



Trade dynamics between Carthage and Iberia at the end of the 3rd century BC: analytical characterisation of central mediterranean amphorae from Qart-Hadasht (Cartagena, Spain)

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Abstract

The founding of Qart-Hadasht, or ‘New Carthage’, in 228/227 BC reaffirmed the Carthaginian presence on the Iberian Peninsula. The city would serve as its main political base and military port in the Western Mediterranean before being lost to Rome in the Second Punic War. Although the conquest was led on the ground by the Barcid family, the town’s flourishing also led to an increase in the metropolis’s economic and commercial activities. In this study, a total of 37 amphorae of Central Mediterranean typology and located in different Punic contexts of the town were analysed using X-ray fluorescence (XRF), thermogravimetry (TG), X-ray diffraction (XRD) and thin-section petrography (OM). The analyses reveal that a significant number of them originated in North Africa, mainly in the area of Tunisia, though some originated from other production centres on the island of Sicily and probably Algeria. The results also confirm the existence of shared amphora types produced in different Punic production areas and workshops. Thus, the central argument here is that the arrival of containers from such diverse provenances allows us to identify the economic opportunity that this foundation represented for the metropolis as a whole and to explore how this new trade relationship was structured.

Keywords Iberian Peninsula · Barcid period · Amphorae · Chemical analysis · Petrographic analysis · Trade networks

Introduction

The founding of Qart-Hadasht in the southeastern vertex of the Iberian Peninsula marked the opening of a new stage of history in the Mediterranean Sea. Following the defeat of Carthage at the hands of Rome in the First Punic War

(264–241 BC), the Carthaginians embarked sought to annex and exploit economically new territories in the west (Polybius, *Histories*, II, 6, translated by Balasch 1983). This led to the landing of Hamilcar Barca in Gadir in 237 BC and the beginning of the conquest of the Iberian Peninsula (González Wagner 1999; Bendala 2015). The Mediterranean coast in general, and that of the southeast in particular, was well known to the Carthaginians. The existence of close relations with the Phoenician-Punic settlements on the Iberian Peninsula was based on shared cultural ties and probably resulted in the Carthaginians having significant political and economic influence in the area from the 6th – 5th centuries BC onwards (López Castro 1995; Ferrer and Pliego 2013). However, this situation changed with the effective occupation and emergence of new needs linked to the control and administration of the recently dominated territories.

In this respect, the founding of the ‘new capital’, or Punic town of reference, on the Iberian Peninsula took place in 228 or 227 BC (Polybius, *Histories*, II, 13, 1–2, translated by Balasch 1983; Diodorus Siculus, *Fragments of Books* XXV, 12, translated by Walton 1980; Silius Italicus, *Punica*,

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XV, 192–199, translated by Villalba 2005). The Carthaginians established Qart-Hadasht, or ‘New Carthage’, on a peninsula defined by five hills at the end of a wide and protected bay (García-León et al. 2017; Torres et al. 2018) in the pursuit of several objectives. They included taking advantage of the natural features of the surroundings to build an impregnable town in one of the best natural ports in the Mediterranean. The town also offered favourable sailing conditions to the North African coasts as well as the means to control and exploit the rich mineral resources of the surrounding mountains (Ramallo 2011). However, the physical environment around the town had several drawbacks. They included a shortage of water, the recurring torrential floods typical of a semi-arid climate and extensive marshland to the north that both limited the land most immediately available for cultivation and constrained urban expansion. On the positive side, it also constituted an essential natural element in the town’s defence.

Intending to build a town in such a location, the Carthaginians planned and undertook an ambitious urban project that

significantly altered the land’s orography, despite the short duration of their presence (Torres et al. 2022). The probable partial draining of the low-lying areas or the flooded interior valley between the Concepción and Molinete hills, as well as the construction of wide terrace walls, are witnesses to this ambitious undertaking. They also contributed to regularising the new urban space, which was largely preserved as part of the subsequent Roman town (Ramallo and Ruiz 2009; Ramallo and Martín 2015). The characteristics of its port and the effort invested in the new urban planning allowed for the creation of a solid, well-protected nucleus that opened a window of direct communication for the Carthaginians with the North African metropolis (Polybius, X, 8, 2). The hegemonic position of the town as the Carthaginian capital on the Iberian Peninsula is also demonstrated by events such as the reception of embassies or the taking of hostages (Polybius, V, 1, 3).

Nonetheless, our current knowledge of the trade and commercial relations between the territories is patchy at

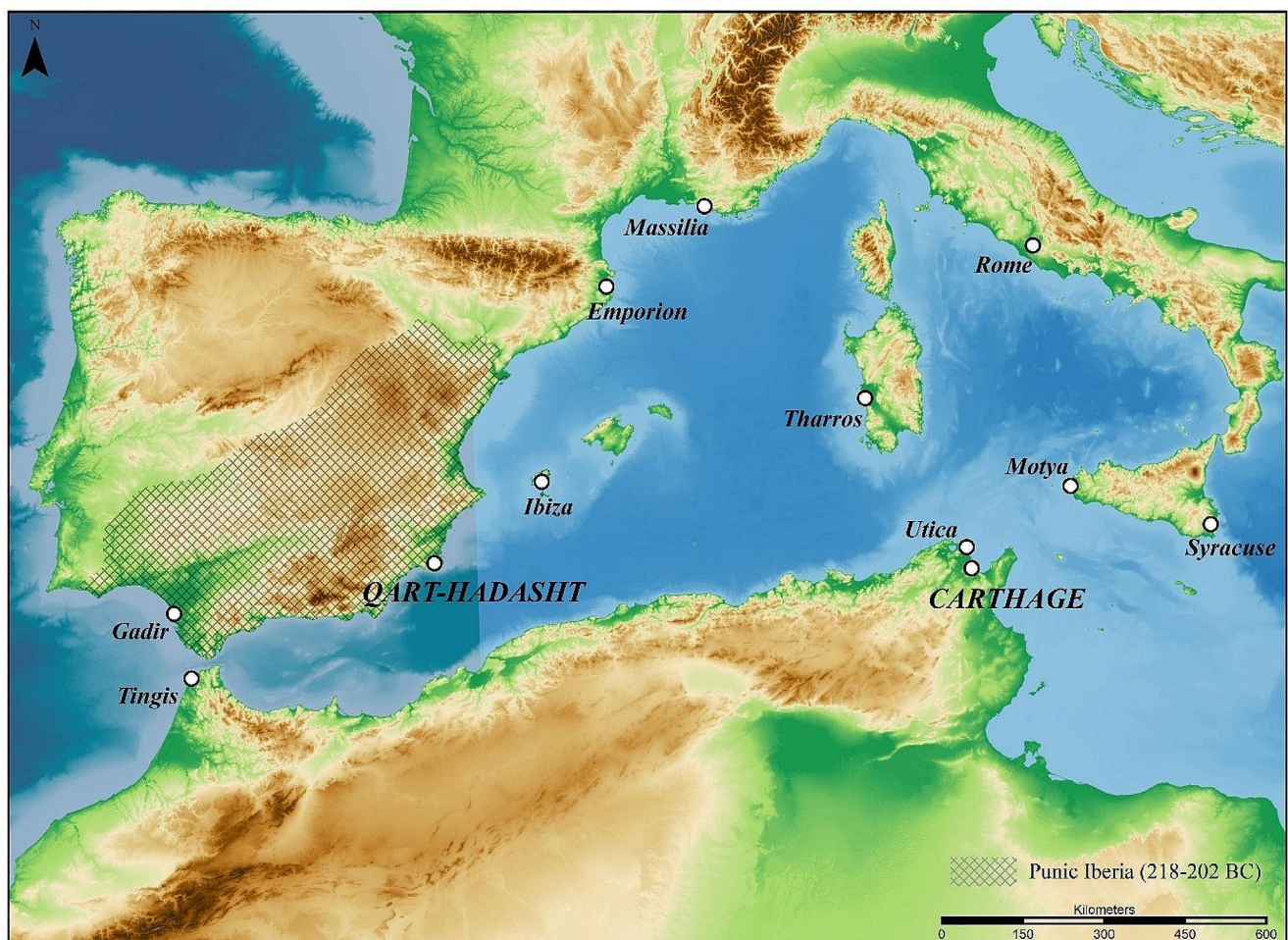


Fig. 1 Location of Qart-Hadasht and Carthage in the context of the Western and Central Mediterranean. (source: Cutillas Victoria after MDT OpenStreetMap)

best (Fig. 1). The identification of Central Mediterranean pottery attributed to this phase of the town is not new (Pérez and Berrocal 2010; Ruiz et al. 2013; Ramallo and Martín 2015), nor is finding it in this region new (Murcia 2011). However, the findings do not stand out at a quantitative level within the ceramic repertoire framework. It is common to find other western Punic (Straits of Gibraltar region), Ibizan or Western Greek productions in significant quantities. The studies undertaken to date have dealt mainly with merely typological and descriptive issues, making them insufficient for accurately evaluating the economic exchanges and trade routes that linked the Central and Western Mediterranean in the 3rd century BC.

In this regard, the application of archaeometric techniques emerges as a valid alternative to begin exploring questions of provenance, which would then make it possible to reconstruct such trade networks. Scholars have barely explored these questions in terms of the Iberian Peninsula for this period (Fantuzzi et al. 2020; Moreno et al. 2020). It is also essential to study existing trade networks to better understand the structuring of commercial traffic between the North African metropolis and the newly occupied territories in the Iberian southeast. Two hypotheses emerge for exploring the issue: on the one hand, the trade took place in a more controlled or centralised way from Carthage and the network was supplied by pottery vessels from a limited number of production areas or workshops; on the other, it represented a more plural enterprise with room for the participation of multiple actors, traders and production centres.

To explore the problem, a research programme was designed to characterise in chemical and mineralogical terms an assemblage of 37 Central Mediterranean amphorae found in various contexts attributed to the town of Qart-Hadasht. The two main objectives of the study were (i) to define the reference groups and petrographic fabrics present among the Central Mediterranean Punic amphorae that arrived in Qart-Hadasht and (ii) to identify possible technological practices or know-how that allow us to recognise the workshops or production areas that participated in this trade. The amphorae correspond to well-defined types within the scope of Central Mediterranean types from the 3rd century BC based on their typological classification and macroscopic observation (Ramon 1995) and are widely represented in the western Mediterranean basin (Martínez 2016; Docter et al. 2022). The sample is highly representative since, as mentioned above, the Central Mediterranean amphorae are not as numerous as one would expect within the framework of the founding of the town (Ramallo and Martín 2015). This situation provides a solid basis for assessing the sample selected for this study.

The results were cross-referenced with archaeological data and reference archaeometric repertories – especially

rich in the area of present-day Tunisia for the late Roman period (i.e. Capelli 2005; Capelli and Bonifay 2007, 2014; Gragueb et al. 2011; Baklouti et al. 2016; Ben Tahar and Capelli 2018) – revealing that almost all the analysed samples belong to the Tunisian/Sicilian circle. However, the image obtained based on the results points to a quite heterogeneous assemblage with amphorae having been produced in various areas and workshops, which suggests the economic opportunity that the founding of the city represented for the entire metropolitan area. At a technological level, it is also interesting to note that no patterns correlating to amphora types and reference groups/fabrics have been identified. Our results reveal shared patterns among the potters of the region during this period as well as the active participation of a significant number of production areas in the trade with the new Punic capital of the Western Mediterranean.

Materials and methods

Materials

The 37 ceramic individuals selected for this research project came from various archaeological excavations carried out in the present-day Cartagena (Región de Murcia, Spain) (Fig. 2). They mainly correspond to domestic contexts from the Carthaginian period, as is the case for those from 8 Serreta Street –37°36'13"N, 0°59'01"W (Ramallo and Martín 2015)-, 29 Saura Street –37°36'12"N, 0°58'53"W (Ramallo and Ruiz 2009)-, 34–36 San Cristóbal la Larga Street –37°36'13"N, 0°58'53"W (García and Giménez 2007)-, 5–7 Palas Street –37°36'03"N, 0°59'03"W (Antolínez 2006)- and Plaza San Ginés –37°36'05"N, 0°58'59"W (Martín 1998)-. We also have studied samples associated with the town wall built by the Carthaginians at La Milagrosa –37°64'14"N, 0°58'43"W (Marín 1998; Ramallo and Martín 2015)- and below the levels of the Roman theatre –37°35'57"N, 0°59'01"W (Ruiz et al. 2013)-, as well as others of more dubious functionality in the amphitheatre –37°36'01"N, 0°58'46"W (Pérez and Berrocal 2010)-. To ensure that the sample reliably reflects the town's Barcid period, other Central Mediterranean amphorae from Roman Republican levels were omitted.

The samples were selected because they are representative of the six Central Mediterranean amphora types attested to date in the Barcid levels of the town, which are characterised by their shape and paste at a macroscopic level (Table 1). They correspond to the following typological categories (Fig. 3):

- T-3.2.1.2, or Merlin-Drappier 3, amphorae are characterised by their small or medium size, high rectilinear rim,

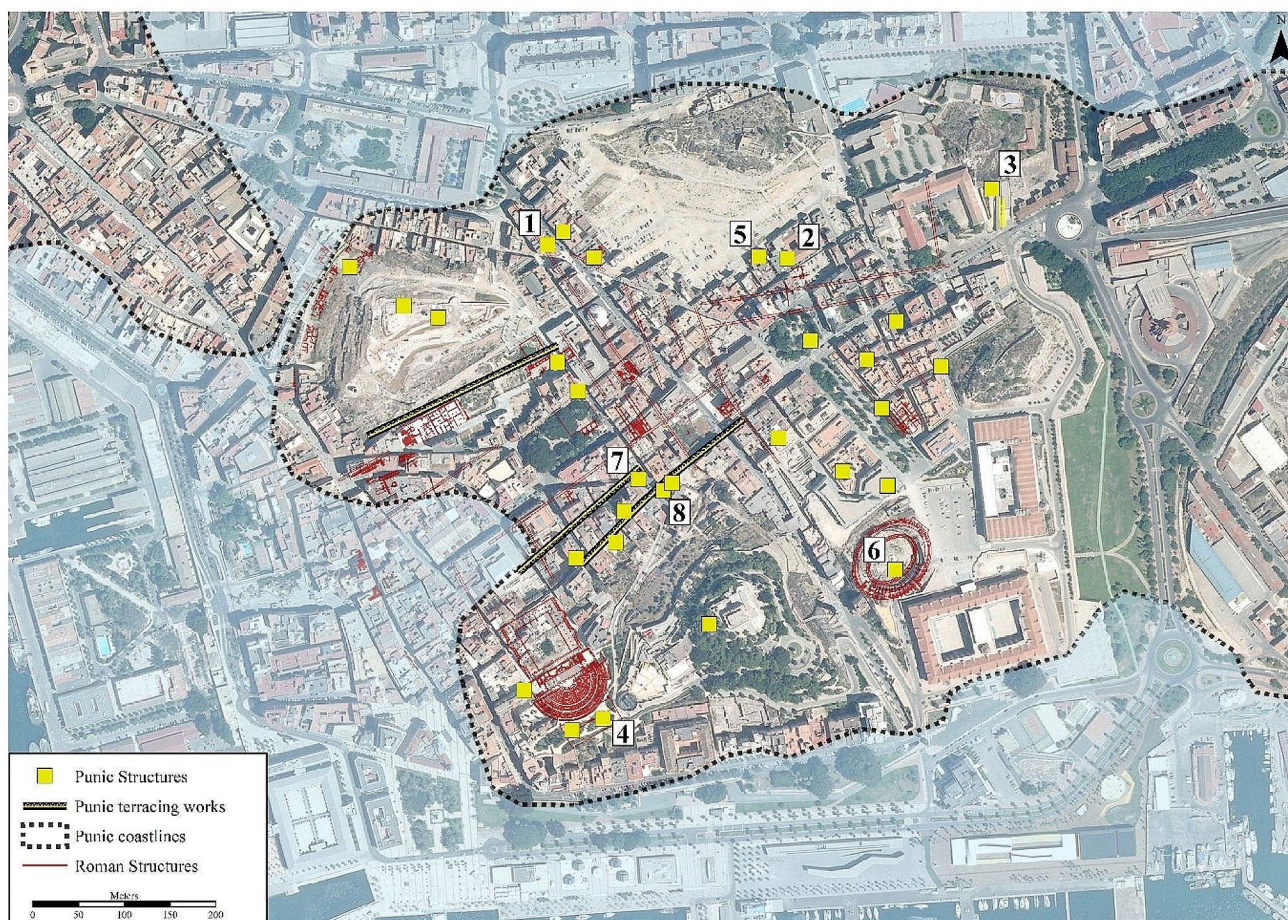


Fig. 2 Map showing the location of the urban excavations from which the analysed samples were taken: (1) Serreta 8; (2) Saura 29; (3) Punic Wall (La Milagrosa); (4) Roman Theatre; (5) San Cristóbal la Larga 34/36; (6) Amphitheatre; (7) Palas 5–7; (8) Plaza San Ginés

Table 1 List of Central Mediterranean amphorae from Qart-Hadasht analysed in this study. Distribution by type and archaeological excavation

Type	T-3.2.1.2	T-5.2.3.1	T-5.2.3.2	T-6.1.2.1	T-7.2.1.1	T-7.3.1.1	Total
Site							
Serreta Street, n° 8		QTH001, QTH004,		QTH002, QTH005, QTH006, QTH007	QTH003		7
Saura Street, n° 29	QTH015	QTH011, QTH012, QTH013, QTH014, QTH016			QTH010		7
Punic Wall (La Milagrosa)	QTH033	QTH019		QTH032	QTH018		4
Roman Theatre			QTH017				1
San Cristóbal la Larga Street, n° 34-36	QTH021	QTH020	QTH026	QTH023, QTH024	QTH022	QTH025, QTH027	8
Amphitheatre	QTH028, QTH029, QTH069		QTH030				4
Palas Street, n° 5-7		QTH031, QTH067					2
San Ginés Square		QTH034, QTH036, QTH037			QTH035		4
Total	6	14	3	7	5	2	37

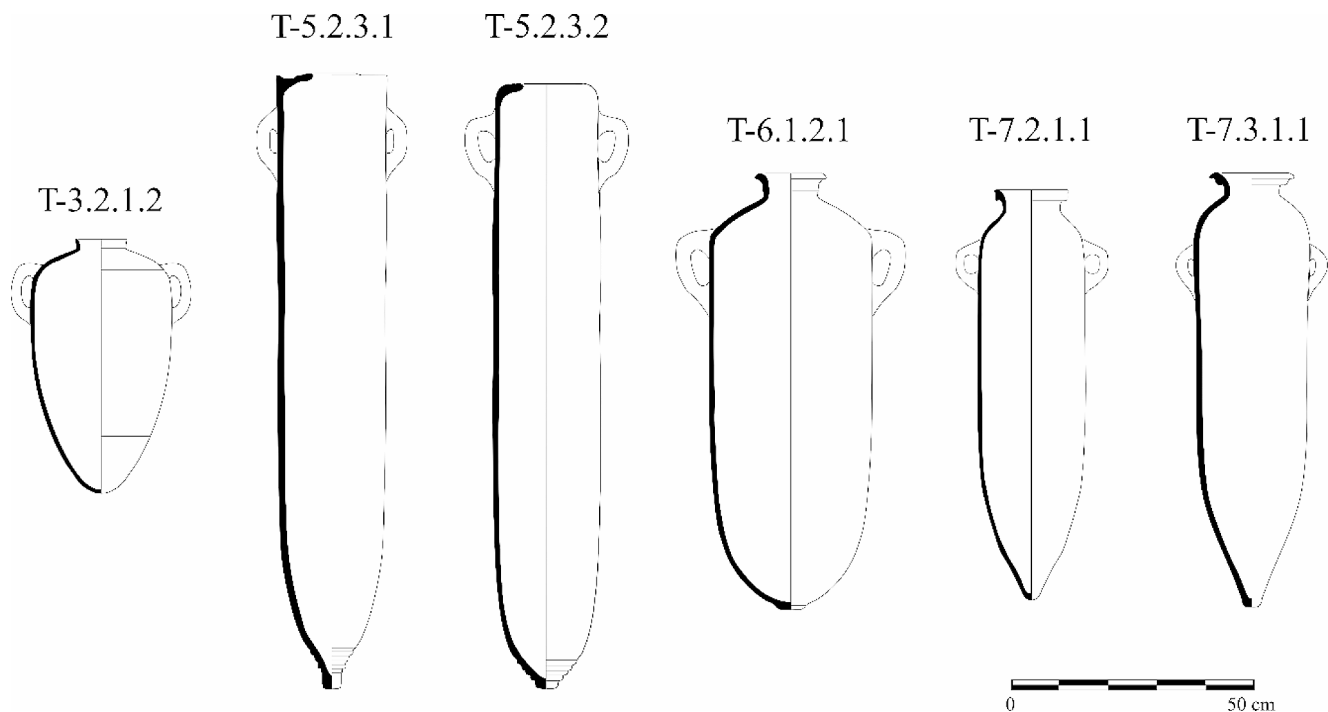


Fig. 3 Central Mediterranean amphora types to which the samples analysed from Qart-Hadasht belong (from Ramon 1995)

ovoid tendency and rounded bottom. Their most peculiar characteristic is the decoration on various parts of their body using horizontal bands in red paint. They were manufactured mainly in the Carthage area, but some scholars have also proposed that they were produced in the ancient Sicilian town of Selinunte (Montana 2013; Foumont 2013; Bechtold 2015) and perhaps in Malta (Ramon 1995).

- Types T-5.2.3.1 and T-5.2.3.2, North African amphorae that succeeded the T-4 series, were the Tunisian productions most often commercially traded in the Western Mediterranean and the Iberian Peninsula (Ramon 1995). In terms of shape, the vessels have a characteristically long cylindrical shape, a rim with a horizontal or oblique tendency towards the interior that joins directly with the back of the amphora furrowed with concentric grooves, and an ogival bottom with sawtooth-shaped grooves. As for the second type, the T-5.2.3.2 are significantly differentiated by their rim, which maintains its horizontal inward tendency but in a less pronounced way, adopting a shape that resembles an extension of the back. These vessels were initially thought to have been manufactured almost exclusively in modern-day Tunisia (Ramon 1995). However, their manufacture has also been attributed to Selinunte (Bechtold 2015), and their presence is well attested on the Iberian Peninsula, highlighting their identification in Iberian contexts from the end of the 3rd century BC, the Cabrera 2 wreck (Cerdà 1978; Guerrero et al. 1989), Villaricos (López Castro et al. 2011) and El Tossal de Manises (Olcina et al. 2017).

- Type T-6.1.2.1 should be considered a genuinely North African production from the Tunisian area, characteristic of the last quarter of the 3rd century BC (Ramon 1995). It constitutes the best-represented type among the large vessels from the late Byrsa levels (Lancel 1987: 108). It is a shape characterised by a cylinder-ogival profile with a short neck and high edge, oblique to the outside. It is well represented on the Iberian Peninsula. However, far fewer samples have been found compared to the other five types (Martínez 2016: 92). Some of the archaeological sites where this type of vessel has been recognised to a greater extent are the Cabrera 2 wreck, Ibiza, Alorda Park (Tarragona) and Gadir (Ramon 1995).

- The T-7.2.1.1 and T-7.3.1.1 variants of the Ramon series are defined by a narrow, elongated profile in the shape of a perfect cylinder the bottom of which has ogival morphology. The difference between the two types of amphorae lies mainly in the rim. The first has a short, thickened edge with a vertical tendency topped by a narrow projection. In contrast, the second has a rim with a horizontal outward tendency and a relatively hanging moulding (Ramon 1995). They are vessels of Central Mediterranean origin, especially Tunisian, although type T-7.2.1.1 could also have been produced in western Sicily. At the end of the 3rd century BC, the amphorae achieved significant distribution throughout the Mediterranean, from the Agora of Athens to the Balearic Islands and the Iberian Peninsula (Ramon 1995).

Methods

Once the macroscopic classification and documentation had been completed, two fragments were removed from each of the 37 analysed individuals and used to prepare the samples for X-ray fluorescence (XRF), X-ray diffraction (XRD), thermogravimetry (TG) and thin-section petrography (OM).

The chemical composition of the 37 samples was determined using X-ray fluorescence (XRF). The surface layers of the specimens were removed mechanically, and the samples were ground in an MM400 mixer mill (Retsch). The resulting powder was used to prepare a pearl of pressed powder using 8 g of sample and 2 g of wax. The sample was analysed using a commercial spectrometer (Bruker S4 Pioneer) equipped with an Rh anticathode X-ray tube (20–60 kV, 5–150 mA and 4 kW maximum), five analysing crystals (LiF200, LiF220, Ge, PET and XS-55), a sealed proportional counter for detecting the light elements and a scintillation counter for heavy elements. The analysis was carried out in vacuum mode, allowing for the detection of elements with a low presence. The recorded spectrum was evaluated using the fundamental parameters method with the SPECTRAplus software linked to the equipment (EVA 1.7, Bruker-AXS and Socabim 2006).

The elements determined were as follows: Na₂O, MgO, Al₂O₃, SiO₂, P₂O₅, K₂O, CaO, TiO₂, V₂O₅, Cr₂O₃, MnO, Fe₂O₃ (as total Fe), CoO, NiO, CuO, ZnO, Ga₂O₃, Rb₂O, SrO, Y₂O₃, ZrO₂, Nb₂O₅, MoO₃, BaO, Cl₂O₃, LaO, CeO₂, PbO and ThO₂. A ‘TGA/DSC 1 HT’ analyser (Mettler-Toledo GmbH) was used for conducting a thermogravimetric examination. The programme temperature used to study the thermal decomposition ranged from 30 to 1100 °C at 10 °C/min. The sum of major, minor, trace element concentrations and LOI is located within a range of 99.65–99.90%, and all the elements are expressed as oxide concentrations (Supplementary Table 1).

The mineralogical composition of the amphorae was obtained via X-ray diffraction (XRD). The measurements were carried out with a Bruker D8 Advance powder X-ray diffractometer (q-qgoniometer) using CuK α radiation, a goniometer radius of 217.5 mm, 40 kV and 30 mA, and a LynxEye linear detector with an aperture angle of 2°. For the analysis, we employed 1 g and scanned the samples in steps of 5 to 45° from 2 θ , with a step size of 0.05° and 2 s and a rotational speed of 30 rpm. The recognition of the crystalline phases present in each sample also served as a basis for calculating the equivalent firing temperature (EFT) (see Roberts 1963; Picon 1973; Tite et al. 1982; Heimann and Maggetti 2014; Gliozzo 2020).

The thin sections for the petrographic analyses were prepared using an epoxy resin impregnation and mounted on glass using Norland Optical UV glue (Norland). Their

reduction was carried out using a Buehler Petro thin system (Buehler), and they were finished by hand with silicon carbide up to a thickness of 30 μ m. Petrographic observations were carried out using a Leica DM2000 polarising microscope with an attached digital camera, at a magnification range between $\times 2.5$ and $\times 40$. The examination and interpretation were based on the description models for the pottery structure and its components developed by Whitbread (1995) and Quinn (2013).

Results

Chemical analyses

The results of the elemental concentrations of the Qart-Hadasht amphorae studied by XRF (Supplementary Table 1) were analysed based on Buxeda’s models (1999; 2018) that, in turn, were based on the statistical works of Aitchison (1986; 2005). The distribution of these concentrations corresponds to a particular case of the projective $d+1$ -dimensional space and projected on the simplex S_d . Projective points are then represented by a $d+1$ -dimensional vector of coordinates that have a constant sum k ($k \in \mathbb{R}^+$), $C(w) = x = [x_1, \dots, x_d, x_{d+1} | x_i \geq 0 \text{ (} i=1, \dots, d+1 \text{)}, x_1 + \dots + x_{d+1} = k$, (in the present case, $k = a$ subset in the positive orthant $\mathbb{R}^{d+1}_+$, following a multiplicative model with logarithmic interval metrics (Barceló-Vidal et al. 2001; Aitchison 2005; Buxeda 2008). For that purpose, in the statistical data processing, raw concentrations were transformed into log-ratios (Aitchison 1986; Buxeda 1999), using the clr transformation in centred log-ratios, based on:

$$x \in S^{d+1} \rightarrow z = \log \left(\frac{x}{g(x)} \right) \in \mathbb{R}^d \quad (1)$$

where S^{d+1} the d -dimensional simplex and $g(x)$ the geometric mean of all $d+1$ components of x and $\mathbb{H} \subset \mathbb{R}^{d+1}$ a hyperplane vector subspace of $\mathbb{R}^{d+1}$ (Aitchison 1986; Buxeda 1999; Egozcue and Pawłowsky-Glahn 2011; Martín-Fernández et al. 2015; Buxeda 2018). However, a series of elements associated with possible contamination was rejected when developing the statistical processing method. This was the case for P₂O₅, Na₂O or PbO, conditioned by various post-depositional processes (Miguel et al. 2015), or for Ce and Th, which have values below the detection limits of the equipment. Therefore, the 19 elements retained for the multivariate treatment of the statistical data developed with R (R Core Team 2023) were the following: MgO, Al₂O₃, SiO₂, K₂O, CaO, TiO₂, V₂O₅, Cr₂O₃, MnO, Fe₂O₃, NiO, CuO, ZnO, Ga₂O₃, Rb₂O, Y₂O₃, ZrO₂, SrO and BaO. The first step involved calculating the compositional variation

matrix to determine the total variation (tv) in the analysed pottery assemblage (Aitchison 1986; Buxeda 1999; Buxeda and Kilikoglou 2003; Buxeda and Madrid 2017). The result showed a high figure of 0.88 for the total variation (Fig. 4), which points to the existence of a polygenic group, as it includes pottery belonging to different chemical groups (Buxeda and Kilikoglou 2003). In this respect, the elements that introduced more significant variability to the compositional data were MnO ($tv/\tau_i < 0.3$), followed by ZnO, BaO and CaO. In contrast, those elements that offered less variability were Fe_2O_3 and TiO_2 (Fig. 4).

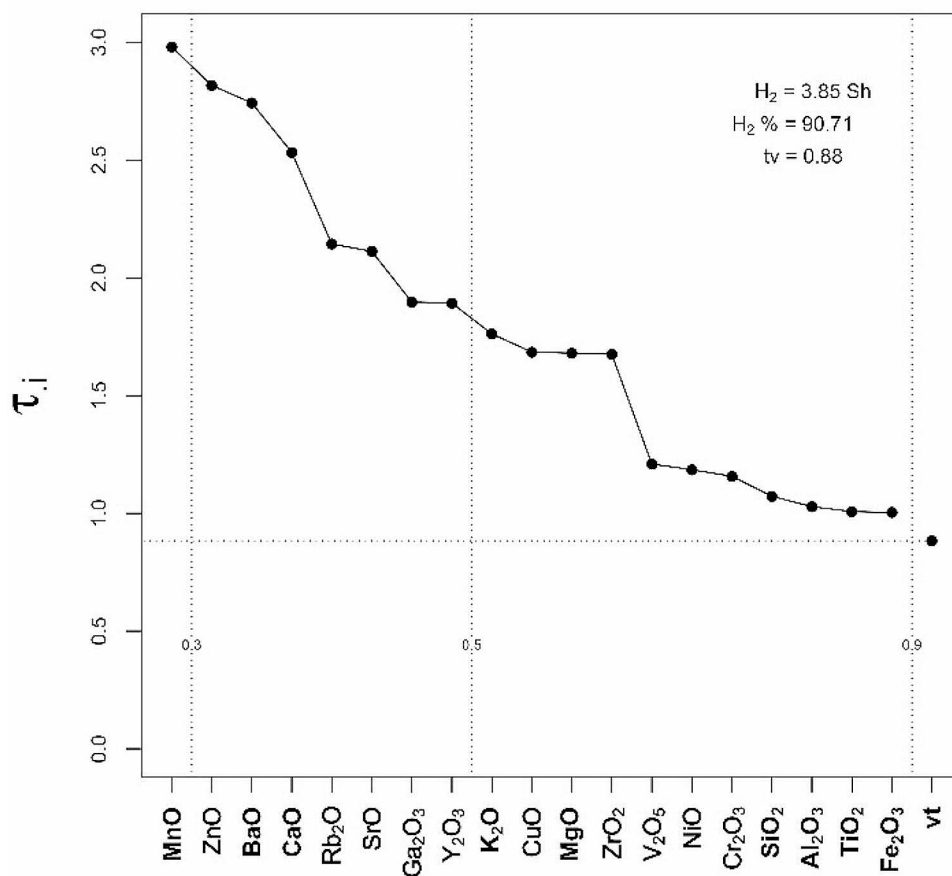
Despite the heterogeneous nature of the elements from a chemical standpoint, the first statistical results revealed a clear agglomerative tendency in which a generic cluster that groups a significant part of the samples was easily recognisable. The principal component analysis (PCA) executed after normalising the values and based on the singular value decomposition of the transformed double clr data (van de Boogaart and Tolosana-Delgado 2013) revealed this tendency, even though the two main represented components only reached 44% of the total variability (Fig. 5). Without being definitive, the result portrays a panorama in which a large grouping is recognised in the middle and middle-right section, along with seven individuals that are distanced

from it based on a difference in some elements, such as Fe_2O_3 , NiO, Al_2O_3 or K_2O . Nevertheless, the graph suggests certain similarities among the samples, as might well have been anticipated due to the selection of productions that, at a macroscopic level, had already revealed the typical characteristics of Central Mediterranean amphorae.

A third statistical processing consisted of hierarchical clustering analysis (HCA) based on the squared Euclidean distance and the centroid algorithm, done to explore the geochemical results in greater depth. The resulting dendrogram (Fig. 6) presented a complex structure with several clusters, subclusters and isolated individuals. Of particular note was the existence of a main branch under which the main clusters and groupings were distributed (QTH010 to QTH067), which allowed an initial generic grouping with a tv of 0.61. Ten individuals isolated by their differential values in elements lay outside this large cluster, including Fe_2O_3 (QTH015, 023), Al_2O_3 and CaO (QTH003), MgO (QTH019, 069), K_2O (QTH004, 069), SiO_2 (QTH011, 012, 023), BaO and SrO (QTH013, 018) or Y_2O_3 (QTH002) (Table 2).

Focusing again on the main branch of the dendrogram, we see five main clusters, QTH-A, QTH-B, QTH-C, QTH-D and QTH-E (Fig. 6). QTH-A is the group identified

Fig. 4 Compositional evenness plot for the 37 samples analysed. H2, information entropy (in Shannons, Sh); H2%, percentage of the possible maximum; tv, total variation of the assemblage



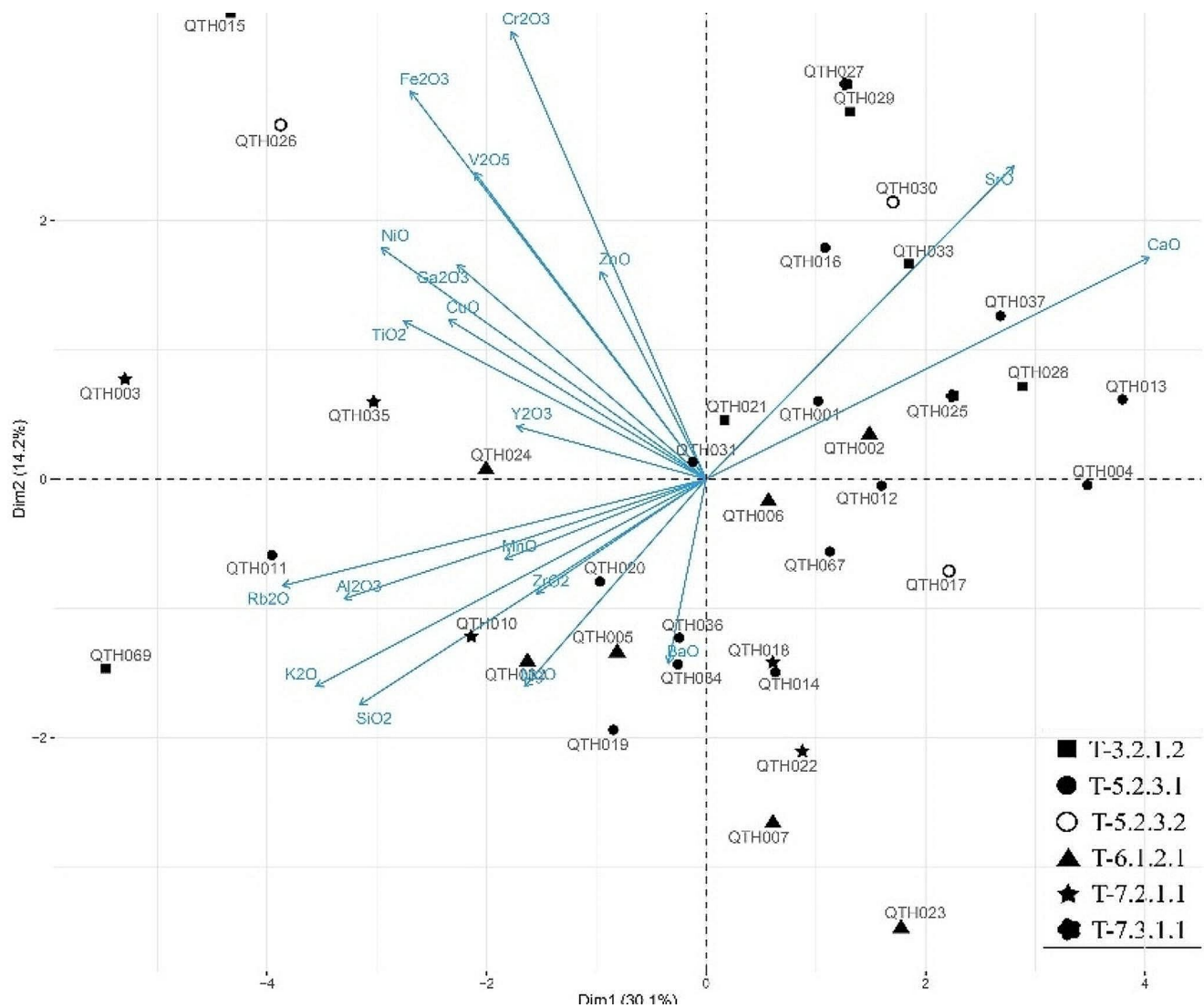


Fig. 5 Principal Component Analysis results for the 37 individuals performed on the sub-composition MgO , Al_2O_3 , SiO_2 , K_2O , CaO , TiO_2 , V_2O_5 , Cr_2O_3 , MnO , Fe_2O_3 , NiO , CuO , ZnO , Ga_2O_3 , Rb_2O , Y_2O_3 , ZrO_2 , SrO and BaO , clr transformed

with the most significant number of individuals, including ten amphorae whose total variation is 0.29. It has a tv below 0.30, revealing the monogenic nature of the cluster following the principles established by Buxeda and Kilikoglou (2003). The grouping of these samples is also consistent based on the PCA results. The cluster contains individuals of types T-3.2.1.2, T-5.2.3.1, T-5.2.3.2 and T-7.3.1.1, which already makes it possible to identify morphologically distinct amphorae within the same groups.

The group QTH-B includes two amphorae ($\text{tv}=0.18$) corresponding to type T-5.2.3.1. Again, this cluster presents a low tv and is revealed as a compact group in the PCA. Its chemical composition is not very different from that of the previous cluster, although the slightly higher SiO_2 values and lower CaO values lead to its individualisation (Table 2). QTH-C is the third of the main groups, with a tv of 0.36,

a figure that is slightly elevated by the variability of CuO but still lies within the borderline range of the monogenic group (Buxeda and Kilikoglou 2003). The main difference between this groups and the previous groups is the lower CaO and higher SiO_2 and MgO values it presents. The similarities with this group are also reflected in the PCA, except for QTH035, which is distanced due to the slightly higher TiO_2 value. This cluster includes four T-5.2.3.1 amphorae and one T-7.2.1.1 amphora.

QTH-D refers to a group consisting of four T-6.1.2.1 amphorae and one T-7.2.1.1 amphora, which has a tv of 0.38. Though these amphorae share similar petrographic characteristics, internal differences regarding Fe_2O_3 , Al_2O_3 and Ba account for a lower level of homogeneity within the group. Despite this fact, it is well-located compared to the rest of the groups and individuals that show

Table 2 Mean (m) and standard deviation (sd) of the chemical composition groups and loner samples

Elements	Grupo QTH-A (<i>n</i> = 10)			Grupo QTH-B (<i>n</i> = 2)			Grupo QTH-C (<i>n</i> = 6)			Grupo QTH-D (<i>n</i> = 5)			Grupo QTH-E (<i>n</i> = 2)			Loners
	m	sd		m	sd		m	sd		m	sd		m	sd		
Fe ₂ O ₃	7.510	0.482		7.516	0.238		7.413	0.351		7.858	0.531		7.753	0.089		QTH002
Al ₂ O ₃	13.413	0.716		13.805	0.502		13.806	0.571		14.172	0.678		13.225	0.318		7.876
MnO	0.052	0.006		0.057	0.009		0.040	0.008		0.083	0.028		0.064	0.014		13.740
TiO ₂	0.885	0.042		0.878	0.045		0.994	0.062		0.938	0.078		0.873	0.082		0.031
MgO	1.622	0.291		1.630	0.156		1.900	0.348		1.725	0.249		1.560	0.057		0.815
CaO	22.479	2.985		20.530	1.909		15.886	0.311		16.304	2.351		19.345	1.902		1.700
K ₂ O	2.102	0.198		2.411	0.207		2.967	0.257		2.827	0.192		1.905	0.304		19.360
SiO ₂	45.363	3.685		47.845	2.553		52.272	1.940		51.376	2.278		47.160	2.645		2.304
BaO	0.035	0.006		0.060	0.000		0.042	0.005		0.074	0.019		0.047	0.003		47.620
Rb ₂ O	0.009	0.002		0.011	0.000		0.013	0.003		0.013	0.001		0.010	0.001		0.032
ZrO ₂	0.042	0.007		0.045	0.011		0.056	0.008		0.054	0.011		0.058	0.005		0.011
Y ₂ O ₃	0.003	0.000		0.003	0.000		0.004	0.000		0.004	0.000		0.003	0.001		0.038
SrO	0.092	0.012		0.094	0.002		0.078	0.018		0.067	0.011		0.086	0.011		0.001
Ga ₂ O ₃	0.004	0.000		0.003	0.000		0.003	0.001		0.003	0.001		0.003	0.000		0.073
V ₂ O ₅	0.025	0.003		0.025	0.001		0.026	0.003		0.024	0.004		0.024	0.007		0.002
ZnO	0.023	0.004		0.031	0.004		0.020	0.002		0.019	0.002		0.044	0.001		0.028
NiO	0.008	0.001		0.008	0.000		0.007	0.001		0.008	0.001		0.008	0.001		0.033
Cr ₂ O ₃	0.022	0.002		0.021	0.003		0.024	0.003		0.020	0.002		0.022	0.001		0.008
CuO	0.008	0.002		0.007	0.001		0.009	0.003		0.008	0.001		0.011	0.000		0.023
Elements	QTH003	QTH004		QTH011	QTH013		QTH015	QTH018		QTH019	QTH022		QTH023	QTH026		QTH028
Fe ₂ O ₃	7.948	6.966		8.247	7.385		9.980	7.419		7.526	6.626		4.997	9.729		QTH069
Al ₂ O ₃	17.160	12.380		15.300	12.020		15.810	13.320		14.340	14.380		15.620	14.520		7.768
MnO	0.049	0.050		0.032	0.061		0.044	0.053		0.077	0.058		0.031	0.062		14.330
TiO ₂	0.859	0.851		1.050	0.882		1.140	0.820		0.880	0.936		0.823	1.040		0.196
MgO	1.935	2.022		1.570	1.570		1.820	2.951		2.914	2.131		1.160	1.610		0.895
CaO	8.900	22.000		10.520	23.460		17.380	18.540		16.190	18.890		20.270	17.040		2.881
K ₂ O	3.704	1.350		3.021	2.300		3.432	2.857		3.421	2.090		3.602	2.448		11.010
SiO ₂	54.980	48.170		58.760	38.020		43.250	49.860		47.280	50.230		39.920	51.350		4.140
BaO	0.044	0.057		0.043	0.086		0.043	0.090		0.032	0.039		0.039	0.048		54.080
Rb ₂ O	0.020	0.005		0.015	0.008		0.020	0.011		0.015	0.009		0.018	0.015		0.048
ZrO ₂	0.032	0.049		0.070	0.048		0.041	0.046		0.036	0.048		0.034	0.066		0.017
Y ₂ O ₃	0.002	0.004		0.005	0.003		0.004	0.003		0.003	0.004		0.003	0.005		0.048
SrO	0.060	0.113		0.055	0.132		0.094	0.101		0.072	0.057		0.070	0.062		0.004
Ga ₂ O ₃	0.004	0.003		0.004	0.002		0.005	0.003		0.004	0.003		0.003	0.004		0.057
V ₂ O ₅	0.029	0.021		0.030	0.025		0.032	0.033		0.024	0.024		0.020	0.031		0.003
ZnO	0.061	0.021		0.018	0.023		0.023	0.014		0.015	0.013		0.018	0.034		0.029
NiO	0.011	0.006		0.008	0.007		0.011	0.007		0.008	0.007		0.007	0.010		0.021
Cr ₂ O ₃	0.026	0.022		0.023	0.022		0.027	0.020		0.019	0.019		0.015	0.028		0.012
CuO	0.015	0.007		0.008	0.007		0.009	0.006		0.007	0.007		0.006	0.010		0.023
																0.010

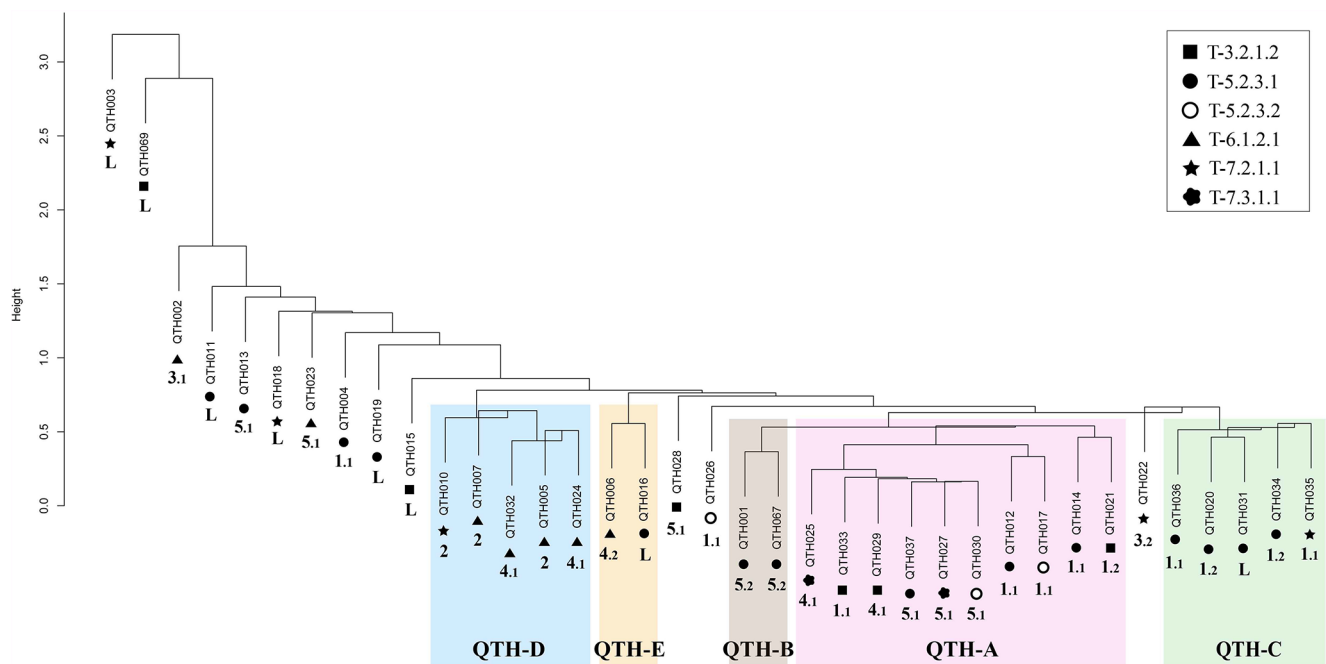


Fig. 6 Dendrogram of 37 individuals after a cluster analysis performed on the subcomposition MgO, Al₂O₃, SiO₂, K₂O, CaO, TiO₂, V₂O₅, Cr₂O₃, MnO, Fe₂O₃, NiO, CuO, ZnO, Ga₂O₃, Rb₂O, Y₂O₃, ZrO₂, SrO and BaO, clr transformed

differences due to their higher Al₂O₃ and MnO values, as well as lower CaO values (Table 2). A last group, QTH-E, is formed by the amphora T-5.2.3.1 and a T-6.1.2.1 whose chemical composition, vt 0.28, is not very different from that of clusters A and C, but its higher average values in such elements as Fe₂O₃ and ZnO individualise it as a distinct group. This clustering remains stable if we eliminate isolated individuals, and their differences are also evident in elements such as BaO, ZrO₂, ZnO, Rb₂O or Ga₂O₃ (Fig. 7).

The assessment of loners or isolated individuals presented more challenges, including those outside the main branch of the dendrogram described above, but also QTH022, QTH026 and QTH028, which are embedded within that branch. Nevertheless, their compositions reveal specific parameters that distance them from these defined groups, as indicated by the PCA (Fig. 4), such as high MgO, Fe₂O₃ and CaO values, respectively (Table 2).

Mineralogy

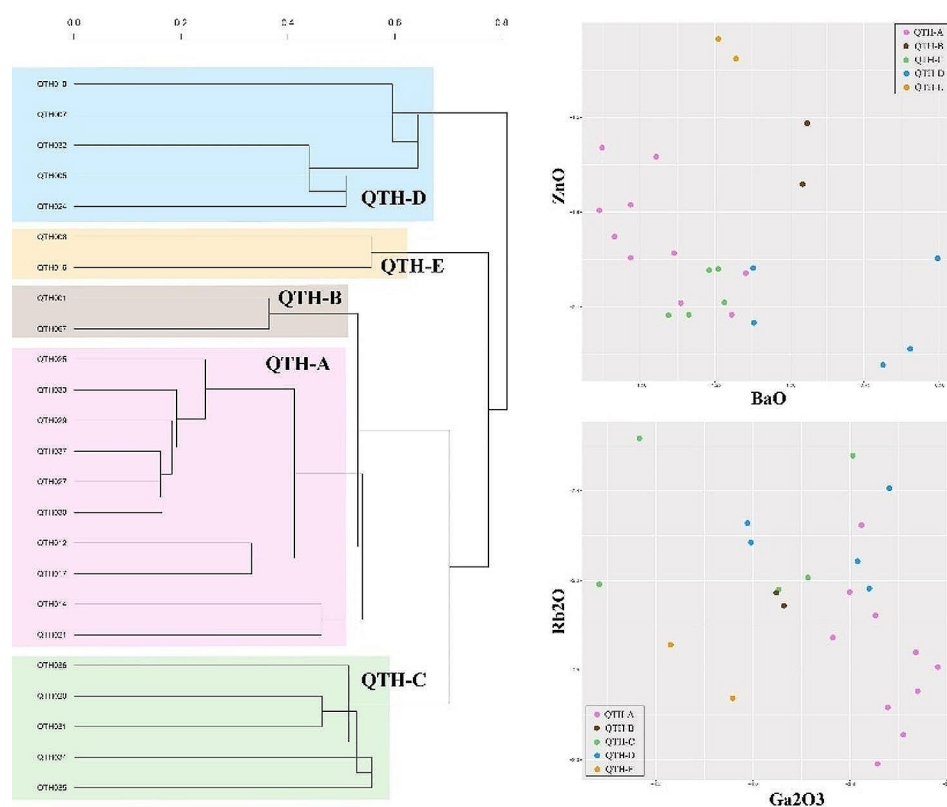
The chemical characterisation reveals that all the analysed amphorae comprise individuals with calcareous clays (5–6% < CaO < 15–25%). This implies a certain technical homogeneity in selecting raw materials and manufacturing strategies. However, as stated in the previous section, we also perceived important differences in the CaO values when analysing the ternary diagram (CaO + MgO + Fe₂O₃)-Al₂O₃-SiO₂ or ‘ceramic triangle’ (Fig. 8). In this regard, the majority of the individuals are located in the quartz-anorthite-wollastonite

thermodynamic equilibrium triangle, which characterises the calcareous pottery. In contrast, four individuals from Cluster A, one from Cluster B and the isolated individuals QTH013 and 028 all reach the wollastonite-anorthite-gehlenite triangle due to their higher CaO values. It is also interesting to note that four individuals distance themselves from the others due to having lower CaO values – specifically QTH003, 010, 011 and 069 – and a small group of three loners – QTH015, 023, 026 – separated by the greater weight that Al₂O₃ attains in their compositions.

We also explored this amphorae assemblage using XRD to recognise the primary mineral phases present in the ceramics, making it possible to estimate the equivalent firing temperature (EFT) (Roberts 1963; Picon 1973; Tite et al. 1982; Heimann and Maggetti 2014; Gliozzo 2020). Mineralogical groups were defined according to the mineral phases detected in each chemical cluster as well as in individuals without a clear grouping. The study of the diffractograms points to a general homogeneity in the crystalline phases, with firing temperatures that tend to be low. However, minor differences allow for a more precise characterisation of each chemical cluster at a mineralogical level (Table 3).

QTH-A was subdivided into three groups based on the proposed EFTs in which the phases related to illites are no longer present, which indicates a firing temperature above 800/850 °C when the mineral decomposes (Maritan et al. 2006; Gliozzo 2020). QTH-α1 reflects the mineralogy of an individual QTH027 in which the beginning of the firing phases is recognised, with very incipient pyroxene peaks but

Fig. 7 Dendrogram of 24 clustered individuals after a hierarchical cluster analysis performed on the same subcomposition than the previous one, clr transformed. Binary variation diagrams, using normalised data, of BaO vs. ZnO and Ga₂O₃ vs. Rb₂O for the amphorae analysed from Qart-Hadasht, correspondence with chemical cluster indicated for each sample



still without gehlenite, which points to an EFT of between 800 and 850 °C. The firing phases are already recognisable in the individuals of the QTH-α2 group, having developed pyroxene and gehlenite peaks that allow us to propose a higher EFT of between 850 and 950 °C. The highest EFT is in QTH-α3, with pyroxene peaks and the appearance of diopside, which allows its EFT to be placed between 900 and 950 °C.

QTH-B presents illite-muscovite peaks and relatively homogeneous EFTs, with the QTH-β1 group lacking firing phases and QTH-β2, with incipient gehlenite peaks pointing to a higher EFT. However, the presence of illite in both groups limits the temperature to less than 850 °C. On the other hand, QTH-C exhibits a more varied range of temperatures and up to four subcompositions can be differentiated: QTH-γ1 at a low temperature with the presence of illite and the absence of firing phases; QTH-γ2 and QTH-γ3, with the presence of illite and initial pyroxenes and gehlenite peaks, which points to an EFT of approximately 850 °C; and QTH-γ4, with the illite absent after its decomposition and with developed phases of pyroxenes and gehlenite, which reveal a firing temperature of approximately 850–950 °C.

Among the QTH-D diffractograms, we find two initial subgroups, δ1 and δ2, in which the presence of illites-muscovites is detected along with incipient peaks of pyroxenes and pyroxenes and gehlenite, respectively. This lets us place

the temperature range at approximately 800–850 °C. Greater intensity during the firing process reveals the δ3 subgroup in which the illites have already disappeared, and the first peaks related to pyroxenes and gehlenite appear incipiently. Lastly, QTH-E comprises two very similar groups, except for the presence of plagioclase in ε2. In both cases, they are low-temperature-fired ceramics, with the presence of illite peaks and very incipient gehlenite.

The loners exhibit different crystalline phases, although they all point to a firing with an EFT at a low temperature (Table 3). With the weakest ranges, we find an individual without firing phases, QTH003 (λ1), followed by QTH015 (λ2), QTH019 (λ3) and QTH023 (λ4), which have illite-muscovite peaks still present along with incipient firing phases, specifically pyroxenes and gehlenite. We believe that QTH013 (λ5) fits into this same range, as it lacks firing phases, but neither does it exhibit illite peaks. The remaining eight individuals (λ6 to λ13) have EFTs between 850 and 950 °C since the illite-muscovite phases are absent in their diffractogram and they present pyroxene peaks of greater or lesser intensity (QTH011, QTH069, QTH022, QTH026) and pyroxene and gehlenite peaks (QTH002, QTH019, QTH028, QTH004) (Table 3).

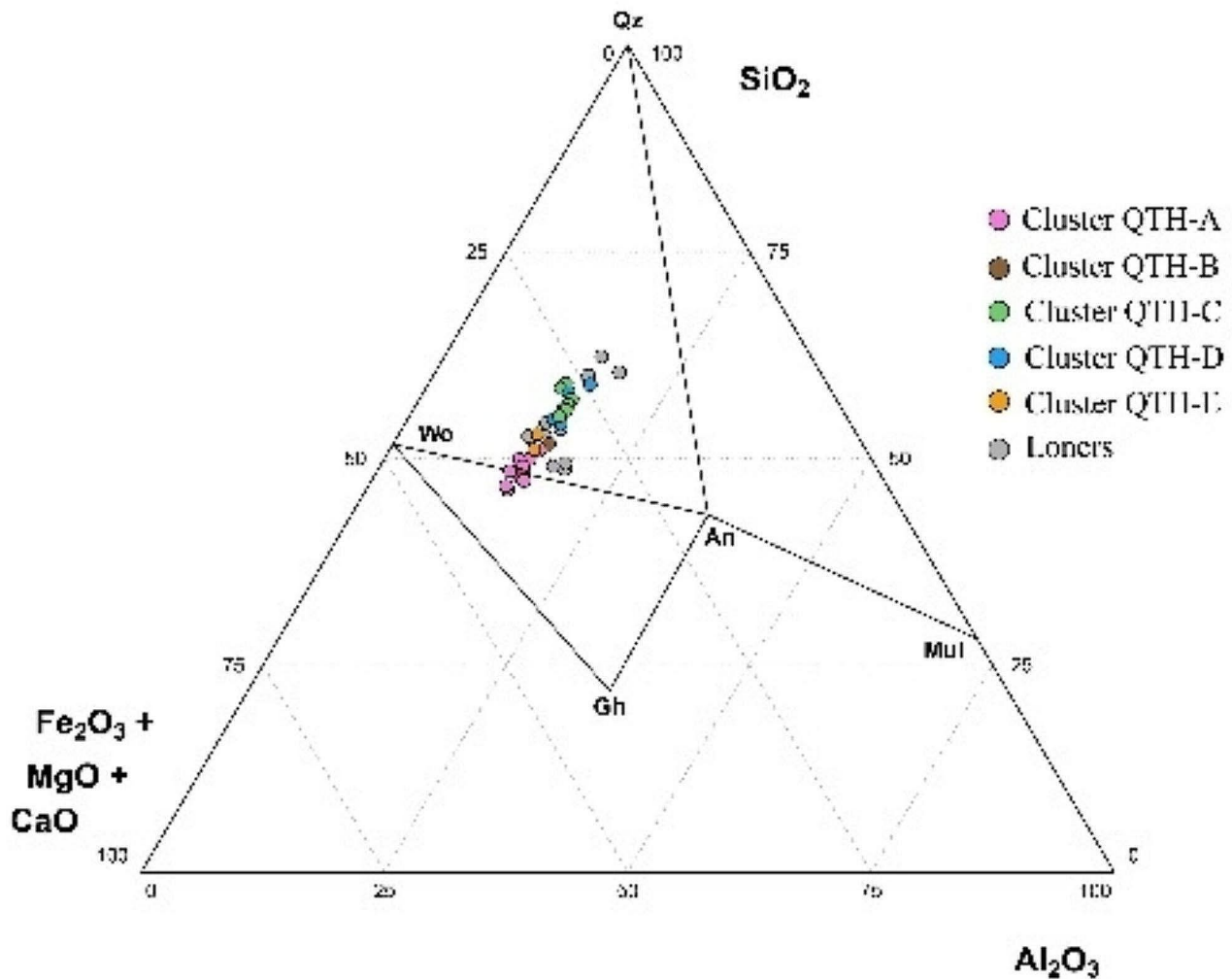


Fig. 8 $(\text{CaO} + \text{MgO} + \text{Fe}_2\text{O}_3)\text{-Al}_2\text{O}_3\text{-SiO}_2$ ternary diagram. An anorthite, Gh gehlenite, Mul mullite, Qz quartz, Wo wollastonite (abbreviations following Whitney and Evans 2010)

Petrographic analysis

The results from the amphora assemblage characterised at a petrographic level reveal a high degree of heterogeneity, although most of the samples could initially be included in the ‘Tunisian Group’. However, the predominance of aeolian quartz sands did not prevent us from recognising significant differences among the assemblage or observing major variability that agrees with what has been evident regarding Tunisian ceramic products since late antiquity (Capelli 2005; Capelli and Bonifay 2014). In this regard, we have distinguished five main fabric groups (Fig. 9) and eight samples defined as loners (Fig. 10).

Fabric 1 aeolian fabric ($n=10$). Aplastic inclusions present a poorly sorted distribution mode according to a bimodal grain-size scheme, with a single to open-spaced

coarse fraction. The coarse fraction (CF onwards) comprises coarse sand (<0.96 mm) to fine sand (>0.12 mm) represented by predominant subangular to rounded monocrystalline quartz. Other aplastics include very rare clay pellets, chert and dolomite. Fine fraction (FF onwards) is also characterised by the predominance of quartz and very few muscovite. The colour of the groundmass is homogeneous, dark brown in PPL and brown to reddish brown in XP. The voids have micro to meso-sized with mainly elongated and parallel channels, some filled with secondary calcite. There are also isolated vughs and vesicles.

Still, it has also been possible to recognise internal differences in the size parameters that led to identifying two different sub-fabrics: PF-1 A ($n=7$; c:f:v: ca. 20:70:10; QTH004, 012, 017, 026, 033, 035, 036) with a limited presence of the aplastic inclusions; and PF-1B ($n=3$; c:f:v: ca.

Table 3 Mineralogical fabrics and estimated EFT of the analysed samples from Qart-Hadasht based on XRD results. EFT, equivalent firing temperature. Afs: alkali feldspar; Cal: calcite; Di: diopside; Gh: gehlenite; Hem: hematite; Ilt: illite-muscovite; Pl: plagioclase; Px: pyroxene; Qz: quartz. Abbreviations according to Whitney and Evans (2010)

Chemical cluster	XRD Group	Individuals	Mineralogical Assemblage	EFT
QTH-A	$\alpha 1$	QTH0027	Qz, Cal, Afs, Px, Hem	800–850 °C
	$\alpha 2$	QTH012, 014, 017, 025, 029, 030, 033, 037	Qz, Cal, Afs, Pl, Px, Hem, Gh	850–950 °C
	$\alpha 3$	QTH021	Qz, Cal, Afs, Px, Hem, Di	900–950 °C
QTH-B	$\beta 1$	QTH001	Qz, Cal, Ilt, Afs, Pl, Hem	750–850 °C
	$\beta 2$	QTH067	Qz, Cal, Ilt, Afs, Pl, Hem, Gh	800 - 850 °C
QTH-C	$\gamma 1$	QTH031	Qz, Cal, Ilt, Afs, Pl, Hem	750–850 °C
	$\gamma 2$	QTH034	Qz, Ilt, Afs, Pl, Px, Hem	800 - 850 °C
	$\gamma 3$	QTH035, 036	Qz, Cal, Ilt, Afs, Pl, Px, Hem, Gh	800 - 850 °C
	$\gamma 4$	QTH020	Qz, Cal, Afs, Pl, Px, Hem, Gh	850–950 °C
QTH-D	$\delta 1$	QTH010	Qz, Cal, Ilt, Afs, Pl, Px, Hem	800 - 850 °C
	$\delta 2$	QTH024, 032	Qz, Cal, Ilt, Afs, Pl, Px, Hem, Gh	800 - 850 °C
	$\delta 3$	QTH005, 007	Qz, Cal, Afs, Pl, Px, Hem, Gh	850–900 °C
QTH-E	$\varepsilon 1$	QTH016	Qz, Cal, Ilt, Afs, Hem, Gh	800 - 850 °C
	$\varepsilon 2$	QTH006	Qz, Cal, Ilt, Afs, Pl, Hem, Gh	800 - 850 °C
<i>Loners</i>				
Lon.QTH-003	$\lambda 1$	QTH-003	Qz, Ilt, Afs, Pl, Hem	750–850 °C
Lon.QTH-015	$\lambda 2$	QTH-015	Qz, Cal, Ilt, Afs, Pl, Px, Hem, Gh	800 - 850 °C
Lon.QTH-019	$\lambda 3$	QTH-019	Qz, Cal, Ilt, Afs, Pl, Px, Hem, Gh	800 - 850 °C
Lon.QTH-023	$\lambda 4$	QTH-023	Qz, Cal, Ilt, Pl, Gh	800 - 850 °C
Lon.QTH-013	$\lambda 5$	QTH-013	Qz, Cal, Afs	800–850 °C
Lon.QTH-002	$\lambda 6$	QTH-002	Qz, Cal, Afs, Pl, Px, Hem, Gh	850–950 °C
Lon.QTH-011	$\lambda 7$	QTH-011	Qz, Cal, Afs, Pl, Px, Hem	850–950 °C
Lon.QTH-018	$\lambda 8$	QTH-018	Qz, Afs, Pl, Px, Gh	850–950 °C
Lon.QTH-028	$\lambda 9$	QTH-028	Qz, Cal, Afs, Pl, Px, Hem, Gh	850–950 °C
Lon.QTH-069	$\lambda 10$	QTH-069	Qz, Afs, Pl, Px, Hem	850–950 °C
Lon.QTH-022	$\lambda 11$	QTH022	Qz, Cal, Afs, Pl, Px, Hem	850–900 °C
Lon.QTH-026	$\lambda 12$	QTH026	Qz, Afs, Pl, Px, Hem	850–950 °C
Lon.QTH-004	$\lambda 13$	QTH004	Qz, Cal, Afs, Pl, Px, Hem, Gh	850–950 °C

40:50:10; QTH020, 021, 034) with a higher percentage of inclusions characterising a coarser CF.

Fabric 2: aeolian fabric and calcrete ($n=3$, c:f:v: ca. 30:60:10; QTH005, 007, 010). The bimodal distribution of aplastic inclusions features a poorly sorted mode with a single to double-spaced CF. The CF includes dominant subangular to rounded monocrystalline quartz, very few calcretes and carbonates, rare iron-rich clay pellets, microcline and plagioclase, and very rare pyroxenes, quartzite and benthic microfossils. The FF is characterised by predominant quartz and rare muscovite. The inclusions represent coarse sand (<0.72 mm) to fine sand (>0.16 mm), but calcrete granules can reach larger sizes (≤ 2.88 mm). The clay matrix is homogeneous in colour, umber brown in PPL and brown to reddish brown in XP. There are a few meso-sized voids in the form of vesicles, vughs, and channels in QTH010, some with secondary calcite.

Fabric 3: aeolian fabric and mudstone ($n=3$). The aplastic inclusions present a well-sorted mode with a close to double-spaced distribution, but the distribution parameters allow for a sub-classification of individuals. PF-3.1 ($n=2$, c:f:v: ca. 15:80:5; QTH002, 014) is characterised by a

predominance of FF (<0.14 mm), composed of rounded to angular monocrystalline quartz. The CF exhibits coarse sand (<0.64 mm) to fine sand with few quartz, mudstone, and very rare iron-rich clay nodules, quartzite, anisotropic iron nodules, chert, and plagioclase. QTH002 also presents very rare pyroxenes. The colour of the groundmass is homogeneous, dark greenish brown in PPL and brown to greenish brown in XP. The voids follow a micro to meso-sized pattern in the form of vesicles and vughs, all with secondary calcite remains. PF-3.2 ($n=1$, c:f:v: ca. 25:70:5; QTH022) exhibits similar characteristics in terms of the identified minerals, shade and void structure, but the CF is more important because it reaches very coarse sands (<1.36 mm), including a particular type of calcareous mudstone.

Fabric 4: aeolian fabric and microfossiliferous matrix ($n=5$, c:f:v: ca. 25:65:10). The bimodal distribution of aplastic inclusions features a poorly sorted mode with a close to double-spaced CF. The colour of the groundmass is relatively homogeneous, brown in PPL and reddish brown to orange-brown in XP. The uneven particle size and the structure of the voids allowed us to identify two sub-fabrics. PF-4.1 ($n=4$, QTH024, 025, 029, 032) exhibits coarse sand

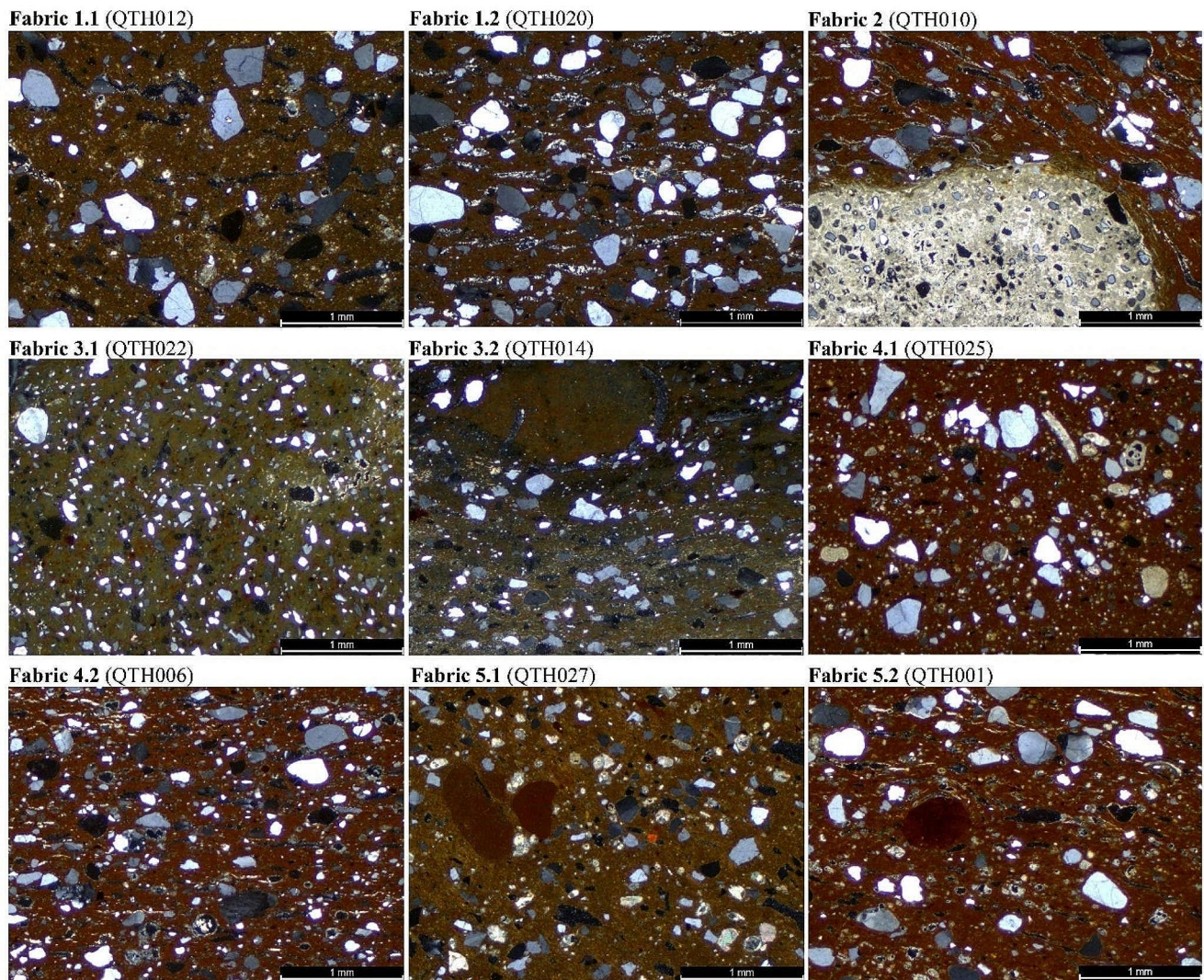


Fig. 9 Representative photomicrographs of fabrics identified in Qart-Hadasht, crossed polars (XP)

(<0.80 mm) to very fine sand (>0.10 mm) with predominant rounded to angular monocrystalline quartz, common microfossils (benthic, globigerina, planktonic) and few shells, few carbonates, and very rare quartzite, plagioclase, and clay pellets. The FF is dominated by quartz, very rare carbonates and microcline. We have identified meso and macro-sized voids in the form of vughs. PF-4.2 ($n=1$, QTH006) exhibits two significant differences from the previous sub-group. The CF reaches a smaller size of medium sand (<0.40 mm) where quartz continues to predominate, but pyroxene also occurs quite rarely, and the voids exhibit a channel-shaped parallel pattern, some of them with secondary calcite.

Fabric 5: aeolian fabric with mudstone and microfossils ($n=8$). Aplastic inclusions present a moderately sorted distribution with a bimodal grain-size pattern of close to double-spaced inclusions in a calcareous matrix. However, we recognised some internal differences in terms of the

frequency and the size of minerals and voids that allows us to posit the existence of two sub-fabrics. PF-5.1 ($n=6$, c:f:v: ca. 25:70:5, QTH013, 023, 027, 028, 030, 037) exhibits a CF of coarse sand (<0.80 mm) to fine sand (>0.12 mm) represented by dominant angular to rounded monocrystalline quartz, common carbonates, including dolomite and calcite, few benthic microfossils and globigerina, benthic, very few clay pellets and iron-rich clay nodules, and very rare pyroxenes, plagioclase, quartzite and chert. The FF is characterised by predominant quartz, and few carbonates and iron-rich clay particles. The colour of the groundmass is homogeneous, brown in PPL and orange-brown to golden brown in XP. There are micro to meso-sized voids in the form of vughs, some with secondary calcite. PF-5.2 ($n=2$, c:f:v: ca. 30:60:10, QTH001, 067) exhibits a coarser CF with the same kind of aplastics, but with a lower presence of carbonates. QTH001 also presents shells. The color of the

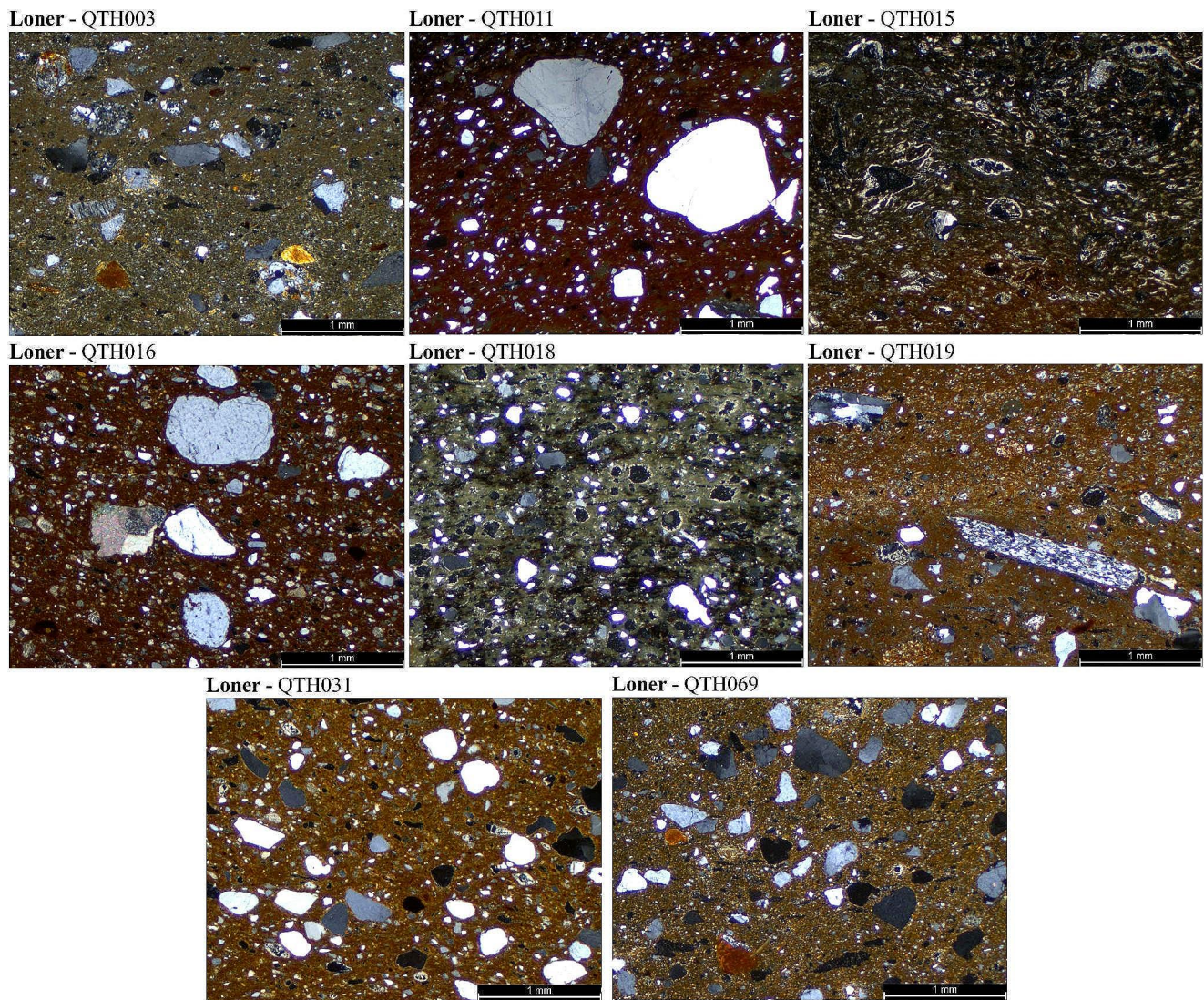


Fig. 10 Representative photomicrographs of loner fabrics identified in Qart-Hadasht, crossed polars (XP)

matrix is dark brown in PPL and reddish brown in XP, and the presence of voids is slightly different and higher, with parallel and orientated channels, some of them filled with secondary calcite.

Loner QTH003: quartz, metamorphic rocks, and serpentine in a calcareous groundmass ($n=1$, c:f:v: ca. 20:77:3). The aplastic inclusions exhibit a poorly sorted mode with a bimodal grain-size pattern of single to double-spaced inclusions. The CF comprises medium sand (<0.32 mm) to fine sand (>0.12 mm), mainly represented by frequent subangular monocrystalline quartz and common quartzite and chert. It also consists of few serpentine, altered red-orange serpentine, and rare plagioclase, phyllite and clay pellets. The FF is predominantly composed of quartz and rare microcline. The groundmass presents a fibrous pattern and is homogeneous in colour, greyish-brown tone in PPL and olive brown in XP, with very few vugh-shaped meso-sized voids.

Loner QTH011: coarse aeolian fabric ($n=1$, c:f:v: ca. 20:75:5). The aplastic inclusions present a very poorly sorted mode with a bimodal grain-size pattern. The CF contains single to open-spaced coarse sand (<1.04 mm) of predominant subangular to rounded monocrystalline quartz, few rounded iron-rich clay pellets, and rare quartzite. Quartz is also predominant in the fine fraction, together occasionally with few muscovite, very rare plagioclase and microfossils (benthic foraminifera). The colour of the groundmass is heterogeneous, brown in PPL and red in XP, with dark layers on the external surfaces. The sample also includes micro to meso-sized planar voids with a homogeneous distribution and random vesicles.

Loner QTH015: microfossiliferous matrix with very few inclusions ($n=1$; c:f:v: ca. 5:92:3). The aplastic inclusions exhibit a moderately sorted mode of single to open-spaced inclusions comprising fine sand (<0.24 mm), except for

some rare clay pellets (<1.44 mm). The matrix is dominated by microfossils (mainly benthonic, but also planktonic foraminifera, shells and radiolaria), few clay pellets, and very rare sub-angular to sub-rounded quartz. The FF (<0.10 mm) exhibits very few subrounded monocrystalline and polycrystalline quartz. The groundmass presents a heterogeneous colour pattern of brown with a dark black core in PPL and brown/red with a greenish-dark core in XP. Voids are also rare, following a micro to macro-sized pattern in the form of channels, some of them with secondary calcite.

Loner QTH016: aeolian fabric and marble grains ($n=1$, c:f:v: ca. 10:87:3). The bimodal distribution of aplastic inclusions features a poorly sorted mode with a single to an open-spaced coarse fraction of coarse sand (<0.88 mm) to fine sand (>0.12 mm). The CF contains frequent rounded to subangular monocrystalline quartz, common carbonates including some marble grains, very few quartzites, iron-rich clay pellets and microfossils (planktonic, benthonic), and very rare plagioclase. The FF is characterised by monocrystalline quartz, and very few carbonates and microfossils. The colour of the groundmass is homogeneous, brown in PPL and brownish orange in XP. The presence of voids is scarce, with only some examples of vugh-shaped and vesicles-shaped meso-sized voids.

Loner QTH018: aeolian fabric in a greenish groundmass ($n=1$, c:f:v: ca. 30:40:30). The main characteristic of this sample is that it is homogeneous in colour, greyish-green groundmass in PPL and green in XP. The aplastic inclusions follow a moderately sorted mode, with a single to double-spaced CF ranging from coarse sand (<0.56 mm) to very fine sand (>0.08 mm). The CF predominantly comprises sub-rounded to sub-angular monocrystalline quartz and very rare calcite and plagioclase. The FF exhibits dominant quartz. The presence of micro and meso-sized voids with planar structure is well-attested, following a homogeneous distribution. Some macro channels and meso vesicles have also been identified.

Loner QTH019: metamorphic rocks and serpentine ($n=1$; c:f:v: ca. 20:75:5). The microstructure of the section is characterised by a poorly sorted mode with the aplastic inclusions in a single to an open-spaced bimodal distribution. The CF comprises very coarse sand (<1.6 mm) to fine sand (<0.2 mm), including few coarse mica-schist, quartzite, monocrystalline quartz, feldspar (plagioclase) and altered serpentine, and very rare calcite, clinopyroxenes and microfossils (*Lenticulina* sp, benthic foraminifera, globigerina). The FF is composed of dominant quartz and common muscovite. The groundmass is heterogeneous, light brown with a grey core in PPL and brown with a grey-green core in XP. Voids are rare, following a meso to macro-sized pattern in the form of channels and vughs.

Loner QTH031: aeolian fabric and benthonic microfossils-rich clay ($n=1$, c:f:v: ca. 10:85:5). The bimodal distribution of aplastic inclusions features a poorly sorted mode with a single to open-spaced CF of coarse sand (<0.96 mm) to fine sand (>0.12 mm). The CF exhibits predominantly rounded to subangular monocrystalline quartz and common benthonic microfossils. The sample also includes very few shell fragments and different types of microfossils, such as radiolaria, globigerina or spherulites. The FF is dominated by quartz and rare plagioclase. The groundmass is homogeneous in colour, light brown in PPL and brown in XB, with meso and macro-sized voids in vugh-shaped and more rarely channels.

Loner QTH069: aeolian fabric and serpentine ($n=1$; c:f:v: ca. 20:75:5). The aplastic inclusions follow a bimodal distribution and a moderately sorted mode, with a close to double-spaced CF ranging from coarse sand (<0.64 mm) to very fine sand (>0.08 mm). The CF exhibits predominant subangular to rounded monocrystalline quartz, rare altered serpentine and quartzite, and very rare carbonates. The FF is dominated by quartz. The groundmass has a fibrous pattern of homogenous color, namely light brown in PPL and brown in XP, with vugh-shaped voids and rare vesicles.

Discussion and archaeological implications

Clustering, manufacturing patterns and provenance

Chemical and petrographic characterisation revealed different clusters and isolated individuals to which the Central Mediterranean amphorae from Qart-Hadasht correspond. Despite the macroscopic and typological similarity of the assemblage, statistical processing of the results identified four well-defined clusters – QTH-A, QTH-B, QTH-C, QTH-D and QTH-E – making it possible for us to recognise specific workshops or production areas in the Central Mediterranean circle. The differences in significant elements, such as CaO, Mn or SiO₂, along with other minor elements, such as ZnO, BaO or Rb₂O, serve as the basis for marking their particular characteristics, which can also be recognised on a petrographic level and, to a lesser extent, in the determined firing patterns.

In this respect, one of the aspects that attracts the most attention is the complexity detected in the clusters themselves, especially concerning the preparation patterns and the potters' choices regarding the manufacture of the amphorae. Although aware of the fact that we are starting from a biased reality when analysing this pottery from a consumer centre (Buxeda and Madrid 2017), the results provide us with useful information that has deepened our knowledge of

these amphorae, mainly since no other studies into potential manufacture areas are currently being done.

Some of the main questions that arose on a technical level regarding the provenance workshops or production areas were as follows: What amphora types were being produced? What clays were being? Was there any degree of specialisation or determinism with respect to the selection of raw materials and the vessel to be manufactured?

The combination of archaeological and archaeometric data has confirmed that various workshops produced the same types of Central Mediterranean amphorae in the last third of the 3rd century BC. Of the six types of amphorae analysed in our study, all except for T-7.3.1.1 were recognised in different clusters and isolated individuals; both T-7.3.1.1 individuals are grouped within QTH-A (Fig. 6). In this respect, T-5.2.3.1 stands out, with representative samples found in clusters A, B, C and E and four loners, followed by T-7.2.1.1, recognised in clusters C and D and three loners, and T-6.1.2.1, evident in clusters D and E and two isolates. We also identified three T-3.2.1.2 amphorae produced within cluster A and three corresponding to loners (Fig. 6).

The sharing of amphora types among potters was not unusual in the Mediterranean area during the first millennium BC. Examples of earlier types were widespread, including the Phoenician T-10.1.2.1 amphorae (Ramon 1995), reproduced in autochthonous pottery workshops (Cutillas-Victoria et al. 2021) or contemporaneously with Greek amphorae produced on the Italian Peninsula (Olcese 2012; Carratonia et al. 2016), in Sicily (Olcese et al. 2013) and on the Iberian Peninsula (Sáez and Díaz 2007). The variability of the types, however, does not seem to affect the homogeneity that has been chemically detected in the four recognised clusters, with tv figures that are close to or below the 0.3 level that places them as monogenic assemblages (Buxeda and Kilikoglou 2003).

The recognition of different petrographic fabrics within each cluster is also essential for exploring pottery practices linked to the selection of raw materials. The acquisition of various types of clay by the same workshop is not unusual, and scholars have found numerous examples of the coexistence of raw materials in workshops in the Tunisian area from the Roman period to late antiquity (e.g. Baklouti et al. 2016; Ben Tahar and Capelli 2018; Hasenzagl and Capelli 2020). In this respect, our results point not only towards this practice as an extended strategy, but also to variability among the selected clays, as can be seen in the QTH-A, C and D clusters, with potters having used both clays rich in microfossils and those lacking in them. Furthermore, the QTH-C and E clusters also include isolated fabrics that enable us to accurately evaluate the complexity and variability behind these ceramic containers. Such heterogeneity

is contrasted when evaluating the isolated individuals on a chemical and petrographic level (Figs. 6 and 10), confirming the diversity of workshops and production areas that dealt with these amphorae and their participation in the existing trade networks. The two ascribed individuals in QTH-B belong to the same petrographic group, making it the only exception to this situation.

One final issue is the firing temperature used to manufacture the analysed amphorae. This was an important step in the chaîne opératoire, one that can be explored thanks to the equivalent firing temperature and its effects on the mineralogical composition (Roberts 1963; Picon 1973; Tite et al. 1982; Gliozzo 2020). The XRD results reveal EFTs that generally follow a pattern of low to very low firing temperatures that did not exceed 950°C. On the one hand, clusters B and C, like loner QTH003, comprise individuals whose firing phases are absent and present a high presence of illite-muscovites. However, they also include subgroups with somewhat higher temperatures, where the appearance of pyroxenes and/or gehlenite points to a broader EFT, although still in the low-temperature range. On the other hand, illites are already absent in the individuals assigned to clusters A and D, or else the pyroxene phases are respectively recognised, which points to a somewhat higher EFT arc, although one that did not rise above 900°C. Individuals isolated at a chemical level also offer temperatures within this range of parameters (Table 3).

The diversity of workshops and production areas that took part in the circuits established with Qart-Hadasht also raises a question that is usually fundamental in archaeometry studies: the provenance, i.e. determining the origin of the analysed ceramics. Nevertheless, we should emphasise that this study is conditioned by the lack of reference materials for pottery production in the Punic era and the late Punic period in particular (Bechtold and Docter 2010), as well as by the scarcity of petrographic studies carried out on materials contemporary to those analysed here (Amadori et al. 2002; Bechtold 2012; Montana and Randazzo 2015).

When focusing on Central Mediterranean amphorae, scholars have made several proposals over the years to define the pottery from Carthage. They include Amadori and Fabbri's hypothesis (1998) linking samples characterised by CaO greater than 16% and SiO₂ less than 60% with an origin in the metropolis. Another attempt was proposed by Capelli (2005) based on petrographic analyses of Roman and late-Roman finds. He defined the 'Tunisian Fabric' or 'Aeolian Fabric', as being characterised by the dominant presence of quartz, although recognising considerable internal variability within this group. Capelli's results have served as a good basis for establishing the association between such fabrics and the Tunisian area, including with some particularities, the west coast of Algeria. However, the

latest studies done in Sicily reveal clays practically identical to those defined within that Tunisian aeolian fabric (Alaimo et al. 1997; Fabrizio et al. 2020; Montana et al. 2020). This complexity, together with the variability in fabrics detected in the workshops of the Tunisian and Sicilian areas, makes it much more complicated to propose specific provenances.

Thus, the results obtained in Qart-Hadasht reveal a panorama characterised by the arrival of calcareous composition amphorae, which, in petrographic terms, are mainly characterised by the predominance of quartz with diverse variants that link it with the Central Mediterranean aeolian group. This finding would suggest a main point of origin in the Tunisian area, opening up the possibility that some could also have come from the western part of Sicily. However, recognising certain characteristics allows us to tentatively consider certain hypotheses to try to determine the origin of some of these amphorae.

In this regard, perhaps two fabric samples from those identified at Qart-Hadasht could be related to products originating from Carthage itself, specifically PF-3.2, which presents clay pellets such as those seen in late-antiquity productions linked to the town (Fantuzzi et al. 2015: 5–6), and the loner QTH-018, with green clays also visible with the naked eye resembling earlier productions associated with local vessels from Carthage (Orsingher et al. 2020, M167/5 and M164/189). Another, different provenance could be proposed for PF-2, with the presence of micrite suggesting an origin in the southern zone of Tunisia, where individuals with micrite have also been detected in the workshops of Henchir Chougoff (Ben Tahar and Capelli 2018: 164; Fig. 8.16) and Salakta (Capelli 2015: 247–248).

QTH-003, 019 and 069 also exhibit compositions in line with different provenance sources. The more significant number of inclusions of metamorphic origin and their calcareous clay matrix is compatible with that seen in some individuals from the Algerian east coast (Capelli and Bonifay 2014: 236, 250, Fig. 5a). Finally, amphora QTH-015 presents a matrix with a type of clay in which microfossils predominate and very rare aplastic inclusions similar to those identified at Selinunte (Montana et al. 2022: 15; Fig. 13) and Monte Iato (Russenberger et al. 2016: 13; Fig. 11), which allows us to propose a Sicilian origin for this amphora.

The central mediterranean amphora trade with Qart-Hadasht

A second interpretative level involves Qart-Hadasht as a consumer centre. During the town's Punic period, provisioning must have been a sensitive issue for Carthaginian logistics, especially after the start of the Second Punic War in 218 BC. The town's central role as a merchandise reception

centre is noted in written sources. Titus Livius (*History of Rome*, 26, 43, translated by Villar 2001) reminds us that the town served as granary, treasury, arsenal, repository and port of refuge for all enterprises in the region. The Latin historian even emphasises the four hundred thousand *modii* of wheat and two hundred and seventy thousand *modii* of barley captured by the Romans following the conquest of the town in 209 BC.

The structure of the relations between the metropolis and the surrounding territories under Punic control in Iberia in general, and Qart-Hadasht in particular, has been the subject of intense debate among researchers (Ferrer and Pliego 2013; López Castro 2021). Initiatives like the founding of the town itself, together with other towns or fortifications such as Tossal de Manises in Alicante (Olcina et al. 2017) or Giribaile in Jaén (Gutiérrez et al. 2017), give an idea of the hegemony or imperialism that Carthage was able to exercise over the Iberian Peninsula in the last third of the 3rd century BC. This relational framework would have allowed certain transactions to occur safely, such as the one described by the sources regarding grain, which was abundant in the metropolis. However, until now, scholars have not explored whether such political control mechanisms over trade relations could also have included the products contained in the Central Mediterranean amphorae sent to the Iberian Peninsula.

Focusing on the situation offered by Qart-Hadasht, the archaeological contexts excavated to date (e.g. Roldán y Martín 1996; García y Giménez 2007; Ramallo and Martín 2015) reveal a heterogeneous amphora repertoire characterised by the presence of Central Mediterranean vessels of Punic production such as those shown here, together with containers from the so-called Strait Group (mainly Cádiz, but also Málaga), the island of Ibiza and Greek amphorae from Campania (Ramallo 2011). However, one issue that has attracted significant attention is the limited presence of Central Mediterranean amphorae in the town ($n=37$), given that, although different types of the Ramon T-3, T-5, T-6 and T-7 series (1995) have been detected, one would expect a much larger number as a result of the hegemonic role between the metropolis and colony.

The use of chemical, mineralogical and petrographic characterisation analysis was essential to evaluating the reason for such a situation. The results of our study reveal the arrival of Central Mediterranean vessels mainly from workshops in Carthage, Tunisia, Sicily and probably the coast of Algeria. However, this perspective exhibits a much wider diversity than expected. There are four main clusters, to which we can add another thirteen loner individuals. This represents a complex and varied amalgam of workshops producing and participating in the trade circuits.

The archaeometric results preclude us from proposing the existence of a trade network directed or politically controlled by Carthage, at least concerning the Central Mediterranean amphorae that arrived at Qart-Hadasht. State control of certain manufactures was occasionally reflected in ancient political economies by the pre-eminence or promotion of specific artisans or workshops. However, this situation is most clearly seen in the production of prestige goods (e.g. Schortman and Urban 2004; Costin 2005). Our data from Qart-Hadasht, in contrast, reveal a panorama in which the variability of workshops and similar amphora types is so extensive that it is difficult to think of an iron-fisted control or pre-eminence of certain areas over others due to state decision-making practices. The results point more towards a situation in which commercial enterprises were undertaken by private initiative, although this would have required collaborating with the state, which could favour the businesses involved in such trade (Ferrer Maestro 2009).

The effective Carthaginian conquest of the Iberian Peninsula undoubtedly resulted in a period of commercial and economic revitalisation, including the new Western Mediterranean territories and towns now under Carthaginian rule. The metropolis itself benefited from this open, interconnected environment (Docter 2022), as did other Punic regions, such as Cadiz (Sáez 2008) and the island of Ibiza

(Ramon 1991). Nevertheless, the markets were not closed to the participation of other Mediterranean actors. The important presence of Western Greek amphorae and Campanian pottery from Cales and Ischia in Qart-Hadasht (Ruiz 1999) shows the entanglement of these economic circuits and the probable intermediation or mediation on the part of the Carthaginian merchants. This situation is comparable to that of Carthage, where Western and Eastern Mediterranean amphorae and vessels converged (Bechtold and Docter 2010).

Moreover, the commercialisation of Central Mediterranean amphorae must have taken place freely once they had arrived at the port of Qart-Hadasht, as our results have not allowed us to detect a specific distribution pattern in the contexts excavated so far (Fig. 11). Thus, we find the identified geochemical clusters and fabrics spread across different areas and contexts of the town, highlighting, for example, 8 Saura Street, with seven vessels from seven different origins, or 34–36 San Cristóbal la Larga, where, although the QTH-A cluster has three amphorae, another five amphorae of different provenance were found. A closer relationship does not even exist between amphorae and clusters within the context of the military structure of the Punic wall, with four containers from four different origins.

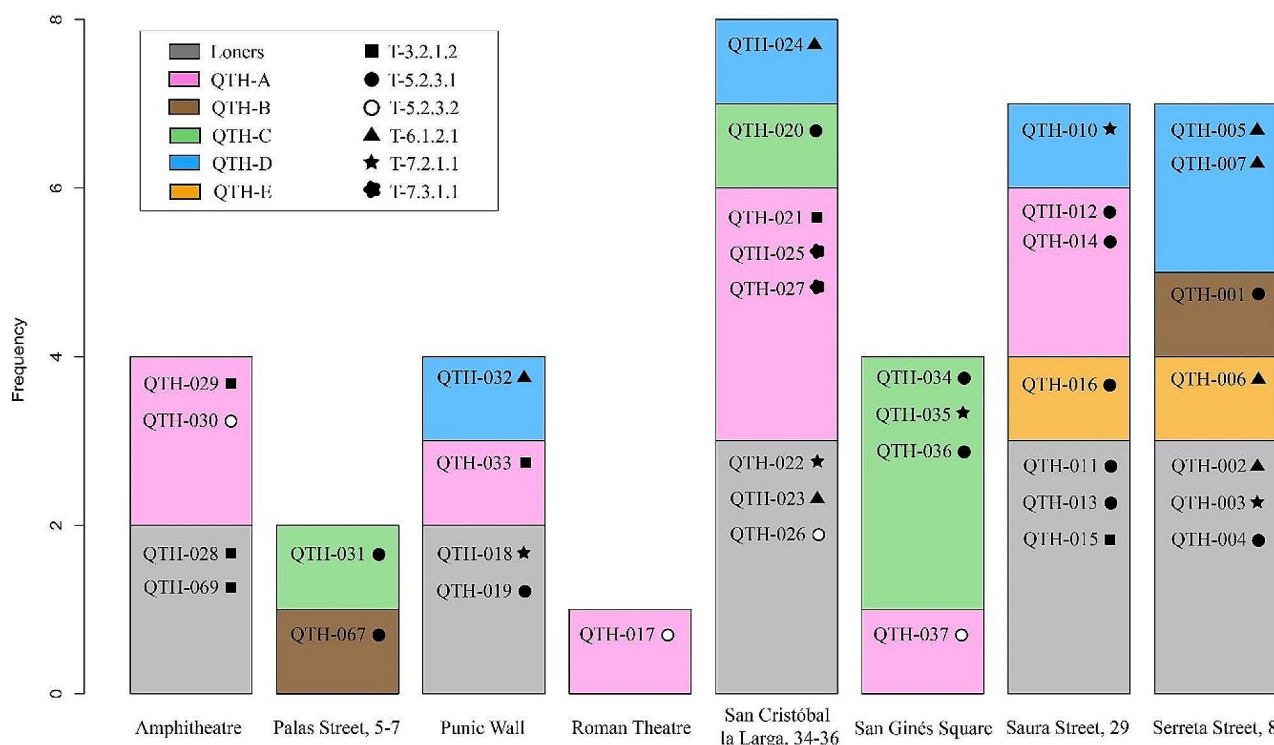


Fig. 11 Graphic representation of the distribution of the samples according to their geochemical cluster assignment and location in the town's excavations

This relationship reinforces the idea of the arrival of Central Mediterranean amphorae as part of private initiatives within a general framework of commercial incentives for Carthage. This would have represented a substantial economic and commercial opportunity for Tunisian products on the Iberian Peninsula, including the pottery workshops responsible for manufacturing the amphorae.

Final remarks

The analytical programme undertaken offered a diversity of results, with the primary conclusion relating to the complexity presented by the study of consuming centres. Despite analysing quite specific amphora types within a very limited time frame (228/227–209 BC), the identification of numerous chemical groups and fabrics based on the macroscopic analyses revealed the complexity behind the Central Mediterranean pottery. The results reveal four chemical clusters linked to specific petrographic fabrics, as well as another series of loner individuals that allowed us to recognise the arrival at Qart-Hadasht of amphorae from Carthage, the Tunisian area, the island of Sicily and most probably the Algerian coast.

In this regard, the multidisciplinary approach has served as a basis for exploring results that, precisely because of their heterogeneity, open up interesting perspectives on the commercial and economic relations between the Carthaginian metropolis and the conquered territories in Iberia. The Qart-Hadasht results are the first to comprehensively investigate clustering and provenance issues in Central Mediterranean amphorae brought to the Iberian Peninsula in the last third of the 3rd century BC. This perspective has allowed us to obtain a more detailed picture of the structure of economic relations and trade routes between the new Punic capital in Iberia and the metropolis. It also revealed a specific participation of the Carthaginian state in trade, although probably through incentives for merchants and private initiatives. The plural and diverse nature of the flow of trade are specifically reflected in the different provenances recognised in the Central Mediterranean amphorae that reached the town.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Competing interests The authors declare no competing interests.

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