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A harbour–canal at Portus: a geoarchaeological approach to the *Canale Romano*: Tiber delta, Italy

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Abstract This paper presents a detailed description of the sediments trapped by the *Canale Romano* in the Imperial harbour complex of Portus (Rome). The study confirms the hypothesis of a Roman canal (active during the early 2nd century AD and the 3rd/5th century AD) with a maximum water-depth between 4.36 and 7.37 m. The function of this canal as a harbour seems to particularly fit with the data available. This study follows a multidisciplinary approach. It combines all previous data available on the *Canale Romano*

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(geophysical surveys, archaeological and historical data) and provides a new palaeoenvironmental dataset in order to draw a more complete overview about its history. Three cores drilled in the *Canale Romano* are analyzed using sedimentological data, CM diagram and bioindicators, ^{14}C and archaeological data. Four main sedimentation phases were identified: (1) Pre-canal deposits; (2) relatively quiet fluvial environment deposits; (3) flood sediments inputs; and (4) fine sediment infill after the cut-off of the canal. In the discussion, the paper attempts to put this stratigraphic sequence into context of the reorganization of the harbour of Imperial Rome during the reign of Trajan (early 2nd century AD) and its subsequent evolution.

Keywords Geoarchaeology · Portus · Roman canal · Roman harbour · CM diagram · Tiber delta · Rome

Introduction

In the Roman Imperial period, Portus was an essential node in the economic system intended to supply commodities to Rome. By the time that Portus was first established in the middle of the 1st century AD, the population of Rome had already grown to circa one million inhabitants (Lo Cascio 1997, 2004; Storey 1997; Corvisier 2001) and the City controlled an Empire extending across the Mediterranean and temperate Europe. In this context, Portus acted as a central hub for the maritime, fluvial and road transport in and out of Rome (Fig. 1).

The maritime harbour basins have been intensely studied over the past 10 years. A significant amount of data has been accumulated about its chronology, with particular reference to the Claudian, Neronian and Trajanic periods (Keay et al. 2005; Keay and Paroli 2011; Boetto et al. 2010; Bukowiecki et al. 2011). Furthermore, geophysical survey has been used extensively around the area of Portus (Keay et al. 2005, 2011). Geoarchaeological and palaeoenvironmental research about the harbour basin sediments has been conducted through the analysis of cores. This research has revived discussions about the Claudian harbour entrances and enabled a new reconstruction of how the harbour basins were configured and used (Morelli 2005; Arnoldus-Huyzendveld 2005; Giraudi et al. 2009; Bellotti et al. 2009; Goiran et al. 2008, 2010).

The role of the river Tiber within the port system of Portus has not received much academic attention. The discovery of Claudian (*CIL* XIV 85 = *ILS* 207) and Trajanic inscriptions (*CIL XIV 88* = *CIL* VI 964 = *ILS* 5797a) in the 19th century provided information about the construction of several canals. Today one Roman canal survives, the Canale di Fiumicino. It is still used for river and maritime traffic and has been a component of the progradation of the Tiber delta for the past 2,000 years. It was identified as a Roman canal (*Fossa Traiana*) by Fea (1824a, b) on the basis of descriptions of the Tiber mouths by Roman authors. At the end of the 19th century/beginning of the 20th century AD, definitive evidence for its Roman origin were discovered during the enlargement of the canal and the excavation of the remains of a Roman wharf (Testaguzza 1970).

Analysis of aerial photographs taken during the Second World War, together with other more recent photographies, allowed the identification of other canals that are today completely filled in by sediment: one lies to the north of the harbour complex whilst another one has been identified between the river Tiber and the *Fossa Traiana* and is known as the *Canale Romano* (Testaguzza 1970) (Fig. 1). The location of these canals has also been

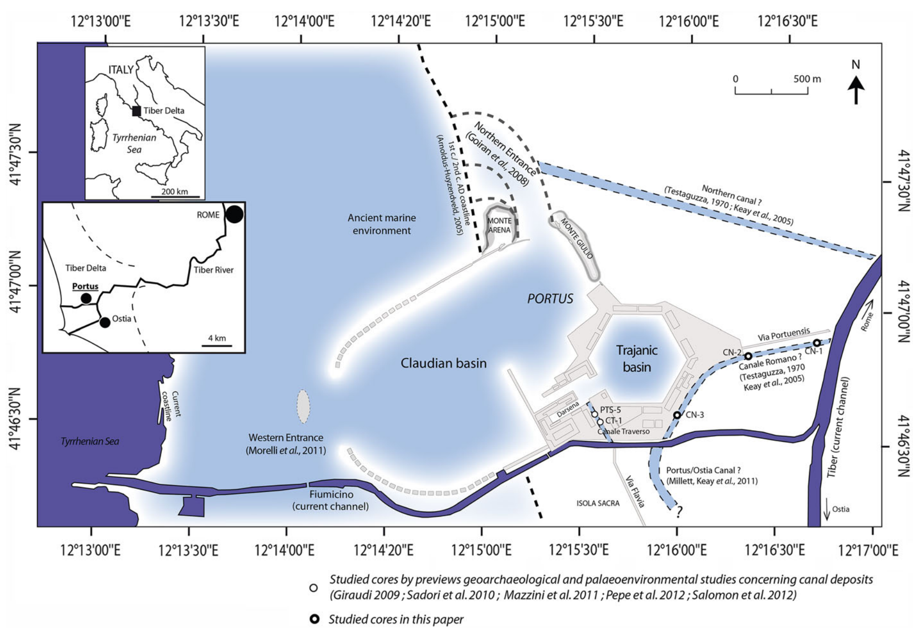

Fig. 1 General location

confirmed by geophysical survey (Keay et al. 2005). Furthermore, a unknown canal has also been hypothesised by the geophysical survey in the area of Isola Sacra (Keay and Paroli 2011).

This paper will focus upon the so-called *Canale Romano*. The gradiometer surveys recorded a linear feature 1,400 m in length crossing all the ancient beach ridges present in this area (Keay et al. 2005) (Fig. 2). The feature is 35 m in width, making it highly unlikely that it might have been a road, and it has been identified as a canal although this had yet to be confirmed through excavation. The aim of this paper is to confirm its interpretation as a canal through sedimentological analysis. The validation of this hypothesis will lead to further questions. Is the canal ancient or was it dug in more recent times (for example during the 19th century with the reclamation of the deltaic area)? The geophysical survey implemented in the 2000s was complemented by a surface survey collection. Combining archaeological and gradiometer data, the canal has been dated to after the 1st century AD, because it cuts through more ancient structures dating back to this period (Keay et al. 2005). Finally, this paper will deal with the singular history of the canal as given by sediment analysis: different phases of use and hydrosedimentary activity. The paper concludes with a re-interpretation of the data available for this canal to offer a history of the canal.

Regional setting

Geology and geography

The River Tiber drains the most important watershed of the Italian Peninsula (17 375 km^2). Flowing for 405 km, it rises in the Apennine Mountains (at 1,268 m) to join the Tyrrhenian

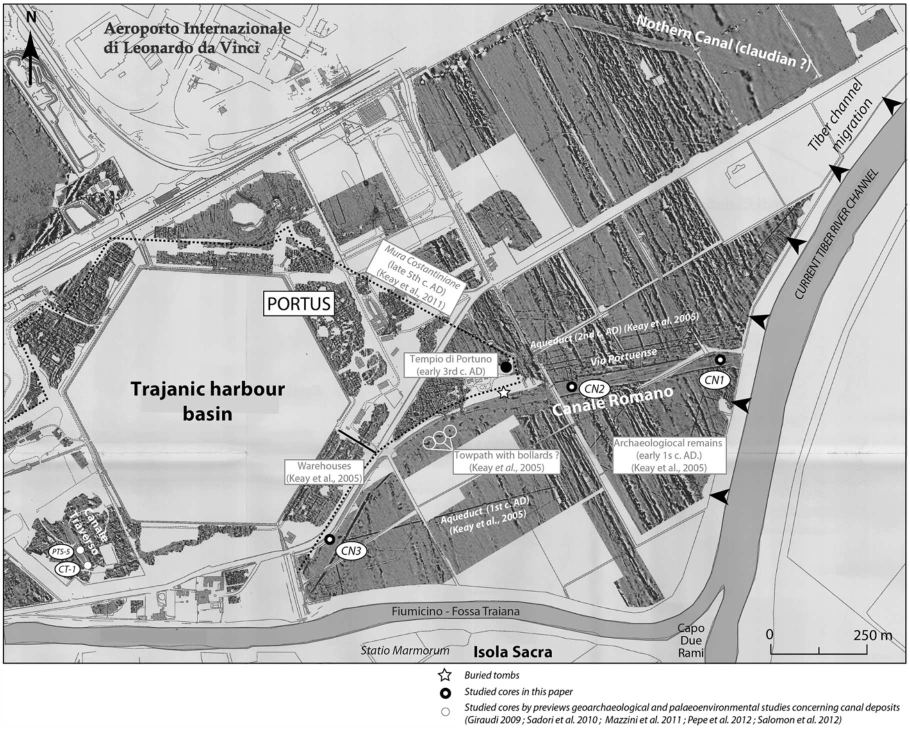

Fig. 2 Cartography of the *Canale Romano—archaeological and geophysical synthesis*

Sea. The river discharges at an annual average rate of 240 m^3/s at the Ripetta gauging station (Rome). During the 30 year prior to 1963 (1934–1963), the river transported an estimated mean of 4.3–7.2 million tons of suspended sediment per year at Ripetta (Iadanza and Napolitano 2006). Over the last 50 years this mean number was only 1.1–1.4 million tons per year. The reduction in suspended sediment load at Ripetta station is the result of alterations to the sediment budget by dams (Iadanza and Napolitano 2006). This reduction in the sediment flux impacts on coastal erosion (Bellotti and De Luca 1979).

The Tiber delta plain can be divided into two different geomorphological units. The *inner delta* located in the eastern part, is characterized by low topography and palaeo-lagoonal formations. The *outer delta,* located in the western part of the Tiber delta, is composed by a system of beach-ridges and dune-ridges (Bellotti et al. 1989, 1995; Amorosi and Milli 2001; Bellotti et al. 2007; Milli et al. 2013). During the Roman period, Portus and its canals were dug in this strand plain which is composed principally by progradational sands. The velocity of the sea level rise decreased significantly circa 7,000–6,500 BP. These conditions allowed more easily the formation of a deltaic plain at the Mediterranean river mouth. Several periods of coastal progradation have been identified in the Tiber delta strand plain (Giraudi 2004; Bicket et al. 2009).

The dynamics of the river Tiber have been the subject of few studies (Arnoldus-Huyzendveld and Paroli 1995; Arnoldus-Huyzendveld 2005). Nevertheless, studies of the Tiber canals make it possible to define a preliminary hypothesis about fluvial dynamics in antiquity (*Canale Traverso* in Salomon et al. 2012).

From maritime to fluvial harbour: archaeology and geoarchaeology

The only buried canal to have been studied by archaeologists and geoarcheologists at Portus to date is the *Canale Traverso*. After Testaguzza (1970), brick bonds are quite similar if one considers the Fiumicino embankment and the Portus' Darsena wharf. It is the only canal identified so far that permits a waterborne connection between the harbour basins and the River Tiber system. This canal has a sand–silt facies representative of a quiet harbour basin environment (Salomon et al. 2012). Nevertheless, the *Canale Traverso* deposit is distinct since it displays sediment layers that may be related to episodic high energy spates of activity driven from the Tiber through the *Fossa Traiana* (Salomon et al. 2012). Evidence for fluvial inputs from the River Tiber is also provided by pollen indicators (Sadori et al. 2010), ostracods (Goiran et al. 2010; Mazzini et al. 2011) and by macro-remains (Pepe et al. 2013). Comparatively, the *Canal Romano* considered in this study is directly connected upstream to the river Tiber channel and downstream to the *Fossa Traiana* (Figs. 1, 2).

Methods

Three cores were drilled into the *Canale Romano* in 2010, a canal that is usually regarded by archaeologists as dating to the Roman period. The *Canale Romano* was hypothesized for the first time by Testaguzza (1970) and precisely identified by geomagnetic survey (Keay et al. 2005). The three 10 m deep cores were located between the current river Tiber channel, the Trajanic harbour basin and the *Fossa Traiana* canal (Figs. 1, 2). The drilling method involved the use of a mechanical rotary core barrel 10 cm in diameter. The methods adopted in this research are the same as those used in the *Canale Traverso* in a previous publication (Salomon et al. 2012).

The cores were described and analyzed in the OMEAA laboratory at Lyon in France (CNRS-UMR-5600 and UMR-5133). Preliminary stratigraphic units were described using simple features (texture, colour) and magnetic susceptibility analysis. Magnetic susceptibility provides a non-destructive analysis that makes it easier to define units. It is a complex indicator that primarily integrates mineral characteristic of the sediment (linked to the watershed lithologies and theirs layouts), but also grain size, organic matter content, transport and depositional processes, sorting index and pedogenesis. Magnetic susceptibility was measured every centimeter with a Bartington MS2E1 in CGS (Dearing 1999).

Particular attention was subsequently paid to grain size analysis, by using sieving for the coarsest particles and a *Malvern Mastersizer 2000* for sediment fractions smaller than 1.6 mm. Current indicators were used to determine general grain size characteristics (Folk and Ward 1957; Rivière 1977). We also engaged systematic research using the C/M diagram proposed by Passega (Passega 1957, 1964; Bravard 1983; Arnaud-Fassetta 1998; Bravard and Peiry 1999). This diagram uses the median (*D50*) and the coarsest percentile (*D99*) to determine depositional and transport processes. Previous applications of CM image to the Tiber delta were very conclusive, and provide clues for identifying coarse fluvial inputs, probably driven by floods, in a harbour deposit environment (Goiran et al. 2012; Salomon et al. 2012) (Fig. 4). In this paper, we complemented the usual CM method with a statistical approach to predetermine different functional units, which were then interpreted using their position on the C/M diagram. We used the statistical tools proposed by Peiry (1994) and Tronchère (2010): namely, the principal component analysis and the hierarchical clustering. Further details on the methodology will soon be published (Salomon, in preparation). Some palaeoenvironmental indicators were also taken into consideration. Rare shell fragments were identified and provided us with significant informations about the types of water (fresh water *vs* salt water); ostracods, however, could not be found, probably as a result of high energy flow.

Radiocarbon dates given in Table 1 were calibrated using "Calib 6" by Reimer et al. (2009). Finally, all the ceramics discovered in the cores were identified by Sabrina Zampini (ceramic specialist in the *Portus Project*). Only recognizable ceramics are reported here.

All altimetric levels are expressed in reference to the biological sea level of Portus. This Roman sea level (*r.s.l.*) at Portus during the 3rd–5th centuries AD has been fixed 80 cm below the current sea level (IGM, Genova), by using as indicators barnacle shells fixed on the northern Claudian moles (Goiran et al. 2009). We can extend this height of the sea level back to the early Imperial period with a limited margin of error. This marine level may be considered as the base level used to locate the water level of the deltaicTiber characterized by a very low gradient.

Results

The results of the core analysis are described in detail in the following paragraphs. Special attention will be paid to cores CN-1 and CN-3, which display different stratigraphic sequences (Fig. 3). For reasons of clarity, the third core (CN-2) has not been described in detail. This core displays stratigraphic units which are similar to the upstream (CN-1) and downstream (CN-3) (Fig. 4) cores.

Analysis of core CN-1: the upstream stretch of the *Canale Romano*

CN-1 coring was located approximately 150 m away from the current Tiber River channel. The core presents 5 main units (Figs. 3, 4):

- *Unit A (−7.50 to −4.36 m r.s.l.)* This unit is composed of medium to fine grey sands with poor organic matter content (<2 %). The deposits were divided into two sub-units. The first sub-unit (*A1*) is laminated, with an alternation of sand and layers of scattered small flat pebbles. A thin silty–clay layer has been identified. A fragment of marine bivalve has been observed with some others indeterminable pieces of shell. The second sub-unit (*A2*) does not display laminations. Its sand content rises from 70 to 80 %. Sediment of sub-unit A2 is better sorted than sediment of unit A1 (Trask index: respectively 1.7 and 2.7).
- *Unit B (−4.36 to −4.03 m r.s.l.)* The sandy fraction of this yellow–brown sandy facies contains some micro-ceramics. The sediment is poorly sorted (Trask index: 3.1) with 74 % of sands, 24 % of silt and clay and 4 % of coarse fraction. The organic content rises up to 2.4 %.
- *Unit C (−4.03 to −2.51 m r.s.l.)* Hydrodynamic activity changes abruptly in this unit. The energy of flow allows the transfer and settling of particles with a D99 up to 7.7 mm. Units A and B have a D99 of 1,500 µm. It is possible to distinguish three subunits. Sub-unit (*C1*) is mostly composed of well sorted coarse to very coarse sand (Trask index: 1.9). About 30 sherds of pottery were discovered in this unit. Some of these ceramics have been identified as *terra sigillata* and African amphorae. On the base of these identifications, S. Zampini proposes a period between 90 and 250 AD (pers. comm.). Ceramics and coarse sediments are poorly rounded. Chronology

Table 1 Radiocarbon and archaeological datings results. Only identified ceramics are reported here

Samples	Laboratory samples	Sample description	Activity (in %)	Radiocarbon dating	Age calibrated (Reimer et al. 2009)—2σ
Radiocarbon datings—ARTEMIS program—Lyon					
CN-1/475–477	Lyon-8073	Charcoal	81.446 ± 0.258	1650 ± 25 BP	265–530 AD
CN-1/600–650	Lyon-6866	Bone	78.800 ± 0.270	1915 ± 30 BP	25–130 AD
CN-1/820	Lyon-6867	Organic matter	53.080 ± 0.220	5085 ± 35	3965–3790 BC
CN-2/324–327	Lyon-8075	Charcoal	82.366 ± 0.276	1560 ± 25 BP	425–560 AD
CN-2/715	Lyon-6891	Bone	78.820 ± 0.250	1910 ± 30 BP	30–130 AD
CN-3/674–677	Lyon-8077	Charcoal	79.287 ± 0.245	1865 ± 25 BP	80–225 AD

Samples	Identification	Age (AD)
Archaeological datings—Sabrina Zampini		
CN1—600/-650	1 Sherd African sigillata ceramic A; 1 sherd of african sigillata ceramic A	90–250
CN1—640	1 African sigillata ceramic A sherd; 2 pieces of common ceramic	100–700
CN2—174/177	2 African anforae side	100–700
CN2—706/709	1 Fragments *laterizio*; ceramic sigillata italica: 1 cup side type *Conspectus* 34	30–100

proposed by the archaeological data is supported by the radiocarbon date obtained from a bone fragment. It is older, but confirms a date in the early Imperial period (25–130 cal. AD, Lyon-6866). Finally the influence of the Tiber River is confirmed by the identification of very well preserved shells of *Theodoxus fluviatilis* and *Bithynia tentaculata* living in freshwater. The overlying sub-unit (*C2*) is a succession of coarse sand and artefacts (bricks fragments, pieces of wood and travertine etc.) which are strongly compacted. Finally the upper part of this unit (*C3*) includes finer fraction (42 % of silt and clay) in balance with the sand fraction (42 %). The median grain size drops from 625 μm in sub-unit (C2), to 41 μm in sub-unit (C3). We can also observe some scarce rounded pebbles. The diversity of grain sizes evidently negatively affects the grain size sorting (Trask index: 7.2).

– *Unit D* (*−2.51 to +0.69 m r.s.l.*) Silt and clay (70–75 %) replaces sand fraction, which was predominant in the lower part of the stratigraphic sequence. The sediments are assigned to two sub-units: the basal unit (D1) is made up by sterile grey silty sand; progressively sediment gets finer and it consists of a sequence of sterile yellow sandy silt (D2). The ^{14}C age of sub-unit D1 spans from 265 to 530 AD (Lyon-8073).
– *Unit E* (*+0.69 to +2.48 m r.s.l.*) Unit E is the upper unit. It shows root pieces in a yellow laminated sandy silt (E1) underlying a reworked brown sandy silt layer. The organic content rises up to 6 %.

Analysis of core CN-3: the downstream stretch of the *Canale romano*

This core is the most downstream stratigraphical sequence drilled into the *Canale Romano*. It comprises four main units (Figs. 3, 4).

– *Unit A* (*−7.35 to −6.95 m r.s.l.*) Laminated very fine sand and fine sand form basal unit A. Sediments are composed of 66 % of sand and 34 % of silt and clay (Poor Trask sorting index: 3.6). Macrofauna is scarce and microfauna is absent. Shell remains were determined as marine bivalves fragments.

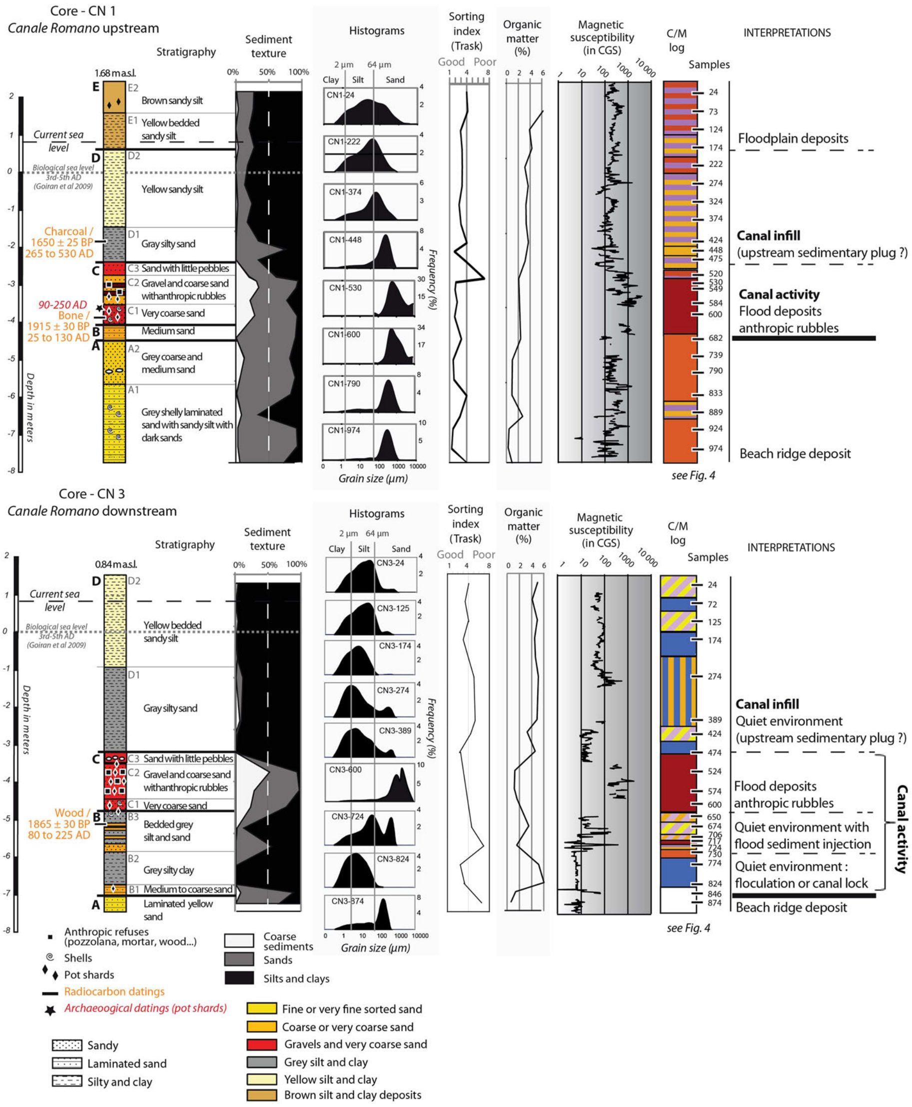

Fig. 3 *CN-1* core and *CN3* core analysis

– *Unit B (−6.95 to −4.76 m r.s.l.)* The underlying deposits of sub-unit (B1) are mostly medium to coarse sands (81 %) with a high proportion of micro-sherds of pottery in the sandy fraction. The organic matter rises from 0.6 % in unit A to 1.4 % in unit B. Sub-unit (B2) corresponds to a thick layer (1 m) composed of 74 % of silt and 25 % of clay. No microfauna have been found nor any macrofauna. The organic content increases up to 5.6 %. The upper part of sub-unit (B3) consists of silty clay (88 %) with frequent intercalated sandy levels. Coarser fraction (>2 mm) is characterized by ceramics content. The age of this deposit is attributed to the Imperial Roman times by radiocarbon dating (wood—1,865 ± 25 BP, cal. at 80–225 AD, Lyon-8077).

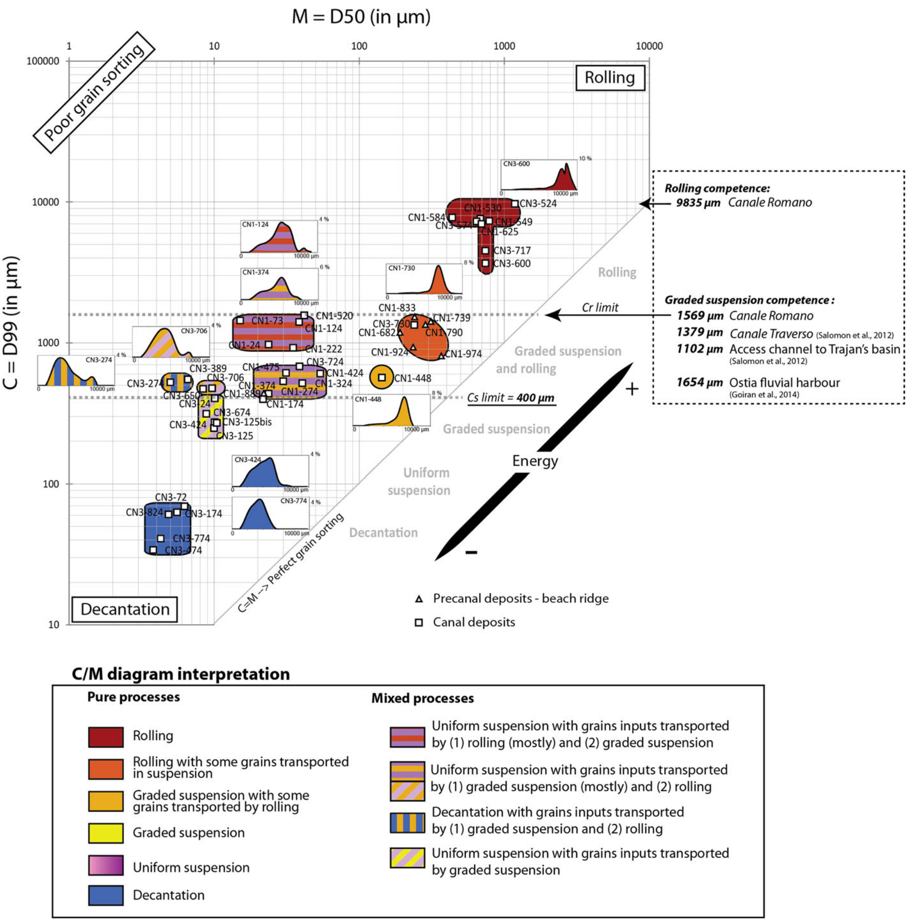

Fig. 4 CM pattern of the *Canale Romano*

- *Unit C* (*−4.76 to −3.30 m r.s.l.*) This deposit results from a higher hydrodynamic activity. Coarse to very coarse sand is dominant with a high density of ceramic sherds. Layer C1 is composed by very coarse sand, and it is overlaid by sub-unit C2 in which the density of artefacts increases. We can observe very poorly rounded ceramic sherds. Fragments of brick, wood and mortar were sampled. A large (6 × 3 cm) horizontal piece of wood and scattered very fine fragments of wood (2 mm) were found in this unit, amongst other artefacts. Shells observed in this unit belong to the species *Theodoxus fluviatilis* and *Bithynia tentaculata*. Rounded material (ceramics and pebbles) have a higher density in sub-unit (C3). This sub-unit ends with a large sherd of pottery which was broken by the mechanical coring (diameter 10 cm).
- *Unit D* (*−3.30 to +1.64 m r.s.l.*) Two sub-units are composed of grey silty sand (D1) and yellow bedded sandy silt (D2). The deposit is composed of 95 % of silt and of 5 % of sand. Organic content, low above unit B2, increases up to 4.6 % of the total weight of the sediment.

Discussion

The Roman canal hypothesis: a valid assumption

The results obtained from the analysis of the cores samples confirm the presence of a canal dated to the Roman Imperial period. All the palaeoenvironmental indicators coincide with the Roman canal hypothesis: (1) hydrodynamic environment with high energy; (2) a channel cutoff-type stratigraphy corresponding to a coarse sediment at the bottom and suddenly fine sediments deposits; (3) molluscan shells corresponding to freshwater environment; (4) archaeological dates; (5) radiocarbon dates.

Three major phases of sediment deposition were observed in the three cores (Figs. 3, 5). The base of each core (units A) consists of sand which may be related to coastal progradation dynamics. Upper beach ridge deposits have been truncated during the Roman Imperial period by the digging of the canal (*−4.36 m r.s.l.* in CN1; *−7.37 m r.s.l.* in CN2; *−6.95 r.s.l.* in CN3). The second depositional phase corresponds to a period of activity of the Roman canal (CN-1, units B and C; CN-2 CN-3 units B, C and D). Sedimentation is quite complex, including coarse sand to clayey texture. Finally, the third and final phase, at the top of the three cores (*from −2.50 m r.s.l. in CN-1 or −3.30 m r.s.l. in CN2, to top*), is the end of the period of canal activity. This deposit is characterized by fine sediment.

The CM pattern of the *Canale romano*

The CM diagram provides us a very useful synthesis to describe precisely the different depositional processes involved in the sediment sequences. The analysis of CN cores displays a wide diversity of sedimentary environments (Fig. 4 and C/M logs in the Fig. 3). The CM pattern describes pure processes (rolling, rolling and graded suspension, graded suspension and rolling, uniform suspension, decantation). When mixing occurred, particles were deposited in quiet environments (decantation or uniform suspension) susceptible to be reached by coarser particles issued from graded suspensions or rolled on the channel bottom. Such inclusion of coarse particles may be interpreted as the result of flood events, as they are frequently recorded in secondary channels or cutoff channels.

As previously proposed, the early geomorphological context of Portus corresponds to a progradational beach ridge (Bellotti et al. 2007). Beach ridges are mainly composed of well sorted sand. This type of deposit has been observed at the base of all the cores drilled in Portus' basins (Goiran et al. 2010; Salomon et al. 2012). It corresponds to very well sorted graded suspension with some rolled particles moving as bedload (Fig. 4). All the basal units A of CN cores are mainly composed of coastal sand.

The CM units related to fluvial processes operating in the former canal (units B–C–D of each core) are more complex (Fig. 4 and C/M logs in the Fig. 3). They include several types of processes ranging from decantation to rolling. The bottom of CN-1 canal stratigraphic sequence shows medium sand (CN-1 unit B) but most importantly very coarse sandy sediments transported as bedload (CN-1 unit C). The upper canal sequence consists of silty sand to sandy silts particles with a high coarsest percentile (D99) (CN-1 unit D and E). This canal infill is mainly composed of deposits originating from uniform suspension, with frequent inputs of particles which were transported as graded suspension or as bedload during flood events.

Units CN3-C and CN3-D may be correlated to units CN1-C and CN-1-D, respectively. Below these stratigraphical series, CN3 offers quieter depositional environments (CN3-B). Unit CN3-B is composed of very fine sediment issued from the decantation or from

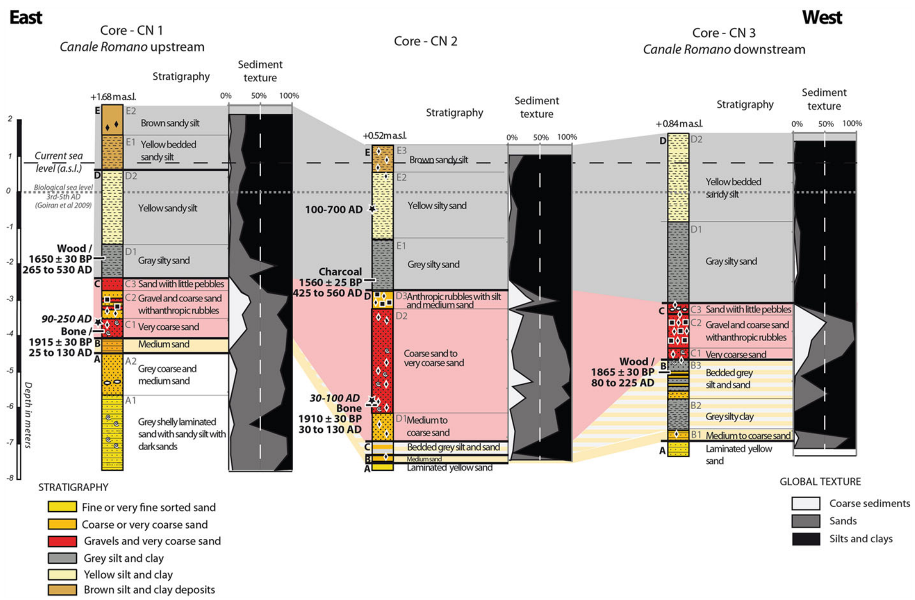

Fig. 5 Cross-section from upstream to downstream of the *Canale Romano* (*CN-1*, *CN-2* and *CN-3*)

uniform suspension; they are interrupted by layers deriving from graded suspension and bedload-rolling, or are composed of mixed deposits.

Statistical tools were the principal component analysis and the hierarchical clustering. They provide a good delineation of lower limit of the coarsest suspended particles issued from pure graded suspension (*Cs*). These particles are estimated finer than 400 μm in the *Canale Romano*. The grain size histograms of samples located above Cs value display a complementary mode in the coarse particles domain. The *Cs* limit is exceeded when coarser sand from rolling is injected into the deposit composed of graded suspension.

In the context of the *Canale Romano*, more attention is paid to the *Cr* line which is both the upper value of particles transported as graded suspension and the lower limit of transport as bedload (rolling) (Fig. 4). This secondary channel is concerned by high energy, in the continuity of the Tiber River. The coarsest particles transported as graded suspension peak at 1,569 μm (*Cr*) in the *Canale Romano*. This limit is observed at the entrance of the *Canale Romano* (CN1-520, Fig. 4). This maximum limit is very close to the *Cs* limit observed in the Republican harbour basin at Ostia, directly connected to the Tiber River (Goiran et al. 2012, 2014). The *Cr* limit decreases downstream along the *Canale Traverso* and in the access channel to the Trajan's basin (Salomon et al. 2012; Fig. 4).

Stratigraphic interpretation

Initially, the *Canale Romano* was excavated into the sandy beach ridge system of the Tiber delta. The bottom of the canal was situated between −4.36 m (CN-1) and −7.37 (CN-2) below the biological Roman sea level (*r.s.l.*) (Fig. 5). Its irregular bottom topography can be interpreted as either man-made or natural if floods allowed bed erosion. Unlike the studies of harbour basins with recognized man-made bottoms, the mobility of the canal bottom over time has to be taken into account. The *Canale Romano* forms part of the Tiber channel system that is controlled by water discharge and sediment transport. Consequently, erosion or sediment accumulation in the canal alternately modified the topography of the excavated alluvial bottom of the canal. The low level of the deepest fluvial sediment in CN2 core (Fig. 5) can be interpreted as a natural excavated pool, related to the response of the channel bottom to the imposed curvature of the canal, which in turn influenced direction of flow, turbulence and local over-deepening (Fig. 2).

In each core, canal sediments begin with medium sand issued from graded suspension (units B in CN1, CN2 and CN3) above the upper boundary of progradational coastal sands. These units can be interpreted as a mix of sandy river sediments and reworked coastal sand. Unfortunately, radiocarbon and ceramic dating do not allow the excavation of the canal to be ascribed to the reign of Claudius or Trajan. Instead dating evidence suggests a chronological range lying between 25 and 130 AD (Lyon-6891; Lyon-6866; ceramics CN2—706/709). We thus support the Trajanic chronology for the excavation of the canal proposed by Keay et al. 2005 (see above). Subsequent to this, there is a very fine sedimentation, mainly in core CN3. One metre of grey silty clay was deposited primarily through decantation processes (CN3-D1). These fine deposits were later inter-bedded with sediments derived from graded suspension (CN3-D2). They are also observed in the CN2 core (CN2-C) but are entirely lacking in core CN1. How can this be interpreted? Did it derive from an upstream or a downstream depositional control?

In the case of upstream control, we may imagine there might have been a lock across the canal. Decantation processes would occur in the 'locked' reach and graded suspension would have been deposited when the canal was opened with higher energy of flow. A canal lock was previously hypothesized at Portus by Testaguzza (1970) for the *Canale Traverso* and by Danti for the *Fossa Traiana* (1582). Nevertheless there is no archaeological evidence to confirm whether or not such a device existed at Portus or elsewhere in the Mediterranean area in antiquity. Nevertheless, three texts suggest that there is a strong likelihood that did exist in the Roman period (Moore 1950).

Most probably, fine sediment deposition was partly controlled by flocculation, as usually observed in river mouths. Today, the salt-water wedge can extend upstream of the bifurcation of the *Fossa Traiana* and the Fiumara (Mikhailova et al. 1999; Capelli and Mazza 2008), known today as the Capo Due Rami; today this is located 7 km upstream of the Tiber mouth and 5 km from the mouth of the Fiumicino. The inland extent of the salt-water wedge is especially important during summer time. On the contrary, graded suspension occurs principally during the period of Tiber flooding from autumn to spring (Frosini 1977). It must be noted that the core CN3 was located no more than 1,000–1,500 m from the mouth of the *Fossa Traiana* River mouth during the Roman Imperial period. These two hypotheses of decantation downstream by means of a lock or flocculation are not mutually exclusive. All the core stratigraphic sequences record high energy deposits as demonstrated by the occurrence of bedload (CN1-C, CN2-D and CN3-C). This coarse layer is mixed with or interrupted by anthropogenic elements (CN1-C2 and CN3-C2). This facies succession, which is mostly composed by unrounded particles, reveals infrequent high energy flood events.

The connection between the Tiber and the *Canale Romano* stopped abruptly. Before this cut-off, silty sand and sandy silt deposits infilled the canal. We can observe a gradient of upstream—downstream grain size decrease. Furthermore, the grain size median (*D50*) progressively got finer in the upper part of all the canal infills (see sediment texture Fig. 5). Apart from the sediment texture, magnetic susceptibility allows us to precisely correlate the three infill sequences (CN1-D, CN2-E and CN3-E). The origin of this abrupt cut-off is probably related to the formation of a sediment plug. This event occurred between the mid 3rd century and the mid. 5th century AD.

The *Canale Romano* was thus active for a minimum of 250 and a maximum of 450 years. The short activity hypothesis is deduced from the radiocarbon dating of a piece of wood calibrated at 2σ between 80 and 225 AD (Lyon-8077) in the CN-3 core, unit B3. It remains difficult to establish a chronological correlation between the phases of activity as described in the three cores. During the 16th century, the Portus landscape did not reveal any evidence of the former *Canale Romano* (Danti 1582).

Canal operation and subsequent use

The Canale Romano: a harbour–canal

The right hand side of Fig. 6 presents the defining elements from the cores for the history of the canal, notably the characteristics of the sedimentary facies and their interpretation. This data makes it possible to define the bottom of the canal (−4.35 in CN-1 to −7.35 in CN-2) and its cut-off limit (−2.50 to −3.30 m). Since no cross profile of this canal is available, the minimal observed depth is used, i.e. around 4.35 m obtained from the core CN-1. We delineate the ancient water level in accordance with the biological sea level observed at Portus (Goiran et al. 2009). Indeed, in this deltaic plain area, the sea level can be used as the minimal fluvial water surface. Finally this figure provides representations of some of the known ancient ships and boats that could have navigated the *Canale Romano*.

The *Canale Romano* was clearly used as a waterway. Connected upstream to the Tiber and downstream to the Fiumicino canal [called *Fossa Traiana* during the Roman times—Fea (1824a, b)], the *Canale Romano* was used for navigation (Fig. 6). The canal offered a minimal draught of around 4.35 m (CN-1), which is enough to carry maritime vessels up to 350–390 tons (Gassend 1982; Pomey and Rieth 2005; Boetto 2006, 2010). Others vessels called *caudicariae*, were designed for navigation along inland waterways and transported food upstream to Rome; these could potentially transport cargoes of up to 200 tons (Boetto 2010) and could also have used this canal. However, the canal was more than a mere waterway; it was more of a harbour–canal. The canal ran alongside the ancient warehouses of Portus on one side of the hexagonal Trajanic basin and probably had a quay side (Keay et al. 2005; Fig. 2). This archaeological area between the Trajanic basin and the *Canale Romano* was interpreted as a transhipment area between sea and river transport (Keay et al. 2005). The *Canale Romano* was thus undoubtedly constructed to ensure improved transhipment of cargoes between maritime and inland waterways, and was part of the new harbour system created by the emperor Trajan.

The Canale Romano: a flood relief canal?

A Trajanic inscription discovered at Portus does not specifically allude to either a waterway or a harbour–canal dug by the Emperor, but to a flood relief canal (*CIL XIV 88* = *CIL* VI 964 = *ILS* 5797a). Was the secondary function of the *Canale Romano* a flood relief canal? Firstly, particular attention should be paid to the better-preserved Claudian inscription which concerns the canals at Portus (*CIL* XIV 85 = *ILS* 207). Basically, this inscription informs us that the first canals were excavated to facilitate the construction of the Claudian harbour and to help alleviate the risk of flooding at Rome. It is unknown whether the Claudian port was conceived with definitive waterways or only dug to facilitate the construction of Portus. The Fiumicino was probably one of these canals (Keay

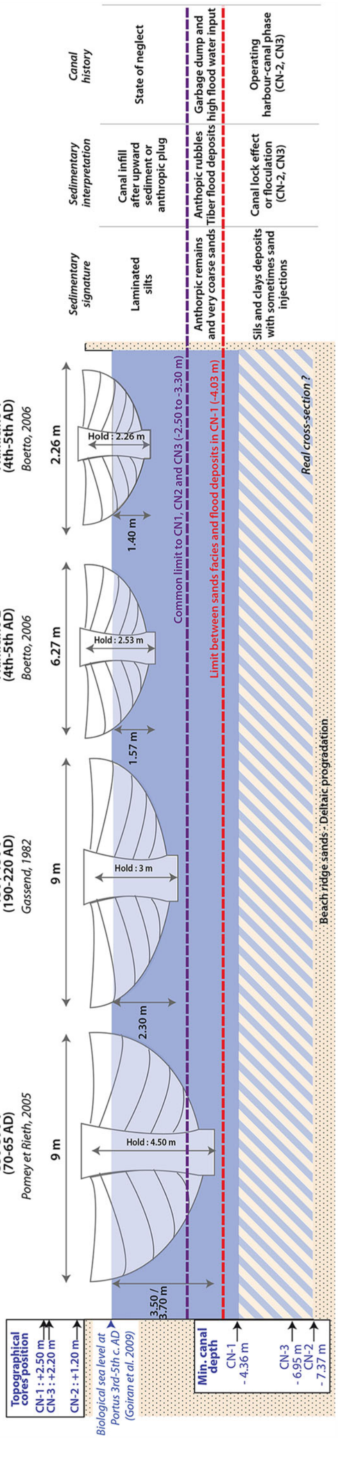

Fig. 6 The *Canale Romano* as a waterway

et al. 2005). According to the Claudian inscription during the construction of Portus, floods entered the canals. The Claudian inscription establishes a cause and effect relationship between the digging of the canals and the preservation against inundations Nonetheless, today it is unknown whether these canals were really efficient against floods. No major flood is recorded during Claudius' reign in the ancient texts (Le Gall 1953). Perhaps, floods mentioned by the Claudian inscription existed, but caused probably less damage in the lower Tiber valley than previous floods of the 1st century BC and beginning of the 1st century AD recorded by ancient authors. Furthermore, despite these canals, catastrophic floods occurred at Rome in AD 69 (Tacitus, *Histories*, I, 86; Suetonius, *Otho*, 8; Plutarch, *Otho*, 4) and during Nerva's reign (Aurelius Victor, *Epitome de Caesaribus*, 13). Nevertheless, it is important to emphasize the experimental aspect of flood control by these Claudian canals.

Taking into account the problems of the Claudian basin (unprotected basin against big storms *in* Tacitus, *Annals*, 15, 18), Trajan excavated a second basin totally protected from the swell passing through the Claudian basin, as well as restructuring the inland harbour system. Under Trajan the *Canale Romano* was constructed (Keay et al. 2005) and the *Fossa Traiana* was modified (Fea 1824a, b; Testaguzza 1970; Keay et al. 2005). The Trajanic inscription (*CIL XIV 88* = *CIL* VI 964 = *ILS* 5797a) could refer to either of these canals or to a third one.

The *Canale Romano* does not seem to have been designed to receive floods. Its width (35 m) is narrower than that of the *Fossa Traiana* (50 m) and it is curved rather than straight. Furthermore, the Claudian inscription indicates that flood relief canals clearly connected the Tiber channel with the sea (*CIL* XIV 85 = *ILS* 207). The *Canale Romano* is directly connected to the Tiber, but also has secondary bifurcations to the sea by means of the downstream section of the *Fossa Traiana* and by the hypothetical Portus–Ostia canal (Keay and Paroli 2011). If the *Canale Romano* was not a flood relief canal, how did the Roman engineers prevent floodwaters entering into it from upstream? As argued before, there is no definitive sedimentological evidence to support the existence of a lock, but the existence of one can surely be considered on hypothetical grounds; archaeological excavation of the canal is the only way to resolve the question definitively. It is thus conceivable that the *Canale Romano* was not designed as a flood-relief canal, but that floods unavoidably entered into it and deposited coarse flood sediments within it (bedload; units CN1-C, CN1-D and CN3-D). Initial use of the *Canale Romano* as a canal alongside which river-boats could be moored would have been compromised by strong flood energy during the flood season, but would have served well for the rest of the season. Further analysis of the so called 'Portus–Ostia canal' will shed light on the question as to whether it was a canal designed to evacuate flood waters from the *Canale Romano*.

Major floods were already occurring during the reign of Trajan, and the system of flood protection became rapidly obsolete. According to Pliny the Younger, the maximum capacity of Trajan's canal near Portus was soon reached and its banks overflowed (Pliny the Younger, *Letters,* VIII, 17). The Claudian harbour basin experienced a storm surge that resulted in the destruction of 200 vessels in AD 62 (Tacitus, *Annals*, XV, 18). It is possible that the indirect connection between the *Canale Romano* and the sea by way of the *Fossa Traiana* and the possible Portus–Ostia canal, helped to isolate the Canale from eventual inland storm surges.

When considering a hydroclimatical crisis during the Imperial period (Bravard et al. 1992; Bruneton et al. 2001; Arnaud-Fassetta 2002; Benvenuti et al. 2006), the stratigraphic sequence in the *Canale Romano* alone does not provide enough evidence. While we can highlight the importance of floods for the units CN1-C, CN2-D and CN3-D, we cannot establish flood frequency series.

Subsequent functions and uses

There is no evidence for the dredging of the *Canale Romano*, but this possibility should be considered during the period of its construction under Trajan to its abandonment between the 3rd/5th century AD. Dredging clearly occurred in the *Canale Traverso* (Sadori et al. 2010; Salomon et al. 2012). Just before the cut-off of the *Canale Romano*, it could still be navigated by small vessels (*caudicariae*) with draughts up to 2.50 m and larger maritime vessel of century 130–150 tons (Fig. 6). The latest dated use of the *Canale Romano* may have been connected indirectly to the defensive system of Portus, as a ditch in front of the surrounding wall built in the late 5th century AD. At that time, the *Canale Romano* had already been cut-off upstream.

Conclusion

It is clear from the result of this study that the *Canale Romano* can be definitively interpreted as a Roman canal. The sedimentary infill of this structure provides clear clues of fluvial influence during the Roman Imperial period. Geophysical data, Roman textual sources and inscriptions, archaeological discoveries understood in the context of palaeoenvironmental analysis, allow us to reconstruct its history. The canal was probably created under Trajan, it seems to form an integral part of the broader scheme of the wider harbour. The *Canale Romano* reveals the Trajanic perspectives at Portus. Indeed, the hexagonal basin offers a secure anchorage for maritime boats and in the same way, the *Canale Romano* was designed as an operating harbour canal initially devoted to transhipment linked to the Trajanic basin. In the absence of archaeological evidence, it is difficult to conclude whether or not a lock was initially built upstream from the canal. It is likely that the canal was not designed as a flood relief canal, but floods naturally entered into the canal some time later after its excavation. The function of harbour canal could nevertheless continue seasonally until the cut-off in late Antiquity (3rd/5th century AD). Geoarchaeological studies are currently being conducted on the *Northern canal* and the *Portus–Ostia canal* in order to complete our understanding of the Roman canal system at Portus.

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