Journal of Archaeological Science 41 (2014) 389–398

Contents lists available at ScienceDirect

Journal of Archaeological Science

journal homepage: http://www.elsevier.com/locate/jas

Geoarchaeology confirms location of the ancient harbour basin of Ostia (Italy)

Jean-Philippe Goiran [a,*], Ferréol Salomon [b], Ilaria Mazzini [c], Jean-Paul Bravard [b], Elisa Pleuger [a], Cécile Vittori [a], Giulia Boetto [d], Jonatan Christiansen [e], Pascal Arnaud [e], Angelo Pellegrino [f], Caterina Pepe [g,h], Laura Sadori [g]

[a] CNRS – UMR 5133, Maison de l'Orient et de la Méditerranée, 7 rue Raulin, 69007 Lyon, France
[b] UMR 5600, Université de Lyon, France
[c] Dipartimento di Scienze, Università Roma TRE, Italy
[d] Aix-Marseille Université, CNRS, Centre Camille Jullian (UMR 7299), France
[e] UMR 5189, Université de Lyon, France
[f] Soprintendenza Speciale per i beni Archeologici di Roma, Italy
[g] Dipartimento di Biologia Ambientale, Università degli Studi di Roma "La Sapienza", Italy
[h] Dipartimento di Scienze della Terra, Università degli studi di Roma "La Sapienza", Italy

A R T I C L E I N F O

Article history:
Received 10 April 2013
Received in revised form
17 August 2013
Accepted 22 August 2013

Keywords:
Harbour
Geoarchaeology
Stratigraphy
Ostia
Rome
Tiber
Mediterranean Sea

A B S T R A C T

To the northwest of the ancient city of Ostia, the analysis of cores revealed a stratigraphic sequence, which we interpret as the filling of a harbour basin. This basin, located at the west of the so-called "Palazzo Imperiale" presents seven characteristics: (1) The maximum depth is 6 m below the Roman sea level. This depth allowed any type of ship (even heavy tonnage) to access the harbour. (2) A chronostratigraphic gap at −6 m below Roman sea level suggests digging operations in the basin (or subsequent dredging) that have caused the loss of sedimentary archives. (3) The filling consists of dark clays typical of a quiet environment but open to marine and river influences. (4) The dates at the base of this sequence give a range between the 4th and the 2nd century BC. (5) In the harbour sequence, a facies change at −2.5 m under the Roman sea level involves a change in the processes of sedimentation and/or operation. (6) No later than the beginning of the 1st century AD, the thickness of the water column in the basin is less than 50 cm and seems to be caused by a massive siltation following a succession of floods of the Tiber. (7) This basin was thus already abandoned during the start-up of Portus.

1. Introduction

Many attempts have been carried out to locate the ancient, river mouth, harbour basin of Ostia. In the 19th century, an Italian archaeologist and an architect (Fea, 1824, 1831, 1835; Canina, 1830) both defined an area with a topographical depression in the north of the city to the west of the so-called "Palazzo Imperiale" where it could be situated. In the early 2000s, a team of German and American archaeologists (Heinzelmann and Martin, 2002) used geomagnetic instruments, to corroborate the hypothesis of a localization of the basin in this area. Geomagnetic surveys effectively indicate that this area is structureless with different surface sediment relative to the proximity (Figs. 1 and 2). We can propose two hypotheses: the presence of a harbour basin or the presence of a place, used to boat landing and handling of goods (Canina, 1830). The presence of groundwater did only permit the conduction of two shallow trenches, which do not prove the presence of a basin or harbour structures like breakwater or embankments. So, from our point of view, there is still not sufficient scientific evidence and there is still no consensus about the location of the harbour basin; the debate is still alive.

A Franco-Italian multidisciplinary team (CNRS, Université Lyon 2, Aix-Marseille Université, Ecole Française de Rome, Soprintendenza Speciale per i Beni Archeologici di Roma – Sede di Ostia, Università Roma 3, Università degli Studi di Roma "La Sapienza") finally decided to validate or refute the hypothesis of a harbour basin situated in the location of the trough-shaped depression sloping down the Tiber between the supposed ancient lighthouse "Torre Boacciana" to the west and the so-called "Palazzo Imperiale" to the east (Fig. 3), using a mechanical drill. The goal was to obtain

* Corresponding author. Tel.: +33 683727866.
E-mail address: Jean-Philippe.Goiran@mom.fr (J.-P. Goiran).

0305-4403/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jas.2013.08.019

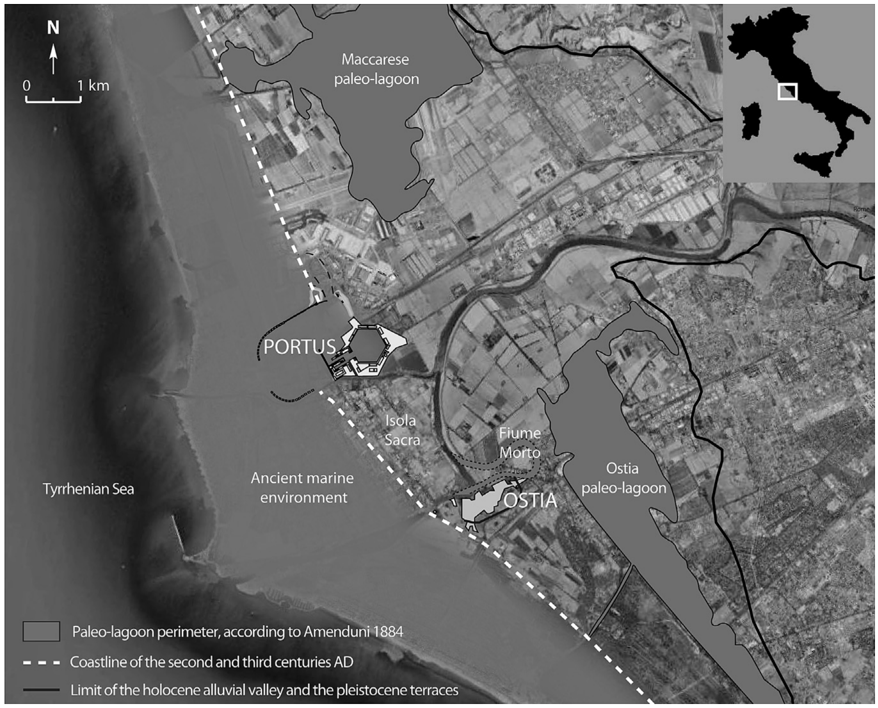

Fig. 1. General location map of the Tiber Delta.

sedimentary pieces of evidence about the ancient harbour basin of Ostia. This technology solves the problem of groundwater, which makes this area rather difficult for archaeologists to excavate beyond 2 m depth (Goiran and Morhange, 2003; Marriner et al., 2010; Goiran et al., 2012).

In order to reach this goal, two 12 m cores were drilled in the depression structureless area, which could coincide with the location of a harbour basin. The coring PO1 is located in the south of the area and PO2 in the north, near the present day Tiber River (Fig. 2). The stratigraphy of the two cores being similar, we will focus our discussion on PO2, which benefits from a detailed analysis in the laboratory (Fig. 4). We will integrate this data with pollen analyses carried out on the more suitable lithologies of PO1 (Fig. 5).

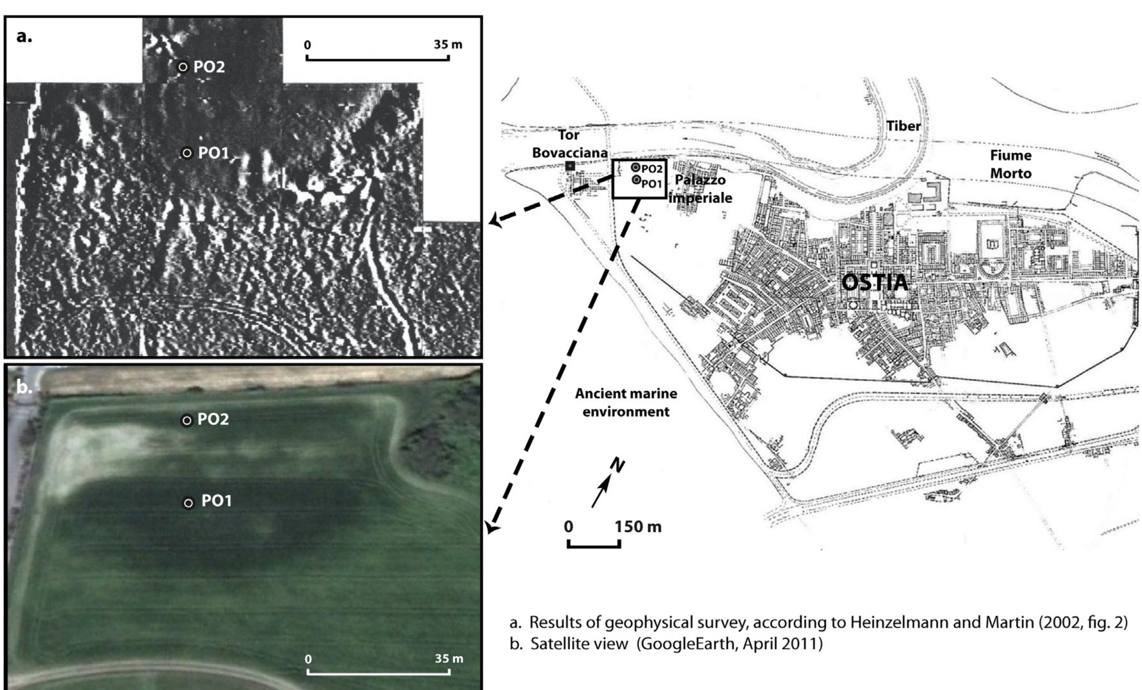

Fig. 2. Location map of the two cores, compared to the geophysical studies of Heinzelmann and Martin (2002).

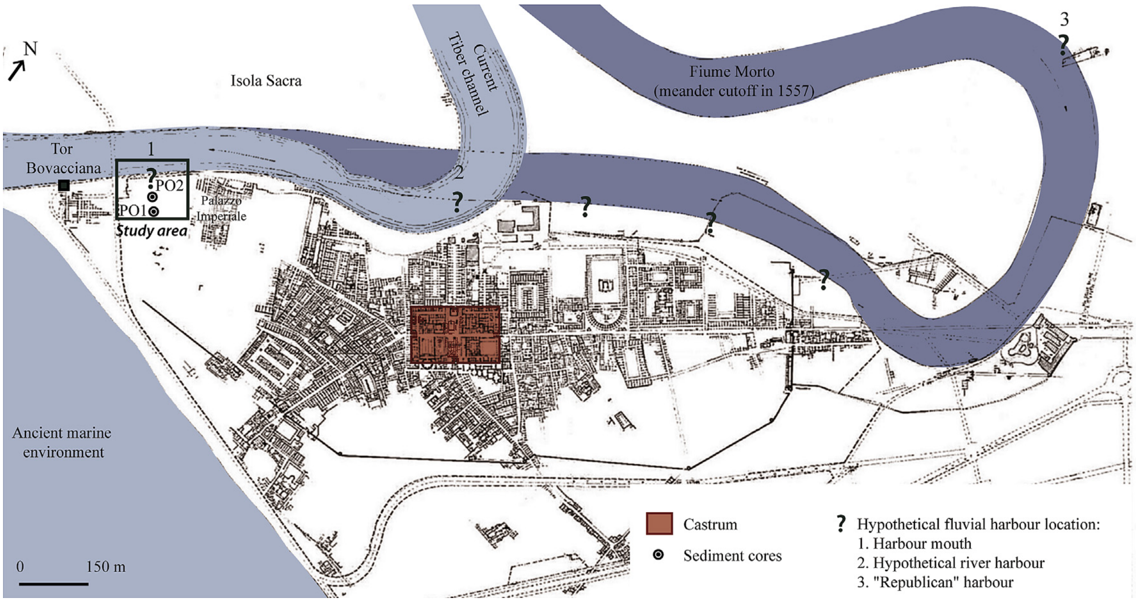

Fig. 3. Location map of Ostia Antica hypothetical river harbours.

2. Regional setting

According to the Roman literary tradition, Ostia was founded in the 7th century BC during the reign of Ancus Marcius, fourth king of Rome. Titus Livius (*Ab Urbe condita libri* I, 33, 6–9) wrote that the city was founded in order to make use of the salt works (lagoons). Its link with the river and the sea is however unquestionable given the etymology and the meaning of the name Ostia, deriving from the Latin noun *ostium* which actually means “mouth”. A couple of ancient authors claim that Ostia was already functioning as a port since its very foundation (Pseudo-Aurelius Victor, *De Viris illustribus urbis Romae* V, 3; Quintus Ennius, *Annales*, frag. 22), but this function might have retrospectively been assigned to the city by these authors and could actually be more recent (Le Gall, 1953; Zevi, 2001a).

From an archaeological point of view, little evidence allows us to go back to such an ancient date for the foundation of Ostia. The urban nucleus of Ostia did not appear before the 4th century BC as a fortress, *castrum*, made of large blocks of tufa. However, there are hypotheses about the location of a palaeo-Ostia before the 4th or

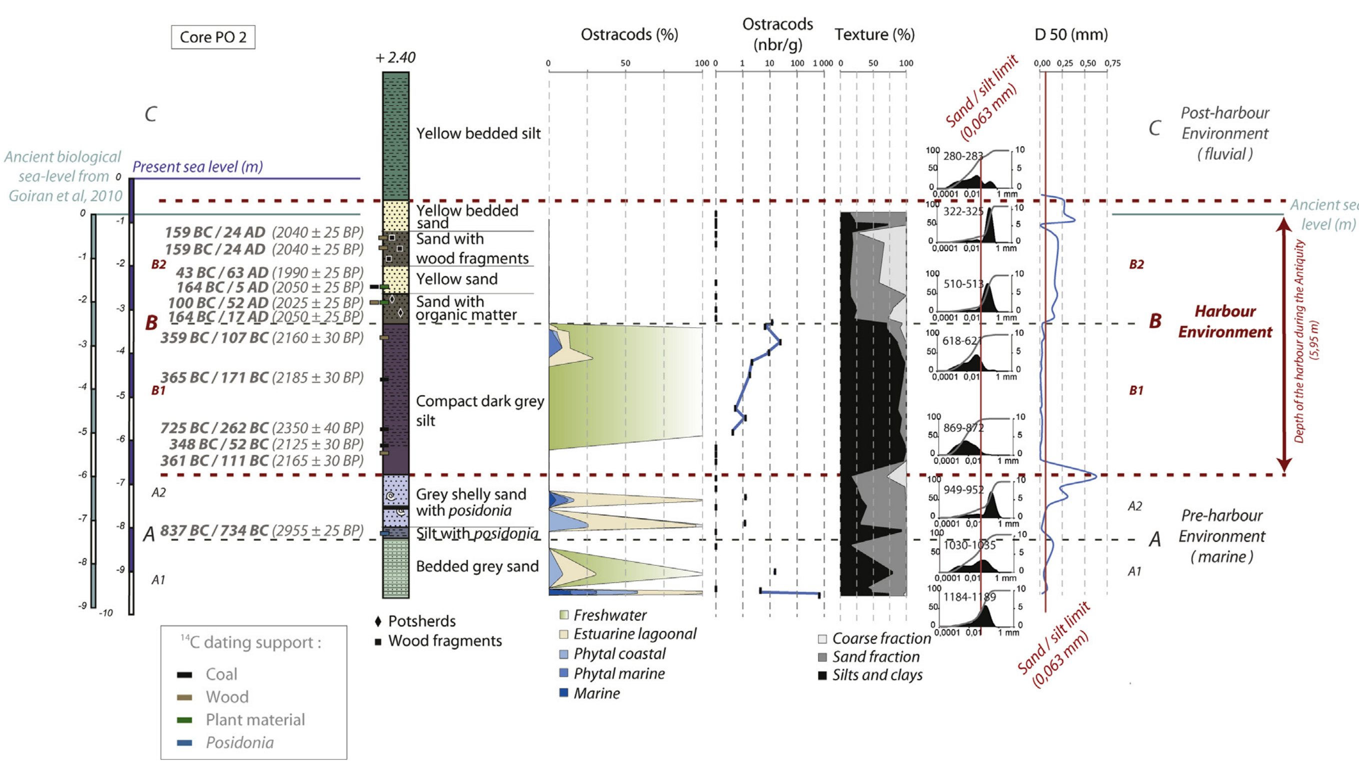

Fig. 4. Summary of the analyses performed on the core PO2.

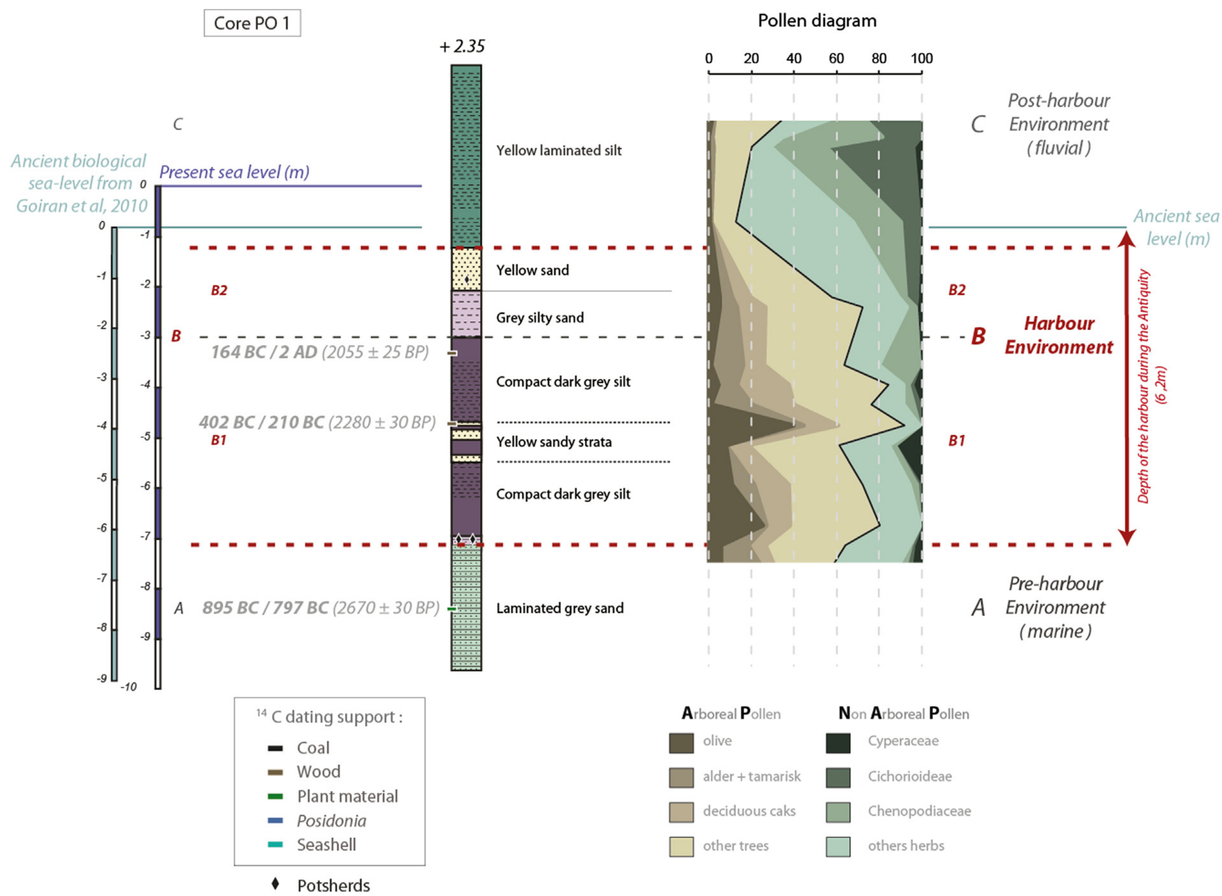

Fig. 5. Simplified pollen diagram for PO1.

beginning of the 3rd century BC (Vaglieri, 1911; Coarelli, 1988; Martin, 1996; Brandt, 2002; Zevi, 2002).

Correlation between textual and archaeological evidences about the existence of Ostia is finally found in the 3rd century BC. The *castrum* was then built and Ostia became the theatre of history in this century (Valerius Maximus, *Dictorum factorumque memorabilium libri novem*, III, 7–10; M. Ivnianvs Ivstinvs, *Epitoma Historiarum Philippicarum*, XVIII, 2, 1–2). The texts reveal that it is during the Punic wars that the harbour became a commercial and military port (Titus Livius, *Ab urbe condita libri*, XXII, XLV). During the 1st century BC, Ostia played a vital role providing Rome with food supplies. This key role is illustrated in 87 BC, when Marius took over Ostia in order to deprive Rome from its supply of goods (L. Annaeus Florus, *De gestis Romanarum*, III, 22; Plutarchus, *Life of Marius*, XLV) (Le Gall, 1953; Zevi, 2001b).

If it is very difficult to find irrefutable archaeological evidence of an original Ostia dating before the 4th–3rd century BC, it is equally difficult to find tangible archaeological clues to locate a harbour at Ostia, especially during the Republican period as well as during the Imperial one. It is likely that the harbour infrastructure (i.e. docks for loading and unloading of goods) were located along the riverbanks in direct connection with the city and the storage facilities (warehouses).

The evolution of the Tiber delta is globally well studied for the Holocene period (Bellotti et al., 1994, 1995, 2007; Giraudi, 2004). But currently, only scarce pieces of information are known about the palaeogeographical context of the Tiber mouth and its dynamics during Roman times. The coastline and the position of the Tiber channel are difficult to locate precisely around the Roman Ostia (Bellotti et al., 2011):

- Concerning the Tiber channel during Ancient times, some indirect indications about its position are available in the Ostian palaeolagoon study by Bellotti et al. (2011); about the channel dynamics, that influenced the Portus basins deposits, some indications can be found in Giraudi et al. (2009), Goiran et al. (2010), Sadori et al. (2010), Mazzini et al. (2011), Salomon et al. (2012) and Pepe et al. (2013).
- During the Republic-Imperial times, the position of the Tiber mouth is without doubt in the vicinity of the “Torre Boacciana” (Tomassetti, 1897). This structure is effectively built on an Imperial structure (probably dated to the 2nd–3rd century AD, Martin, 1996, p. 279) which is the most seaward archaeological remain we know for this period. More information about the coastline comes from the direct surroundings of Portus (Arnoldus-Huyzendveld, 2005; Giraudi, 2004, 2009) or from the south of the Tiber delta, on the Laurentine shore (Bicket et al., 2009). In this last publication, a rapid progradation of the coastline is recorded during Imperial Time on the Tiber delta. This seaward progression of the coastline could have been more active at the river mouth.

3. Materials and methods

Radiocarbon datings were carried out using the AMS method and were calibrated as described by Reimer et al. (2009).

The texture analysis has been realized from a fraction of 30 g of dry, raw sediment. Coarse fraction (>2 mm), sand (2 mm–63 μm) and silts/clays fraction (<63 μm) were differentiated through weighing sieve residue.

Laser Granulometry was performed using a Malvern Mastersizer 2000. This technique allows the acquisition of the texture diagram, the particle size histogram with its cumulative curve, and the median grain (D50), which provides information on the intensity of the hydrodynamics (Storti and Balsamo, 2010). In addition to this, the CM image technique was used to contribute understanding depositional processes (Passega, 1957, 1964; Bravard and Peiry, 1999; Salomon et al., 2012). This technique, based on the median M (average energy) and the coarsest percentile C (maximum energy of the flow) of the grain size cumulative curve for each sample, allows precise interpretation of the processes involved in the successive phases of deposition in depositional environments. The two main processes described in Ostia harbour are (1) "uniform suspension" (silt and fine sand transported in a laminar flow with reduced turbulence), and (2) "graded suspension" (medium and coarse sand transported by a turbulent flow). High C value may be related to a high degree of turbulence, notably during floods.

Biological indicators were essentially focused on the ostracod fauna, because these small bivalve crustaceans are valuable palaeoenvironmental indicators in marginal marine environments (Boomer and Eisenhauer, 2002). Salinity and substrate are the main factors controlling the occurrence of ostracods in brackish waters (Frenzel and Boomer, 2005). Whenever possible, 40 valves were handpicked under a stereomicroscope and each species frequency was normalized to 1 g of dry sample. Information about the environment such as depth, occurrence of vegetation and water flow could be inferred through the auto-ecological analyses of the dominant species (Carbonel, 1991; Lachenal, 1989; Meisch, 2000). The ostracod assemblages were separated in five ecological groups: marine, phytal marine, coastal phytal, brackish lagoonal, freshwater (Cabral et al., 2006; Goiran et al., 2010; Mazzini et al., 2011). In marginal marine environments, the boundary between these groups is indistinct and can only be determined by analysing the dominant association.

Pollen and microcharcoal analyses have been carried out on 25 samples from PO1 core. Each sediment sample was chemically processed following a standard procedure (Faegri and Iversen, 1989) but only 15 contained enough pollen grains, as the general concentration of pollen grains is very low. Pollen data, although still preliminary, provided information about flora and vegetation around the site.

On ancient quays, it is common to find fixed fauna (oysters, barnacles). The upper level of these fixed fauna corresponds to the ancient biological sea level (*absl*). Several times spotted on the quays of Portus (Goiran et al., 2009), this level is positioned at 80 cm below the current biological sea level and has been dated to 2115 ± 30 BP, so 230–450 AD (LY-4198).

4. Results

The altitude of the two points of coring, with respect to the current marine zero sea level, is +2.35 m for PO1 (Fig. 5) and +2.40 m for PO2 (Fig. 4). Based on the stratigraphy and dating, the cores PO1 and PO2 can be divided into three major units: unit A corresponds to the pre-harbour environment, unit B is a typical harbour environment, and unit C corresponds to the post-harbour state.

4.1. Unit A

Unit A is dated from the 9th–8th century BC and is divided into two stratigraphic subunits A1 and A2.

4.1.1. Subunit A1: bedded grey silty sands

The basis of the core consists of laminated grey sands (55–80% of the total sample weight[1]). The coarse fraction, almost absent, mainly consists of plant material. This sandy facies is frequently intercalated with silty clay strata (75–80%). The median grain reaches 20 μm for the siltiest samples and 150 μm for the sandiest samples. This highlights changing hydrodynamics, which can be relatively important. The CM image suggests a deposition mostly derived from graded suspension very well sorted, characteristic of beach-ridge deposits (Fig. 6). At the basis, sample at −9.54 m includes rolled particles inputs that may be of fluvial origin.

The base of the unit consists of a silty level (from 9.52 to 9.57 m), in which the ostracod fauna is extremely abundant (672 valves per gram of dry sediment). The ostracod assemblage is dominated by brackish lagoonal (*Palmoconcha turbida*) and phytal marine and coastal taxa (*Semicytherura* spp. and *Pontocythere turbida*). The remaining part of the subunit is an alternate deposit either barren of ostracods or characterized by brackish lagoonal to coastal assemblages. In the core PO1, ceramic shards are found at the top of the unit A, at about 7 m. This part of the sediment core is correlated to Subunit A1 of PO2 core. Pollen data shows high percentages of alder, mainly accompanied by deciduous and evergreen oaks, hornbeams, olive and tamarisk. Among herbs, grasses and sedges are abundant, while herbs of freshwater environment are absent.

4.1.2. Subunit A2: silt and shelly sands with Posidonia

Pre-harbour deposits that compose this subunit can be differentiated in two types.

(1) The *silts* (95% silty clay) with *Posidonia* from 8.12 to 8.04 m, are dated at 2955 ± 25 BP, or 837–734 BC, at 8.1 m. Their median grain shows a low hydrodynamic (M = about 25 μm). These silts contain no ostracod fauna, but they contain foraminifera (*Elphidium* sp. and *Ammonia* sp.) typical of a coastal lagoon environment. (2) The *grey shelly sands* (55–75% of sands) with *Posidonia* occur from 8.04 to 6.75 m. Their coarse fraction is generally sparse (less than 1.5%), nevertheless, it reaches 30% at the top of unit A2. The median grain, which can be very high (92–630 μm), corresponds to variable hydrodynamics. The CM image identifies in unit A2: (1) a mixture of sediment originating from uniform and graded suspension between −8.08 and −7.92 m; (2) graded suspension well sorted similar to the unit A1 around −7.53 m; and (3) well sorted graded suspension with rolled particles between −7.33 and −6.85 m. This ultimate deposit reveals a high hydrodynamic context, probably from fluvial influence in coastal context. Broadly, the unit A2 corresponds to an instable depositional context.

Shell elements cannot be determined being too fragmentary. The ostracod fauna is often absent or limited to a few numbers of valves, belonging to species typical of a brackish lagoon environment, occasionally marked by contributions of marine origin.

4.2. Unit B

Unit B is divided into two stratigraphic subunits B1 and B2.

4.2.1. Subunit B1: dark grey silts

The base of the harbour unit consists of compact dark grey silts (85–99.9% of silty clay) from 6.75 to 3.31 m, in which the coarse fraction is scarce. The hydrodynamics highlighted by the median grain (5–50 μm) remains very low. The CM image of unit B1 includes two different periods. Basal deposits are mainly from decantation (−6.30 m) to uniform suspension (−6.03 m) with rare inputs of graded suspension (−6.48 and −6.48 m). It corresponds to a very quiet environment well protected against high water flow currents. Upper deposits, from −5.82 m to −3.31 m, reveal a quiet environment context (decantation mostly uniform suspension) with regular graded suspension inputs, sometimes rolled (−4.25 m). Coarse inputs could correspond to coastal sand or fluvial flood inputs. The ostracod fauna supports this observation. Indeed

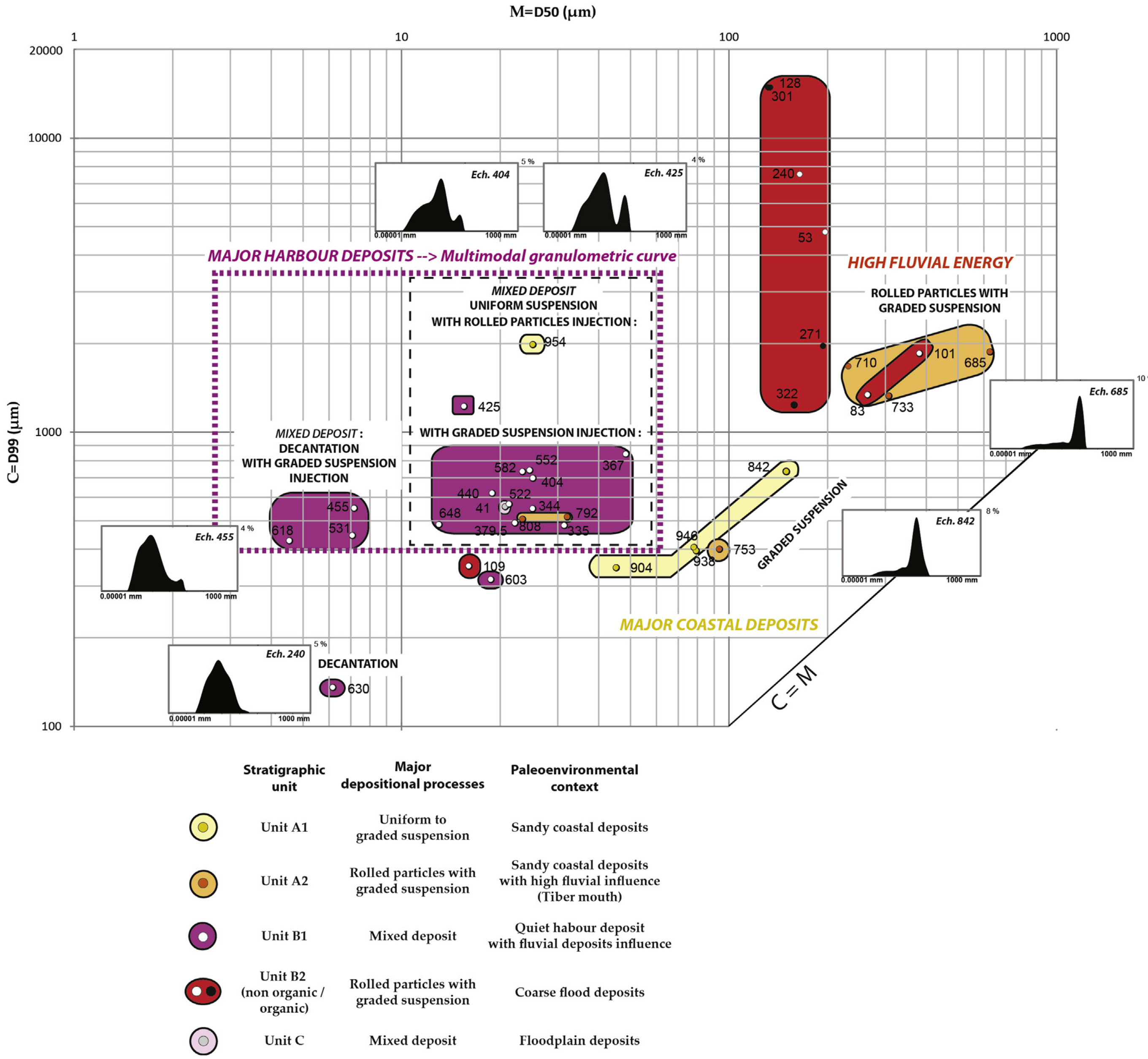

Fig. 6. C/M diagram for PO2.

from 6.75 to 4.24 m, ostracods are represented by some valves of *Ilyocypris gibba* and *Candona* sp juv. and thus reflect the presence of freshwater, subject to low currents. From 4.03 to 3.31 m, they are characterized by oligohaline freshwater assemblage influenced by marine inputs as represented by *Xestoleberis communis*, a marine phytal ostracod whose occurrence in such an environment may be linked to storms. The occurrence of scattered valves of open marine species such as *Henryhowella asperrima* that could have been displaced during sea storms, could confirm this theory. This subunit is chronologically anchored by five dates: 361 BC to 111 BC (2165 ± 30 BP) at ± 6.305 m; 348 BC to 52 BC (2125 ± 30 BP) at ± 6.125 m; 725 BC to 262 BC (2350 ± 40 BP) at 5.75 m; 365 BC to 171 BC (2185 ± 30 BP) at ± 4.635 m; 359 BC to 107 BC (2160 ± 30 BP) at ± 3.645 m.

In PO1, a strong change in pollen taxa is found at the transition from zone A to B. At the beginning of the unit B alder strongly decreases, while olive increases (overpassing 30% at 4 m) and a sharp increase of cereals, from ca. 2–6% is found. Trees of the coastal plain forest such as deciduous oaks are accompanied and at times overwhelmed by olive. Riparian trees such as alder are present and show oscillations.

4.2.2. Subunit B2: alternating sandy strata

Deposits of this subunit, which range from 3.3 to 1.17 m, are composed of alternating facies of clear sand (50%) and sands rich in organic and plant material (from 3.3 to 2.6 m and from 2 to 1.17 m).

The coarse fraction, which is essentially mineral in the base of the subunit and organic in its centre, corresponds to 20–45% of the sediment texture. The median grain of these sands (140–200 µm) highlights relatively important hydrodynamics. The mineral fraction is generally poorly sorted or very heterogeneous.

At the top of the subunit B2, from 1.17 to 0.5 m, these yellow sands are laminated. They are then very sandy (75–85%). The median grain, between 260 and 380 μm, highlights a significant hydrodynamics. Regarding the CM image, sand originates from well-sorted graded suspension, with rolled particles. Samples at −301 m, −240 m, −128 m and −53 m are mainly composed by rolled particles. This subunit B2 clearly reveals a high fluvial influence.

All the samples analysed in the subunit B2 were barren. Unidentifiable potsherds were found at the base of this subunit, between 3.3 and 2.6 m. In addition to this, the base is chronologically anchored by three dates: 159 BC to 17 AD (2050 ± 25 BP) at 2.86 m; 164 BC to 5 AD (2050 ± 25 BP) at 2.5 m; 159 BC to 24 AD (2040 ± 25 BP) at 1.6 m.

A clear change in pollen content marks as well the passage to unit B2. Deciduous oaks and olive decrease while cereals continue to be present or even increase. Alder still shows high values up to 1.45 m, to decrease in the following. An anomaly is found at −0.05 m, where there is a strong expansion of crucifers. Very high values of this pollen type were recently found in the port of Naples (Russo Ermolli et al., 2013a, 2013b). Considering the morphology of pollen grains we can exclude the presence of salt tolerant herbs. Aquatic plants are typical of freshwater. Top samples of this unit show a strong increase of herbs such as chenopods and Cichorioideae.

4.3. Unit C

Unit C represents a relatively homogeneous set that consists of laminated yellowish silty clay (about 75%) that ranges from 0.5 m to the top of the core. The median grain (about 20 μm) indicates very low hydrodynamics. It corresponds to uniform suspension with graded suspension inputs, probably floodplain deposits.

5. Interpretation and discussion

5.1. Pre-harbour environment

Basal unit A, prior to the foundation of Ostia, is composed of fluvio-marine sediments, and dates from the early first millennium BC (837–734 BC, or 2955 ± 25 BP, Ly 8066 for PO2 and 895 to 797 BC, or 2670 ± 30 BP, Ly 8047 for PO1).

The base of this core, laminated grey sands, shows coastal brackish sediments well sorted, which were subjected to freshwater inflows (unit A1), evidenced by the occurrence of the ostracod *Ilyocypris gibba*, by CM image and by the presence of pollen of riparian trees (unit A, PO1). After the 9th and 8th centuries BC (unit A2) the fluvial influence becomes weaker and occasional marine incursions are recorded (occurrence of *Aurila convexa*, *Costa batei*, *Leptocythere ramosa*, *Neocytherideis subulata*, *P. turbida*, *P. turbida*). Well-sorted texture from graded suspension and rolled particles reveals regular coarse fluvial deposits sorted by coastal processes (Fig. 6). This unit, which is characterized by alternation of marine and fluvial influence, suggests a coastal mobility of an estuarine river mouth.

5.2. Harbour basin environment

Sediments change from a grey coarse sandy texture (estuarine context) to a dark grey fine texture, which is deposited in a quiet environment with fluvial influence.

The so-called harbour basin sequence is divided into two units: Unit B1 consists of dark grey clays and unit B2 composed of yellowish sands and silts with alternated bedding.

For unit B1, only the silty-clay fraction is trapped (95%) indicating a quiet depositional environment. Colour ranging from dark grey to blackish indicates containment. The environment remained largely under the influence of river water, despite occasional traces of salty water contributions, which are probably related to marine incursions during storms or a higher salt water intrusion in the Tiber channel due to a relatively quiet fluvial hydrology phase (Capelli and Mazza, 2008). Such an environment remains protected and stable, as evidenced by CM image which show a B1 context very quiet, dominated by decantation and uniform suspension. These fine sediments are frequently mixed with particles from graded suspension, deposited by fluvial or coastal processes.

This is the portion of the PO1 core in which pollen is better preserved, with very high olive pollen percentages and presence of cereals, pointing out land-use (Fig. 5). In the surroundings, plain forest is however widespread, while alder shows many oscillations.

This unit B1, rich in dark grey clays, is typical of a well-protected harbour still connected to fluvial-marine environments.

5.3. Silting up and abandonment of the harbour basin: no later than at the beginning of the 1st century AD

Gradually, silt-clay sediments (unit B1) from the Tiber and its watershed filled in the harbour. Then a sandy loam sequence rich in organic debris (unit B2) took over. Pollens show a decrease of plain forest trees and an increase of synanthropic and probably pioneer taxa.

This generalized silting with sterile sands only occurred at the end of the harbour basin use (unit B2). Particles from the unit B2 are clearly deposited by fluvial inputs, certainly during high-energy floods. These coarse particles are mostly rolled, coming from the channel bed load.

Then, it is possible to put forward the hypothesis that a succession of major flooding episodes has permanently sealed the harbour basin of Ostia at the beginning of the imperial era (Le Gall, 1953; Bersani and Bencivenga, 2001). This hypothesis is supported by an extract from the ancient author Strabo (64–58 BC–21–25 AD): "Ostia had the inability to maintain or consider a convenient sheltered harbour due to the amount of Tiber sediments transported down to the seashore" (Strabo, *Geographica, V,3,5.*). Ongoing analyses will clarify the nature and pace of the Ostia fluvial harbour abandonment, but it nonetheless already seems to occur between the 1st century BC and the 1st century AD. To further support the chronostratigraphy, the 6 radiocarbon datings from unit B2 were performed on 3 different types of material: organic matter, coal and wood (Table 1). Anyway, the occurrence of *navalia* not far from the silting up basin is difficult to explain. These buildings, interpreted as *navalia*, were built during the Early-Imperial period (Heinzelmann and Martin, 2002, p. 16). We could propose the hypothesis that at that time the basin at the mouth of the Tiber River was not actively used.

The process of abandonment actually seems to take place before the foundation (in the middle of the 1st century AD) of the new Portus harbour complex, located at 3 km north of Ostia and at the mouth of the Tiber. This result is an important piece of discussion concerning the reasons why Portus was built in the middle of the 1st c. AD, during which the Romans were unable to maintain a deep and permanent access to Ostia harbour. The new harbour was built to accommodate the increasing number of merchant and military ships arriving from the provinces.

Another point concerns the abandonment or the change of function of the river harbour basin of Ostia which occurs not earlier than to 160 BC and at the very latest, around 25 AD (Ly-8059 and Ly-8060). The construction of Claudius harbour only begins around 40 AD and is inaugurated by Nero in 64 AD. In other words the time between the abandonment of Ostia harbour and the construction of the new port (Portus) is of the order of 80–100 years maximum, or 15–35 years at least. During this transition period, the Tiber banks must have been used only as linear fluvial harbour (Fig. 3). The

Table 1
Summary of dating.

Cores	Depth (below ancient sea level)	Code laboratoire	Dating support	14 C age in BP	Age calibrated (Reimer et al., 2009)	Maximum likelihood interval	
PO-1	2.9 m	Ly-8045 (GrA)	Wood	2295 ± 30	−405 to −231		
	3.35 m	Ly-8046 (GrA)	Wood	2055 ± 25	−164 to 2		
	8.45 m	Ly-8047 (GrA)	Plant material	2670 ± 30	−895 to −797		
PO-2	1.38 m	Ly-8059 (GrA)	Wood	2040 ± 25	−159 to 24		
	1.60 m	Ly-8060 (GrA)	Wood	2040 ± 25	−159 to 24		
	2.50 m	Ly-8061 (GrA)	Charcoal	1990 ± 25	−43 to 63		
	2.50 m (bis)	Ly-8062 (GrA)	Organic material	2050 ± 25	−164 to 5		
	2.86 m	Ly-8063 (GrA)	Plant material	2025 ± 25	−100 to 52		
	2.86 m (bis)	Ly-8064 (GrA)	Wood	2050 ± 25	−164 to 17		
	3.63–3.66 m	Ly-9096 (GrA)	Wood	2160 ± 30	−359 to −107		
	4.67–4.60 m	Ly-9095 (GrA)	Charcoal	2185 ± 30	−365 to −171		
	5.75 m	Ly-9094 (GrA)	Charcoal	2350 ± 40	−725 to −262	91%	−543 to −341
	6.11–6.14 m	Ly-9093 (GrA)	Charcoal	2125 ± 30	−348 to −52	88%	−207 to −52
	6.29–6.32 m	Ly-9092 (GrA)	Wood	2165 ± 30	−361 to −112		
	8.10 m	Ly-8066 (GrA)	Posidonia	2955 ± 25	−837 to −734		

filling of the basin corresponds to the end of an important component of a wider harbour system that could be composed by other port facilities along the riverbanks.

Finally, the uppermost unit (unit C), consisting of silt Tiber overflows, covers the remains of a now obsolete harbour basin.

5.4. The depth of the basin and the implications in naval archaeology

In PO2 core, a sharp contact between the lower unit A2 and the clay harbour unit B1 occurs. The depth of this sudden change is -6.70 m below the present sea level and 5.90 m below the *absl*. For PO1, the depth of the initial harbour basin is 6.2 m below the *absl* as foreseen by the presence of ceramic shards in correspondence of the same sharp contact (Fig. 7).

So, at the beginning of its history (prior to 2165 ± 30 BP), the harbour basin of Ostia had a depth of about 6 m. At 40 cm above the sharp contact between the unit A2 and unit B (for core PO2), a radiocarbon dating gives 2165 ± 30 BP, so 361–111 BC. In other words, the contemporary depth of this harbour bottom, dated from the mid-4th century and the beginning of the 2nd century BC, was 5.50 m below the *absl*.

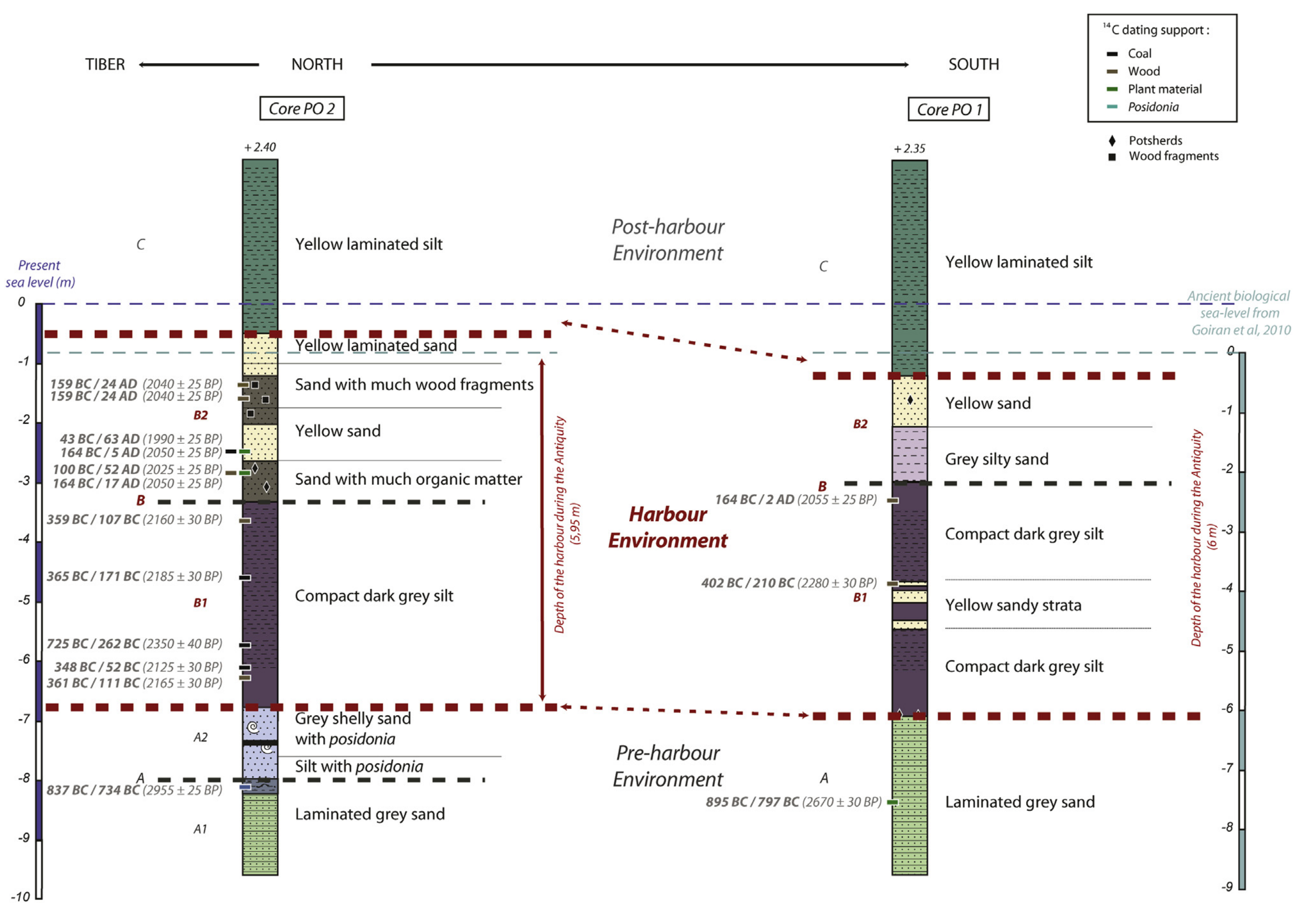

Fig. 7. Summary of the analyses performed on the cores PO1 and PO2.

By comparison, stratigraphic investigations carried out at Portus showed the original average depth of 7 m for the basin of Claudius (northern area) and 6 m at the entrance of the hexagon of Trajan (Goiran et al., 2010).

At the top of the unit B2, a radiocarbon dating indicates 2040 $\pm$ 25 BP, so 159 BC to 24 AD. At this time, the depth of the basin did not exceed 0.5 m and navigation was no longer possible. If we take into account the tide of 40 cm, we obtain a maximum depth of 90 cm for the water column. In other words, at the latest at the end of the 1st quarter century AD, the basin depth ranged from approximately 50 cm to 1 m. The basin was therefore periodically accessible depending on the conditions of tidal ranges and drafts boats.

Hypothesis of dredging phases, like in the harbour of Marseille (Morhange and Marriner, 2009) and Tyre (Marriner and Morhange, 2006) have to be considered in order to maintain harbour activity. Two indicators have been noticed: (1) an abrupt facies change between the bottom clay harbour unit B1 and sandy unit B2 and (2) a chronological gap is observed in the range of radiocarbon dating.

The depth of the basin of Ostia is very important and is much higher compared to drafts full load that can be estimated for marine vessels used in Roman times for shipping (Boetto, 2010). In this basin, all types of vessels could find shelter, particularly marine vessels of large tonnage.

According to Dionysos of Halicarnassus (*Ant. Rom*., III, 3.), who writes during the 1st century BC, the tonnage of the ships that could cross the bar mouth of the Tiber (close to the harbour basin studied here) was 3000 amphorae (τρισχιλιοφοροι) or 20,000 *modii* of wheat, which corresponds to 150–200 tons. Their draft at full load can be estimated at 2.20/2.30 m. Only vessels of less than 2.50 m draft could enter full load in the mouth of the Tiber (Boetto, 2010, p. 121).

Currently, no wreckage dated 4th–3rd century BC has yet been the subject of extensive excavations, which could have brought to a certain idea of the shapes and tonnage of the original vessels. The largest Roman ship studied is the Madrague Giens (65–70 BC). This one, of a returned length of 40 m, with a width of 9 m and a wedge depth of 4.50 m, had a capacity of 400 tons deadweight for moving the about 500 tons (Pomey and Tchernia, 1978; Pomey, 1982, 1997). Its draft at full load was estimated from 3.5 to 3.7 m.

5.5. The harbour location

The harbour basin is less than 600 m west from the *castrum* and shows no particular connections with it (Fig. 3). The location should be understood, as the end of an ancient itinerary already used, before the establishment of the *castrum*. This route, coming from south along the beach, joined the river mouth (Calza et al., 1953; Zevi, 2001a). It seems to be resumed by the Via Laurentina, which is dated from the 4th century BC. The basin could be contemporary to the Via Laurentina, and possibly previous to the establishment of the *castrum*.

The dating of the port requires making a connection with the 'republican' mole located in the north to the oxbow bend of Trastevere (Pellegrino et al., 1995). Remains of this structure are still visible but the dating is not certain. Until further research has been conducted, there is no evidence that they were used during the same period.

If the close environment around the basin, at north and east, has been recently studied (Heinzelmann and Martin, 2002), there is very little information about the south. The exact relation between the harbour basin and the ancient remains of the "Torre Boacciana" is still to be determined. The medieval tower, located 150 m southwest from the basin, is built on a roman nucleus. Some stamped bricks are dated from the 2nd century AD, but the construction presents obviously several ancient states (Meiggs, 1973). The construction could have been used for controlling and/or signalling the river mouth. If a tower is most probable, it has no direct connections with the basin, which was, at this time, silted. However, there is no clue of a tower here, between the 4th and the 2nd century BC.

6. Conclusions

For the first time, a multidisciplinary research combining archaeologists, historians, geographers, sedimentologists, geomorphologists, micropalaeontologists and palynologists focussed on the Ostia harbour issue. The research identified the location of the river mouth harbour basin of Ostia in the north of the city, to the west of the "Palazzo Imperiale". Coring helped highlighting a stratigraphic sequence in the depression that was interpreted as the phase of a sedimentary filling of a harbour basin. Four main chrono-stratigraphic arguments reinforce this interpretation. (1) By -6 m below the *absl* (*ancient biological sea level*), blackish mud indicates a quiet environment dated between the 4th and 2nd century BC, contemporary of Ostia. (2) Three ruptures are observed: (2.1) a stratigraphical rupture: an abrupt facies change appears between sand and mud. (2.2) A chronological rupture: a gap in sedimentation is observed at -6 m below *absl*; this fact indicates a loss of sedimentary archives to correlate with the idea of a basin digging or its maintenance by dredging. (2.3) A palaeoenvironmental rupture: the microfauna identified in this sequence shows a quiet and protected environment, but still semi-open to river and marine influences; indeed, there is a drastic fall in the number of species and a shift from an open to a semi-open environment is observed; moreover, palynological signals show a decrease in the arboreal species and a sharp increase in anthropogenic markers (cereals, olive).

All these changes in the ecosystem seem more to be attributed to human activity than to the nature.

This study, as well as current on-going researches in laboratory and in the field will help to advance our understanding of the relationship between Ostia, its river mouth harbour and the creation of the imperial harbours in the 1st and 2nd centuries AD. The river mouth basin of Ostia knew a widespread silting at the latest at the beginning of the 1st century AD. This element brings two pieces of thoughts: (1) At the end of the first quarter of the 1st century AD, taking the tide into account, the basin had no more than 50 cm to 1 m maximum of water column. (2) The basin thus remained functional for boats with low draft. Then Ostia had no more deep harbour and the new harbour, Portus, was not yet built at this time. It can be assumed that the banks of the Tiber, probably managed, served as platforms unless silting was widespread in the Tiber. At the 1st century AD it can also be assumed that the function of the river mouth harbour of Ostia has changed.

Although the presence of the basin is now documented and validated by the use of coring which allowed a palaeoenvironmental reconstruction and a chronostratigraphic study, the presence of harbour structures like breakwater and quays by archaeological excavations, remains to be proven.

Acknowledgements

Ecole Française de Rome, Soprintendenza Speciale per i Beni Archeologici di Roma – Sede di Ostia, Maison de l'Orient et de la Méditerranée (UMR 5133), Maison Méditerranéenne des Sciences de l'Homme (UMR 6573), Università la Sapienza & Roma 3, CNRS, Université de Lyon, Institut Universitaire de France: chaire P. Arnaud, J. Cavero (topographer), OMEAA platform, ARTEMIS-SHS program and radiocarbon laboratory of Lyon, Labex IMU, ANR JC Pol-Tevere. F. Bernhardi, C. Davaud and A. Filloux for their helps.

References

Arnoldus-Huyzendveld, A., 2005. The natural environment of the Agro Portuense. In: Keay, S., Millett, M., Paroli, L., Strutt, K. (Eds.), Portus, an Archaeological Survey of the Port of Imperial Rome. The British School, Rome, pp. 14–30.

Bellotti, P., Chiocci, F.L., Milli, S., Tortora, P., Valeri, P., 1994. Sequence stratigraphy and depositional setting of the Tiber delta: integration of high-resolution seismics, well logs, and archeological data. J. Sedim. Res. B Stratigr. Glob. Stud. 64, 416–432.

Bellotti, P., Calderoni, G., Carboni, M.G., Bella, L.D., Tortora, P., Valeri, P., Zernitskaya, V., 2007. Late Quaternary landscape evolution of the Tiber River delta plain (Central Italy): new evidence from pollen data, biostratigraphy and 14C dating. Z. Geomorphol. 51, 505–534.

Bellotti, P., Calderoni, G., De Rita, F., D'Orefice, M., D'Amico, C., Esu, D., Magri, D., Martinez, M.P., Tortora, P., Valeri, P., 2011. The Tiber River Delta Plain (Central Italy): coastal evolution and implications for the Ancient Ostia roman settlement. The Holocene 21, 1105–1116.

Bellotti, P., Milli, S., Tortora, P., Valeri, P., 1995. Physical stratigraphy and sedimentology of the Late Pleistocene-Holocene Tiber Delta depositional sequence. Sedimentology 42, 617–634.

Bersani, P., Bencivenga, M., 2001. Le Piene Del Tevere a Roma Dal V Secolo a.C. all'anno 2000. Servizio Idrografico e Mareografico Nazionale. Presidenza del Consiglio dei Ministri Dipartimento per i Servizi Tecnici Nazionali, Roma.

Bicket, A.R., Rendell, H.M., Claridge, A., Rose, P., Andrews, J., Brown, F.S.J., 2009. A multiscale geoarchaeological approach from the Laurentine shore (Castelporziano, Lazio, Italy). Géomorphologie 4, 257–270.

Boetto, G., 2010. Le port vu de la mer: l'apport de l'archéologie navale à l'étude des ports antiques. In: Keay, S., Boetto, G. (Eds.), Portus, Ostia and the Ports of the Roman Mediterranean. Contributions from Archaeology and History. Ministero per i Beni e le Attività Culturali, Rome, pp. 112–128.

Boomer, I., Eisenhauer, G., 2002. Ostracod faunas as palaeoenvironmental indicators in marginal marine environments. In: Holmes, A.H., Chivas, A.R. (Eds.), The Ostracoda: Applications to Quaternary Research, pp. 135–149.

Brandt, J.R., 2002. Ostia and Ficana: two tales of one city? Mediterr. Archaeol. 15, 23–39.

Bravard, J.-P., Peiry, J.-L., 1999. The CM pattern as a tool for the classification of alluvial suites and floodplains along the river continuum. In: Geological Society, vol. 163 (1). Special Publications, London, pp. 259–268.

Canina, L., 1830. Indicazione delle rovine di Ostia e di Porto e della supposizione dell'intero loro stato delineate in quattro tavole dall'architetto Luigi Canina. Tipi di Mercuri e Robaglia, Roma.

Cabral, M.C., Freitas, M.C., Andrade, C., Cruces, A., 2006. Coastal evolution and Holocene ostracods in Melides lagoon (SW Portugal). Mar. Micropaleontol. 60, 181–204.

Calza, G., Becatti, G., Gismondi, I., De Angelis D'Ossat, G., Bloch, H., 1953. Topografia Generale, Scavi di Ostia, vol. I. Libreria dello Stato, Roma.

Carbonel, P., 1991. Les ostracodes du paleolac Haijad. In: Petit-Maire, N. (Ed.), Paleoenvironnements du Sahara. Lacs holocènes à Taoudenni. Editions du CNRS, Mali, pp. 91–102.

Capelli, G., Mazza, R., 2008. Intrusione Salina Nel Delta Del Fiume Tevere. Evoluzione Del Fenomeno Nei Primi Anni Del Terzo Millennio. La Geologia Di Roma: Dal Centro Storico Alla Periferia – Seconda Parte – Memorie Descrittive Della Carta Geologica d'Italia vol. 80, 237–260.

Coarelli, F., 1988. I santuari, il Fiume, gli Empori. In: Momigliano, A., Schiavone, A. (Eds.), Storia di Roma, 1, pp. 127–152 (Turin).

Faegri, K., Iversen, J., 1989. In: Faegri, K., Kaland, P.E., Krzywinski, K. (Eds.), Textbook of Pollen Analysis, fourth ed. John Wiley & Sons, Chichester.

Fea, C., 1824. Alcune osservazioni sopra gli antichi porti d'Ostia, ora di Fiumicino, Roma.

Fea, C., 1831. Storia delle Saline d'Ostia introdotte da Anco Marcio quarto re di Roma dopo la fondazione di quella, Roma.

Fea, C., 1835. Il Tevere navigabile oggidì come nei suoi più antichi secoli, e la citta di Ostia ivi edificata dal re Anco Marcio, emporio di Roma, Roma.

Giraudi, C., 2004. Evoluzione tardo-olocenica del delta del Tevere. Il Quat. It. J. Quat. Sci. 17, 477–482.

Frenzel, P., Boomer, I., 2005. The use of ostracods from marginal marine, brackish waters as bioindicators of modern and Quaternary environmental change. Palaeogeogr. Palaeoclimatol. Palaeoecol. 225 (1–4), 68–92.

Giraudi, C., Tata, C., Paroli, L., 2009. Late Holocene evolution of Tiber river delta and geoarchaeology of Claudius and Trajan Harbour, Rome. Geoarchaeology 24, 371–382.

Goiran, J.-Ph., Morhange, C., 2003. Géoarchéologie des ports antiques de Méditerranée: problématiques et études de cas. Topoï 11, 645–667.

Goiran, J.-Ph., Tronchère, H., Collalelli, U., Salomon, F., Djerbi, H., 2009. Découverte d'un niveau marin biologique sur les quais de Portus: le port antique de Rome. Méditerranée 112 (1), 59–67.

Goiran, J.-Ph., Tronchère, H., Salomon, F., Carbonel, P., Djerbi, H., Ognard, C., 2010. Palaeoenvironmental reconstruction of the ancient harbours of Rome: Claudius and Trajan's marine harbours on the Tiber delta. Quat. Int. 216, 3–13.

Goiran, J.-Ph., Salomon, F., Pleuger, E., Vittori, C., Mazzini, I., Boetto, G., Arnaud, P., Pellegrino, A., 2012. Résultats préliminaires de la première campagne de carottages dans le port antique d'Ostie. Chron. Mélanges l'Ecole Fr. Rome 123, 2–7.

Heinzelmann, M., Martin, A., 2002. River port, navalia, and harbour temple at Ostia: new results of a DAI-AAR Project. J. Roman Archaeol. 15, 5–19.

Lachenal, A.M., 1989. Écologie des ostracodes du domaine méditerranéen. Application au Golfe du Gabès (Tunisie orientale): les variations du niveau marin depuis 30 000 ans. Doc. Lab. Géol. Lyon 108, 1–239.

Le Gall, J., 1953. In: Presses Universitaires de France (Ed.), Le Tibre, fleuve de Rome, dans l'antiquité. Publications de l'Institut d'Art et d'Archéologie de l'Université de Paris, I et II, Paris.

Marriner, N., Morhange, C., 2006. Geoarchaeological evidence for dredging in Tyre's ancient harbour, Levant. Quat. Res. 65, 164–171.

Marriner, N., Morhange, C., Goiran, J.-Ph., 2010. Coastal and ancient harbour geoarchaeology. Geology Today 26 (1), 21–27.

Martin, R., 1996. Un saggio sulle mura del castrum di Ostia (Reg. I, ins. X.3). In: Zevi, A.G., Claridge, A. (Eds.), "Roman Ostia" Revisited. Archaeological and Historical Papers in Memory of Russell Meiggs, pp. 19–38. Rome.

Mazzini, I., Faranda, C., Giardini, M., Giraudi, C., Sadori, L., 2011. Late Holocene palaeoenvironmental evolution of the ancient harbour of Portus (Latium, Central Italy). J. Palaeolimnol. 46, 243–256.

Meiggs, R., 1973. Roman Ostia. Clarendon Press, Oxford (1960; second ed. 1973).

Meisch, C., 2000. Freshwater ostracoda of Western and Central Europe. In: Schwoerbel, J., Zwick, P. (Eds.), Süsswasserfauna von Mitteleuropa. Spektrum Akademischer Verlag 8/3, Heidelberg, pp. 1–522.

Morhange, C., Marriner, N., 2009. Roman dredging in ancient Mediterranean harbours. Boll. Archeol., 23–32 (Online Vol. Spec. IAAC).

Passega, R., 1957. Texture as characteristic of clastic deposition. Am. Assoc. Petrol. Geol. 41 (9), 1952–1984.

Passega, R., 1964. Grain size representation by CM patterns as a geologic tool. J. Sediment. Res. 34 (4), 830–847.

Pellegrino, A., Olivanti, P., Panariti, F., 1995. Ricerche archeologiche nel Trastevere Ostiense. Archeol. laz. 12, 393–400.

Pepe, C., Giardini, M., Giraudi, C., Masi, A., Mazzini, I., Sadori, L., 2013. Plant landscape and environmental changes recorded in marginal marine environments: the ancient Roman harbour of Portus (Rome, Italy). Quat. Int. 303, 73–81.

Pomey, P., 1982. Le navire romain de la Mandrague de Giens. CRAI 126 (1), 133–154.

Pomey, P., 1997. La Navigation Dans L'Antiquité. Édisud ed., Aix-en-Provence.

Pomey, P., Tchernia, A., 1978. Le tonnage maximum des navires de commerce romains. Archaeonautica 2, 233–251.

Reimer, P.J., Baillie, M.G.L., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Ramsey, C.B., Buck, C.E., Burr, G.S., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Hajdas, I., Heaton, T.J., Hogg, A.G., Hughen, K.A., Kaiser, K.F., Kromer, B., McCormac, F.G., Manning, S.W., Reimer, R.W., Richards, D.A., Southon, J.R., Talamo, S., Turney, C.S.M., Plicht, J., van der et Weyhenmeyer, C.E., 2009. IntCal09 and Marine09 radiocarbon age calibration curves, 0–50,000 years cal BP. Radiocarbon 51 (4), 1111–1150.

Russo Ermolli, E., Romano, P., Ruello, M.R., 2013a. Human–environment interactions in the southern Tyrrhenian coastal area: hypothesis from Neapolis and Elea-Velia. In: Harris, W.V. (Ed.), History and Environment in the Ancient Mediterranean. Columbia University Press, New York.

Russo Ermolli, E., Romano, P., Barone-Lumaga, M.R., Ruello, M.R., 2013b. The natural and cultural landscape of Naples (southern Italy) during the Graeco-Roman and Late Antiquity times. J. Archaeol. Sci. (in press).

Salomon, F., Delile, H., Goiran, J.-Ph., Bravard, J.-P., Keay, S., 2012. The Canale di Comunicazione Traverso in Portus: the Roman sea harbour under river influence (Tiber delta, Italy). Géomorphol. Relief Process. Environ. 1 (2012), 75–90.

Sadori, L., Giardini, M., Giraudi, C., Mazzini, I., 2010. The plant landscape of the imperial harbour of Rome. J. Archaeol. Sci. 37, 3294–3305.

Storti, F., Balsamo, F., 2010. Particle size distributions by laser diffraction: sensitivity of granular material strength to analytical operating procedures. Solid Earth 1, 25–48.

Tomassetti, G., 1897. Della Campagna romana nel medioveo. Archiv. della Soc. Romana Storia Patria (ASRSP) 20 (1), 45–94.

Vaglieri, D., 1911. Ostia – Scoperte varie. Avanzi repubbilcani. Not. Scavi, 193–201.

Zevi, F., 2001a. Les débuts d'Ostie. In: Descoeudres, J.P. (Ed.), Ostia, port et porte de la Rome antique. GEORG, Geneve, pp. 3–9.

Zevi, F., 2001b. Ostie sous la République. In: Descoeudres, J.P. (Ed.), Ostia, port et porte de la Rome antique. GEORG, Geneve, pp. 10–18.

Zevi, F., 2002. Origini di Ostia. In: Bruun, C., Zevi, A.G. (Eds.), Ostia e Portus nelle loro relazioni con Roma. Istitutum Romanum Finlandiae, Roma, pp. 11–32.