



# Origins and Distribution of Hellenistic and Late Republican Transport Amphorae in the Dalmatian Region and its Implications for Adriatic Trade and Economy

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Received: 23 July 2022 / Accepted: 31 October 2022 / Published online: 19 November 2022  
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## Abstract

The presence of Hellenistic and Late Republican transport amphorae at numerous sites along the Adriatic and within shipwrecks off the coast indicates that intense trade and/or exchange in commodities such as olive oil and wine took place in this region from the fourth until the first century BC. The details of this commercial activity are nevertheless unclear in terms of the sources, destinations, and routes via which transport containers and their contents were circulated. The present study brings compositional data to bear on this topic by analysing petrographically and geochemically 248 amphorae sherds from 15 sites along the Dalmatian coast of present-day Croatia, including production sites, places of consumption, and shipwrecks. This revealed the existence of several larger amphora workshops whose amphorae were used to export goods to Dalmatia during the fourth and third centuries BC. They were involved in direct trade or through intermediaries in the redistribution centres. In the second and first centuries BC, only one workshop supplied amphorae in the region, which is probably the Dalmatian town of Issa. Aspects of the regional and inter-regional distribution and redistribution of amphorae from these workshops have been reconstructed, as well as changes within the trading system over time.

**Keywords** Amphorae · Ceramic petrography · Geochemistry · Workshops · Shipwrecks · Trade

## Introduction

Maritime connectivity was one of the main characteristics of the ancient Mediterranean world. Its extensive coastline was crisscrossed by a complex web of trade routes from as early as the Bronze Age, peaking in the late third century BC to second century AD (Parker 1992; Strauss 2006). This maritime activity was recorded by ancient writers (Arnaud 2012) and is manifested in numerous well-known shipwrecks carrying amphorae as cargo (Figs. 1, 2). These ceramic containers were designed specifically to transport liquid goods over large distances (Bevan 2014) and are common finds at archaeological sites in the Greco-Roman periods. Studies of the ancient Mediterranean economy have used the distribution of amphorae to reconstruct maritime trading routes by identifying their manufacturing

locations/departure points via shape or compositional data. The occurrence of distinctive vessel types at locations distant from their sources provides evidence for the sailing routes and destinations of merchant ships, and therefore the commercial connections between different settlements, colonies, and cultures in the past.

Early studies of the distribution of transport amphorae made use of the shape of containers, which can be a trademark of a particular workshop and product, for example, amphorae from the Aegean islands of Chios and Thasos that were used to carry high-quality wine (Horden and Purcell 2000: 225). Epigraphic evidence such as stamps on the handles of amphorae, indicating a particular producer, can also be used to determine their source and therefore the scale and direction of distribution. Unfortunately, not all producers stamped their amphorae handles and those that did stamped only certain containers. Added to this, amphorae of the same or very similar shapes were sometimes produced by several workshops in quite different regions, for example, Corinthian type B amphorae, which were made in Corinth, and the Corinthian colony Corcyra on Corfu (Koehler 1978 and 1992; Whitbread 1995), but also in southern Italy and Sicily

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**Fig. 1** Photo of sunken merchant ship with transport amphorae, Žirje shipwreck with Corinthian or type B amphorae (Photo: D. Frka)

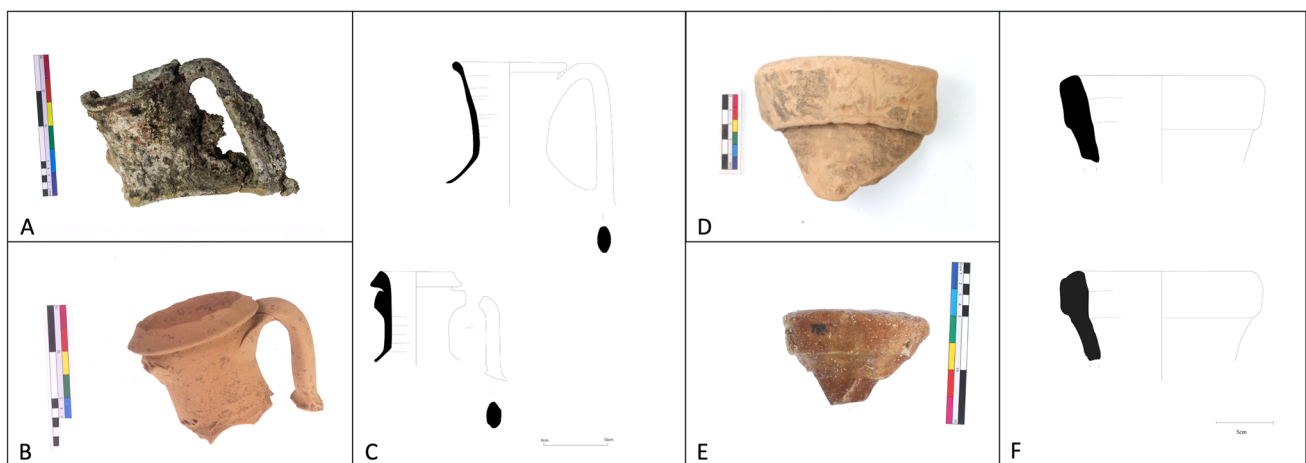
(Barone et al. 2004a, b, 2011; Swift 2011; Finocchiaro et al. 2018) during the Hellenistic period. Furthermore, morphological differences between transport amphorae of the same general type existed within single workshops (Coto-Sarmiento et al. 2018). These issues make it difficult to ascribe certain amphorae to specific workshops, or even particular regions, based solely on shape and epigraphy.

Archaeological studies of amphorae distribution and maritime trade therefore combine a traditional stylistic approach with scientific characterisation of the clay paste from which the ceramics were manufactured. Petrographic and geochemical provenance determination can detect vessels constructed from different geological materials and therefore in specific geographic locations (Quinn 2022: 167–171). Compositional data is used to link ceramics to the landscape and/or workshops. Such an approach has made a significant contribution to the study of ancient trade in

the western (Martínez Ferreras et al. 2007, 2015; Fantuzzi et al. 2016, 2019; Moreno Megías et al. 2020) in the Central Mediterranean; Italy (Barra Bagnasco et al. 2001; Olcese 2007; Olcese et al. 2013; Pecchioni et al. 2007; Swift 2011; Miriello et al. 2015) and Sicily (Barone et al. 2004a, b, 2011, 2014), as well as in the Adriatic (Machut et al. 2015; Ceccarelli et al. 2016; Maritan et al. 2019; Miše et al. 2019) and the Aegean regions (Hein et al. 2008; Day et al. 2011; Hein 2014).

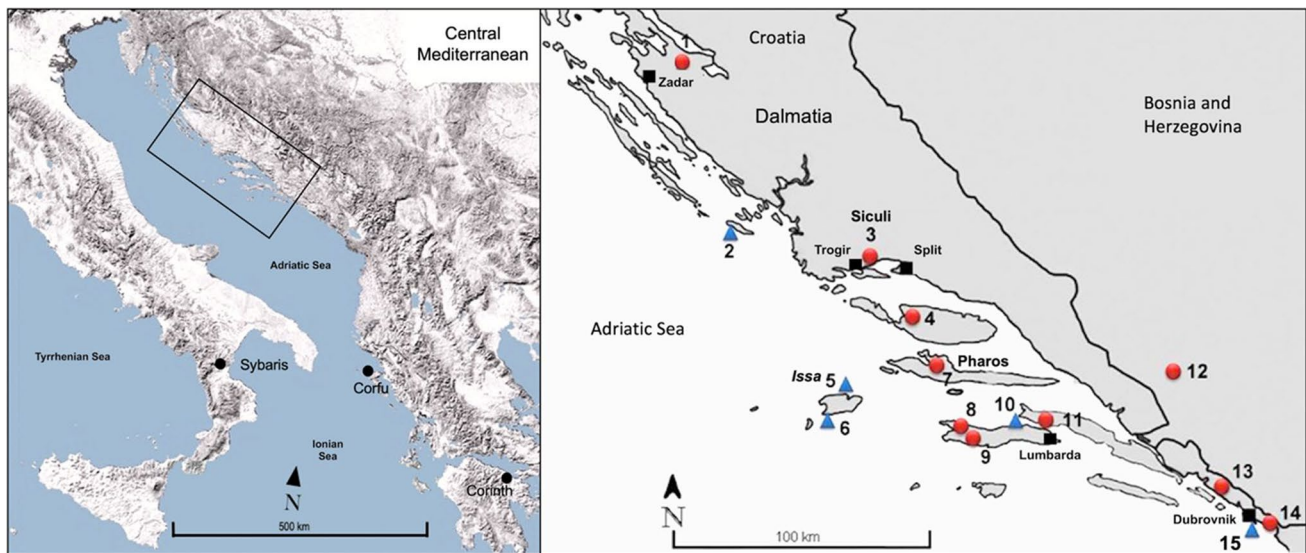
Initial scientific provenance studies on Hellenistic and Roman amphorae circulation in the Adriatic region (Machut et al. 2015; Maritan et al. 2019; Miše et al. 2019) have highlighted the potential of this approach in the central Mediterranean. However, the low number of studies and samples analysed makes it difficult to identify the main workshops in the area and to detect the distribution of amphorae and, therefore, movement of goods. Lively debate exists among scholars as to whether Late Roman Republican Lamboglia 2 amphorae were produced in the western Adriatic (Cipriano and Carre 1989; Menchelli et al. 2013; Carre et al. 2014; Van Limbergen 2018) or on the eastern Adriatic coast (Cambi 1972 and 1989; Kirigin et al. 2006a; Lindhagen 2009). These studies have examined this question based on the criterion of abundance. However, a large number of amphorae at a given site may indicate a practice of consumption or redistribution, that is, places where amphorae were discarded after use, and not necessarily places of production.

The present paper outlines the results of the largest scientific study of Adriatic amphorae circulation to date, including 248 well-dated, typologically classified sherds from 15 different sites: production sites, places of consumption, and shipwrecks along the Dalmatian coast of present-day Croatia (Fig. 3). These are characterised petrographically in thin section and geochemically via instrumental neutron activation



**Fig. 2** Photo and drawings of amphorae: **A** Corinthian, or type B amphorae from Rat near Vičja luka on the island of Brač; **B** Corinthian, or type B amphora from the Gnjilna shipwreck near island of

Vis; **C** drawings of A and B; **D** Greco-Italic amphora from Pharos; **E** Lamboglia 2 amphora from the Polačišće shipwreck near the island of Korčula; **F** drawings of D and E



**Fig. 3** Map of the Central Mediterranean with the Adriatic Sea and the location of the archaeological sites analysed in this study. 1 Iron Age settlement of Zemunik; 2 Žirje shipwreck; 3 Late Hellenistic/Late Roman Republican harbour of Resnik/Siculi; 4 Iron Age settlement of Vičja luka/Rat on the island of Brač; 5 Vela Svitnja shipwreck; 6 Gnjilna shipwreck (5 and 6 both near the island of Vis); 7 Greek city of Pharos on the island of Hvar; 8–9 Iron Age settlements of Kopila and Stine, both on the island of Korčula; 10 Polachišće ship-

wreck in the Pelješac channel; 11 Sanctuary of Nakovana Cave on the Pelješac peninsula; 12 Iron Age settlement of Crveni Grm in southern Herzegovina; 13 Sanctuary of Vilina Cave; 14 Iron Age settlement of Sokol fortress; 15 Supetar–Cavtat shipwreck near Dubrovnik (with red dots for terrestrial sites and blue triangles for shipwrecks). A detailed list of amphora sherds collected for analysis are in Table 1, and the coordinates of the target sites and locations mentioned in the text can be found in Supplement 3

analysis (INAA), to detect the products of distinct amphorae workshops and the distribution patterns from the fourth to first century BC. The study sheds new light on regional and inter-regional commerce in the Adriatic during the Hellenistic and Late Roman Republican period, as well as changes within the trading system over time.

## Historical and archaeological context

The arrival of Greeks on the Dalmatian islands in the early fourth century BC and the establishment of two colonies, Pharos on the island of Hvar and Issa on the island of Vis (Fig. 3), marked the beginning of political and economic change in the Adriatic. The newly arrived settlers instigated trade with local communities along the eastern Adriatic, which can be followed by an increase in imported fine ware (Miše 2015), as well as the wide circulation of transport amphorae (Kirigin 1994; Radić 2003; Kirigin et al. 2006a; Šešelj 2009; Lahi 2009; Royal 2012; Borzić 2017). Pharos' connection with the indigenous population is assumed based on a fragment of an amphorae incised with the name of the city, recovered inland in present-day Bosnia and Herzegovina (Kirigin 2018). On the other hand, a short note by Agatharhidus from the second century BC that Issa produced and exported wine in Alexandria in Egypt (Kirigin et al. 2006a and Kirigin et al. 2006b), provides a glimpse into the

colonies' economic activity. However, the exact roles of both Dalmatian Greek settlements within the complex maritime trading system of the Adriatic in the last centuries BC are yet to be determined, for example, whether they produced and exported their own goods to local communities in the hinterland or served as intermediaries.

Archaeological evidence from Issa and Pharos suggests that pottery was produced on both islands. Excavations on Pharos have unearthed remains of possible kiln, moulds for making terracotta figurines and a deformed waster fragment (Katić 2000 and 2005; Popović and Devlahović 2018). Pottery kilns have also been found on Issa, together with wasters and moulds for manufacturing Hellenistic relief ware (Čargo and Miše 2010). Stylistic examination of fine tableware from Issa suggests the production of a specific type of decorated pottery, Issaeon Gnathia, from the beginning of the third to the end of second century BC (Miše 2015: 18–41), which was confirmed through compositional analysis (Miše et al. 2020). It is reasonable to assume that one or other of the two Dalmatian Greek settlements also manufactured transport ceramic containers—amphorae for use in the export of wine and perhaps other commodities (Kirigin 1994, 2018; Katić 2005; Kirigin et al. 2006a). However, analysis of amphorae from Pharos (Miše et al. 2019) suggests that distinguishing between production on one or other of the islands may not be straightforward due to their similar geology and involvement in maritime trade. It

is not yet clear whether they acted as redistribution centres, as well as exporting their own products. In addition, the origins, and routes via which amphorae and their contents passed along the Dalmatian coast in Hellenistic and Late Roman Republican times are yet to be discerned.

## Materials

With the aim to address the above themes and obtain a clearer picture of the nature of maritime trade in the Adriatic, a total of 248 amphorae sherds from 15 archaeological sites were selected for scientific compositional analysis (Table 1). These include samples from the Vela Svitnja shipwreck near Issa; amphorae excavated in the south-eastern residential complex in Pharos; sherds from land port facilities in Resnik (ancient Siculi); material from the Iron Age settlements in Zemunik in northern Dalmatia, Rat near Vičja luka on the island of Brač, Stine and Kopila on the island of Korčula, Crveni Grm in southern Herzegovina in present-day Bosnia and Herzegovina, Sokol Fortress near Dubrovnik; amphorae from two maritime sanctuaries, one in the Nakovana Cave on the Pelješac Peninsula and the other in the Vilina Cave near Dubrovnik; and finally amphorae from the shipwrecks near the island of Žirje, Gnjilna on the southern cape of Stupišće on the island of Vis, Polačišće near the island of Korčula and Supetar-Cavtat near Dubrovnik (Fig. 3). All selected sherds were typologically classified as either Corinthian

amphorae A', Corinthian B or type B, Greco-Italic, or Lamboglia 2 amphorae (Fig. 2, Table 1), which are most common forms that circulated within the Adriatic during the fourth to the first century BC. Samples were selected based on an estimate of the total size of the amphorae assemblage from each target site; e.g. in archaeological assemblages with more than 100 unearthened amphorae, the minimum number of collected and analysed samples is 30, and in assemblages with less than 100 unearthened amphorae, we collected all available samples. This strategy was applied to keep a statistically relevant number of samples similar, as much as possible, from each target site, bearing in mind their different contexts (from production sites to consumption sites) and excavation strategies.

Corinthian type B amphorae, or type B (Fig. 2A and B), are thought to have originated from Corinth, hence the name “Corinthian”, and were produced also in the Corinthian colony Corcyra on the island of Corfu in Late Classical and Hellenistic periods (last quarter of the sixth to late second century BC) (Koehler 1978 and 1992). This assumption has been supported by petrographic and geochemical analysis (Newton et al. 1988; Whitbread 1995). It also appears to have been produced on Greek colonies in southern Italy and Sicily (Barone et al. 2004a, b, 2011, 2014; Swift 2011; Finocchiaro et al. 2018). Although produced at different locations in the Ionian region, the name “Corinthian” for type B is still used in the archaeological literature (Göransson 2013; Radić Rossi et al. 2020). Another version of Corinthian amphora types is type A', which was produced

**Table 1** Details of archaeological sites and amphorae from the Dalmatian region analysed in this study. G-I=Greco-Italic (G-I); L2=Lamboglia 2 and “Hellenistic type”

Site	ID	Context	Type of amphorae	No of analysed samples
Issa/Vela Svitnja	VS	shipwreck/production site	L2	32
Pharos	SG	production site	Corinthian A' and Corinthian type B, “Hellenistic type” and L2	27
Resnik/Siculi	RES	port (land facilities)	L2	35
Rat Vičja luka	RAT	Iron Age settlement	Corinthian type B	8
Nakovana Cave	NAK	sanctuary	L2	18
Vilina Cave	VIC	sanctuary	Corinthian type B	32
Stine	STN	Iron Age settlement	Corinthian type B, G-I	2
Kopila	KOP	Iron Age settlement	Corinthian type B, G-I	2
Crveni Grm (BH)	CG	Iron Age settlement	Corinthian type B	6
Zemunik	ZEM	Iron Age settlement	Corinthian type B	3
Sokol	SOK	Iron Age settlement	Corinthian type B and “Hellenistic type”	15
Supetar-Cavtat	SUP	shipwreck	L2	13
Polačišće Bay	POL	shipwreck	L2	24
Žirje	ZIR	shipwreck	Corinthian type B	22
Gnjilna	GN	shipwreck	Corinthian A' and Corinthian type B	9
			Total	248

in Corinth from the fifth century BC to 146 BC (Koehler 1992; Whitbread 1995:270–271).

Greco-Italic amphorae (Fig. 2C) circulated within the Mediterranean from the third century BC, and it is assumed that they were produced in both Greek and Italian workshops (Lyding 1982). Their production was confirmed via petrographic analysis in Sicily (Olcese et al. 2013) and Campania in southern Italy (Olcese 2007; Cibecchini and Capelli 2013). Only five definite Greco-Italic amphorae have been included in this study (Table 1). Sixteen samples in our database due to the lack of diagnostic typological features are characterised as amphorae of the Hellenistic period, and hence broadly called “Hellenistic type”.

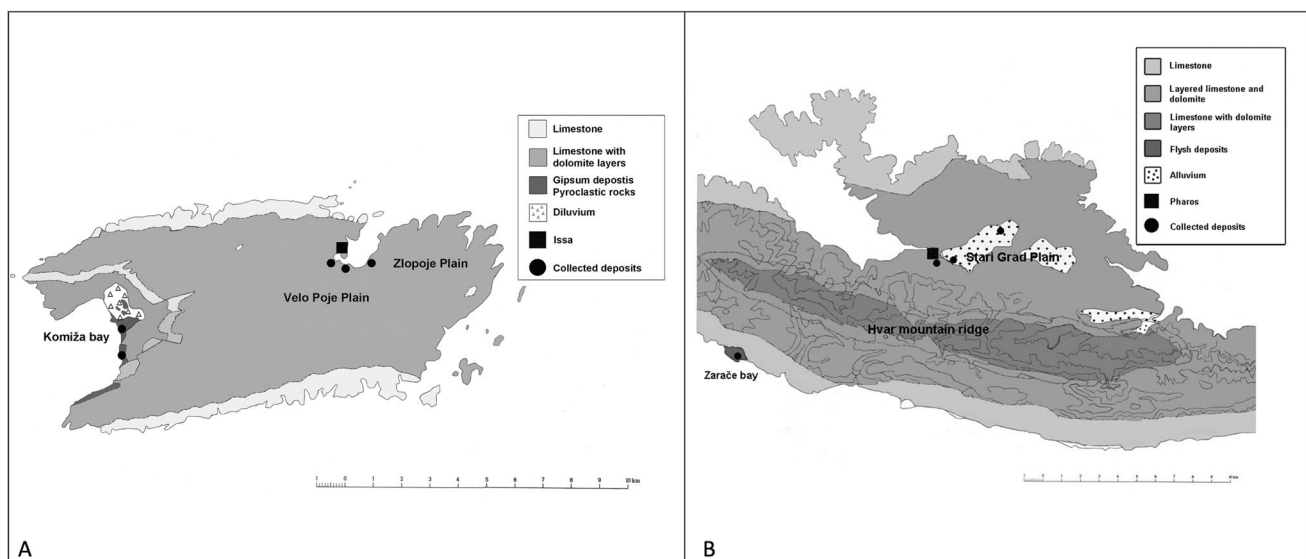
Lamboglia 2 amphorae (Fig. 2D) appear to have been the most common type of transport containers distributed within the Adriatic in the second and first century BC. They have been found in more than 100 shipwrecks along the Croatian (Radić 2003), Montenegrin and Albanian coasts (Royal 2012). Due to their widespread occurrence in the Adriatic, it is assumed that they were produced in this region.

## Geological background

To identify the centre of amphora production and determine whether they were produced locally in Dalmatia or imported from other regions we consulted the geological maps of the islands of Vis and Hvar where, as mentioned above, archaeological evidence for pottery production in Hellenistic and late Roman Republican periods were confirmed (Fig. 4). Both islands are characterised by a karst landscape composed of homogeneous geology, limestone,

and limestone with dolomite layers. In this landscape, clay deposits are rare. On the island of Hvar, the crops of the terra rossa deposits extend along the southern side of Stari Grad plain. The soil in these areas is a mixture of terra rossa and parent stones, and sand cannot be found anywhere around the large Stari Grad plain. So, it is likely that terra rossa deposits are in situ karstic, derived from the karstic dissolution of a limestone bedrock. They are usually found in small depressions, such as valleys, fields, and coves in the Dalmatian karst landscape. Alternatively, the terra rossa deposit may be alluvial in origin, i.e., derived from the dissolution of terra rossa formed on the steep northern slopes of the calcareous, karstic ridge of the island of Hvar, and then transported down to the Stari Grad depression by run-off. On the other hand, its origin may be a combination of both processes. Whatever the process may be, the terra rossa all throughout the Stari Grad Plain is compositionally (geochemically and mineralogically) homogeneous. On the island of Hvar, Eocene flysch, which in hand samples is green clay, was found and collected from a large outcrop in the beach slope of Zarače bay on the south side of the island (Miše et al 2019). This clay was analysed and proven to correspond to local fine Hellenistic pottery from both Greek cities, Issa on the island of Vis and Pharos on the island of Hvar (Miše et al 2020).

During the extensive geological mapping of the island of Vis, Eocene flysch clay was not geologically recorded on the island (pers. comm. with T. Korbar from Croatian Geological Survey). Most of the terra rossa on the island, as well as on the island of Hvar, was created as a result of the karst dissolution of the limestone bedrock. On the southern side of the island, clay material that was formed on pyroclastic



**Fig. 4** Map indicating location of raw material field samples collected from the islands of Hvar (A) and Vis (B), including simplified bedrock geology. Based on Oštrić et al. (2015) and Korbar et al. (2012), respectively

rocks above Komiža Bay was collected and analysed. However, the analysis showed that this material is not suitable for modelling because it lacks plasticity, and its geochemical composition does not match the archaeological pottery found on the island (Miše et al 2020).

## Methods

All 248 fragments were analysed by a combination of ceramic petrography and instrumental geochemistry. Samples were thin sectioned to 30 µm in a vertical orientation (Quinn 2022: 23–24) and studied under a polarising light microscope at magnifications of ×25–200. The samples were classified based on the nature of their inclusions, matrix, and voids into petrographic fabrics characterised by the use of specific raw materials and paste preparation recipes. These were then described using established procedures (Quinn 2022: 98–124). Post-depositional mineral alteration, particularly in those sherds recovered from shipwrecks, was assessed in thin sections (Cau Ontiveros et al. 2002; Miše et al. 2021; Quinn 2022: 280–298).

The bulk geochemical composition of 248 amphorae sherds was characterised via instrumental neutron activation analysis (INAA) at the University of Missouri Research Reactor (MURR). The surfaces of the c. 1 cm<sup>2</sup> samples were cleaned with a silicon carbide drill bit before they were crushed and ground into a powder. Approximately 150 mg of powder was placed in a high-density polyethylene vial and used for short irradiations, and c. 200 mg was transferred to a high-purity quartz vial for long irradiations. The amphorae powders were analysed along with NIST certified standard reference materials SRM-1633b (Coal Fly Ash), SRM-688 (Basalt Rock), SRM-278 (Obsidian Rock) and an in-house standard (New Ohio Red Clay; Glascock 1992) for calibration and quality control purposes. The samples were exposed to two irradiations and three gamma counts (Glascock 1992), resulting in the qualification of a total of 33 elements (Al, As, Ba, Ca, Ce, Co, Cr, Cs, Dy, Eu, Fe, Hf, K, La, Lu, Mn, Na, Nd, Ni, Rb, Sb, Sc, Sm, Sr, Ta, Tb, Ti, Th, U, V, Yb, Zn, and Zr).

A comparison of the geochemical composition of amphorae of the same petrographic fabric and typological category recovered from land and the sea permitted the identification of elements that were enriched (As, Na, Sb, Sr and U) or depleted (Ba, Cs, K and Rb) in the latter (Miše et al. 2021). These were removed from the dataset before the values for the remaining 23 elements (Al, Ce, Co, Cr, Dy, Eu, Fe, Hf, La, Lu, Mn, Nd, Ni, Sc, Sm, Ta, Tb, Th, Ti, V, Yb, Zn, and Zr) were log-ratio transformed and submitted to multivariate statistical analysis using principal component analysis (PCA). This was used to examine the geochemical structure of the dataset and those elements responsible for any

patterning. The identified geochemical groups were compared to the petrographic fabrics and typology of the sherds to identify amphorae's origins.

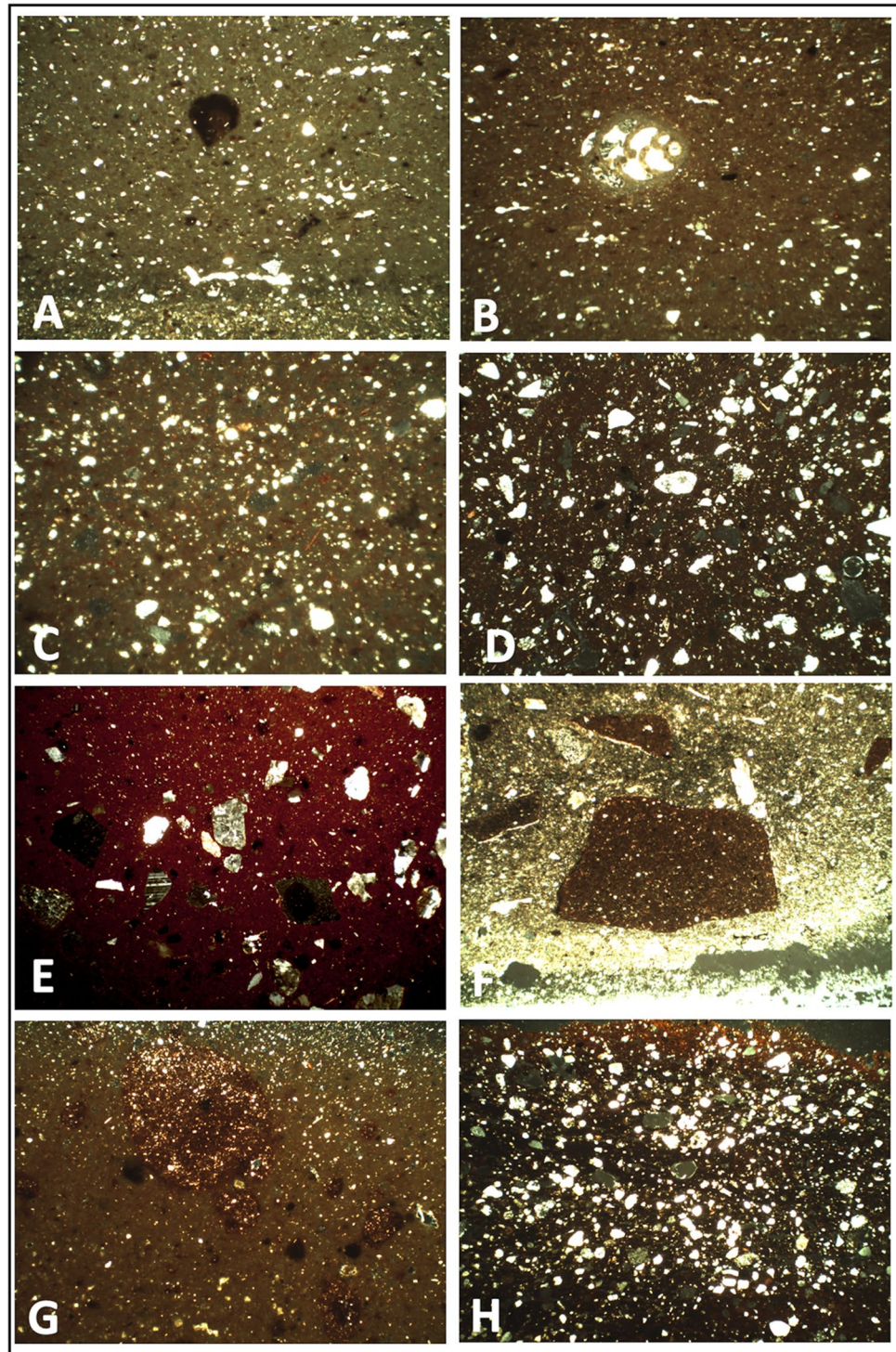
Finally, the integrated petrographic and geochemical classification was compared with geological information on the Dalmatian coast and further afar, with the aim of detecting the sources of the compositional groups and possible imports. Due to different changes in the composition of amphorae in our dataset recovered from different environments, marine and terrestrial, comparison with legacy data can be challenging. We therefore proceeded with a more direct comparative approach with published results of the same type of amphora produced in the Adriatic-Ionian region in the Hellenistic and Late Roman Republican periods. Where possible, direct comparisons of thin sections were made with a microscope, for example, with thin sections of amphorae in the collection of Prof Ian Whitbread at the Fitch Laboratory at the British School of Athens. Amphorae that did not match the Fitch Laboratory amphora collection were compared to published studies and photomicrographs of contemporaneous amphorae from the Adriatic-Ionian region, as well as to local geological maps. Their distribution at the analysed sites was then used to reconstruct patterns of trade in amphorae and their commodities.

## Compositional classification

### Petrographic classification

Through the study of the thin sections, 202 of the amphorae sherds were classified into seven petrographic fabrics (Supplement 1). The remaining 46 were heavily altered, which hindered their classification. Fabric 1 is fine and calcareous with clay pellets (Fig. 5A) and foraminifera microfossils (Fig. 5B). It consists of 39 sherds from terrestrial sites (Nakovana Cave and Resnik harbour) and 49 from shipwrecks (Vela Svitnja, Polačišće and Supetar-Cavtat) (Fig. 6). All samples from this fabric can be classified as Lamboglia 2 amphorae. Fabric 2 consists of 60 Corinthian type B, four Greco-Italic, and seven can be broadly categorised as “Hellenistic type” amphorae. It is characterised in thin section by a very fine yellow paste (Fig. 5C) and has been detected at the terrestrial sites of Pharos, the Vilina Cave sanctuary, and the indigenous settlements Sokol, Rat Vičja luka and Zemunik, as well as the Gnjilna and Žirje shipwrecks (Fig. 6). These 71 sherds are a good petrographic match for the Corinthian type B Whitbread's Fabric Class 2 (1995: 276–277). Nine amphorae from the terrestrial sites of Pharos, Vičja luka, Crveni Grm, and Stine and 13 samples from the Žirje shipwreck (Fig. 6) have a distinctive petrographic composition within the analysed assemblage in terms of their dark red homogeneous paste (Fig. 5D) and

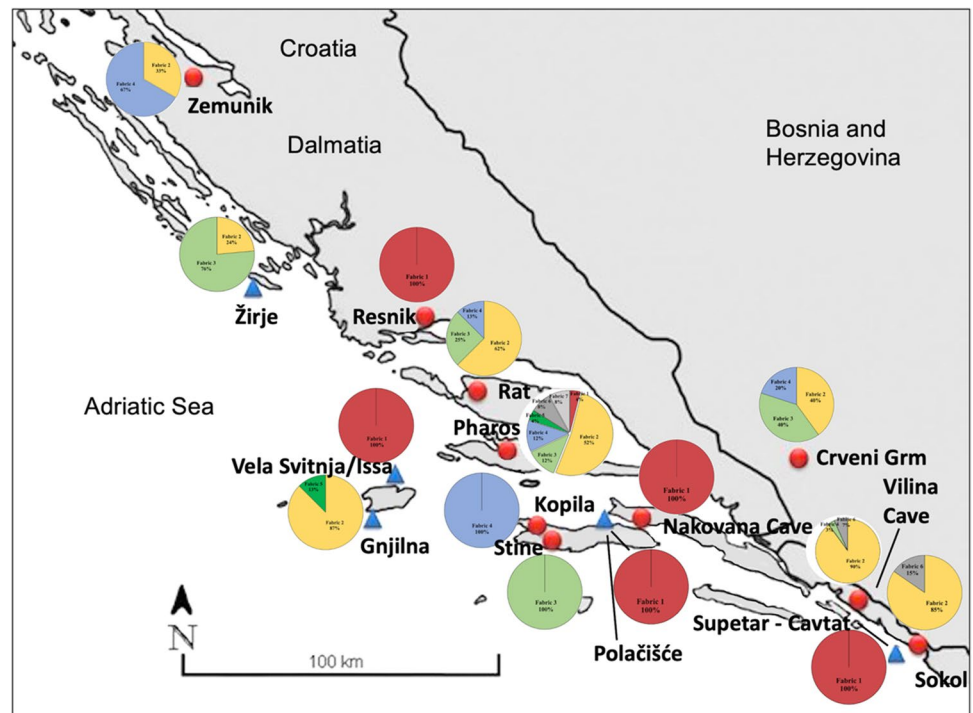
**Fig. 5** Photomicrographs of petrographic fabrics detected in Hellenistic and Late Republican transport amphorae from terrestrial sites and shipwrecks along the Dalmatian coast in this study. **A** and **B** fabric 1, **C** fabric 2, **D** fabric 3, **E** fabric 4, **F** fabric 5, **G** fabric 6, **H** fabric 7. All images taken in crossed polars. Image width = 2.9 mm



have been classified as Fabric 3. All sherds from this fabric come from Corinthian type B amphorae and correspond well to the Corinthian type B Fabric Class 3 of Whitbread (1995: 277–278). Ten sherds of Corinthian type B amphorae, characterised in thin sections by a distinctive fabric containing fragment of granitic rocks added to fine non-calcareous clay (Fig. 5E), are classified here as Fabric 4. They occur at the

terrestrial sites of Pharos, Rat, Kopila, Vilina Cave, Crveni Grm, and Zemunik (Fig. 6). Fabric 5 consists of only two Corinthian type A' amphorae sherds, one from Pharos and one from the Gnjilna shipwreck (Fig. 6). It is characterised by mudstone temper and a greenish yellow clay matrix (Fig. 5F) and therefore matches Corinthian Fabric Class 1 of (Whitbread 1995: 271). Four so-called “Hellenistic type”

**Fig. 6** Distribution and relative abundance of petrographic fabrics detected in Hellenistic and Late Republican transport amphorae at terrestrial sites and shipwrecks along the Dalmatian coast in this study (with red dots for terrestrial sites and blue triangles for shipwrecks)



and three Corinthian type B amphorae from Pharos, Vilina Cave, and Sokol fortress (Fig. 6), which have a reddish-brown paste with large argillaceous clay pellets (Fig. 5G) are classified as Fabric 6. Finally, two so-called “Hellenistic type” amphorae from Pharos (Fig. 6) form Fabric 7, which is characterised by a non-homogeneous red paste, with large quartz inclusions, and voids, with a distinctive firing colour difference between the margins and core (Fig. 5H).

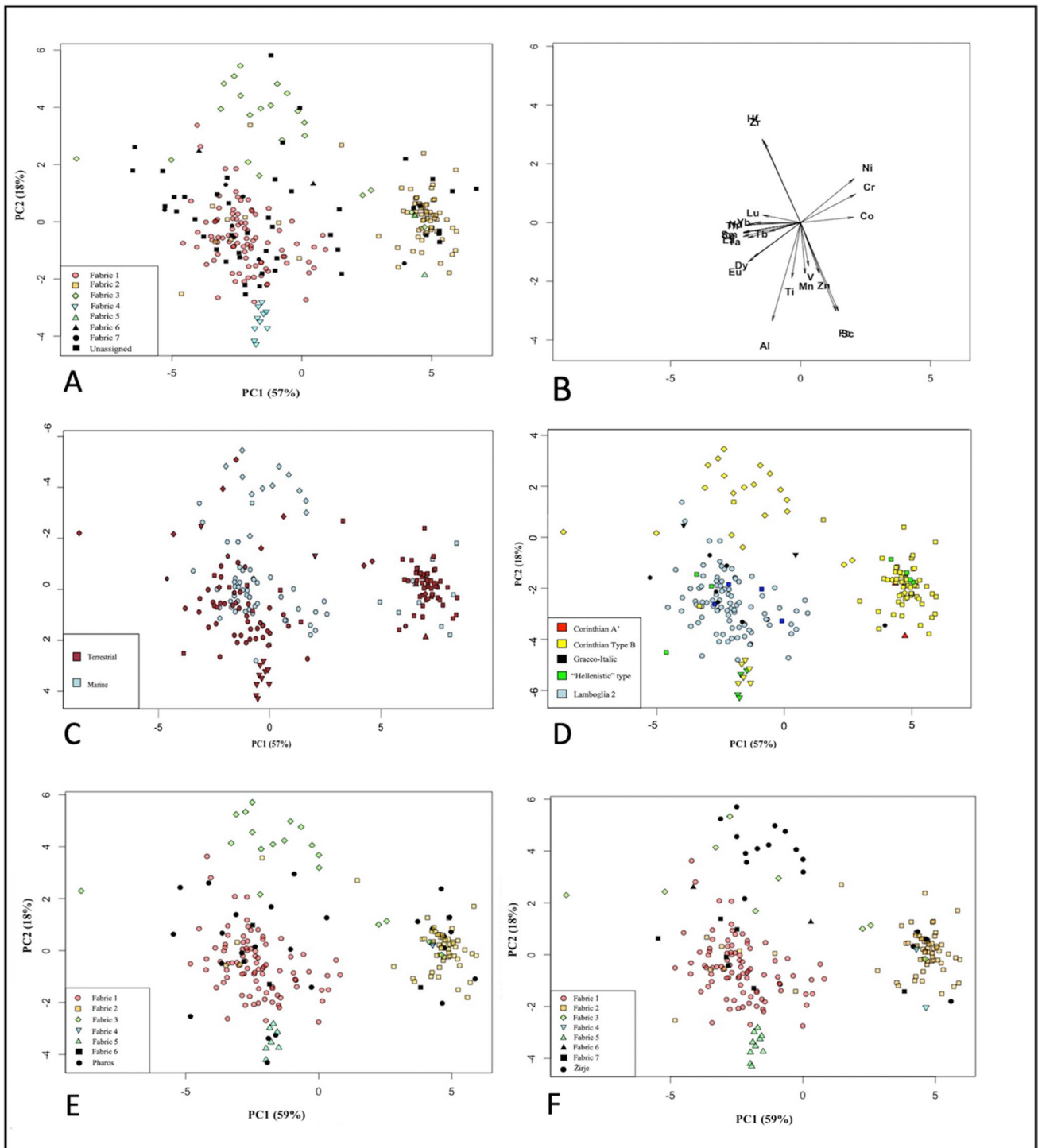
Many of the analysed amphorae sherds contain evidence for alteration during burial in hand specimen, including bioencrustation, and in thin section, in terms of the precipitation and/or removal of carbonate material (Miše et al. 2021). This is more common in the amphorae from shipwrecks; however, secondary calcite is also present in voids in certain amphorae from terrestrial sites, e.g., Resnik/Siculi. Extreme alteration combined with the fine nature of several of the fabrics hindered the petrographic classification of 46 of the sherds. The presence of secondary calcite was taken into account when examining the geochemical data below.

### Chemical classification

One sherd was removed from the geochemical dataset of 23 elements not affected by alterations (Al, Ce, Co, Cr, Dy, Eu, Fe, Hf, La, Lu, Mn, Nd, Ni, Sc, Sm, Ta, Tb, Th, Ti, V, Yb, Zn, and Zr) (Supplement 2) due to missing values or zeros. Principal component analysis conducted on the log-ratio transformed elemental values of the remaining 247 samples explains 75% of the total variation in the dataset. When plotted against each other, the

scores for PC1 and PC2 reveal several concentrated or more dispersed chemical groups, which correspond to the main petrographic fabrics (Fig. 7A). Sherds belonging to fabric 4 form a clear group characterised by high Al, Eu, Fe, and Sc, as do those of fabric 2 due to their high Co, Cr, and Ni relative to the other samples. The fabric 3 sherds are more dispersed but occur in a specific part of the score plot due to their generally high Hf and Zr (Fig. 7B) and the dominant fabric 1 samples form a cloud in the centre of the plot due to their low values for the elements Co, Cr, and Ni. The petrographically unassigned samples show chemical correspondence with those of fabrics 1, 2, and 3, perhaps suggesting that they originally belonged to several different paste compositions before alteration. A comparison of the geochemical composition of all petrographically assigned samples with their amphorae type indicates that the fabric 1/chemical group 1 sherds are mainly Lamboglia 2, the fabric 2/chemical Group 2 samples are mostly Corinthian type B sherds, the fabric 3/chemical group 3 specimens are Corinthian type B, and the fabric 4/chemical group 4 sherds have either Corinthian type B or “Hellenistic type” (Fig. 7D). Two Corinthian A’ sherds plot in chemical group 2 and are petrographically assigned to fabric 5. The same plot labelled by context reveals that the chemical groups/petrographic fabrics contain samples from both terrestrial sites and shipwrecks (Fig. 7C). Sherds from several of these compositional groups occur at single sites in both contexts, for example, the terrestrial site of Pharos (Fig. 7E) and the Žirje shipwreck (Fig. 7F).





**Fig. 7** Geochemical patterning within the dataset of the abundance of 23 elements within 247 Hellenistic and Late Republican transport amphorae from terrestrial sites and shipwrecks along the Dalmatian coast in this study, as revealed by principal component analysis. **A** Score plot of components 1 and 2, labelled by petrographic fabric. **B** Loading of score plot. **C** Score plot of components 1 and 2 labelled by context, excluding petrographically unassigned sherd. **D** Score plot

of components 1 and 2 labelled by amphorae type, excluding petrographically unassigned sherds. **E** Score plot of components 1 and 2 excluding petrographically unassigned sherds, with labelled sherds from the terrestrial sites of Pharos. **F** Score plot of components 1 and 2 excluding petrographically unassigned sherds, with labelled sherds from the shipwreck of Žirje

## Amphorae production locations

The Corinthian type B amphorae analysed in this study belong to three different compositional groups (Supplement 1; Fig. 7A and D) that may have been produced by separate workshops. Fabrics 2 and 3 (chemical groups 2 and 3) correspond to Corinthian type B fabric classes 2 and 3 of Whitbread (1995: 276–279), which are thought to have originated from either Corinth or Corfu (Fig. 2). Distinguishing between these possibilities is likely to be difficult without field sampling (Whitbread 1995: 278–283). The distinct chemical difference between the Corinthian type B sherds of fabrics 2 and 3 (chemical groups 2 and 3) (Fig. 7A and D) might suggest that they have different geographical origins, or that they may have been made by separate workshops using geologically different raw materials.

The provenance of the distinctive granite-tempered fabric 4 sherds (Fig. 7A), which occur in Corinthian type B amphorae, can be sought on the opposite coast of the Ionian Sea. A possible compositional match exists in Calabria, perhaps in Sybaris (Barone et al. 2004a) (Fig. 2), where clay paste of the same type of amphorae, the Corinthian type B, have fragments of granitic rocks as well. As this type of rock is unknown in the local geology (Fig. 4), the paste prepared by tempering with crushed granite rocks is not of local origin. The identification of the same prepared clay pastes may point to the same origin of the vessels (Sterba et al. 2009; Quinn 2022: 177), as in the case of Corinthian amphorae type B Fabric 4, to their origin in Calabrian workshop. Several “Hellenistic type” sherds also belong to fabric 4/chemical group 4 (Fig. 7A and D), suggesting that they could also have been produced in southern Italy.

The two Corinthian A’ sherds analysed in this study belong to fabric 5, but plot in chemical group 2 (Fig. 7A and D), are a close match for amphorae analysed by Whitbread (1995: 271–272). These are thought to have been made in Corinth. This is confirmed by their chemical correspondence with sherds of fabric 2 and has implications for the provenance of these Corinthian type B amphorae discussed above.

The Lamboglia 2 amphorae, which represent the commonest shape in the dataset and belong to fabric 1/chemical group 1 (Fig. 7A and D), may have originated from the workshop of Issa (Fig. 2) which is located on the Dalmatian island of Vis. According to geological maps (Fig. 4), the island of Vis is characterised by dolomite and limestone with foraminifera microfossils that were found in amphorae of calcareous fabric 1/chemical group 1 (Figs. 5B and 7A). Following the results of previous studies of pottery production on the island of Vis and the neighbouring island of Hvar (Miše et al. 2020), these types of microfossils were also found in raw clays used in the local production of Hellenistic fine tableware.

Among the Lamboglia 2 amphorae of this fabric and chemical group recovered from the Vela Svitnja shipwreck (Fig. 2), one is stamped with the abbreviation “L.POT” meaning Lucius Pontius, who Cambi (1989) identified as a wealthy merchant from Issa. Namely, his name also appears as a donor of a monument erected at the main forum of Issa in honour of Mercury, the god of trade (Cambi 1972). Four Greco-Italic type amphorae sherds also belong to fabric 1/chemical group 1 (Fig. 7A and D) and can therefore be assumed to have been made by the same workshop as the compositionally related Lamboglia 2 amphorae samples.

It is not possible at present to determine the provenance and production locations of the “Hellenistic” and Corinthian type B amphorae that belong compositionally to Fabrics 6 and 7 due to the small number of samples that can be classified in these groups. Nevertheless, an origin of Fabric 7, plotted close to Fabric 1, assumed to be produced in Issa (Fig. 7A), can also be of local origin. On the other hand, for fabric 6 an origin outside of the Adriatic is suspected.

Based on the above compositional provenance determination, certain Hellenistic and Late Roman Republican amphorae appear to have been made in a single location, for example Lamboglia 2, Greco-Italic and perhaps Corinthian A’. In contrast, other types such as Corinthian type B and “Hellenistic type” amphorae may have been produced in two or perhaps three different locations. Another interpretation that can be made from the present dataset is that certain production centres, such as those that produced Corinthian type A’ and type B amphorae of fabrics 2 and 5 corresponding to chemical group 2 manufactured more than one shape of amphorae using the different paste recipes. This may also be related to technological changes over time within the same workshop, and thus to changes in clay paste recipes. As suggested by Whitbread, fabric tempered with mudstone was replaced by fabric without a mudstone around the middle of the fifth century BC in the Corinthian type A’ in Corinth (Whitbread 1995: 278). This consequently opens up the questions of chronology and the production of Corinthian types A’ and B in the same workshop. Namely, if the amphorae with clay paste tempered with mudstone were produced before the middle of the fifth century BC, then their presence in Dalmatia before the establishment of Greek colonies (at the beginning of the fourth century BC) testifies to the pre-colonial trade in Dalmatia. Or, on the other hand, the need to reconsider the chronological framework of the production of Corinthian amphorae. More recently, James (2014) and Sanders et al. (2014) have proposed lowering the chronology of Corinthian pottery production by 150–100 years. Considering that previous scientific results showed that Corinthian type B amphorae were produced in both Corfu and Corinth, and Corinthian type A’ in Corinth (Whitbread 1995: 260–261), the matching chemical composition of these two types of amphorae, found in the same

context of the Gnjilna shipwreck, sheds new light on their production in Corinth.

On the other hand, the Dalmatian makers of the Lamboglia 2 amphorae in fabric 1/chemical group 1, manufactured one shape of amphorae using the same paste recipe. The existence of 10 different stamps on amphorae from the Vela Svitnja shipwreck (Cambi 1989) belonging to fabric 1/chemical group 1 may provide evidence for the internal organisation of the workshop at Issa and its relationship to trade in the contents of the amphorae. Namely, since they were all produced in the same workshop, the different stamps do not point to their different origin, but rather stamps served so that potters could sort batches for different clients. Coto-Sarmiento and Rubio-Campillo (2021) also came to the same conclusion that the potters did not stamp the name of the workshop owner on the amphorae, but the names of the landowners or merchants who ordered their production (Table 2).

## Distribution and trade

Having interpreted the production locations of the various amphora types and compositional groups, it is possible to reconstruct their circulation both within the Dalmatian region and the Adriatic and Ionian Seas, based upon their probable points of departure, the terrestrial locations at which they were stored or used and discarded, and the shipwrecks that sank while carrying them as cargo. Corinthian type B amphorae and their contents were being imported into the Adriatic from several workshops along the Ionian Sea coast, most likely in Calabria, Corinth, and perhaps Corfu (Fig. 8). These have been detected at terrestrial consumption sites, as cargo within shipwrecks and perhaps at redistribution centres. The analysed dataset also reveals the smaller scale movement of Lamboglia 2 and Greco-Italic amphorae within the Dalmatian region from their source on the island of Vis (Fig. 8). These containers ended up at terrestrial sites and on the seabed due to the sinking of merchant ships en route to unknown locations. It is not clear from the present dataset whether such amphorae were leaving the Dalmatian region and travelling elsewhere in the Mediterranean.

The detected movement of amphorae was almost certainly the result of commercial activity, namely, trade in the commodities that these transport containers contained. It is not possible at this point to determine the exact products that were being traded; however, possible candidates are wine and olive oil. Organic residue analysis on transport amphorae have confirmed that these commodities were shipped in these containers in the Bronze Age (e.g. Serpico et al. 2003; Steele and Stern 2017), Hellenistic (Zlateva and Rangelov 2015) and Roman periods (e.g. Pecci et al. 2013, 2017).

The amphorae originating from Vis, the town of Issa, probably contained wine, given that, according to the archives, winemaking was the main economic activity on this Dalmatian island from the 14th to the mid-twentieth century AD (Kirigin et al. 2006a). Although no written documents survived from Hellenistic and Roman periods, archaeological evidence strongly suggests that wine was an important commodity for the Issaeans. Namely, a wine drinking cup (*kantharos*) and grape were minted on Issaeian coins; the name of Dionysius—the god of wine—was a common name on Issaeian tombstones at the Hellenistic and Early Roman necropolis, wine drinking set containing a pitcher (*oinochoe*), a jug (*pelike*) and cup (*skyphos*) were placed in the tombs next to each deceased, and finally, numerous amphorae sherds were found around the fertile fields on the island (Kirigin et al. 2006a and Kirigin et al. 2006b). Planned organic residue analysis on these Lamboglia 2 sherds and the other amphorae coming from workshops outside of the Adriatic will hopefully shed light on their contents. It is highly likely that the distribution patterns are related to refilling and reusing amphorae, and possibly with different commodities, such as wine and then olive oil (Pecci et al. 2017), or as in case of the Žirje shipwreck, raw materials. Namely, two sealed amphorae recovered at the site of the shipwrecks contained raw clay (Miliša et al. 2022: 181). Whether this raw clay was used to make pottery will only be determined through detailed analyses.

Comparison between the provenance and movement of amphorae provides possible insights into differences in the system of trade in Dalmatia between fourth and first century BC. The Žirje shipwreck, dated to the fourth century BC sank while carrying Corinthian type B amphorae from both Corinth and Corcyra on Corfu (Figs. 1 and 8). It is difficult to determine whether these amphorae were loaded on the ship in Corinth and then on Corcyra, and whether the ship was engaged in “cabotage” or “tramping”. This type of trade, sailing from port to port in search of markets for part of the cargo, is thought to have been common in the ancient Mediterranean (Horden and Purcell 2000: 140, 150). However, as Arnaud (2012) points out, it may have been illegal in Hellenistic times, as commerce was controlled by the state and regulated by treaties. Considering this point, as well as its small size, the departure port of the ship that sank near the island of Žirje may have been in Dalmatia, with the most likely candidate being Pharos. The same two compositional groups of Corinthian type B amphorae were found in this Greek colony. This suggests that Pharos received goods from different parts of the region and could have acted as an intermediary in regional trade during the Hellenistic period. Merchants at Pharos may have reused amphorae from different suppliers and sailed to northern Dalmatia (Fig. 8). The analysis of amphorae from Zemunik, the settlement of the Liburnian community in northern Dalmatia, in this study

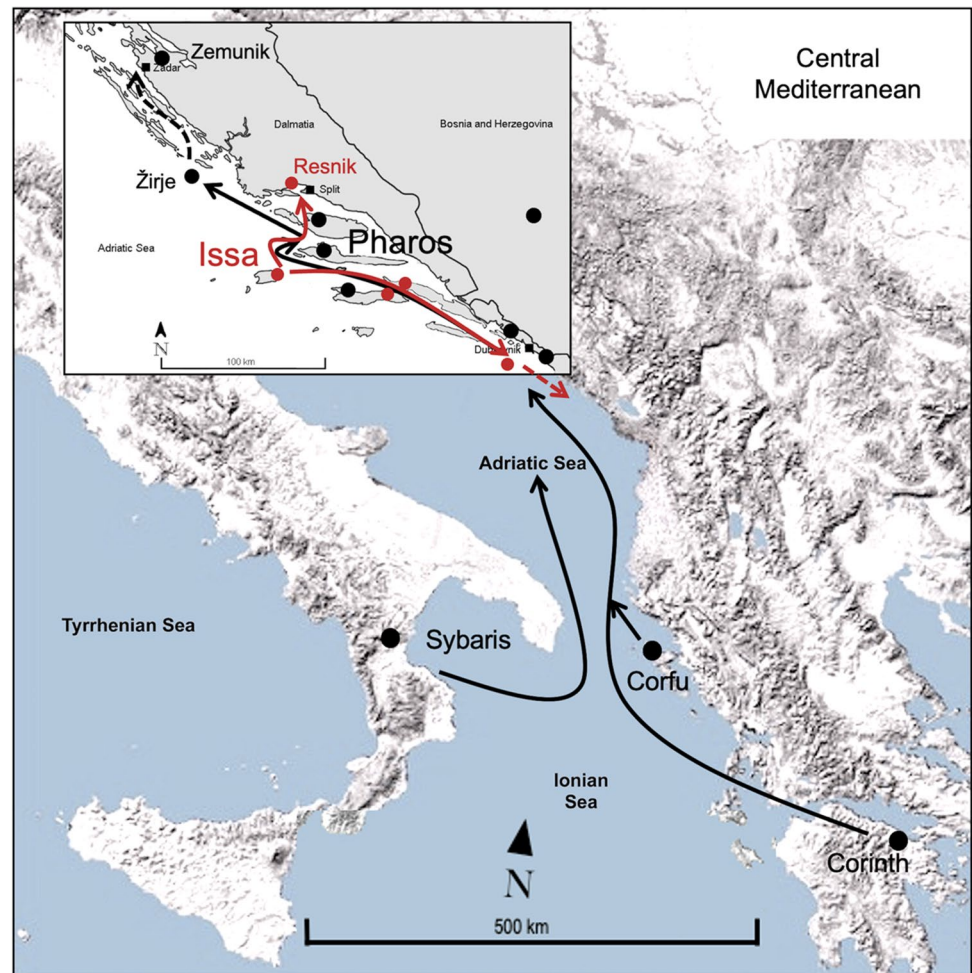
**Table 2** Summary of the results of the petrographic and chemical analysis of amphorae from Dalmatia with an interpretation of their origin

Site	Context	Type of archaeological site	Type of amphorae	Chronological range of production	Fabric group	Chemical group	Workshop
Pharos	Greek colony, residential complex	production site or distribution site	Corinthian A'	Early fifth to second c. BC (146 BC)	5	2	Corinth/Corfu
			Corinthian type B	Last quarter of sixth to second c. BC	2	2	Corinth/Corfu
			Corinthian type B	Last quarter of sixth to second c. BC	3	3	Unknown
			Greco-Italic	Third c. BC	3	Scattered	Unknown
			"Hellenistic" type	Late fourth to end third c. BC	2	2	Corinth/Corfu
					4	4	Calabria
					6	Scattered	Unknown
		7	Scattered	Unknown			
		Lamboglia 2	Second and first c. BC	1	1	Issa	
Crveni Grm	Indigenous Iron Age settlement	consumption site	Corinthian type B	Last quarter of sixth to second c. BC	2	2	Corinth/Corfu
					3	3	Unknown
					4	4	Calabria
Kopila	Indigenous Iron Age settlement	consumption site	Corinthian type B	Last quarter of sixth to second c. BC	4	4	Calabria
Rat	Indigenous Iron Age settlement	consumption site	Corinthian type B	Last quarter of sixth to second c. BC	2	2	Corinth/Corfu
					3	3	Unknown
					4	4	Calabria
Sokol	Indigenous Iron Age settlement	consumption site	Corinthian type B	Last quarter of sixth to second c. BC	2	2	Corinth/Corfu
					6	Scattered	Unknown
Stine	Indigenous Iron Age settlement	consumption site	Corinthian type B	Last quarter of sixth to second c. BC	3	3	Unknown
Vilina Cave	Cave sanctuary	consumption site	Corinthian type B	Last quarter of sixth to second c. BC	2	2	Corinth/Corfu
					4	4	Calabria
					6	Scattered	Unknown
Zemunik	Indigenous Iron Age settlement	consumption site	Corinthian type B	Last quarter of sixth to second c. BC	2	2	
					4	4	Calabria
Gnjilna	Shipwreck	shipwreck	Corinthian A'	Early fifth to second c. BC (146 BC)	5	2	Corinth/Corfu
			Corinthian type B	Last quarter of sixth to second c. BC	2	2	Corinth/Corfu
Žirje	Shipwreck	shipwreck	Corinthian type B	Last quarter of sixth to second c. BC	2	2	Corinth/Corfu
					3	3	Unknown
Issa/Vela Svitnja	Shipwreck	shipwreck near production site	Lamboglia 2	Second and first c. BC	1	1	Issa
Resnik/Siculi	Port	land port facilities	Lamboglia 2	Second and first c. BC	1	1	Issa

**Table 2** (continued)

Site	Context	Type of archaeological site	Type of amphorae	Chronological range of production	Fabric group	Chemical group	Workshop
Nakovana Cave	Cave sanctuary	consumption site	Lamboglia 2	Second and first c. BC	1	1	Issa
Polačišće	Shipwreck	shipwreck	Lamboglia 2	Second and first c. BC	1	1	Issa
Supetar—Cavtat	Shipwreck	shipwreck	Lamboglia 2	Second and first c. BC	1	1	Issa

**Fig. 8** Map of the Central Mediterranean with the Adriatic Sea and the reconstructed trading routes: Hellenistic period in the Adriatic-Ionian region (fourth and third century BC marked with black arrows) compared to and Late Roman Period (second and first century BC marked with red arrows)



reveals that they consumed goods carried in amphorae produced in the Ionian basin. The Žirje shipwreck seems to prove for the first time that Hellenistic maritime trade in the Adriatic involved redistribution and shed a new light into trading activities. The complex picture of the Hellenistic trade is also strengthened by the cargo of the Gnjlina shipwreck (Fig. 2). This merchant ship that sank near the southern cape of the island of Vis, carried two different types of amphorae, the Corinthian A' and type B of fabrics 2 and 5/chemical group 2, but produced in the same workshop.

In contrast, to the mixed cargo of Hellenistic shipwrecks indicating a complex redistribution system, the amphorae that sank with the Late Roman Republican vessels in this study belong to the same type, Lamboglia 2, and have a single interpreted origin, namely, Issa on the Dalmatian island of Vis. The homogeneity of Lamboglia 2 amphorae suggests that one dominant workshop was manufacturing and supplying amphorae in Dalmatia in the Late Republican period of the second and first century BC. These amphorae were also recovered from land port facilities in Resnik.

These possible changes in trading patterns should be viewed in the light of political events that took place on the Adriatic in the late third century BC. Namely, Issa complained to the Roman Senate about Illyrian piracy and how it harmed their trade. Rome, prior to that time, did not show interest in the Eastern Adriatic, preoccupied with the wars on the Apennine peninsula, took this as an invitation. The wars of 219, 209, and 168 BC ended the Illyrian kingdom, and the Roman army destroyed Pharos because the city sided with the Illyrians. Consequently, Issa as a Roman ally became the most powerful city in the region in the next century and established some form of alliance with the neighbouring communities on mainland, in Tragurion, today Trogir and Epetion, today's eastern suburbs of Split (Čače 1999). Both positions allowed Issa control of the port at Resnik, ancient Siculi (Fig. 2), and the mountain pass that connects coastal Dalmatia with the hinterland (Šuta 2012–2013). Issa organised a possible military station or settlement on the southern part of the island of Korčula in Lumbarda (Radić and Borzić 2017) overlooking the narrow maritime canal between the island of Korčula and the Pelješac peninsula where also Polačišće shipwrecks is located (Fig. 2). The distribution amphorae from fabric 1, produced in Issa, overlaps with sites that were under Issa's remit, permitting control of the main maritime trading routes in Dalmatia (Figs. 6 and 8). Further to the south of the eastern Adriatic, in today's Boka Kotorska in Montenegro, Lamboglia 2 amphora with the same M. POT stamp, as it was found in the Vela Svitnja (Cambi 1989), has been found (Royal 2012). In the light of these new results, the statement by Agatharhidus from Alexandria in the second century BC, that Issa produced and exported wine (Kirigin et al. 2006a), may seem plausible.

## Conclusions

The sourcing of several hundred transport amphorae sherds from a large number of production sites, consumption contexts, and shipwrecks along the Dalmatia coast of Croatia in this study has shed new light on the nature of maritime trade and commerce between Adriatic communities and other centres in the central Mediterranean in the second half of the last millennium BC. The scientific study of the raw materials and paste preparation technology and its comparison to amphorae type, geographic occurrence and published data from possible source areas has permitted the reconstruction of trade patterns in several directions, revealed the stopping points and the strategies of merchant ships, as well as identifying changes within the trading system between Hellenistic and Late Roman Republican times.

In Dalmatia, during the Hellenistic period, goods were mainly transported in Corinthian type amphorae, A' and type B, which were produced in several workshops, Corfu, Corinth, and a workshop in southern Italy, possibly in Sybaris

in present-day Calabria. The mixed cargo of amphorae from the Žirje and Gnjilna shipwrecks points to a complex pattern of trade in this period that may have included reloading and redistribution. In contrast, the compositional homogeneity of cargo on ships loaded with Lamboglia 2 amphorae in the Late Roman Republican period reveals a different economic strategy whereby amphorae and their contents consumed in Dalmatia were obtained from a single workshop/producer.

The analysis of Lamboglia 2 amphorae from Issa, as well as Greco-Italic amphorae, seems to confirm archaeological and historical evidence that it produced amphorae as containers to export its own wine in the late Hellenistic and Late Roman Republican periods. The same cannot be claimed for the Corinthian type B found on neighbouring Pharos, which are likely to have originated from workshops in Corfu, Corinth, and southern Italy. The occurrence of transport containers from such diverse foreign locations strongly suggests that it was a centre of redistribution rather than the place of production.

The study further demonstrates the value of scientific compositional analysis of the paste of transport amphorae, given the difficulty of interpreting their sources based on amphorae shape and epigraphic evidence alone. The application of such data to sherds from shipwrecks and consumption sites can provide new insights into the complex patterns of trade and ancient economy in the Mediterranean.

**Supplementary information** The online version contains supplementary material available at <https://doi.org/10.1007/s12520-022-01689-x>.

**Acknowledgements** The authors of the paper would like to thank Dr Branko Kirigin, Dr Sara Popović, Andrea Devlahović, and Aldo Čavić from the City Museum in Stari Grad on Hvar; Boris Čargo from the Archaeological Museum in Split; Ivan Šuta from the Municipality Museum Kaštela; Dr Irena Radić Rossi and Dr Igor Borzić from the Department of Archaeology at the University of Zadar; Dr Domagoj Perkić from Dubrovnik Museums; Jurica Bezjak from the Croatian Conservation Institute, Department of Underwater Archaeology; and Dr Vedran Barbarić from the University of Split for kindly providing the material for analysis. We would also like to thank Prof Irena Radić Rossi and Daniel Frka for providing the photo of the Žirje shipwreck. Special thanks go to Prof Ian Whitbread who sat patiently with me while we compared thin sections of Dalmatian amphorae with his collection of Corinthian and Corfu amphorae at the British School of Athens, and to Dr Evangelia Kiriati, the director of the Fitch Laboratory, for permission to examine the collections. Many thanks to Dr Michael Charlton from the UCL Institute of Archaeology for his guidance and assistance with statistical analyses, and many colleagues for their suggestions and advice while researching this complex topic.

**Author contribution** All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by MM. The first draft of the manuscript was written by MM with edits and comments from PSQ. All authors read and approved the final manuscript.

**Funding** The research that has led to these results has received funding from the European Commission Marie Skłodowska-Curie Actions – Individual Fellowship, as part of the project *Economy of Pre-Roman*

*Adriatic Communities: amphora production and trade patterns in a changing world*, EPRAC, Award Number: 17737. Partial financial support was received from a subsidy from US National Science Foundation grant number 191277.

**Data availability** All data generated or analysed during this study are included in this published article (as Supplement 1, detailed description of petrographic fabrics; Supplement 2, raw data on geochemical composition of all analysed samples; and Supplement 3, the list of targeted sites in the study and sites mentioned in the paper).

**Code availability** Not applicable.

## Declarations

**Ethics approval** There were not ethical issues as the research involved human participants, and a statement on welfare of animals if the research involved animals.

**Consent to participate** Not applicable.

**Consent for publication** All authors consent to the publication of the results presented in the manuscript.

**Conflict of interest** The authors declare no competing interests.

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