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Archaeometric investigation of the Hellenistic period Colchian amphoras from Pichvnari (Western Georgia)*

Key words: Colchis, Hellenistic period, Colchian "brown-clay" amphora, Archaeometry, Petrography, Production technology, Provenance.
Cuvinte-cheie: Colchida, perioada elenistică, amforă de colchida „din argilă brună", arheometrie, petrografie, tehnologie de producție, proveniență.

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Archaeometric investigation of the Hellenistic period Colchian amphoras from Pichvnari (Western Georgia)
The article presents a first extensive archaeometric (macroscopic and petrographic) analysis of the Hellenistic period Colchian "brown-clay" amphoras discovered at Pichvnari, one of the most representative sites for the study of this type of transport containers. The material consists of 44 amphora and 3 sand samples taken for comparative reasons in the broad surrounding of the site. The macroscopic fresh break and petrographic thin section analysis is set in the context of previous work done by other authors. The Pichvnari material reveals various fabric recipes that largely correspond to the already determined fabric groups. However, in contrast to the previous works, the study also manages to show the compositional profiles of the fabric groups in a greater detail and therefore supposes the possibility of a minor fabric variations eventually linked to sub-regional productions. Mineralogical comparison with the sand samples allows us to carefully suppose that the tempering material originated in the riverine and/or coastal sedimentary environment in the area around Pichvnari. However, due to the lack of a more extensive and systematic raw material sample collection from the region of interest, the question of the exact provenance of Pichvnari "brown-clay" amphoras remains open.

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Investigație arheometrică a amforelor colchice din perioada elenistică de la Pichvnari (vestul Georgiei)
Articolul prezintă o primă analiză arheometrică extinsă (macroscopică și petrografică) a amforelor colchice din perioada elenistică, din „argilă brună", descoperite la Pichvnari, unul dintre cele mai reprezentative situri pentru studiul acestui tip de containere de transport. Materialul constă din 44 de amfore și 3 probe de nisip, prelevate în scop comparativ din împrejurimile sitului. Analiza macroscopică a rupturilor proaspete și a secțiunilor subțiri petrografice se plasează în contextul lucrărilor anterioare efectuate de alți autori. Materialul de la Pichvnari dezvăluie diverse rețete de țesături care corespund în mare măsură grupurilor de țesături deja determinate. Cu toate acestea, spre deosebire de lucrările anterioare, studiul reușește, de asemenea, să arate profilurile compoziționale ale grupurilor de țesături într-un detaliu mai mare și, prin urmare, presupune posibilitatea unor variații minore ale țesăturilor, legate în cele din urmă de producții subregionale. Comparația mineralogică cu probele de nisip ne permite să presupunem cu atenție că materialul de revenire își are originea în mediul sedimentar riveran și/sau costier din zona din jurul sitului Pichvnari. Cu toate acestea, din cauza lipsei unei colectări mai extinse și sistematice de mostre de materii prime din regiunea de interes, problema provenienței exacte a amforelor „din argilă brună" Pichvnari rămâne deschisă.

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Introduction

Colchian "brown-clay" amphoras produced in the large period of mid. 4th century BC – 7th century AD represents one of the most iconic features of Antique and Late Antique material culture in the Eastern Black Sea region. Based on previous integrated macroscopic and comparative petrographic studies of mid. 4th century BC – 4th century AD examples a first foundation was laid to consider the local Colchian provenance of these vessels on an interdisciplinary basis, underlining the importance of a trade and exchange network between western Transcaucasia and northern Pontic region [Tsetskhladze, Vnukov 1992; Vnukov 2006, 77-85; Lordkipanidze 1966, 138-139]. However, a small number of samples analysed archaeometrically did not allow a confident differentiation of various technological groups and pinpointing of "brown-clay" amphora production sites.

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The aim of this study is to carry out a more detailed study on the basis of the Hellenistic period Colchian amphoras from Pichvnari, including both the cemetery and the settlement, which is up to date the most representative site in southwestern Georgia in terms of this specific amphora finds. Besides, this pottery will be compared to potential tempering material in the form of three sand samples from the broader region around Pichvnari (fig. 1). This way we will be able to evaluate the validity of the results by Tsetskhladze, Vnukov and Lordkipanidze [Tsetskhladze, Vnukov 1992; Vnukov 2006, 77-85; Lordkipanidze 1966, 138-139] and therefore try to draw a more nuanced picture of the "brown-clay" amphora production and provenance.

Archaeological background

Based on the evolution of certain morphological attributes, four chronological groups can be differentiated within the whole production period of the "brown-clay" amphoras: Ch IA[1], Ch IB, Ch IC and Ch ID [Vnukov 2011, 271, 277, Fig. 8]. From these, only two forms, Ch IA and IB are made during the Hellenistic period. The distribution area of Ch IA and IB is confined to the eastern, northern (mainly Crimea) and southern Black Sea coastal areas. A number of finds are also known from shipwrecks discovered at Phanagoria [Boetto *et all.* 2022, 1-25] and Kinburn Spit [Gerasimov *et all.* 2018, 190-192, Fig. 13] (fig. 1).

The earliest well-dated "brown-clay" amphoras (middle of the 4th – late 3rd / beginning of 2nd centuries BC) [Lordkipanidze *et all.* 1972; Vnukov, Tsetskhladze 1991, 171], Ch IA, very much resemble the Sinopean transport containers, more precisely the type II [Monakhov, Kuznetsova 2022, 276, 300, Pl. VII]. The neck is either cylindrical, slightly bulging or flaring and ends typically in a roller-shaped rim. The upper part of the handles, which are flattened ovals in section, are attached under the rim and in most cases descend vertically down on the shoulders. The ovoid body of the "brown-clay" amphora ends in a conical foot terminating in a profiled cylindrical or slightly widening heel, which sometimes can be button-shaped.

The resemblance of Colchian amphoras with the Sinopean type II persists in the 3rd – beginning of the 2nd centuries BC [Tsetskhladze, Vnukov 1992, 362-365, Fig. 3-4, 5]. However, towards the end of the 3rd century BC these containers develop a "waist" in the lower part of the body. Compared to Ch IA, this new form, Ch IB, is characterized by a shorter neck and loop-shaped handles; All dimensions are in general smaller. The inner side of the base is always "adorned" with a flourish [Tsetskhladze, Vnukov 1992, 365 370]. Nevertheless this "specific technological protuberance" [Vnukov 2011, 274, Fig. 4.1] is not always present on the earlier and later (Roman period) Colchian amphora forms.

Based on certain morphological details the group B is further subdivided in two typochronological subgroups: Ch IB1 (end of 3rd / beginning of 2nd – middle of 1st centuries BC) and Ch IB2 (middle of 1st century BC – last quarter of 1st century AD). The bulging rims of Ch IB1 vessels retain similarities with the earlier Ch IA. However, all other details (neck, handles) differ significantly. Whereas in Ch IB2 the cylindrical neck is sometimes replaced by a funnel-shaped one, the handles are always loop-shaped and the "waist" in the lower body becomes more sharply defined [Vnukov 2010, 29-30, Pl. 15.1-2].

Other characteristic morphological features of the Hellenistic period "brown-clay" amphoras are epigraphical and non-epigraphical stamps, as well as marks incised in wet clay: 1. marks similar to Greek letters, 2. marks that possibly resemble letters and 3. fingerprints [Tsetskhlaze, Vnukov 1992, 371, Fig. 13].

Epigraphical stamps are made in Greek. Four types are known within this category. The first one, ΔΙΟΣ | ΚΟΥ, is encountered on handles found in the surroundings of Dioscuria and Eshera (Hellenistic layer) in Colchis and Nymphaeum and Panticapaion in Crimea and can be dated of the 3rd century BC [Tsetskhladze, Vnukov 1992, 371, Fig. 13.2, 372]. The second one, ΔΡ, is known only from a single handle fragment from the territory of Dioscuria [Phiphia *et all.* 2022, 64, 413]. The third stamp type, ΤΙΜΑΡΧΟΥ, is found on several "brown-clay" amphora fragments discovered in or in the vicinity of Bosphorus, Scythian Neapolis, Chersonesus and Patraeum in northern Black Sea region. It is dated either of the second half of the 3rd or 2nd centuries BC [Vinogradov, Onaiko 1975, 88-89] or of the second half of the

1. "Ch" is an abbreviation for "Colchian" (note by the authors).

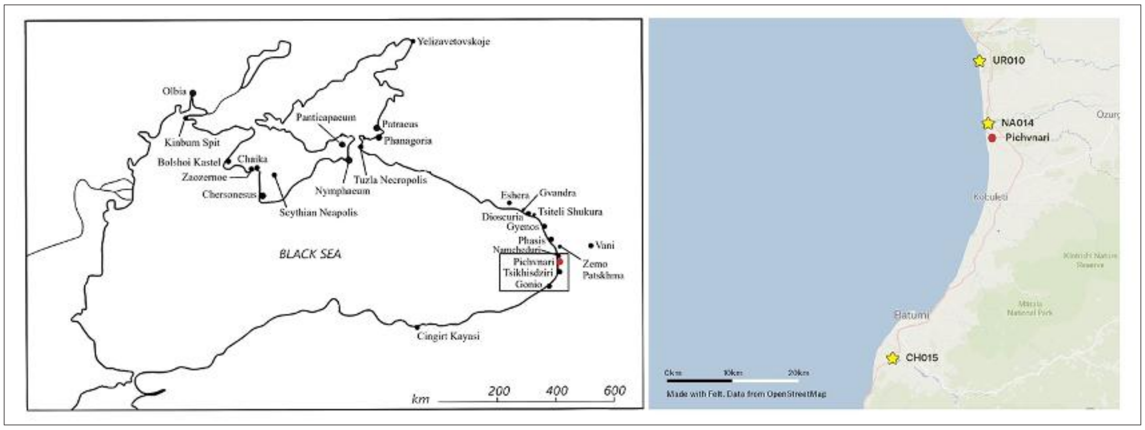

Fig. 1. Main sites of discovery of Hellenistic period "brown-clay" amphoras (left map) [map is based on: Tsetskhladze 2023, 2, Fig. 1. The data is compiled from: Tsetskhladze, Vnukov 1992, 360-361, Fig. 1 and 2; Boetto *et all.* 2022; Erol, Tamer 2020; Gerasimov *et all.* 2018 and Greek amphora from the Northern Pontus Euxinus (database)], Pichvnari (red dot) and sand sampling locations (yellow stars) (right map) (created on Felt.com).

2nd century BC. While the fourth one is a unique, miniature three-line stamp containing two Greek names [Tsetskhladze, Vnukov 1992, 373].

The first two epigraphic stamps are considered to denote the city name of Dioscurias, suggesting that the ceramic workshop(s) producing the brow-clay amphoras in question was/were officially owned by the polis of Dioscurias, where Greek artisans should have been among the producers of these containers [Phiphia *et all.* 2022, 62, 64, 411-413; Tsetskhladze, Vnukov 1992, 373-374] (see: below). However, its interpretation as a personal name Dioskos is also not excluded [Kac 2008, 107]. The third and fourth type probably denominate several of such Greek artisans who worked in Colchis [Tsetskhladze, Vnukov 1992, 373-374].

Within the non-epigraphic stamps, only two types are known: first, a cross with a round frame from Pichvnari and Vani and a round stamp with the imprint of a horseman, six-pointed star and a bird [Tsetskhladze, Vnukov 1992, 372-373 Fig. 13.3-4]. The first one is especially interesting, since two similar stamps are also known from *pithoi* rims in Vani [Tsetskhladze 1991, 361-381]. Tsetskhladze and Vnukov eventually connect the cross stamp to the aristocrat-owned workshops [Tsetskhladze, Vnukov 1992, 373-374].

Concerning the three types of marks incised in wet clay, because of their abstract nature, there is no consensus among the scholars with respect to their meaning [Tsetskhladze, Vnukov 1992, 373-374].

The provenance of "brow-clay" amphoras has been and still remains a matter of discussion among the scholars (for a review of different contributions see: Khalvashi 2002, 12-13; Matera *et all.* 2024, 61-62). However, the petrographic study done by Tsetskhladze and Vnukov on 49 mid. 4th century BC – 4th century AD "brown-clay" amphora samples from different sites all over Colchis and the northern Black Sea littoral (mainly Crimea) [Tsetskhladze, Vnukov 1992, 374-386] represents a strong piece of archaeometric evidence, which cannot be avoided when discussing the issue, especially in the light of a new archaeometric analysis. The study managed to identify two main groups: Fabric 1 (or A) and Fabric 2 (or B2). Both fabric groups are iron-rich, non-calcareous and seem to contain hydromicaceous (illite-smectite) minerals [Tsetskhladze, Vnukov 1992: 372-385; Vnukov 2010, 30; 2011, 271-272] and 5 to 15% of ore mineral grains, together with "grains of quartz, plagioclase, pyroxene and moderately alkaline and acidic effusive rocks of normal alkalinity" [Vnukov 2006, 78].

Fabric 1 is mainly composed of pyroxene (50-90% of all inclusions). The rest of the inclusions is dominated by fragments of basalt [Tsetskhladze, Vnukov 1992, 380]. However, quartz, plagioclase and acid rock fragments are also present (usually up to 5-7%). Other mineral and rock types only occur sporadically in a few samples. The authors conclude that a pyroxene-basaltic rich sand was used to prepare the fabric in question [Vnukov 2006, 80; Tsetskhladze, Vnukov 1992, 382]. A very similar temper is also attested in Sinopean amphoras [Tsetskhladze, Vnukov 1992, 380]. Fabric 1 is used for the "brown-clay" containers from the 4th-1st centuries BC as well as the later Ch IC form from the Roman period [Vnukov 2011, 277, Fig. 8].

Fabric 2 is characterized by a larger petrographic and mineralogical variation compared to Fabric 1. We encounter varying amounts of quartz, plagioclase, pyroxene, various types of volcanic rock fragments. Plutonic rock fragments are present up to 5% and olivine, mica, sedimentary rock (sandstone) and shale together rarely rise above 5% [Vnukov 2006, 79]. The fabric group entails "brown-clay" amphora samples from virtually all periods (4th century BC – 4th century AD), as well as comparative pottery samples: four *pithoi* (4th-2nd centuries BC) and two domestic vessel fragments from southwestern Colchis (Ajara region)[2], one *pithos* (4th-3rd centuries BC) and one jug (1st century AD) from Vani [Tsetskhladze, Vnukov 1992, 381-382; Vnukov 2010, 30; Vnukov 2017, Pl. IV.21-24].

Interesting to note is the fact that the 4th-2nd centurie BC samples from north-western Georgia (Abkhazia) and the 4th-1st centuries BC samples from southwestern Georgia both contain quartz-sericitic schist fragments, while this rock type is absent from the Ch IC vessels of the 1st-4th centuries AD belonging to the same fabric group [Tsetskhladze, Vnukov 1992, 382].

In some of the publications a third fabric, the so-called transitional variety is also identified [Tsetskhladze, Vnukov 1992, 381; 1993, 91; Vnukov 2017, Table IV.20]. Here pyroxene is still dominant (over 40%). However other mineral and rock fragments not observed in Fabric 1 (e.g., orthoclase, magmatic rock fragments) also appear in minor quantities [Tsetskhladze, Vnukov 1992, 381][3]. The authors interpret the more diversified composition of temper material as a less strict selection of raw materials compared to Fabric 1. This recipe turns out to be used for Ch IA as well as Ch IB vessels, probably even into the 1st century AD [Tsetskhladze, Vnukov 1992, 381; Vnukov 2017, Pl. IV.20].

Based on the morphological and fabric similarities between the earliest Ch IA and Sinopean amphoras Tsetskhladze and Vnukov conclude that the production of former containers in Colchis could have been introduced by Sinopean artisans. This idea is further supported by the fact that the "brown-clay" amphoras with Greek stamps have only been attested within the first fabric group. Vnukov suggested that the production could have been based in Trapezus [Vnukov 2006, 81-82], "a colony of Sinope in the land of Colchis" [Xenoph, *Anab*. IV, 8, 20].

On the other hand, the mineralogical similarity of Fabric 2 group to the local pottery from southwestern Georgia allows us to link at least a part of the "brown-clay" amphora production to this very region, probably in a coastal environment, which would typically yield sands with such a varied mineralogy [Vnukov 2006, 80. also: Kac 2008, 104-105]. The authors assume that the containers made in Fabric 2 could have been rather produced by local craftsmen "who had adopted (to all intents and purposes) the new technology for the production of such vessels, without changing their traditional clay formula" [Tsetskhladze, Vnukov 1992, 384].

Within this paper we would like to assess whether the technological and productive groups outlined by the above-mentioned authors can be objectively defined in the light of a bigger sample size from a single site. We believe that the interpretative power of the comparison between 7 amphora and a few various types of domestic pottery samples from a wide chronological range is not enough to confidently argue that the Fabric 2 group vessels should have been made in southwestern Colchis per se. We think that rather a comparative archaeometric study of these transport containers and local raw materials from a wider region of the southern, eastern and northern Black Sea region has the power to finally resolve this issue.

Material and methods

The Hellenistic period amphoras considered in this study were discovered in the years 1965-2010 in Pichvnari, both on the cemetery and settlement areas. For the current study 44 representative

2. The date of these vessel fragments is unfortunately not given [Tsetskhladze, Vnukov 1992, 375].

3. These authors also mention Epidote as typical for the Fabric 2 and "transitional fabric" [Tsetskhladze, Vnukov 1992, 381-382]. However, this mineral is never mentioned in later publications [Tsetskhladze, Vnukov 1993; Vnukov 2006, 77-85; 2010, 30; 2011, 271-272] (see: below).

	Ch IA	Ch IA(?)	Ch IB	Ch IB(?)	CH IA/B	Total
Settlement	4	2	4	2	14	26
Cemetery	9	1	4	2	2	18
Total	13	3	8	4	16	44

Table 1. Statistics of selected petrographic samples per typological category.

samples were selected and their fabrics documented and described (Appendix A, Table A.1, A2, fig. A.1). 18 samples come from the cemetery, while 26 _ from the settlement area (for detailed statistics see Table 1). The material can be subdivided into three main typological categories: Ch IA (certainly or probably), Ch IB (certainly or probably) and Ch IA/B (Appendix A, Table A.1; fig. 2).

As a comparative material, three sand samples were taken on three locations: the estuary areas of two rivers, Chorokhi (CH015) and Natanebi (NA014) and one sample from the beach of Ureki (UR010) (fig. 1). Sand is a potential tempering agent, fulfilling the role of giving strength to the clay vessel and allowing "to control excessive shrinkage and cracking of the ceramic object during drying and firing" [Montana 2017, 98]. Therefore, the aim of such comparison was to assess whether a part of the local raw materials could have been used within the "brown-clay" amphora production.

Petrographic analysis was used to investigate both pottery and sand samples. This method is one of the cost-effective and powerful research tools to describe in detail the composition of ceramics, as well as raw materials necessary for its' production and explore the evidence for specific ceramic technologies that is hard to identify by the naked eye (from raw material processing and paste preparation to firing and use) and provenance [Quinn 2022, 13, 205-286; Braekmans, Degryse 2017, 233-261]. Petrographic analysis is especially useful in differentiating fabrics that are macroscopically difficult to separate. Therefore, by taking a large sample number from a single site we think to be able to test the petrographic classification by Vnukov and Tsetskhladze and eventually discover a more nuanced picture of petrographic variation within the "brown-clay" amphora group.

Results

Macroscopic analysis

Macroscopic study allowed us to subdivide the assemblage into two large groups: Group 1 and 2. The distinction is based mainly on the abundance of black versus white admixtures observed by naked eye. In Group 2 the black inclusions predominate over the white ones, while Group 1 is characterized by the opposite amounts of white and black mineral/rock grains. Besides, the white and black inclusions have a more regular and even distribution in Group 2 fabric group than in Group 1. Concerning the brown and grey inclusions, they were not always well visible by naked eye and the general impression is that they should be of secondary importance in macroscopic fabric group differentiation. However, it can be said that the abundance of brown admixtures is more typical for Group 1 (Appendix A, Table A.2).

Besides the well-differentiated samples there were also a dozen (no. 78, 81, 96, 97, 105, 109, 113, 114, 117 and 119) of which the belonging could not be determined with certainty seen the fact that they displayed non-typical patterns. They 1. Either had a more or less same amount of black and white inclusions (Group 1?) or 2. The black admixtures predominated, while the general appearance of the sample was still not typical for Group 2 (Group 2?). Therefore, the issue of the final fabric classification was taken to the petrographic level of analysis.

Petrographic analysis

Pottery samples

Petrographic analysis allowed us to clearly define two microscopic fabric groups, Pm-1, Pm-2 and a loner Pm-3. The descriptions were made according to the chart proposed by Quinn [Quinn 2022, 108]. However, the abundance of each inclusion category was estimated semi-quantitatively using (+/-) percentages, in order to render the comparison with the data presented by Vnukov and Tsetskhladze (see: above) easier. Detailed petrographic descriptions are provided in Appendix B.1.

Pm-1 comprises 5 samples (no. 80, 86, 102, 104 and 106). It is characterized by an iron-rich

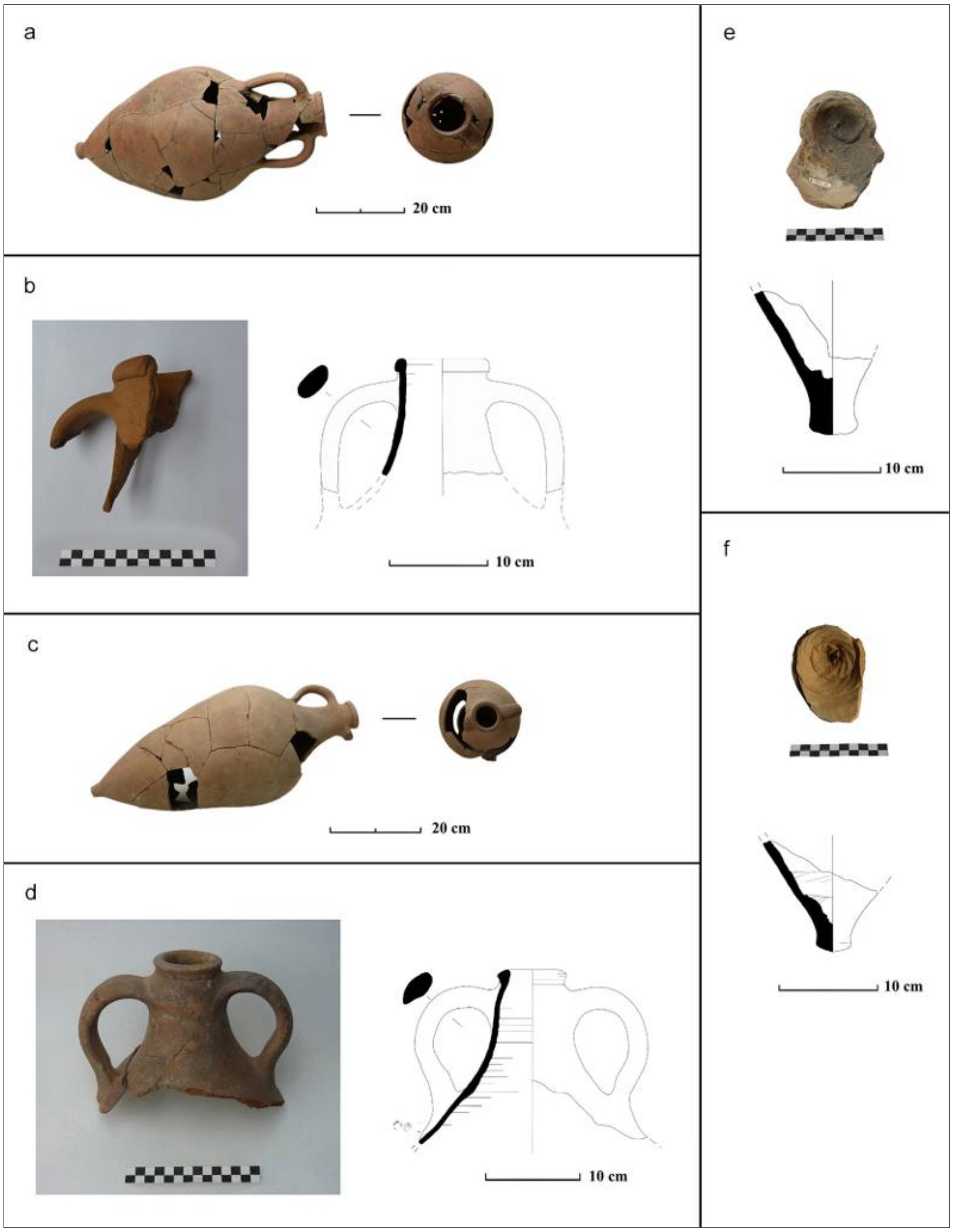

Fig. 2. Fragments and reassembled amphoras from Pichvnari. Ch IA: a – QP07-01(not sampled), b – sample no. 105; Ch IB: c – sample no. 115-116, d – sample no. 97, Ch IA/IB: e – sample no. 80, f – sample no. 88 (photos and drawings: A. Rogava).

fabric dominated by pyroxene (+/- 13,5-19%) and volcanic rock fragments (+/- 1-5%) (fig. 3). Black opaque iron-rich ore mineral fragments range from around < 0,5 to 1% and iron-rich rock fragments from around 1,5 to 4%. While quartz (+/- 1-3%) and feldspar (< 0,5-1%) are of low significance. Occasionally Pm-1 fabric group also includes sporadic intrusive rock (up to +/- 1%) fragments. The silt fraction is mainly composed of quartz and/or feldspar (up to +/- 1,5%), with some black opaque ore mineral fragments (up to +/- 0,5%), while mica flakes are only exceptional. The fabric group has a clearly bimodal grain size distribution. The matrix contains some amount of iron rich clay pellets

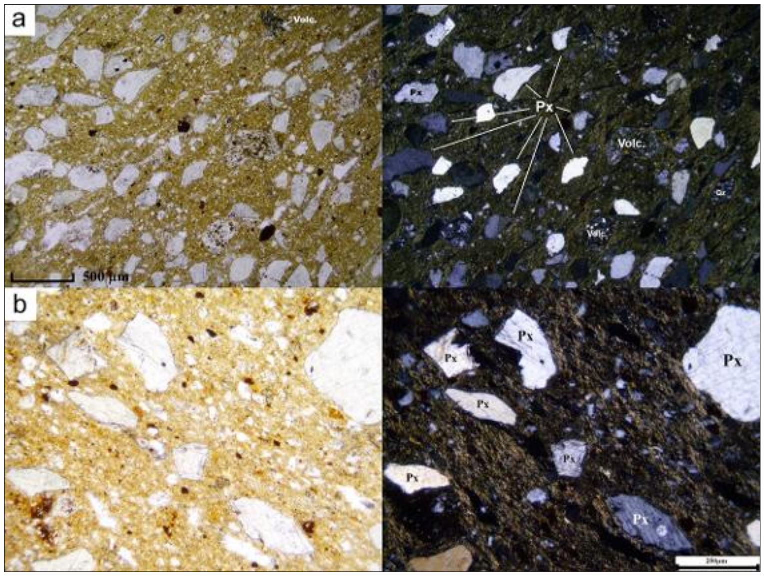

Fig. 3. Pm-1 microscopic fabric group: a – 40x (sample no. 80), b – 100x (sample no. 102). Abbreviations: Px – pyroxene, volc. r. – volcanic rock (Photos: A. Rogava).

and in the majority of the thin sections a thread-like texture is observed, implying the presence of montmorillonite clay. Optical anisotropy is weak to strong suggesting an equivalent firing temperature of below 800-850 °C [Quinn 2022, 269].

Pm-2 comprises the majority of the studied thin sections, 38 in total (no, 79, 81, 82, 83, 84, 85, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 103, 105, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116 117, 118, 119, 120 and 121). The grain size distribution can be described as moderately bimodal. The dominant inclusion types are volcanic rock fragments of various type (+/- 4-11%) and pyroxene (+/- 1-9%). The distinguishing rock types, completely or virtually absent in Pm-1 are: siltstone-sandstone (< 0,5-3%), yellowish-greenish inclusions of possible volcanic glass (< 0,5-3%) and metamorphic rock admixtures (up to 5%, only absent in two thin sections) (fig. 4,a-c). Compared to Pm-1, a more felsic nature of the Pm-2 microscopic fabric group is demonstrated by higher amounts of quartz (+/- 1-7%), feldspar (< 0,5-3%) and intrusive rock fragments consisting mainly of quartz and feldspar (< 0,5-4%). Another typical feature of Pm-2 are silt-sized mica and yellowish-greenish volcanic glass(?) fragments, more or less evenly distributed within the matrix and varying from around 0,5 to 1%. Less diagnostic inclusion categories (also present in Pm-1) are: iron-rich rock (+/- 0,5-6%) and black opaque iron-rich ore mineral (< 0,5-2%) fragments. The matrices of 35 samples are characterized by weak/medium to strong anisotropy. Only in the case of three samples (no. 85, 89 and 94) vitrification can be observed, which can probably be considered as accidental (heat effect during a post-firing fire event), rather than indicating an equivalent firing temperature of 800-850 °C or above [Quinn 2022, 269].

Pm-3 loner (sample no. 78 – QS144-4) is characterized by the prominence of volcanic and iron-rich rock fragments, each documented as +/- 10%. Within the volcanics the admixtures with abundant rutile dominate. Less important are: pyroxene (+/- 3%), quartz (+/- 1%), feldspar (+/- 1%) and black opaque iron-rich ore mineral fragments (+/- 1). Compared to Pm-1 and Pm-2, the clay of the Pm-3 loner is clearly siltier (+/- 4% in total) and is dominated by quartz and/or feldspar grains (+/- 3%), while mica, yellow-greenish volcanic glass(?) and black isotropic iron-rich ore mineral fragments are of secondary importance (each documented as < 0,5%). The matrix of the Pm-3 loner is very iron-rich and seems to have been fired on an equivalent temperature of less than 800-850 °C [Quinn 2022, 269], as indicated by a medium – strong anisotropy (fig. 4,d-e).

Sand samples

The sand samples, where all the four rock categories found in Pm-2 were encountered, are

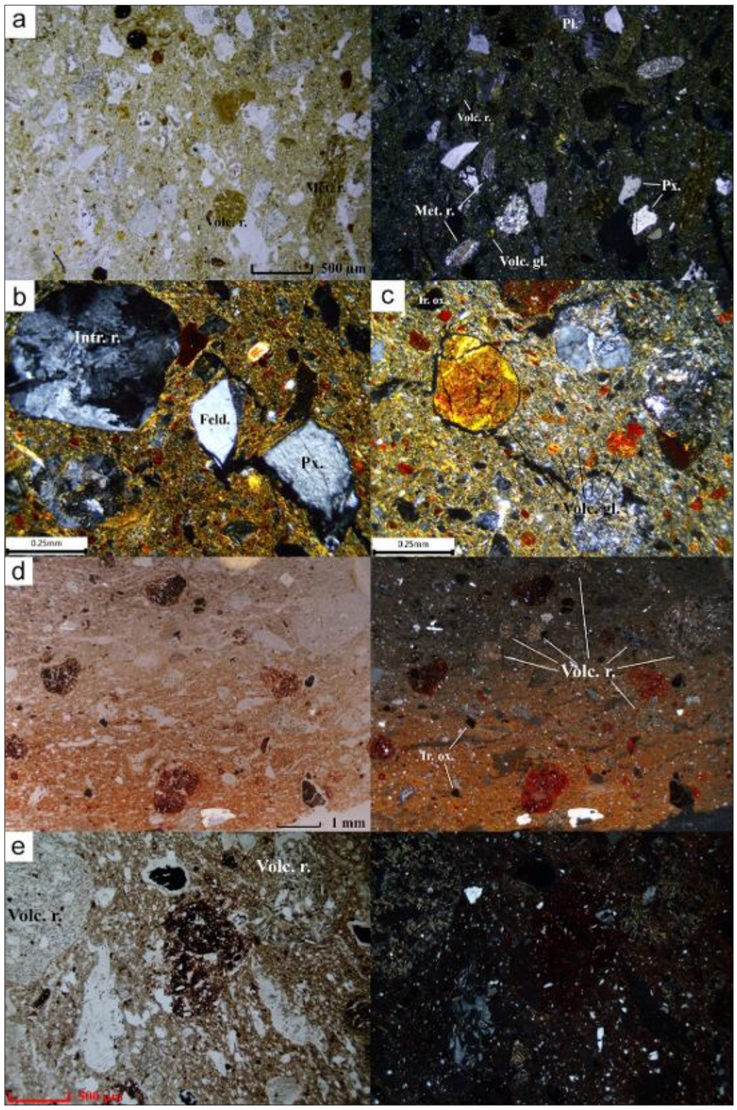

Fig. 4. Pm-2 petrographic fabric group (a – 40x (sample no. 81), b and c – 100x (sample no. 87)) and Pm-3 (loner) (d – 12x (sample no. 78), e – 40x (sample no. 78)). Abbreviations: Feld. – Feldspar, Px. – Pyroxene, Pl. – Plagioclase, Volc. r. – Volcanic rock, Volc. gl. – Volcanic glass, Intr. r. – Intrusive rock, Met. r. – Metamorphic rock, Ir. ox. – Iron ore fragments (photos: A. Rogava).

NA014 and UR010, respectively Natanebi river and Ureki beach sands. In case of Natanebi the main part of the inclusions consists of volcanic (+/- 8%), silt-sandstone (+/- 7%) and metamorphic rock fragments (+/- 7%). Pyroxene amounts to around 2,5%, however the felsic inclusions, composed of quartz (+/- 4%, mainly monocrystalline), feldspar (+/- 3%) and intrusive rock fragments consisting mainly of quartz and feldspar (+/- 3%) are still an important category. Less significant are: yellowish-greenish volcanic glass(?) (+/- 2%), iron-rich rock (+/- 2%) and mica (< 0,5%) fragments. The silt fraction is mainly composed of quartz and/or feldspar (+/- 3%), followed by black isotropic iron-rich ore (< 0,5%) and mica and yellowish-greenish mineral fragments (+/- 0,5%) (full petrographic description of all sand samples are provided in Appendix B.2) (fig. 5,b).

Within the Ureki beach sand sample (UR010) volcanic rock fragments are even more important (+/- 12%), while sandstone-siltstone and metamorphic rock inclusions amount to around 4 and 3% respectively. Pyroxene seems to be more important here than in Natanebi river sand, amounting to around 5%, while the felsic component, consisting of only feldspar (+/- 1,5%) and quartz (+/- 3%)

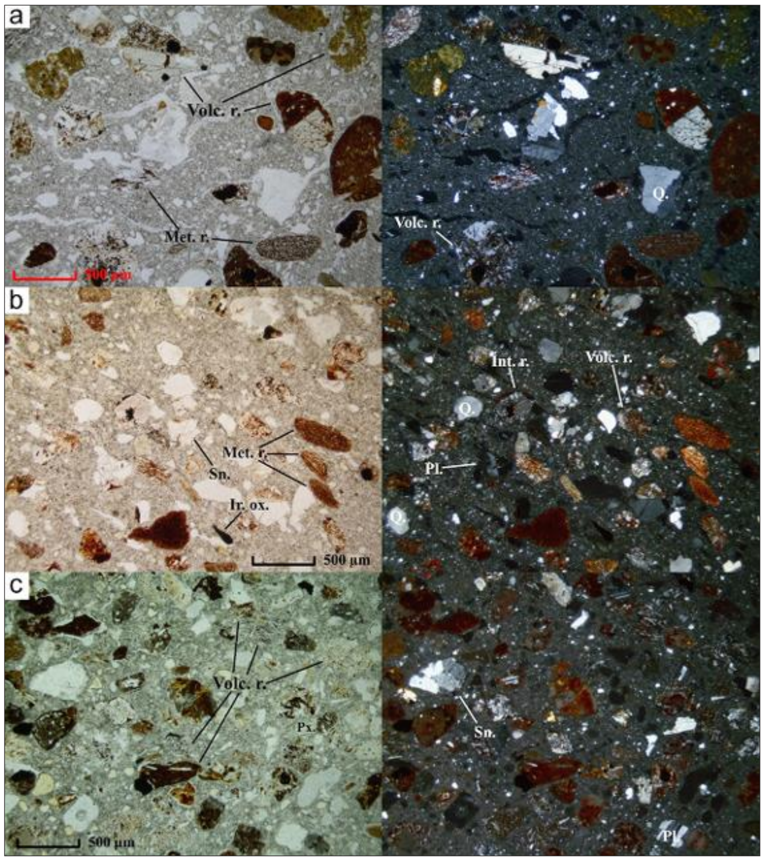

Fig. 5. Sand samples under magnification of 40x: a – UR010; b – NA014; c – CH015. Abbreviations: Q. – Quartz, Pl. – Plagioclase, Px. – Pyroxene, Met. r. – Metamorphic rock, Volc. r. – Volcanic rock, Intr. r. – Intrusive rock, Sn. – Sandstone, Ir. ox. – Iron oxide (photos: A. Rogava).

is somewhat less significant. Besides, low amount of iron-rich rock fragments (+/- 1%) also occur in Ureki beach sand. Concerning the silt fraction, its' composition is practically the same as in the case of Natanebi river sand, with the only difference that yellowish-greenish volcanic glass(?) fragments seem to be absent here (fig. 5,a).

Chorokhi river sand (CH015) appears as petrographically the most distinct from the other two sand, as well as all the ceramic samples. It is dominated by volcanic rock fragments (+/- 16%), followed by sandstone-siltstone (+/- 5%) and feldspar (+/- 4%). The river sand sample also contains a certain amount of iron-rich rock fragments (+/- 3%). Other inclusion types, such as pyroxene (+/- 2%) and intrusive rock admixtures (+/- 1%), are only of secondary importance, while quartz is sporadically present (+/- 0,5%). The silt fraction of Chorokhi river sand appears compositionally the same as the river sand of Natanebi (see: above) (fig. 5,c).

Discussion and conclusions

Following the analysis of the material, it is now possible to examine the results in relation to the data presented by Tsetskhaldze and Vnukov (see: above). Concerning the Pm-1, we observe that the approximate share of pyroxene is around 50%, while volcanic rock fragments represent the second most important inclusion type; Therefore, this fabric group is most consistent with the pyroxene-rich Fabric 1 (or A) defined by Tsetskhladze and Vnukov [Tsetskhladze, Vnukov 1992: 380; Vnukov 2006, 80; Vnukov 2010: 30; see also: above]. While Pm-2 appears mineralogically very close to Fabric 2, presented as a mix of volcanic, intrusive, metamorphic and sedimentary (sandstone) rock types. However, olivine, which was present in 80% of the samples of Fabric 2 [Vnukov 2006, 79] was practically undetected in any of our 38 samples. Therefore, it is even possible that this large group from Pichvnari might represent a specific fabric variation, eventually linked to a specific production sub-region.

Due to a larger number of samples, we were able to ascertain that the majority of Pm-2 group specimens contains both siltstone-sandstone and metamorphic rock fragments. However, there were a few samples without either of the two (sample no. 116) or containing higher and larger amounts of yellow-greenish volcanic glass(?) (sample no. 121) (Appendix B.1). What all the thin sections of Pm-2 fabric group share is the abundance of silt-size mica and yellow-greenish volcanic glass(?) inclusions, together with other above mentioned sand sized rock and mineral admixtures. Therefore, based on our material we conclude that the metamorphic rock and sandstone fragments are indeed found in the "brown-clay" amphoras discovered on the south-western Colchis, as noted by Vnukov and Tsetskhladze [Tsetskhladze, Vnukov 1992, 382]. However, that's not always the case.

The loner Pm-3 (= sample no. 78, QS144-4) represents an interesting case. In terms of mineralogy, it shows similarities to Pm-2 fabric group, suggesting that the source for the raw material should not have been very different from the raw material(s) used for Pm-2. We could be dealing here with an alternative geographical source, used only in a limited way in the "brown-clay" amphora production in the Hellenistic period.

Concerning the firing conditions of the studied amphoras, it is evident that the majority of them were fired at an equivalent firing temperature of less than 800-850 °C. Only three samples from Pm-2 fabric group (no. 85, 89 and 94) display some vitrification. All three of them were found in the settlement context and therefore it is not excluded that a fire event, rather than a relatively high firing temperature, was responsible for vitrification.

Another interesting issue is the relationship between macroscopic and microscopic fabric characteristics of the studied Colchian amphoras. It turns out that the differences between the pyroxene-rich (Pm-1) and "mixed" fabric groups (Pm-2) are not always clearly detectable macroscopically (Appendix A, Table A.2). The share of black vs. white-coloured inclusions and their distribution within the matrix appears to be enough in the majority of cases to differentiate these two fabric groups correctly. However, one might mismatch around 1/4th of sherds when classifying the material only by naked eye. Therefore, it is advisable to inspect as many fresh breaks and surface areas as possible.

Evaluating the provenance of the studied "brown-clay" amphoras can still not be direct, seen the lack of evidence in the form of production remains (kiln or wasters) and a substantial corpus of raw material (sand and clay) samples from a wide region. The limited amount of sand samples that we were able to examine in our preliminary analysis, however, indicates that the tempering material originated in the riverine and/or coastal sedimentary environment in the area around Pichvnari. In any case, the comparison between the 3 sand and 44 pottery samples analysed within the scope of this article gives us a hint about how useful such a comparative study can be and suggests that the searching for potential temper (and clay?) sources should start from the immediate surroundings of the site itself.

Appendix A – Macroscopic description of analysed amphora samples

Sample no.	Inv. no.	Fragment	Type	Context
78	QP99-144	FW	Ch IA/B	settlement
79	QP99-142	FW	Ch IA/B	settlement
80	05N80-52	FW	Ch IA/B	settlement
81	N65-241	RNH	Ch IA	settlement
82	QP99-191	FW	Ch IA(?)	settlement
83	QP04-7	HN	Ch IA(?)	settlement
84	QP19-3	RNH	Ch IA/B	settlement
85	N2.19-41	RNH	Ch IA/B	settlement
86	05NII81-55	FW	Ch IA/B	settlement

87	05NII81-28	FW	Ch IA/B	settlement
88	QP84-615(1)	FW	Ch IA/B	settlement
89	QP79-724	FW	Ch IA	settlement
90	QP84-609	NHW	Ch IA/B	settlement
91	QP84-617(2)	RNH	Ch IB1	settlement
92	QP84-617(3)	RNH	Ch IB1	settlement
93	QP81-252	FW	Ch IB(?)	settlement
94	QP77-111	FW	Ch IA/B	settlement
95	QP76-8	RN	Ch IA	settlement
96	QP81-245	FW	Ch IA/B	settlement
97	QP84-591(1)	RNHW	Ch IB	settlement
98	QP80-54	FW	Ch IA/B	settlement
99	QP65-912	FW	Ch IA/B	settlement
100	QP99-124	FW	Ch IB (?)	settlement
101	QP84-591(2)	RNHW	Ch IB	settlement
102	QP77-53	FW	Ch IA/B	settlement
103	QP80-51	FW	Ch IA	settlement
104	QP02-01	RNHW	Ch IB	cemetery
105	QP04-16	RNHW	Ch IA	cemetery
106	QP08-31	FW	Ch IA	cemetery, small ritual platform, NO I 21 sect. sq. 46
107	QP04-16	FWH	Ch IA	cemetery, ritual platform N3
108	QP04-08	RNHW	Ch IA	cemetery
109	QP80-9*	RNH	Ch IA(?)	cemetery
110	QP80-9*	FW	Ch IA(?)	cemetery
111	QP02-33	HW	Ch IA(?)	cemetery, grave N 173, SW 61 sect. sq. 70-60
112	QP08-69	?	Ch IA	cemetery, large ritual platform, NO I 21 sect. sq. 55
113	QP80-86	FW	Ch IA	cemetery
114	QP06-01	RNHW	Ch IB(1)	cemetery, ritual platform, NO I 21 sect. sq. 76
115	QP06-42*	RNHWF	Ch IB1	cemetery
116	QP06-42*	RNHWF	Ch IB1	cemetery
117	QP06-44	RNHWF	Ch IB1(?)	cemetery
118	QP80-06	FW	Ch IA/B	cemetery
119	QP08-67	RNH	Ch IB(?)	cemetery, large ritual platform, NO I 21 sect. sq. 55
120	QP80-05	FW	Ch IA/B	cemetery
121	QP02-58	RNHWF	CH IA	cemetery, ritual platform N1

Table A.1. Sample list with corresponding inventory numbers and information about the fragment (F – Foot, W – Wall, R – Rim, N – neck, H – Handel), type of amphora and context. Starred amphora / amphora fragments represent the same vessels sampled at two different parts of the body.

Fig. A.1.1. Fabrics of analysed pottery samples (photos: A. Rogava).

Fig. A.1.2. Fabrics of analysed pottery samples (photos: A. Rogava).

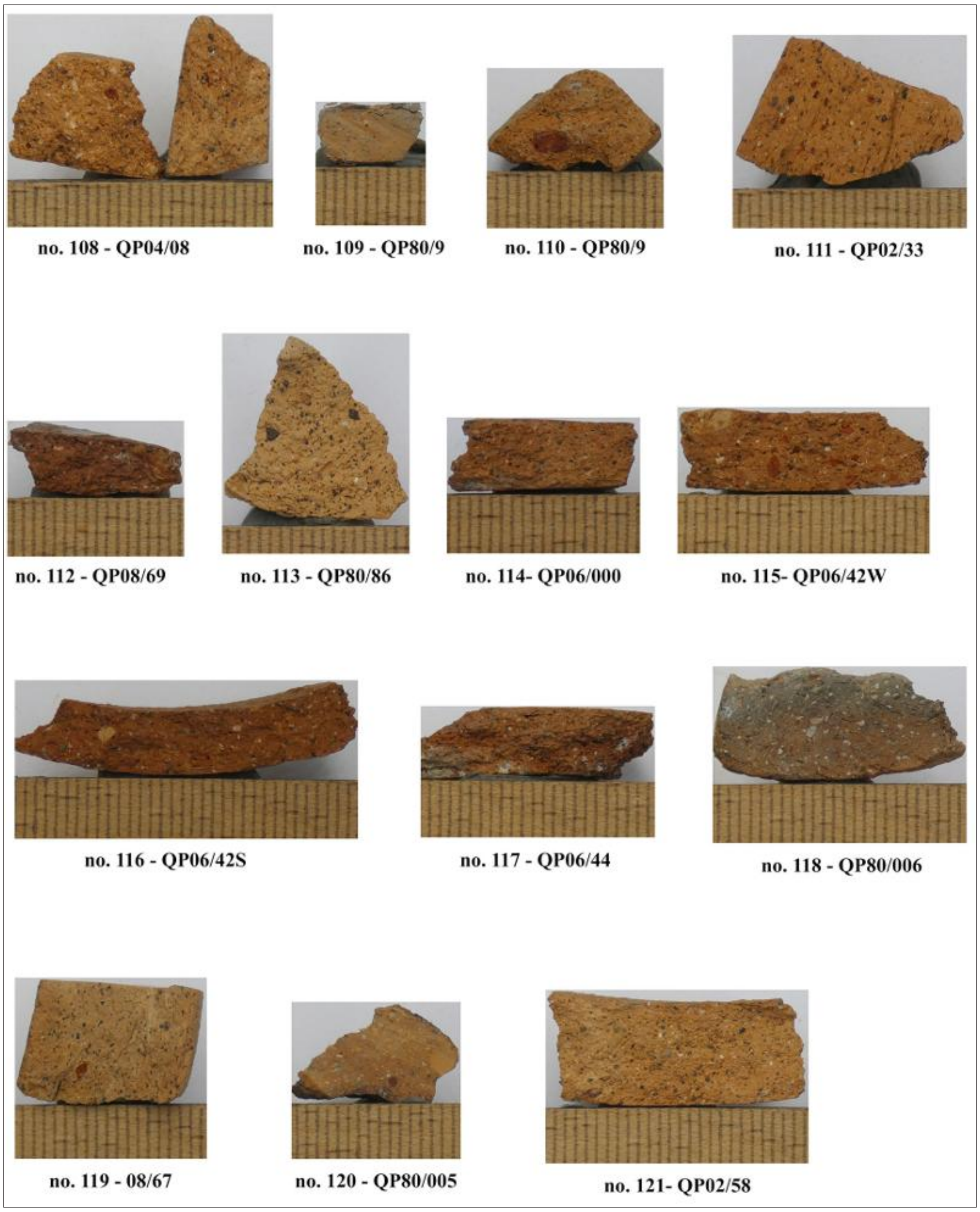

Fig. A.1.3. Fabrics of analysed pottery samples (photos: A. Rogava).

Sample no.	Black	White	Red-brown	Grey	Macr. grouping
78	1-3% (< 1mm)	2-3% (< 0.25mm)	<0.5% (< 1mm)	0.5-2% (up to 1mm)	Group 1?
79	2-5% (< 1mm)	2-5% (up to 1mm)	0.5-2% (< 1mm)	?	Group 1
80	5-10% (< 1mm)	2-5% (< 2mm)	0.5-1% (up to 1mm)	?	Group 2
81	4-7% (< 1mm)	2-5% (up to 0.5mm)	<0.5% (up to 1mm)	?	Group 2?
82	3-5% (up to 1mm)	2-5% (< 1mm)	0.5-1% (up to 1mm)	0.5-1% (> 1mm)	Group 1
83	3-5% (< 1mm)	3-7% (< 0.5mm)	0.5-1% (< 1mm)	1-2% (> 1mm)	Group 1

84	1-3% (< 1mm)	3-7% (> 1mm)	0.5-1% (< 1mm)	1-2% (< 1mm)	Group 1
85	2-5% (< 1mm)	5-10% (up to 1mm)	1-2% (up to 1mm)	1-2%? (up to 1mm)	Group 1
86	5-8% (up to 0.5mm)	1-2% (< 0.25mm)	0.5-1% (up to 1mm)	< 0.5%? (< 1mm)	Group 2
87	2-4% (up to 0.5mm)	3-5% (< 1mm)	0.5-1%? (up to 1mm)	0.5-1%? (< 1mm)	Group 1
88	2-3% (< 1mm)	3-7% (< 1mm)	0.5-1% (< 1mm)	1-2% (> 1mm)	Group 1
89	1-3% (< 1mm)	3-7% (> 1mm)	2-3% (< 1mm)	1-2% (< 1mm)	Group 1
90	0.5% (< 1mm)	1-2% (< 1mm)	0.5%? (up to 1mm)	< 0.5% (< 1mm)	Group 1
91	2-4% (up to 0.5mm)	2-5% (< 1mm)	0.5%? (up to 1mm)	0.5-1%? (< 1mm)	Group 1
92	2-4% (> 1mm)	4-8% (< 1mm)	2-4% (> 1mm)	0.5%? (> 1mm)	Group 1
93	2-5% (up to 1mm)	3-7% (< 1mm)	0.5%? (up to 1mm)	0.5-1% (> 1mm)	Group 1
94	2-4% (up to 1mm)	2-5% (< 1mm)	0.5%? (< 1 mm)	0.5-1%? (up to 1mm)	Group 1
95	2-5% (< 1mm)	2-5% (< 1mm)	2-4% (> 1mm)	0.5-1% (up to 1mm)	Group 1
96	2-4% (< 1mm)	1-3% (up to 0.5mm)	2-3% (> 1mm)	0.5-2%? (up to 1mm)	Group 2?
97	2-3% (up to 0.5mm)	1-3% (< 1mm)	0.5% (< 0.5mm)	?	Group 1?
98	2-4% (< 1mm)	3-6% (< 1mm)	0.5-1%? (up to 2mm)	1-2%? (up to 1mm)	Group 1
99	1-3% (< 1mm)	3-6% (up to 1mm)	2-5% (> 2mm)	0.5%? (< 1mm)	Group 1
100	1-2% (up to 0.5mm)	2-6% (up to 1mm)	0.5-1%? (up to 1mm)	0.5%? (< 1mm)	Group 1
101	2-5% (up to 1mm)	3-7% (< 1mm)	0.5-1% (< 1mm)	0.5-1% (up to 1mm)	Group 1
102	5-8% (< 1mm)	2-3% (up to 1mm)	0.5-1%? (< 1mm)	?	Group 2
103	3-5% (up to 1mm)	4-6% (> 1mm)	1-3% (up to 1mm)	0.5-1%? (< 1mm)	Group 1
104	6-8% (< 1mm)	1-3% (up to 1mm)	1-3% (> 2mm)	0.5%? (< 1mm)	Group 2
105	4-5% (< 1mm)	2-4% (up to 1mm)	0.5-1%? (> 1mm)	?	Group 2?
106	4-6% (< 1mm)	1-3% (< 1mm)	0.5%? (up to 1mm)	0.5-1% (up to 1mm)	Group 2
107	2-3% (up to 1mm)	3-5% (< 1mm)	0.5-1% (up to 1mm)	0.5%? (< 1mm)	Group 1
108	1-2% (< 1mm)	3-7% (up to 1mm)	0.5-1% (< 2mm)	?	Group 1
109	1-2%? (< 1mm)	1-2%? (< 0.5mm)	?	?	Group 1?
110	2-3% (< 6mm)	2-4% (up to 0.5mm)	2-4% (> 3mm)	0.5%? (up to 1mm)	Group 1
111	2-3% (> 1mm)	2-4% (< 1mm)	1-2% (> 1mm)	0.5% (< 1mm)	Group 1
112	1-2% (< 1mm)	2-4% (up to 1mm)	0.5%? (< 1mm)	?	Group 1
113	2-5% (> 1mm)	2-4% (< 1mm)	1-2% (up to 0.5mm)	< 0.5%? (up to 0.5mm)	Group 2?
114	2-3% (> 1mm)	1-2% (< 1mm)	0.5%? (< 1mm)	< 0.5%?	Group 2?
115	1-2% (< 1mm)	3-6% (up to 1mm)	1-3% (up to 2mm)	?	Group 1
116	1% (< 1mm)	2-5% (> 2mm)	0.5-1%? (< 1mm)	0.5-1%? (< 1mm)	Group 1
117	2-3% (< 1mm)	2-3% (< 1mm)	0.5%? (< 1mm)	0.5-1%? (> 1mm)	Group 1?
118	1-2% (< 1mm)	3-6% (> 1mm)	0.5% (< 1mm)	0.5%? (< 1mm)	Group 1
119	3-5% (< 1mm)	2-3% (< 0.5mm)	1-2% (> 2mm)	?	Group 2?
120	1% (< 0.5mm)	2-3% (< 1mm)	1% (up to 1mm)	1%? (< 1mm)	Group 1
121	1-2% (< 1mm)	2-3% (< 1mm)	0.5-1% (< 1mm)	0.5% (< 1mm)	Group 1

Table A.2. Macroscopic description and grouping of amphora samples.

Appendix B – Petrographic descriptions

B.1. Pottery samples
Pm-1: Pyroxene and volcanic rock fabric (Fig. ...)

Samples: no. 80, 86, 102, 104 and 106.

Inclusions (23,5-36%)[1]

Sorting: moderate to poor.
Grain size distribution: bimodal

Silt fraction (eq. & el., a to wr) (+/- 0,5 – < 2%)
0,5-1,5% quartz/feldspar
< 0,5-0,5% black isotropic iron-rich ore mineral fragments
0 – < 0,5% mica (only sample no. 102)

Sand fraction (el & eq, a to sr) (+/- 23-35%)
13,5-19% Pyroxene (up to 830 μm)
1-5% Volcanic rock fragments (up to 840 μm)
0 – < 0,5% Volcanic (?) rock fragment (up to 315 μm) (present only in sample no. 80).
1-3% polycrystalline quartz (up to 1560 μm)
1,5-4% largely isotropic, black or reddish-black rock fragments (up to 1280 μm)
0,5-3% quartz and/or feldspar (up to 505 μm)
< 0,5-1% black isotropic iron-rich mineral fragments (up to 190 μm)
< 0,5-1 % feldspar (up to 680 μm)
0-1% intrusive rock fragments (up to 735 μm). It is absent in sample no. 104.
0-0,5% intrusive(?) rock fragments (up to 700 μm). It is present in sample no. 104 and 106.
0-1% Sandstone(?) (up to 370 μm). It is only present in sample no. 80, 86 and 102.
0 – < 0,5% unidentified yellowish to reddish volcanic glass(?) fragments (up to 240 μm). It is present only in sample no. 86.
< 0,5-2% unidentified rock fragments (up to 900 μm).

Matrix (57-71%)
Matrix is iron-rich. However, its' content is variable: judging from the samples' colour in XPL the sample no. 104 contains less iron (and less quartz and/or feldspar inclusions in silt fraction) compared to the samples no. 80, 86, 102 and 106 (which also contain more quartz and/or feldspar inclusions in silt fraction). The colour of matrix in XPL is orangish-brown (seldom yellow-orangish) to greenish(-yellowish), mostly with weak to strong pleochroism. In 4 out of 5 thin sections a thread-like texture can be observed, suggesting the presence of montmorillonite clay. Iron-rich clay pellets can be clearly identified in samples no. 80, 86 and 104. The colour in PPL is light orangish brown to orange – brown or dark brown.

Voids (5-8%)

Pm-2: "Mixed" fabric (magmatic, sedimentary and metamorphic rock) fabric (Fig. …)

Samples: no. 79, 81, 82, 83, 84, 85, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 103, 105, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116 117, 118, 119, 120 and 121.

Inclusions (13-37%)

Sorting: moderate to poor
Grain size distribution: bimodal – moderately bimodal

Silt fraction (eq. & el. a. to r):
0,5-1% mica + unidentified yellow-greenish mineral fragments
< 0,5-1,5% quartz and/or feldspar
< 0,5% black isotropic iron-rich ore mineral fragments

1. All abundance estimation numbers are approximative (+/-).

Sand fraction (el. & eq. a. to sr):
4-11% volcanic rock fragments (up to 1390 μm)
1-9% pyroxene (up to 860 μm)
1,5-7% mainly polycrystalline and some monocrystalline quartz (up to 1000 μm)
0,5-6% largely isotropic, black/reddish-black rock fragments (up to 1800 μm)
< 0,5-3% feldspar (up to 840 μm)
< 0,5-4,5% quartz and/or feldspar (up to 485 μm)
< 0,5-4% intrusive rock fragments (up to 955 μm)
0-2% intrusive(?) rock fragments (up to 490 μm). Present only in samples: no. 101, 105, 107, 111, 112, 113, 114, 115, 116, 118.
0-5% metamorphic rock fragments (up to 910 μm). It is absent in samples: no. 86, 115, 116 and 121.
0 – < 0,5% metamorphic(?) rock fragments (up to 545 μm). Present only in samples: no. 83, 84, 91 and 119.
< 0,5-3% Siltstone – Sandstone (up to 580 μm)
0-2% Siltstone – Sandstone(?) (up to 640 μm). It is present in samples: no. 81, 83, 84, 86, 107, 110, 111, 113, 114, 115, 118, 119, 120, 121.
< 0,5-2% black isotropic iron-rich ore mineral fragments (up to 330 μm)
< 0,5-3% unidentified yellowish to reddish volcanic glass(?) fragments (up to 1210 μm)
< 0,5-2% other unidentified rock fragments (up to 590 μm)
0 – < 0,5% amphibole (up to 440 μm). It is only present in samples: no. 81, 84 and 117.
0 – < 0,5% olivine (230 μm). Present only in sample no. 110.
0 – < 0,5% olivine(?) (200 μm). Present only in sample no. 79.

Matrix (54-83%)
Matrix has a variable iron content. Iron rich clay cloths and iron poor zones are often visible, as well as iron rich streaks in some cases. The colour in XPL is mostly orangish-brown to light greenish/yellowish with a weak/medium to strong pleochroism. Exceptions are samples no. 85, 89 and 94, which have weak to medium pleochroism and partly vitrified matrices. Majority of thin sections have a thread-like texture, suggesting the presence of montmorillonite clay. The matrix colour in PPL is mostly light (orangish) brown to orange-brown, dark brown or reddish brown. Seldom _ light grey to dark grey.

Voids (4-10%)

Comments
Samples no. 115, 116 and 121 contain no metamorphic rock fragments and sample the first two also lack sandstone admixtures. However, their matrices and silt fraction is typical for Pm-2. Therefore, based on general criteria these three thin sections should also be considered as belonging to Pm-2 microscopic fabric group.
The low inclusions share in samples no. 90 and 91 is due to the fact that these thin sections were made from thin wall parts, where the inclusions are well-spread across the matrix. On the outer surface of thin section no. 85 traces of smoothing is visible.

Pm-3 (Loner) – sample no. 78 (QS144-4): Silty with volcanic rock and opaques

Inclusions (32%)

Sorting: Moderate
grain size distribution: moderately bimodal

Silt fraction (eq. & el. a. to r.):
+/- 3% quartz/feldspar
< 0,5% mica
< 0,5% unidentified yellow-greenish mineral fragments
< 0,5% black isotropic iron-rich ore mineral fragments

Sand fraction (el. & eq. a. to sr.):
+/- 10% volcanic rock fragments (up to 1160 μm). Large part of them are of the same type and contain tiny Rutile needles. The rest is mostly mafic in composition.
+/- 10% largely isotropic, black/reddish-black rock fragments (up to 2100 μm)
+/- 3% pyroxene (up to 850 μm)
+/- 2% quartz and/or feldspar (up to 150 μm)
+/- 1% feldspar (up to 560 μm)
+/- 1% polycrystalline quartz (up to 540 μm)
+/- 1% black isotropic iron-rich ore fragments (up to 210 μm)
< 0,5% metamorphic rock fragments (possibly schist) (up to 345 μm)

Matrix (60%)
The colour of the matrix in XPL is orange brown to greenish with traces of montmorillonite. Pleochroism is medium to strong. The colour in PPL is light brownish-grey to orangish/reddish brown, suggesting the presence of a certain amount of iron. It contains large amount of partly isotropic iron-rich concretions and iron oxides (up to 2100 μm). It is difficult to judge whether they form part of the temper or belong to the original raw clay.
Silt size inclusions are evenly distributed within the matrix, suggesting a primary silty raw material.

Voids (8%)

B.2. Sand samples

1. CH015 (Chorokhi river sand – briquette fired at 980 °C)

Inclusions (38,5%)

Silt fraction (eq. & el. a. to r.):
3% quartz / feldspar
< 0,5% black isotropic iron rich ore mineral fragments (incl. magnetite?)
0,5% mica and other indefinite yellowish mineral fragments

Sand fraction (el. & eq. a. to r.):
16% volcanic rock fragments (up to 700 μm)
5% sandstone (up to 480 μm)
4% feldspar (up to 515 μm)
3% mainly isotropic, iron rich rock fragments (up to 540 μm)
2% pyroxene (up to 410 μm)
2% quartz and/or feldspar (up to 365 μm)
1% intrusive rock fragments (up to 700 μm)
1% unidentified rock fragments (up to 650 μm)
0,5% quartz (up to 260 μm)
< 0,5% amphibole (hornblende?) (a single fragment, 210 μm)

Comments
Zoning occurs in the case of two plagioclase crystals within the volcanic rock and a few loose plagioclase crystals.

2. NA014 (Natanebi river sand – briquette fired at 980°C)

Inclusions (44,5%)

Silt fraction (eq. & el. a. to r.):
3% quartz/feldspar
0,5% mica + undefined mafic (often yellowish mineral fragments)
< 0,5% black isotropic iron rich ore mineral fragments (incl. magnetite?)

Sand fraction (el. & eq. a. to r.):
8% volcanic rock fragments (up to 860 μm)
2% yellowish-greenish volcanic glass(?) fragments (up to 680 μm)
7% sandstone (consisting mostly of quartz) (up to 980 μm)
7% metamorphic rock fragments (up to 950 μm)
3% feldspar (up to 470 μm)
2,5%: pyroxene (up to 310 μm)
3% monocrystalline quartz (up to 400 μm)
1% polycrystalline quartz (or rocks consisting mainly of polycr. quartz) (up to 400 μm)
3% intrusive rock fragments (265-630 μm)
2% black or reddish-black, partly isotropic iron rich rock fragments (up to 420 μm)
2% quartz and/or feldspar (up to 545 μm)
< 0,5% mica (a single fragment, 135 μm)

Comments
Zoning occurs in the case of a plagioclase crystal within a volcanic rock and a loose plagioclase fragment. Yellowish volcanic glass fragments often contain silt sized accessory minerals.

3. UR010 (Ureki beach sand – briquette fired at 980 °C)

Inclusions (35,5%)

Silt fraction (eq. & el, a. to r.):
3% quartz/feldspar
0,5% mica
< 0,5% black isotropic iron rich ore mineral fragments

Sand fraction (el. & eq, a. to r.):
12% volcanic rock fragments (165-975 μm)
5% pyroxene (220-800 μm)
4% sandstone (up to 950 μm)
3% metamorphic rock (shale?) fragments (up to 970 μm)
1,5% monocrystalline quartz (up to 585 μm)
2% polycrystalline quartz (or rocks consisting mainly of polycr. quartz) (up to 500 μm)
2% intrusive rock fragments (up to 600 μm)
1% black or reddish-black, iron-rich, partly isotropic rock fragments (up to 400 μm)
1,5% feldspar (up to 830 μm)

Comments
Zoning occurs in the case of plagioclase crystals within two volcanic rock and one plagioclase crystal.

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