comptes rendus palevol
2023 • 22 • 21

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art. 22 (21) — Published on 26 June 2023
www.cr-palevol.fr

PUBLICATIONS SCIENTIFIQUES

Couverture / *Cover* :
Made from the Figures of the article.

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diff.pub@mnhn.fr / https://sciencepress.mnhn.fr

Académie des sciences, Institut de France, 23 quai de Conti, 75006 Paris.

ISSN (imprimé / *print*) : 1631-0683/ ISSN (électronique / *electronic*) : 1777-571X

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Submitted on 22 February 2022 | Accepted on 29 June 2022 | Published on 26 June 2023

urn:lsid:zoobank.org:pub:EAFFCF5C-5D7E-4A42-B711-42A973492780

Abad M., Ruiz F., Arroyo M., Gómez G., Muñoz A. F., Campos J. M., Bermejo J., Fernández L., Bermejo A., González-Regalado M. L., Tosquella J., Rodríguez Vidal J., Muñiz F., Pozo M., Cáceres L. M., Gómez P., Toscano A., Izquierdo T. & Romero V. 2023. — Late Holocene filling of the Canale di Imbocco (Portus, central Italy): a multidisciplinary palaeoenvironmental perspective. *Comptes Rendus Palevol* 22 (21): 467-478. https://doi.org/10.5852/cr-palevol2023v22a21

ABSTRACT
Portus was the main port of imperial Rome from the 2nd century AD to the 5th century AD, with an inner, hexagonal port (Trajan basin) and an outer port (Claudius basin) linked by a channel bounded by quays. Six sedimentary facies have been differentiated in the geological analysis of a core extracted in this channel, basically composed of poorly classified bioclastic muds typical of restricted environments, accumulations of *Posidonia oceanica* (Linnaeus) Delile, 1813 and a final anthropic fill. The subfossil record of bivalves, foraminifera and ostracods is characteristic of Mediterranean brackish environments (lagoons, estuaries, deltas) with significant environmental stress, due to changes in the physical-chemical parameters and probably the periodic dredging of this seaway during a period of about 300 years. The presence of "Neptune balls" points to the development of probable stormy periods that deposit these unique structures in the internal areas of this historic port.

KEY WORDS
Sedimentology,
fossil record,
channel fill,
paleoenvironments,
Portus,
imperial Rome,
Central Italy.

RÉSUMÉ
Comblement du Canale di Imbocco (Portus, Italie centrale) à l'Holocène supérieur : une perspective paléoenvironnementale pluridisciplinaire.
Portus était le principal port de la Rome impériale du IIe siècle après J.-C. au Ve siècle après J.-C., avec un port intérieur hexagonal (bassin de Trajan) et un port extérieur (bassin de Claudius) reliés par un canal délimité par des quais. Six faciès sédimentaires ont été différenciés dans l'analyse géologique d'une carotte extraite dans ce chenal, composée essentiellement de boues bioclastiques mal classées typiques des milieux restreints, d'accumulations de *Posidonia oceanica* (Linnaeus) Delile, 1813 et d'un dernier remblai anthropique. Le registre subfossile des bivalves, des foraminifères et des ostracodes est caractéristique des milieux saumâtres méditerranéens (lagunes, estuaires, deltas) avec des contraintes environnementales importantes, dues aux modifications des paramètres physico-chimiques et probablement au dragage périodique de cette voie maritime pendant une période d'environ 300 ans. La présence de « boules de Neptune » indique le développement de périodes orageuses probables qui déposent ces structures uniques dans les zones internes de ce port historique.

MOTS CLÉS
Sédimentologie,
registre fossile,
remplissage de canal,
paléoenvironnements,
Portus,
Rome impériale,
Italie centrale.

INTRODUCTION

The current coastline is the transitory result of the interaction between numerous factors, such as fluvial action, wave direction and intensity, near-shore drift currents, sedimentary dynamics or human interactions. Its Holocene evolution is reconstructed based on the multidisciplinary analysis and interpretation of the sedimentary facies that make up its geological record, both in exposed sections and continuous sediment cores. The study is multidisciplinary and comprises the sedimentological characterization, the analysis of the fauna and flora or the distribution of the mineralogical components, with an unavoidable integration of radiometric dating (Zanor *et al.* 2013; González-Regalado *et al.* 2020).

This study is especially interesting in certain archaeological contexts, such as ancient cities or ports, whose development could have been conditioned by coastal erosion or sedimentation processes, by specific episodes of clogging or even by high-energy events, such as large storms or tsunamis (Kaniewski *et al.* 2018; Giaime *et al.* 2019). In these environments, the geoarchaeological analysis and especially the paleontological record is of special interest to infer the environmental conditions of each defined evolutionary phase, as well as the paleogeographic scenarios that occurred in the past (Salomon *et al.* 2012; Amato *et al.* 2020).

This paper carries out a multidisciplinary analysis of a continuous core obtained in Portus (Italy), one of the main Mediterranean ports during the Roman imperial era. It is intended to obtain a paleoenvironmental interpretation of its surroundings based on the application of different geological techniques. This study is part of the DEATLANTIR-I and DEATLANTIR-2 projects developed by the University of Huelva in the Lanterna dock and adjacent areas of Portus. A summary of the first findings can be consulted in Bermejo *et al.* (2021).

STUDY AREA

The ancient port of Portus was located about 30 km southwest of Rome, near the mouth of the Tiber River (Fig. 1A). Currently, it is a protected area within the Riserva Naturale Statale di Litorale Romano, which is about 2 km from the Tyrrhenian Sea and is bordered to the north by the Leonardo Da Vinci International Airport and to the west by the town of Fiumicino (Fig. 1B). This huge port was basically made up of an outer port or Claudius basin (*c.* 200 ha), which jutted out into the sea sheltered by two artificial breakwaters, a dock (*c.* 1 ha) and the inner hexagonal port of Trajan (*c.* 32 ha) (Keay 2012). Both ports communicated through the Canale di Imbocco, limited by wharves, among which was the elongated wharf of the Lanterna (Fig. 1B-D), and in turn with the Tiber river through an artificial canal (Fig. 1B: Fossa Traiana). This channel of communication between both ports had a draft of about 6-7 m, while both the outer and inner ports reached 7-8 m in depth (Goiran *et al.* 2010; Mazzini *et al.* 2011).

In 42 AD, Emperor Claudius started the construction of Portus due to: 1) the growing commercial demands of Rome, with more than a million inhabitants at this time (Mar *et al.* 2015); 2) the insufficiency of the port of Ostia (Fig. 1B) to satisfy their needs; and 3) its clogging problems linked to the flooding of the Tiber River and the coastal drift currents, which run from the NW-SE direction in this sector of the Italian coast. Its exposure to storms, with the destruction of 200 ships in 62 AD, coupled with continued silting, forced Emperor Trajan to expand it in the early 2nd century AD (100-112 AD; Keay *et al.* 2005).

Between the 2nd-5th centuries AD, Portus was one of the main ports of the Roman Empire, both for the import of raw materials and food, and for the export of products from the Tiber River valley. Its decline began due to progressive silting, Vandal incursions and the Gothic wars of the mid-6th century AD. From the 7th century AD, port activities continued only in the Trajan hexagon, but littoral progradation caused its abandonment and conversion to a swamp during the Medieval Warm Period (*c.* 950-1250 AD) (Di Bella *et al.* 2011; O'Connell *et al.* 2019).

Several studies have addressed the paleoenvironmental reconstruction of Portus and its surroundings, based on the analysis of continuous cores extracted in the interior port (e.g. Mazzini *et al.* 2011; Pepe *et al.* 2013; Delile *et al.* 2014) or the Claudio basin (Di Bella *et al.* 2011). Some additional researchs were focused on the connection channel between both ports (e.g. Goiran *et al.* 2010).

MATERIAL AND METHODS

Field work

Core PT (Fig. 1D, E: 5 m depth; 41°46'24"N, 12°15'11"E) was extracted in 2020 by the company Geocompany using usual rotation techniques in the entrance channel to Trajan basin, in the vicinity of the Lanterna dock. In an initial phase, a visual differentiation of the sedimentary facies was carried out, taking into account the lithology, the color, the contact between the different sedimentary units, the macrofaunistic content and the visible plant remains.

Sedimentological analysis

Sixteen representative samples of the identified facies were identified (Fig. 1E). They were sieved through a sieve column (2-0.063 mm), with a homogenization of the results in percentages of the different grain sizes. This grain size distribution was analyzed using the GRADISTAT software (Blott & Pye 2001), while the parameters (mean, classification, asymmetry and kurtosis) were calculated through the logarithmic graphical method of Folk & Ward (1957).

Faunal analysis

Forty grams of each sample were separated for paleontological study, which were processed through a 125 µm mesh diameter sieve. The entire bivalve macrofauna was extracted and classified according to Trainito & Doneddu

Table 1. — Main textural parameters of the studied samples.

Sample	PT-1	PT-2	PT-3	PT-4	PT-5	PT-6	PT-7	PT-8	PT-9	PT-10	PT-11	PT-12	PT-13	PT-14	PT-15	PT-16
Sample type	Unimodal very poorly sorted	Trimodal very poorly sorted	Polymodal very poorly sorted	Trimodal poorly sorted	Bimodal very poorly sorted	Bimodal very poorly sorted	Bimodal poorly sorted	Polymodal very poorly sorted	Bimodal very poorly sorted	Bimodal very poorly sorted	Polymodal very poorly sorted	Polymodal very poorly sorted	Bimodal very poorly sorted	Polymodal very poorly sorted	Bimodal very poorly sorted	Trimodal poorly sorted
Textural group	Muddy gravel	Muddy sandy gravel	Gravelly muddy sand	Gravelly mud	Gravelly mud	Muddy gravel	Gravelly mud	Gravelly mud	Muddy gravel	Muddy gravel	Gravelly mud	Gravelly mud	Gravelly mud	Gravelly mud	Muddy gravel	Slightly gravelly muddy sand
Mean	Coarse sand	Coarse sand	Medium sand	Very fine sand	Fine sand	Fine sand	Very fine sand	Fine sand	Fine sand	Fine sand	Fine sand	Fine sand	Fine sand	Fine sand	Medium sand	Very fine sand
Sorting	Very poorly sorted	Very poorly sorted	Very poorly sorted	Poorly sorted	Very poorly sorted	Very poorly sorted	Poorly sorted	Very poorly sorted	Very poorly sorted	Very poorly sorted	Very poorly sorted	Very poorly sorted	Very poorly sorted	Very poorly sorted	Very poorly sorted	Poorly sorted
Skewness	Very fine skewed	Very fine skewed	Symmetrical	Very coarse skewed	Very coarse skewed	Very coarse skewed	Very coarse skewed	Very coarse skewed	Very coarse skewed	Very coarse skewed	Very coarse skewed	Very coarse skewed	Very coarse skewed	Very coarse skewed	Symmetrical	Very coarse skewed
Kurtosis	Platykurtic	Very platykurtic	Very platykurtic	Leptokurtic	Very platykurtic	Very platykurtic	Extremely leptokurtic	Very platykurtic	Very platykurtic	Very platykurtic	Platykurtic	Mesokurtic	Platykurtic	Very platykurtic	Very platykurtic	Mesokurtic
% Gravel	67.4	55.9	19	6.4	24.6	30.4	9.6	24.6	33.1	33.1	17.9	16.2	20.2	28.5	37.3	3.1
% Sand	13.7	25.3	42.6	25	12.6	16.1	15.8	26	10.7	10.5	30.9	22.8	18.5	24.6	21.8	48.8
% Mud	18.9	18.8	38.4	68.5	62.8	53.5	74.6	49.4	56.2	56.4	51.2	61	61.4	46.9	40.8	48.1

(2005) and the World Register of Marine Species (WoRMS). In addition, the analysis of the most abundant species of foraminifera was carried out, which were classified according to Loeblich & Tappan (1988) updated in the World Foraminifera Database (Hayward *et al.* 2021) and Milker & Schmiedl (2012). An analysis of the ostracod distribution was also carried out and individuals were classified according to Bonaduce *et al.* (1976), Meisch (2000), Mazzini *et al.* (2011) and WoRMS.

Dating

Two radiometric dates were obtained at the Beta Analytic laboratories (Miami, United States). They were calibrated with the Calib 8.2 program, using the reservoir effect (58 ± 85 yr) indicated by Reimer & McCormac (2002) for this sector of the Western Mediterranean during this time interval.

RESULTS

Sedimentary facies and malacofauna

Six sedimentary facies were differentiated (Fig. 2: F-1 to F-6). F1 (5-4.75 m depth) is composed of poorly classified, poorly compacted, gray sandy muds with a strongly asymmetric and mesokurtic distribution (Table 1: silt + clay: 48.6%; sands: 48.2%). This facies includes few valves of the bivalves *Polititapes rhomboides* (Pennant, 1777) (Fig. 3B) and *Modiolus* spp. (juvenile forms), as well as balanid plates and fragments of bryozoan colonies. F2 is formed by fairly compact bioclastic muds (silt + clay: 41-47%; gravel-sized bioclasts: 28-37%), very poorly classified and with a highly asymmetric and very platykurtic distribution in most samples. The macrofaunistic content of the bioclastic gravel fraction makes it possible to differentiate between two subfacies (Table 2): 1) F2a (4.75-4.25 m; 4-3.3 m; 2.85-2.2 m), characterized by the predominance of valves and fragments of the bivalve *Polititapes rhomboides*; and 2) F2b (4.25-4 m; 1.85-1.65 m), with a greater abundance of the bivalve *Cerastoderma glaucum* (Bruguière, 1789) (Fig. 3A). Both species present similar proportions in the central part of the core (F2a-F2b: 2.2-1.85 m).

F3 (3.3-2.85 m; 1.65-1.25 m) is made up of compact accumulations of fibers from the seagrass *Posidonia oceanica* (Linnaeus) Delile, 1813 (Fig. 3E) with a muddy matrix (silt + clay: 60-62%; gravel-sized bioclasts: 16-28%). This facies includes hemispherical structures of fibers of this phanerogam called “Neptune balls” (Fig. 3F), as well as shells and fragments of *Cerastoderma glaucum* and remains of serpulid calcareous tubes.

In the uppermost 1.25 m of core PT, the grain size and its composition make it possible to differentiate three facies, as follows: 1) F4 (1.25-0.65 m), composed of poorly selected sandy muds and muddy sands with variable classification and symmetry; 2) F5 (0.65-0.4 m), made up of very poorly classified fine gravels (gravel: 55.9%), very platykurtic and with a slightly asymmetrical distribution; and 3) F6 (0.4-0 m), with unimodal medium to coarse gravels (gravel: 67.3%)

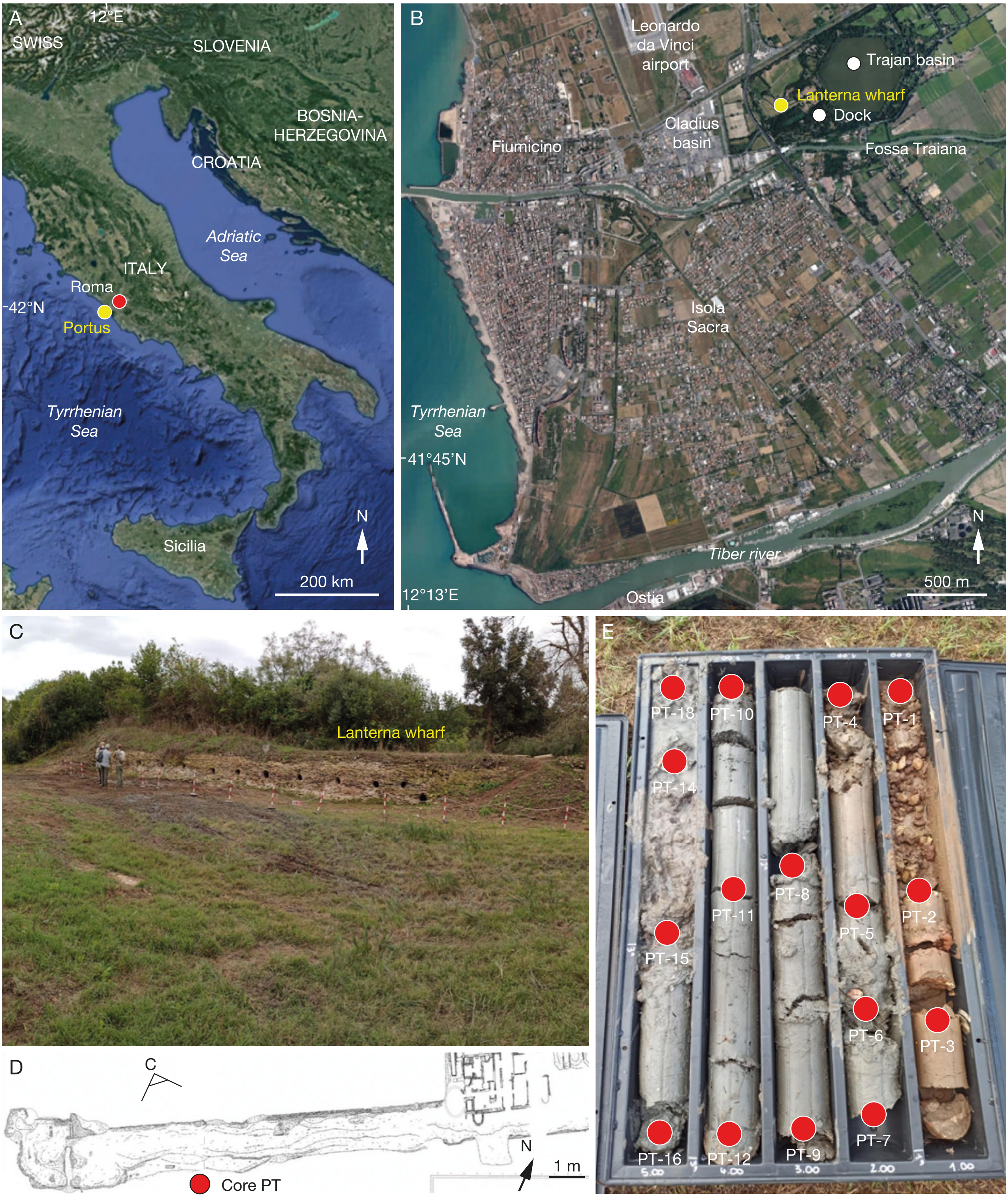

Fig. 1. — **A**, Location of Portus; **B**, present-day map of Portus and the adjacent areas; **C**, Lanterna dock, located in the Canale di Imbocco; **D**, map of Lanterna dock, with location of core PT; **E**, core PT, with the situation of the studied samples. Credits: A, B, courtesy of Google Earth.

with numerous quartzite edges. These three facies are distinguished by a scarcity of bioclastic fragments and the presence of construction material of anthropic origin (residues of mortar, cement, etc.).

Microfauna

Foraminifera and ostracods are present in all facies except F6. Benthic foraminifera are scarce in F1 (<5 individuals/gram) and are composed by rare specimens of *Ammonia beccarii*

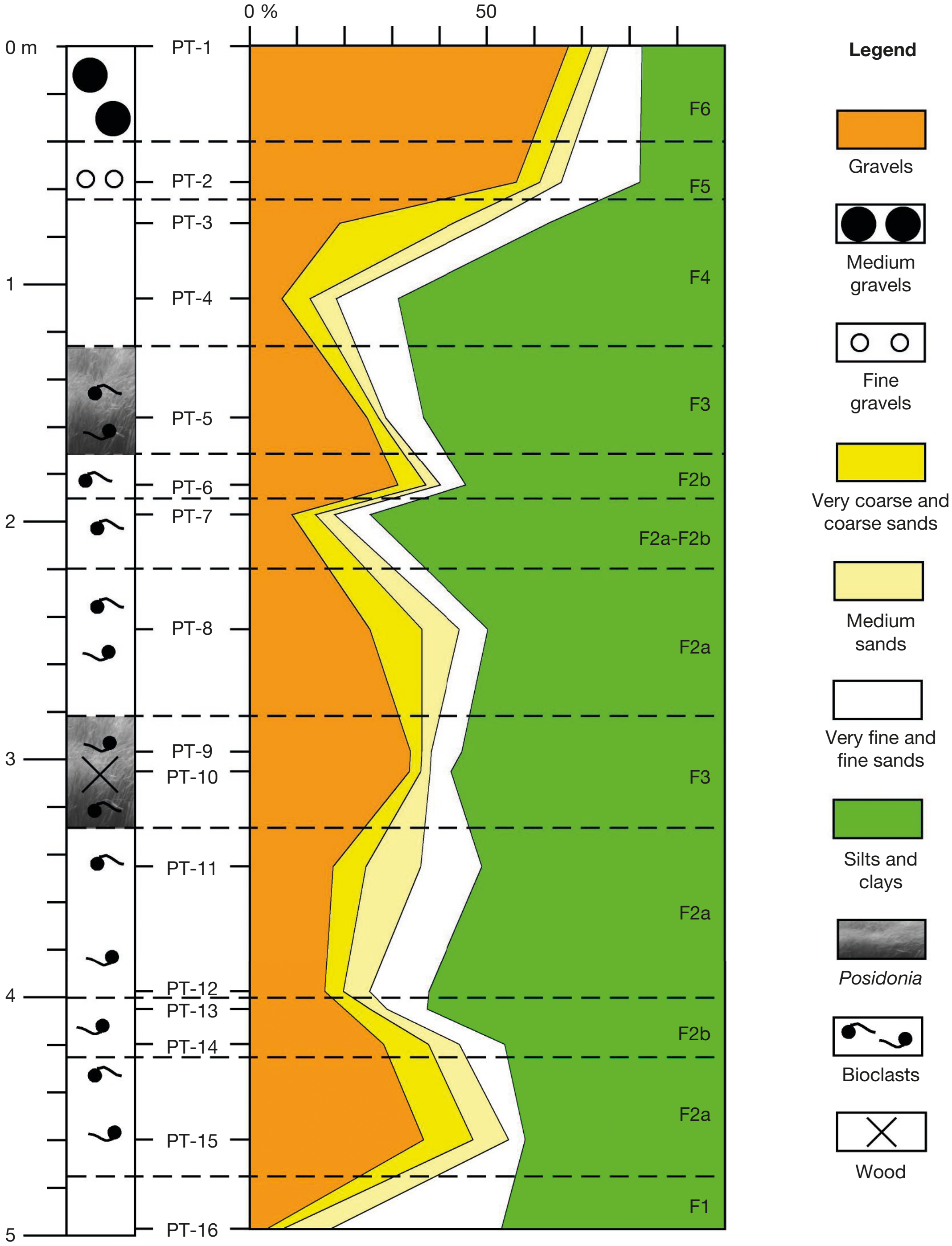

FIG. 2. — Grain-size analysis of core PT, with the delimitation of the different sedimentary facies.

(Linnaeus, 1758), *Elphidium crispum* (Linnaeus, 1758), and miliolid fragments (mainly *Quinqueloculina* and *Triloculina*), heavily reworked with loss of the last chambers. Ostracods are mainly represented by moults and adults of *Cyprideis torosa* (Jones, 1850) (Fig. 3E) and *Pontocythere turbida* (Müller, 1894), together with some loose valves of *Carinocythereis* spp.

The density of these microfaunistic groups increases in F2 (15-20 individuals/gram). *Ammonia beccarii* (Linnaeus, 1758) and *Ammonia tepida* (Cushman, 1926) (Fig. 3C) are the most representative benthic foraminifera of F2a, frequently accompanied by the ostracods *Cyprideis torosa* and *Pontocythere turbida*. *Ammonia tepida* is more abundant in F2b, while *Loxoconcha elliptica* Brady, 1868 and *Cyprideis torosa* are the most representative ostracod species.

Benthic foraminifera are abundant in F3, with *A. tepida* (>70%) as the most significant species (10-20 individuals/gram). Ostracods are notably more abundant than foraminifera, with numerous valves and shells of *C. torosa* (>300 individuals/gram) and frequent specimens of *Loxoconcha elliptica* and *Pontocythere turbida*. The abundance of benthic foraminifera

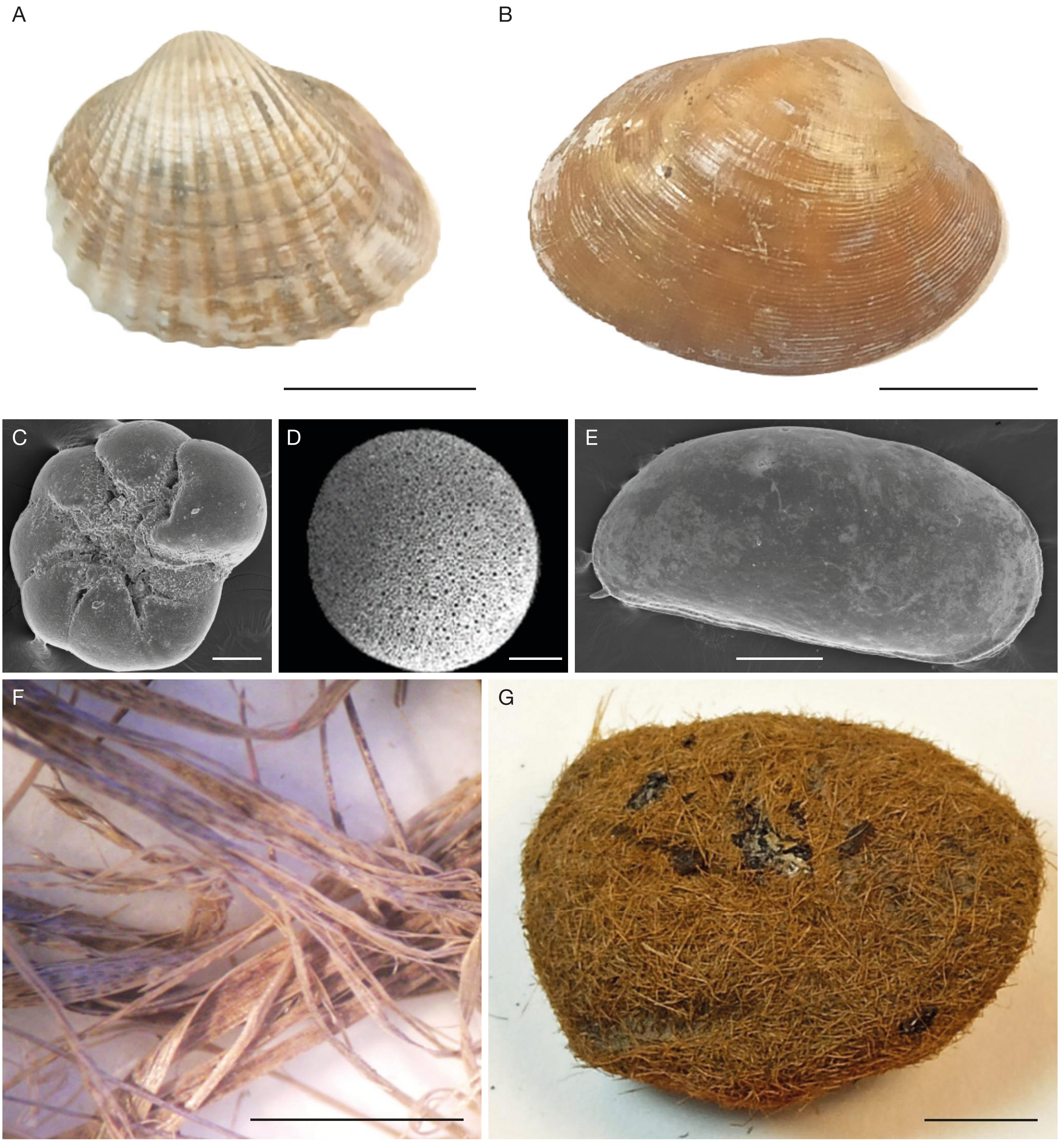

Fig. 3. — Main species of core PT: **A**, **B**, bivalves: **A**, *Cerastoderma glaucum* (Bruguière, 1789); **B**, *Polititapes rhomboides* (Pennant, 1777); **C**, **D**, foraminifera: **C**, *Ammonia tepida* (Cushman, 1926), umbilical view; **D**, *Orbulina universa* d'Orbigny, 1839; **E**, Ostracoda: *Cyprideis torosa* (Jones, 1850), right valve; **F**, **G**, plant remains: **F**, fibers of *Posidonia oceanica* (L.) Delile; **G**, "Neptune ball" of *Posidonia oceanica*. Scale bars: A, B, G, 1 cm; C, D, 100 µm; E, 200 µm: F, 3 mm.

is even higher in F4, with a high number of individuals of *Ammonia tepida* (>80% of the specimens; >50 individuals/gram) and frequent *Haynesina depressula* (Walker & Jacob, 1798) and *Elphidium crispum*. In this facies, the planktonic forms are represented by *Globigerina bulloides* d'Orbigny, 1826, while *Loxoconcha elliptica* (30-40 individuals/gram) is the most representative ostracod.

Benthic foraminifera notably decrease in F5 (<20 individuals/gram), with predominance of *Ammonia tepida* and, to a lesser extent, *Ammonia beccarii* and *Haynesina depressula*. It is noteworthy the presence of frequent individuals of planktonic foraminifera (>5 individuals/gram), especially belonging to *Globigerina bulloides*, *Trilobatus trilobus* (Reuss, 1850) and *Orbulina universa* d'Orbigny, 1839 (Fig. 3D).

TABLE 2. — Main paleontological features of the different sedimentary facies.

Facies	Bivalves	Benthic foraminifera	Planktonic foraminifera	Ostracoda	Main plant remains	Others
F1	*Polititapes rhomboides*	Rare *Ammonia beccarii* *Elphidum crispum*	Fragments	Frequent *Cyprideis torosa* *Pontocythere turbida*	Very scarce fibers of *Posidonia oceanica*	Balanids Bryozoans
F2a	*Polititapes rhomboides*	Frequent *Ammonia beccarii* *Ammonia tepida*	Fragments	Frequent *Cyprideis torosa* *Pontocythere turbida*	Very scarce fibers of *Posidonia oceanica*	Fragments of gastropods
F2b	*Cerastoderma glaucum*	Abundant *Ammonia tepida*	Fragments	Frequent *Cyprideis torosa* *Loxoconcha elliptica*	Very scarce fibers of *Posidonia oceanica*	–
F3	*Cerastoderma glaucum*	Abundant *Ammonia tepida*	Fragments	Extremely abundant *Cyprideis torosa* *Loxoconcha elliptica* *Palmoconcha turbida*	Compact accumulations and Neptune balls of *Posidonia oceanica*	Serpulids
F4	Fragments of *Cerastoderma glaucum*	Extremely abundant *Ammonia tepida* *Haynesina depressula* *Elphidium crispum*	Frequent *Globigerina bulloides*	Frequent *Loxoconcha elliptica*	Very scarce fibers of *Posidonia oceanica*	–
F5	–	Rare *Ammonia tepida*	Frequent *Globigerina bulloides* *Trilobatus trilobus* *Orbulina universa*	–	–	–
F6	–	–	–	–	–	–

Ostracods are absent in this facies. Finally, no microfauna has been found in F6.

Dating

The calibration of two samples indicates an age of the sediments consistent with the historical data from Portus. The mean calibrated age of the base of the core PF (Table 3: sample PT-16; 5-4.9 m depth) is placed towards the end of the 1st century AD, although it extends to the 4th century AD (range: 200 BC-330 AD). The second dating (sample PT-6; 1.9-1.8 m depth) was deposited between the 1st and 6th centuries AD, with a mean probability towards the 4th century AD (range: 90-585 AD).

DISCUSSION

Sediment chronology

According to its depth (5 m), this core would comprise part of the geological fill of the Canale di Imbocco, given that the boundary between the sediments prior to the construction of Portus and the first evidence of dredging and port activity (2nd century AD) is found at approximately 8-8.5 m depth in this area (Goiran *et al.* 2010; Delile *et al.* 2014). In addition, several previous geological and historical investigations have confirmed that this channel was active between the beginning of the 2nd century AD and the beginning of the 5th century AD (Goiran *et al.* 2010).

The two radiometric dates obtained in this study coincide with the range of ages documented in the literatura and, consequently, the sediments studied in this paper were probably deposited in an interval of about 300 years. However, the sedimentation rates cannot be calculated due to the dredging to which this port was subjected, which caused the extraction of part of the sedimentological record (Salomon *et al.* 2016).

Palaeoenvironmental interpretation

Sedimentological Perspective

Samples present unimodal, bimodal or trimodal distributions (Table 1), in which the use of statistical parameters such as kurtosis or asymmetry is problematic and not advisable (Blott & Pye 2001). All are poorly selected or very poorly selected, indicating sedimentary environments with highly variable hydrodynamics, frequent episodes of rapid erosion and sedimentation of particles with well-differentiated grain sizes and different transport vectors (Baraniecki & Racinowski 1996).

This scarce selection generally occurs in restricted environments, relatively quiet, where the accumulation of mud predominates. Occasionally, the occurrence of coarser sediments (mainly F5 and F6) may be related to different sources (fluvial floods, storms, anthropic contributions, etc.) (Le Roux & Rojas 2007).

Faunal perspective: palaeoenvironmental reconstruction

The fossil record allows interpreting the paleoenvironmental conditions in the entrance channel to the Trajan basin. A first general analysis of the fauna of the access channel to the inner port of Portus indicates that this record is similar to that extracted from other cores obtained in the dock and surroundings of the Trajan hexagon, in the innermost areas of Portus (Goiran *et al.* 2010; Mazzini *et al.* 2011). Synthetically, the malacofauna of core PT is dominated by the bivalves *Polititapes rhomboides* and *Cerastoderma glaucum*. *Ammonia tepida* is the most abundant benthic foraminifera, mainly associated with *Ammonia beccarii* in the lower part of the core and with *Haynesina depressula* towards the top. Among the ostracods, the most abundant (>80% of the total) is *Cyprideis torosa*, frequently associated with *Pontocythere turbida* and *Loxoconcha elliptica*.

These bivalve species are typical of brackish coastal environments, subject to significant environmental stress. *Cerastoderma*

Table 3. — Database of ^{14}C results.

Sample	Depth	Material	Laboratory number	Uncalibrated C14 age (BP)	Error	Calibrated C14 age (2σ) (BC/AD)	Mean C14 calibrated age (BC/AD)
PT-6	1.8-1.9	*Cerastoderma glaucum* (Bruguiére)	Beta-602823	2250	30	90 BC-585 AD	339 AD
PT-16	4.9-5	*Polititapes rhomboides* (Pennant)	Beta-602826	2480	30	200 BC-330 AD	63 AD

glaucum is a very abundant species in transitional ecosystems (coastal lagoons, estuaries, deltas, etc.) in the Mediterranean Sea and the eastern Atlantic Ocean, with a high tolerance to a wide range of salinities (5-38‰) and temperatures (0-25°C) (Boyden 1972; Leontarakis *et al.* 2009). *Polititapes rhomboides* (synonym of *Venerupis rhomboides* or *Tapes rhomboides*) has been cited from the Mediterranean Sea and the Atlantic Ocean and from Norway to Morocco, in marine environments with variable substrate (gravel to mud), and from the intertidal zone to 183 m depth, although it usually occurs less than 20 m depth in most of this coastal strip (Tebble 1966; Montero 1971; Yamuza-Clavijo *et al.* 2010). Consequently, this species would come from the shelf of the Tyrrhenian Sea adjacent to Portus.

Among benthic foraminifera, *Ammonia tepida* is usually very abundant in coastal lagoons and deltas, where it exhibits a strong correlation with restrictive and variable salinity conditions and high percentages of organic matter (Almogi-Labin *et al.* 1992; Debenay *et al.* 2005; Di Bella *et al.* 2011), as is the case with most of the samples from core PT due to the presence of *Posidonia* detritus. *Ammonia tepida*, together with *Haynesina depressula*, are representative of an assemblage tolerant to moderate environmental stress that is adapted to a wide range of oxygenation levels, salinities and temperatures (Vanicek *et al.* 2000).

The constant presence of *Ammonia beccarii* and *Haynesina depressula* identifies a permanent marine connection, since these two species are typical of shallow marine environments (see review in Debenay *et al.* 1998; Asimina *et al.* 2013). The appearance of planktonic foraminifera (*Globigerina*, *Orbulina*, *Trilobus*) reinforces this continuous marine component of the microfauna and would indicate a suspended transport by tidal flows from the adjacent marine environments, a fact frequently observed in cores obtained in estuaries, deltas or lagoons (e.g. Ruiz *et al.* 2004). These data would confirm the presence of a brackish and confined palaeoenvironment, with changing physical-chemical parameters (salinity, temperature, oxygen content), similar to those measured in a tidal channel of an estuary or coastal lagoon, where the fluvial contributions of the Tiber river (mainly F5 and F6) and tides would interact.

This observation is confirmed by the distribution and abundance of ostracods. *Cyprideis torosa*, the most abundant species, usually develops an opportunistic strategy and has been found in a wide range of salinities (2‰->100‰), although its optimal range is between 2‰ and 16.5‰ (Meisch 2000). It is a typical species of coastal lagoons, estuaries, deltas or marshes, where it usually coincides with *Loxoconcha elliptica* (Ruiz *et al.* 2006a, b; Pint & Frenzel 2017). The marine component of the ostracofauna is represented by *Pontocythere turbida* or *Carinocythereis* spp., frequent in shallow coastal environments of Italy (Frezza & Di Bella 2015; Barbieri *et al.* 2019).

Facies F5 is interpreted to derive from fluvial inputs of the Tiber river, although the marine connection although the marine connection was still active as demonstrated by the presence of re-sedimented planktonic foraminifera. The identified species (e.g. *Globigerina bulloides*, *Orbulina universa*) lived in marine paleoenvironments of the western Mediterranean Sea during the Holocene (Frigola *et al.* 2007; Lirer *et al.* 2013) and were transported by tidal flows towards the inner areas of Portus, where they have been found in other cores extracted in the Canale di Imbocco (Goiran *et al.* 2010). Facies F6 is interpreted as an anthropic fill after the abandonment of the port, characterized by a drastic disappearance of the paleontological record and by the frequent presence of construction materials. This surface filling has also been confirmed in the upper part of other cores obtained at the entrance to the Trajan hexagon and the adjacent dock (Di Bella *et al.* 2011; Lisé-Provonost *et al.* 2019).

Interest of *Posidonia oceanica*

Core PT presents frequent remains of *Posidonia oceanica*, with massive accumulations that are common in F3. It is the dominant seagrass in the subcoastal strip (up to 40 m deep) of the Mediterranean Sea (1.2 million hectares; Telesca *et al.* 2015), where it forms extensive meadows. Consequently, some inferences can be drawn considering its abundance in the geological record of Portus:

1) this species was already present in the Mediterranean at least 1 800 years ago (2nd century AD) and was still present around the 4th-5th centuries AD (Table 3; upper part of Facies F3);

2) based on its habitat, these accumulations come from the action of waves and tides and the transport of its fibers and leaves towards the internal areas of Portus from the adjacent coastal sector of the Tyrrhenian Sea. These accumulations are present in most of the cores studied close to core PT (Goiran *et al.* 2010; Delile *et al.* 2014);

3) in the modern Mediterranean environments, "Neptune balls" are expelled from these meadows during periods of strong waves or storms and usually end up on adjacent beaches (Sánchez-Vidal *et al.* 2015). Consequently, their presence in the fossil record of core PT can be tentatively associated with stormy periods that devastated Portus. More detailed studies of Facies F3 would be required to

corroborate historical episodes of high-energy events at Portus. Such events are not unusual in this area as a severe storm caused the destruction of 200 ships in the Claudius Basin in 63 AD (Tacitus 2010);

4) part of the filling problems of Portus would come from these accumulations of *Posidonia aceanica*, which acted as sediment traps and required periodic dredging of this port (Keay *et al.* 2005).

CONCLUSIONS

The multidisciplinary analysis (sedimentology, malacofauna, microfauna, plant remains, dating) of a core extracted from the communication channel between the inner and outer ports of Portus, the imperial port of Rome, has allowed us to obtain a general view of the paleoenvironmental variations that happened on this channel for about *c*. 300 years. In the three centuries of main activity of this great port (2nd-5th centuries AD), this channel was progressively filled with poorly selected bioclastic muds, typical of restricted environments, as well as by accumulations of the seagrass *Posidonia oceanica*, with a final fluvial and anthropic filling. The autoecology of the occuring bivalves, foraminifera and ostracods is similar and it is indicative of a brackish environment with significant rates of environmental stress including important fluctuations in salinity, oxygen content and periodic dredging. In this scenario, the fluvial contributions of the Tiber converge with the tidal flows, which likely transported allochthonous species towards the interior of the port from the coastal areas adjacent to Portus. In these nearby coastal sectors, extensive meadows of the seagrass *Posidonia oceanica* were developed, whose remains were be transported by tides and storms towards the interior of the port and deposited at the bottom of the channel.

Acknowledgements

This study was supported by the folowing projects: 1) project DGYCIT CTM2006-06722/MAR; 2) project DGYCIT CGL2006-01412; 3) “Del Atlántico al Mediterréano (DEATLANTIR): Investigaciones en las infraestructuras de *Portus-Ostia Antica*: el muelle de la Lanterna” (Programa de Proyectos de Arqueología en el Exterior, Ministerio de Cultura y Deportes); 4) ´Del Atlántico al Tirreno. Los puertos hispánicos y sus relaciones comerciales con Ostia Antica (DEATLANTIR II) – HAR2017-89154-P – (Plan Nacional de I+D+i); and 5) proyecto FEDER 2014-2020 UHU-1260298. Other funds come from the research groups HUM-132, RNM-238, RNM-293 and RNM-349 of the Junta de Andalucía. It is a contribution to the Center for Research in Historical, Cultural and Natural Heritage of the University. The paleontological record is deposited in the Paleontology and Applied Ecology Laboratory of the University of Huelva. We also thank the two anonymous reviewers, the associated editor, Maria Rose Petrizzo, and the editor-in-chief, Michel Laurin.

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Submitted on 22 February 2022;
accepted on 29 June 2022;
published on 26 June 2023.