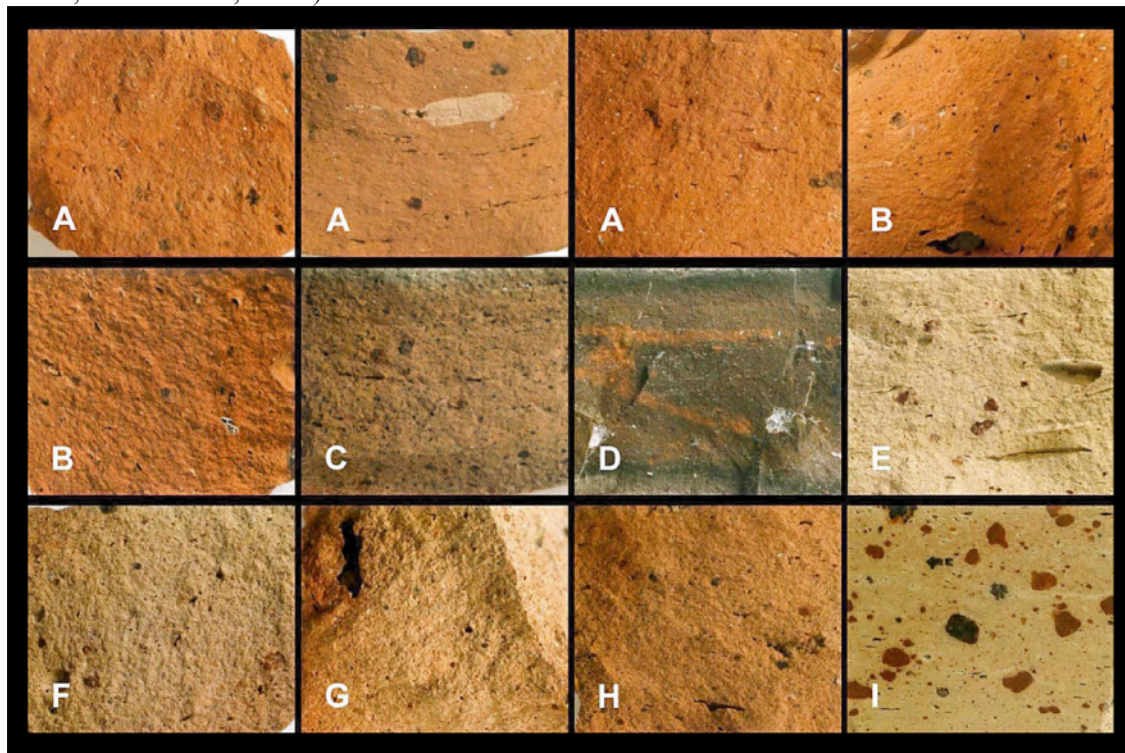
of the grains. (c) Size of the inclusions. (d) Rounding grade: angular, subrounded,

Table I. Fabric groups of the Laecanius amphorae sherds and their percentage distribution in each group.

Fabrics	A	B	C	D	E	F	G	H	I	Total
%	40.9	26.6	2.7	9.8	8.2	1.6	2.3	7.0	0.9	100

rounded. The inclusions were only slightly rounded in most of the products of the Fazana workshop. (e) Composition: a measure of the percentage distribution of individual inclusions in sherd thin sections was given by Whitbread (1995, Table A3.1, p. 379) for Greek transport amphorae as: predominant > 70 %, dominant 50–70%, frequent 30–50%, common 15–30%, few 5–15%, very few 2–5%, rare 0.5–2%, and very rare < 0.5%. Percentages of inclusions in the Fazana workshop’s amphorae are given in the Appendix. Photographs in Figure 5a, made under the stereo microscope, depict representative specimens from each fabric group.

Microscopic inspection revealed differences both in the groundmass and in clast content, even in amphorae marked with the same stamps. It is possible that such amphorae were produced in different years with the raw material coming from a different bed of the same clay outcrop or from another location. The individual analysis of the rim, neck, body, and handle of one particular amphora revealed that the handle was made of a stronger material, suggesting that either the phases of the manufacturing were well coordinated (i.e., different paste was used for different parts of the amphorae according to their functions) or this reflects the potter’s skill (Bezczky, 1987; Manacorda, 1994).



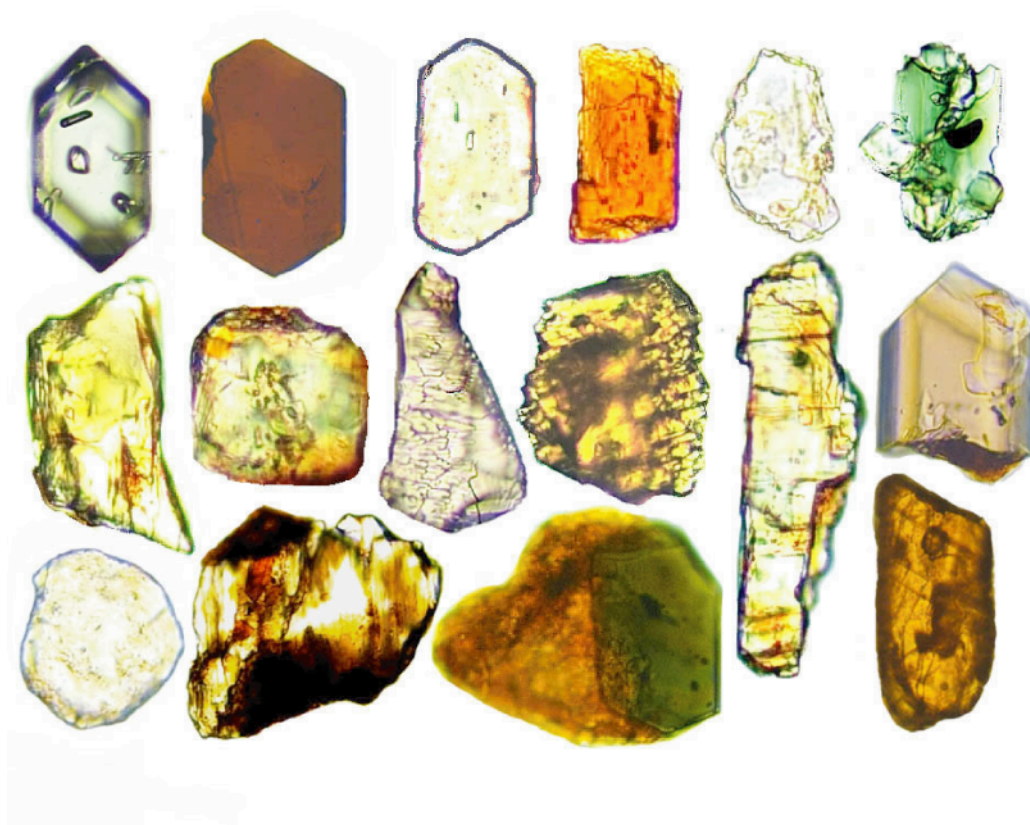


Figure 5. (a) Representative sherds from each fabric group. (b) Photomicrographs of heavy minerals in the sherds. Top row: a. euhedral volcanogenic zircon; b. hexagonal volcanogenic biotite; c. apatite, gently rounded euhedral, also of volcanic derivation; d. brown hornblende of probably volcanic origin; e. volcanic glass shard, note the very low relief of the grain; f. fresh blue-green hornblende, presumably temper-derived. Middle row: a and b. epidote grains; c. etched garnet; d. etched staurolite showing characteristic “cockscomb” character; e. kyanite with rounded edges; f. broken sharp euhedral tourmaline. Bottom row: a. rounded apatite grains; b. etched pyroxene; c. slightly rounded green tourmaline prism, note adhering matrix; d. rounded rutile prism.

X-Ray Diffraction (XRD)

XRD analysis of the Dressel 6B amphora sherds from the Fazana workshop was performed by Weiszburg and Papp (1987) and later by Józsa et al. (as cited in Bezezcky, 1994). Quartz is the dominant mineral phase in all samples. Calcite, clinopyroxene (diopside) gehlenite, mica (illite), and plagioclase feldspars were found only in low proportions. Weiszburg (as cited in Jòzsa et al., 1994), using XRD analysis alone, was unable to determine whether diopside was formed during the firing of the amphorae, was added to the paste as temper, or was present in the raw material. Our optical analyses showed that the pyroxenes, crystallized during the firing of the amphorae, are submicroscopic in size and have no relationships to detrital pyroxenes encountered in the heavy mineral fraction.

XRD provided the key for the reconstruction of firing temperatures that varied between 750 and 900°C. The range of the firing temperature was constrained by the stability of carbonate components and by the neoformation of calcium silicates. At “low” temperatures, carbonate (added to the clay as temper, indicated by the study of inclusions) is present, but pyroxene and gehlenite are absent. “Moderate”

firing temperature initiates the transformation of carbonate, though it is still recognizable. At this temperature, pyroxene and gehlenite also appear. At “high” temperatures, carbonate is no longer present, whereas calcium silicates (pyroxene and gehlenite) can be positively identified. There is a clear relationship between particular fabric groups and the temperatures at which the amphorae were fired. For example, sherds from fabric A contained the largest amount of remaining carbonates, indicating that most of them were fired at low or medium temperatures. Samples from fabric B contained specimens that were fired at all three temperatures. The black-colored amphorae, assigned to fabric D, were fired mostly at low temperature, deduced from the presence of carbonate in all the investigated sherds.

Temperature/Fabrics	A	B	D	E	F	H
‘low’	26	2	3			
‘moderate’	9	2				
‘high’	1	4	1	2	2	2

Table II. The distribution of the analyzed sherds according to “low,” “moderate,” and “high” firing temperatures.

Their dark color was probably caused by a subsequent fire, occurring only at low or moderate temperatures. Such dark sherds were found mainly in Fazana, Aquileia and two in Magdalensberg. All specimens of fabrics E, F, and H were fired at high temperatures. The ultimate, nondetrital composition of the examined sherds thus clearly reflects the impact of the particular firing temperature; in sherds from groups A and B, fired at low to moderately high temperature, the carbonate particles are either intact or show partial destruction. Carbonate was completely eliminated from amphorae fired at high temperatures. In these, the loci of carbonate inclusions exhibit a clear, well-defined reaction rim. The distribution of the analyzed samples according to firing temperature is shown in Table II, and indicates that firing temperatures were predominantly in the low range.

Thin-Section Analysis: Framework Components

Qualitative and quantitative analyses on 174 thin sections were conducted by Józsa and Szakmány (1987) and Józsa et al. (1994). Their overall characteristics are summarized below and illustrated in Figure 6. The clayey groundmass is mostly medium or dark brown or reddish-yellow; only a few samples show grayish-brown shades. Clastic particles, comprising 4–8% of the total, are generally angular, with the siliciclastic types appearing in three size populations: 30–60, 40–80, and 100–150 μ m. These include monocrystalline quartz, polycrystalline quartz, low quantities of plagioclase and potassium-feldspar, and small amounts of chert. The latter is limited to particular fabric groups only. Micaceous minerals include biotite and fine flakes of white mica. Lithic fragments, detected in a few sherds, include micaschists, phyllite, fine sericitic schists,

sandstone and, rarely, volcanic particles. Almost every amphora sherd contains groundup carbonate fragments, mostly sparry or micritic carbonate from tempering the clay with limestone. Such additives were also discerned during the examination of the fabric. In thin section, these fragments are readily distinguished by their conspicuously large size and the absence of microfauna (Figure 6). There were also microfossils embedded in the groundmass, including foraminifera, various shell fragments, and siliceous sponge spicules. Sherds from amphorae fired at high temperature have a glassy groundmass with secondary calcite crystals. Figure 7 illustrates such calcite crystals in the mounted bulk material prior to heavy mineral separation.

Systematic variations in the percentages of the major components, monocrystalline and polycrystalline quartz, feldspars (potassium feldspar and plagioclase), carbonate, and lithic fragments permitted the establishment of 15 petrographic groups. Statistical analysis was performed on the thin-section data from groups with

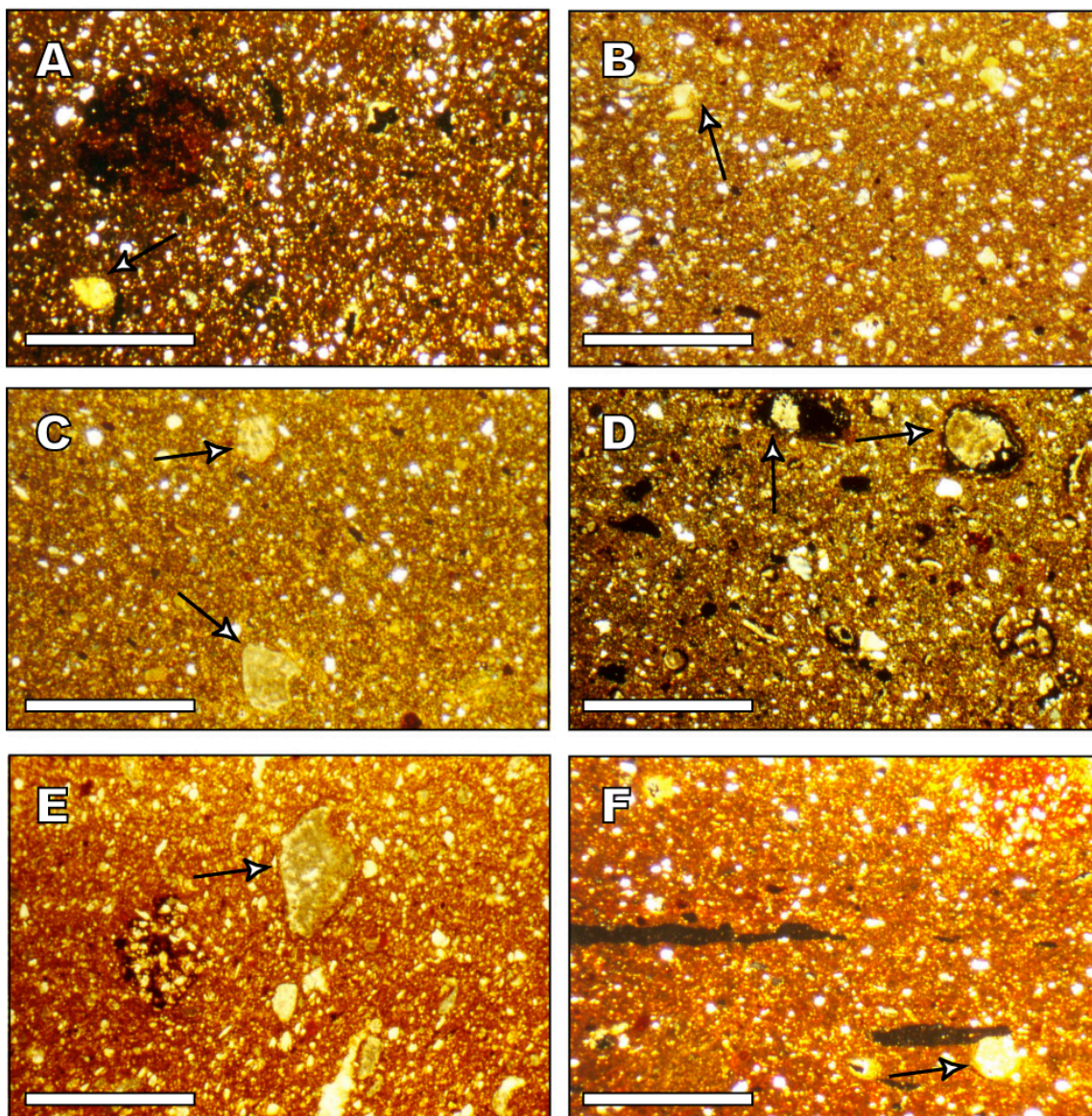


Figure 6. Thin sections of sherds from different fabric groups. Arrows show carbonate inclusions. B, C, E from group A; A, F from group H; and D from group C. Scale bar: 600 μ m.

an appreciable number of samples. The mean values of quartz, feldspars, and lithic fragments were plotted in a QFL (Dickinson, 1985) diagram that shows the dominance of quartz, characteristic of residual deposits (Figure 8).

The bivariate plot in Figure 9, with the mean of quartz abundance against standard deviation, signals affinities between the petrographic groups. Four separate clusters indicate particular relationships: Groups 1, 6, and 11, with the highest quartz content (and little or no carbonate) form a discrete cluster. Groups 4 and 13 have the lowest amount of quartz (and varying proportions of carbonate) and occupy a separate field. Groups 2, 7, and 15, with moderate to high quantities of quartz and carbonate and the

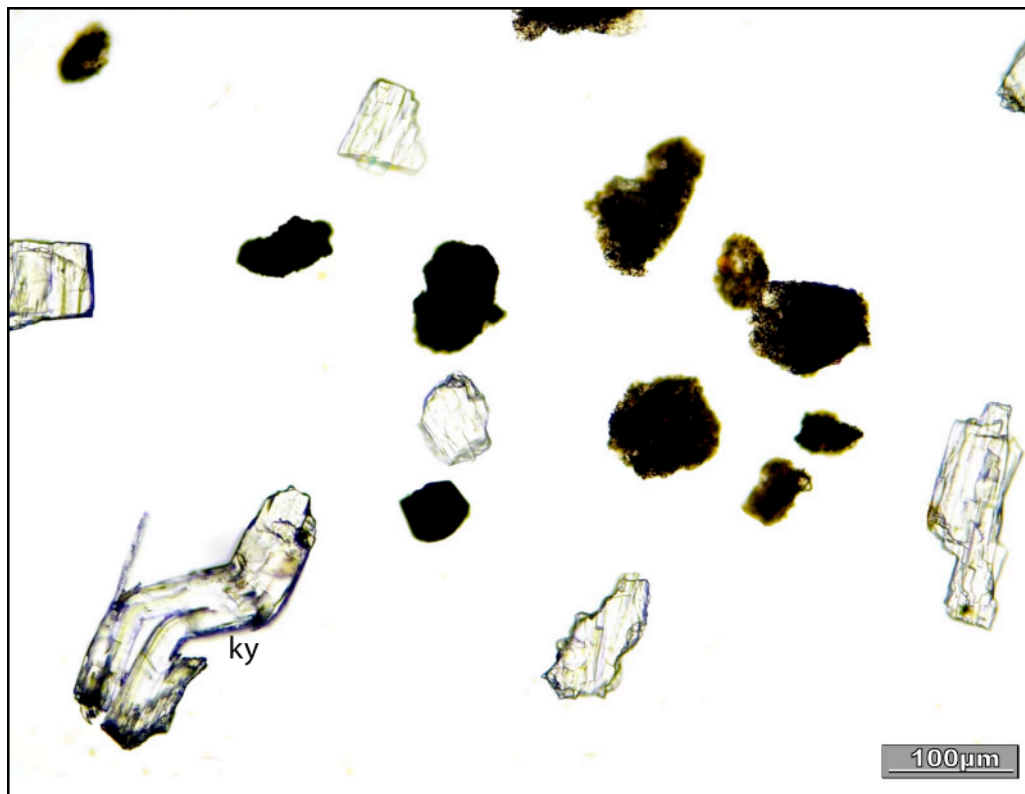


Figure 7. Grain mount of a high-temperature fired specimen containing newly formed calcite crystals and a bent, etched kyanite (ky) grain.

lowest standard deviation, can also be differentiated. Groups 5 and 9 occupy an intermediate position in the plot characterized by intermediate amounts of quartz, either abundant or absent carbonate, and moderate standard deviation.

Heavy Mineral Analysis

The sherds contain diverse, well-preserved heavy mineral suites enriched in epidote-group minerals (epidote, zoisite, clinozoisite) and garnet. Zircon, tourmaline, and

brown hornblende are present in moderately high proportions. Apatite, rutile, and sphene are common. Other species occurring frequently but at low abundance include green and brown spinel, several amphibole varieties, pyroxenes, staurolite, kyanite and, rarely, anatase, brookite, allanite, corundum, blue sodic amphibole, serpentine, and sillimanite. Point-counting data, recalculated into number percentages, is shown in Table III. In the mica group, biotite is the most common, chlorite was occasionally found in small amounts, and white mica is rare. The original grain shapes may be modified during manufacturing. However, euhedral or prismatic forms are common and dissolution features on some pyroxenes, staurolite, and kyanite produced

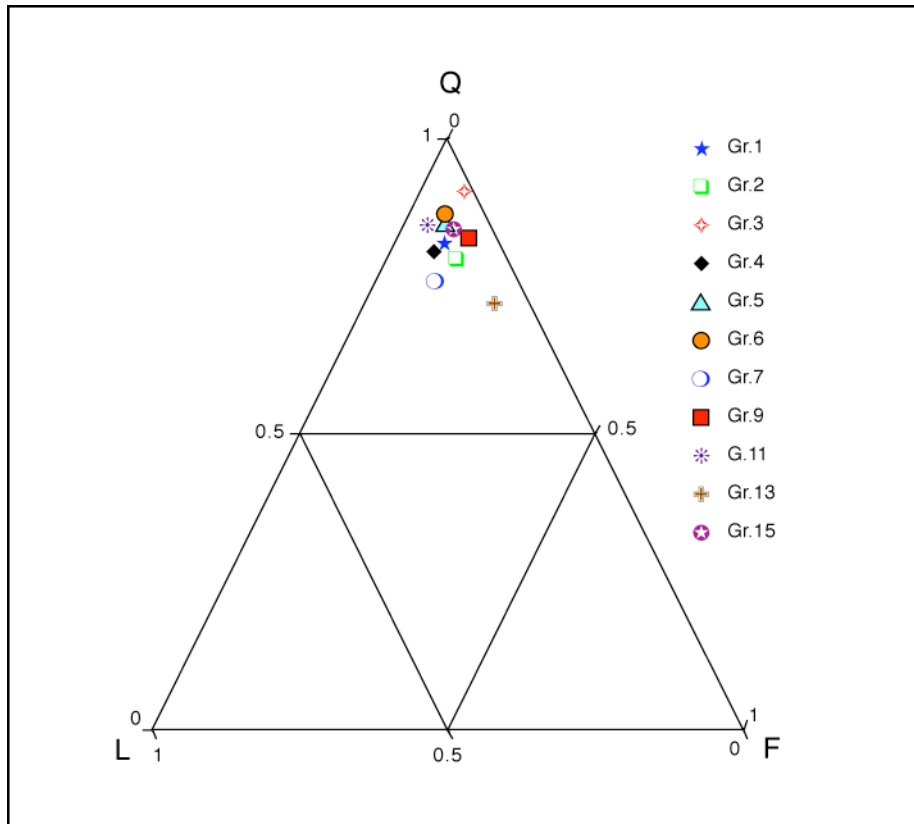


Figure 8. Ternary plot based on the mean values of quartz (Q), feldspar (F), and lithic fragments (L).

during diagenesis in their host sediments are preserved, suggesting that the intensity of grinding could not have been severe (Figure 5b, middle row c, d). The limited rounding of the inclusions revealed during fabric analysis also indicates this.

When a low number of samples precludes numerical analysis, presentation and evaluation of data is best achieved by graphical means. Therefore, histograms were created (Figure 10) using principal heavy minerals from representative Laecanius amphorae sherds, amphorae sherds from other workshops, our current terra rossa analyses from Istria and published data by Durn (1996). The zircon content in terra rossa samples analyzed by Sinkovec (1974) is anomalously high and differs considerably from our results. Data by Durn and Sinkovec are also contrasting, even between samples taken from the same location. Sinkovec (1974) did not describe his analytical

methods and size interval counted, and because we have no means to interpret such different results, Sinkovec's data were not included in Figure 10.

Compositional trends of each group, especially the abundance variations of their major heavy mineral components, are clearly discernible in the histograms and are summarized in Table IV. The heavy mineral characteristics of the groups can be assessed as follows: Groups A and B are similar in their main species, garnet/epidote ratios are consistently < 1 , and they contain varying amounts of zircon ($< 10\%$).

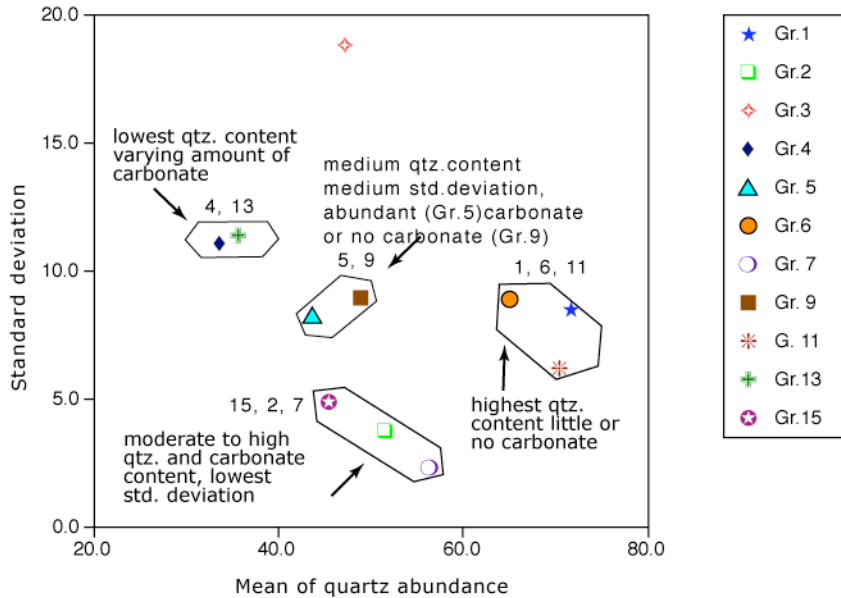


Figure 9. Cross plot based on data from statistical analysis, illustrating the relationship of petrographic groups.

Garnet/epidote ratios are > 1 in group C, and zircon abundance is higher than 20%. Group D contains abundant garnet ($> 40\%$) and small amounts of zircon, whereas in group E, garnet/epidote ratios are > 1 and zircon is more abundant. The zircon content is the highest in group F where garnet/epidote < 1 . Group G is rich in epidote, garnet abundance is low, and the group is exceptional in containing over 5% green clinopyroxene (augite). Epidote is abundant in group H, zircon is not common, and garnet quantities vary. Group I is the richest in epidote ($> 45\%$) and contains low quantities of garnet and varying amounts of zircon.

The strength of this method is demonstrated by the clear differentiation of amphora sherds, manufactured elsewhere, from the Laecanius pieces. Dressel 6B amphorae produced at other workshops include sherds from Costini, Apici, Vari Pacci, and Calvia Crispinilla. Only the location of the latter is known, excavated in Loron near Parentium, others probably originate from northern Italy. The use of a different raw material is shown by the high garnet proportions (garnet/epidote > 1), variable, but often high, zircon and apatite abundance and the frequency of clinopyroxene. Their distinctive signature is the appreciable amounts of clinopyroxene. Costini sherds contain fairly coarse heavy minerals (average 150 μm with several coarser epidote and garnet grains) and many fine botryoidal pyrites. Apici's heavy mineral suite is characterized by an unusually high quantity of sphene and a few grains of andalusite that are absent in the

	Zircon	Tourmaline	Apatite	Rutile	Staurolite	Kyanite	Epidote-group	Sphene	Hornblende	Pyroxene Spinel, brown	Garnet	Others	Remarks; other species	
Amphora sherds	b													
A 62	11	14	9	4	0	1	29	1	7	0	1	23	0	Anthophyllite tr.
A 75	11	14	8	5	0	0	29	3	8	0	0	22	0	
A 336	18	7	5	10	0	0	27	0	9	0	0	24	0	
A 388	4	13	15	3	0	1	31	2	20	0	0	12	0	
A 414	6	9	7	5	1	1	30	1	25	0	1	12	2	Anthophyllite, tremolite
A 433	8	12	4	8	0	1	30	1	15	1	1	19	2	Tremolite
A 656	4	12	4	2	0	0	38	3	11	1	0	25	0	
B 151	8	18	6	1	0	0	26	4	1	3	0	28	3	Sillimanite, orthopyroxene
B 453	7	9	20	2	0	2	29	1	10	0	0	21	0	
B 339	1	3	7	6	0	1	38	2	15	0	0	28	0	Volcanic glass shards
C 169	21	17	5	8	0	1	17	2	8	0	1	20	2	Allanite, tremolite, kyanite tr.
D 461	4	4	7	3	1	0	33	5	4	1	1	36	2	Allanite
D 595	4	5	12	1	1	1	23	3	4	0	1	43	1	Allanite
E 71	10	12	4	8	2	0	23	0	12	0	0	29	0	
E 362	16	1	13	7	0	1	15	4	12	1	2	28	0	Orthopyroxene tr.
F 161	17	10	10	2	0	0	27	0	8	0	0	25	0	
F 254	16	11	6	2	0	0	32	3	13	1	0	16	1	Pale blue amphibole
G 459	11	3	13	2	0	0	38	1	12	5	1	12	3	Corundum, green spinel
H 467	3	2	10	1	0	1	43	2	19	0	0	16	4	Glaucophane, serpentine, tremolite
H 125	2	5	9	0	0	0	36	3	11	0	1	32	1	Sillimanite
I 370	6	6	9	4	0	0	46	1	15	0	0	12	1	Tremolite, sillimanite tr.
I 472	9	5	5	2	0	1	48	3	9	1	0	17	0	Orthopyroxene tr.
I 611	2	7	2	3	0	1	47	3	18	0	0	12	4	Tremolite
Spica, Verige Bay	19	5	5	11	0	6	9	1	20	18	0	3	2	Orthopyroxene, baryte other amphiboles
Different workshops														
29 Costini	2	3	10	1	0	2	19	1	14	1	0	45	0	Allanite tr.
17 Apici	2	1	22	1	0	0	21	7	13	3	0	28	3	Andalusite
116 Vari Pacci	27	2	5	2	0	0	20	0	5	7	0	30	2	Allanite
118 Vari Pacci	3	3	23	1	0	1	23	4	12	2	0	29	0	Orthopyroxene tr.
822 Calvia-Crispinilla	17	21	3	3	0	0	21	0	0	0	0	34	0	
Terra rossa														
Pula 1	1	5	5	3	3	1	34	3	17	1	3	21	3	Pale blue amphibole
Pula 2	7	7	1	2	2	1	41	2	17	0	1	9	11	Glaucophane, chloritoid,
Pula region 03/1	15	23	2	10	2	1	12	4	6	2	4	19	0	
Pula region 03/2	11	26	5	11	2	1	8	9	2	0	10	16	0	
Pula quarry 03/1	10	34	9	4	1	1	9	8	5	0	5	12	1	Glaucophane
Rovijin quarry 03	7	5	1	4	3	1	46	1	7	0	1	10	13	Glaucophane, green spinel, tremolite

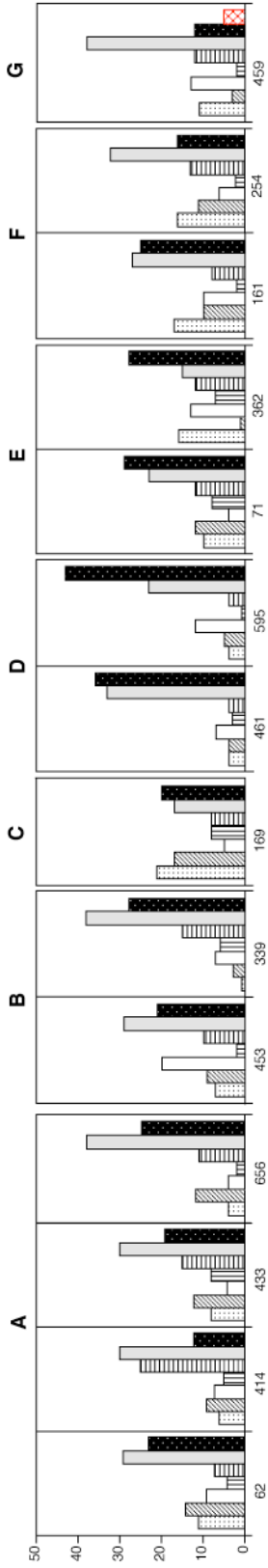
Table III. Heavy mineral composition of the Laecanius amphora sherds, products of other workshops and terra rossa.

Laecanius sherds, an elevated amount of chlorite, rare in the Laecanius samples, and some white mica. The two Vari Pacci sherds are coarse-grained and rich in either zircon or apatite. The single Calvia Crispinilla sherd yielded a low amount of fine-grained heavy mineral residue with high zircon and tourmaline quantities. The distinctly coarser grained (150–200 μm) spica sample, found in a press room in Verige Bay (Val Catena), can also be distinguished by its unique heavy mineral suite, containing abundant pyroxene and having low garnet and epidote proportions.

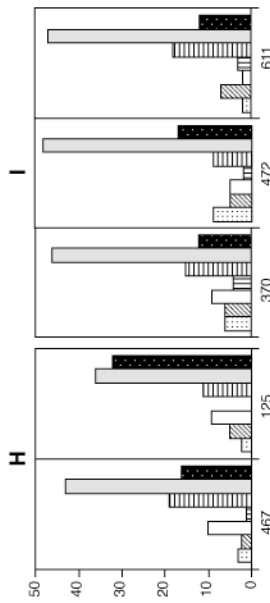
Epidote, garnet, and zircon percentages were plotted in a ternary diagram to gain further constraints on the grouping. Figure 11 depicts the clustering of data from groups A and B, with E and I forming another cluster close to them. The separation of groups C and D from the former and the wide spread of data points of other workshops also proves the potential use of the method.

To augment information from heavy mineral and thin-section analyses, the loose light mineral grain fractions were scanned in clove oil mounts under the polarizing microscope (Figure 12). This facilitated observation of a considerably larger amount of material and, by rolling the particles in the clove oil, a three-dimensional view of grain morphology was achieved. The chance of finding identifiable microfauna was also enhanced. Relatively thick clayey fragments comprise the bulk, which appear opaque under the polarizing microscope. However, the thin platelets of clay aggregates are translucent and show the incorporation of “rock flour” (5–20 μm) made up of subangular to subrounded, occasionally rounded quartz grains. Faunal remains include embryonic planktonic foraminifera and a variety of sponge spicules. This qualitative approach yielded further information that supported this categorization. The characteristics of each group are summarized in Table V: Groups A and B share many similarities; they contain low quantities of quartz, few feldspars, but relatively abundant chert, and a small amount of chalcedony. Sponge spicules are common in these groups. In addition, B 339 contains hexagonal biotite, volcanic glass shards (Figure 5b, top row b, e), and hexagonal apatite of 80–120 μm in size, probably originating from airborne volcanic ash. Group C is distinguished by the presence of metamorphic lithic fragments in higher proportions, in addition to abundant polycrystalline quartz, chert, and chalcedony. Sponge spicules are also present. Group D sherds are variable; D 461 yielded relatively abundant heavy minerals but the amount of quartz is low. It contains volcanic glass shards, botryoidal pyrite, and some microfauna. D 595, one of the high-temperature-fired dark pieces, is also low in quartz, includes a few botryoidal pyrites, shows abundant neoformed calcite (Figure 6), and is free of microfauna. Chert is absent in both samples. Groups E and F are “sandy,” the quartz content is high, and chert and microfauna are common. G 459 is markedly different with its abundant polycrystalline quartz, chalcedony, volcanic grains (clinopyroxene, hexagonal biotite, and volcanic glass shards), and traces of microfauna. Groups H and I have low quartz content, siliceous or schistose fragments are more prominent than in the other samples and chert, and chalcedony and microfauna are rare.

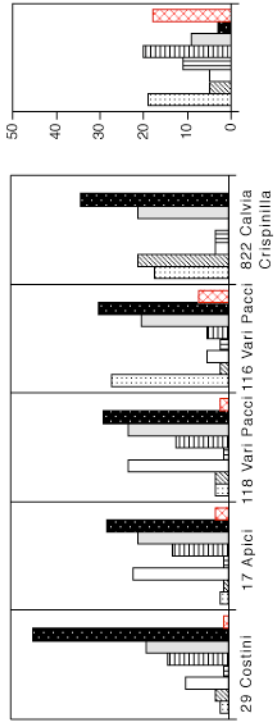
Combined fabric and heavy mineral groups



Combined fabric and heavy mineral groups



Products of different workshops



Terra rossa analyses

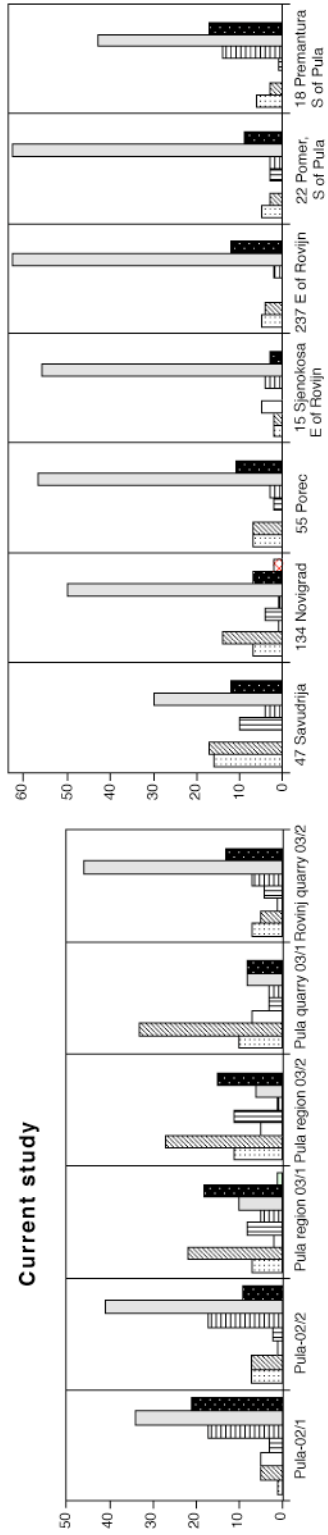


Figure 10. Histograms showing the abundance of heavy minerals (zircon, tourmaline, apatite, rutile, hornblende, epidote-group, garnet, and pyroxene) in representative samples from the combined fabric and heavy mineral groups of Laecanius amphorae sherds, sherds from other workshops, and in terra rossa samples.

Groups	Garnet and epidote ratios or quantity%	Zircon quantity %	Tourmaline quantity %	Pyroxene quantity %
A and B	<1	varying; <1	5-10	trace
C	>1	>20	>10	0
D	>1	<5	<5	trace
E	>1	10-16	varying %	trace
F	<1	>15	~10	trace
G	high epidote %	~10	<5	~5
H	high epidote %	<5	<5	trace
I	epidote >45%	2-9	5-7	trace
Various other workshops	very high garnet %	variable, often high	<5	1-7
Calvia Crispinilla	very high garnet %	high	>20	0
Spica, Verige Bay	<1	>15	~5	18

Table IV. Fabric groups of the Laecanius amphorae sherds, and sherds from other workshops with their heavy mineral signatures

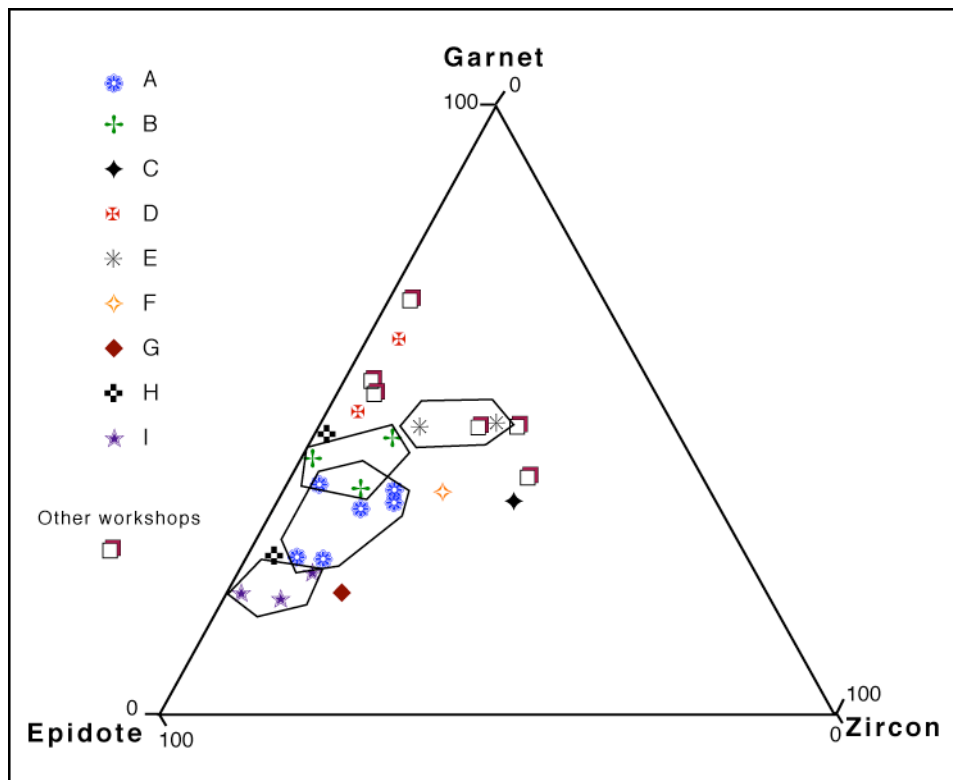


Figure 11. Ternary plot illustrating the mineralogical relationship of the combined fabric and heavy mineral groups of the Laecanius amphorae sherds and the different heavy mineral proportions in the sherds of other workshops.

The textural characteristics of the loose material from each analyzed sherd also support the presence of distinctive groups. The matrix of pieces from groups A and B is very fine and the crushed loose material appears powdery, containing very little silt and sand-size detritus. Group C appears somewhat “gritty” with an abundance of heavy minerals and polycrystalline quartz. Group D shows a burnt overprint over a somewhat gritty matrix. The crushed samples from groups E and F are distinctly sandy because of the higher proportions of clastic content. Sherds from the very fine-grained group H have low amounts of sand, and consequently, low yields of heavy minerals. Group I is typified by similar characteristics to those of group H, but the color of the former is markedly paler.

All sherds from the other workshops contain varying proportions of quartz and some feldspars. Costini is quartz-rich with common potash feldspar, many fine botryoidal pyrites, formed probably as foraminifera-infill, and relatively abundant planktonic foraminifera. It is important to note that these are all fossil forms and the shells are recrystallized. Apici is also rich in quartz. The two Vari Pacci sherds are coarsegrained but have low amounts of quartz. A few botryoidal pyrite grains were detected, but no microfauna. The clastic particles in the single Calvia Crispinilla sherd are not abundant and very fine, and microfauna was not observed.

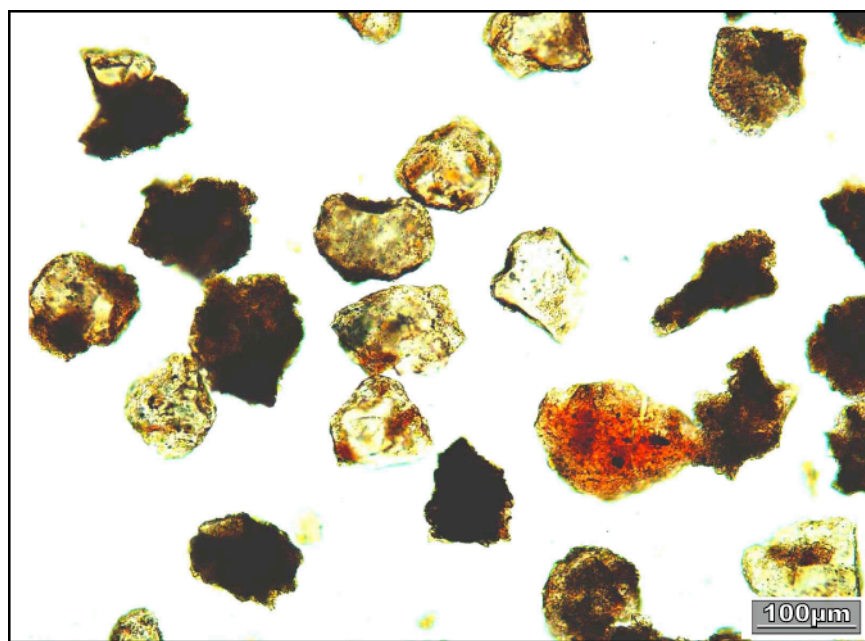


Figure 12. Photomicrograph illustrating a quartz-dominated, loose light fraction of a Laecanius amphora sherd.

DISCUSSION

Provenance of Raw Material

The close proximity and adequate supply of raw material over time was essential to the operation of a cost-effective ceramic workshop under the Roman infrastructure. The Laecanius-owned villas managing large-capacity workshops (10,000 or

Groups	Monocrystalline quartz	Polycrystalline quartz	Chert chalcedony	Metamorphic rock fragments	Microfauna	Volcanogenic grains
A and B	low quantities	small amount	abundant	rare	fairly common	in B 339
C	common	abundant	abundant	common	present	in D 461
D	low quantities	trace	absent	trace	absent	absent
E	high quantities	small amount	common	trace	common	absent
F	high quantities	small amount	common	trace	common	absent
G	common	abundant	abundant	trace	trace	common
H	low quantities	small amount	rare	abundant	rare	absent
I	low quantities	small amount	rare	abundant	rare	absent

Table V. Fabric groups of the Laecanius amphorae sherds, components, and characteristics of the light mineral fraction.

12,000 amphorae per annum) were evidently able to fulfill these prerequisites. Their prosperity, first under the Laecanius family (80–90 years) then under the ownership of the Emperor (50 years), reflects a well-organized enterprise with continued access to raw material and skilled managers and workers. By integrating the results of archaeological and geological analyses, we have obtained sufficient information to constrain the provenance of clay and temper used for the paste.

The first consideration in provenance reconstruction is a geological survey of the potential source region: Istria is dominated by Mesozoic carbonates, whereas Paleocene-Eocene carbonate-clastic sequences of variable thickness are confined to the narrow central zone. Both types of sediments are unsuitable for pottery and are thus irrelevant in the search for raw material. Late Neogene to Quaternary deposits include loess and terra rossa. The terra rossa, with its high clay-mineral content, is a suitable raw material for ceramics. It is widespread as a red soil in the southern and western parts of the peninsula, reaching a thickness up to 14 m (Durn et al., 1999). Until recently, such occurrences were quarried and used for brick and cement manufacturing.

The origin, chemistry, and environmental implications of Istrian terra rossa have been investigated extensively, especially in recent years, and their results provided a valuable source of reference in our efforts to reconstruct the provenance of raw material quarried and handled by ancient Istrian potters. (Sinkovec, 1974; Skoric, 1987; Durn and Aljinovic, 1995; Durn, 1996; Prohic et al., 1997; Durn et al., 1999, 2001, in press; Miko et al., 1999). The studies of Sinkovec (1974) and Durn (1996) were especially relevant because they used heavy mineral analysis.

The histograms in Figure 10, where heavy mineral proportions in the sherds and in six terra rossa samples were potted together with terra rossa data from Durn (1996), indicate similarities in overall heavy mineral composition between the terra rossa analyzed by Durn, our currently analyzed terra rossa, and the Laecanius sherds. However, epidote content is considerably higher and garnet proportions are lower in Durn's samples. Terra rossa is a polygenetic soil (Durn, 1996; Durn et al., 1999, in press); therefore, it is highly heterogeneous and variations in mineral proportions are common. These are detectable between localities or even in different layers within the same outcrop. For example, some of the currently analyzed terra rossa samples

from the Pula region are rich in unusually coarse tourmaline and also contain fossils, both probably reworked from adjacent Mesozoic rocks. Another cause for the differences in mineral proportions between our data and Durn's is that Durn analyzed a narrower and finer (45–63 μ m) grain size interval than we used (45–250 μ m range), and this inevitably causes grain size-controlled fluctuations in heavy mineral proportions. Garnet usually appears in the coarser-size grades, thus the reason for the discrepancy between the two analytical data sets is likely to be difference in grain size. This emphasizes that analytical methods and operating conditions used by various authors need to be stringently assessed before attempting data comparison. Variations can also be ascribed to the fact that in Roman times different outcrops/beds were accessible.

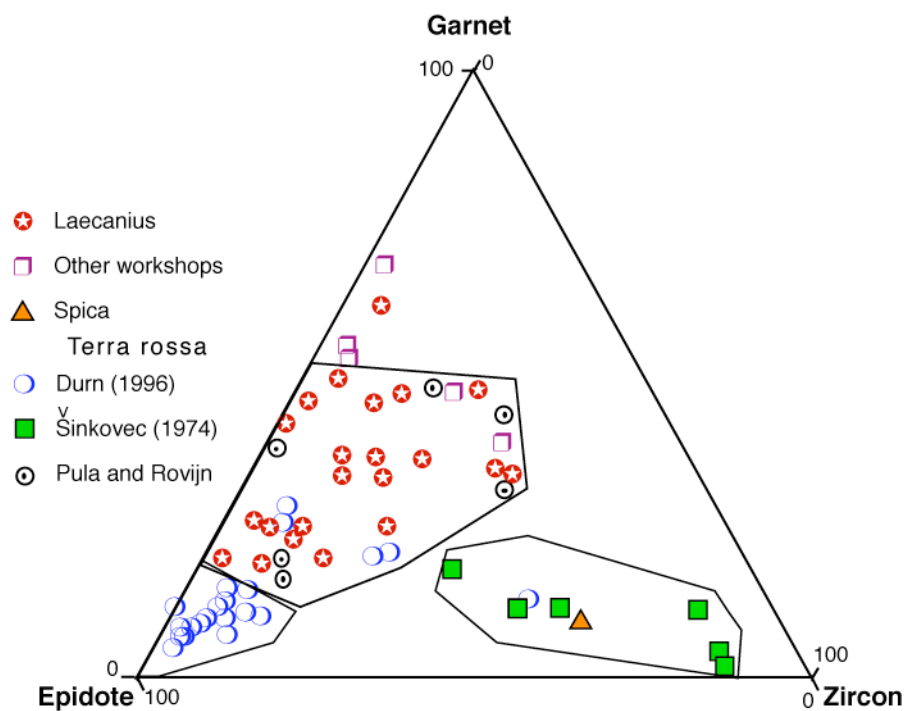


Figure 13. Comparative ternary plot based on epidote, zircon, and garnet proportions, using data from Laecanius sherds, other workshops, and terra rossa.

Figure 13 permits evaluation of the mineralogical linkage between the analyzed terra rossa and sherds. Laecanius amphora sherds cluster in a well-defined field, whereas data from other workshops are more scattered. Our terra rossa analyses plot within the Laecanius field; Durn's (1996) epidote-rich samples form a tight cluster, close to and somewhat overlapping data points of the Laecanius sherds. The zircon-dominant terra rossa samples of Sinkovec (1974) fall in a separate area, coinciding only with the spica sample. The overlapping or adjacent clustering of amphorae sherds together with terra rossa indicates a linkage of the principal components between the two data sets, suggesting that the clay used for the paste was likely local terra rossa. Logistics also suggest this because it is widespread in the region (Durn, 1996). For example, ancient, overgrown quarries are known within the Pula area, indicating that it was available locally and that the workers presumably mapped and quarried outcrops

of suitable quality. Clayey bauxite, forming thick deposits mostly in central Istria, is rejected as a clay source, because bauxite-specific minerals and anatase, common in Istrian bauxites (Sinkovec, 1973), were not found in the ceramics. However, both Figures 10 and 13 show that there is an appreciable mineralogical difference between the sherds and the terra rossa. We suggest that this reflects the diluting effect of added temper. Temper petrography is a highly important source of information in geoarchaeology (Dickinson et al., 1990; Dickinson, 2001; Dorais et al., 2004). Tracing the source of temper in the Laecanius amphorae drew complementary information from thin-section and fabric analyses. These showed that besides carbonate fragments, comprising either dolomite or limestone, fine-grained clastic sand and silt is invariably present in the sherds. Dolomite and limestone, probably taken from local outcrops, were ground to a fine size and added to the clay. However, they are inherently free of clastic grains, and this raises the question: Where did the other “sandy-silty” temper come from? Two lines of evidence, one mineralogical and the second paleontological, indicate that its source was the local, silty, sandy deposits of the Adriatic Sea.

First, the majority of the sherds contain fresh brown hornblende and abundant brown biotite, some with a hexagonal shape (Figure 5b, top row b, d), indicating a volcanogenic (tephra) origin. The presence of sharp euhedral volcanic zircon (Figure 5b, a), euhedral pyroxene and apatite in the sherds is another signal of volcanic derivation. Previous studies in the Adriatic region have also documented the occurrence of volcanogenic heavy minerals in recent sediments. Durn (personal communication, 2001) found abundant volcanoclastic grains in deep paleosol profiles on the Island of Hvar, Croatia, and interpreted them as the products of Mediterranean volcanic eruptions. Sinkovec (1974) analyzed the heavy mineral composition of one modern sand from the northern part of the Adriatic Sea and one eolian sand from the Island of Susak. He reported high proportions of hornblende (> 30%) associated with pyroxenes in the Adriatic sand and found apatite both in the modern Adriatic and in the eolian sediments. By contrast, brown hornblende is present in low proportions in the terra rossa (e.g. there is only 1–5% hornblende in samples analyzed by Durn [1996] while apatite content is minor). Though two of the terra rossa samples in Table III (Pula 1 and 2) have high percentages of hornblende, it is predominantly the green, blue-green variety formed under different petrogenetic conditions and has a different chemistry. Brown hornblende that characterizes the ash-fall suite, and also common in the sherds, is rare in all of the analyzed terra rossa samples. The presence/absence of apatite is also meaningful. It occurs up to 20% in the sherds but is rare in the terra rossa. All these signatures suggest that the potters used clastic temper, which contained diverse and well-preserved heavy mineral assemblages that were different from those in the terra rossa. This clearly explains the bimodality of heavy mineral compositions in the sherds. Our interpretation for the dominantly Adriatic provenance of the temper is supported further by the microfauna in the sherds. This will be addressed later, after considering a separate provenance effect.

Because the Adriatic sediments, loess, and terra rossa incorporate some detritus from a common source, the silty alluvium of the Po River, their heavy mineral suites share similar characteristics. The Po River carries diverse Alpine assemblages to

the Adriatic and deposits them on its floodplain (Van Straaten, 1970; Rizzini, 1974; Gandolfi et al., 1982; Marchesini et al., 2000). During the Pleistocene, fine sediment was blown from the floodplain, dispersed over a wide area (Durn and Aljinovic, 1995), and was intermixed with the terra rossa (Durn et al., in press). Thus, traces of diagnostic Alpine-derived species (e.g., glaucophane and chrome spinel) appear in the terra rossa. They are common in the Adriatic sediments and were occasionally encountered in the sherds (Table III).

Second, fresh and unusually small planktonic foraminifera and sponge spicules are present in the majority of the sherds. Though the dominantly embryonic or fragmentary nature of the foraminifera precluded precise identification, the well-preserved fresh sponge spicules have provided definitive evidence for the source of the temper. The globular sponge spicules (Figure 14) were identified by Prof. Jean Vacelet and Dr. Klaus Rützler (personal communication, 2003) as spicules from the cortex of the contemporary (modern) sponge *Geodia cydonium* (Jam.) (order Tetractinellida). These almost-spherical spicules are sterrasters, which are microsclere spicules forming a dense cortex at the surface of the Geodiidae. Megasclere spicules with triactine and monactine types are frequent (Figure 14 Sp.) and probably belong to the same Geodiidae.

Mineralogy and microfauna in the ceramics thus constrain the source of the temper added to the paste. It was probably dredged from the Adriatic Sea. Microfauna is markedly more common in sherds with relatively high detrital grain content, suggesting that the fine clastic temper and not the clay contributed the microfauna. The modern origin of the sponge spicules is suggested by their excellent preservation and supports our conclusion on temper provenance. If they were reworked and redeposited in the terra rossa, they should show abrasion, and if they were Mesozoic or Paleocene in age, recrystallization of the opaline silica to chalcedony, as seen in almost all fossilized sponge spicules (Figure 14 Sp.R), would likely have taken place; however, recrystallization has not been observed in any of them.

CONCLUSIONS

Our interdisciplinary study, which integrated traditional fabric analysis with petrography, XRD, and heavy mineral analysis has added new dimensions to the study of Roman Dressel 6B-type amphorae sherds, manufactured in the Laecanius workshop in Istria between 10–5 B.C. and 78 A.D.. Fabric analysis has established nine fabric groups, A–I. The majority of the sherds belong to groups A and B, suggesting that the bulk raw material used for the paste and manufacturing methods were relatively constant throughout the operation of the workshop.

Heavy mineral analyses have pinpointed the sources of raw material used for the paste and temper that, despite numerous studies on the Laecanius amphorae, have not been identified previously. Our comparative study of the heavy mineral composition of Istrian terra rossa and the Laecanius sherds shows an appreciable correspondence, indicating that the workshops used the widely available terra rossa for the clay base, which was

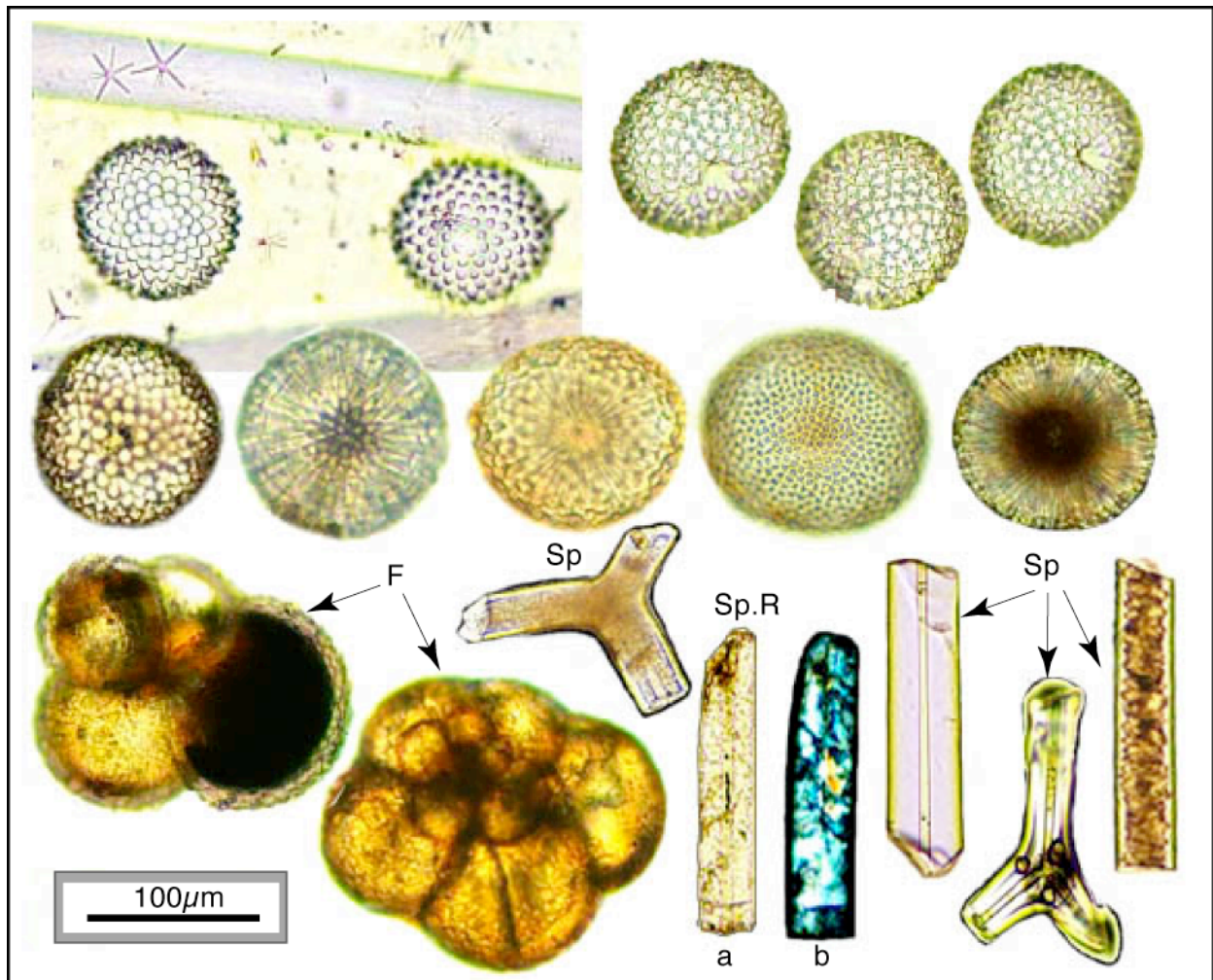


Figure 14. Geodia sponge spicules (sterrasters) and planktonic foraminifera in the Laecanius amphora sherds (second row) and in top row, sterrasters from Geodia sp. Belize for comparison. F: planktonic foraminifera, Sp. Trilete spicules and mono spicules, Sp.R recrystallized fossil sponge spicule, a: plane polarized light, b: crossed polars. Note the worn appearance of this spicule.

mixed with either carbonate or clastic temper or both. A shift detected in the principal heavy mineral compositions between the sherds and terra rossa is attributed to the polygenetic origin of the terra rossa, which entails temporal and spatial heterogeneity.

The provenance of the raw material as an abundant, locally available, cost-effective source promoted the long prosperity of the workshop. Our finding that much of the temper was taken from a local, Adriatic source gives further evidence of its efficient operation. Fresh, modern sponge spicules in the sherds, similar to forms in the Adriatic Sea, and the presence of specific heavy mineral species of Alpine provenance, via the Po River, constrain the Adriatic derivation of the sandy temper. Different material was used for light-colored, relatively silty/sandy amphorae; the presence of microfauna points to Adriatic material, probably mixed with loess from local sources. The finely dispersed carbonate in the matrix may also suggest loess because most loess contains poorly crystallized carbonate.

The firing temperature of the amphorae, estimated by XRD, ranges between 750 and 900°C. Such a wide variation may indicate that the nature of the initial material may have

been taken into account during the firing process; alternatively, the workers may have adjusted the paste composition according to the availability of the firing substances.

Sherds of amphorae manufactured in other workshops have heavy mineral characteristics that are different from those in the traditional Laecanius amphorae. Differentiation between the Laecanius amphorae and those of other workshops, including the spica sample, demonstrates the potential of the heavy mineral technique as a useful archaeometric tool.

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APPENDIX

Fabric Analysis: Macroscopic and Petrological Characteristics

Fabric A

Macroscopic description:

Color: Light red or red (2.5YR 6/6–5/6–5/8) to reddish-yellow (5YR 6/6–7/6)

Hardness: Soft

Feel: Smooth

Fracture: Hackly

Inclusions frequency Moderate

Sorting: Poorly assorted

Average size: 20–60 μ m

Maximum size: 200–500 μ m

Rounding: Angular to subrounded

Composition:

(a) Predominant: White inclusions, probably quartz.

(b) Common: White and golden mica

(c) Few: Very pale white, angular to rounded inclusions; probably limestone fragments

(d) Few: Reddish-brown inclusions, probably clay pellets, grog or argillaceous rock fragments.

(e) Rare Dull-red iron ore

(f) Rare Microfossils

Voids: Rare vugs, commonly 0.3–1 mm in size.

Petrological description:

The fabric has a dark reddish to reddish (xp yellowish-red) groundmass with common voids. Inclusions are very few, angular to subrounded, and moderately to poorly sorted. Grain-size analysis resulted in the isolation of two groups, one fine and the other coarse. The inclusions are predominant in the fine group and few (mainly limestone) in the coarse group. Inclusions consist of frequent quartz, frequent to few limestone, few to very few golden and white mica, quartzite, grog, or clay pellets. The few to rare microfossils are the most characteristic feature of this fabric. Other constituents include rare plagioclase and very rare potash feldspar, opaque grains, sericite and phyllite fragments, mica schist, chert, and heavy minerals.

Fabric B

This ware is similar to fabric A, but under the groundmass, the microscope shows white reaction rims around voids, indicating where the limestone grains once existed. Compared with fabric A, the inclusions are dominantly quartz and rare microfossils.

Fabric C

This ware is similar to fabrics A and B, but the color is light reddish-brown (5YR 6/4), whereas the groundmass is reddish-brown. In these amphorae, the limestone grains were black burnt and the reaction rims around the voids are dark brown to white.

Fabric D

This ware is similar to fabrics A and B, but the color is dark gray (2.5YR 4/0) and the groundmass is dark brown to dark yellowish brown. Many of these amphorae were black and burnt. They were recovered from the area in the workshop where broken and useless pieces were dumped.

Fabric E

Macroscopic description:

Color: Pale pink (10YR 7/3–8/4) to pink (7.5YR 8/4–7/4)

Hardness: Hard

Feel: Smooth

Fracture: Hackly

Inclusions frequency Moderate

Sorting: Poorly sorted

Average size: 20–60 μ m

Maximum size: 250 μ m

Rounding: Angular to subrounded

Composition:

(a) Predominant: White inclusions, probably quartz.

(b) Common: White and golden mica, red and light-red inclusions

(c) Few: Reddish-brown inclusions, probably clay pellets or grog

(d) Rare Dull-red iron ore

(e) Rare Dark brown to black particles

Voids: Few vugs, commonly 0.3–1.5 mm in size.

Petrological description:

Under the microscope, this differs from the previous fabrics in having abundant quartz particles about 30–80 μ m in size in the groundmass, which is yellowish-to brownish-red with few voids where limestone grains have been lost.

Voids occupy 10–15% of the field. Inclusions are very few to few, predominantly angular to subangular. They are composed of dominant to predominant quartz, few plagioclase, very few to few potash feldspar, few to common mica flakes, very few sericite, very rare quartzite, very rare to very few mica schist, and few clay pellets. Microfossils are very rare.

Fabric F

This ware is similar to fabric E, but the groundmass is yellowish-red (xp) or light brown. The inclusions consist of dominant quartz.

Fabric G

This ware shows the characteristics of fabrics A and E. The differences are probably due to the different firing.

Fabric H

Macroscopic description:

Color: Light red (2.5 YR 6/6) to yellowish-red (5 YR 5/8–6/8) to pink (7.5 YR 7/4)

Hardness: Hard

Feel: Smooth

Fracture: Hackly

Inclusions frequency Moderate

Sorting: Poorly sorted

Average size: 20–60 μ m

Maximum size: 150 μ m

Rounding: Angular to subrounded

Composition:

(a) Predominant: White inclusions, probably quartz

(b) Common: White and golden mica, red and light-red inclusions

(c) Rare Dull-red iron ore

(d) Rare Dark inclusions

Voids: Few vugs, commonly 0.3–1 mm in size

Petrological description:

The groundmass is grayish brown to dark brown (xp reddish-brown). Voids occupy between 5 and 10% of the field. The inclusions are very few to few, angular to subangular. In the groundmass, the reaction rims around the voids are white where limestone grains have been lost. Inclusions comprise dominant to predominant quartz, rare to few quartzite, rare plagioclase, rare to very few potash feldspar, and very rare heavy minerals. There are very few clay pellets, very few sericite, rare limestone, and rare to few mica schist.

Fabric I

This type is the same as fabric E. Only a few amphorae belong to this group. The fabric incorporates a large number of 1–3-mm-size red and black clay pellets.