Eastern Mediterranean amphorae from Late Antique urban centers of the northeastern Iberian Peninsula: archaeometric characterization

Leandro Fantuzzi, Miguel Ángel Cau Ontiveros, Josep Maria Macias Solé and Francesc Rodríguez Martorell

Revista	Archeosciences. Revue d'Archéométrie, 43-2 (2019), p. 229-247
DOI	https://doi.org/10.4000/archeosciences.6897

Disponible en línia		**Data de publicació**	2020

Per citar aquest document:

Fantuzzi, L.; Cau, M. A.; Macias, J. M.; Rodríguez, F., "Eastern Mediterranean amphorae from Late Antique urban centers of the northeastern Iberian Peninsula: archaeometric characterization", Archeosciences. Revue d'Archéométrie, 43-2 (2019), p. 229-247. https://doi.org/10.4000/archeosciences.6897

Eastern Mediterranean amphorae from Late Antique urban centers of the northeastern Iberian Peninsula: archaeometric characterization

Amphores de la Méditerranée orientale dans les centres urbains de l'Antiquité tardive du nord-est de la Péninsule Ibérique: caractérisation archéométrique

Leandro Fantuzzi[1,*], Miguel Ángel Cau Ontiveros[1, 2, 3,†], Josep Maria Macias Solé[4], Francesc Rodríguez Martorell[4]

1. ERAAUB, Universitat de Barcelona, Facultat de Geografia i Història, Departament d'Història i Arqueologia, c/ Montalegre 6-8, 08001 Barcelona, Spain
2. ICREA, Pg. Lluís Companys 23, 08010 Barcelona, Spain
3. Joukowsky Institute for Archaeology and the Ancient World, Brown University, Providence (RI), USA
4. ICAC-Institut Català d'Arqueologia Clàssica, Pl. Rovellat s/n, 43003, Tarragona, Spain

Abstract

Amphorae from Palestine, Turkey, the Aegan and other areas of the eastern Mediterranean are frequently documented in Late Antique archaeological contexts in northeastern Spain, in relation to the transport of wine and other products. In order to gain further information on their compositional variability, provenance and production technology, a series of these amphorae was archaeometrically characterized. The amphorae were sampled from various contexts found in consumption centres of the current Catalan coastal territory, dated between the 5th and 7th centuries AD. Various types of eastern Mediterranean amphorae were characterized, including the most common ones, such as LRA 1, LRA 4, LRA 2 and LRA 3, but also others less represented in the ceramic assemblages. The selected samples were analyzed using a combination of techniques (WD-X-ray fluorescence, X-ray powder diffraction and optical microscopy by thin section analysis) for their chemical, mineralogical and petrographic characterization. The results show the presence of well differentiated fabrics and chemical compositions for each of the amphora types analyzed as well as certain variability in some of them, related to differences in provenance and/or production technology. Comparison with available archaeometric and archaeological data from eastern Mediterranean production centers enabled for provenance hypotheses for many of the amphorae under study.

[*] Corresponding author: lfantuzzi@ub.edu
[†] Senior author: macau@ub. edu

Keywords: amphorae, petrography, archaeometry, Hispania, Eastern Mediterranean, Late Antiquity

Résumé

Des amphores de Palestine, de Turquie, d'Égée et d'autres zones de Méditerranée orientale sont fréquemment retrouvées dans des contextes archéologiques de l'Antiquité tardive du nord-est de l'Espagne, liées au transport du vin et d'autres produits. Afin d'obtenir de plus amples informations sur leurs techniques de production, la provenance et leur variabilité en termes de composition élémentaire, une série de ces amphores a fait l'objet d'une caractérisation archéométrique. Les amphores ont été échantillonnées dans divers contextes de consommation du littoral Catalan actuel, datées entre le 5ème et 7ème siècles de notre ère. Différents types d'amphores de Méditerranée orientales ont été caractérisés, y compris les plus courants, tels que LRA1, LRA 4, LRA 2 et LRA3, mais aussi d'autres moins représentés dans les assemblages céramiques. Les échantillons sélectionnés ont été analysés en utilisant une combinaison de techniques (la spectrométrie de fluorescence des rayons X (WDXRF), diffraction des rayons x (XRD) et microscopie optique (OM) par l'analyse de lame mince) pour leur caractérisation chimique, minéralogique et pétrographique. Les résultats montrent la présence de fabriques et de compositions chimiques bien différenciées pour chacun des types d'amphores analysés, ainsi qu'une certaine variabilité pour certains d'entre eux, liées aux différences de provenance et/ou de techniques de production. La comparaison avec des données archéologiques et archéométriques disponibles pour les centres de productions méditerranéens, permet de proposer une hypothèse de provenance pour bon nombre des amphores en question.

Mots clés: amphores, pétrographie, archéométrie, Hispania, Méditerranée orientale, Antiquité tardive

1. Introduction

Transport amphorae from the eastern Mediterranean have been widely attested in many Late Antique contexts from the northeastern Iberian Peninsula (Keay, 1984; Reynolds, 1995, 2010a; Cerdà *et al*., 1997; Aquilué & Burés, 1999; Remolà, 2000; Cela & Revilla, 2004; Járrega, 2010, 2013; Macias *et al*., 2008; Carreras, 2012; Fantuzzi *et al*., 2013). They evidence the arrival of foodstuffs (mainly wine, and possibly oil in some cases) from various areas, including Palestine, Asia Minor and the Aegean, among others (Piéri, 2005; Reynolds, 2010a). In the current Catalan coastal territory, these amphorae are frequent from the 5th century AD; at this moment, they represent 22-31% of the total amphorae (MNI) found in rubbish dumps from the urban centers of *Tarraco*/Tarragona and *Emporiae*/Empúries (Aquilué & Burés, 1999; Remolà, 2000). This trade was still significant until the 7th century AD in the coastal urban centers, although eastern Mediterranean amphorae were less frequent in rural sites (*e.g.* Carreté *et al*., 1995; Castanyer & Tremoleda, 1999; Reynolds, 2010a).

The significant presence of eastern Mediterranean imports in some urban centers, including not only amphorae but also a minor amount of fine wares (Phocean Late Roman C and Cypriot Late Roman D) and cooking wares, is a reflection of the relations between the East of the Mediterranean and *Hispania* in the Late Antique period, well attested by numerous historical and archaeological evidences (García Moreno, 1972; Blázquez, 1988; García Vargas, 2011). These relations are strong from the second half of the 4th century, but, as concerns the trade of products transported in amphorae, eastern Mediterranean imports in the northeastern Iberian Peninsula are more significant from the first half or mid 5th century.

In recent years, a systematic research program focused on the archaeometric study of Late Roman amphorae in northeastern Spain has been carried out, with the aim of gaining knowledge on the characterization of the materials, the provenance determination and the investigation of their production technology (Fantuzzi *et al*., 2015, 2016; Fantuzzi & Cau, 2016). The ultimate goal of this analytical program is to shed more light on the patterns of production, distribution and consumption of the products transported in amphorae, and, on this basis, to contribute new evidence on the Mediterranean trade networks in Late Antiquity. Within the framework of this broader program, a series of transport amphorae from the eastern Mediterranean, found in consumption centers of the northeastern Iberian Peninsula (the former province of *Hispania Tarraconensis*), were analyzed. Prior to this research program, only very few compositional studies of eastern Mediterranean amphorae in our study area had been published (Remolà *et al*., 1993, 1996; Uscatescu & García, 2005), with certain constraints (see Fantuzzi *et al*., 2013). The objective of this paper is to present the integrated results of the archaeometric analysis of various eastern Mediterranean amphorae, which included a combined chemical, mineralogical and petrographic characterization. The variability of fabrics and chemical compositions is examined, and a comparison with existing information from production centers/areas is made, in order to provide further details on the provenance of the amphorae and on some technological considerations.

2. Archaeological contexts and sampling

A total of 40 samples of eastern Mediterranean amphorae from different consumption centers in the current Catalan coastal territory were selected for archaeometric analysis. The selected individuals belong to the most widespread eastern Mediterranean amphora types (such as LRA 1, LRA 4, LRA 3 and LRA 2), as well as to other less represented types in the archaeological contexts (Table I; Figure 1a). These amphorae had been initially studied and typologically classified according to their macroscopic characteristics of fabric and shape, what served as a basis for initial hypotheses about their probable area of origin.

The sampling was carried out in three Late Antique urban centers: *Tarraco* (Tarragona), *Emporiae* (Empúries) and *Iluro* (Mataró) (Figure 1b). The samples from Tarragona were taken mainly from two contexts. On the one hand, from a context found in the cloister of the Medieval Cathedral and dated to the first half of the 6th century, although containing many residual materials from reused fifth-century deposits (Teixell *et al*., 2005; Macias *et al*., 2008; Fantuzzi *et al*., 2015); few samples were taken also from leveling layers, dated to a later Medieval reuse of the same area but including many residual ceramics from the 5th-6th centuries. On the other hand, amphorae were sampled from recently studied contexts found at c/Cardenal Vidal i Barraquer nº 27, dated to between the second half of the 7th century and the early 8th century (Rodríguez & Macias, 2016). The selected amphora samples from *Emporiae* come from 5th and 6th century contexts in Plaça Major and Plaça Petita, in the current town of Sant Martí d'Empúries (Aquilué & Burés, 1999; Fantuzzi *et al*., 2016). Finally, a few samples of Eastern Mediterranean amphorae were also taken from various excavations at the ancient urban center of *Iluro*, currently Mataró, mainly from 6th century contexts (Cerdà *et al*., 1997; Cela & Revilla, 2004; Fantuzzi & Cau, 2016).

Considering all the selected archaeological contexts together, Eastern Mediterranean amphorae are dominated by type LRA 1, followed by a lower frequency of types LRA 4, LRA 2 and LRA 3, and a subordinate presence of other amphora types. Sample selection was initially intended to be representative of these relative frequencies in the archaeological contexts. However this was not always possible due to the small size of the preserved fragments for some amphora types and, consequently, the impossibility of reaching a minimum sample weight for a combined chemical, mineralogical and petrographic analysis for some the vessels (this is the case especially for type LRA 3). For this reason, the frequencies of the compositional groups in this study are not thought to be a direct reflection of their relative frequencies in the archaeological assemblage, but only an approximation. Nevertheless, this limitation does not prevent analyzing a diversity of amphora types from the selected contexts and shedding new light into their characterization and provenance.

3. Analytical methods

The analytical research program involved the application of various archaeometric techniques on the selected amphora samples. This included optical microscopy (OM) through thin sections for the petrographic-mineralogical analysis, X-ray diffraction (XRD) for further information on the mineralogical composition, and wavelenght dispersive X-ray fluorescence (WDXRF) for the chemical characterization.

For XRF and XRD analyses, a sample of each specimen was powdered and homogenized in a tungsten carbide mill, and dried at 100ºC for 24 hours. The chemical composition of the amphorae was determined by means of WDXRF, using a Panalytical-Axios PW 4400/40 spectrometer. A part of the powdered sample of each individual was used to prepare, on the one hand, fused beads for the determination of major and minor elements, and, on the other hand, pressed pellets for the determination of trace elements. A small part of the powdered sample of each specimen was used for the XRD mineralogical analysis, which was performed using a PANalytical X'Pert PRO MPD alpha 1 diffractometer. For further details on the analytical routine performed for XRF and XRD, see Cau (2003) and Fantuzzi *et al*. (2015).

The petrographic-mineralogical analysis of thin sections was conducted using an optical microscope Olympus BX41, equipped with a digital camera Olympus DP-70, and working between ×20 and ×200 of magnification. The methodology proposed by Whitbread (1989, 1995) and Quinn (2013) was followed for the study of the petrographic fabrics.

4. Results and discussion

Petrographic-mineralogical fabrics

Thin section analysis under the optical microscope allowed for the differentiation of thirteen petrographic fabric groups (ORI-1 to ORI-13), based on the characteristics of the inclusions, clay matrix and porosity (Whitbread, 1989, 1995; Quinn, 2013). Five of them are represented by more than one individual (ORI-1, ORI-2, ORI-3, ORI-6 and ORI-7), while there are eight individuals representing each one a distinct fabric (ORI-4, ORI-5, ORI-8 to ORI-13). In addition to the data from OM analysis, complementary information on the mineralogical composition of each fabric or group was provided by XRD. The identification of primary mineral phases and firing phases through this technique enabled an estimation of equivalent firing temperatures or EFT (*e.g.* Cultrone *et al*., 2001; Buxeda & Cau, 2004; Maggetti *et al*., 2011), while the identification of secondary phases provided, in specific cases, information about postdepositional alteration and/or contamination processes.

The five petrographic fabric groups, represented by more than one individual in the analyzed assemblage, are (Figure 2):

Fabric group ORI-1: 'calcareous and ophiolitic temper, calcareous matrix' (Figure 2a-b). It gathers a total of 16 samples, including 7 individuals from *Tarraco* (CAT202, CAT206, CAT233, CAT241, HST010, TAR017 and TAR075), 5 from *Emporiae* (EMP306, EMP309, EMP310, EMP326 and EMP351) and 4 from *Iluro* (ILU072, ILU079, ILU080 and ILU081), all belonging to the amphora type LRA 1, in different variants, mainly 1A and 1B. The fabrics in this group are generally characterized by a calcareous matrix, a scarce fine fraction (<0.1 mm) and a dominant sandy temper, moderately to well sorted, composed of both calcareous inclusions (limestone and microfossils) and ophiolitic inclusions (serpentine, iddingsite, clinopyroxene, orthopyroxene, olivine, amphibole and igneous rocks of basic/ultrabasic composition, rarely of intermediate composition). A variable frequency of quartz, plagioclase and chert is found, as well as, more rarely, alkali feldspar, metamorphic rocks and acidic plutonic rocks. Various fabrics have been distinguished based on variations in the relative frequencies of these components and/or textural differences. A detailed discussion of this variability will not be provided here since it has been already object of a specific study (Fantuzzi *et al*., 2017). XRD patterns reflect the highly calcareous composition of these fabrics, with intense reflections of calcite and low of phyllosilicates in three low-fired samples (EFT ≤800/850ºC), and development of gehlenite and diopside in the rest of the samples, which are higher fired (EFT usually 850-950ºC) (Figure 3); very low pyroxene is also seen as a primary phase in the former. Only in two individuals the complete decomposition of phyllosilicates points to an EFT higher than 950/1000ºC. The results of OM and XRD suggest that, in many cases, changes in the macroscopic colour and texture of the fabrics are related to differences in firing temperatures (Figure 3), from a buff-orange colour in samples with the lowest EFT, to a yellowish cream colour in those fired at the highest temperatures (≥950/1000ºC). The provenance of these fabrics, according to the comparison with archaeometric and archaeological data from production centers of LRA 1, must be located between *Cilicia* and northern Syria, and possibly Cyprus (see references in Fantuzzi *et al*., 2017) (Figure 4). Even if the production of LRA 1 in Cyprus is well attested and shows many similarities in composition to the products from *Cilicia* and northern Syria, the fabrics identified in our study, mostly related to variants LRA 1A and 1B, seem to come, in most cases, from the Gulf of Iskenderun area, rather than from Cyprus (see discussion in Fantuzzi *et al*., 2017).

Fabric group ORI-2: ‘quartz and calcite, with accessory heavy minerals’ (Figure 2c). It includes eight individuals (CAT216, TAR016, TAR062, TAR065, TAR069, TAR076, EMP320 and EMP331), mostly of type LRA 4, but also a ‘late bag-shaped amphora’ of type LRA 5 (TAR069). These samples exhibit a calcareous clay matrix, rich in fine inclusions (<0.15 mm) of quartz and carbonates, along with plagioclase, quartzite and accessory heavy minerals (pyroxenes, tourmaline, zircon, hornblende and epidote). The coarse fraction, >0.15 mm, probably added as temper though not very abundant, is mainly formed by medium sand inclusions of rounded quartz and carbonates (limestone and few/rare microfossils). The mineral assemblage identified through XRD suggests an EFT not higher than 800/850ºC (Figure 3); plagioclase in these samples can be interpreted as a primary phase. All the samples show the same fabric, quite homogeneous, except for slight variations in the frequency of the coarse fraction. Based on the petrographic characteristics of this fabric and the comparison with data from production centers, a provenance in southern Levant can be proposed, in particular in Late Antique *Palaestina*, most probably in the area of Gaza and Ashkelon, or possibly western Negev (Peacock, 1984; Blakely, 1988), where various workshops of LRA 4 have been identified (Piéri, 2005; Reynolds, 2005) (Figure 4). Production of bag-shaped amphorae is attested in other areas of *Palaestina*, as well as in southern *Phoenice* and *Aegyptus* (Piéri, 2005, Reynolds, 2005; Dixneuf, 2011), however the sample TAR069 shows exactly the same fabric as the LRA 4 amphorae analyzed in this work and seems to come from the same workshop/s.

Fabric group ORI-3: 'iron-rich micaceous matrix with fine quartz and heavy minerals' (Figure 2d). Two samples are included in this group (TAR057 and ILU048), both of the Aegyptian amphora type LRA 7. They show fine grained fabrics, with an iron-rich clay matrix and fine inclusions (mostly <0.10/0.20 mm) of quartz, iron nodules, plagioclase, biotite, muscovite and clinopyroxene, as well as other accessory heavy minerals (orthopyroxene, epidote and tourmaline), basalt rock fragments and very rare remains of carbonized vegetal matter. There is no evidence of tempering. XRD spectra for the two samples in ORI-3 show the presence of clear primary phases as well as peaks of plagioclase and pyroxene (Figure 3), which could be interpreted as firing phases and/or primary phases, since they were also observed in thin section. A small reflection of gehlenite in ILU048 suggests, at least for this sample, an EFT around 850-950ºC. The two samples are slightly different in texture, with a more refined fabric in TAR057 than in ILU048. In any case, both can be associated with similar LRA 7 fabrics defined from the middle Nile valley, produced using silty alluvial clays rich in iron oxides and silicates (Peacock & Williams, 1986; Empereur & Picon, 1998; Tomber & Williams, 2000; Dixneuf, 2011). Several LRA 7 amphora workshops have been attested in this area (Figure 4), however the lack of archaeometric studies does not enable a precise attribution to any of them.

Fabric group ORI-6: 'fine quartz and micas' (Figure 2e). It contains two individuals found in *Emporiae* (EMP303 and EMP334), one related to the so-called 'Ikarian amphora' type (Reynolds, 2010b) and one possible Samos Cistern Type amphora. These are fine-grained micaceous fabrics, rich in muscovite and quartz, with a subordinated presence of argillaceous clayey fragments (clay pellets and possibly ARF, see Whitbread, 1986) and calcite, as well as very rare basalt. Both individuals show differences in the mode of the inclusions (finer in EMP334, with less frequent fine sand than in EMP303) and the frequency of some accessory components, and may correspond to two related fabrics. They look quite different to the naked eye, especially because of the colour of the matrix, but the OM and XRD results suggest that this variability is due to differences in firing temperatures, with a much higher EFT in EMP303 than in EMP334 (≥950/1000 and ≤800/850ºC, respectively: Figure 3). Approximately similar fabrics have been described by Williams (1990) and Bezeczky (2013) for Samos Cistern Type amphorae. Archaeological evidence so far points to Samos as a possible production area (Arthur, 1990; Piéri, 2005), but other eastern Aegean islands or the western coast of Turkey cannot be excluded based on the petrographic composition.

Fabric group ORI-7: 'coarse limestone and chert, fine calcite and quartz' (Figure 2f). Four samples are included here (TAR068, TAR077, EMP343 and ILU030), all belonging to amphora type LRA 2. They all show the same fabric, with a coarse fraction (>0.25 mm), added as temper, composed of dominant limestone fragments and common chert, and a fine fraction of carbonate inclusions, quartz and chert. Very rare fine volcanic rocks can be observed (EMP343). Clay pellets are frequent to few. There is evidence of possible mixing between two different clays, one of them relatively calcareous. Sample EMP343 seems a lower fired version of the fabric, as suggested by the optical activity of the matrix. This is confirmed by XRD results, since it contains primary mineral phases only (EFT ≤800/850ºC), while in the other samples analyzed there is formation of firing phases (gehlenite, diopside and increased plagioclase) and partial decomposition of phyllosilicates (EFT 850-950ºC) (Figure 3). Even if there are still important gaps in the knowledge of LRA 2 production centers, which are supposed to be located in various areas including the Argolid, the Aegean, and even possibly the Chalkidiki and the western Black Sea (see Piéri, 2005), the samples included in group ORI-7 show the same fabric and would come from the same provenance area. Comparison of petrographic fabrics with reference samples from Argolis ―where a workshop of LRA 2 has been identified (Megaw & Jones, 1983; Zimmerman Munn, 1985)— suggests this area as a highly plausible provenance hypothesis for this fabric (Figure 4).

In addition to these five fabric groups, another eight fabrics, each represented by one individual in the analyzed assemblage, were identified (ORI-4, ORI-5 and ORI-8 to ORI-13).

Fabric ORI-4: 'fine fabric, Fe-rich muscovitic matrix' (Figure 5a), related to an amphora LRA 3 (sample CAT213). An iron-rich, muscovitic and non-calcareous clay was used for this fabric. The fine fraction, <0.15 mm, is composed of dominant muscovite, common quartz and iron oxides. The coarse fraction is almost absent but shows accessory metamorphic rocks (schist). The abundance of phyllosilicates is also reflected in the intense peaks of illite-muscovite identified through XRD (Figure 3). Similar fabrics have been described for other LRA 3 amphorae (*e.g.* Peacock, 1984; Bezeczky, 2013). The provenance can be located in western Turkey, in particular in the area of *Ephesus* (Figure 4), based on comparison with petrographic fabrics (Bezeczky, 2013) and reference materials from this center.

Fabric ORI-5: 'metamorphic temper, Fe-rich muscovitic matrix' (Figure 5b), observed in an indeterminate amphora rim possibly related to LRA 3 (sample EMP352). The fabric shows a similar clay matrix to ORI-4, rich in iron oxides and muscovite. However, in ORI-5 a coarse, poorly sorted temper was added, though not very abundant; it is composed of dominant metamorphic rocks (quartz-mica schist, quartzite, phyllite and gneiss). The provenance of ORI-5 might be approximately similar to the one for ORI-4, i.e. the Ephesus region, or more generally western Turkey or the eastern Aegean (Piéri, 2005; Bezeczky, 2013).

Fabric ORI-8: 'fine calcite and angular quartz' (Figure 5c), found in an amphora of type Agora M235/Vila-roma 8.198 (sample EMP327). It is composed of fine inclusions, mostly <0.15 mm, of dominant calcite, common quartz, few microfossils and very few metamorphic rocks (quartzite, phyllite and schist). A calcareous clay was used, with no added temper. For this amphora type a possible production in Crete and Messenia has been proposed (Reynolds, 2010a, 2010b; Bonifay *et al.*, 2013; Yangaki, 2014); the composition of ORI-8 does not provide strong evidence for assessing these hypotheses, although the low mica content of this fabric seems to exclude any relation to the fabric from Messenia described by Yangaki (2014).

Fabric ORI-9: ‘carbonates and metamorphic with accessory ophiolite’ (Figure 5d), observed in an indeterminate amphora bearing a *titulus pictus* (sample CAT212). It is a fine-grained fabric characterized by a calcareous matrix, with fine inclusions (mostly <0.15 mm) of dominant micritic calcite, common quartz and iron oxides, few micas, epidote and plagioclase. The scarce coarse fraction is formed by few fragments of limestone and acidic metamorphic rocks. Accessory serpentine, chlorite and peridotite are observed. The joint presence of inclusions derived from a greenschist facies, peridotites and acidic metamorphic rocks points to a provenance in the Aegean area for this fabric.

Fabric ORI-10: ‘quartz, calcareous microfossils, chert and metamorphic rocks’ (Figure 5e), found in a sample (TAR067) probably related to the globular amphora type LRA 13 or Yassi Ada 2. It is a fabric rich in inclusions of quartz, calcareous microfossils (foraminifera mainly, but also others such as algae and echinoids), chert and metamorphic rock fragments (quartzite, schist and phyllite). The fine fraction, <0.15 mm, is dominant, although the high frequency of fine-medium sand might suggest tempering. Production of LRA 13 type and other related amphorae from the same period has been documented in areas such as Cyprus (Demesticha, 2005) and Kos (*e.g.* Didioumi, 2014), however the fabrics described for these production sites are quite different from the fabric ORI-10 in this sample found in *Tarraco*. Therefore, beyond a broad relation to the Aegean region, it is not possible for the moment to propose any precise provenance hypothesis on a secure basis.

Fabric ORI-11: ‘quartz, muscovite and calcareous inclusions’ (Figure 5f), observed in an amphora LRA 2 (sample TAR018). This fabric contains dominant inclusions of quartz and mica (mostly muscovite), in addition to carbonates (calcite and few microfossils). There are also fragments of mudstone and a minor metamorphic contribution (quartz-mica schist). A calcareous clay was used, and the abundance of fine and medium sand suggest that a temper was possibly added. The provenance of this LRA 2 amphora fabric is unknown so far, although the information from production centers would suggest a general region between the Argolid, the Aegean or possibly other areas further north (Piéri 2005).

Fabric ORI-12: ‘mudstone’ (Figure 5g), found in a ‘late bag-shaped amphora’ of type LRA 6/Saraçhane Type 7b (sample TAR013). This fabric is well differentiated due to the presence of predominant coarse mudstone fragments, wich are yellowish in colour but apparently non-calcareous.

The clay matrix is iron-rich, and contains fine inclusions of mudstone, quartz and common calcareous microfossils. According to the archaeological information from production centers of 'late bag-shaped amphorae', this amphora TAR013 might have been produced in northern *Palaestina* or southern *Phoenice* (Piéri, 2005; Reynolds, 2005); however, few fabrics have been described in thin section so far (*e.g.* Glass, 1980; Peacock, 1984; Peacock & Williams, 1986), and no similarities are observed between these latter and the fabric ORI-12.

Fabric ORI-13: 'fine quartz, micas and carbonates, iron-rich matrix' (Figure 5h), found in a possible LRA 2 amphora sample (TAR070). It is a fine-grained fabric, with no temper, containing abundant inclusions of quartz, muscovite, biotite, carbonates (calcite mainly), and a subordinated presence of alkali feldspar, plagioclase and heavy minerals, especially epidote. There is also an accessory metamorphic contribution (quartzite and schist). It is not possible to propose any provenance hypothesis based on the published data from production centers so far.

For these fabrics, poorly represented in the assemblage analyzed, the mineral phases identified through XRD indicate relatively low firing temperatures (EFT usually below 800/850ºC) for the samples in fabrics ORI-4, ORI-8 and ORI-10. Conversely, the association of mineral phases in samples of fabrics ORI-9, ORI-11, ORI-12 and ORI-13, with development of firing phases in all the cases, suggests an estimation of EFT in the range 850-950ºC (Figure 3).

Chemical composition

Chemical analysis through XRF allowed determination of concentrations for 24 major, minor and trace elements: Fe_2O_3 (as total Fe), Al_2O_3, MnO, P_2O_5, TiO_2, MgO, CaO, Na_2O, K_2O, SiO_2, Ba, Rb, Nb, Pb, Zr, Y, Sr, Ce, Ga, V, Zn, Cu, Ni and Cr. Other elements had been also determined but were finally discarded from the statistical treatment due to possible contamination problems during the sample preparation (W, Co), analytical accuracy problems (Th) or analytical imprecision (Sn, W, Mo) (see Hein *et al.*, 2002).

The calculation of the compositional variation matrix or CVM enabled a quantification of the total variation (*vt*) in the data set, as well as the identification of the elements that contribute most to this variability (Aitchison, 1986, 2005; Buxeda, 1999; Buxeda & Kilikoglou, 2003). The total variation in the assemblage of eastern Mediterranean amphorae analyzed is high (vt = 3.74) and indicates the presence of various products quite different in terms of their chemical composition. The CVM provides information on the origin of this variability; given an element i, a high $\tau.i$ value in the matrix indicates a high variation associated with this element. In the amphora assemblage analyzed, the elements that account for a higher variability in the data set are Cr ($\tau.i$ = 17.06), CaO ($\tau.i$ = 13.56), Ni ($\tau.i$ = 12.67), Zr ($\tau.i$ = 9.84) and Na_2O ($\tau.i$ = 8.85) (Figure 6).

The results show that each of the fabric groups defined through OM were also characterized by a distinctive chemical composition (Table II; for ORI-5 no chemical data is available so far). A general assessment of the chemical data suggests that the variability associated with the above-mentioned elements is significant for the differentiation between the fabrics of eastern Mediterranean amphorae identified.

As concerns the variability in CaO content, almost all the amphorae analyzed are characterized by a calcareous composition (CaO $\geq$ 5%), even if with variations between 5% and 29%. The samples in fabric group ORI-3 are border calcareous (CaO 4-5%), while the only low-calcareous sample from the assemblage is CAT213 (Fabric ORI-4), a LRA 3 amphora from the Ephesus area. Among the calcareous materials, the samples in ORI-1 (LRA 1 amphorae) show the highest calcareous composition, with CaO ranging from 20% to 29%. These differences are observed in the bivariate diagram CaO vs MgO (Figure 7a), where it is also clear the higher percentage of MgO in ORI-1 (4-6%) than in the rest of the amphora fabrics.

Apart from CaO, the most variable elements in the data set are Cr and Ni, according to the CVM (Figure 6). This is due to the fact that several fabrics are characterized by high concentrations of Ni and Cr, with values higher than 100 ppm for both elements (ORI-1, ORI-6, ORI-7, ORI-8, ORI-9, ORI-10 and ORI-11), while in the rest of the fabrics these values tend to be lower, especially for Ni (Table II). However, ORI-1 is clearly differentiated due to a higher content in Cr than all the other fabrics. The bivariate diagram Ni vs Cr (Figure 7b) best illustrates these three general patterns: high Ni and very high Cr in ORI-1 (LRA 1 amphorae from the Gulf of Iskenderun area and/or Cyprus), high Ni and Cr in ORI-6 to ORI-11 (various amphorae from the Aegean and Peloponnese), and, finally, low

Ni and low to slightly high Cr in the rest of the fabrics, related to the southern Levant (ORI-2 and ORI-12), Egypt (ORI-3), Ephesus (ORI-4) and an indeterminate area (ORI-13). The very high concentrations of Ni, Cr and MgO in ORI-1 are associated with the high frequency of inclusions derived from an ophiolitic source, as was observed through thin section analysis (Fantuzzi *et al.*, 2017); also the low percentages of SiO_2 and Al_2O_3 in this group (Table II) can be related to the low content in aluminosilicates observed through OM and XRD.

Another highly variable element in the data set, according to the CVM, is Zr. About this, it can be noticed that the fabrics with a provenance in southern Levant (ORI-2 and ORI-12) show remarkably higher concentrations of Zr (>300 ppm) than the rest of the assemblage (Table II). Also TiO_2% is high in both fabrics, as well as in fabric ORI-3 from Egypt.

The differences in chemical composition between the eastern Mediterranean amphora fabrics can be better observed through multivariate statistical treatment. The chemical concentrations were transformed into additive log-ratios (Aitchison, 1986, 2005; Buxeda, 1999), using Fe_2O_3 as divisor, since this is the less variable element in the data set according to the MVC ($\tau.i$ = 4.27) (Figure 6). Principal component analysis (PCA) allows for a clear differentiation between the several fabric groups and fabrics (Figure 8a), mainly based on the differences in CaO, MgO, Ni, Cr, Zr and TiO_2 referred above, in addition to other elements such as Rb and K_2O, which are both low in the samples from the Levant (ORI-1, ORI-2 and ORI-12) and Egypt (ORI-3) (Table II). The good correspondence between chemical and petrographic results is also clear from cluster analysis (Figure 8b), where the various fabric groups and fabrics tend to separate due to their particularities in chemical composition.

It can be noticed that the fabrics ORI-6 to ORI-11 form a broad chemical group in the multivariate analysis due to some significant similarities in composition (Figure 8), despite the internal variability of this group. ORI-6 to ORI-9 are clearly associated with amphorae from the Aegean and Peloponnese; therefore, the chemical similarities suggest a provenance in the same general region for fabrics ORI-10 and ORI-11, what would be reasonable also considering the typology of the amphorae included in these fabrics (LRA 13 and LRA 2, respectively).

5. Conclusions

The results of the archaeometric analysis of eastern Mediterranean amphorae found in archaeological sites of northeastern Spain show the presence of well-differentiated fabrics and chemical compositions for each of the amphora types analyzed, as a reflection of different provenance areas, also related to different paste recipes and/or production techniques, as indicated by the variability observed in a number of technical aspects (*e.g.* tempering, types of clays used, firing conditions, etc.). The only exception is given by a few cases of different types of amphorae showing the same chemical-petrographic composition, *e.g.* a LRA 5 (TAR069) and all the LRA 4 samples (Fabric Group ORI-2). Comparison with published archaeometric and archaeological data from production areas, with reference materials and with the regional geology, has provided further information on the provenance of these amphora fabrics in most cases. The diversity of transport amphorae that have been identified and characterized is indicative of the arrival of foodstuffs from various eastern Mediterranean areas to the consumption centers in the northeastern Iberian Peninsula.

In the present analytical program, a total of thirteen petrographic fabric groups or distinct fabrics have been identified so far (ORI-1 to ORI-13), initially based on the OM thin section analysis, although each of these groups or fabrics has also showed a well differentiated chemical (XRF) and mineralogical (XRD) composition. Summarizing the results, there are two main fabric groups (ORI-1 and ORI-2) and one fabric (ORI-12) related to a provenance in the Late Roman dioecesis of *Oriens* (Figure 4), broadly corresponding to the Levant. One fabric group (ORI-3) came from Egypt. Finally, there are two fabric groups (ORI-6 and ORI-7) and six fabrics (ORI-4, ORI-5, ORI-8, ORI-9, ORI-10 and ORI-11) for which a general provenance in Greece, the Aegean region and/or western Turkey can be proposed (Figure 4).

All the LRA 1 amphorae form a single compositional group (ORI-1: Figure 9), with a quite characteristic chemical and petrographic composition that has been thoroughly analyzed in a specific work (Fantuzzi *et al.*, 2017). It is related to a provenance in *Cilicia*/N Syria mainly, although the latest samples of the type, from the 7th century AD, could possibly come from Cyprus. Similarly, all the samples analyzed of the Palestinian amphora LRA 4, along with a bag-shaped amphora LRA 5, present a quite homogeneous fabric and chemical composition (ORI-2: Figure 9), and seem to have been imported from one workshop or closely related workshops. Also the two examples of Egyptian LRA 7 amphorae analyzed have shown a similar fabric (ORI-3: Figure 10) and chemical composition, and come from the same area, in this case the middle Nile valley. Conversely, the samples of another common type of Late Roman amphora, LRA 2, have shown a higher diversity of chemical-petrographic compositions (ORI-7, ORI-11 and ORI-13: Figure 10), indicative of its arrival from various eastern Mediterranean production centers or zones; nevertheless, there is one fabric, ORI-7, that is the best represented in the LRA 2 amphorae in this work, coming from the Argolid most probably.

Other amphora types are less represented in the analyzed assemblage, even if some of them are quite frequent in the Late Antique archaeological contexts of northeastern Spain (*e.g.* LRA 3); further analytical research over a larger number of samples will provide more information on the variability of compositions associated with these amphorae. In any case, the analytical program carried out so far has enabled the characterization of several fabrics from the Aegean and/or western Asia Minor areas, including amphorae of types LRA 3 (ORI-4) or related (ORI-5), Agora M235 / Vila-roma 8.198 (ORI-8), a possible Samos Cistern Type (ORI-6), a so-called ‘Ikarian’ amphora (ORI-6), a globular amphora LRA 13 or Yassi Ada 2 (ORI-10) and an indeterminate amphora type (ORI-9) (Figure 10).

For these Aegean and western Asia Minor amphorae, there is not only a lack of comparative archaeometric data from the production sites, but the main problem is that much archaeological research is still needed in order to identify their possible production centers. This contrasts with the available information for the Levant and Egypt, where several workshops are known for Cilician/Syrian/Cypriot amphorae (LRA 1 and others), Palestinian amphorae (LRA 4 and others) and Egyptian amphorae (LRA 7 mostly), even if a systematic archaeological and archaeometric study is still needed on many of them.

In any case, the analysis of these amphorae from consumption centers, like the ones in the northeastern Iberian Peninsula, has provided a compositional characterization of the materials and an insight into some of their technological aspects, as well as an overview of the diversity of eastern Mediterranean amphora fabrics represented in our area of study. We expect to enhance our knowledge of this diversity through additional studies of other amphorae following the same integrated archaeological and archaeometric methodology. Such an approach will undoubtedly contribute significant new evidence on the trade of products transported in amphorae between the eastern Mediterranean and *Hispania Tarraconensis* in the Late Antiquity.

Acknowledgements

This research was carried out through the project *Late Roman Pottery in the Western Mediterranean: exploring regional and global trade networks through experimental sciences* (LRPWESTMED) (ref. HAR2013-45874-P), funded by the Plan Nacional de I+D+I Ministerio de Economía y Competitividad, Secretaría de Estado de Investigación, Desarrollo e Innovación, with contributions from FEDER funds (PI: Miguel Ángel Cau Ontiveros). This is part of the activities of the Equip de Recerca Arqueològica i Arqueomètrica de la Universitat de Barcelona (ERAAUB), Consolidated Group (2017 SGR 1043), thanks to the support of the Comissionat per a Universitats i Recerca del DIUE de la Generalitat de Catalunya.

XRF and XRD analyses were undertaken at the Centres Científics i Tecnològics of the University of Barcelona. We thank Imma Teixell and Andreu Muñoz for providing the samples from the Cathedral of Tarragona; Moisés Díaz and Josep Francesc Roig for the samples from the context at c/Cardenal Vidal i Barraquer nº 27 in Tarragona; the Museu Nacional Arqueològic de Tarragona (MNAT) and particularly J. A. Remolà for the sample from Hospital de Santa Tecla; the Museu de Mataró and J. Garcia for the samples from Mataró; and Xavier Aquilué and other colleagues from the Museu d'Arqueologia de Catalunya-Empúries for the samples from Empúries.

References

Aitchison, J., 1986. *The statistical analysis of compositional data*. Chapman and Hall, London.

Aitchison, J., 2005. A concise guide to compositional data analysis. In *2nd Compositional Data Analysis Workshop (CoDaWork'05)*. Universitat de Girona, Girona. Available: http://ima.udg.edu/Activitats/CoDaWork05/A_concise_guide_to_compositional_data_analysis.pdf (accessed 1/2/2018).

Aquilué, X., Burés, L., 1999. La ciutat en l´antiguitat tardana: fase V. In X. Aquilué (ed.), *Intervencions arqueològiques a Sant Martí d'Empúries (1994-1996). De l'assentament precolonial a l'Empúries actual*. Museu d'Arqueologia de Catalunya, Empúries, 389-422.

Arthur, P., 1990. Anfore dall'Alto Adriatico e il problema del Samos Cistern Type. *Aquileia Nostra*, 61: 281-296.

Bezeczky, T., 2013. *The amphorae of Roman Ephesus*. Verlag der Österreichischen Akademie der Wissenschaften, Wien.

Blakely, J. A., 1988. Ceramics and commerce: amphorae from Caesarea Maritima. *Bulletin of the American School of Oriental Research*, 271: 31-50.

Blázquez, J. M., 1988. La Hispania del Bajo Imperio. Relaciones con Oriente. In G. Pereira (ed.), *Actas del I Congreso Peninsular de Historia Antigua. Santiago de Compostela 1-5 julio de 1986, vol. 3*. Servicio de Publicaciones de la Universidad de Santiago de Compostela, Santiago de Compostela, 177-186.

Bonifay, M., Capelli, C., Franco, C., Leitch, V., Riccardi, L., Berni, P., 2013. Les Thermes du Levant à Leptis Magna: quatre contextes céramiques des IIIe et IVe siècles. *Antiquités Africaines*, 49: 67-150.

Buxeda, J., 1999. Alteration and contamination of archaeological ceramics: the perturbation problem. *Journal of Archaeological Science*, 26: 295-313.

Buxeda, J., Cau, M. A., 2004. Annex I. Caracterització arqueomètrica de les produccions tardanes d'Iluro. In X. Cela, V. Revilla (eds.), *La transició del municipium d'Iluro a Alarona (Mataró). Cultura material i transformacions d'un espia urbà entre els segles V i VII dC*. Laietània 15, Museu Municipal de Mataró, Mataró, 449-498.

Buxeda, J., Kilikoglou, V., 2003. Total variation as a measure of variability in chemical data sets. In L. Van Zelst (ed.), *Patterns and process: a Festschrift in honor of Dr. Edward V. Sayre*. Smithsonian Center for Materials Research and Education, Washington DC, 185-198.

Carreras, C. 2012. Circulació amfòrica al port de la Barcino tardoantiga: segles V a VII dC. *Quarhis*, 8: 38-52.

Carreté, J. M., Keay, S. J., Millett, M., 1995. *A Roman Provincial Capital and its Hinterland. The Survey of the Territory of Tarragona, Spain, 1985-1990*. Journal of Roman Archaeology Suppl. 15, Ann Arbor.

Castanyer, P., Tremoleda, J., 1999. *La vil·la romana de Vilauba. Un exemple de l'ocupació i explotació romana del territori a la comarca del Pla de l'Estany*. Ajuntament de Banyoles, Banyoles.

Cau, M. A., 2003. *Cerámica tardorromana de cocina de las Islas Baleares. Estudio arqueométrico*. BAR International Series 1182, Archaeopress, Oxford.

Cela, X., Revilla, V., 2004. *La transició del municipium d'Iluro a Alarona (Mataró). Cultura material i transformacions d'un espia urbà entre els segles V i VII dC*. Laietània 15, Museu de Mataró, Mataró.

Cerdà, J. A., García, J., Martí, C., Pera, J., Pujol, J., Revilla, V., 1997. *El cardo maximus de la ciutat romana d'Iluro (Hispania Tarraconesis)*. Laietània 10, Museu de Mataró, Mataró.

Cultrone, G., Rodriguez-Navarro, C., Sebastian, E., Cazalla, O., De la Torre, M. J., 2001. Carbonate and silicate phase reactions during ceramic firing. *European Journal of Mineralogy*, 13: 621-634.

Demesticha, S., 2005. Some thoughts on the production and presence of the Late Roman Amphora 13 on Cyprus. In M. B. Briese, L. E. Vaag (eds.), *Trade Relations in the eastern Mediterranean from the Late Hellenistic Period to Late Antiquity. The Ceramic Evidence*. University Press of Southern Denmark, Odense, 169-178.

Didioumi, S., 2014. Local pottery production in the island of Cos, Greece from the early Byzantine period. A preliminary report. In N. Poulou-Papadimitriou, E. Nodarou, V. Kilikoglou (eds.), *LRCW 4. Late Roman Coarse Wares, Cooking Wares and Amphorae in the Mediterranean. Archaeology and Archaeometry. The Mediterranean: a market without frontiers*. Archaeopress, Oxford, 169-180.

Dixneuf, D., 2011. *Amphores égyptiennes. Production, typologie, contenu et diffusion (IIIe siècle avant J.-C. - IXe siècle après J.-C.)*. Centre d'Études Alexandrines, Alexandrie.

Empereur, J. Y., Picon, M., 1998. Les ateliers d'amphores du lac Mariout. In J. Y. Empereur (ed.), *Commerce et artisanat dans l'Alexandrie hellénistique et romaine, actes du colloque d'Athènes, 11-12 décembre 1988*. École Française d'Athènes, Athens, 75-91.

Fantuzzi, L., Cau, M. A., 2016. Archaeometric characterisation of amphorae from the Late Antique city of Iluro (Mataró, Spain). *Journal of Archaeological Science: Reports*, doi: https://doi.org/10.1016/j.jasrep.2016.11.017

Fantuzzi, L., Cau, M. A., Macias, J. M., 2015. Amphorae from the Late Antique city of Tarraco-Tarracona (Catalonia, Spain): archaeometric characterization. *Periodico di Mineralogia*, 84(1): 169-212.

Fantuzzi, L., Cau, M. A., Aquilué, X., 2016. Archaeometric characterization of amphorae from the Late Antique city of Emporiae (Catalonia, Spain). *Archaeometry*, 58 (Supplement S1): 1-22.

Fantuzzi, L., Cau, M. A., Reynolds, P., 2013. Late Roman amphorae from the Eastern Mediterranean in North-eastern Spain: Some Remarks on their Distribution and Provenance. In L. Bombardieri, A. D'Agostino, G. Guarducci, V. Orsi, S. Valentini (eds.), *SOMA 2012. Identity and Connectivity: Proceedings of the 16th Symposium on Mediterranean Archaeology, Florence, Italy, 1–3 March 2012*. BAR International Series 2581, Archaeopress, Oxford, 1023-1032.

Fantuzzi, L., Cau, M. A., Reynolds, P., 2017. Archaeometric characterisation of Late Roman Amphora 1 imports in north-eastern Spain. In D. Dixneuf (ed.), *LRCW 5. Late Roman coarse wares, cooking wares and amphorae in the Mediterranean. Archaeology and archaeometry (vol. 1)*. Centre d'Études Alexandrines, Alexandrie, 93-116.

García Moreno, L. A., 1972. Colonias de comerciantes orientales en la Península Ibérica, s. V-VII. *Habis*, 3: 127-155.

García Vargas, E., 2011. Oriental trade in the Iberian Peninsula during Late Antiquity (4th-7th centuries AD): an archaeological perspective. In D. Hernández (ed.), *New Perspectives on Late Antiquity*. Cambridge Scholars, Newcastle upon Tyne, 76-117.

Glass, J., 1980. Petrographic study. In J. Briend, J. B. Humbert (eds.), *Tell Keisan (1971-1976), une cité phénicienne en Galilée*. Éditions Universitaires, Fribourg, 77-80.

Hein, A., Tsolakidou, A., Iliopoulos, I., Momsen, H., Buxeda, J., Montana, G., Kilikoglou, V., 2002. Standardisation of elemental analytical techniques applied to provenance studies of the archaeological ceramics: an inter laboratory calibration study. *Analyst*, 127: 542-553.

Járrega, R., 2010. The late roman pottery imports in the east of Hispania Tarraconensis. In S. Menchelli, S. Santoro, M. Pasquinucci, G. Guiducci (eds.), *LRCW3. Late Roman Coarse Wares, Cooking Wares and Amphorae in the Mediterranean: archaeology and archaeometry. Comparison between western and eastern Mediterranean*. BAR International Series 2185, Archaeopress, Oxford, 167-172.

Járrega, R., 2013. Las últimas importaciones romanas de cerámica en el Este de Hispania Tarraconensis: una aproximación. *Spal*, 22: 143-172.

Keay, S. J., 1984. *Late Roman Amphorae in the Western Mediterranean. A tipology and economic study: the Catalan evidence*. BAR International Series 196, Oxford.

Macias, J. M., Menchon, J. J., Muñoz, A., Teixell, I., 2008. Contextos cerámicos derivados de la transformación cristiana de la acrópolis de Tarragona (s. V/VI d.C.). In *SFECAG - Actes du congrès de l'Escala-Empúries, 1er-4 mai 2008*. Société Française d'Étude de la Céramique Antique en Gaule, Marseille, 287-293.

Maggetti, M., Neururer, C., Ramseyer, D., 2011. Temperature evolution inside a pot during experimental surface (bonfire) firing. *Applied Clay Science*, 53: 500-508.

Megaw, A. H. S., Jones, R. E., 1983. Byzantine and allied pottery: a contribution by chemical analyses to problems of origin and distribution. *Annual of the British School at Athens*, 78: 235-263.

Peacock, D. P. S., 1984. Petrology and origins. In M. G. Fulford, D. P. S. Peacock (eds.), *Excavations at Carthage: the Bristish Mission, vol. I.2. The Avenue du Président Habib Bourguiba, Salammbo. The pottery and other ceramic objects from the site*. University of Sheffield, Sheffield, 6-28.

Peacock, D. P. S., Williams, D. F., 1986. *Amphorae and the Roman economy, an introductory guide*. Longman, London/New York.

Piéri, D., 2005. *Le commerce du vin oriental à l'époque Byzantine (Ve-VIIe siècles). Le témoignage des amphores en Gaule*. Institut Français du Proche Orient, Beyrouth.

Quinn, P. S., 2013. *Ceramic petrography. The interpretation of archeological pottery and related artefacts in thin section*. Archaeopress, Oxford.

Remolà, J. A., 2000. *Las ánforas tardo-antiguas en Tarraco (Hispania Tarraconensis)*. Publicacions Universitat de Barcelona, Barcelona.

Remolà, J. A., Lozano, J., Ruisánchez, I., Larrechi, M. S., Rius, F. X., Zupan, J., 1996. New chemometric tools to study the origin of amphorae produced in the Roman empire. *Trends in Analytical Chemistry*, 15(3): 137-151.

Remolà, J. A., Rius, X., Larrechi, M., 1993. 5th century AD amphora producing centres in the Mediterranean. Chemometrical characterization. *Talanta. The International Journal of Pure and Applied Analytical Chemistry*, 40(11): 1749-1757.

Reynolds, P., 1995. *Trade in the Western Mediterranean, AD 400-700: The ceramic evidence*. BAR International Series 604, Oxford.

Reynolds, P., 2005. Levantine amphorae from Cilicia to Gaza: a Typology and Analysis of Regional Production Trends from the 1st to 7th Centuries. In J. M. Gurt, J. Buxeda, M. A. Cau (eds.), *LRCW 1: Late Roman Coarse Wares, Cooking Wares and Amphorae in the Mediterranean. Archaeology and archaeometry*. BAR International Series 1340, Archaeopress, Oxford, 563-612.

Reynolds, P., 2010a. *Hispania and the Roman Mediterranean, AD 100-700. Ceramics and Trade*. Duckworth, London.

Reynolds, P., 2010b. Trade networks of the East, 3rd to 7th centuries: the view from Beirut (Lebanon) and Butrint (Albania) (fine wares, amphorae and kitchen wares). In S. Menchelli, S. Santoro, M. Pasquinucci, G. Guiducci (eds.), *LRCW3. Late Roman Coarse Wares, Cooking Wares and Amphorae in the Mediterranean: archaeology and archaeometry. Comparison between western and eastern Mediterranean*. BAR International Series 2185, Archaeopress, Oxford, 89-114.

Rodríguez, F., Macias, J. M., 2016. Un nuevo contexto cerámico de la segunda mitad del siglo VII d.C. en Tarracona (Tarraconensis, Regnum Visigothorum). In R. Járrega, P. Bierni (eds.), *Amphorae ex Hispania: paisajes de producción y consumo. III Congreso Internacional de la SECAH - Ex Officina Hispana (Tarragona, 10-13 diciembre 2014)*. Institut Català d'Arqueologia Clàssica, Tarragona, 936-952.

Teixell, I., Macias, J. M., Menchon, J. J., 2005. *Memòria de les intervencions arqueològiques a la Catedral de Tarragona - Museu Diocesà*. Unpublished report, Servei d'Arqueologia i Paleontologia de la Generalitat de Catalunya, Barcelona.

Tomber, R., Williams, D., 2000. Egyptian Amphorae in Britain and the Western Provinces. *Britannia*, 31: 41-54.

University of Southampton, 2014. Roman Amphorae: a digital resource [data-set]. Archaeology Data Service, York. https://doi.org/10.5284/1028192

Uscatescu, A., García, R., 2005. Pottery wares from a fifth century deposit found at Iesso (Guissona, Lleida): archaeological and archaeometrical analyses. In J. M. Gurt, J. Buxeda, M. A. Cau (eds.), *LRCW 1: Late Roman Coarse Wares, Cooking Wares and Amphorae in the Mediterranean. Archaeology and archaeometry*. BAR International Series 1340, Archaeopress, Oxford, 81–104.

Whitbread, I. K., 1986. The characterisation of argillaceous inclusions in ceramic thin sections. *Archaeometry*, 28(1): 79-88.

Whitbread, I. K., 1989. A proposal for the systematic description of thin sections towards the study of ancient ceramic technology. In Y. Maniatis (ed.), *Archaeometry: proceedings of the 25th international symposium*. Elsevier, Amsterdam, 127-138.

Whitbread, I. K., 1995. Appendix 3. The collection, processing and interpretation of petrographic data. In *Greek transport amphorae: a petrological and archaeological study*. British School at Athens, Athens, 365-396.

Williams, D. F., 1990. A note on the petrology of a Samos Cistern Type amphora from excavations at the Castello di Udine. *Aquileia Nostra*, 61: 296.

Yangaki, A. 2014. Late Roman pottery from Funerary Monument 18 and the adjacent monuments of the Arcadian gate (Ancient Messene, Peloponnese). In N. Poulou-Papadimitriou, E. Nodarou, V. Kilikoglou (eds.), *LRCW 4. Late Roman Coarse Wares, Cooking Wares and Amphorae in the Mediterranean. Archaeology and Archaeometry. The Mediterranean: a market without frontiers*. Archaeopress, Oxford, 769-776.

Zimmerman Munn, M. L., 1985. A late Roman kiln site in the Hermionid, Greece. *American Journal of Archaeology*, 89: 342-343.

Table captions

Table I. List of the eastern Mediterranean amphorae selected for archaeometric analysis from various Late Antique contexts in the northeastern Iberian Peninsula

Table II. Normalized chemical composition of the petrographic fabric groups and fabrics identified in this study. Mean (m) and standard deviation (sd) values are presented for each element. In ORI-1, m and sd values for Cr (*) were calculated excluding one individual, TAR017, with anomalous high Cr (2030 ppm)

Figure captions

Figure 1. (a) Main types of eastern Mediterranean amphorae included in this study; illustrations from University of Southampton (2014) (a-e, g-h and j-k) and Remolà (2000) (f and i). (b) Location of the archaeological sites in northeasten Iberian Peninsula that were sampled for archaeometric analysis

Figure 2. Photomicrographs of ceramic thin sections of eastern Mediterranean amphorae fabric groups, taken under crossed polars at 40x. (a) Group ORI-1: TAR017. (b) Group ORI-1: CAT241. (c) Group ORI-2: TAR069. (d) Group ORI-3: ILU048. (e) Group ORI-6: EMP303. (f) Group ORI-7: ILU030

Figure 3. XRD spectra for selected samples of each fabric group or fabric, and photographs of each sample taken at 15x. In some of the fabric groups, macroscopic changes related to variations in firing temperatures are seen. Abbreviations for minerals: Q, quartz; P, plagioclase; KF, K-feldspar; C, calcite; G, gehlenite; Px, pyroxene; H, hematite; I-M, illite-muscovite; An, analcime

Figure 4. Provenance regions in the eastern Mediterranean for the amphora fabric groups and fabrics identified in the study. The location of Late Antique amphora production centers in each region is provided, based on existing archaeological evidence (map data: Google, Basarsoft, Mapa GISrael, ORION-ME)

Figure 5. Photomicrographs of ceramic thin sections of eastern Mediterranean amphorae fabrics, taken under crossed polars at 40x. (a) Fabric ORI-4: CAT213. (b) Fabric ORI-5: EMP352. (c) Fabric ORI-8: EMP327. (d) Fabric ORI-9: CAT212. (e) Fabric ORI-10: TAR067. (f) Fabric ORI-11: TAR018. (g) Fabric ORI-12: TAR013. (h) Fabric ORI-13: TAR070

Figure 6. Distribution of the variability associated with each of the 24 chemical elements determined through XRF in the data set, based on the $\tau_{.i}$ values obtained through calculating the compositional variation matrix

Figure 7. Binary diagrams, using normalized data, of: (a) CaO vs MgO; (b) Ni vs Cr, for the amphora samples analyzed. An indication of the fabric group or fabric for each individual is given. Sample TAR017 (ORI-1), with anomalous high Cr, was not considered in (b)

Figure 8. Multivariate analysis on the XRF chemical data of the amphorae. (a) PCA based on the alr transformed subcomposition Fe_2O_3, Al_2O_3, MnO, P_2O_5, TiO_2, MgO, CaO, Na_2O, K_2O, SiO_2, Ba, Rb, Nb, Pb, Zr, Y, Sr, Ce, Ga, V, Zn, Cu, Ni and Cr (Fe_2O_3 was used as divisor); plot of the principal components 1 and 2 (PC1 vs PC2) with the respective scores and loadings. (b) Cluster analysis, using the centroid agglomerative method and squared Eculidean distance, based on the same alr transformed subcomposition as the PCA

Figure 9. Illustrations of the amphora samples analyzed, organized by petrographic fabric group, according to the analytical results

Figure 10. Illustrations of the amphora samples analyzed, organized by petrographic fabric group, according to the analytical results

Titres des tableaux

Tableau I. Liste des amphores de la Méditerranée orientale sélectionnées pour l'analyse archéométrique de divers contextes de l'Antiquité tardive dans le nord-est de la Péninsule Ibérique

Tableau II. Composition chimique normalisée des groupes pétrographiques et pâtes identifiés dans cette étude. La moyenne (m) et l'écart-type (sd) sont présentées pour chaque élément. Dans ORI-1, les valeurs de m et sd pour le Cr (*) ont été calculés sans un échantillon, TAR017, qui a des valeurs élevées anormales de Cr

Titres des figures

Figure 1. (a) Illustrations de quelques amphores analysées, représentatives des principaux types d'amphores de la Méditerranée orientale dans les contextes archéologiques sélectionnés. (b) Localisation des sites archéologiques du nord-est de la Péninsule Ibérique échantillonnés pour l'analyse archéométrique

Figure 2. Photomicrographies en lame mince (XP, 40x) des groupes pétrographiques d'amphores de Méditerranée orientale. (a) Groupe ORI-1: TAR017. (b) Groupe ORI-1: CAT241. (c) Groupe ORI-2: TAR069. (d) Groupe ORI-3: ILU048. (e) Groupe ORI-6: EMP303. (f) Groupe ORI-7: ILU030

Figure 3. Diffractogrammes d'échantillons sélectionnés de chaque groupe pétrographique ou pâte, et des photographies de chaque échantillon (15x). Dans certains groupes, on observe des changements macroscopiques liés aux variations des températures de cuisson. Abréviations pour les minéraux: Q, quartz; P, plagioclase; KF, feldspath alcalin; C, calcite; G, gehlénite; Px, pyroxène; H, hématite; I-M, illite-muscovite; An, analcime

Figure 4. Régions de provenance en Méditerranée orientale pour les groupes pétrographiques et pâtes identifiés dans l'étude. Pour chaque région, il est indiqué l'emplacement des centres de production d'amphores de l'Antiquité tardive, d'après les preuves archéologiques existantes (données cartographiques Google, Basarsoft, Mapa GISrael, ORION-ME)

Figure 5. Photomicrographies en lame mince (XP, 40x) des pâtes d'amphores de Méditerranée orientale. (a) Pâte ORI-4: CAT213. (b) Pâte ORI-5: EMP352. (c) Pâte ORI-8: EMP327. (d) Pâte ORI-9: CAT212. (e) Pâte ORI-10: TAR067. (f) Pâte ORI-11: TAR018. (g) Pâte ORI-12: TAR013. (h) Pâte ORI-13: TAR070

Figure 6. Distribution de la variabilité associée à chacun des 24 éléments chimiques déterminés par XRF dans le jeu de données, sur la base des valeurs $\tau_{.i}$ obtenues par le calcul de la matrice de variation compositionnelle

Figure 7. Diagrammes binaires, utilisant des données normalisées, de: (a) CaO vs MgO; (b) Ni vs Cr, pour les amphores analysées. Le groupe pétrographique ou pâte est indiqué pour chaque individu. L'échantillon TAR017 (ORI-1), avec très haut Cr, a été exclu pour (b)

Figure 8. Analyse multivariée sur les données chimiques (XRF) des amphores. (a) Analyse en composantes principales -ACP- basée sur la sous-composition transformée (alr) Fe_2O_3, Al_2O_3, MnO,

P_2O_5, TiO_2, MgO, CaO, Na_2O, K_2O, SiO_2, Ba, Rb, Nb, Pb, Zr, Y, Sr, Ce, Ga, V, Zn, Cu, Ni et Cr (Fe_2O_3 a été utilisé comme diviseur); diagramme des composantes principales 1 et 2 (PC1 vs PC2). (b) Analyse de cluster, utilisant la méthode d'agglomération centroïde et la distance euclidienne au carré, basée sur la même sous-composition transformée que l'ACP

Figure 9. Illustrations des échantillons d'amphores analysés, organisées par groupe pétrographique, en fonction des résultats de l'analyse

Figure 10. Illustrations des échantillons d'amphores analysés, organisées par groupe pétrographique, en fonction des résultats de l'analyse

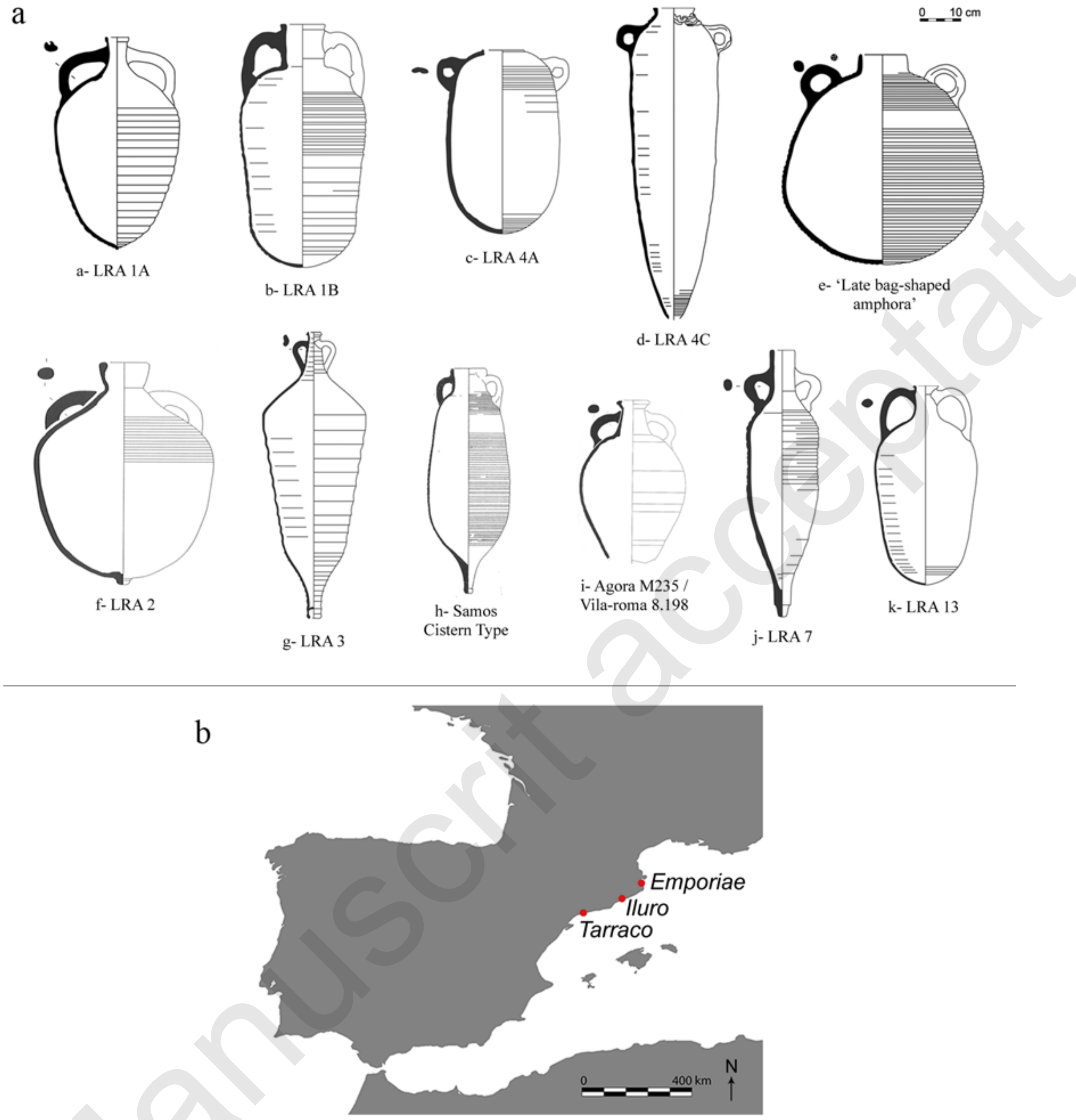
a
0 10 cm
a- LRA 1A
b- LRA 1B
c- LRA 4A
d- LRA 4C
e- 'Late bag-shaped amphora'
f- LRA 2
g- LRA 3
h- Samos Cistern Type
i- Agora M235 / Vila-roma 8.198
j- LRA 7
k- LRA 13
b
Emporiae
Iluro
Tarraco
0
400 km
N

Figure 1

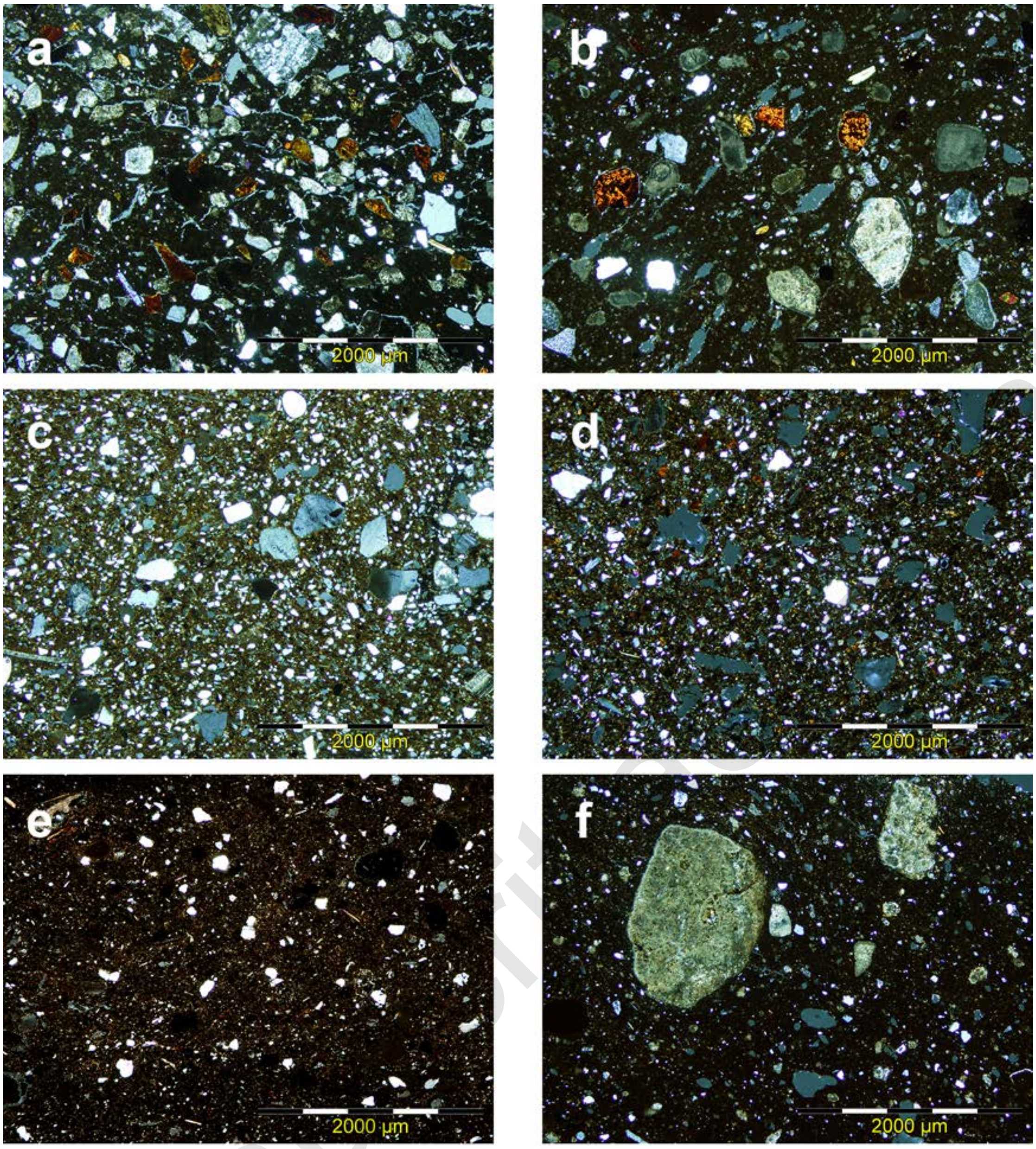

Figure 2

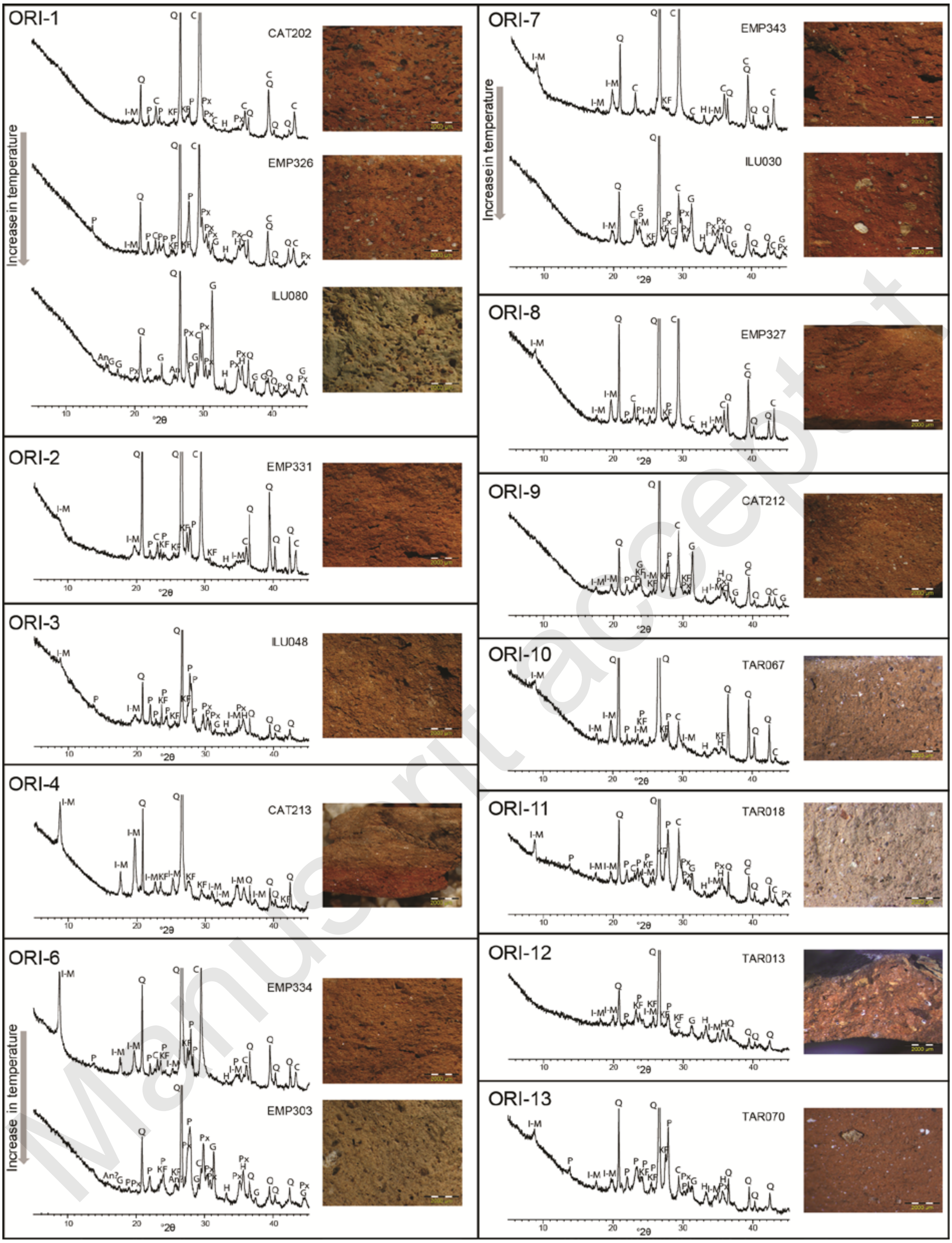
ORI-1
CAT202
EMP326
ILU080
Increase in temperature
°2θ
ORI-2
EMP331
ORI-3
ILU048
ORI-4
CAT213
ORI-6
EMP334
EMP303
ORI-7
EMP343
ILU030
ORI-8
EMP327
ORI-9
CAT212
ORI-10
TAR067
ORI-11
TAR018
ORI-12
TAR013
ORI-13
TAR070

Figure 3

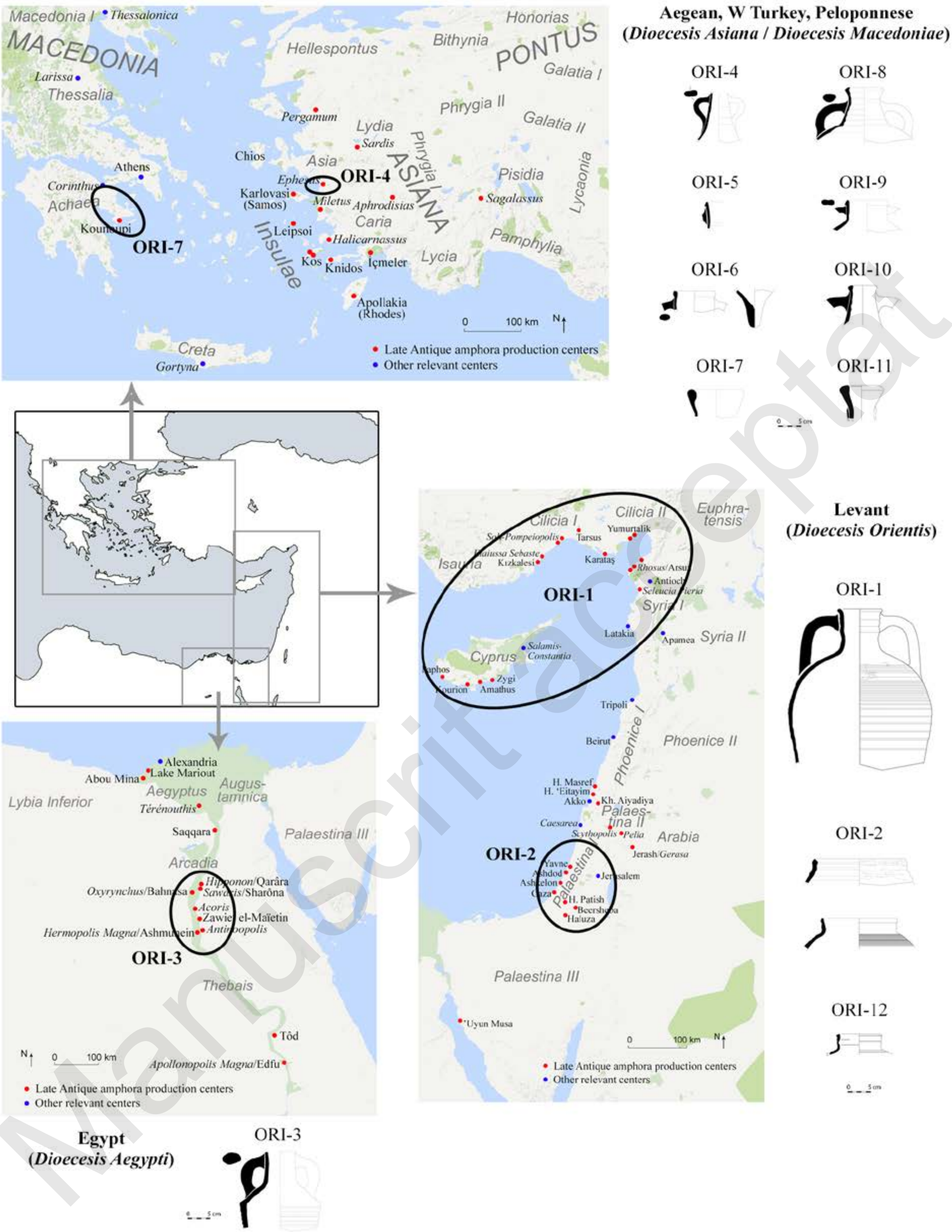
Aegean, W Turkey, Peloponnese
(Dioecesis Asiana / Dioecesis Macedoniae)
ORI-4
ORI-8
ORI-5
ORI-9
ORI-6
ORI-10
ORI-7
ORI-11
Macedonia I
Thessalonica
MACEDONIA
Larissa
Thessalia
Hellespontus
Bithynia
Honorias
PONTUS
Galatia I
Phrygia II
Galatia II
Pergamum
Lydia
Sardis
Chios
Asia
ASIANA
Athens
Corinthus
Achaea
Kounoupi
Karlovasi (Samos)
Ephesus
Miletus
Aphrodisias
Pisidia
Sagalassus
Lycaonia
Caria
Leipsoi
Insulae
Halicarnassus
Pamphylia
Kos
Knidos
Içmeler
Lycia
Apollakia (Rhodes)
Creta
Gortyna
0 100 km
Late Antique amphora production centers
Other relevant centers
Levant
(Dioecesis Orientis)
ORI-1
Cilicia I
Cilicia II
Euphratensis
Tarsus
Yumurtalik
Isauria
Karataş
Rhosus/Arsuz
Antioch
Seleucia Pieria
Syria I
Latakia
Apamea
Syria II
Cyprus
Salamis-Constantia
Amathus
Zygi
Tripoli
Beirut
Phoenice I
Phoenice II
H. Masref
Akko
Kh. Aiyadiya
Palaestina II
Caesarea
Scythopolis
Pelia
Arabia
Jerash/Gerasa
ORI-2
Yavne
Ashdod
Ashkelon
Gaza
Jerusalem
Palaestina I
H. Patish
Beersheba
Haluza
Palaestina III
'Uyun Musa
0 100 km
Late Antique amphora production centers
Other relevant centers
ORI-2
ORI-12
Alexandria
Lake Mariout
Abou Mina
Aegyptus
Augustamnica
Lybia Inferior
Térénouthis
Saqqara
Palaestina III
Arcadia
Hipponon/Qarâra
Oxyrynchus/Bahnasa
Sawaris/Sharôna
Acoris
Zawiet el-Maïetin
Hermopolis Magna/Ashmunein
Antinoopolis
ORI-3
Thebais
Tôd
Apollonopolis Magna/Edfu
0 100 km
Late Antique amphora production centers
Other relevant centers
Egypt
(Dioecesis Aegypti)
ORI-3

Figure 4

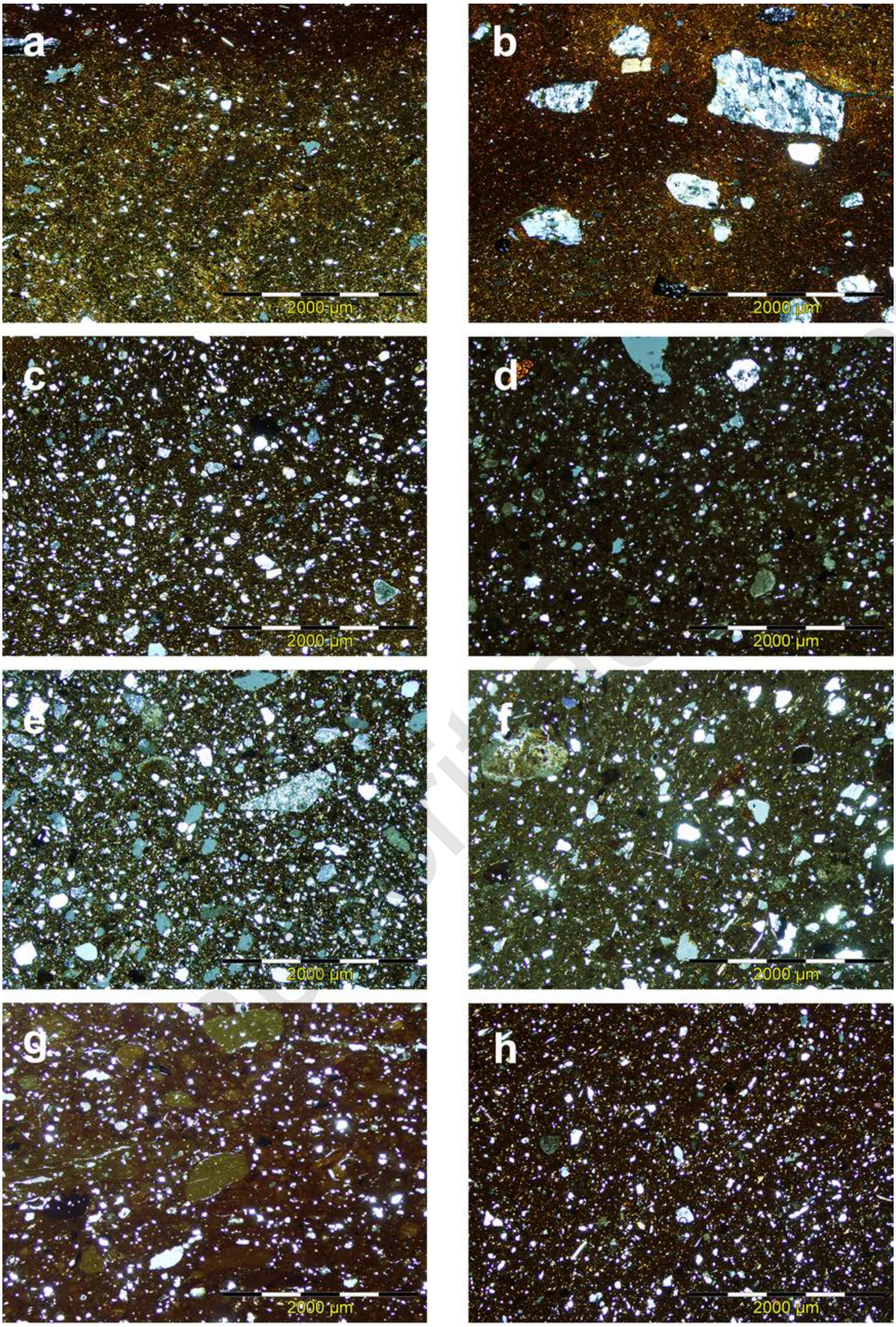
a
2000 µm
b
2000 µm
c
2000 µm
d
2000 µm
e
2000 µm
f
2000 µm
g
2000 µm
h
2000 µm

Figure 5

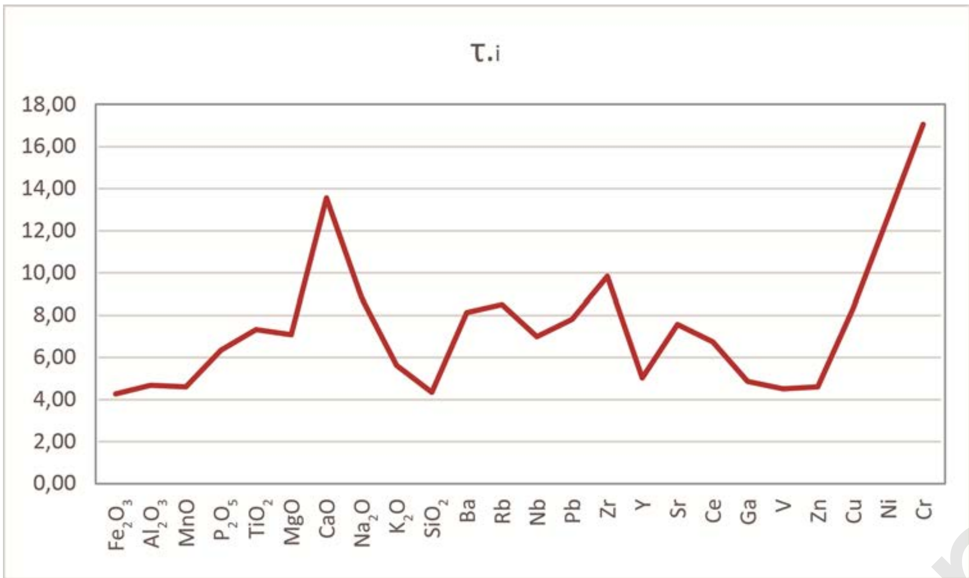
τ.i
18,00
16,00
14,00
12,00
10,00
8,00
6,00
4,00
2,00
0,00
Fe2O3
Al2O3
MnO
P2O5
TiO2
MgO
CaO
Na2O
K2O
SiO2
Ba
Rb
Nb
Pb
Zr
Y
Sr
Ce
Ga
V
Zn
Cu
Ni
Cr

Figure 6

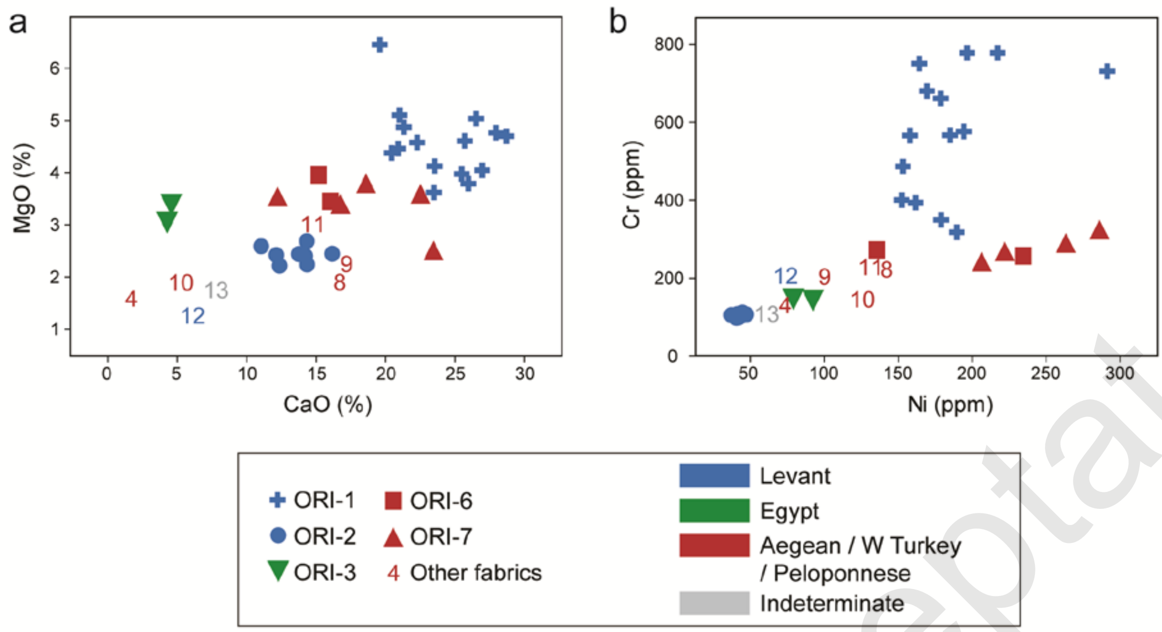
a
MgO (%)
CaO (%)
b
Cr (ppm)
Ni (ppm)
ORI-1
ORI-2
ORI-3
ORI-6
ORI-7
4 Other fabrics
Levant
Egypt
Aegean / W Turkey / Peloponnese
Indeterminate

Figure 7

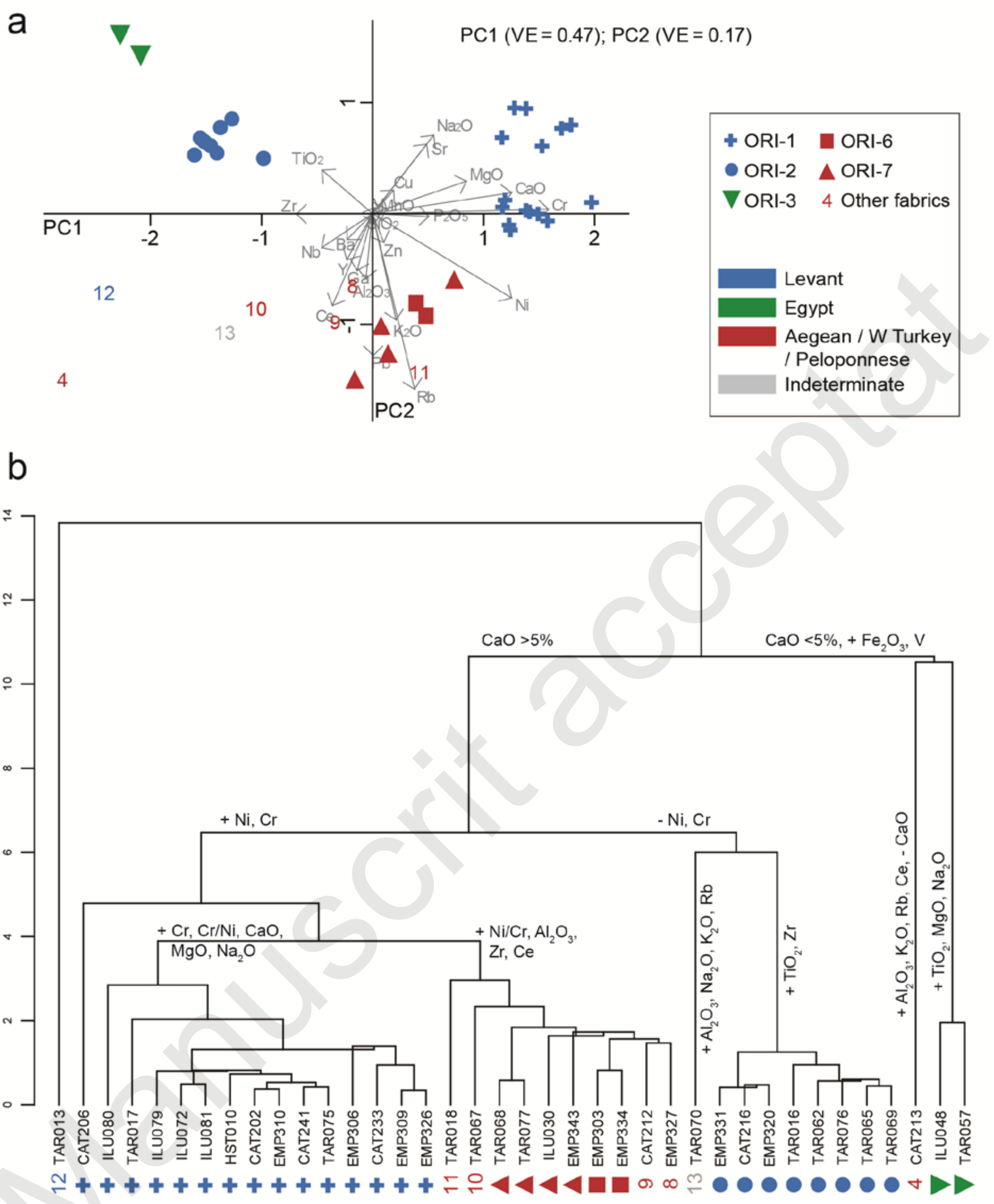
a
PC1 (VE = 0.47); PC2 (VE = 0.17)
PC1
PC2
-2
-1
1
2
1
-1
Na2O
Sr
TiO2
MgO
Cu
CaO
Zr
MnO
Cr
P2O5
Nb
Ba
Zn
Ni
Al2O3
Ce
K2O
Rb
12
10
13
4
8
9
11
ORI-1
ORI-6
ORI-2
ORI-7
ORI-3
4 Other fabrics
Levant
Egypt
Aegean / W Turkey / Peloponnese
Indeterminate
b
0
2
4
6
8
10
12
14
CaO >5%
CaO <5%, + Fe2O3, V
+ Ni, Cr
- Ni, Cr
+ Cr, Cr/Ni, CaO, MgO, Na2O
+ Ni/Cr, Al2O3, Zr, Ce
+ Al2O3, Na2O, K2O, Rb
+ TiO2, Zr
+ Al2O3, K2O, Rb, Ce, - CaO
+ TiO2, MgO, Na2O
TAR013
CAT206
ILU080
TAR017
ILU079
ILU072
ILU081
HST010
CAT202
EMP310
CAT241
TAR075
EMP306
CAT233
EMP309
EMP326
TAR018
TAR067
TAR068
TAR077
ILU030
EMP343
EMP303
EMP334
CAT212
EMP327
TAR070
EMP331
CAT216
EMP320
TAR016
TAR062
TAR076
TAR065
TAR069
CAT213
ILU048
TAR057
12
11
10
9
8
13
4

Figure 8

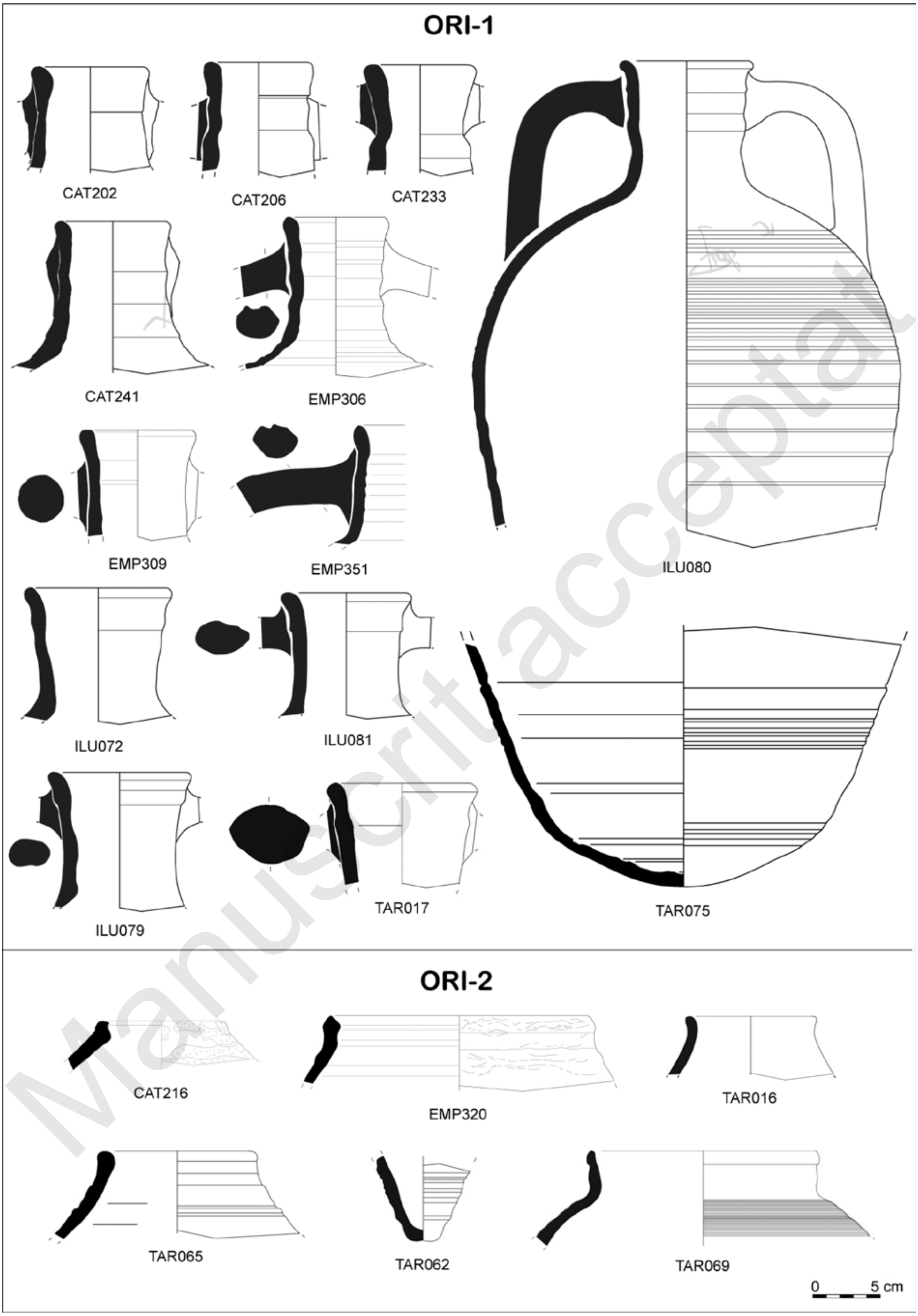
ORI-1
CAT202
CAT206
CAT233
CAT241
EMP306
EMP309
EMP351
ILU080
ILU072
ILU081
ILU079
TAR017
TAR075
ORI-2
CAT216
EMP320
TAR016
TAR065
TAR062
TAR069
0
5 cm

Figure 9

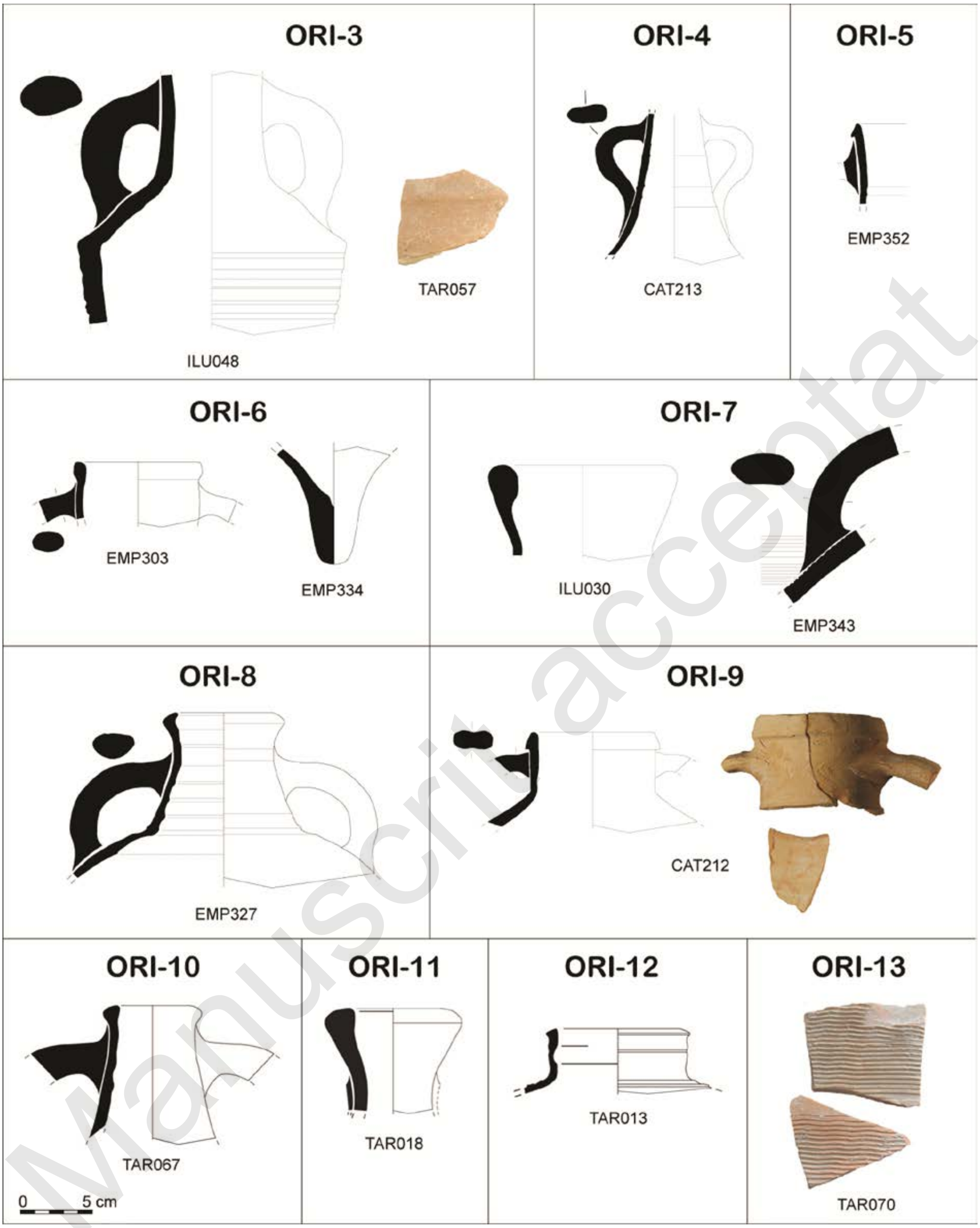
ORI-3
ILU048
TAR057
ORI-4
CAT213
ORI-5
EMP352
ORI-6
EMP303
EMP334
ORI-7
ILU030
EMP343
ORI-8
EMP327
ORI-9
CAT212
ORI-10
TAR067
0
5 cm
ORI-11
TAR018
ORI-12
TAR013
ORI-13
TAR070

Figure 10

Archaeological context	Chronology of stratigraphic unit	Sampled amphorae
Tarraco : Cathedral	500-550	LRA 1A (CAT202, CAT206, CAT241)
		LRA 3 (CAT213)
		Indet. with titulus pictus (CAT212)
	Medieval (with residual 5th-6th cent. ceramics)	LRA 1 (CAT233)
		LRA 4 (CAT216)
Tarraco : Hospital de Santa Tecla	425-475	LRA 1A (HST010)
Tarraco : c/ Cardenal Vidal i Barraquer nº 27	650-700	LRA 1 (TAR017)
		LRA 2 (TAR018)
		LRA 4C (TAR016)
		'Late bag-shaped amphora' / LRA 6 (TAR013)
	650-700/720	LRA 1 (TAR075)
		LRA 2 (TAR068, TAR070, TAR077)
		LRA 4C (TAR062, TAR065)
		'Late bag-shaped amphora' / LRA 5 (TAR069)
		LRA 7 (TAR057)
		Globular amphora LRA 13 / Yassi Ada 2 (TAR067)
		Indet. (TAR076)
Emporiae : Plaça Major	400-425/450	LRA 1A (EMP306, EMP309, EMP351) LRA 2 (EMP343) Simile LRA 3 (EMP352) 'Ikarian' amphora (EMP303)
	S. VI	LRA 1 (EMP326)
		LRA 4 (EMP331)
		Agora M235 / Vila-roma 8.198 (EMP327)
		Samos Cistern Type? (EMP334)
Emporiae : Plaça Petita	500-550	LRA 1A (EMP310)
	550-600	LRA 4 (EMP320)
Iluro : c/ Sant Cristòfol nº 12	475-535	LRA 2 (ILU030)
Iluro : c/ d'en Pujol nº 43-45	475-535	LRA 7 (ILU048)
Iluro : El Carreró nº 49	525-575	LRA 1B1 (ILU072)
Iluro : c/ Magí de Villalonga nº 8-12	525/550-600	LRA 1 (ILU079)
Iluro : c/ de la Palma nº 15	550-575	LRA 1 (ILU080, ILU081)

Table I

Sample	*Fe_2O_3*	*Al_2O_3*	*MnO*	*P_2O_5*	*TiO_2*	*MgO*	*CaO*	*Na_2O*	*K_2O*	*SiO_2*	*Ba*	*Rb*	*Nb*	*Pb*	*Zr*	*Y*	*Sr*	*Ce*	*Ga*	*V*	*Zn*	*Cu*	*Ni*	*Cr*
Fabric group ORI-1 (n=15)																								
CAT202	5.65	10.82	0.09	0.32	0.58	4.06	27.05	1.20	2.73	47.31	458	73	13	20	118	21	441	40	13	111	85	37	162	395
CAT206	6.14	10.97	0.14	0.58	0.65	4.78	27.92	1.28	1.89	45.43	329	45	11	16	116	21	562	32	12	107	153	206	184	567
CAT233	5.54	9.96	0.13	0.44	0.64	4.71	28.65	1.51	1.73	46.48	284	40	10	14	108	19	458	30	12	98	66	40	169	681
CAT241	5.87	11.41	0.08	0.30	0.66	4.14	23.60	1.03	2.11	50.58	348	73	13	21	129	20	565	44	12	108	64	31	177	663
EMP306	6.72	11.82	0.09	0.40	0.69	6.46	19.52	1.39	1.85	50.84	280	60	13	11	117	20	392	47	13	106	74	38	290	735
EMP309	6.93	12.58	0.15	0.39	0.77	4.46	20.88	1.81	2.11	49.73	366	51	12	18	126	21	326	34	13	121	87	77	194	577
EMP310	5.38	10.72	0.09	0.26	0.59	3.80	25.86	1.46	2.82	48.85	292	68	12	20	126	21	384	44	12	99	66	33	152	401
EMP326	6.61	12.12	0.14	0.51	0.80	5.11	20.98	1.90	1.84	49.79	270	44	10	15	120	21	374	34	13	128	85	69	157	569
HST010	6.24	12.07	0.09	0.47	0.70	4.39	20.55	1.34	2.12	51.80	282	83	13	23	136	22	473	43	14	105	85	44	196	779
ILU072	5.72	10.71	0.09	0.55	0.53	5.05	26.45	1.37	2.29	47.04	576	75	9	16	104	20	457	48	12	97	71	31	190	317
ILU079	5.80	10.95	0.10	0.59	0.57	3.98	25.49	1.07	2.44	48.78	433	72	9	18	127	20	350	44	13	101	73	31	164	752
ILU080	6.48	11.94	0.08	0.45	0.67	4.87	21.25	1.60	1.36	51.07	390	53	11	6	124	22	477	48	14	112	84	16	217	779
ILU081	5.91	11.31	0.08	0.31	0.55	4.62	25.65	1.49	2.05	47.82	553	71	9	18	109	20	463	46	13	106	76	28	179	351
TAR017	6.31	11.16	0.11	0.34	0.67	4.58	22.15	1.28	1.66	51.37	462	67	12	26	138	22	451	46	12	123	88	43	231	2030
TAR075	5.70	11.41	0.08	0.24	0.64	3.63	23.48	1.26	1.96	51.37	448	72	10	21	134	20	610	55	11	103	68	35	153	489
m	*6.07*	*11.33*	*0.10*	*0.41*	*0.65*	*4.58*	*23.97*	*1.40*	*2.06*	*49.22*	*385*	*63*	*11*	*18*	*122*	*21*	*452*	*42*	*13*	*108*	*82*	*51*	*188*	*575**
sd	*0.47*	*0.68*	*0.03*	*0.11*	*0.08*	*0.69*	*2.96*	*0.24*	*0.39*	*2.02*	*100*	*13*	*2*	*5*	*10*	*1*	*81*	*7*	*1*	*9*	*22*	*46*	*36*	*163**
Fabric group ORI-2 (n=8)																								
CAT216	6.39	11.82	0.11	0.21	1.28	2.61	11.06	1.15	1.79	63.40	450	44	22	16	389	30	405	61	15	109	62	35	43	113
EMP320	6.93	12.50	0.11	0.23	1.32	2.42	12.15	1.00	2.23	60.95	462	41	22	21	346	29	281	61	16	113	64	45	46	112
EMP331	5.70	10.80	0.10	0.17	1.16	2.44	13.87	0.79	1.95	62.87	361	37	21	13	400	28	277	59	14	90	62	40	38	108
TAR016	6.53	11.43	0.12	0.47	1.27	2.23	12.32	0.77	1.33	63.29	923	29	20	28	368	29	444	66	14	105	109	49	45	116
TAR062	6.34	11.55	0.11	0.20	1.29	2.68	14.31	1.05	1.39	60.81	908	33	20	23	395	29	738	69	14	113	66	40	44	114
TAR065	5.99	11.31	0.08	0.22	1.21	2.39	14.28	0.76	1.39	62.15	841	27	20	20	426	29	396	66	14	98	67	52	42	102
TAR069	5.78	10.67	0.08	0.29	1.16	2.24	14.38	1.01	1.32	62.88	642	29	18	16	354	27	431	58	12	94	82	48	41	102
TAR076	5.43	10.46	0.09	0.25	1.14	2.47	16.22	1.12	1.44	61.17	674	38	17	21	367	28	457	65	12	104	67	53	42	115
m	*6.14*	*11.32*	*0.10*	*0.25*	*1.23*	*2.44*	*13.58*	*0.96*	*1.60*	*62.19*	*658*	*35*	*20*	*20*	*381*	*29*	*429*	*63*	*14*	*103*	*72*	*45*	*43*	*110*
sd	*0.50*	*0.67*	*0.01*	*0.09*	*0.07*	*0.16*	*1.63*	*0.16*	*0.34*	*1.08*	*219*	*6*	*2*	*5*	*27*	*1*	*143*	*4*	*1*	*9*	*16*	*7*	*3*	*5*
Fabric group ORI-3 (n=2)																								
ILU048	11.18	16.18	0.16	0.48	1.99	3.10	4.35	1.74	2.20	58.44	552	49	21	11	242	34	283	65	21	192	108	68	79	157
TAR057	12.16	17.68	0.19	0.36	2.10	3.42	4.73	1.52	1.31	56.23	1251	34	25	21	255	35	497	77	22	214	110	97	92	153
m	*11.67*	*16.93*	*0.17*	*0.42*	*2.04*	*3.26*	*4.54*	*1.63*	*1.75*	*57.34*	*902*	*41*	*23*	*16*	*249*	*35*	*390*	*71*	*22*	*203*	*109*	*83*	*85*	*155*
sd	*0.70*	*1.06*	*0.02*	*0.09*	*0.07*	*0.23*	*0.27*	*0.16*	*0.63*	*1.56*	*494*	*10*	*3*	*7*	*10*	*1*	*151*	*9*	*0*	*16*	*2*	*20*	*9*	*2*
Fabric group ORI-6 (n=2)																								
EMP303	6.06	16.78	0.10	0.41	0.70	3.47	16.11	0.94	2.88	52.35	452	120	16	23	159	32	266	59	19	114	86	63	135	276
EMP334	6.33	14.17	0.13	0.50	0.67	3.97	15.15	1.03	3.50	54.38	454	104	19	26	189	29	266	71	17	87	80	45	234	260
m	*6.19*	*15.48*	*0.12*	*0.46*	*0.69*	*3.72*	*15.63*	*0.99*	*3.19*	*53.36*	*453*	*112*	*17*	*25*	*174*	*31*	*266*	*65*	*18*	*100*	*83*	*54*	*185*	*268*
sd	*0.19*	*1.84*	*0.01*	*0.07*	*0.02*	*0.35*	*0.68*	*0.06*	*0.44*	*1.43*	*1*	*11*	*2*	*2*	*21*	*2*	*0*	*8*	*2*	*19*	*4*	*13*	*70*	*11*
Fabric group ORI-7 (n=4)																								
EMP343	6.25	13.57	0.12	0.30	0.67	3.61	22.54	0.49	2.65	49.60	352	73	15	22	154	26	268	61	16	97	87	92	285	321
ILU030	7.02	15.90	0.14	0.22	0.72	3.71	18.61	0.50	2.33	50.64	526	102	15	31	180	31	199	85	18	104	94	32	262	287
TAR068	6.60	17.92	0.11	0.26	0.77	3.49	12.25	0.84	2.93	54.55	1050	119	20	62	253	30	345	119	19	94	89	47	206	237
TAR077	6.50	16.08	0.12	0.31	0.75	3.37	16.70	0.59	2.53	52.81	759	107	18	47	211	31	348	102	17	97	92	42	221	266
m	*6.59*	*15.87*	*0.12*	*0.28*	*0.73*	*3.54*	*17.53*	*0.61*	*2.61*	*51.90*	*672*	*100*	*17*	*41*	*199*	*29*	*290*	*92*	*18*	*98*	*90*	*53*	*243*	*277*
sd	*0.32*	*1.78*	*0.01*	*0.04*	*0.04*	*0.15*	*4.28*	*0.16*	*0.25*	*2.22*	*302*	*20*	*2*	*18*	*42*	*3*	*71*	*25*	*1*	*4*	*3*	*27*	*36*	*35*
Fabric ORI-4																								
CAT213	9.02	24.74	0.11	0.28	0.85	1.57	1.64	0.61	4.77	56.17	937	168	25	36	267	48	148	140	30	162	100	41	73	132
Fabric ORI-8																								
EMP327	6.88	14.98	0.12	0.33	0.75	1.92	16.82	0.57	2.68	54.80	333	107	15	24	141	23	192	59	17	136	113	68	142	223
Fabric ORI-9																								
CAT212	6.34	17.54	0.09	0.36	0.87	2.27	17.21	0.87	2.77	51.53	359	114	17	33	197	28	166	75	19	127	84	46	100	207
Fabric ORI-10																								
TAR067	6.13	12.76	0.11	0.22	0.81	1.88	5.46	0.86	2.36	69.26	406	80	19	35	235	31	223	78	15	108	89	43	126	149
Fabric ORI-11																								
TAR018	5.70	16.67	0.09	0.71	0.64	2.99	14.74	0.82	3.30	54.10	815	141	14	46	146	36	461	75	19	106	100	61	132	229
Fabric ORI-12																								
TAR013	8.26	24.66	0.10	0.49	2.29	1.26	6.11	0.23	2.49	53.92	197	72	63	18	496	53	310	153	32	166	173	19	74	204
Fabric ORI-13																								
TAR070	6.19	20.33	0.09	0.18	0.73	1.73	7.85	1.82	2.81	58.10	714	112	16	42	207	32	161	71	21	86	87	24	62	108

Table II