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Amphorae from the Late Antique city of *Tarraco-Tarracona* (Catalonia, Spain): archaeometric characterization

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Abstract

This paper presents the results of the petrographic, mineralogical and chemical characterization of Late Roman amphorae from a sixth-century context found in the Medieval Cathedral of Tarragona (Catalonia, Spain). This city had an intense port activity in Late Antiquity as the capital of *Hispania Tarraconensis* and, from the late 5th century, as an important Visigothic centre. A total of 41 amphora samples were analyzed using a combination of techniques, including optical microscopy by thin-section analysis, X-ray fluorescence and X-ray diffraction, in order to obtain information on their provenance and technology. They comprise African, southern Hispanic and eastern Mediterranean types, mainly dated to the 5th and 6th centuries. The analysis revealed a wide diversity of chemical-petrographic groups and subgroups, indicating the import of amphorae from several production centres, in many cases being possible to determine their particular provenance. A large part of the analyzed samples corresponds to Tunisian amphorae, arriving in the 5th century mainly from workshops located in the *Zeugitana* region, while later amphora types, more typical of the 6th to early 7th centuries, are mostly related to a provenance in the *Byzacena*. For southern Hispanic and eastern Mediterranean amphorae different workshops seem to be represented, even for a same amphora type. The results of this study provide new important evidence for a better understanding of the trade networks of *Tarraco-Tarracona* in Late Antiquity.

Key words: amphorae; OM; XRF; XRD; Hispania; Late Antiquity.

Introduction

The ancient city of *Tarraco* (Tarragona, Spain) (Figure 1a) played a major role during the Late Roman period as the capital of *Hispania Tarraconensis* and continued to have a strategic relevance after its incorporation to the Visigothic kingdom from the last quarter of the 5th century, now known as *Tarracona*. Its central position was reflected -among other evidence- in the activity of its port, where a variety of import products arrived from several Mediterranean regions (Aquilué, 1992; Macias, 1999; Remolà, 2000).

Some significant Late Antique rubbish dumps were excavated in the urban centre (*e.g.* TED'A, 1989; Dupré and Carreté, 1993; see Remolà, 2000), generally related to an urbanistic transformation of the former Provincial *Forum* (dated to the Flavian period) that took place from the second quarter of the 5th century and, more intensively, from the 6th century, within a process of monumentalization of the Visigothic episcopal complex (Macias and Remolà, 2004; Macias et al., 2008). In this framework, the excavation of a rubbish dump in this area, in the place where the Medieval Cathedral stands (Figure 1b), provided one of the main amphora assemblages known in the Late Antique city up to date, along with a large amount of common wares and, to a lesser degree, fine wares, revealing a very high percentage of imported products (Macias et al., 2008); many faunal and, especially, architectural elements have also been found, the latter coming from the dismantling of the old imperial cult area or *temenos* (Àlvarez et al., 2012). Based on the material context -especially on the ceramic findings- this deposit was dated to the mid- or second half of the 6th century; however, since its formation was related to the urbanisation activities in the zone, former fifth-century rubbish dumps were affected, what accounts for a large part of the ceramic findings being residual materials from this century (Bosch et al., 2005; Macias et al., 2008).

In Late Antiquity, amphora containers, which were essential for the transport of foodstuff (especially oil, wine and *garum*), were traded from different regions out of the *Tarraconensis* province (Keay, 1984; Remolà, 2000; Macias et al., 2008; Reynolds, 2010). Major production areas of the Late Roman amphorae usually represented in *Tarraco* and other sites of the *Tarraconensis* are especially the regions of *Africa* (Bonifay, 2004; Capelli and Bonifay, 2014), *Baetica* (Bernal, 2001; Bernal and Lagóstena, 2004; García Vargas and Bernal, 2008), *Lusitania* (Alarção and Mayet, 1990; Mayet et al., 1996; Fabião, 2004, 2008) and the eastern Mediterranean (Piéri, 2005; Reynolds, 2005), among others. These materials are remarkable for the information they provide concerning the commercial dynamics of the city in Late Antiquity. For this reason, the present contribution aims to present the results of the archaeometric analysis of these amphorae in order to obtain information on their provenance and to a lesser extent on some aspects of their technology. The objective is to examine the diversity of amphorae that were arriving and to shed light on the production centres from where they came from, contributing new evidence on the trade networks of Late Antique *Tarraco-Tarracona* within the Mediterranean context.

Very few studies on the archaeometric characterization of Late Roman amphorae in the current Catalan area have been conducted so far. In particular, it is worth mentioning the studies by Remolà et al. (1993, 1996) on materials from the rubbish dumps of Vila-roma, Antic Hospital de Santa Tecla and Torre de l'Audiència in the urban centre of *Tarraco*. The obtained results can be useful for comparison with the present study though in a limited way since those works were based only on the chemical analysis of major and minor elements of the amphorae. On the other hand, some Late Roman amphorae

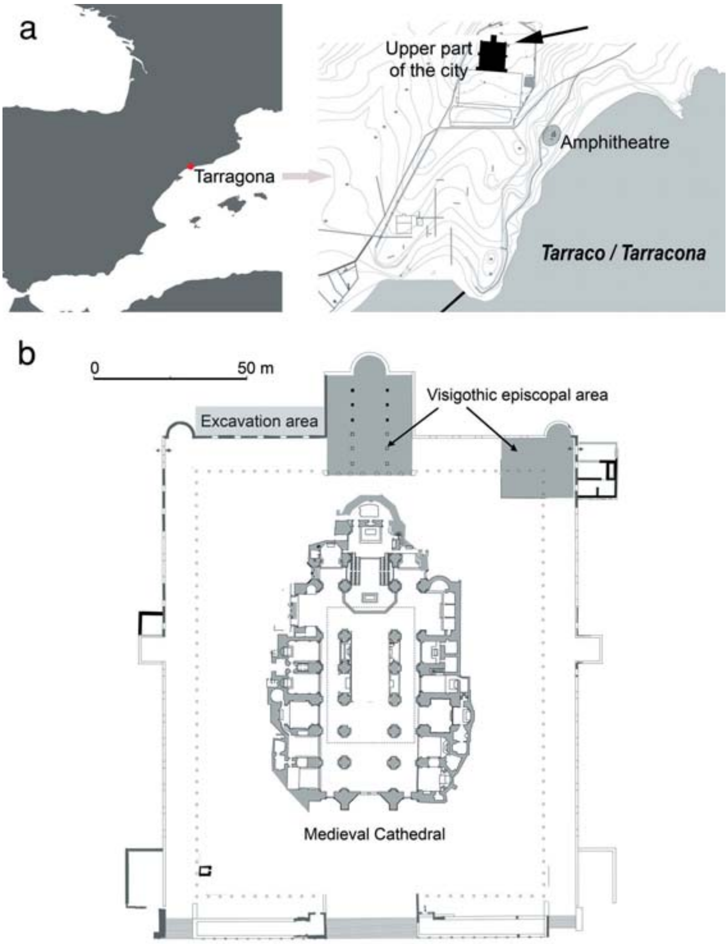

Figure 1. (a) Location of Tarragona and plan of the Late Antique city, indicating the situation of the Medieval Cathedral archaeological context. (b) Plan of the Medieval Cathedral context with an indication of the excavated area.

from other urban centres like *Iesso*/Guissona (Uscatescu and García, 2005) and *Iluro*/Mataró (Buxeda and Cau, 2004) were also analyzed, however as part of a broader study of the ceramic assemblage in the first case or within a research focused on the common and cooking wares in the second, not allowing in both papers for detailed discussion on the amphora materials. In an effort to improve our knowledge concerning the archaeometric characterization of Late Roman amphorae in the Catalan area, the analysis of a large amphora assemblage from *Tarraco*-*Tarracona* is presented in this paper, based on an integrated chemical, petrographic and mineralogical approach.

Materials and methods

The majority of the amphorae recovered in the Cathedral context may be related from a first

Table 1. List of the amphora samples analyzed with their typological classification.

Sample	*Amphora type*	*Sample*	*Amphora type*
CAT200	Indeterminate rim	CAT223	*Spatheion* 1?
CAT201	Keay 41	CAT224	Keay 62A
CAT202	LRA 1A	CAT225	*Spatheion* 1
CAT203	Keay 61C	CAT226	Keay 35A
CAT204	Keay 61D	CAT227	Dressel 23a / Keay 13A
CAT205	Almagro 50 (late variant)	CAT228	Keay 57
CAT206	LRA 1A (var. Kellia 169)	CAT229	Keay 35A
CAT207	Keay 35B	CAT230	Keay 36
CAT208	Dressel 23a / Keay 13A	CAT231	Keay 62D
CAT210	Almagro 51A-B	CAT232	*Spatheion* 1
CAT211	Almagro 51A-B	CAT233	LRA 1
CAT212	Indeterminate rim (with *titulus pictus*)	CAT234	Keay 35B
CAT213	LRA 3	CAT235	Keay 7 / Africana IID.2
CAT214	Keay 62D	CAT236	*Spatheion* 1?
CAT215	Almagro 50	CAT237	Keay 35B
CAT216	LRA 4	CAT238	Keay 35B
CAT217	Keay 4 / Africana IIA *senza gradino*	CAT239	Keay 35B
CAT218	Keay 35B	CAT240	Almagro 51A-B
CAT220	Keay 62E	CAT241	LRA 1A (var. transition)
CAT221	*Spatheion* 1	CAT242	Almagro 50 (late variant)
CAT222	Keay 35A		

macroscopic examination to African, eastern Mediterranean and, to a lesser degree, southern Hispanic products (Macias et al., 2008). From this assemblage, a total of 41 samples were selected for archaeometric analysis (Table 1; Figures 2-4). Special emphasis was placed on the study of African amphorae, since -despite being equally represented as eastern Mediterranean ones in this particular archaeological assemblage- they are usually the most frequent amphora imports in Late Antique contexts in the *Tarraconensis*. In addition, a major progress has been made in the characterization of many Tunisian amphora workshops in the last years,

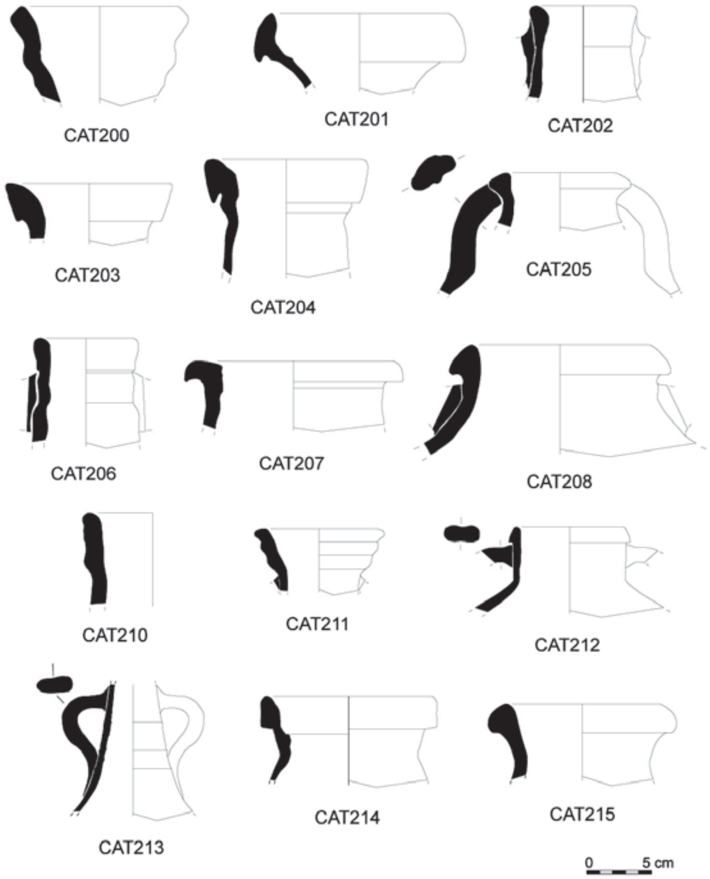

Figure 2. Illustrations of the analyzed amphora samples.

what allows for improved comparative studies with data from consumption centres. On the other hand, eastern Mediterranean amphora sampling was constrained to some practical limitations, since the most represented types in this assemblage are usually much smaller in size than African amphorae and in many cases they do not reach an adequate sample size for an integrated petrographic, chemical and mineralogical analysis. For these reasons, sample selection in this work does not pretend to be representative of the frequencies of the materials from each Mediterranean region in the archaeological assemblage; however an attempt was made to include the most representative amphora types within these regions in order to obtain adequate evidence of the diversity of products in each case.

In this way, most of the selected samples (25) can be ascribed to presumably African amphorae, especially to types Keay 35A, Keay 35B, *Spatheion* 1 and Keay 62 (variants A, D and E), as well as a few samples related to types Africana IIA *senza gradino*/Keay 4, Africana IID.2/Keay 7, Keay 36, Keay 41, Keay 57 and Keay 61 (variants C and D).

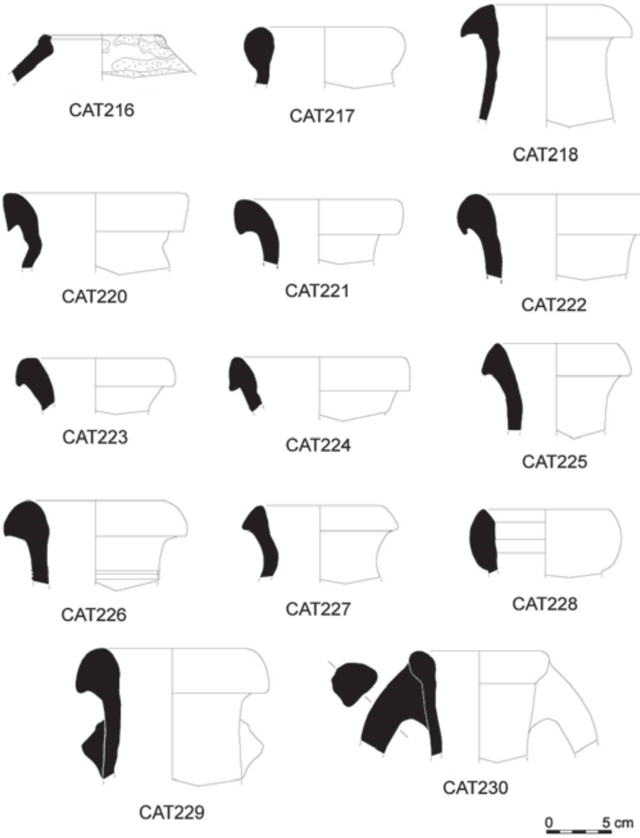

Figure 3. Illustrations of the analyzed amphora samples.

Eight samples are related to southern Hispanic amphorae, in particular types Dressel 23a/Keay 13A, Almagro 50 and Almagro 51A-B. Eastern Mediterranean amphorae are represented by types LRA 1 (including variants 1A/Kellia 169 and 1A/transition), LRA 3 and LRA 4. Two samples could not be related to any typology, although one amphora bearing a *titulus pictus* seems to be an eastern Mediterranean product.

In order to obtain a detailed characterization of these amphorae a combination of analytical techniques were applied on all of them, including X-Ray Fluorescence (XRF), X-Ray Diffraction (XRD) and Optical Microscopy (OM).

The chemical composition of the amphorae was obtained by XRF using an PANalytical-Axios Advanced PW 4400/40 spectrometer. Samples were powdered in a tungsten carbide mill (after remotion of the surface layer for avoiding possible contamination) and dried at 100 °C for 24 h. Duplicates of glassy pills were prepared (using 0.3 g of powdered specimen in an alkaline fusion with lithium tetraborate at a 1/20 dilution) to determine major and minor elements (Fe_2O_3, Al_2O_3, MnO, P_2O_5, TiO_2, MgO, CaO, Na_2O, K_2O, SiO_2), while pressed powdered pellets (with 5 g of the sample) were used for determination of trace elements (Ba,

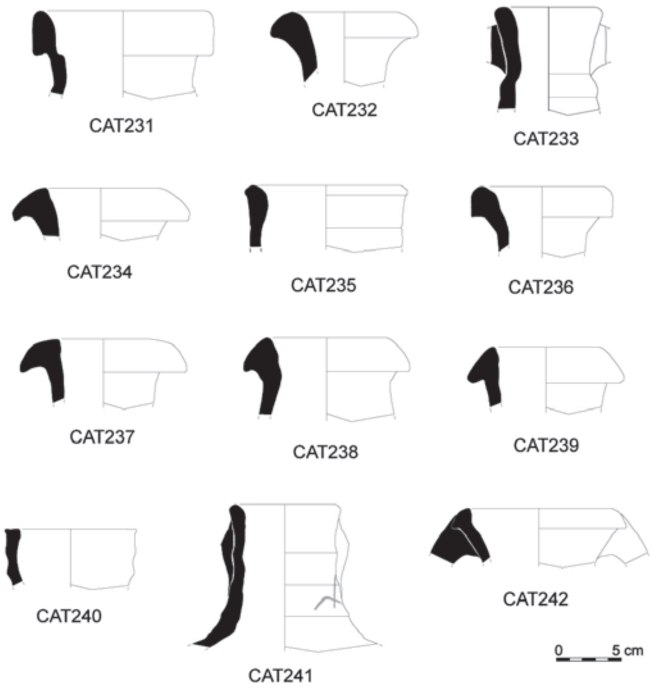

Figure 4. Illustrations of the analyzed amphora samples.

Rb, Th, Nb, Pb, Zr, Y, Sr, Ce, Ga, V, Zn, Cu, Ni, Cr, Mo, Sn, Co, W). A total of 60 International Geological Standards were used for calibration. The loss on ignition (LOI) was estimated after heating 0.3 g of dried specimen at 950 °C for 3 h.

For the mineralogical analysis a PANalytical X'Pert PRO MPD alpha 1 diffractometer was used, with Cu–Kα radiation (l = 1.5406 Å), working with spectra from 5 to 80°2θ, a step-size of 0.026°2θ and a step-time of 47.5 s. The tube current was 40 mA and the voltage 45 kV. Crystalline phases were examined through the software High Score Plus by PANalytical, including the Joint Committee of Powder Diffraction Standards (JCPDS) data bank. From the different primary and firing phases an estimation of equivalent firing temperatures (EFT) (Roberts, 1963) was achieved (e.g. Maggetti, 1982; Cultrone et al., 2001; Buxeda and Cau, 2004; Maggetti et al., 2011; Martínez, 2014).

The petrographic analysis of thin sections was conducted using an Olympus BX41 optical microscope, working with a magnification between ×20 and ×400. Description of ceramic fabrics was made following a modified version of the system proposed by Whitbread (1989, 1995) (see Quinn, 2013); grain size modes have been determined measuring the major axis of the grains of the more represented granulometric classes both for the fine and the coarse fractions.

Chemical results

The normalized chemical data for all the 41 samples are presented in Table 2; the elements

Table 2. Normalized chemical results of the amphora samples, determined by XRF. Concentrations of major and minor oxides are in %, other minor and trace elements are in ppm. Lost on ignition (LOI) values are also presented.

Sample	Fe_2O_3	Al_2O_3	*MnO*	P_2O_5	TiO_2	*MgO*	*CaO*	Na_2O	K_2O	SiO_2
CAT200	4.55	12.52	0.04	0.28	0.77	2.27	9.83	1.09	2.78	65.74
CAT201	6.46	15.43	0.05	0.35	0.76	1.94	15.21	1.23	2.06	56.35
CAT202	5.65	10.82	0.09	0.32	0.58	4.06	27.05	1.20	2.73	47.31
CAT203	5.24	13.58	0.04	0.20	0.77	2.50	10.84	0.40	2.56	63.58
CAT204	4.01	10.92	0.03	0.14	0.62	1.84	16.69	0.32	2.28	63.03
CAT205	5.57	16.60	0.09	0.05	0.78	1.16	0.20	0.35	3.38	71.68
CAT206	6.14	10.97	0.14	0.58	0.65	4.78	27.92	1.28	1.89	45.43
CAT207	6.69	16.04	0.04	0.18	0.84	1.81	3.76	0.19	2.08	68.25
CAT208	6.28	14.29	0.05	0.42	0.76	2.68	12.19	0.79	2.35	60.04
CAT210	4.19	14.38	0.02	0.06	0.72	1.00	0.52	0.54	3.20	75.23
CAT211	4.39	15.39	0.02	0.06	0.67	1.01	0.56	0.83	3.63	73.30
CAT212	6.34	17.54	0.09	0.36	0.87	2.27	17.21	0.87	2.77	51.53
CAT213	9.02	24.74	0.11	0.28	0.85	1.57	1.64	0.61	4.77	56.17
CAT214	5.68	15.01	0.04	0.30	0.82	2.65	8.84	0.49	2.55	63.46
CAT215	5.77	16.94	0.03	0.11	0.84	1.08	0.31	0.67	3.98	70.10
CAT216	6.39	11.82	0.11	0.21	1.28	2.61	11.06	1.15	1.79	63.40
CAT217	5.91	14.02	0.04	0.37	0.67	1.55	17.03	1.09	2.16	56.97
CAT218	5.72	14.64	0.03	0.21	0.87	1.90	5.37	0.46	2.69	67.95
CAT220	4.46	12.13	0.03	0.24	0.66	2.14	16.24	0.25	2.33	61.38
CAT221	4.25	11.03	0.02	0.41	0.65	1.18	19.01	0.43	2.07	60.79
CAT222	5.82	15.01	0.03	0.16	0.87	2.05	4.56	0.61	2.68	68.05
CAT223	5.37	12.95	0.05	0.23	0.72	2.77	8.63	0.32	2.11	66.72
CAT224	5.76	15.12	0.04	0.21	0.84	2.84	10.08	0.62	2.39	61.96
CAT225	5.55	14.21	0.03	0.24	0.87	1.86	4.34	0.53	2.66	69.57
CAT226	5.90	14.97	0.03	0.21	0.89	1.95	4.85	0.49	2.74	67.83
CAT227	6.29	14.10	0.05	0.33	0.75	2.70	14.67	0.51	2.19	58.26
CAT228	5.79	15.19	0.03	0.17	0.89	2.11	4.05	0.56	2.86	68.20
CAT229	5.58	14.59	0.03	0.19	0.86	1.91	3.26	0.58	2.72	70.12
CAT230	5.48	13.60	0.04	0.34	0.76	1.32	10.41	0.27	1.75	65.89
CAT231	4.90	11.75	0.04	0.21	0.67	1.98	11.11	0.40	2.35	66.44
CAT232	5.71	14.13	0.03	0.14	0.74	1.95	4.45	0.48	2.35	69.89
CAT233	5.54	9.96	0.13	0.44	0.64	4.71	28.65	1.51	1.73	46.48
CAT234	5.91	15.22	0.03	0.29	0.87	2.03	6.15	0.45	2.72	66.16
CAT235	5.55	12.96	0.04	0.29	0.73	1.95	11.88	1.08	2.25	63.09
CAT236	5.24	12.98	0.03	0.34	0.66	1.99	15.68	0.41	1.88	60.64
CAT237	5.77	14.38	0.03	0.18	0.85	1.92	6.10	0.53	2.52	67.58
CAT238	6.08	15.20	0.02	0.19	0.88	2.01	3.70	0.45	2.69	68.61
CAT239	5.93	15.66	0.03	0.22	0.87	2.03	5.10	0.43	2.77	66.80
CAT240	4.22	13.80	0.02	0.15	0.83	0.65	0.58	0.56	2.37	76.69
CAT241	5.87	11.41	0.08	0.30	0.66	4.14	23.60	1.03	2.11	50.57
CAT242	5.59	16.52	0.02	0.05	0.72	1.35	0.27	0.47	3.51	71.35

Table 2. Continued ...

Sample	*Ba*	*Rb*	*Th*	*Nb*	*Pb*	*Zr*	*Y*	*Sr*	*Ce*	*Ga*	*V*	*Zn*	*Cu*	*Ni*	*Cr*	*LOI*
CAT200	347	97	7	15	19	215	26	227	62	15	84	65	23	27	77	3.10
CAT201	242	82	7	20	40	168	24	510	75	19	125	208	20	31	117	2.93
CAT202	458	73	6	13	20	118	21	441	40	13	111	85	37	162	395	16.62
CAT203	362	81	6	19	16	296	26	1732	64	17	101	74	15	28	94	4.90
CAT204	270	70	6	17	16	222	21	251	60	14	104	53	11	21	88	6.93
CAT205	501	166	10	16	34	180	34	69	77	19	87	47	16	34	72	1.13
CAT206	329	45	3	11	16	116	21	562	32	12	107	153	206	184	567	16.27
CAT207	300	82	9	21	22	250	25	154	79	19	122	83	14	34	138	0.90
CAT208	290	92	7	17	21	195	24	418	66	18	141	85	21	33	128	4.30
CAT210	515	148	8	15	42	181	31	131	60	18	72	44	20	21	60	2.73
CAT211	577	168	7	15	28	146	26	99	41	19	66	42	21	22	57	2.37
CAT212	359	114	12	17	33	197	28	166	75	19	127	84	46	100	207	7.33
CAT213	937	168	18	25	36	267	48	148	140	30	162	100	41	73	132	3.50
CAT214	373	89	8	23	20	274	28	318	82	19	122	87	17	31	113	2.20
CAT215	521	218	15	18	32	297	38	61	77	21	71	77	15	24	56	1.00
CAT216	450	44	5	22	16	389	30	405	61	15	109	62	35	43	113	5.87
CAT217	436	73	7	17	55	197	24	492	65	18	126	154	23	36	125	8.73
CAT218	366	94	9	22	22	350	30	232	79	18	109	86	16	30	109	1.17
CAT220	332	74	7	18	18	235	24	241	69	16	112	68	14	25	95	6.76
CAT221	329	72	5	17	17	271	20	487	59	14	105	61	15	24	111	7.03
CAT222	315	96	9	22	19	345	29	286	83	19	117	86	18	30	113	0.90
CAT223	290	65	5	20	17	217	22	240	73	16	101	74	17	25	106	2.07
CAT224	296	82	7	21	19	261	27	279	83	18	121	77	15	31	120	1.13
CAT225	350	86	7	20	22	358	28	190	76	17	105	74	13	28	100	0.93
CAT226	327	90	8	21	20	318	28	206	78	18	109	78	16	30	106	1.56
CAT227	279	84	6	17	24	183	23	332	65	17	144	77	18	32	122	6.46
CAT228	355	93	9	21	22	337	28	211	85	19	113	81	15	30	104	0.90
CAT229	334	87	7	20	20	317	26	187	79	17	103	72	15	29	98	1.30
CAT230	326	66	6	18	20	247	24	311	72	16	104	66	18	26	118	1.53
CAT231	406	56	5	17	19	228	21	257	68	15	108	61	16	25	97	8.79
CAT232	228	75	6	18	18	178	20	192	65	16	105	67	10	26	95	0.90
CAT233	284	40	2	10	14	108	19	458	30	12	98	66	40	169	681	18.06
CAT234	436	93	8	22	23	316	28	233	78	20	113	84	16	30	106	1.50
CAT235	479	65	6	22	32	251	24	411	71	16	110	87	22	28	108	6.26
CAT236	256	67	6	16	28	159	21	444	67	16	105	112	16	30	124	4.40
CAT237	333	88	8	21	21	327	28	217	83	18	112	81	10	28	108	0.77
CAT238	330	93	8	21	22	326	29	192	90	19	116	81	13	30	110	0.87
CAT239	334	96	9	22	21	304	28	243	85	19	118	85	15	29	105	1.50
CAT240	454	98	8	15	30	238	21	176	42	15	73	34	23	14	54	2.83
CAT241	348	73	6	13	21	129	20	565	44	12	108	64	31	177	663	11.53
CAT242	588	167	8	15	32	178	36	63	66	19	91	51	21	28	75	1.00

Mo, Sn, Co and W were excluded from the analysis, due to problems of analytical imprecision (Mo, Sn) or possible contamination during sample preparation (Co, W).

The compositional variation matrix was calculated as a first approach to the chemical variability of the data set, obtaining a total variation (*vt*) of 4.57 that is very high and indicative of a polygenic population (Buxeda and Kilikoglou, 2003). The elements that introduce more variability in the data set are CaO ($\tau._{CaO}$ = 42.43), Sr ($\tau._{Sr}$ = 12.73), Ni ($\tau._{Ni}$ = 11.00), Cr ($\tau._{Cr}$ = 10.46), P_2O_5 ($\tau._{P2O5}$ = 9.90), Cu ($\tau._{Cu}$ = 9.71), Rb ($\tau._{Rb}$ = 9.45), MnO ($\tau._{MnO}$ = 9.40), Na_2O ($\tau._{Na2O}$ = 9.07), Th ($\tau._{Th}$ = 8.38) and Zr ($\tau._{Zr}$ = 8.29).

The compositional data were subjected to Cluster Analysis and Principal Component Analysis (PCA) using the software S-PLUS 2000, after an additive log-ratio (alr) transformation of the values obtained by XRF (Aitchison, 1986; Buxeda, 1999). The subcomposition taken into account for these statistical treatments is Al_2O_3, TiO_2, MgO, CaO, Na_2O, K_2O, SiO_2, Ba, Rb, Th, Nb, Zr, Y, Sr, Ce, Ga, V, Zn, Ni and Cr; Fe_2O_3 was used as divisor in the log-ratio transformation of the data. MnO, P_2O_5, Pb and Cu were removed due to possible analytical or alteration/contamination problems, as it was noticed after a first assessment of the chemical results. Although all statistical treatments have been made on the alr-transformed data, in the discussion of the results the values are expressed according to the normalized data in Table 2.

From the cluster tree in Figure 5 -obtained using the centroid agglomerative method and the squared Euclidean distance- a first group division can be made. Three major clusters are found, in which is possible to define a number of chemical groups (CG) that can be associated with particular types of amphorae, as it is the case for southern Hispanic types Almagro 50 (CG I), Almagro 51A-B (CG II) and Dressel 23a (CG IVc), for eastern Mediterranean type LRA 1 (CG III) and for African types Keay 35 (CG IVa) and Keay 62 (CG IVb and IVd). The mean chemical compositions for groups CG I to CG IV are given in Table 3.

A similar group division results from PCA. The biplot of the first two PCs (Figure 6a) -accounting for 81% of the total variance- allows for a clear differentiation among the major chemical groups. CG I and II are characterized by a quite low PC1 score (≤ -2.36), explained by their low CaO, Sr and Cr concentrations (Table 3). These groups are less calcareous than the rest of the assemblage, this being associated also with their low Sr concentrations. The CaO and Sr content is higher in CG II (CaO 0.52-0.58%, Sr 99-176 ppm) than in CG I (CaO 0.20-0.31%, Sr 61-69 ppm), which is accounting for the lower PC1 score in the latter (-3.42 to -3.67, compared with the -2.36 to -2.51 values for CG II). In CG II a higher percentage of Fe_2O_3 and Al_2O_3 than in CG I is also observed. In addition, they both exhibit the lowest Cr and P_2O_5 concentrations within the data set, as well as relatively high percentages of K_2O and low of MgO and MnO.

On the other hand, CG III is defined by a high score for both PC1 (2.43 to 3.10) and PC2 (1.49 to 2.08). The first one is mainly explained by the high calcareous nature of the four samples of the group (CaO 23.60-28.65%, Sr 441-565 ppm) and their high Cr content, while the PC2 values are related to the high Ni, Cr and Na_2O and low Zr concentrations. The significant differences in CaO, MgO, SiO_2, Ni and Cr content when compared with the rest of the data set are indicating their relevance for the definition of this group (Figure 6a; Tables 2 and 3).

The large CG IV along with a series of loners within Cluster C (Figure 5) are grouped together in the center of the diagram in Figure 6a, making necessary a new PCA without Clusters A and B in order to better appreciate the internal differences. The biplot of this new PCA is shown in Figure 6b. PC1 score is dominated by the CaO, Sr and Na_2O content, while PC2 is

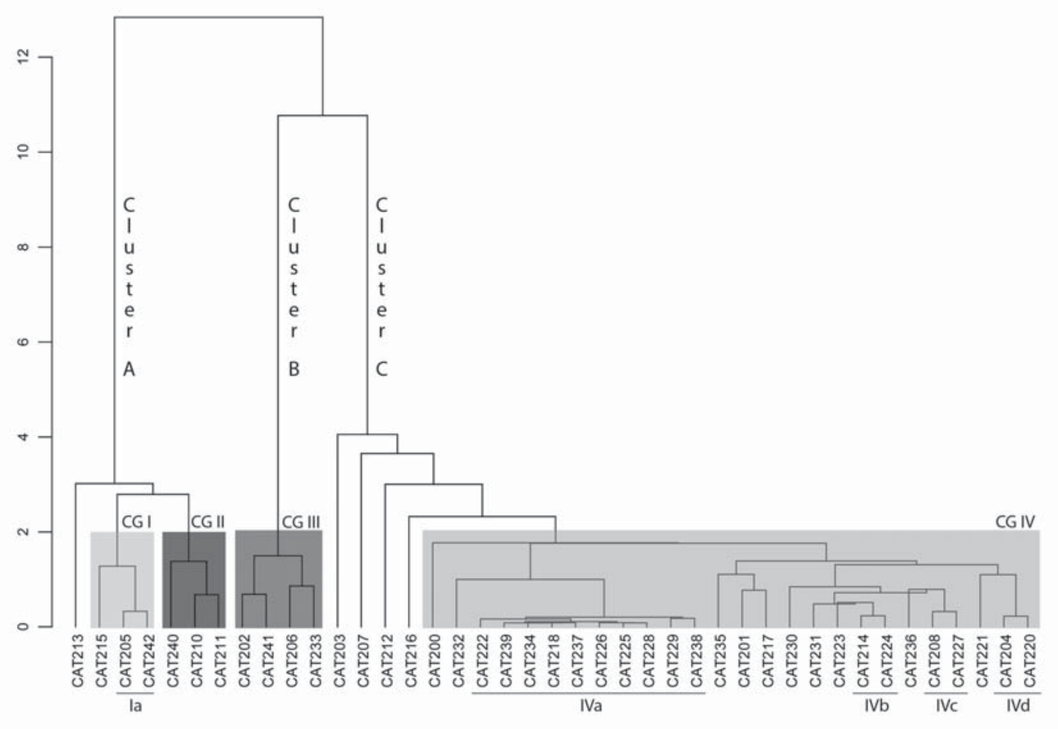

Figure 5. Dendrogram resulting from cluster analysis (using the centroid agglomerative method and the squared Euclidean distance) on 41 samples, including the subcomposition Al_2O_3, TiO_2, MgO, CaO, Na_2O, K_2O, SiO_2, Ba, Rb, Th, Nb, Zr, Y, Sr, Ce, Ga, V, Zn, Ni and Cr; Fe_2O_3 was used as divisor in the log-ratio transformation of the data. CG: chemical group.

related to Na_2O, CaO, Sr and Ni; both together account for 62% of the total variance.

The most distinctive feature for the separation of subgroup CG IVa (Figures 5 and 6b; Table 3) is its relatively low CaO content (3.26-6.15%), which is responsible for the low PC1 score (-0.55 to -1.08). Sr concentration tends to be also lower than in the remaining samples, although some exceptions prevent using this as a clearly distinctive element. Instead, as can be seen in Table 2, it is possible to notice a higher Zr content (304-358 ppm) than in the rest of the samples, something also reflected when performing the PC1-PC3 analysis (PC3 being dominated by Sr and Zr). Percentages of Al_2O_3 (14.2-15.7%) and SiO_2 (66.2-70.1%) are also relatively high in this subgroup.

The other CG IV subgroups (IVb to IVd) in the dendrogram of Figure 5 can also be observed in the PCA, and even better in a second PCA excluding CaO, Sr and Na_2O which provides therefore strong evidence for this subgroup division (Figure 7). Here PC1 score is dominated by Zr, Zn, K_2O and Ba while PC2 is mainly associated with MgO -and to some extent also with Zn and Zr-, both accounting for 62% of the total variance (Figure 7a); in addition, the biplot PC1-PC3 (Figure 7b) -this latter dominated by Ba and to a lesser degree Th, Cr, Rb and V- explains 57% of the total variance.

Table 3. Mean chemical composition of groups CG I to CG IV and subgroup CG IVa. Mean (m) and standard deviation (sd) values are presented for each element.

	Fe_2O_3	Al_2O_3	MnO	P_2O_5	TiO_2	MgO	CaO	Na_2O	K_2O	SiO_2	Ba	Rb	Th	Nb	Pb	Zr	Y	Sr	Ce	Ga	V	Zn	Cu	Ni	Cr
CG I (n=3)																									
m	5.64	16.69	0.05	0.07	0.78	1.20	0.26	0.50	3.62	71.04	536	184	11	16	33	218	36	65	74	20	83	58	17	28	68
sd	0.11	0.22	0.04	0.04	0.06	0.14	0.05	0.16	0.31	0.83	45	30	3	2	1	68	2	4	7	1	11	16	4	5	10
CG II (n=3)																									
m	4.27	14.52	0.02	0.09	0.74	0.89	0.55	0.64	3.07	75.07	515	138	8	15	33	188	26	135	48	17	70	40	21	19	57
sd	0.11	0.80	0.00	0.05	0.08	0.21	0.03	0.16	0.64	1.70	61	36	1	0	7	46	5	39	11	2	4	5	2	5	3
CG III (n=4)																									
m	5.80	10.79	0.11	0.41	0.63	4.42	26.80	1.25	2.11	47.45	355	58	4	11	18	118	20	506	36	12	106	92	78	173	576
sd	0.26	0.60	0.03	0.13	0.03	0.38	2.23	0.20	0.44	2.22	74	18	2	2	4	9	1	66	6	1	6	42	85	10	131
CG IV (n=26)																									
m	5.54	13.92	0.04	0.26	0.78	2.06	9.59	0.57	2.42	64.67	333	82	7	19	23	262	25	293	74	17	113	85	16	29	108
sd	0.63	1.37	0.01	0.08	0.09	0.41	4.98	0.27	0.30	4.07	60	12	1	2	8	63	3	103	9	2	12	31	4	3	12
Subgroup CG IVa (n=10)																									
m	5.80	14.91	0.03	0.21	0.87	1.98	4.75	0.51	2.71	68.09	348	91	8	21	21	330	28	220	82	18	112	81	15	29	106
sd	0.16	0.44	0.00	0.04	0.01	0.08	0.96	0.06	0.09	1.17	34	4	1	1	1	17	1	30	4	1	5	5	2	1	4

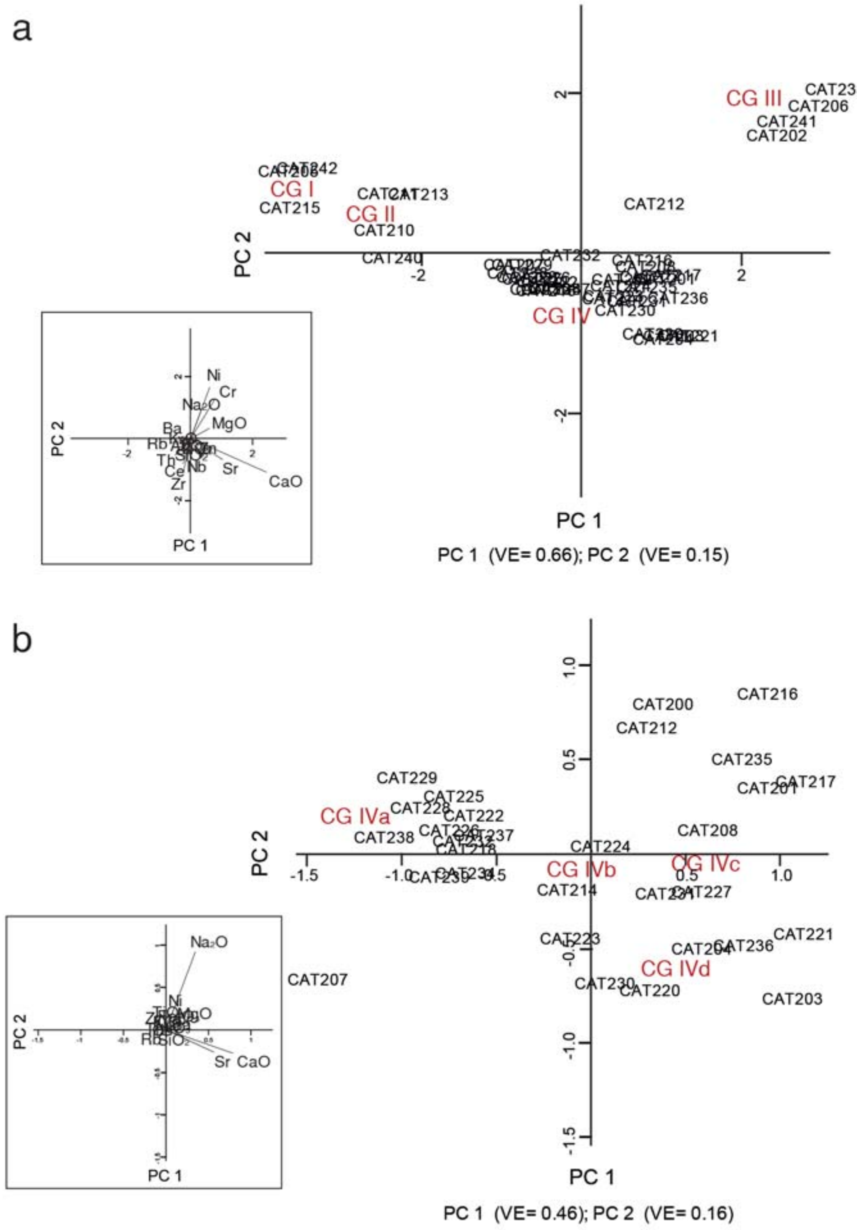

Figure 6. PCA of the alr-transformed chemical data obtained by XRF; the analysis was performed on the covariance matrix. (a) PCA for the total data set (41 samples): plot with the first two principal components (PC1 and PC2); in the bottom left-hand corner there is a plot of the variables, labelled as elements, according to the loadings in the two first principal components. (b) PCA for the 30 samples grouped as Cluster C in Figure 2: plot PC1-PC2.

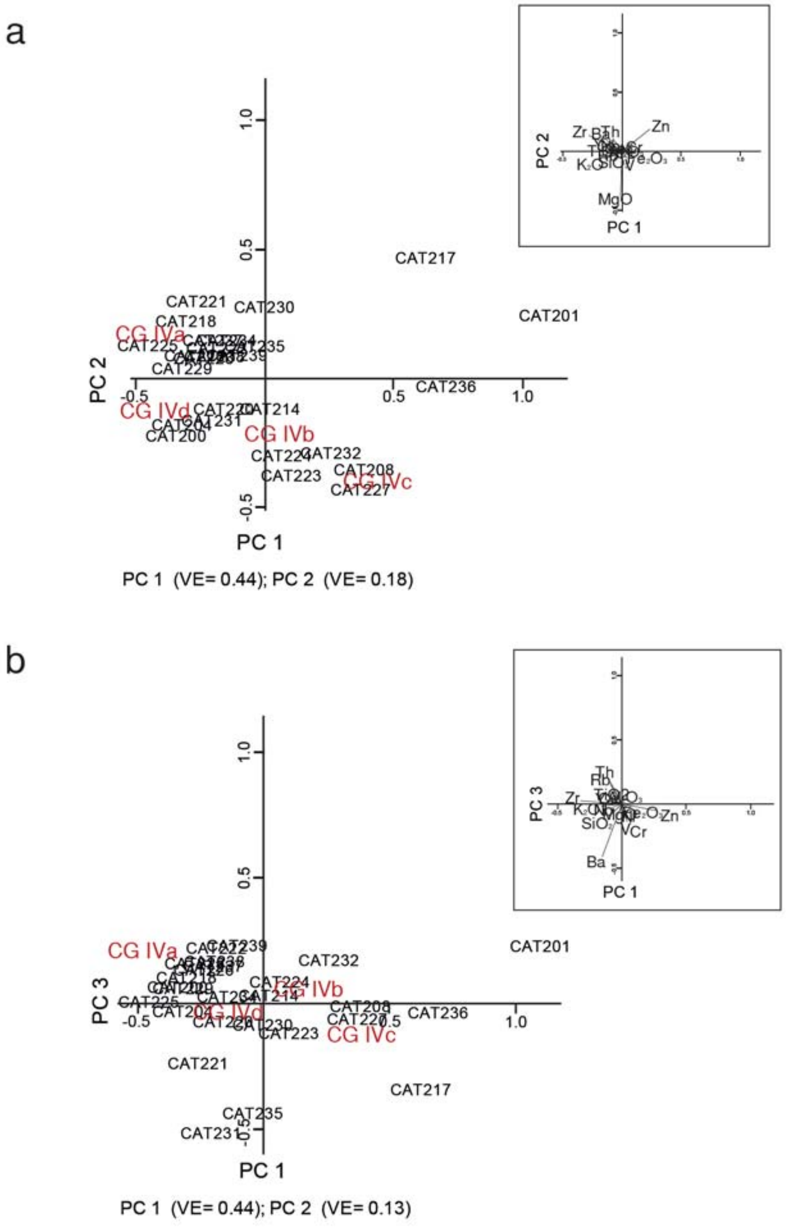

Figure 7. PCA (performed on the covariance matrix) of the alr-transformed chemical data for CG IV samples (n = 26), after the exclusion of CaO, Sr and Na_2O from the analysis. (a) Plot with the principal components PC1 and PC2. (b) Plot PC1-PC3. In the upper right-hand corner we provide the plots of the variables, labelled as elements, according to the loadings in the two first principal components.

In this PCA the distinctive feature of CG IVa is its low PC1 score -due mainly to the higher Zr concentrations- combined with positive values for PC2 and PC3.

Combining the two PCAs in Figures 6 and 7 it is possible to observe that -apart from CG IVa- subgroups CG IVb (CAT214, 224), IVc (CAT208, 227) and IVd (CAT204, 220) are internally consistent, while the remaining samples of CG IV behave as loners, since they are close to different samples in each plot.

In the first PCA both CG IVc and IVd show a relatively high PC1 score (Figure 6b) due specially to their CaO and Sr content; CaO is higher in CG IVd (16.2-16.7%) than in IVc (12.2-14.7%), however the latter shows a higher Sr content (332-428 ppm) than the former (241-251 ppm). The lower PC2 values in CG IVd are mainly explained by its lower Na_2O percentages (0.2-0.3% against 0.5-0.8% in IVc) (Table 2). In comparison with these subgroups, CG IVb can be differentiated for its lower PC1 values, which are in any case not as low as those observed in CG IVa; this is mainly explained by its CaO content (8.8-10.1%), which is intermediate between the low percentages found in CG IVa and the high ones found in CG IVc and IVd. Concerning CaO and Sr content, a relatively direct relationship can be observed when comparing subgroups CG IVa, IVb and IVc, in contrast to the inverse relationship found after comparing these subgroups with CG IVd (Figure 8).

From the second PCA (Figure 7) CG IVc is distinguished by its higher PC1 and PC2 scores associated with a relatively low content of Zr (183-195 ppm) and high of MgO (2.7%), respectively; it presents also higher

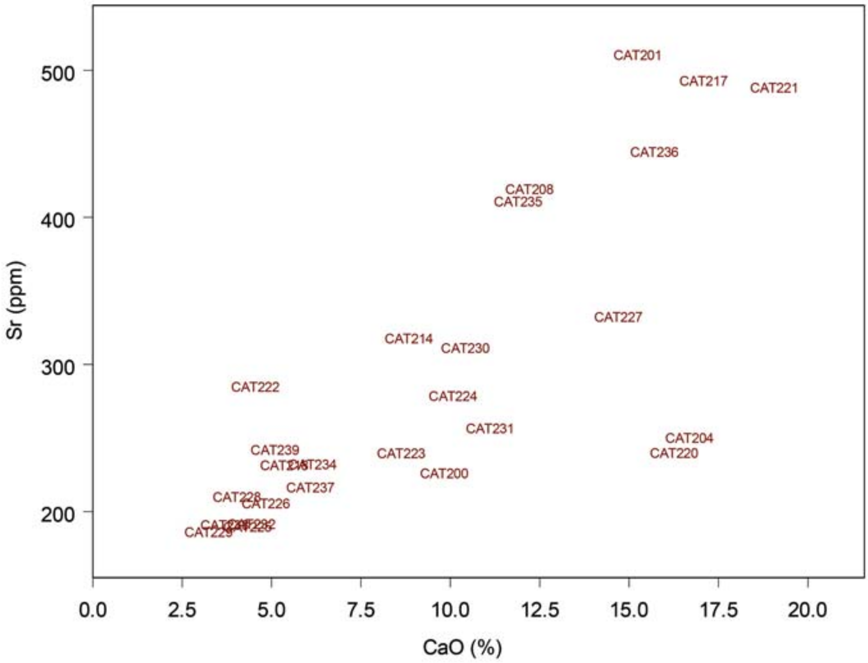

Figure 8. A CaO versus Sr binary diagram (using normalized data) for the samples in CG IV, showing an inverse relationship in CAT204 and CAT220 (subgroup CG IVd).

concentrations of V (141-144 ppm) and Cr (122-128 ppm) than the other subgroups, however the PC3 value is compensated by a relatively low Ba content (279-290 ppm). On the other hand, the negative PC1 and PC2 scores in CG IVd (Figure 7) are mainly explained by its lower Zn concentrations (53-68 ppm), while CG IVb shows intermediate PC1 scores and relatively low of PC2, the latter related to the high MgO content (2.6-2.8%) as happens in CG IVc. Apart from these differences among the chemical subgroups, other compositional aspects -not well appreciated in the PCA- can be noticed, for example concerning their Al_2O_3 and SiO_2 content; the first one is less relevant in CG IVd (10.9-12.1%, against 14.1-15.7% in the other subgroups), while silica percentages are higher in CG IVa (66.2-70.1%) and lower in CG IVc (58.3-60.0%).

From the several loners in CG IV, a possible chemical relationship can be proposed for CAT201 and CAT217 (Figure 5), both with high CaO (15.2-17.0%) and Sr concentrations (492-510 ppm) -responsible for their high PC1 score in Figure 6b- as well as a very high content of Zn (154-208 ppm) and low of Zr (168-197 ppm), what accounts for their high PC1 and PC2 score in Figure 7. However some important chemical differences, especially in their MgO and Ba concentrations (Table 2; Figure 7), do not suggest for the moment their grouping together.

Petrographic and mineralogical results

The petrographic analysis of thin-sections allowed dividing the 41 samples into nine petrographic fabric groups (PF) (Table 4), although some of them comprise different subgroups while others are represented only by individual samples. Information concerning the presence and relative abundance of different mineral phases as well as an estimation of equivalent firing temperatures (EFT) were obtained from XRD results for all the samples (Table 5).

The larger fabric group is PF 1, characterized by an iron-rich matrix and a non-plastic inclusion composition that comprises mainly monocrystalline quartz -usually with aeolian features in the coarse fraction- and variable amounts of calcareous microfossils and limestone fragments; metamorphic or volcanic inclusions can be present but only as accessory components. A total of 25 samples belong to this group, although an important fabric variability can be found on the basis of inclusion composition and textural characteristics such as packing, grain-size distribution and frequency and roundness of inclusions. Following these criteria, a number of subgroups can be defined (Table 4: PF 1.1 to 1.13), most of them -with the exception of PF 1.1, 1.2 and 1.3- represented by only one sample since a remarkable petrographic diversity is found (Figure 9). By far the most represented subgroup is PF 1.1 (Figure 9a), comprising ten samples (Table 4) that are characterized by a predominant fine fraction mainly composed of angular quartz (mode 0.10-0.05 mm) and a less relevant coarse fraction dominated by quartz (< 1.2 mm; in many cases with aeolian features) and fragments of quartz-sandstone with a calcareous cement (< 3.9 mm). Subgroup PF 1.2 (Figure 9b) resembles PF 1.1 in many textural and compositional features but shows -when compared to the latter- a lesser content of quartz-sandstone fragments and, conversely, higher presence of calcareous inclusions, particularly microfossils; in addition, quartz inclusions are more abundant in the fraction between 0.20-0.35 mm than in PF 1.1, although the fine fraction is still predominant, especially in sample CAT214 (Table 4). On the other hand, PF 1.3 (Figure 9c) presents a quite distinctive fabric with a fine fraction dominated by microfossils (especially foraminifera and ostracods, with rare echinoids) and angular-subangular quartz, while in the coarse fraction these inclusions are also present -being the quartz more rounded (aeolian)- though a more evident component here are large sedimentary rock fragments (micritic and fossiliferous limestone), up to 3.6 mm. Petrographic fabrics PF 1.4 to 1.13 are formed by single individuals and should be therefore considered as loners within the Tunisian fabric group (PF 1); their fabric description is presented in Table 4 and some are illustrated in Figure 9d-f.

Samples in PF 1 are usually high-fired products, what can be inferred from their optically inactive matrix when seen in thin section as well as from the different mineral phases that are present according to the XRD results (Table 5). The presence of firing phases (e.g. gehlenite, pyroxene, and plagioclase) as well as the presence of phyllosilicates suggest an EFT around 850-950 ºC for most of these samples, with the exception of very high firing temperatures (≥ 9 50/1000 ºC) in PF 1.9, 1.12 and in some samples of PF 1.1 and, conversely, low firing temperatures (≤ 800/850 iron ºC) in PF 1.5, 1.6 and 1.11.

PF 2 resembles PF 1 in its mainly quartz-calcitic inclusion composition in an iron-rich matrix, in this case low-fired (≤ 800/850 ºC), but can be differentiated by the accessory presence of different heavy minerals (tourmaline, zircon, hornblende, epidote, pyroxenes) and a higher presence of plagioclase (Table 4). Calcareous inclusions and quartz are also relevant components in PF 3, however this is a quite different fabric in which polycrystalline quartz and metamorphic rock fragments are also common components as well (Figure 10a).

Other petrographic groups are PF 4 and 5, which seem to be actually interrelated since they share many similarities in their inclusions, comprising mainly quartz and a variable presence of muscovite, feldspars (especially alkali feldspars), polycrystalline quartz and, to a lesser degree, quartzite and biotite, while calcareous inclusions are absent. They differ basically in their matrix -which is non-calcareous in both cases but apparently associated with different clays-, apart from the particularities of each subgroup concerning the relative abundance of their components as well as textural characteristics (Table 4; Figure 10b-c). They present in general a high porosity and a low-fired optically active matrix, in consistence with their low EFT, under 850 ºC (Table 5).

On the other hand, PF 6 comprises four samples with a quite characteristic non-plastic inclusion composition, dominated by calcareous sand (including many microfossils) and a significant presence of basic-ultrabasic inclusions, especially red-orange serpentine (derived from the alteration of pyroxene and olivine) and iddingsite (from the alteration of olivine) as well as clinopyroxenes (altered in some cases into serpentine). Other subordinate or accessory components are quartz, plagioclase, chert, amphiboles, alkali feldspars, polycrystalline quartz, igneous rock fragments and orthopyroxenes. Differences in the relative frequencies of these inclusions and/or textural particularities allow distinguishing two subgroups (Table 4; Figure 10d-e). They were usually fired between 850-950 ºC, except for sample CAT202 that was fired under 800/850 ºC (Table 5); the presence of clinopyroxenes in the XRD pattern of this latter must be related to their presence as primary inclusions rather than to a firing phase formation.

In PF 8 there is also a dominant -though different- calcareous component and some basic-ultrabasic inclusions (i.e. serpentine, peridotite, pyroxenes), but the latter are much less relevant than in PF 6, while other components like acid metamorphic rock fragments, micas and epidote are here more important (Table 4; Figure 10f).

In PF 9 inclusions are mainly comprising quartz with a subordinate presence of alkali feldspars, plagioclase, polycrystalline quartz, calcite and microfossils, all set in a well-fired (850-950 ºC) calcareous matrix (Tables 4-5).

Table 4. Petrographic characteristics of the amphora samples analyzed.

	Matrix	Voids	Non-plastic inclusions
PF 1: Quartz and calcite in a Fe-rich matrix			
PF 1.1: Quartz-sandstone and fine quartz (CAT218, 222, 225, 226, 228, 229, 234, 237, 238, 239)	58-73%. Dark brown or dark reddish-brown (PPL). Optically inactive	5-7%. Mainly mesovughs and mesovesicles	20-30%. Predominant FF (<0.20 mm): dominant qtz (mode 0.10-0.05 mm); few-very few: fe.inc, micas (ms, bt), cal; rare-very rare: pl, cal.mf; very rare-absent: p.qtz, kfs, ch, cpx. CF usually less important: dominant qtz (<1.20 mm, usually <0.35 mm); frequent-common: qtz.sds with calcareous cement (<3.90 mm, usually <0.80 mm); common-few: ARF / fe.inc (<2.70 mm, usually <0.40 mm); few-rare: qtz.sds with Fe-rich cement (<4.90 mm, mostly <1 mm); very few-very rare: lms; rare-absent: cal.mf, quartzite; very rare-absent: p.qtz, kfs, bt
PF 1.2: Fine quartz, with quartz-sandstone and microfossils (CAT214, 224)	68-73%. Dark reddish-brown (PPL). Optically inactive	7%. Mainly mesovughs and mesovesicles	20-25%. Predominant FF (<0.20 mm; less present in CAT224): dominant qtz (mode 0.10-0.05 mm); few: cal.mf, cal; few: fe.inc; rare-very rare: pl, micas (ms, bt), p.qtz, kfs, ch, cpx, ep. CF subordinated (but more important than in PF 1.1): dominant qtz (<0.75 mm, mode 0.20-0.35 mm); common-very few: qtz.sds with calcareous cement (usually <1.00 mm); few-very few: cal.mf (<0.85 mm), lms (<1.20 mm, mode <0.30 mm); few-rare: fe.inc (<2.50 mm, mode <0.40 mm); rare-absent: qtz.sds with Fe-rich cement; very rare-absent: pl, kfs, p.qtz, quartzite, ms, cpx
Related to PF 1.2: More microfossils than in PF 1.2 (CAT203)	70%. Similar to PF 1.2	5%. Similar to PF 1.2	25%. Predominant FF (<0.20 mm): dominant qtz; common: cal.mf, cal; few: fe.inc; rare: pl, ms, bt, p.qtz; very rare: kfs, ep, cpx. CF subordinated: dominant qtz (<0.95 mm, mode 0.25-0.35 mm); common: cal.mf (<1.4 mm, mode <0.50 mm), qtz.sds with calcareous cement (<2.5 mm, mode 0.75-1.50 mm); few: lms (<1.50 mm), qtz.sds with Fe-rich cement (<1.20 mm); rare: p.qtz, fe.inc
PF 1.3: Microfossils, limestone and quartz (CAT204, 220)	63-70%. Dark reddish-brown (PPL). Optically inactive	5-7%. Mainly mesovughs and mesovesicles	25-30%. Poorly sorted. CF (>0.15 mm) equally or more important than FF. CF with frequent cal.mf (<1.75 mm, mode <0.30 mm but larger fragments are common), qtz (<1.70 mm, mode 0.20-0.35 mm) and lms (usually >0.50 mm, up to 3.60 mm); very few: ARF, fe.inc; rare: p.qtz; very rare: kfs, pl. FF: dominant-frequent cal.mf, cal and qtz; very few: fe.incl; rare: pl; rare-very rare: bt, ms, p.qtz; very rare: kfs, cpx, ep
PF 1.4: Microfossils, quartz and limestone; finer and well-sorted than PF 1.3 (CAT221)	58%. Dark reddish-brown (PPL). Optically inactive	7%. Mainly mesovughs and mesovesicles	35%. Well sorted. Predominant FF (<0.20 mm, mode 0.05-0.15 mm) dominated by cal. mf and qtz. Scarce CF, finer than PF 1.3 (max. dim. 1 mm), with dominant qtz (<1.00 mm, mostly <0.35 mm), frequent cal.mf (<1.00 mm, mode <0.30 mm, larger fragments are rare) and few cal / lms (<1.00 mm, mostly <0.30 mm). Subordinate and accesory components are similar to PF 1.3

PF: petrographic fabric; FF: fine fraction; CF: coarse fraction. Categories for the frequency of inclusions are based on Whitbread (1995).

Table 4. Continued ...

	Matrix	Voids	Non-plastic inclusions
PF 1.5: Medium- and fine-grained quartz with few limestone and microfossils (CAT231)	70%. Brown-orange (PPL); heterogeneous (many dark, not well oxidised sectors). Optically active	5%. Mainly mesovughs and mesovesicles	25%. Moderately sorted. The CF (>0.10 mm) is predominant with a mode 0.10-0.30 mm, while the FF (<0.10 mm) is important but subordinated. CF with predominant qtz (<0.70 mm, mode 0.10-0.30 mm); few: lms (<4.50 mm, mode ~0.30 mm), cal.mf (<2.40 mm, but mostly <0.20 mm); rare: pl, p.qtz, fe.inc, ARF; very rare: kfs, quartzite. FF: predominant qtz; common-few cal and cal.mf; very few pl; rare: kfs, p.qtz, ms, fe.inc; very rare: ep, bt, ch, cpx
PF 1.6: Fine microfossils, calcite and quartz, with coarse limestone, ARFs and clay pellets (CAT217)	63%. Red-orange (PPL), heterogeneous (darkened sectors). Optically active. Abundant large clay pellets and streaks	7%. Mainly mesovesicles, few vughs	30%. Predominant FF (<0.20 mm, mode 0.10-0.15 mm): dominant cal and cal.mf; frequent qtz; very few: fe.inc, p.qtz; rare: pl, kfs; very rare: ms, ch, quartzite. CF clearly differentiated: a dominant feature are large clay pellets (<2.8 mm) and ARFs (<1.70 mm) as well as common lms (<1.4 mm) and qtz.sds (<5.5 mm), all of them usually <1 mm; few: cal.mf (<0.4 mm), qtz (<0.60 mm); rare: ch; very rare: p.qtz, qtz.sds
PF 1.7: Coarse aeolian quartz, moderately sorted (CAT232)	60%. Dark reddish-brown (PPL). Optically inactive	15%. Elongated, strong parallel orientation	25%. Predominant CF (>0.10 mm), moderately sorted: predominant qtz (<1.10 mm, mode 0.40-0.60 mm); few: lms (<2.30 mm), p.qtz (<1.80 mm, mode 0.60-0.80 mm); very few fe.inc; rare kfs; very rare qtz.sds. Very scarce FF (<0.10 mm), predominant qtz; few: cal; rare: bt, ms, p.qtz; very rare: kfs, pl, cpx
PF 1.8: Coarse aeolian quartz, finer than PF 1.7 (CAT223)	65%. Dark reddish-brown (PPL). Optically inactive	10%. Elongated, moderate parallel orientation	25%. Predominant CF (>0.10 mm), better sorted and finer than PF 1.7: predominant qtz (<0.85 mm, mode 0.30-0.40 mm); few lms (<0.85 mm, mode 0.30-0.40 mm); very few fe.inc, ARF; rare: p.qtz (<0.55 mm, mode <0.25 mm), kfs, cal.mf; very rare: rad.ch, pl. Very scarce FF (<0.10 mm), similar to PF 1.7
PF 1.9: Coarse aeolian quartz and calcite (CAT201)	70%. Dark reddish-brown (PPL). Optically inactive	10%. Elongated, strong parallel orientation	20%. Largely predominant CF (>0.20 mm): frequent qtz (<0.80 mm, mode 0.40-0.50 mm), cal.mf and lms (both affected by high firing temperature; <1.5 mm, mode 0.45-0.60 mm); few: p.qtz (<0.55 mm, mode 0.40 mm), fe.inc (<0.70 mm, mode ~0.50 mm); rare: ARF, ch, kfs, pl; very rare: MRF (quartzite, schist), qtz.sds, sts. Very scarce FF (<0.20 mm), dominant qz; common: cal / cal.mf, fe.inc; very few: p.qtz; very rare: kfs, pl, ch, bt, cpx, ep
PF 1.10: Coarse aeolian quartz and calcite; higher % of inclusions and finer than PF 1.9 (CAT236)	65%. Dark reddish-brown (PPL). Optically inactive	10%. Mainly elongated, but meso-/macro-vughs and vesicles are also important	25%. Largely predominant CF (>0.15 mm), finer than in PF 1.9: dominant qtz (<0.75 mm, mode 0.30-0.35 mm); frequent lms (<2.30 mm, mode <0.40 mm); few-very few (<0.85 mm, mode <0.25 mm): cal.mf, fe.inc, p.qtz; rare: ch; very rare: qtz.sds, kfs, bt, hbl, quartzite. Very scarce FF (<0.15 mm), dominant qtz; frequent cal; few: cal.mf, fe.inc; rare bt; very rare: p.qtz, ch, pl, cpx

PF: petrographic fabric; FF: fine fraction; CF: coarse fraction. Categories for the frequency of inclusions are based on Whitbread (1995).

Table 4. Continued ...

	Matrix	Voids	Non-plastic inclusions
PF 1.11: Medium- and fine-grained quartz (CAT235)	75%. Brown-orange (PPL); heterogeneous (many dark, not well oxidised sectors). Optically active. Some clay pellets; clay mixing?	5%. Mesovughs and mesovesicles, apart from some macro-/mega-vughs	20%. The CF (>0.10 mm) is predominant, with a variable mode between 0.10-0.40 mm; the FF (<0.10 mm) is subordinated but also important. CF: predominant qtz (<1.00 mm, mode 0.10-0.40 mm); few ARF (<1.5 mm); few-very few: cal (<0.55 mm) and cal.mf (<0.30 mm), both usually <0.20 mm; rare: p.qtz, kfs, fe.inc; very rare: quartzite, pl. FF: predominant qtz; few cal / cal.mf; very few: p.qtz, fe.inc; rare: kfs, pl; very rare: ms, bt, quartzite, rad.ch
PF 1.12: Medium- and fine-grained quartz with coarse ferruginous inclusions (CAT207)	65%. Dark reddish-brown (PPL). Optically inactive. Some very large Fe-rich clay pellets	5%. Mainly meso-sized vughs, vesicles and elongated voids	30%. CF (>0.10 mm): dominant qtz (<0.55 mm, mode 0.20-0.25 mm); frequent fe.inc (<2.50 mm, usually large but <1.00 mm); few lms (<0.75 mm, mostly <0.40 mm); very few p.qtz (<0.45 mm, mode 0.15-0.20 mm); rare: ARF, kfs, pl; very rare: qtz.sds, ms, bt. FF (<0.10 mm) equally important, dominant qtz; common fe.inc; other components similar to CF (in addition to very rare cpx)
PF 1.13: Medium- and fine-grained quartz with quartz-sandstone (CAT230)	70%. Dark brown or reddish brown (PPL). Optically inactive. Clay mixing; very large calcareous clay streaks	5%. Mainly mesovughs and mesovesicles	25%. Dominant CF (>0.10 mm): predominant qtz (<0.65 mm, mode 0.15-0.30 mm); few: qtz.sds (mainly 0.80-1.80 mm), lms (<0.75 mm, mode <0.25 mm), fe.inc; very few p.qtz (both with mode <0.20 mm); rare kfs; very rare: quartzite, pl. FF (<0.10 mm) predominant qtz; common cal; few fe.inc; very few bt; rare kfs; very rare: p.qtz, ms, pl, ep, cpx
PF 2: Quartz and calcite, with fine accesory heavy minerals (CAT216)	63%. Reddish-brown (PPL). Low optical activity	7%. Mainly mesovesicles and meso-/macro-vughs	30%. Dominant FF (<0.15 mm): frequent qtz; common fe.inc; few: cal, pl; very few-very rare: heavy minerals (cpx, hbl, tur, zrn, ep, opx); rare: kfs, bt, ms; very rare: ch, quartzite, chl. CF (>0.15 mm), moderately sorted: dominant qtz (<1.00 mm, mode 0.30-0.40 mm); common lms (<1.10 mm, mode 0.20-0.30 mm); few cal.mf (<0.85 mm); very few p.qtz (<0.30 mm); rare: quartzite, kfs, ARF; very rare: fe.inc, ch, pl, grog?, ms, bt, hbl, cpx, ep
PF 3: Calcite, microfossils, quartz (mono- and poly-crystalline) and metamorphic inclusions			
PF 3.1: Less metamorphic inclusions (CAT208)	83%. Reddish brown to greenish brown (PPL). Inactive. Clay mixing; Ca-rich and Fe-rich clay pellets and streaks	7%. Mainly small vesicles (micro- and meso-sized); few macrovoids	10%. Well sorted. CF (>0.15 mm): frequent calcareous inclusions -lms and cal.mf- (<0.95 mm, mode 0.20-0.30 mm); common qtz (<0.45 mm, mode 0.35-0.40 mm), p.qtz (<0.50 mm); very few: MRF (quartzite, schist, phyllite, more rarely metagranite; <0.55 mm), ms; rare: kfs, fe.inc; very rare: ch, hbl. FF (equally important as CF): dominant cal / cal.mf; frequent qtz; few fe.inc; very few ms; rare: p.qtz, kfs, pl; very rare: MRF, ch, rad.ch

PF: petrographic fabric; FF: fine fraction; CF: coarse fraction. Categories for the frequency of inclusions are based on Whitbread (1995).

Table 4. Continued ...

	Matrix	Voids	Non-plastic inclusions
PF 3.2: More metamorphic inclusions (CAT227)	80%. Reddish brown to greenish brown (PPL). Optically inactive. Few Fe-rich clay streaks	5%. Mainly small vesicles (micro-/meso-sized); few macrovoids	15%. Well sorted. CF (>0.15 mm): more calc. inclusions -lms and cal.mf- than PF 3.1 but finer and better sorted (<0.40 mm, mode 0.15-0.25 mm); MRF (quartzite, schist, phyllite, more rarely metagranite; <1.35 mm but usually <0.50 mm) are subordinate but more abundant than in PF 3.1; few qtz (<0.20 mm); very few: ms, p.qtz; rare: kfs, fe.inc, ms; very rare: ch, rad.ch, hbl, bt. FF (equally important as CF): similar to PF 3.1 (also very rare ep)
PF 4: Quartz (with k-spars and/or muscovite) in a buff-yellow non calcareous matrix			
PF 4.1: Abundant fine quartz and muscovite, well sorted (CAT211)	55%. Buff-yellow (PPL). Heterogeneous (many dark, not well oxidised sectors) High optical activity. Few clay pellets	10%. Meso- and macro-sized vughs and vesicles	35%. Well sorted. Scarce CF (>0.35 mm): frequent qtz (<0.70 mm, mode <0.45 mm) and ms (<0.75 mm, mode <0.50 mm); few: fe.inc / ARF, kfs; very few: p.qtz; rare: quartzite, granite. Dominant FF (<0.35 mm; scarce inclusions <0.10 mm): frequent ms (mode 0.20-0.25 mm) and qtz (mode 0.10-0.20 mm); few: bt (mode 0.20-0.25 mm), kfs, pl, p.qtz (all with mode 0.10-0.15 mm); rare: quartzite, fe.inc; very rare: granite, phyllite, ch, chl, ep, cpx
Related to PF 4.1: Coarser and less sorted, with less muscovite than in PF 4.1 (CAT210)	63%. Similar to PF 4.1 (but with many clay pellets, sometimes >1 mm)	7%. Similar to PF 4.1	30%. Moderately sorted. Coarser than PF 4.1, with a CF (>0.35 mm) subordinated to FF but still important: dominant qtz (<1.15 mm, without a clear mode), common: ms (<0.90 mm); few: kfs; very few: p.qtz, quartzite; rare: granite. Dominant FF (<0.35 mm but inclusions <0.15 mm are very scarce): frequent qtz (mode 0.15-0.25 mm); few: ms (mode 0.15-0.30 mm), kfs, pl, p.qtz (all with mode 0.15-0.25 mm); very few: bt; same accesory components as PF 4.1
PF 4.2: Quartz (mono- and poly-crystalline) and k-spars, bad sorted (CAT240)	73%. Buff-yellow (PPL). Heterogeneous (many dark, not well oxidised sectors). High optical activity. Small clay pellets	7%. Mesovoids and a few but large macro-sized vughs and elongated voids	20%. Bad sorted. Dominant CF (>0.10 mm): dominant qtz (<1.50 mm, mode 0.20-0.40 mm); common: p.qtz (<1.35 mm, mode 0.30-0.40 mm); few: ARF / fe.inc (<1.05 mm), kfs (<0.50 mm, mode 0.15-0.25 mm), qtz.sds (<1.15 mm, usually >0.50 mm); very rare: pl, ms, quartzite. FF (<0.10 mm) important but subordinated to CF; dominant qtz; few: fe.inc; kfs; rare: p.qtz, pl, ms; very rare: ch
PF 5: Quartz (with k-spars and muscovite) in a reddish non calcareous matrix			
PF 5.1:Fine quartz with k-spars and muscovite, well sorted (CAT205)	60%. Red-orange but very darkened throughout due to incomplete oxidation (PPL). High optical activity. Many small clay pellets	15%. Meso-/macro-vughs, vesicles and elongated (strong parallel orientation)	25%. Well sorted. Dominant FF (<0.30 mm; mostly 0.10-0.30 mm, very scarce under 0.10 mm), with dominant qtz; few: kfs, p.qtz, ms; very few: pl; rare: granite, MRF (quartzite, phyllite), fe.inc; very rare: ep, bt, hbl. CF (0.30-1.10 mm) less relevant: dominant qtz (<0.75 mm, most <0.45 mm); common ms (<0.75 mm, most <0.50 mm) and kfs (<0.70 mm, most <0.45 mm); few: p.qtz (<0.60 mm); very rare: fe.inc, quartzite, bt, qtz.sds with Fe-rich cement

PF: petrographic fabric; FF: fine fraction; CF: coarse fraction. Categories for the frequency of inclusions are based on Whitbread (1995).

Table 4. Continued ...

	Matrix	Voids	Non-plastic inclusions
Related to PF 5.1: Coarser and less sorted than PF 5.1 (CAT242)	60%. Red-orange (PPL), except darker, not oxidised core. High optical activity. Some clay pellets (one very large, 6.7 mm)	10%. Meso-/ macro-vughs, vesicles and elongated (strong parallel orientation)	30%. Moderately sorted. CF (>0.30 mm) more important than PF 5.1 (but still subordinated to FF): frequent qtz (<1.15 mm, mode 0.45-0.60 mm) and kfs (<1.05 mm, same mode as qtz); common p.qtz (<1.90 mm, same mode as qtz); few: ms (<2.10 mm, mode 0.50 mm), ARF / fe.inc (<1.60 mm), granite (<1.50 mm); very rare: MRF (quartzite, phyllite), pl. Dominant FF (<0.30 mm; very scarce under 0.10 mm), similar to PF 5.1 but with more pl and bt, both as subordinate (few) components
PF 5.2:Quartz, k-spars, muscovite and biotite, bad sorted (CAT215)	70%. Red-brown to orange (PPL). High optical activity. Many small clay pellets (one very large, 3.0 mm)	5%. Meso- and macro- voids (vesicles, vughs and some large elongated voids)	25%. Bad sorted. CF (>0.10 mm) and FF both important. CF: dominant qtz (<3.30 mm, mode 0.15-0.25 mm though larger crystals are frequent); common kfs (<0.95 mm, variable dimensions, mostly 0.25-0.60 mm); few: p.qtz (<1.25 mm, mode 0.40-0.50 mm); very few: ARF / fe.inc, pl, ms, bt; very rare: granite, ch. FF (<0.10 mm): dominant qtz; common: ms, bt; few: fe.inc, kfs; very few pl; rare p.qtz; very rare: ep, phyllite
PF 6: Calcareous and basic/ultrabasic inclusions in a calcareous matrix			
PF 6.1: Well sorted (CAT206, 233)	65-72%. Dark brown to greenish brown (PPL). Optically inactive. Many clay pellets in CAT206. Abundant secondary calcite	3-5%. Meso- (more rarely macro-) sized vesicles and vughs	25-30%. Well sorted. CF (>0.10 mm) largely predominant: dominant cal and cal.mf (<2.05 mm, mode 0.25-0.35 mm); few: srp/idd (<0.45 mm, mode 0.20-0.25 mm), qtz (<0.40 mm, mode 0.20-0.30 mm), cpx (<0.30 mm, mode 0.10-0.20 mm), IRF (mainly basic, with pl and cpx; also rare ultrabasic and intermediate; <0.35 mm), pl (<0.30 mm); few-very few: hbl (<0.30 mm, mode 0.10-0.20 mm), p.qtz (<0.40 mm, mode 0.25-0.30 mm; sometimes grading to quartzite); very few: kfs (<0.35 mm), opx (<0.25 mm); very few-rare: ch (<0.40 mm, mostly <0.20 mm; some rad.ch); rare: ol, bt, fe.inc; very rare: schist, ep, ms, spl. Very scarce FF (<0.10 mm), mainly of cal, qtz, and secondary or accesory presence of pl, cpx, kfs, fe.inc, srp/idd, p.qtz, hbl, bt, ep, spl, ol
Related to PF 6.1: Similar texture but with differences in secondary components (CAT202)	68%. Brown-orange to reddish brown (PPL). Very low optical activity. Many clay pellets	7%. Meso- (more rarely macro-) sized vesicles and vughs; few elongated voids	25%. Well sorted. CF (>0.10 mm) largely predominant: dominant cal and cal.mf (<1.50 mm, mode 0.25-0.35 mm); few: srp/idd (<0.40 mm, mode 0.20-0.30 mm), ch (<0.45 mm, mode 0.20-0.30 mm; some rad.ch), cpx (<0.40 mm, mode 0.10-0.20 mm); very few: qtz (<0.55 mm, mode 0.15-0.20 mm), p.qtz (<0.35 mm; very rarely grading to quartzite); rare: bt, opx, fe.inc, hbl, IRF (mainly basic); very rare: pl, kfs, ol, ep, schist. Very scarce FF (<0.10 mm), mainly of cal, qtz, and secondary /accesory presence of pl, cpx, kfs, fe.inc, srp/idd, p.qtz, hbl, bt, ch, ep

PF: petrographic fabric; FF: fine fraction; CF: coarse fraction. Categories for the frequency of inclusions are based on Whitbread (1995).

Table 4. Continued ...

	Matrix	Voids	Non-plastic inclusions
PF 6.2: Coarser and less sorted, with more serpentine as secondary component (CAT241)	75%. Dark brown (PPL). Optically inactive. Some secondary calcite	5%. Meso- and macro-vesicles and vughs, and important elongated voids	20%. Moderately sorted. CF (>0.10 mm) largely predominant: dominant cal and cal.mf (<1.70 mm, mode 0.40-0.60 mm); common: srp (<0.95 mm, mode 0.30-0.50 mm) and some idd; few: ch (<0.70 mm, mode 0.40-0.60 mm; some rad.ch), qtz (<0.80 mm, mode 0.30-0.40 mm); very few: cpx (<0.55 mm, mode 0.20-0.25 mm), hbl (<0.40 mm, mode 0.20-0.25 mm), p.qtz (<0.90 mm), IRF (<0.65 mm; mainly basic/ultrabasic), kfs (<0.50 mm), opx (<0.55 mm), fe.inc (<0.55 mm); rare: pl, bt; very rare: ol, spl, qtz.sds. Very scarce FF (<0.10 mm), similar components to CF, with very rare ep
PF 7: Scarce inclusions in a Fe-rich muscovitic matrix (CAT213)	92%. Light brown; dark red-brown in outer wall (PPL). High optical activity	3%. Mesovughs, mesovesicles and rare macrovughs	5%. FF (<0.15 mm) largely predominant: dominant micas (ms; and accesory bt and chl), with common qtz and fe.inc; rare ep; very rare: kfs, czo, cpx, p.qtz, MRF (schist), cal. CF (>0.15 mm) is very scarce: ms (<0.25 mm), MRF (schist, 1.30 mm), qtz (<0.20 mm), p.qtz (<0.60 mm), fe.inc (<0.20 mm), lms (0.75 mm), bt (0.20 mm)
PF 8: Coarse metamorphic and fine limestone in a calcareous matrix (CAT212)	82%. Brown; greenish brown in outer wall (PPL). Calcareous. Optically inactive	3%. Mesovughs, mesovesicles and rare macrovughs	15%. Moderately sorted. FF (<0.25 mm) largely predominant: dominant lms (mode 0.05-0.15 mm); common: qtz, fe.inc; few: micas (bt, ms, chl), ep, MRF; very few: pl; rare: cpx, kfs, srp, p.qtz; very rare: czo, opx, cal.mf. Very scarce CF (>0.25 mm): frequent acid MRF (quartz-mica schist, quartzite; <0.60 mm, mode 0.35-0.50 mm) and lms (<0.90 mm, mode <0.30 mm); few: srp (<0.45 mm), qtz (<0.40 mm), fe.inc (<0.40 mm); very rare: act, peridotite, cal.mf, ARF, p.qtz
PF 9: Quartz (mono- and poly-crystalline), feldspars, micas and calcareous inclusions, in a calcareous matrix (CAT200)	75%. Greenish brown (PPL). Calcareous. Optically inactive	5%. Mainly micro- and meso-sized vesicles and vughs	20%. Dominant FF (<0.20 mm): dominant qtz (without a clear mode); few: ms, bt, pl, p.qtz, kfs, cal, cal.mf, fe.inc; very few: ch; rare: MRF (quartzite, very rarely phyllite), hbl; very rare: ep, cpx. Scarce CF (>0.20 mm): dominant qtz (<1.15 mm, mode 0.40-0.50 mm); common: kfs (<0.70 mm, mode 0.40-0.50 mm), p.qtz (<0.80 mm, mode >0.50 mm); very few: quartzite (<0.65 mm), fe.inc; rare: ARF, ch; very rare: qtz.sds, ms, bt, cal.mf

PF: petrographic fabric; FF: fine fraction; CF: coarse fraction. Categories for the frequency of inclusions are based on Whitbread (1995).
Abbreviations for rock-forming minerals (based on Kretz 1983): act, actinolite; bt, biotite; cal, calcite; chl, chlorite; cpx, clinopyroxene; czo, clinozoisite; ep, epidote; hbl, hornblende; kfs, K-feldspar; ms, muscovite; ol, olivine; opx, orthopyroxene; pl, plagioclase; qtz, quartz; spl, spinel; srp, serpentine; tur, tourmaline; zrn, zircon.
Abbreviations for other inclusions: ARF, argillaceous rock fragments; cal.mf, calcareous microfossils; ch, chert; fe.inc, ferruginous inclusions; idd, iddingsite; IRF, igneous rock fragments; lms, limestone; mds, mudstone; MRF, metamorphic rock fragments; p.qtz, polycrystalline quartz; qtz.sds, quartz-sandstone; rad.ch, radiolarian chert; sts, siltstone.

Table 5. Mineralogical composition and equivalent firing temperature (EFT) of the amphora samples, determined from XRD analysis. PF: petrographic fabric.

Sample	*PF*	*Qtz*	*Pl*	*Kfs*	*Cal*	*Gh*	*Px*	*Hem*	*Ill-Ms*	*Spl*	*EFT (ºC)*
CAT218	1.1	+	+	+	+	+	+	+	+		850-950
CAT222	1.1	+	+	+	Trace		+	+		+	≥ 950/1000
CAT225	1.1	+	+	+	Trace		+	+		+	≥ 950/1000
CAT226	1.1	+	+	+	+	+	+	+	+		850-950
CAT228	1.1	+	+	+		Trace	+	+	+		850-950
CAT229	1.1	+	+	+	+	Trace	Trace	+	+		850-950
CAT234	1.1	+	+	+	+	+	+	+	+		850-950
CAT237	1.1	+	+	+	Trace		+	+			≥ 950/1000
CAT238	1.1	+	+	+			+	+		+	≥ 950/1000
CAT239	1.1	+	+	+	+	+	+	+	+		850-950
CAT214	1.2	+	+	+	+	+	+	+	+		850-950
CAT224	1.2	+	+	+	+	+	+	+	+		850-950
CAT203	1.2 rel.	+		+	+	+	+	+	+		850-950
CAT204	1.3	+	+	+	+	+	+	+	+		850-950
CAT220	1.3	+	+	+	+	+	+	+	+		850-950
CAT221	1.4	+	+	+	+	+	+	+	Trace		850-950
CAT231	1.5	+		+	+			+	+		≤ 800/850
CAT217	1.6	+	+	+	+			+	+		≤ 800/850
CAT232	1.7	+	+	+	Trace		+	+	+		850-950
CAT223	1.8	+	+	+	+	+	+	+	+		850-950
CAT201	1.9	+	+	+	+		+	+	Trace		950-1000
CAT236	1.10	+	+	+	+	+	+	+	+		850-950
CAT235	1.11	+	+	+	+			+	+		≤ 800/850
CAT207	1.12	+	+	+			+	+		+	≥ 950/1000
CAT230	1.13	+	+	+	+	+	+	+	+		850-950
CAT216	2	+	+	+	+		+	+	+		≤ 800/850
CAT208	3.1	+	+	+	+	+	+	+	+		850-950
CAT227	3.2	+	+	+	+	+	+	+	+		850-950
CAT211	4.1	+	+	+					+		≤ 850
CAT210	4.1 rel.	+	+	+					+		≤ 850
CAT240	4.2	+	+	+					+		≤ 850
CAT205	5.1	+		+				+	+		≤ 850
CAT242	5.1 rel.	+	+	+					+		≤ 850
CAT215	5.2	+	Trace	+				+	+		≤ 850
CAT206	6.1	+	+	Trace	+	+	+	+	Trace		850-950
CAT233	6,1	+	+	+	+	+	+	+	Trace		850-950
CAT202	6.1 rel.	+	+	+	+		+	+	+		≤ 800/850
CAT241	6,2	+	+	+	+	+	+	+	Trace		850-950
CAT213	7	+		+					+		≤ 850
CAT212	8	+	+	+	+	+	+	+	+		850-950
CAT200	9	+	+	+	+	+	+	+	+		850-950

Abbreviations for minerals (based on Kretz 1983): Qtz = quartz; Pl = plagioclase; Kfs = K-feldspar; Cal = calcite; Gh = gehlenite; Px = pyroxene; Hem = hematite; Ill-Ms = illite-muscovite; Spl = spinel.

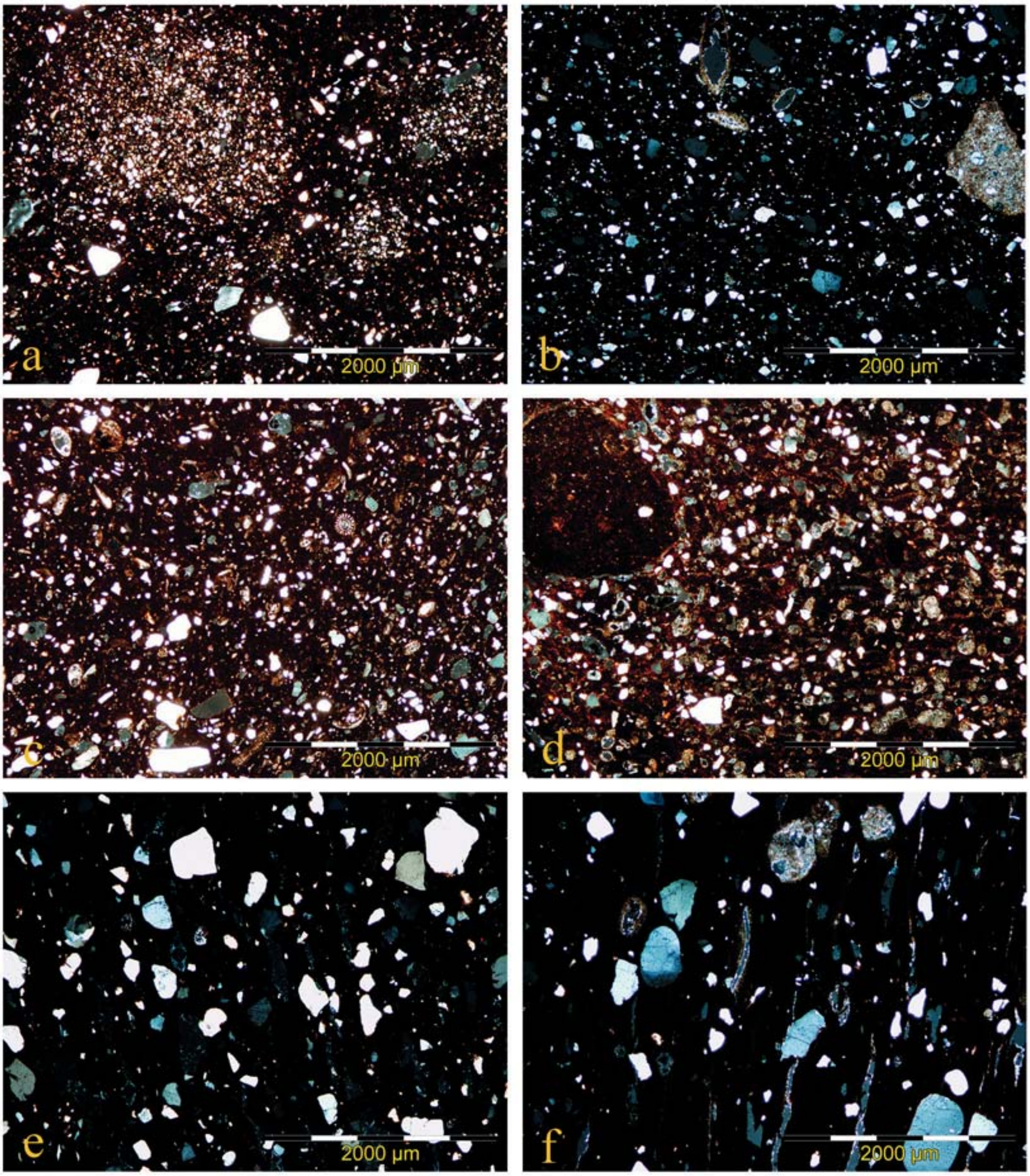

Figure 9. Microphotographs of thin sections from Tunisian petrographic fabrics (PF), all taken in cross-polarized light at the same magnification (40x). (a) PF 1.1: sample CAT229. (b) PF 1.2: sample CAT214. (c) PF 1.3: sample CAT220. (d) PF 1.6: sample CAT217. (e) PF 1.7: sample CAT232. (f) PF 1.9: sample CAT201.

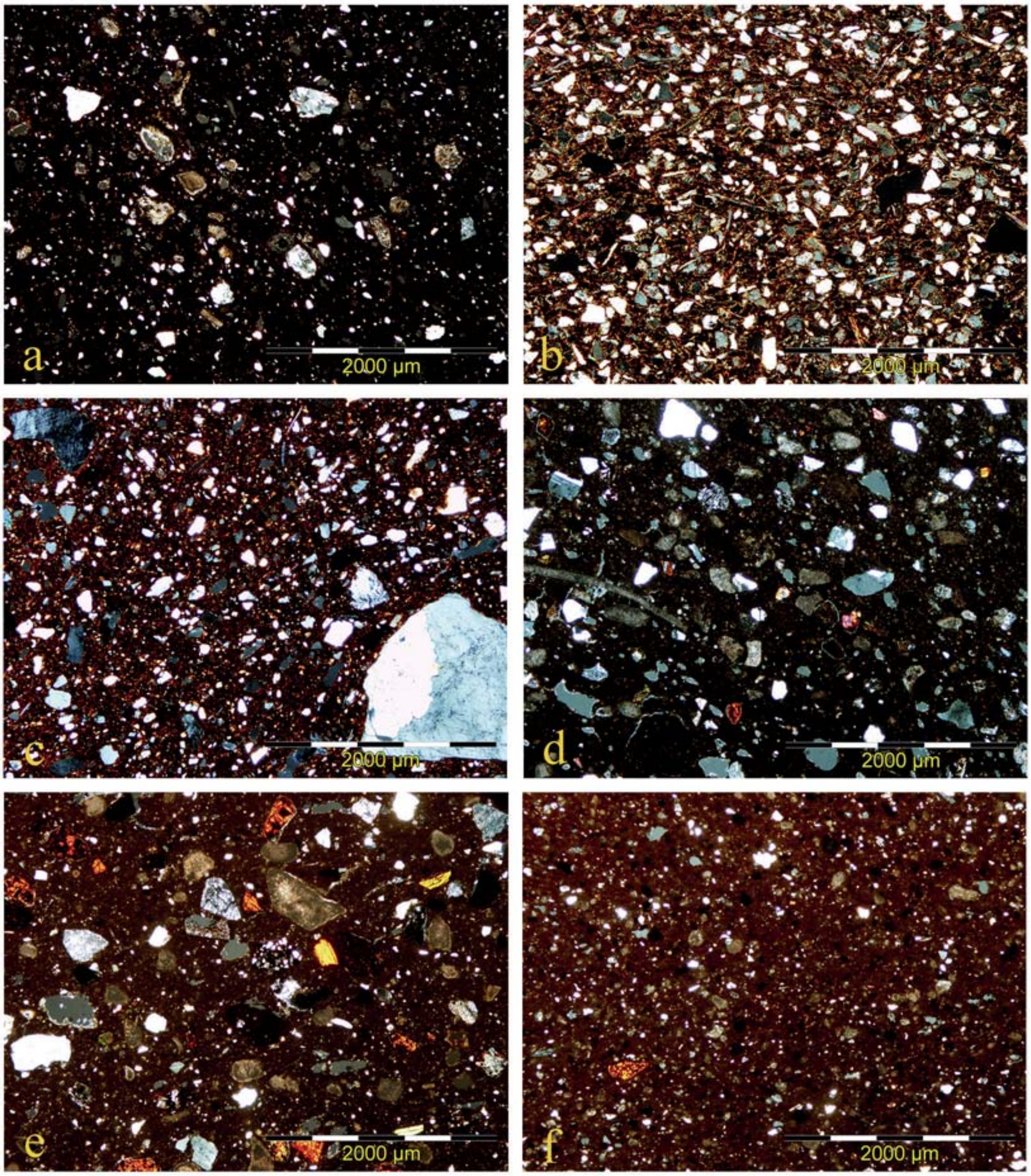

Figure 10. Microphotographs of thin sections from different petrographic fabrics (PF), all taken in cross-polarized light at the same magnification (40x). (a) PF 3.1: sample CAT208. (b) PF 4.1: sample CAT211. (c) PF 5.2: sample CAT215. (d) PF 6.1: sample CAT206. (e) PF 6.2: sample CAT241. (f) PF 8: sample CAT212.

Finally, PF 7 represents a quite different fabric, with very scarce inclusions in an iron-rich muscovitic matrix, fired at ≤ 850 ºC (Tables 4-5).

Discussion

Comparison between the chemical groups defined from XRF results (Figure 5) and the petrographic groups from thin section analysis (Table 4) reveals a general correspondance, despite some particular cases (see below). These archaeometric results, combined with the typological and archaeological data, provide information on the possible provenance of the amphorae as well as on the diversity of production centres that are represented in the analyzed assemblage.

Tunisian amphorae

Fabric group PF 1 is typical of products from northern Africa -particularly from the Tunisian area- and corresponds to what Capelli (2005a, 2005b) defined in a broad sense as 'Tunisian Fabric' or 'Aeolian group', though recognizing its important internal variability. For this reason, a provenance in Tunisia can be proposed for the 25 samples included in this fabric group. Chemical and petrographic data support their division into a number of subgroups, including three represented by more than one sample (PF 1.1/CG IVa; PF 1.2/CG IVb; PF 1.3/CG IVd) and 11 chemical-petrographic loners (Figure 5; Table 4).

The comparison of our results with the petrographic studies conducted in recent years on Tunisian workshops (Peacock and Tomber, 1991; Bonifay et al., 2002, 2010, 2011; Sherriff et al., 2002; Capelli, 2005a, 2005b, 2007; Ghalia et al., 2005; Capelli et al., 2006; Capelli and Bonifay, 2007, 2014; Gandolfi et al., 2010; Lemaître et al., 2011), as well as with other archaeological information on these sites (Peacock et al., 1989, 1990; Stirling and Ben Lazreg, 2001; Bonifay, 2004; Mrabet and Ben Moussa, 2007; Nacef, 2007, 2010; Dore, 2011), makes possible to propose a more specific provenance for many of the samples from the Cathedral of Tarragona (Table 6). It is worth mentioning the almost absence of chemical studies on Tunisian workshops, with only a few early works (Liddy, 1985; Taylor, 1993; Taylor et al., 1997; Sherrif et al., 2002) that -despite some promising results- were not followed by similar studies in recent years. Most of the known African amphora workshops are located in or near the eastern coast of Tunisia, sharing a similar geological setting related to the Saharan Platform, while the western part of the country, including the northwestern coastal area (where some amphora production has also been hypothesized), is associated with the eastern end of the Atlas (i.e. the Tunisian Atlas) and Tell Atlas Mountain ranges. In both cases sedimentary deposits are largely dominant, except for some specific locations with a major presence of metamorphic or volcanic rocks (Capelli and Bonifay, 2014; see also Sherriff et al., 2002). Taking into account the geological and sedimentological similarities over a wide area, responsible for the highly similar petrographic and mineralogical components in Tunisian ceramic fabrics (see Capelli, 2005a, 2005b; Capelli and Bonifay, 2007), archaeometric research on Late Roman amphorae from this area has demonstrated the need for the characterization of specific workshops (with their compositional, textural and/or technical particularities in each case) as well as the integration of their archaeological and typological information in order to propose provenance hypotheses on a more secure basis (Capelli and Bonifay, 2007, 2014). We had the opportunity to compare the thin-sections obtained from the *Tarraco* amphora assemblage with the fabrics from Tunisian workshops in the reference collection of the University of Genova. This comparison allowed a better definition of the provenance for the African materials.

The large subgroup PF 1.1/CG IVa can be certainly associated with a provenance in the Nabeul region (NE Tunisia), particularly in Sidi Zahruni workshop (Capelli, 2005a, 2005b; Ghalia et al., 2005; Gandolfi et al., 2010), located in the zone B of Nabeul (Bonifay et al., 2010). The chemical, mineralogical and petrographic data reveal the use of a border calcareous, quartz-rich clay paste, without evidence of clay mixing. The large quartz sandstone fragments, clearly visible in this fabric, are indicating the use of local raw materials although not necessarily of an added temper, since beds of these rocks can be found intercalated within the clayey deposits of the Chabat al-Qola massif in the workshop surroundings (Ghalia et al., 2005). This subgroup comprises samples of types Keay 35A and Keay 35B, both from the 5th century, as well as individual samples of types *Spatheion* 1 and Keay 57, this latter with a later chronology (second half of 5th century). No remarkable differences were found among these samples except for a higher presence of large quartz-sandstone fragments in the only Keay 57 sample (CAT228), revealing a possible fabric variant.

Another sample of Keay 35B type, CAT207, is different chemically and petrographically (PF 1.12) from PF 1.1/CG IVa, indicating the production of this amphora in some other workshop -unknown so far- possibly out of the Nabeul area. Some trace elements are present in quite different concentrations than CG IVa, especially a higher Cr and lower Zr and Sr content than this latter. Its calcium and alumina percentages are similar to that subgroup, while slightly lower Na_2O and K_2O concentrations can also be observed, although this would not be related to the feldspar content in the non plastic inclusion composition since there are not remarkable differences in feldspar abundance neither in thin section nor in XRD patterns.

In the same way, other samples of type *Spatheion* 1 (CAT221, CAT232 and maybe CAT223 and CAT236, these two latter possibly ascribed to that type) showed archaeometric evidence of its production in different centres. The chemical composition of sample CAT232 is rather similar to CG IVa from Nabeul zone B, differing mainly in its lower Ba and Zr content, however its fabric is quite different (PF 1.7), with a predominant coarse quartz component -possibly added as temper- and without the abundant fine quartz and coarse quartz-sandstone inclusions that characterize PF 1.1. This fabric, as well as its typology, are compatible with a provenance in the zone C of Nabeul, particularly in Labayedh workshop (Bonifay, 2004; Mrabet and Ben Moussa, 2007; Bonifay et al., 2010), where available raw materials are associated with Quaternary sedimentary deposits (Capelli and Bonifay, 2014). On the other hand, sample CAT221 shows lower alumina and potassium percentages than PF 1.1/CG IVa, what can be related to the lower content of illite-muscovite in the clay matrix, as inferred from XRD (Table 5); it presents instead a higher calcareous composition (CaO 19.0%, Sr 487 ppm), probably associated with the abundant microfossils (and few limestone fragments) observed as non plastic inclusions. These latter are an important component in fabrics from the geological/geographical zone A of Nabeul, related to Pliocene sedimentary deposits that are different from the sedimentary formations in zones B and C (Bonifay et al., 2010; Capelli and Bonifay, 2014). In this case, the petrographic fabric (PF 1.4) and the typology are both compatible with a provenance in Nabeul zone A -possibly Choggafia workshop- (Bonifay et al., 2010) for sample CAT221. Concerning the other two samples possibly related to type *Spatheion* 1 (CAT223, CAT236), it is difficult to propose a provenance hypothesis on a secure basis as well as to support or exclude this typological classification. Both present lower alumina and potassium percentages than PF 1.1/CG IVa. They also show a more calcareous composition, especially CAT236 in which the high CaO and

Sr content (15.7% and 444 ppm, respectively) might be mainly related to the calcareous inclusions observed in thin section -especially in the coarse fraction- since the clay matrix does not seem to be more calcareous than in other PF 1 samples. The fabric in this sample (PF 1.10) presents some partial similarities with those from *Leptiminus* (Sherriff et al., 2002; Gandolfi et al., 2010; Lemaître et al., 2011) although other possibilities cannot be excluded, especially when integrating the typological evidence. Similarly, the fabric in sample CAT223 (PF 1.8) cannot be associated to any of the petrographically known workshops (Table 6).

A number of chemical-petrographic loners (CAT201, 217, 230, 235) correspond to different amphora types that are more typical of the the 3rd (Africana IIA *senza gradino*/Keay 4), mid 3rd-early 4th (Africana IID.2/Keay 7) and 5th (Keay 36, Keay 41) centuries (Table 6). Samples CAT201 (Keay 41 type) and CAT230 (Keay 36 type) are representing quite different products chemically (Table 2) and petrographically (PF 1.9 and 1.13, respectively, see Table 4). They both might be related to a provenance in the north of Tunisia (*Zeugitana*) although in its northwestern part, west to Carthage (probably in the Mejerda valley), based especially on petrographic and archaeological evidence (Bonifay, 2004; Bonifay et al., 2011; Capelli and Bonifay, 2014), despite the lack of known amphora workshops in this area. It is worth mentioning in CAT230 the presence of large calcareous clay streaks -visible also to the naked eye- which are indicating an incomplete mixing with a more iron-rich clay; this is a quite characteristic technical aspect usually observed in fabrics of Keay 27 and 36 amphorae (Bonifay et al., 2011). On the other hand, it is difficult to pose a possible provenance for samples CAT217 and CAT235, with particular fabrics (PF 1.6 and 1.11, respectively) that could not be ascribed to any of the already known workshops. The first one has some broad similarities in fabric with southern Tunisian workshops although other possibilities cannot be excluded, especially considering its chemical similarities with CAT201 (Table 2). These two samples, as well as CAT235, show higher Na_2O percentages than other African samples, however their non plastic inclusion composition do not show remarkable differences in Na-rich components; in any case, the presence of Na-plagioclase peaks in the XRD patterns of two low-fired samples (CAT217 and CAT235: Table 5) suggests at least its presence as a primary crystalline phase. Concerning the high-fired sample CAT201 (950-1000 ºC), the absence of analcime in XRD excludes the post-depositional crystallisation of this mineral as a possible explanation for its higher sodium concentration.

Subgroups PF 1.2/CG IVb and PF 1.3/CG IVd are related to later Tunisian amphora types, after the Visigothic occupation of the *Tarraconensis* in the last part of the 5th century. The first one comprises samples of Keay 62 variants A and D (CAT214, 224: Table 6), both from the 6th century, and based on its fabric it can be related to a provenance in Henchir ech Chekaf workshop (Capelli, 2005a, 2005b, 2007) in central-eastern Tunisia. The relative importance of calcareous microfossils (apart from quartz) in this fabric, including the presence of very rare echinoids, suggests the use of a clay deposit of marine origin (Capelli, 2007), related to Pliocene sedimentary deposits available in the area (Capelli and Bonifay, 2014); fabric characteristics, on the other hand, do not provide clear evidence for a deliberately added temper. Despite their strong similarities, sample CAT224 presents a lesser amount of quartz in the fine fraction than CAT214 and, instead, more quartz-sandstone fragments in the coarse fraction, configuring possible fabric variants, but the whole description supports their inclusion into a same chemical-petrographic subgroup, compatible in fabric and typology with this workshop (C. Capelli, pers. comm.). These quartz-sandstone fragments are

Table 6. List of Tunisian amphora samples analyzed with a summary of the results obtained. CG: chemical group; PF: petrographic fabric.

Sample	*Typology*	*CG*	*PF*	*Observations*	*Provenance hypothesis*
CAT218	Keay 35B	IVa	1.1	Typology and fabric compatible with Nabeul zone B, particularly with Sidi Zahruni	Nabeul zone B: Sidi Zahruni
CAT222	Keay 35A	IVa	1.1	Typology and fabric compatible with Nabeul zone B, particularly with Sidi Zahruni	Nabeul zone B: Sidi Zahruni
CAT225	*Spatheion* 1	IVa	1.1	Typology and fabric compatible with Nabeul zone B, particularly with Sidi Zahruni	Nabeul zone B: Sidi Zahruni
CAT226	Keay 35A	IVa	1.1	Typology and fabric compatible with Nabeul zone B, particularly with Sidi Zahruni	Nabeul zone B: Sidi Zahruni
CAT228	Keay 57	IVa	1.1	Typology and fabric compatible with Nabeul zone B, particularly with Sidi Zahruni	Nabeul zone B: Sidi Zahruni
CAT229	Keay 35A	IVa	1.1	Typology and fabric compatible with Nabeul zone B, particularly with Sidi Zahruni	Nabeul zone B: Sidi Zahruni
CAT234	Keay 35B	IVa	1.1	Typology and fabric compatible with Nabeul zone B, particularly with Sidi Zahruni	Nabeul zone B: Sidi Zahruni
CAT237	Keay 35B	IVa	1.1	Typology and fabric compatible with Nabeul zone B, particularly with Sidi Zahruni	Nabeul zone B: Sidi Zahruni
CAT238	Keay 35B	IVa	1.1	Typology and fabric compatible with Nabeul zone B, particularly with Sidi Zahruni	Nabeul zone B: Sidi Zahruni
CAT239	Keay 35B	IVa	1.1	Typology and fabric compatible with Nabeul zone B, particularly with Sidi Zahruni	Nabeul zone B: Sidi Zahruni
CAT214	Keay 62D	IVb	1.2	Typology and fabric compatible with Henchir ech Chekaf	Henchir ech Chekaf
CAT224	Keay 62A	IVb	1.2	Typology and fabric compatible with Henchir ech Chekaf	Henchir ech Chekaf
CAT203	Keay 61C	IV (loner)	1.2 rel.	Partial fabric similarities with Moknine, but other possibilities not discarded	Indet. (Moknine not excluded)
CAT204	Keay 61D	IVd	1.3	Typology and fabric compatible with Moknine	Moknine
CAT220	Keay 62E	IVd	1.3	Typology and fabric compatible with Moknine	Moknine
CAT221	*Spatheion* 1	IV (loner)	1.4	Typology and fabric compatible with Nabeul zone A, particularly with Choggafia	Nabeul zone A: Choggafia?
CAT231	Keay 62D	IV (loner)	1.5	Some fabric similarities with Moknine, but other possibilities not discarded	Indet. (Moknine not excluded)
CAT217	Keay 4	IV (loner)	1.6	Partial similarities with S Tunisian fabrics (i.e. Zytha) but other possibilities not discarded	Indeterminate (Tunisia)
CAT232	*Spatheion* 1	IV (loner)	1.7	Typology and fabric compatible with Nabeul zone C (Labayedh)	Nabeul zone C: Labayedh
CAT223	*Spatheion* 1?	IV (loner)	1.8	No fabric compatibility with any known workshop	Indeterminate (Tunisia)
CAT201	Keay 41	IV (loner)	1.9	Typology and fabric not compatible with E Tunisian workshops	Indet. (NW Tunisia probably)
CAT236	*Spatheion* 1?	IV (loner)	1.10	Partial fabric similarities with *Leptiminus*but other possibilities cannot be excluded	Indeterminate (Tunisia)
CAT235	Keay 7	IV (loner)	1.11	Typology compatible with different workshops, but no fabric compatibility	Indeterminate (Tunisia)
CAT207	Keay 35B	IV (loner)	1.12	Type typical of Nabeul, but fabric not compatible	Indet. (possibly not Nabeul)
CAT230	Keay 36	IV (loner)	1.13	Typology and fabric not compatible with E Tunisian workshops	NW Tunisia? (Carthage region?)

similar to those found in Nabeul zone B fabrics (PF 1.1), however this should not be taken as an indicative feature since they are related to similar clay deposits extended all over the eastern Tunisian area. Nonetheless, differences in the clayey raw materials used in each case are noticed when comparing their respective fine and coarse fractions, especially for the relatively higher presence of a calcareous component in PF 1.2 (Table 4), what might be associated with its higher CaO, MgO and Sr concentrations (Tables 2-3).

In addition to CAT214, included in subgroup PF 1.2/CG IVb, another sample related to variant D of type Keay 62 is CAT231, however its fabric (PF 1.5) is not compatible with known fabrics from Henchir ech Chekaf. This suggests its probable association with a different production centre, maybe Moknine -again in central-eastern Tunisia- though not excluding a possible unknown workshop, also considering that manufacture of this variant has not been attested there (Bonifay, 2004: 35; Gandolfi et al., 2010) but only in Henchir ech Chekaf (Nacef, 2007, 2010) and the nearby Ras Aïed workshop (Peacock et al., 1989; Peacock and Tomber, 1991). Chemical evidence does not provide any further insight to ascertain a provenance for this particular sample (Figures 5-7), although it allows to infer the use of a calcareous clay paste which is also relatively poor in alumina when compared to most of the analyzed Tunisian samples (Table 2).

A similar problem is found in CAT203, a Keay 61C sample -type from the late 6th to first half of 7th centuries- with a fabric close to PF 1.2 though with some particularities that suggest a provenance out of Henchir ech Chekaf workshop. Partial similarities with other fabrics from Nabeul zone A and Moknine are observed, not allowing for the moment a more specific hypothesis, although the first option seems unlikely according to the typological/archaeological evidence (Table 6). Chemically it contains unusually high levels of Sr (1732 ppm); apart from this it is close to CG IVb (CAT214, 224) but still with some relevant differences (Table 2).

The typical fabric from Moknine workshop (Gandolfi et al., 2010) corresponds to the subgroup PF 1.3 defined in this study, which here has been also characterized chemically (CG IVd). Its high CaO percentages can be mainly associated with the abundant non plastic inclusions present in the clay paste, in which is also remarkable the relatively low alumina content. An inverse CaO/Sr relationship is observed in this subgroup when compared to the other African amphora samples (Figure 8); it was not possible so far to associate this characteristic with any particular raw material, although a possible relationship with the abundant calcareous fossils in this fabric should not be discarded. However this consideration should be taken with caution as sample CAT221 is also rich in microfossils and does not show this particularity. In PF 1.3 the presence of large fossiliferous limestone fragments, in which even large microfossils can be observed, suggests that the fossils in this fabric might come from the same source; among these, the presence of rare echinoids allows to infer the use of a marine sediment. These raw materials come from Pliocene clay deposits available in the Tunisian Sahel area that are also similar to those outcropping in the surroundings of Henchir ech Chekaf, what accounts for the similarities in the fossiliferous component of both workshops, despite the different frequencies of these and other inclusions that allow for fabric differentiation in each case (Gandolfi et al., 2010; Capelli and Bonifay, 2014). All these non plastic components (including quartz inclusions as well) are predominant in both the fine and coarse fractions, suggesting their derivation from the same clayey deposits rather than from a different sandy component added as temper. The two analyzed samples in this subgroup (CAT204, 220) belong to types from the late 6th to the beginning (Keay 62E) or first half (Keay 61D) of 7th centuries. Despite their strong chemical-petrographic similarity, sample CAT204 might represent a possible fabric variant with a higher percentage of inclusions.

As a whole, the Tunisian amphora types found in the Cathedral of Tarragona are in general widely documented in other Late Antique contexts throughout the city (see Remolà, 2000; Macias and Remolà, 2005; Macias et al., 2008). Concerning their specific provenance, the present archaeometric analysis reveals the arrival of amphora products from both the *Zeugitana* (northern Tunisia) and the *Byzacena* (central Tunisia) areas, including manufactures from some known workshops (Sidi Zahruni, Labayedh and Choggafia in the former, Henchir ech Chekaf and Moknine in the latter) as well as others from yet unidentified production centres. Evidence was obtained for the arrival of some amphora types from more than one production centre, for example for types Keay 35B, *Spatheion* 1 and Keay 62D; concerning Keay 35B, however, most of the analyzed samples could be archaeometrically related to a provenance in Sidi Zahruni, in consistence with the archaeological evidence available for this amphora (Bonifay, 2004: 135). In addition, the fabric diversity found in association with some of the workshops -i.e. Sidi Zahruni and Moknine- sheds some light on technological aspects (employed raw materials and/or paste preparation process) that still need further research for a certain interpretation, not discarding a possible relationship to chronological or typological characteristics.

Southern Hispanic amphorae

A number of amphorae from the assemblage of Cathedral of Tarragona had been previously ascribed to a southern Hispanic origin based on macroscopic and typological characteristics (Macias et al., 2008). Through the present study, archaeometric data provide further evidence on the diversity of these southern Hispanic manufactures and their possible provenance (Table 7).

The analysis of two Dressel 23a/Keay 13A samples (CAT208, 227) supports the Baetican provenance that is usually proposed for this type, dated -in *Tarraco* contexts- to the 4th to mid-5th centuries (Remolà, 2000). This attribution is based specially on their fabric (PF 3), although slight petrographic differences (subgroups PF 3.1 and 3.2: Table 4) might be indicating some variation within a same workshop or their possible provenance from two different workshops; they both share technical similarities like the mixing of a calcareous clay with a more ferruginous one, what is much more clearly seen in sample CAT208. Chemically (CG IVc) they show relatively high CaO and MgO percentages and a general compositional similarity with many Tunisian amphorae (Table 2, Figures 5-7). When compared to these latter, their higher V and, to a lesser degree, lower Zr and higher Cr content seems to be a useful criterion for their distinction (Table 2), nonetheless a clearer differentiation is provided by their particular petrographic composition, with a metamorphic and sedimentary contribution compatible with many parts of the Baetican area. There is archaeological evidence of the manufacture of type Dressel 23 in some workshops in the Guadalquivir and Genil valleys between Sevilla and Córdoba (Remesal, 1983; Chic and García, 2004; Berni and Moros, 2012) as well as in the coast of Málaga (Serrano, 2004; Corrales et al., 2011) and Granada (Bernal, 1998; Fernández, 2004), although the first one is normally considered the main production area (Remesal, 1991; Berni, 1998; Bernal, 2001; Beltrán, 2004; García Vargas and Bernal, 2008). The archaeometric information published from the Granada coastal workshops (Vigil et al., 1998) allow to discard a provenance here for the analyzed samples, while the fabric is neither similar petrographically to those from the Málaga region (C. Capelli, pers. comm.). Conversely,

Table 7. List of the amphora samples analyzed from the south of *Hispania* and the eastern Mediterranean, with a summary of the results obtained. CG: chemical group; PF: petrographic fabric. Typology for sample CAT200 differs from Table 1 since the analysis allowed for a possible typological ascription.

Sample	*Typology*	*CG*	*PF*	*Provenance hypothesis*
CAT216	LRA 4	Loner	2	*Oriens*: Palestine
CAT208	Dressel 23a / Keay 13A	IVc	3.1	*Baetica* (Guadalquivir/Genil valleys)
CAT227	Dressel 23a / Keay 13A	IVc	3.2	*Baetica* (Guadalquivir/Genil valleys)
CAT211	Almagro 51A-B	II	4.1	W *Lusitania*: Tagus/Sado valleys (most probably Quinta da Alegria, in Sado valley)
CAT210	Almagro 51A-B	II	4.1 rel.	W *Lusitania*: Tagus/Sado valleys (possibly Quinta da Alegria, in Sado valley)
CAT240	Almagro 51A-B	II	4.2	W *Lusitania*: Tagus/Sado valleys
CAT205	Almagro 50 (late variant)	Ia	5.1	W *Lusitania*: Tagus/Sado valleys
CAT242	Almagro 50 (late variant)	Ia	5.1 rel.	W *Lusitania*: Tagus/Sado valleys
CAT215	Almagro 50	I (loner)	5.2	W *Lusitania*: Tagus/Sado valleys
CAT206	LRA 1A (var. Kellia 169)	III	6.1	*Oriens*: most probably Cilicia/N Syria
CAT233	LRA 1	III	6,1	*Oriens*: most probably Cilicia/N Syria
CAT202	LRA 1A	III	6.1 rel.	*Oriens*: most probably Cilicia/N Syria
CAT241	LRA 1A (var. transition)	III	6,2	*Oriens*: most probably Cilicia/N Syria
CAT213	LRA 3	Loner	7	*Asiana*: W Asia Minor (Meander Valley, *Ephesus* or Sardis region)
CAT212	Indeterminate rim	Lonerz	8	*Asiana*: Aegean area
CAT200	Simile Almagro 51A-B?	IV (loner)	9	Possibly southern *Lusitania* (Algarve)

macroscopic characteristics of this fabric support an origin from the Guadalquivir/Genil area (e.g. Berni, 1998: 61; Berni and Moros, 2012). The lack of published archaeometric studies on production centres from this area do not allow for further conclusions, however its geological context is compatible with this general provenance hypothesis, considering the metamorphic contribution from different sources around the Guadalquivir basin (i.e. the Sierra Morena); in addition, the observation of some marine microfossils (like echinoids) in the fabric is consistent with the presence of Upper Miocene-Pliocene marine sediments in this geological basin (Solé, 1983; González-Delgado et al., 2004). In any case, archaeometric characterization of production centres will be crucial for verifying the provenance hypotheses formulated on this amphora type in the consumption centres and for a better understanding of their technology of production.

On the other hand, two chemical-petrographic groups can be related to a western Lusitanian production, PF 4/CG II (comprising amphorae of type Almagro 51A-B) and PF 5/CG I (samples of type Almagro 50), however both with an internal heterogeneity (Table 7). The six samples in these groups share the use of a non-calcareous clay paste which is, conversely, very rich in silica and also show (except in CAT240) relatively high percentages of potassium and alumina (Tables 2-3); this accounts for the abundant presence of quartz, alkali feldspars and illite-muscovite that can be observed both from XRD and from their petrographic fabrics (Table 4). This composition is perfectly compatible with the geological setting of the Tagus and Sado estuaries in western *Lusitania*, where several amphora workshops producing Almagro 50 and 51A-B types have been found (Mayet et al., 1996; Mayet and Tavares, 2002, 2009; Fabião, 2004, 2008). Despite their general composition, for most of the samples there are not close chemical-petrographic similarities that could be used as an indicator of a same production centre. Samples CAT205 and CAT242 -both corresponding to a late variant (5th century or possibly later) of type Almagro 50- are closely related chemically (CG Ia), but their fabrics -despite some proximity- are not the same. In any case, according to Mayet et al. (1996) petrographic differentiation among western Lusitanian workshops is quite problematic due to their association with a similar geological context, since clayey deposits from the lower Sado and Tagus basins are related to the same sedimentary formations; it would be thus necessary to focus on textural parameters, however the authors point out serious problems for differentiation among workshops on this basis, being Quinta da Alegria -in the lower Sado valley- the only one with a distinctive fabric (Mayet et al., 1996: 163-164). This fabric can be related to the one described for sample CAT211 of type Almagro 51A-B, dated to the late 4th to 5th centuries (an almost identical rim from that workshop is published in Mayet et al., 1996: fig. 56 n. 199), while sample CAT210 -of the same amphora type- shows a slightly different but closely related fabric, being possibly associated with the same workshop. On the other hand, it is worth mentioning that chemical research has been carried out in order to differentiate Lusitanian workshops through instrumental neutron activation analysis (INAA) (Prudencio et al., 2003, 2009; Raposo et al., 2005; Dias and Prudêncio, 2007; Dias et al., 2007, 2010). However it is difficult to compare their results with the evidence obtained through XRF in the present work considering that many of the measured elements in each case are different.

With regard to sample CAT200, chemically it presents some proximity to CG IV (Figure 5), although its petrographic fabric (PF 9) excludes a relationship to the Tunisian amphorae. The main chemical compositional differences from these are its lower V and Cr concentrations, which are only comparable to the Lusitanian amphorae of CG I-II (Tables 2 and 3); however sample CAT200 shows a calcareous composition, with lower silica, alumina and potassium percentages than those western Lusitanian groups. The fabric composition, instead, reminds some products from the Algarve coastal area (e.g. Mayet et al., 1996, 156-162). Different calcareous clay deposits are available in this region, although only those from the eastern side contain calcite as the only carbonate, while the western Algarvian calcareous clay deposits are more related instead to a dolomitic component (Trindade et al., 2009, 2010); in sample CAT200 the CaO/MgO ratio (4.33) -and considering that the calcareous non plastic inclusions are not so abundant to account for the CaO percentage- does not suggest the use of a dolomitic clay. Typologically the only well-known southern Hispanic amphora type for this period that resembles this sample is Almagro 51A-B, which production is widely attested in *Lusitania*, including workshops in the Algarve (Mayet et al., 1996; Fabião, 2004, 2008; Viegas, 2011). Considering all this evidence together, a possible provenance in the central/eastern Algarve could be hypothesized for sample CAT200; however, the adjacent Huelva region -where some production of the same and other related types of amphorae has been attested (Campos et al., 2004; O'Kelly, 2012)- should not be discarded as a possibility, taking into account its geographical/geological continuity with the eastern Algarve, although the lack of archaeometric studies in this region do not allow to draw further conclusions.

Eastern Mediterranean amphorae

Amphorae imported from the eastern Mediterranean were quantitatively important in the ceramic context of the Cathedral of Tarragona, being represented as much as the Tunisian ones (Macias et al., 2008). Information on the characterization and provenance of some representative samples was obtained (Table 7).

The most common eastern amphora in the ceramic assemblage from the Cathedral was type LRA 1, of which four samples were archaeometrically analyzed (CAT202, CAT206, CAT233, CAT241). They correspond mainly to the sub-type LRA 1A, including the variants 1A/Kellia 169 from the first half of the 5th century and 1A/transition (Piéri, 2005) from the late 5th-early 6th centuries. They form together a very distinctive major group both chemically (CG III) and petrographically (PF 6), although a certain diversity is observed into this group (Figure 5; Table 4). It is characterized by a highly calcareous composition, with very high percentages of calcium and relatively low of silica, alumina, titanium and potassium related to the use of a calcareous, non-micaceous clay raw material, poor in illite-muscovite. The scarcity of illite-muscovite can also be inferred from its small peaks in XRD on the low-fired sample CAT202 (when firing phases like gehlenite have not crystallised yet) as well as from its almost total decomposition on well-fired samples (CAT206, CAT233, CAT241) in which gehlenite is present although still subordinated to intense peaks of calcite. This high presence of calcite in samples with an EFT over 850 ºC might be probably due to incomplete decomposition and/or recarbonation of the primary carbonates. Petrographic evidence reveals the probable adding of a moderately to well sorted sandy temper, including both an abundant calcareous component and many inclusions derived from an ophiolitic source; these latter must be related to the remarkably high content of Ni, Cr and MgO, as well as to variations in other heavy metals like Cu and Zn observed in some cases (*e.g.* CAT206: Table 2). This particular composition had been described in early archaeometric works (Williams, 1979, 1982; Peacock, 1984) that allowed those authors to trace the main production area of LRA 1 type in Cilicia/northern Syria and Cyprus, where several workshops have been identified since then (Empereur and Picon, 1989; Piéri, 2005; Reynolds, 2005, 2010; Williams, 2005). It is difficult to differentiate products from the Gulf of Iskenderun area and southwestern Cyprus, since both areas are quite similar geologically, with ophiolite and limestone deposits in each case (Williams, 2005). For that reason an integrated archaeometric and archaeological research of specific production centres is needed. So far, only few studies have been published concerning their archaeometric characterization (Rautman et al., 1999; Gomez et al., 2002; Williams, 2005; Burragato et al., 2007; Waksman et al., 2014) and from the information they provide it is not possible to associate the analyzed samples from Tarragona with any specific workshop, but their attribution to this wide region is reliable. It is possible, at least, to exclude an association with workshops from the Paphos area (western Cyprus) due to their lacking of pyroxene inclusions (Gomez et al., 2002). No one of the samples seems to be related to the fabrics described by Leidwanger (2014) as possibly southern Cypriot products and characterized by a remarkable presence of basic igneous rocks apart from quartz and limestone. Furthermore, higher Sr concentrations in Cypriot workshops (when compared to the ones in the Gulf of Iskenderun area) have been reported by Empereur and Picon (1989) and Waksman et al. (2014: Figure 9) and these values tend to be also higher than the Sr content in the analyzed samples from *Tarraco*. In any case, typological evidence also seems to support a non-Cypriot origin for the analyzed samples since they correspond to variant LRA 1A, considered mainly as a Cilician product (Reynolds, 2005; Piéri, 2007; Demesticha, 2013). After comparing our data with the chemical data from two workshops in Cilicia/northern Syria (Seleucia Pieria and Arsuz) from Picon and Empereur studies provided by Waksman et al. (2014) a trend to form separate clusters is observed, what might be excluding a provenance in those centres. On the other hand, broad similarities can be found with some of the analytical considerations from Elaiussa Sebaste (Burragato et al., 2007). Similar studies from other Cilician workshops are needed in order to make a suitable comparison among them, taking into account the important geological similarities throughout the Iskenderun area.

Apart from type LRA 1, other few samples of eastern Mediterranean types from the 5th-6th centuries were also analyzed. A sample of Palestinian LRA 4 amphora (CAT216) presents a petrographic fabric (PF 2) quite characteristic of this type in other contexts (Peacock, 1984; Blakely, 1988; Uscatescu and García, 2005). Chemically it exhibits a particular composition (Figures 5 and 6b), calcareous and with a relatively high TiO_2, Na_2O and Zr and low K_2O and Rb content (Table 2), what can be related to the importance of plagioclase feldspars and the accessory presence of some heavy minerals in this fabric; these components are observed from both OM and XRD, in this latter showing some clinopyroxenes and high peaks of plagioclase despite being a low fired sample (Table 5). Many LRA 4 workshops are known, especially in the areas of Gaza and the Negev (Piéri, 2005; Reynolds, 2005), although for the moment there is not available enough archaeometric information on them in order to propose a more precise provenance hypothesis.

A sample of LRA 3 type (CAT213) also behaves as a chemical and petrographic loner. It has a very low calcareous composition (CaO 1.6%), only higher than the Lusitanian groups CG I-II (Figure 6a) but with several and clear differences from these latter; it is especially relevant the Fe_2O_3, Al_2O_3, K_2O, Ba, Y, Ce, Ga and V content, all of them with higher values than any other samples in the data set (Table 2). The very high alumina and potassium percentages must be related to the abundance of illite-muscovite reported by XRD and to the predominant muscovitic content of the petrographic fabric (PF 7). This fabric matches the one usually found on LRA 3 type (Peacock, 1984; Capelli, 1998) and for which a provenance in western Asia Minor -particularly in the Meander Valley, *Ephesus* and the Sardis region- has been proposed (Rautman, 1995; Piéri, 2005; Bezeczky et al., 2013).

The archaeometric analysis supports the hypothetical eastern Mediterranean provenance of sample CAT212, an indeterminate amphora with a *titulus pictus* partially preserved. Chemically it presents high CaO, Ni and Cr concentrations, though not as high as those of LRA 1 group, showing instead a higher alumina content than this latter (Table 2; Figure 6a). This composition is related to its particular petrographic fabric (PF 8), with a calcareous clay matrix and non plastic inclusions in which -apart from dominant fine limestone fragments- a combination of acid metamorphic rocks and some basic/ultrabasic components -including minerals related to a greenschist facies (epidote, serpentine, chlorite) as well as peridotite and pyroxenes- can be observed. These petrographic characteristics suggest a provenance in the Aegean area for this amphora.

Conclusion

The archaeometric analysis of this amphora assemblage from the Cathedral of Tarragona provides significant information on the containers that were arriving to this Tarraconensian site in Late Antiquity. Many other amphora contexts from the same period are archaeologically known in several parts of the city (see Remolà, 2000). Archaeometric research conducted in the past in some of these contexts (Remolà et al., 1993, 1996) allowed to identify more or less the same major provenance areas for the amphorae (*Africa*, *Baetica*, *Lusitania*, Palestine, Antioch and western Asia Minor). The general compositional trends reported for some of them could also be observed in the present research, i.e. relatively high MgO and CaO and low SiO_2, TiO_2 and Al_2O_3 percentages for Antioch area products (LRA 1 amphorae), high K_2O, Al_2O_3 and Fe_2O_3 and low CaO for western Asia Minor area (LRA 3 amphorae) and high SiO_2 and low MnO, P_2O_5, MgO and CaO for Lusitanian amphorae. However, despite the large number of samples analyzed in these previous works, their focus on the chemical analysis of major and minor elemental composition limited the results to the grouping of samples in vast Mediterranean regions, without exploring the internal variability. In addition, the differentiation of some of those major areas (e.g. Baetican and African amphorae) was quite problematic due to the fact that trace elements and petrographic/mineralogical composition were not determined. In the present work we consider that the application of an integrated chemical (major/minor and trace element analysis), petrographic and mineralogical approach can help to shed more light on the characterization, provenance and technology of the different amphora imports found in this particular archaeological context, hoping to carry out a similar research in other contexts in order to compare the results with those obtained from the present study.

The evidence from the Cathedral assemblage is indicating that a wide diversity of amphorae were arriving here from each of the major production regions. Even if their Tunisian, southern Hispanic or eastern Mediterranean origin was presumed from the macroscopic examination, the archaeometric results -apart from allowing an assessment of these hypotheses- revealed that a great variety of production centres were represented and in some cases provided evidence of their particular provenance. This diversity is inferred from the large number of chemical-petrographic subgroups and loners that were identified in each case.

Concerning the African products, the analyzed fifth-century amphorae from this context (types *Spatheion* 1, Keay 35A, Keay 35B, Keay 36, Keay 41 and Keay 57) were mainly related to workshops from the *Zeugitana* region, particularly in the area of Nabeul and possibly northwestern Tunisia, while the studied samples of later amphora types like Keay 62 and Keay 61, more typical of the 6th to early 7th centuries, could be generally associated with some of the *Byzacena* production centres. The petrographic evidence revealed a variety of fabrics that must be related to amphorae from different production centres (in many cases not identified yet) or even to different products from a same workshop, sometimes possibly indicating chronological and/or technological changes.

A similar diversity was found in southern Hispanic and eastern Mediterranean imports, despite the lower number of samples analyzed compared to the African ones. Apart from some particular samples of Palestinian and Aegean amphorae, the analyzed samples of Baetican type Dressel 23a and Lusitanian amphorae Almagro 50 and Almagro 51A-B, as well as the LRA 1 containers from Cilicia/northern Syria or Cyprus, showed an internal chemical-petrographic heterogeneity that could be indicative of the arrival of products from different workshops for each amphora type (without discarding in some cases different technological choices within a same workshop). This issue -in addition to the variability related to Tunisian imports- should be in-depth investigated in future research for a better understanding of the commercial dynamics of Late Roman amphorae in *Tarraco*-*Tarracona* or other consumption centres.

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