Palaeoenvironmental reconstruction of the ancient harbors of Rome: Claudius and Trajan's marine harbors on the Tiber delta

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ARTICLE INFO

ABSTRACT

During the first and second centuries AD, Emperor Claudius and then Emperor Trajan successively ordered the construction of two large harbors on the Tyrrhenian coast. Research resulted in advances in understanding the palaeoenvironments of the Portus. From a bathymetric point of view, the drillings indicate a 7/8 m depth for the main basins. Different sedimentary behaviors were observed: Claudius' basin shows sand accretion, whereas the access channel to Trajan's basin shows mud accumulation. Trajan built the second hexagonal basin because Claudius' harbor did not protect the ships from the wind and swell, and not because it was prone to rapid silting. In terms of chronology, the channel between both basins worked between the end of the 2nd century and the beginning of the 5th century, when it became completely clogged. This means that, after the beginning of the 5th century, only the junction channel (canale traverso) remained to provide an access to the Tiber and to the sea.

1. Introduction

During the 1st century AD, a large trade harbor was built for the city of Rome, much later than for any other large Mediterranean city of the time. Claudius built this harbor far from the city, on the Tiber delta, 25 km to the west of Rome and 3 km to the north of Ostia. Claudius built a large basin, which Trajan supplemented with a second hexagonal basin during the 2nd century. Both basins were linked by the main access canal. A second canal, the junction canal, linked the Trajan's channel, allowing access to the Tiber or to the sea.

The goal of this study is to reconstruct the harbor's history by analyzing the sedimentary archives contained within the basins. Several geoarchaeological questions remain: why did Trajan built the second basin, only 50 years after the construction of the first harbor? Trajan's motivations are still debated. Some believe that rapid silting of the basin occurred because of the Tiber alluvia (Reddé, 1986). According to others, who quote Tacitus (Tacite, Annales, XV, 18, 3), the harbor was too exposed and did not protect the ships.

Recent works, led by archaeologists (Keay et al., 2005; Morelli, 2005; Mannucci and Verduchi, 1992; Paroli, 2005; Castagnoli, 1963; Zevi, 2001) and palaeoenvironmentalists (Belluomini et al., 1986; Bellotti et al., 1994, 2007; Giraudi, 2004; Giraudi et al., 2006; Arnoldus-Huyzendveld, 2005; Goiran et al., 2008), has shed new light on the configuration of the harbor and the evolution of deltaic palaeoenvironments. Still, questions remain. What was the depth of Claudius' basin and of the main access canal? How long did this channel, linking both basins, operated?

2. Regional setting

The Tiber delta has been subject of much research since the 19th century, in particular related to reclamation (Moro, 1871; Oberholzer, 1875; Ponzi, 1875; Amenduni, 1884; Bocci, 1892). Thorough studies were made in the second part of the 20th century. The current erosion of the deltaic coastline is one of the important questions that has lead to many studies (Bellotti and De Luca, 1979; Bellotti et al., 1981; Caputo et al., 1986). Another great field of research developed during the construction of the Leonardo da Vinci airport. Deep corings were then done in the delta, permitting understanding of its evolution during the Pleistocene and the Holocene (Dragone et al., 1967; Bellotti et al., 1986, 1989, 1994, 2007; Belluomini et al., 1986; Allessandro et al., 1990; Chiocci and Milli, 1995; Amorosi and Milli, 2001; Giraudi, 2002, 2004; Giraudi et al., 2007).

Since the last glacial maximum, the delta of the Tiber had two main tendencies in its geomorphological evolution: transgression,

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progradation. Before 17,000 BP, the delta was 10 km west of the current coastline (Bellotti et al., 2007). Towards 17,000 BP, the sea level increased and submerged the delta. This transgression continued until 9000 BP, a period marked by a reduction of the pace of marine level rise. A delta bay developed with coastal dunes (Bellotti et al., 2007). Approximately 7000 BP, the pace of marine level rise was very low. The coastal dunes were reinforced. The sedimentary contributions of the Tiber filled the coastal lagoons. Two large lagoons developed on the deltaic landscape on both sides of the Tiber: the lagoon of Ostia in the south and the lagoon of Maccarese in the north (Bellotti et al., 2007). They were still visible in the 19th century before being reclaimed (Amenduni, 1884). It is with this fast progradation that the lobate delta (Giraudi, 2004) formed towards 5000–4500 BP. During the last 2000 years, there were two important phases of progradation at the end of Antiquity and another one between the 16th century and the 19th century (Bellotti et al., 2007).

The modern Tiber's alluvium almost completely covered the harbor structures, complicating the understanding of the palae-olandscape and the location of the structures. During the 20th century, the town of Fiumicino and the international airport were built partly over the ancient harbor (Fig. 1). These facts prevented some archaeological excavations, thus starting again the debate about the configuration of the harbor. Ancient authors (Suetonius, in Graves, 2006 and Pliny the Elder, Eichholz et al., 1938) do not provide much insight about the location of the various structures and the respective aims of the basins and canals.

During the 16th century, Danti drew a map of the remaining archaeological structures. From these remains, he proposed a reconstruction of Claudius' harbor, with two long offshore moles Reinhardt, Raban, 1999. During the 1960s, the construction of the international airport of Rome allowed some large archaeological excavations (Testaguzza, 1964, 1970; Scrinari 1960).

3. Materials, methods and terminology for harbor geoarchaeology

The phreatic level is a common problem when excavating harbor structures and studying the sediments lying in the basins. It is difficult to get a global view of the stratigraphy and to reach the bottom of the moles, without using expensive moulded walls. Thus, in a deltaic environment, a mechanical drill was used to get a complete stratigraphy, encompassing several centuries. A total of 24 boreholes have been made for the PORTUS program (Fig. 1). The geoarchaeological and interdisciplinary study has resulted in a better understanding of the coastal palaeoenvironments, the coastal mor-phodynamic processes, and the organization of ancient harbors.

3.1. Operation of a standard harbor: sea-bed and sea level

A working harbor (Fig. 2) is composed of a container (the harbor structures) and a content (a volume of sediments and a volume of water) (Goiran and Morhange, 2003; Marriner, 2006; Marriner and Morhange, 2006). Two volumes (content) thus compose the harbor basin Goiran, 2001. The first is a sedimentary volume between the katolimenic limit (harbor foundation) and the mesolimenic level (bottom of the basin). When the harbor is operating, the water volume is defined by two interfaces: the sea bottom (the meso-limenic limit) and the sea level. At the harbor's construction, the mesolimenic level is the same as the katolimenic level. A clear limit appears between the pre-limenic coarse sediments (before the harbor) and the fine limenic facies (in the basin). When the harbor is subject to sedimentary accretion, the mesolimenic level rises. The water column is equal to the difference between the sea level and the mesolimenic level. This water column is related to the draught of the ships; is it then possible to deduce the kind of ships that were
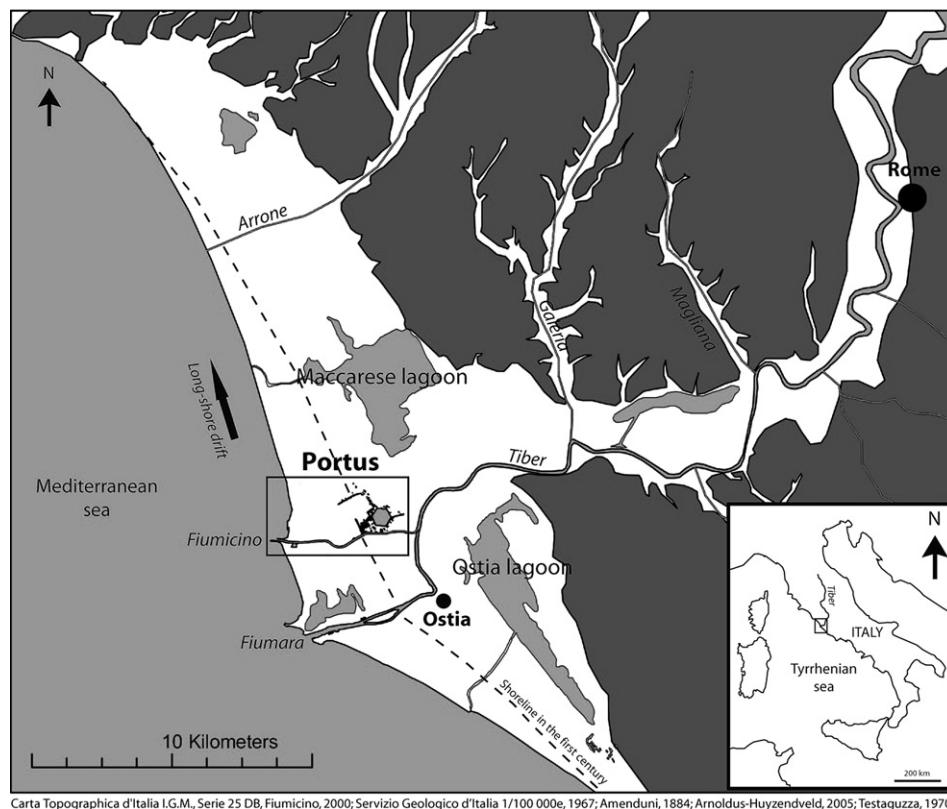

Carta Topographica d'Italia I.G.M., Serie 25 DB, Fiumicino, 2000; Servizio Geologico d'Italia 1/100 000e, 1967; Amenduni, 1884; Arnoldus-Huyzendveld, 2005; Testaguzza, 1970.

Fig. 1. General location map of the Tiber delta.

Modern configuration of the Portus area

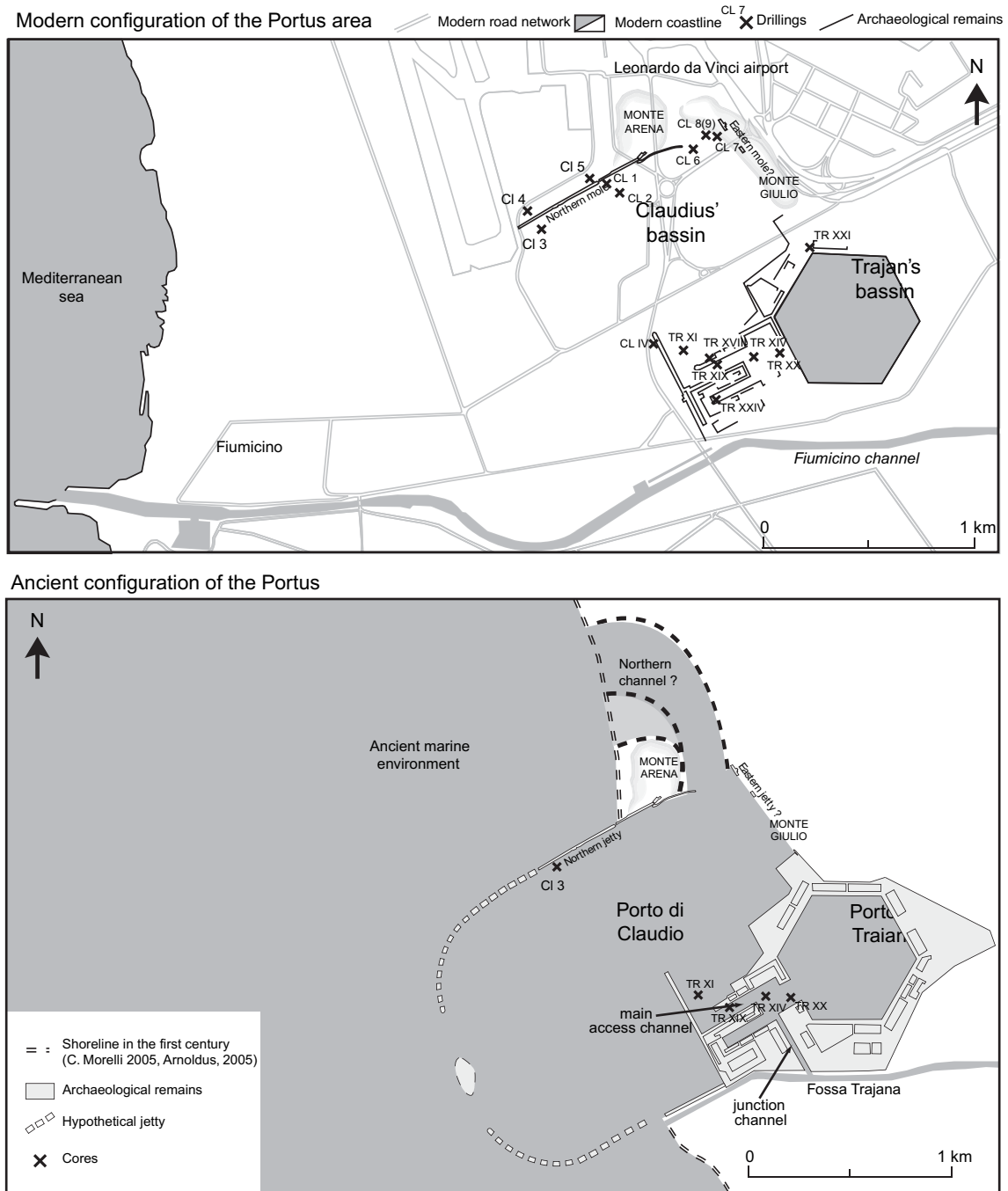Ancient configuration of the Portus

Fig. 2. Location of the boreholes.

able to reach the quays (Morhange et al., 2001). To get the palaeobathymetric information, a drilling is required in the basin (Fig. 3).

In the case of the Portus, the ancient biological mean sea level is revealed by the upper biological limit of shells anchored to the quays (barnacles, oysters, and vermets). This level is 80 cm below the modern biological sea level. In a quiet sedimentary environment, such as a harbor, these proxies allow an altimetric precision around ± 10 cm (Laborel and Laborel-Deguen, 1994). This sea level has been dated from 2115 ± 30 BP, 230 to 450 AD (code LY-4198) (Goiran et al., 2009). This ancient sea level, measured in altimetry and chronology, allows deduction of the depth of the basins and of the moles at their construction.

Radiocarbon datings were used, as it is exceptional to find any datable shards in a core. All the samples have a marine origin. Calib 5 software was used for calibrating the dates with marine curve correction (Hughen et al., 2004). A reservoir age of DR = 57 ± 30 for *posidonia* was used, and DR = 197 ± 30 for shell.

3.2. Macrofauna and microfauna for reconstructing palaeoenvironments

The actualist hypothesis, which states that the ecology did not change during the Holocene, is used (Masse, 1988; Morhange, 1994). From this hypothesis, macro and microfauna can both be used for palaeoenvironmental reconstruction. A comparative analysis was used between ancient macrofaunistic groups and modern groups, (Peres, 1967), based on the modern biocenotic settlements of Mediterranean ecosystems (Peres and Picard, 1964; Bellan-Santini

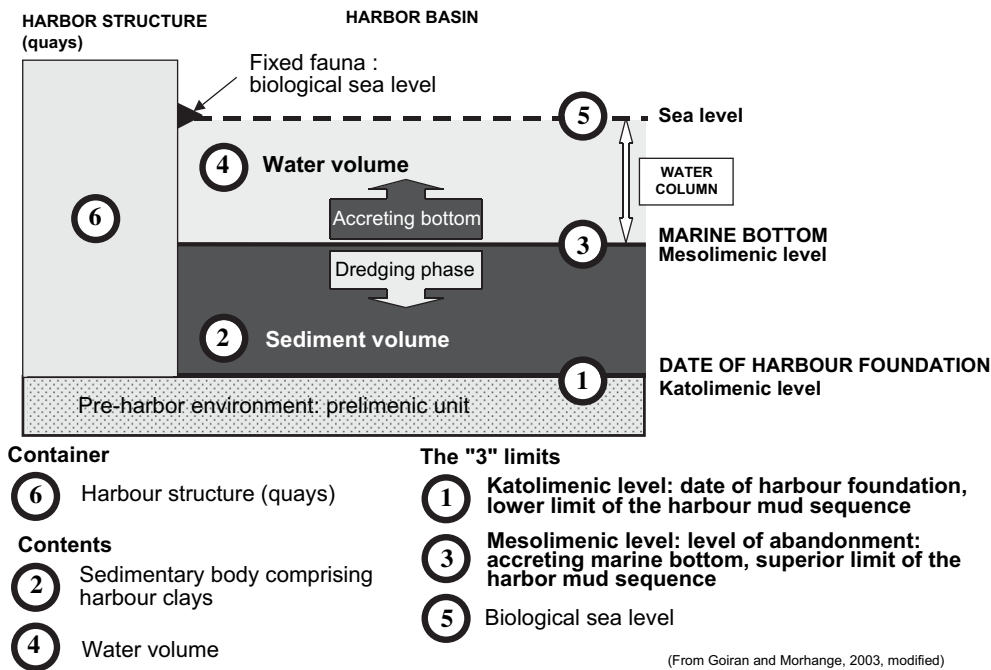## Theoretical cross section of an active harbor basin

Fig. 3. Theoretical working of a harbor.

et al., 1994). The macrofaunistic groups reveal the construction of a harbor through a change in both qualitative and quantitative parameters (Goiran and Morhange, 2003).

Microfauna also bring information about the characteristics of the environment, through faunal density and species diversity. Ostracod groups (micro crustaceans with two calcitic valves) are related to critical elements as salinity, proximity of the shoreline, water temperature and secondary elements as substratum, vegetation, trophic level, hydrodynamism. (Carbonel, 1980, 1988, Ruiz et al., 2006). The faunal assemblages indicate the type of environment where the ostracodes lived: marine, estuarine, lagoonal, freshwater. The dominance of some species indicates the positions of the palaeobiotope: marine lagoonal or estuarine lagoonal (Fig. 3) (Carbonel, 1980, 1988; Carbonel and Moyes, 1987; Clavé et al., 2001; Debenay et al., 2003; Morhange et al., 2001; Ruiz et al., 2005, 2006). In addition, the "phytal" fauna with herbivore species indicates environments with vegetals, which protect the fauna against the coastal dynamics or in infralittoral or lagoonal biotops confer a high trophic level and oxygenate character.

4. Results

4.1. Sedimentary characteristics of Claudius' harbor: analysis of the CL3 core

The CL3 drill hole is located in the western part of Claudius' basin (Fig. 1). It is 10 m deep and allows a global view of the filing of the basin, and the study of the harbor sediments.

4.1.1. Sedimentary unit A: sterile layered sands

The bottom of the CL3 core is composed of a 1 m thick succession of fine and silty sands. This unit is sterile (neither macro nor microfauna), except at the summit, dating from 3070 ± 30 BP (790–540 BC). Sands are stratified and well sorted.

4.1.2. Sedimentary unit B: marine subtidal sands

This sandy unit is 90 cm thick. The bottom dates from 2785 ± 30 BP (635 BC to 360 BC) and the top from 2420 ± 30 BP (160 BC to 75 AD). The sands range from fine to medium grained, and represent 70–90% of the sample weight. The sorting (Folk and Ward, 1957) is good. The macrofauna are composed of species related to coarse sands and deep currents. Ostracods are present, and coastal and marine phytal groups are dominant. A few species revealing salinity variations (brackish to lagoonal) are present. *Posidonia* fibers were recovered.

4.1.3. Sedimentary unit C: dark grey sandy muds

The muddy unit is 80 cm thick. It is older than 2420 ± 30 BP and the top dates to 2400 ± 30 BP (145 BC to 95 AD). The silt and clay fraction ranges from 65% (at the bottom) to 80% (at the top) of the total dry weight of the samples. The coarse sediments (>2 mm) are mostly absent, except for a few shells. *Posidonia* are extensive, and form fine layers. The dominant ostracofauna are from the coastal phytal group.

4.1.4. Sedimentary unit D: shelly sands with Posidonia

The unit D is 7 m deep, and is composed of marine sands, with shells and *Posidonia*. Sands represent 5–30% of the samples. Laser granulometry indicates good to moderate sorting. The ostracofauna are from coastal and marine phytal groups. The macrofauna are from the following groups: subtidal sands, *Posidonia* herbaria, and, at the top, fine well laminated sands. The various sub-units (D1–D5) indicate variability within the sands (coarse to fine, irregular presence of layers). The top of sub-unit D1 has been radiocarbon dated: 2190 ± 30 BP (270–520 AD). Pot shards present are not identifiable.

4.2. Sedimentary characteristics of Trajan's basin: analysis of the TR XIX core

The drill hole is located at the entrance of the canal leading to the hexagonal basin from the basin of Caudius. The TR XIX core is

9 m deep below modern sea level. Four sedimentary units are present.

4.2.1. Sedimentary unit A: stratified sands

The bottom unit is composed of 40 cm of stratified sands. Sands represent 60% of the weight of the samples. Coarse sediments are almost absent (1–2% of the total). The granulometrical curves are unimodal, with the modal class around 125 μm. The mean size is small, at 110 μm. The sands are very well sorted (Fig. 4). There are no malacolofauna or microfauna (Figs. 5 and 6).

4.2.2. Sedimentary unit B: muddy sands

This unit of muddy sands can be further divided into two sub-units. Sub-unit B1 is made of layered sands with a *posidonia* layer at the bottom. However, there is insufficient fiber for AMS dating. Sub-unit B2 comprises muddy sands, rich in *posidonia* and shells. Its color is darker brown than sub-unit B1 (cf. code Munsell, on dry sediments: from 5Y 6/2 to 5Y 6/3). This color also differentiates this sub-unit from unit A, which had the typical yellow color from Tiber sands. This unit is 50 cm thick. Eight ostracod species are present, and constitute five biocenotic groups: marine, coastal phytal, river mouth, estuarine and freshwater. *Cyprideis torosa* appears, a species known as opportunistic and for colonizing new environments. This environment is dual: even if freshwater is dominant (75% of the samples), it remained linked to the sea (Fig. 6). The macrofauna in unit B are not diverse and the shells are broken. *Cerastoderma edule glaucum*, characterizing a low salinity environment, is the dominant specie typical of euryhaline and eurythermal lagoons. Adults as well

as juvenile individuals have been found, and the fauna are thus in situ (Fig. 5). The sandy fraction is the majority (40%), and the proportion of silts and clays varies. The histograms of the sands are always unimodal. The mean grain is 180 μm (fine sands). The sorting index is 0.83, the sands are well sorted. Coarse sediments only represent around 3%, composed of wood and micro shards. These two elements, commonly indicative of anthropic activity, may have been brought by the river. Both biological and granulometrical indicators denote an environment linked to the sea (Fig. 4). [14]C dating from the middle of the B unit on *posidonia* fibers (sample TR XIX 62; Poz-16280) indicates an age of 3100 ± 35 BP (980–775 BC).

4.2.3. Sedimentary unit C: shelly muddy sands

This unit is 6 m thick and is divided into 4 sub-units. C1 is composed of muddy sands with abundant *posidonia*, aged 2375 ± 30 BP (135 BC to 115 AD) at the bottom (sample TR XIX 59 posi, Ly-4244). The top is dated at 2470 ± 30 BP (220 BC to 35 AD, sample TR XIX 46, Poz-16104). C2 is made of shelly muds, with the top being dated at 2455 ± 30 BP (195 BC to 45 AD). C3 is composed of shelly muddy sands, with the top dated at 2125 ± 35 BP (180 AD to 430 AD, on *posidonia* fibers). Unit D presents a succession of sandy and compact silty layers.

4.2.3.1. Sub-unit C1.
This unit of muddy sands is 170 cm thick. The silt and clay fraction is dominant, with 60–70% of the total dry weight. Sands and coarser sediments are rare. The coarse sediment fraction is mostly *posidonia* and shells (90% of the fraction). Laser granulometry emphasizes the unimodal distribution of the sands.
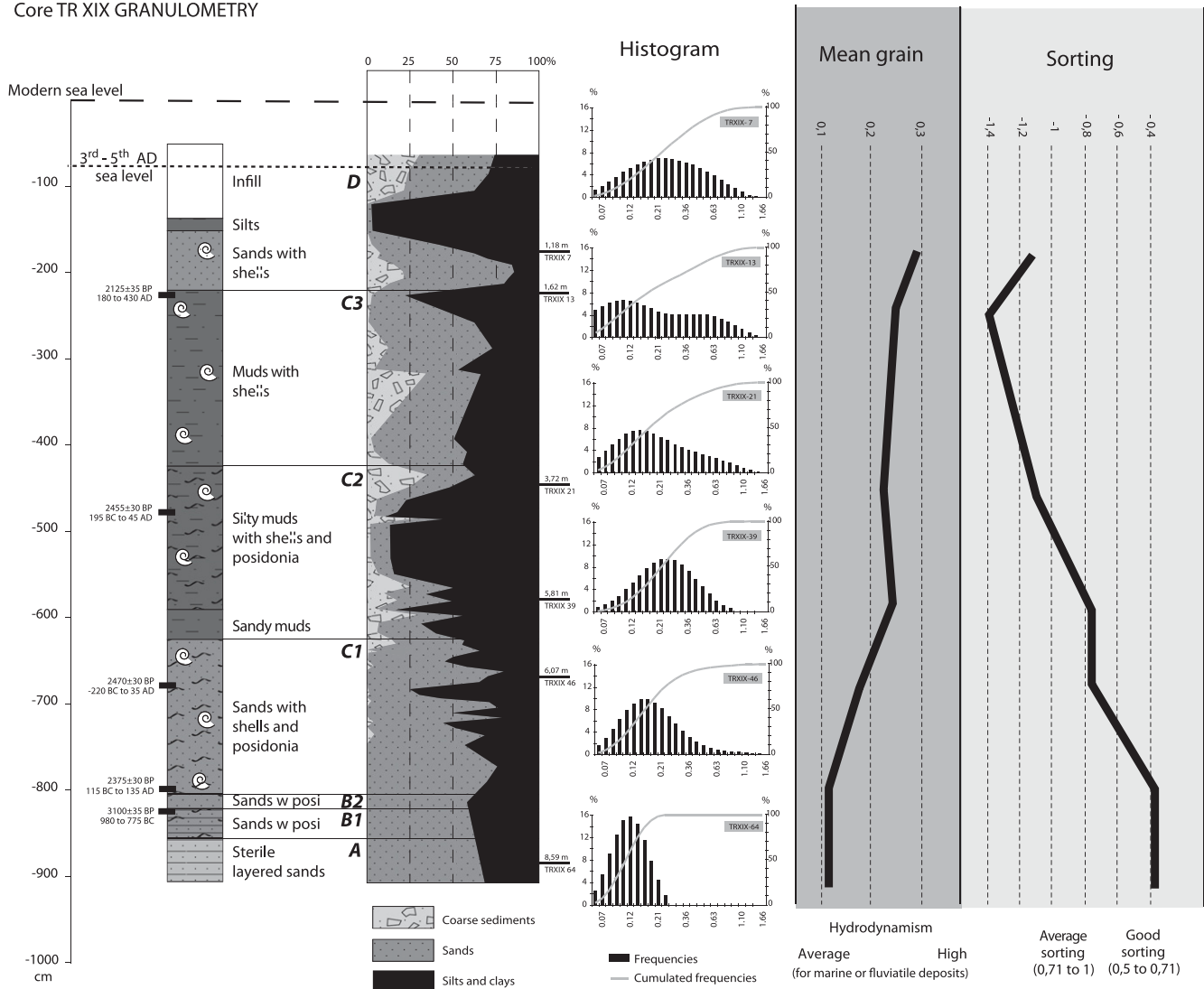

Fig. 4. CL3 core.

Core TR XIX GRANULOMETRY

Fig. 5. TR XIX macrofauna.

The mean grain size is in between fine and medium sands, and sorting is good (Fig. 4). The macrofauna is more diverse than in the underlying unit, and three species are present. *Cerastoderma edule glaucum* is still dominant. *Lutraria* cf. *lutraria* juvenile denotes a sandy-muddy environment. *Hydrobia* sp. is the first gastropod encountered, and indicates a brackish environment (Fig. 5). Six ostracod groups exist here, comprising 21 species. Two thirds are from the coastal phytal and brackish environments (*Cyprideis* and *Ponthocythers*) (Fig. 6). However, three *Tyrrhenocyther* shells (two adults and one juvenile) were found. This demonstrates the presence of a oligohaline and sulfatic water contribution (Schornikov, 1989), thus reinforcing the continental influence. Foraminifera were found: some *Orbulines* (planktonic foraminifer), but primarily *Ammonia becari tepida*, indicating desalinization.

4.2.3.2. Sub-unit C2. This stratigraphical unit is composed of silty muds, with *posidonia* and shells. It is 200 cm thick. The silts and clays fraction is the most important and can represent more than 75% of the sample's weight. Three malacological species can be found: *Cerastoderma edule glaucum*, *Tapes decussatus* and *Cyclope neritea*. The second species is present in quiet muddy sands.

C. neritea indicates desalinization, corresponding with the buckled shape of *Cerastoderma edule glaucum* (Fig. 4). Nine ostracod species coexist: *Ponthocyther* and *Loxoconca* are the dominant ones. Freshwater, lagoonal and river mouth biocenotic groups remain present more than coastal or marine groups. However, the uppermost sample shows more coastal and marine species (Fig. 6).

4.2.3.3. Sub-unit C3. The texture of this unit differs from the previous one. Sands are more common (20–40%). Silt and clay compose 30–60% of the samples. The muds are dark grey. Shells and *posidonia* fibers are abundant. The modal granulometric class is around 170 μm, with a mean of 240 μm. The sorting is quite good, with a 1.13 value. Although the shells are mostly damaged, the macrofauna were increasing. *Cerastoderma edule glaucum* is still the dominant species. *C. neritea* appears. *Nassarius reticulatus* makes an appearance, and is the first marine species (fine subtidal sands), although only one individual was found. Two species living on rocky substrates were observed: *Amyclina* and *Coralliphillia*, probably developing on the ancient moles. The small number of species and the large number of individuals may reveal closure of the environment, and its transformation into a lagoon, where the inter-specific

Fig. 6. TR XIX granulometry.

Fig. 7. TR XIX ostracofauna.

concurrency is minimal (Fig. 5). The microfauna are more homogenous. Marine and coastal groups are almost as well represented as the freshwater group. Continental species are the most common, with *Carino cythereis*, *Loxoconcha* and *Pontocythere* (Fig. 6).

4.2.4. Sedimentary unit D: beige sandy silts

The uppermost unit D, 70 cm thick, is made of beige sandy silts with shells. Sands compose the majority of the samples (up to 80% of the weight). The finest fraction ranges from 10% at the bottom to 90% at the top. *Posidonia* disappear in the coarsest fraction, and only macrofauna remain, with well preserved shells. The granulometric analyses present a transition from a bimodal curve to a unimodal one. The modal classes vary from 115 μm to 630 μm, and the sorting is quite poor. This unit seems to have received several competing influences (Fig. 4). The macrofauna also vary: *Cerastoderma edule glaucum* are present, and two new species indicate an important environmental change: *Tellina serrata*, from detritic silted up environments, and *Hydrobia acuta*, from brackish waters (Fig. 5). The marine influence vanished. The ostracofauna became lagoonal or represented river mouth environments. The colonizing species *Cyprideis torosa* confirms this change. *Ammonia beccarii tepida*, a hypohaline water foraminifer, and calcified stems of charophyts, a fresh to oligohaline water plant, support the hypothesis of a separation from the marine domain (Fig. 6).

5. Discussion

5.1. Palaeobathymetry in the access channel and the basins

The palaeobathymetry can be obtained by using the biological sea level data (ancient sea level set 80 cm below modern sea level, Goiran et al., 2009) and the stratigraphical information of the sea bottom (deducted from the cores) (Fig. 2). The TR XX core, located at the entrance of the of the hexagonal basin in the main access channel, reaches 760 cm below the modern sea level, or 680 cm below the ancient sea level. The depth of the basins was thought to be around 5 m (Lanciani, 1868; Lugli and Filibeck, 1935). The new results imply a depth of almost 7 m at the entrance of the basin, taking into account the error margin (Fig. 7).

5.2. Interpretation of the stratigraphical data in the harbor of Claudius

5.2.1. Pre-harbor period: an 8 m deep sea bottom

Two sedimentary units make the pre-harbor environment (Fig. 2). The basal unit A is composed of layered and sterile, lacking both macro and microfauna) sands with a good sorting index. These proxies tend to imply a fluvial environment. Above, the B unit is defined as an open marine environment with currents (presence of
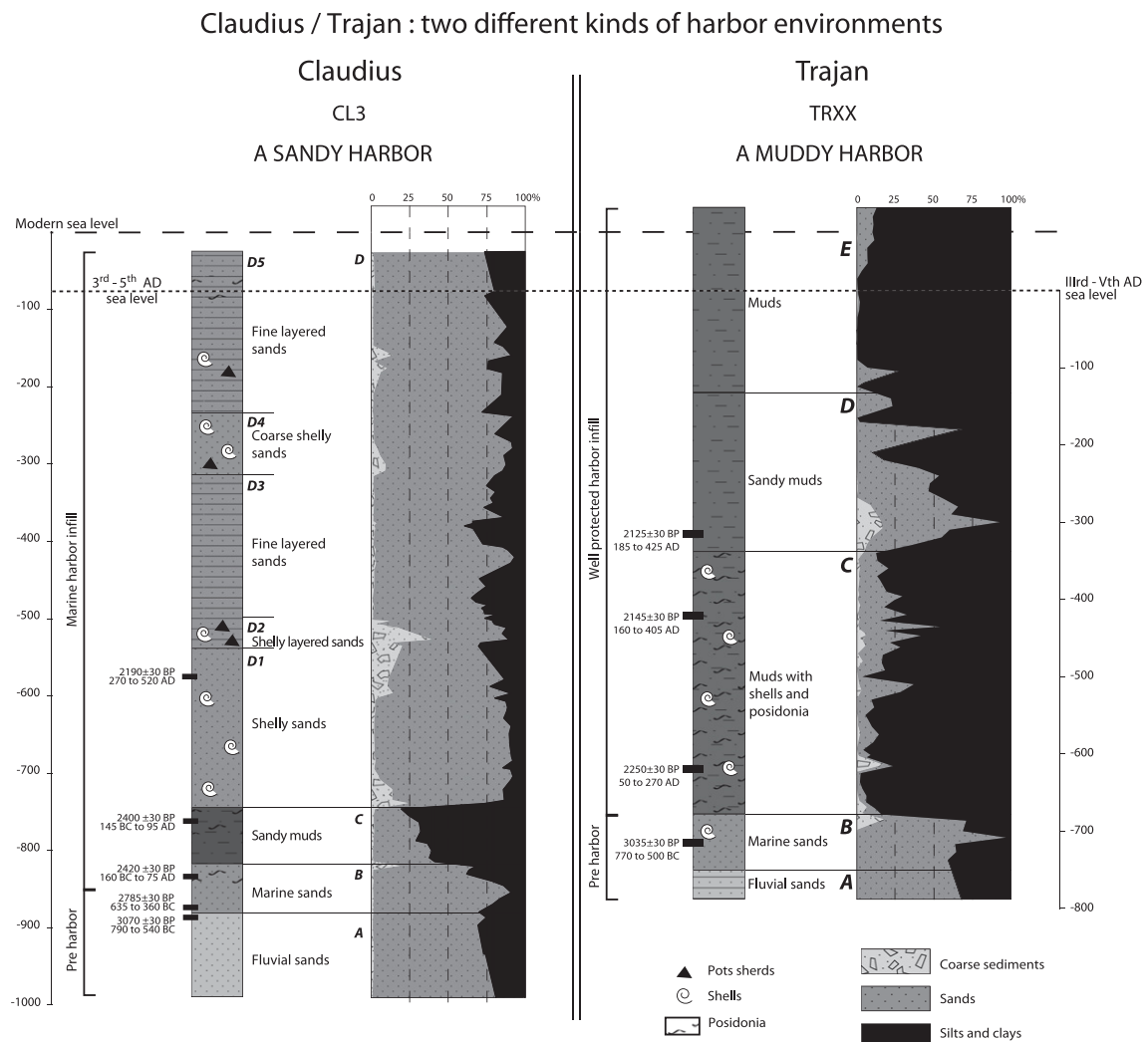

Fig. 8. Two harbor environments.

fauna adapted to currents). This accreting marine level is 9 m below modern sea level, or 8 m below ancient sea level. The bottom of unit B is aged 2785 ± 30 BP (635–360 BC) and the top is aged 2420 ± 30 BP (160 BC to 75 AD). The accretion rate is very slow, around 0.2 cm/y (Fig. 7).

5.2.2. Claudius' harbor infill: mostly sands

Unit C in core CL3 is composed of muddy sands, with abundant *posidonia*. From 2420 ± 30 BP (160 BC to 75 AD), this quiet sedimentary environment replaced the marine sands. Unit C denotes the first silting up phase of the harbor of Claudius. The moles, constructed in the middle of the 1st century (between 42 and 64 AD), slightly protected the environment, allowing the finer sediments to be deposited. The top of this mud accumulation is dated at 2400 ± 30 BP (145 BC to 95 AD). The apparent mean accretion rate is high, about 4 cm/y (between the top of unit C and top of unit B).

Unit D of the CL3 core is composed of sands, from fine to coarse, with numerous shells. There are also *posidonia*, sometimes forming layers. It corresponds to the various infill phases of the basin. This infill is not muddy, but sandy. This sharp facies change between units C and D could mean that the moles were not efficient enough to protect the harbor. It is possible that the moles were damaged by storms. The further lack of maintenance of the long moles would not permit fine sediments to be deposited again.

5.2.3. Why did Trajan build the hexagonal basin: usefulness of the sedimentary approach

From a sedimentological point of view, two elements suggest that the reasons of the hexagonal basin construction (between 100 and 112 AD) are more related to excessive exposure to marine risks than

to rapid sedimentation (Fig. 7). Unit D of CL3 shows that coarse sediments replaced the finer deposits. The accretion rate also diminished from 4 cm/y in unit C to 1 cm/y in unit D. The bathymetric measurements imply that between the end of the 3rd century and the beginning of the 5th century, the depth of the harbor was still around 5 m. This depth was enough for the ships of the time.

The sedimentological analysis made in the harbor of Claudius will have to be completed by other cores to confirm the hypothesis that the harbor was not sufficiently protective against the risks of the sea. This explains Tacitus' writings, according to which a storm in 62 AD sunk 200 ships (Tacitus, Annales, XV, 18, 23).

5.3. Interpretation of the stratigraphical data in the access channel to the harbor of Trajan

5.3.1. Pre-harbor environment

The progressive channel upfilling between the basin of Claudius and the basin of Trajan provides information about the palaeoenvironmental history of the hexagonal harbor (Fig. 1). The bases of all the boreholes of this sector provide insight into the dual nature of the pre-harbor environment (Fig. 8). Unit A is characterized by the lack of biocenosis, a stratified texture, a limited mean grain size and a good sorting. These elements imply a pre-harbor fluvial environment (Fig. 9).

Unit B from cores TR XIX and TR XX shows that a sudden opening to the marine dynamics happened around 3000 BP (between 10th and 8th centuries BC). The environmental proxies changed substantially. The apparitions of the marine fauna (macro and micro) and of the posidonia fibers imply both coastal and marine influences. Marine, coastal and brackish ostracofauna are
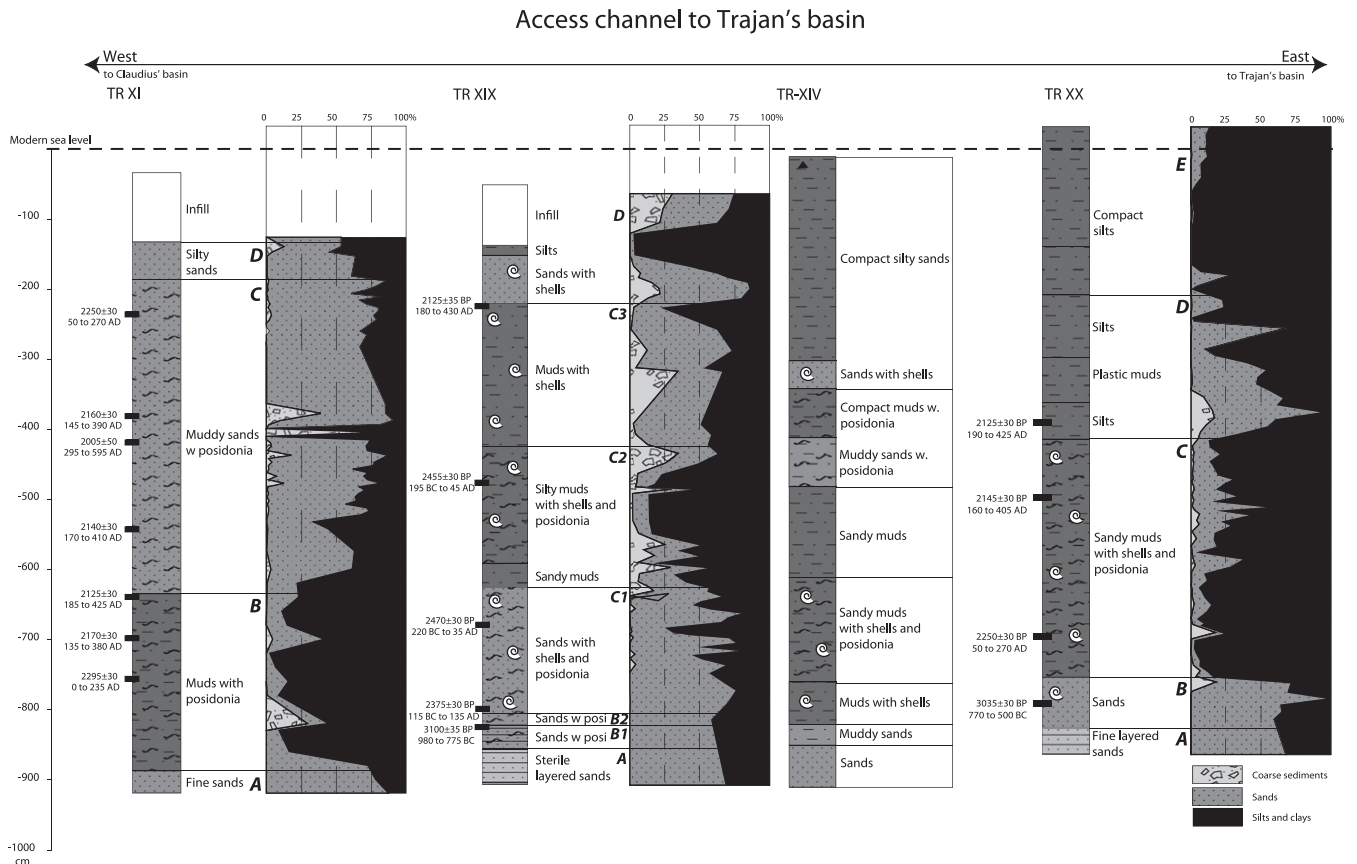

Fig. 9. The access channel.

evenly distributed. *Cyprideis torosa*, a colonizing species, appears, and denotes a disturbed environment. The texture of the sands shows an evolution of the environment, with an increase of the medium and coarse sands proportions. The environment appears to have been a quite deep lagoon, intermittently connected to the sea. Micro shards, probably exogenic, reveal that the area was not fully anthropized.

5.3.2. Harbor and channel activity phase

A thick (6 m) layer of sandy silts (TR XI B and C, TR XIX C, TR XX C, D) covers the pre-harbor units. The sediments are in majority silts and clays, but with a varying sand proportion. The bottom of this layer is date at 2200 or 2300 BP (1st and 3rd centuries AD) and the top is dated at 2100 BP (end of the 2nd century to beginning of the 5th century AD). This corresponds to the limenic phase (harbor activity period). There is a 700-year hiatus between the pre-harbor marine sediments (unit TR XIX B, 3100 ± 35 BP, Fig. 4.) and the limenic phase (unit TR XIX C, 2375 ± 30 BP). This suggests a dredging phase because of the construction of the harbor.

Three steps appear in the TR XIX core, revealing different operation phases of the channel (Fig. 8). At the bottom, C1 is the first filling phase of the canal. The buckled shape of the *Cerastoderma edule glaucum* shells, and the presence of *Tyrrheno cythere* shells, implies both marine and continental influences. From a textural aspect, the sands are dominant, meaning that the channel operating efficiently and fine particle deposition is limited (Fig. 8).

TR XIX's unit C2 is an example of two competing influences. Even if the marine ostracofauna were at the highest number, the continental influence was still important. The lagoonal microfauna, associated with a complex relationship between fresh and salty water, is remarkable. This environment can be interpreted as a buffer zone between fluvial and marine influences. *T. decussatus* and *Cerastoderma* imply a quiet hydrodynamic regim, favoring mud accretion. *C. neritea*, a desalinization proxy, shows the role of the canals in providing water to and draining the hexagonal basin. The channel was still working, but was getting filled by mud instead of sand.

The darker and darker facies of the muddy sands of unit C3 emphasize the increasing anoxic conditions in the harbor. For example, the rocky substratum macrobenthos was growing. The harbor was getting clogged by both sandy and muddy sediments. The drive out water effect seems to disappear, raising the question of the maintenance of the complex. The accretion rate is around 1 cm/y. The top of this unit is dated at 2125 ± 35 BP (end of the 2nd century to beginning of the 5th century) (Fig. 8).

5.3.3. Harbor terminal phase

The stratigraphical units TR XI D, TR XIX D and TR XX E correspond to the last filling phase of the canal, and the disconnection of Trajan's harbor from the sea. The vanishing of the coastal and marine micro and macrofauna indicates this separation, while the return of *Cyprideis torosa* indicates an environmental change. The increase of the number of *Hydrobia* shells denotes a brackish environment. The landscape resembles a swamp area, similar to the one that can be observed today near the coast. The yellow sediments from the Tiber are dominantly present.

6. Conclusions and research perspectives

All these palaeoenvironmental results are interesting for archaeologists and historians: knowing the depth of the basins and canals, it is now possible to think about the kind of ships that could access the quays, depending on their draught. The accretion rate computation allows a more precise estimation of the canal and basin operating durations. It is then possible to reconstruct the history of harbor navigation.

However, these results also provide new information for geoscientists. The shell lines anchored to the quays and moles are precious for understanding the relative variations of the sea level during the later Holocene.

Finally, these first results, obtained on the twin imperial harbors of Rome on the Tiber delta, give some chronological and altimetric benchmarks, useful for subsequent studies, aimed at better understanding the global workings of the Portus.

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