Late Holocene Evolution of Tiber River Delta and Geoarchaeology of Claudius and Trajan Harbor, Rome

Carlo Giraudi,[1,*] Cristiana Tata,[1] and Lidia Paroli[2]

[1]*ENEA C.R. Casaccia, P.O. Box 2400-00100, Roma A.D., Italy*
[2]*Soprintendenza per i Beni Archeologici di Ostia*

This study provides new information on the evolution of the Tiber delta during the late Holocene, and describes the record of sedimentation in the Port of Claudius and Trajan. The Tiber flowed into the Tyrrhenian Sea in the area of the Port of Claudius and Trajan between the 8th and 5th centuries B.C. The harbor basins excavated by the Romans during the 1st and 2nd centuries A.D. were filled with sediments containing saltwater fauna, then brackish-water fauna, and finally by alluvial and marsh deposits. The Port of Claudius and Trajan was silted in as a consequence of episodes of alluviation that correlate with environmental events, possibly triggered by global climate changes. © 2009 Wiley Periodicals, Inc.

INTRODUCTION

In this paper, results of geomorphic, stratigraphic, and geoarchaeological research conducted on the Tiber delta in central Italy are presented (Figure 1). The investigation focused on the area of an ancient harbor built by Roman Emperor Claudius I (1st century A.D.) and modified by Emperor Trajan (2nd century A.D.). The harbor was the world's largest artificial feature of its kind in antiquity. The objective of this study was to define the configuration of the harbor and describe the record of sedimentation in the harbor basins through coring and radiocarbon dating.

The catchment area of the Tiber River is in the northern and central Apennines, and its outlet to the sea is southeast of Rome. In the delta area, the Tiber splits into two channels (Figure 1): The main channel flows into the Tyrrhenian Sea west of Ostia Antica, and the secondary channel, called Fiumicino, reaches the sea at the town of Fiumicino. Part of the Fiumicino channel was excavated in the first half of the 1st century A.D. when Claudius was emperor; it is called "Fossa Traiana" (Trajan canal). Two more canals, now completely filled with sediment, were excavated during Roman times: the "Fossa di Claudio" (Claudius canal) dating to the time of Claudius (Testaguzza, 1970; Keay et al., 2005), and a second canal, constructed by Trajan at the beginning of the 2nd century A.D. and identified by Keay et al. (2005).

*Corresponding author; E-mail: carlo.giraudi@enea.it.

Geoarchaeology: An International Journal, Vol. 24, No. 3, 371–382 (2009)

Published online in Wiley Interscience (www.interscience.wiley.com). DOI:10.1002/gea.20270

versity Press.
ıeology and geochronology
search, 41, 234–244.
ochronology of fills in small
Bulletin, 108, 953–965.
ogy of the Boca Negra Wash
ıckley, M.S., & Weber, R.H.
esearch in the Pleistocene,
ıe Mockingbird Gap Clovis
, 24, 102–104.
al and geological test inves-
Research in the Pleistocene,
of Lake Trinity Basin, White
ds.), La Jornada: Papers in
ciety of New Mexico.
ganic matter fractions from
chronology of the western
D., & Southon, J.R. (2001).
d techniques. Radiocarbon,
orite basin in the northern
Field Conference, Socorro
ology and geomorphology.
story (pp. 407–437). Special
ed streams, and late-glacial-
148.
sits and buried soils in the
plications of late Quaternary
w Mexico. Geomorphology,
tions for the peopling of the
Mexico. In M.S. Duran &
r (pp. 115–122). Las Cruces:
: Excavations in 1967. In
bert H. Weber (pp. 123–127).
on and soil formation in the
nuepfer & L.D. McFadden

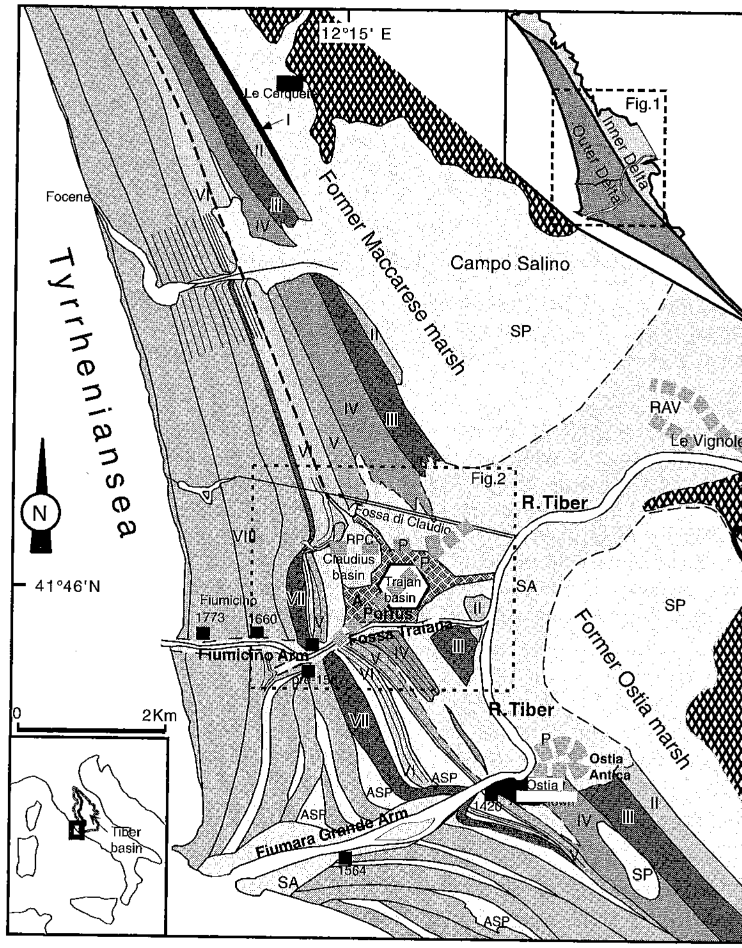
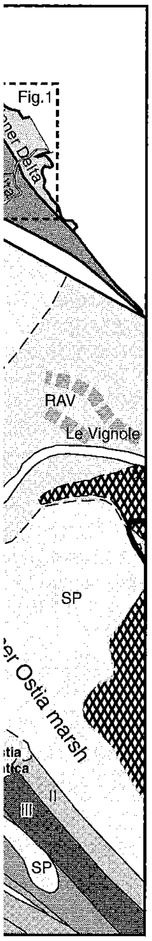


Figure 1. Geology of the central portion of the Tiber delta. Legend: I–VIII = beach ridges of 8 phases from oldest to youngest; SP = mainly marsh sediments; SA = mainly alluvium; ASP = alluvial or beach or marsh sediments, in the areas between beach ridges of various phases; P = ancient channel of the Tiber; RAV = stream beds and crevasse splays of Le Vignole; RPC = deposits in the Claudius harbor; A = areas of human settlement in Roman times (towns, buildings, anthropic sand accumulations). Black squares mark the coastal towers (their age in yr A.D. is reported alongside).

HOLOCENE EVOLUTION OF THE TIBER DELTA

The evolution of the Tiber delta has been studied since the late 19th century (e.g., Oberholtzer, 1875; Bocci, 1892). Geological investigations conducted during the last 40 years have focused on the sedimentology of Late Pleistocene and Holocene deposits stored in the delta (e.g., Belluomini et al., 1986; Bellotti et al., 1987, 1989, 1994, 1995; Chiocci & Milli, 1995; Amorosi & Milli, 2001). Several studies of the evolution of the delta combined geological data with historical records and maps (e.g., Dragone et al., 1967; Belluomini et al., 1986; Bellotti et al., 1987, 1989, 1994, 1995; Segre, 1986). However, a



›each ridges of 8 phases from ASP = alluvial or beach or ancient channel of the Tiber; › Claudius harbor; A = areas ılations). Black squares mark

late 19th century (e.g., ucted during the last 40 and Holocene deposits 1987, 1989, 1994, 1995; he evolution of the delta g., Dragone et al., 1967; ›gre, 1986). However, a

lack of radiocarbon ages for deltaic deposits younger than 5000 years B.P. prevented a reconstruction of the Late Holocene evolution of the Tiber delta. In a recent study by Giraudi (2004), a complex history of delta formation spanning the past 7000 years is described and is based on geomorphic, stratigraphic, radiocarbon, and historical data.

The Tiber River delta consists of two parts: the inner delta, which was occupied by the marshes of Ostia and Maccarese until the delta was artificially drained in the early 20th century, and the outer delta formed by beach ridges and dunes extending almost symmetrically to the north and south of the river mouth (Figure 1).

Dragone et al. (1967) described the morphology of the beach ridges of the outer Tiber delta, and Bellotti et al. (1994) conducted a more detailed study of the evolution of the ridges. Giraudi (2004) reported that there are clusters of beach ridges forming complexes representing eight separate beach progradation phases. Also, according to Giraudi (2004), the delta experienced four retreat phases during the Late Holocene. The beach-ridge complexes in the central portion of the delta are shown in Figure 1. The ages of the beach ridges reported in Giraudi (2004) were inferred from artifacts and the stratigraphic relationship between the beach ridges and radiocarbon-dated marsh deposits of the inner delta. The ages of the beach-ridge complexes, from landward to seaward, are as follows: I, the oldest beach-ridge complex, dates to ca. 3700–4000 B.C.; II dates to ca. 3275–2930 B.C.; III dates to ca. 3275–2930 B.C.; IV dates between 2140–1920 B.C. and 1300–1000 B.C.; V dates to ca. 910–800 B.C.; VI consists of an older part (VI-a) dated between the 4th century B.C. and the 3rd century A.D., and a younger part (VI-b) dated between the 4th and 10th centuries A.D.; and VII and VIII are dated to the period between the 15th and 19th centuries A.D.

The delta underwent four retreat phases: between phase I and II of the progradation of the beach ridges (>3275–2930 B.C.); between phases V and VI (between the 8th and 4th centuries B.C.); during phase VI (3rd century A.D.); and between phases VI and VII (10th–13th centuries A.D.).

According to Giraudi (2004), the cusp formed by the beach ridges of phases IV and V (Figure 1) implies that, at least until the 8th to 9th centuries B.C., the mouth of the Tiber was southwest of the Port of Claudius and Trajan, corresponding to the present Fiumicino channel. Before the 4th century B.C., the channel moved to its present position (Figure 1).

Historical information confirmed the age of the progradation phase VI-b. During the 4th century A.D. the main channel of the Tiber was partly obstructed by sand, and there is an epigraph showing dredging of the Port of Claudius and Trajan at that time (Coccia, 1993; Paroli, 2004). Silting of the port, however, continued, and it was eventually abandoned as an anchorage in the 10th century A.D. (Coccia, 1993; Paroli, 2004). Paroli (2004) noted that the harbor of Claudius was still partly in use in the 12th century A.D.

HISTORY OF THE PORT OF CLAUDIUS AND TRAJAN

The port of Claudius was built during the period A.D. 42–64, then modified by Trajan during the period A.D. 100–112 (Testaguzza, 1970; Coccia, 1993). The remains of the port are in an area covered by post-Roman marsh and alluvial deposits and by

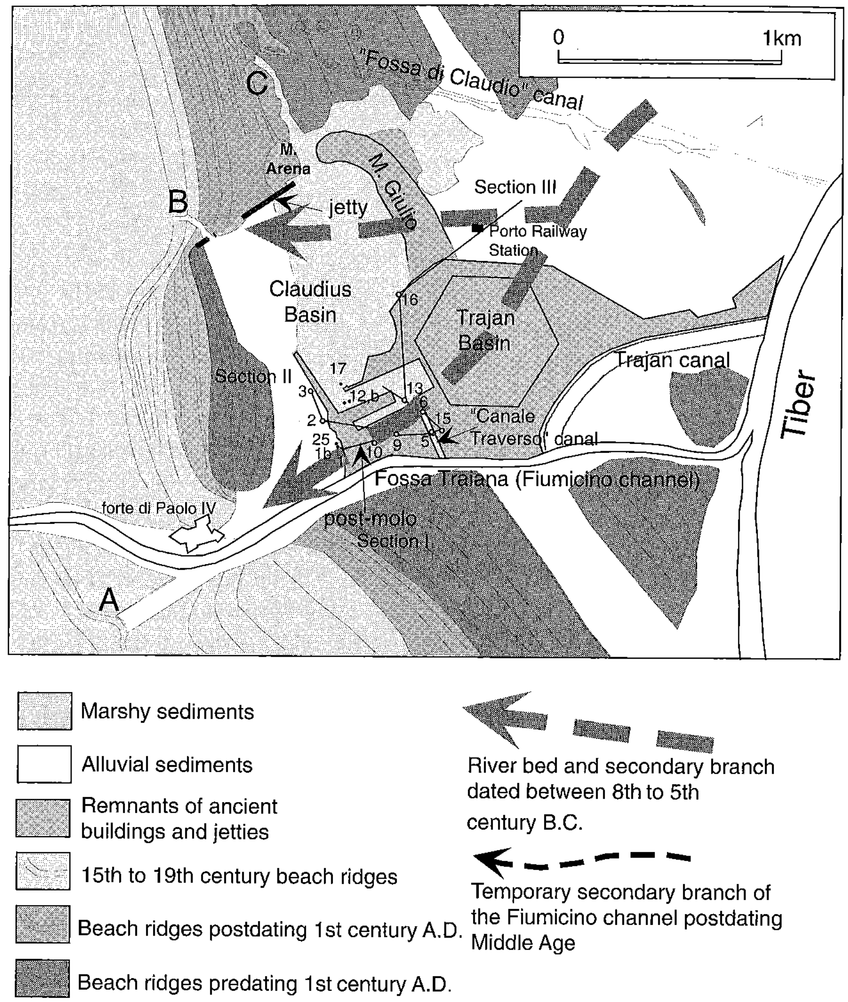


Figure 2. Geological map of the study area, including the Claudius and Trajan harbor. Legend: A = Fiumicino branch dammed by beach ridges; B = mouth of the secondary branch of the Fiumicino; C = northern entrance of the Claudius harbor dammed by beach ridges.

beach ridges of pre-Roman age (Figures 2, 3). The harbor basins are filled with marine deposits that underlie the alluvial and marsh deposits (Dragone et al., 1967).

Historical sources report that the harbor of Claudius and Trajan was mostly excavated in terra firma (Testaguzza, 1970). The geological data generally confirm the historic information; however, thick deposits of sediment in the harbor basins, and the ruins of the city of Portus, make it difficult to reconstruct the surface geology for the period when the harbor was constructed.

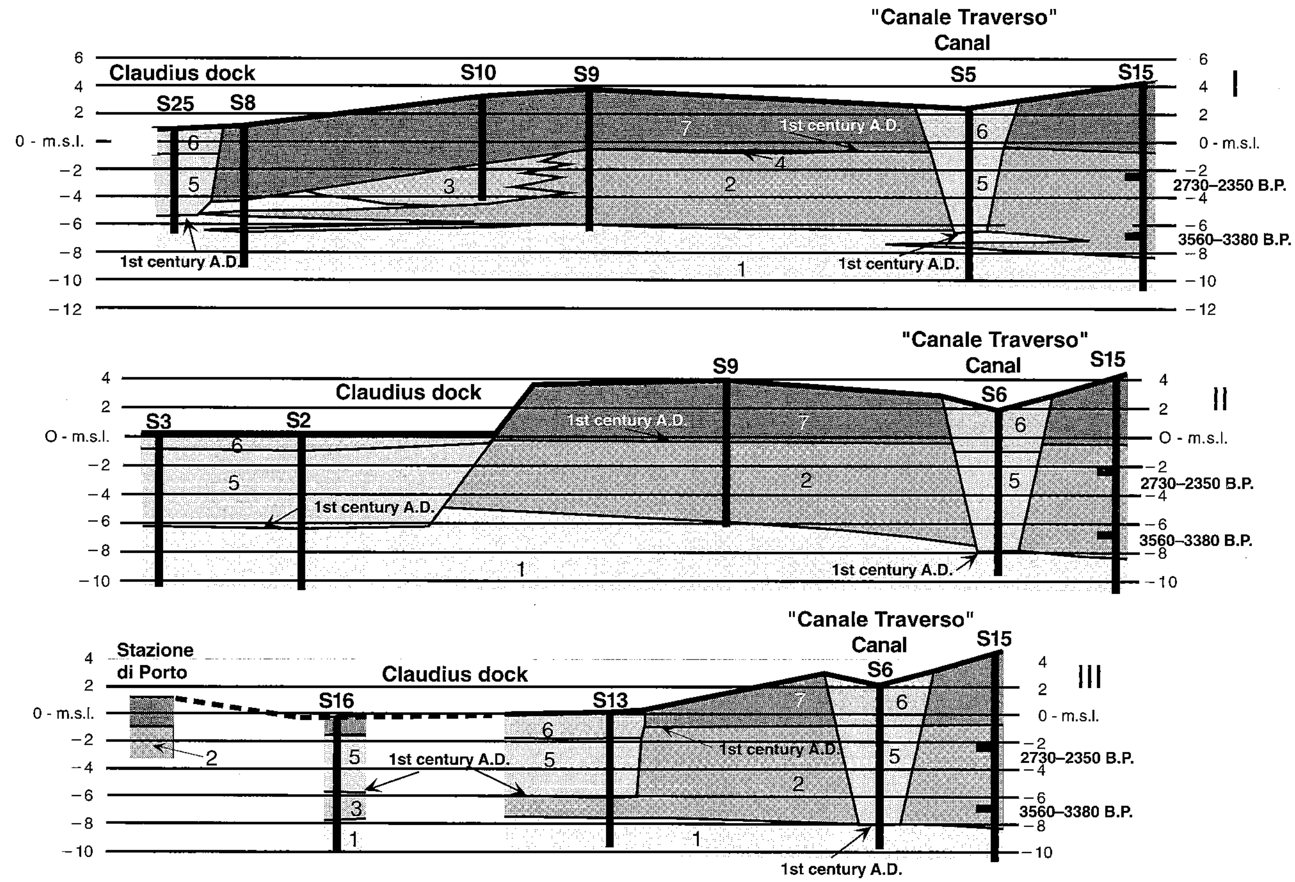


Figure 3. Cross-sections of the stratigraphy through the area of the harbors of Claudius and Trajan. Legend: 1 = alluvial sandy silt; 2 = stratified alluvium, including silt, fine gravel, and coarse sand; 3 = medium sand (alluvium); 4 = silty marsh deposits; 5 = marine deposits filling the canals and basins of the Claudius harbor; 6 = alluvium and marsh deposits filling the Claudius harbor; 7 = remnants of Roman buildings, jetties, and artificial features in the basins.

METHODS

Aerial photographs were used to prepare a geomorphological map of the Tiber River delta. The Soprintendenza per i Beni Archeologici di Ostia conducted deep coring in the Port of Claudius and Trajan to identify morphological features of the Tiber delta that date to the Roman period and to identify and characterize sedimentation phases in the harbor. Also, subsurface data were gleaned from shallow hand excavations and auger holes. A chronological framework was developed through radiocarbon dating of wood fragments and analysis of pottery sherds recovered in the cores. The nature of depositional environments was inferred from fossil invertebrates and the lithology of sediments.

RESULTS

Stratigraphy of the Port of Claudius and Trajan

Remnants of the Port of Claudius and Trajan are located immediately east of an area formed by beach ridges (Figures 1, 2). The beach ridges closest to the port are dated to ca. 8th–9th century B.C. According to Scrinari (1971), the west side of the northern jetty of the port was attached to the dunes of these beach ridges. Some older beach ridges are to the south and east of the port.

Dragone et al. (1967) described deposits in the ancient harbor, noting that they are 8–10 m thick and consist of sand and clay with *Mactra corallina* shells. Ferrara, Reinharz, and Tongiorgi (1959) reported two radiocarbon ages determined on materials from the area of the harbor: A wood fragment associated with material used for jetty construction yielded an age of 1863 ± 135 yr B.P. (two sigma calibrated age: 200 B.C.–A.D. 550), and a *Mactra corallina* shell recovered at a depth of about 8 m yielded an age of 2160 ± 145 yr B.P. (two sigma calibrated age: 150 B.C.–A.D. 550).

The top of the fill in the western basin of the port consists of alluvium—mostly sand and silty sand—while in the rest of the basin silty alluvium and marsh deposits cap the fill. Amenduni (1884) reported that part of the Claudius and Trajan harbor was still occupied by marshes in the 19th century.

The stratigraphy of the port and surrounding area was examined by collecting 17 cores to a maximum depth of 15 m (Figure 2). Twelve cores were taken in harbor fill, including five cores (7, 8, 9, 10, 15) on remnants of jetties and buildings. In those five cores, 4–5 m of urban rubble were penetrated before reaching natural deposits. The base of this rubble was dated to the early phases of port construction (mid-1st century A.D.). Natural deposits in the cores have graded bedding, with medium and coarse sand fining upward to silt. Similar sequences with graded bedding also occur in some excavations outside of the primary study area, including an area near the Porto railway station. Using information gleaned from the cores, three cross-sections were prepared to illustrate the stratigraphy of the study area (Figure 3).

Cross-Section I

Cross-section I (Figure 3) shows the stratigraphy inferred from Cores 15, 10, and 9, collected in the urban area of Portus; Core 5, recovered from a canal ("Canale traverso," described by Testaguzza, 1970) that linked the Fossa Traiana with the port; Core 8, collected on one of the jetties of the port; and Core 25, collected inside the ancient port basin. The bottom of the sediment filling the ancient basin consists of sand, gravel, broken seashells, and pottery fragments. Based on typology, the oldest pottery dates to the 1st century A.D. The following deposits are mostly silty, varying from sandy silt to clayey silt, and contain saltwater and brackish-water invertebrate fossils (*Mactra corallina*, *Chamelea galina*, *Donax trunculus*, *Littorina* sp., *Barbatia* sp., *Cerithium*, *Cerastoderma edule*) and fragments of pottery and ornamental stone. Thin, alternating beds (decimeters to centimeters thick) of medium and fine sand grading to silty alluvium, some with freshwater gastropods and others that are sterile of fauna, cap the saltwater and brackish-water deposits. Thick deposits of silty alluvium and marsh sediments form the top of the sequence. Some of the silt deposits are sterile, but others contain freshwater and terrestrial gastropods (*Planorbis planorbis*, *Pomatias elegans*, *Helicella* sp., *Bithynia tentaculata*) that are affiliated with fluvial and marsh environments.

Gravelly, sandy, and silty deposits underlie the harbor fill and the urban area of Portus. These deposits are part of the wave-dominated delta depositional system described by Bellotti et al. (1995). The middle and upper portion of the sedimentary sequence mostly consists of poorly bedded coarse sand with a few layers of sandy gravel. In the lower part of the sequence, thin beds of medium to fine sand grade upward to silt. The beds are decimeters to centimeters thick and contain microfauna derived from erosion of the Pleistocene marine sediment bordering the eastern margin of the delta. The grain size and sedimentary structure of the deposits are typical of channel-fill and bed-load delta facies, as described by Reineck and Singh (1980).

Fragments of wood and charcoal were found in Core 15. A piece of wood recovered 11.75 m below natural ground level (7.4 m below sea level) yielded a radiocarbon age of 3240 ± 40 yr B.P. (Beta-198940; 1610–1420 B.C.), and a charcoal fragment recovered from a lens of charcoal and plant macrofossils 6.6 m below ground level (2.35 m below sea level) yielded an age of 2450 ± 40 yr B.P. (Beta-200413; 780–400 B.C.). A thin bed of organic-rich silt was recorded at a depth of 0.9 cm below sea level in Core 9, taken beneath Roman structures in the harbor. This silt bed contained the shells of mollusks, including *Cerastoderma edule* and *Donax*, affiliated with brackish-water environments.

Cross-Sections II and III

The stratigraphy shown in cross-sections II and III (Figure 3) is similar to the stratigraphy shown in cross-section I, and provides additional information on sedimentation in the harbor basins. In several cores, layers and fragments of wood (now under study) were sampled. Some of the wood may be from ancient vessels, but additional analysis is needed to confirm this.

In cross-sections II and III, deposits comprising the fill in the ancient port consist mostly of silt, varying from sandy silt to clayey silt, and contain saltwater and brackish-water fossil gastropods (*Mactra corallina, Chamelea galina, Donax trunculus, Littorina* sp., *Barbatia* sp., *Cerithium, Cerastoderma edule*) as well as pottery fragments and ornamental stone. These silty deposits are mantled by sandy silt containing large quantities of plant macrofossils, predominantly seagrass (*Posidonia* sp.). The sequence is capped by silty alluvium containing freshwater and terrestrial gastropods similar to the assemblage described for cross-section I.

In cross-sections II and III, the substratum in which the harbor basins were excavated mostly consists of thin beds (1 to 10 cm thick) of sand that fines upward to silt. Some graded beds contain reworked microfauna, but others are sterile. In Core 16, there are sterile, poorly bedded sands as well as graded beds of sand. Based on granulometry and sedimentary structures, deposits underlying the harbor fill are delta facies of channel-fill and bed-load sands, as described by Reineck and Singh (1980), and form a part of the wave-dominated delta depositional system described by Bellotti et al. (1995).

SUMMARY AND CONCLUSIONS

Geomorphic and stratigraphic data collected in this study provide the basis for a geoarchaeological analysis of the Port of Claudius and Trajan. The data were used to reconstruct the evolution of the Tiber delta during the period prior to the construction of the port, and to identify, at least on a preliminary basis, the history of sedimentation that resulted in the filling of the ancient harbor.

Prior to ca. 700–400 B.C., the Tiber flowed into the sea not far from the area where the Port of Claudius and Trajan was constructed centuries later. The river had two branches: The main one mostly corresponded to the Fiumicino channel, and a second channel reached the sea further north.

Before the construction of jetties and buildings and the excavation of harbor basins, the area occupied by the Port of Claudius and Trajan consisted mainly of alluvium deposited in the channels of the Tiber River. The coarse alluvium, radiocarbon-dated between ca. 1610–1420 yr B.C. and ca. 780-400 yr B.C., was deposited by the stream that flowed among the cusps of the beach ridges formed during phase IV and V (predating the 13th–11th centuries B.C. to a period postdating the 9th–8th centuries B.C.). The alluvium is, therefore, coeval with adjacent beach ridges. Alluvial deposits in Core 16 and in the area of the Porto railway station are associated with the second channel, which reached the sea further to the north. Hence, while the beach ridges of phase V were forming, and perhaps even earlier, the Tiber at times reached the sea through two branches (Figures 1 and 2). Currently, few traces of the second, more northerly channel remain, since a large part of the area was modified by Roman construction in the 1st and 2nd centuries A.D.

As noted earlier, in Core 9 a thin bed of sediment containing fossil mollusks that lived in brackish water caps the sedimentary sequence. Buildings dated to the 1st century A.D. are immediately above this bed. From this it is deduced that, after the diversion to the south of the Tiber, the former channel remained open, leading to the intrusion of seawater. The same phenomenon likely occurred at the mouth of the second Tiber branch, located further north. The absence of pre-Roman surficial sediments in the area of the artificial harbor basins precludes a precise reconstruction of the course of the stream channel and of the coastline during the period just prior to Roman construction. It is likely, however, that the beach ridges of phase V, west of the port, were transformed into an island. The island became separated from the delta proper by marshes and by two inlets formed by marine intrusions into the mouth of the abandoned stream branches.

Stratigraphic data indicate that diversion of the river from the area of the port to its present position took place after the deposition of alluvium containing charcoal dated between ca. 780 and 400 cal. yr B.C. The Fossa Traiana canal, excavated in the depression between the cusps of pre-Roman beach ridges, coincides, at least along one segment, with the branch of the Tiber abandoned before the 4th century B.C.

The age of the diversion of the Tiber inferred from geologic data coincides with the establishment of Ostia in the 4th century B.C. at the mouth of the new channel of the Tiber. According to the writings of Quintus Ennius (3rd century B.C.) and others, at about 620 B.C. King Ancus Marcius founded a colony called Ostia Tiberina on the left bank at the mouth of the Tiber River (Meiggs, 1973). The remains of this ancient settlement, however, have never been discovered. The results of our investigation indicate that during this period the Tiber was in the area where the Port of Claudius and Trajan was constructed. Therefore, it is likely that Ostia Tiberina was situated near that area.

The beach ridges, which are almost straight in most of the study area, have an anomalous morphology in the area west of the Port of Claudius and Trajan (Figures 1, 2). This anomaly is attributed to two factors: (1) the presence of the two branches of the Tiber west of the Port of Claudius and Trajan, which resulted in a more complex development of the beach ridges; and (2) delta retreat phases during the period after construction of the port. Castagnoli (1963) examined the anomalous morphology of the beach ridges, but he did not attempt to date them, nor did he realize the variations in the location of the stream channel and erosion that had occurred. He assumed that the anomalous morphology was caused by the presence of Roman jetties (never found) at the contact between the deposits forming the beach ridges of phases VII and VIII. Giuliani (1992) also attributed the anomalous morphology of the beach ridges to Roman jetties.

Detailed study of the fill phases of the harbor basins excavated in the 1st and 2nd centuries A.D. is still in progress. Nevertheless, the data indicate that at least in the area of cores 1, 2, and 3, sedimentation began immediately after the opening of the port. Specifically, the lower part of the harbor fill contains pottery of the 1st century A.D. Based on the grain size of the sediments (gravel and coarse sand), the area of cores 1, 2, 3, and 25 experienced strong wave motion.

Historical data have also been considered in order to date the silting of the harbor. According to Coccia (1993) and Paroli (2004), in the 9th century A.D. the harbor basins were still in use. We must therefore assume that, at least during the Early

Middle Ages, there was an inflow of seawater into the port, and marine sediments could have been deposited at least until the 9th–10th centuries A.D.

Paroli (2004) provided historical data about the irregular use of the silted port during the 12th century A.D. and the navigability of the Fossa Traiana canal at least until the year A.D. 1118. Sediments were deposited in brackish water when the inflow of seawater was impeded because of silting and the concomitant blockage of the harbor entrance. The brackish environment probably was maintained by the mixing of the seawater with freshwater from the Fossa Traiana canal. It is likely that the brackish environment lasted at least until the 12th century A.D.

The top of the sedimentary sequence of the harbor fill consists of alluvium and marsh deposits that aggraded, mostly after the 14th century A.D., when the Tiber experienced a series of floods (Camuffo & Enzi, 1994) and there was significant progradation of the delta (Dragone et al., 1967; Belluomini et al., 1986; Bellotti et al., 1987, 1989, 1994, 1995; Segre, 1986; Giraudi, 2004). The Fossa Traiana canal was perhaps already partly filled with sand in the year A.D. 1461 (Paroli, 2005). During the 15th century, beach ridges dammed the Fossa Traiana (Figure 2, point A) and the river changed its course, flowing toward the harbor basins. The grain-size distribution of the alluvium suggests that the water flowed from the Fossa Traiana to the southern portion of the Port of Claudius (Figure 2), and then to the sea through a breach in the northern jetty of the port (Figure 2, point B). Discharge through this breach ceased when sedimentation of phase VIII beach ridges began, i.e., in the 16th century. According to Paroli (2005), during the year A.D. 1612, the Fossa Traiana was dredged, its direction was modified, and it was reopened to navigation.

The innermost basins of the harbor were filled by silt carried in suspension by water entering from the "Canale Traverso" canal. Pottery remains dated to the 16th century A.D. have been found in alluvial deposits that filled the canal (Paroli, 2004).

In sum, the Port of Claudius and Trajan was silted in as a result of frequent flooding in the Tiber River and related progradation of the Tiber delta. Over the last 2000 years, the most important progradation phases of the delta were produced by increases in sediment load caused by environmental changes, i.e., cool, moist climatic periods, in the Tiber drainage (Giraudi, 2005). Major episodes of alluviation reported by Camuffo and Enzi (1995) date between the 6th and 9th centuries A.D. and between the 15th and 19th centuries A.D. Both of these episodes correspond with periods of cooling of North Atlantic waters (event of 1400 cal. yr B.P. and 500 cal. yr B.P.), as reported by Bond et al. (1997). Hence, sedimentation that led to the silting of the Port of Claudius and Trajan appears to have been caused by increased alluviation related to environmental changes in the watershed. Those changes were likely triggered by global climatic changes.

The authors are grateful to G. Ricci for his support during the fieldwork, and to T. Kotsakis and D. Esu for their suggestions about the malacofauna identification. J.P. Goiran contributed to the discussion of data in the field. The authors thank J.D. Stanley and an anonymous referee for suggestions and comments on the manuscript.

REFERENCES

Amenduni, G. (1884). Sulle opere di bonificazione della plaga litoranea dell'Agro Romano che comprende le paludi e gli stagni di Ostia, Porto, Maccarese e delle terre vallive di Stracciacappa, Baccano, Pantano e Lago dei Tartari. Relazione del progetto generale 15/7/1880. Min.LL.PP. Ed. Eredi Botta, 1–36, Roma.

Amorosi, A., & Milli, S. (2001). Late Quaternary depositional architecture of Po and Tevere river deltas (Italy) and worldwide comparison with coeval deltaic successions. Sedimentary Geology, 144, 357–375.

Bellotti, P., Carboni, M.G., Milli, S., Tortora, P., & Valeri, P. (1989). La piana deltizia del fiume Tevere: Analisi di facies e ipotesi evolutiva dall'ultimo low stand glaciale all'attuale. Giornale di Geologia, ser. 3a, 51, 71–91.

Bellotti, P., Chiocci, F.L., Evangelista, S., Tortora, P., & Valeri, P. (1987). La superficie di discordanza alla base del delta del Tevere e le sue relazioni con la geometria del corpo deltizio. Memorie della Società Geologica Italiana, 37, 407–415.

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. Journal of Sedimentary Research, B64, 416–432.

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.

Belluomini, G., Iuzzolini, P., Manfra, L., Mortari, F., & Zalaffi, M. (1986). Evoluzione recente del delta del Tevere. Geologica Romana, 25, 213–324.

Bocci, D. (1892). Il delta Tiberino. Giornale del Genio Civile, 30, 1–34.

Bond, G., Showers, W., Cheseby, M., Lotti, R., Almasi, B., deMenocal, P., Priore, P., Cullen, H., Hajdas, I., & Bonani, G. (1997). A pervasive millennial scale cycle in North Atlantic holocene and glacial climates. Science, 278, 1257–1266.

Camuffo, D., & Enzi, S. (1994). Cambiamenti climatici negli ultimi 2000 anni. Il Quaternario, 7, 257–266.

Castagnoli, F. (1963). Astura. Studi Romani, 11, 637–644.

Chiocci, F.L., & Milli, S. (1995). Construction of a chronostratigraphic diagram for a high-frequency sequence: The 20 KY B.P. to present Tiber depositional sequence. Il Quaternario, 8, 339–348.

Coccia, F. (1993). Il "Portus Romae" fra tarda antichità ed altomedioevo. In L. Paroli & P. Delogu (Eds.), Storia economica di Roma nell'Altomedioevo alla luce dei recenti scavi archeologici. Firenze: Atti del Seminario di Roma, 183–188, "All'Insegna del Giglio."

Dragone, F., Maino, A., Malatesta, A., & Segre, A.G. (1967). Note illustrative del Foglio 149 Cerveteri della Carta Geologica d'Italia. Servizio Geologico, 4, 1–93.

Ferrara, G., Reinharz, M., Tongiorgi, E. (1959). Carbon-14 dating in Pisa. American Journal of Science Radiocarbon Supplement, 1, 108–110.

Giraudi, C. (2004). Evoluzione tardo-olocenica del delta del Tevere. Il Quaternario, 17, 477–482.

Giraudi, C. (2005). Late Holocene alluvial events in the Central Apennines (Italy). The Holocene, 15, 768–773.

Giuliani, C. F. (1992). Note sulla topografia di Portus. In V. Mannucci (Ed.), Il parco archeologico naturalistico del porto di Traiano (pp. 28–44). Roma: Metodo e progetto.

Keay, S., Millett, M., Paroli, L., & Strutt, K. (2005). Portus: An archaeological survey of the Port of Imperial Rome. London: Archaeological Monographs of the British School at Rome, 15.

Meiggs, R. (1973). Roman Ostia, 2nd ed. Oxford: Clarendon Press.

Oberholtzer, F. (1875). Le Foci del Tevere. Roma: Paravia.

Paroli, L. (2004). Il porto di Roma nella tarda antichità. In A. Gallina Zevi & R. Turchetti (Eds.), Le strutture dei porti e degli approdi antichi (pp. 247–266). II seminario ANSER, Roma-Ostia Antica, 16–17 aprile 2004. Cosenza: Rubbettino Editore (Soveria Mannelli).

Paroli, L. (2005). History of past research at Portus. In S. Keay, M. Millet, L. Paroli, & K. Staut (Eds.), Portus: An archaeological survey of the Port of Imperial Rome. London: Archaeological Monographs of the British School at Rome, 15.

Reineck, H.E., & Singh, I.B. (1980). Depositional sedimentary environments. New York: Springer-Verlag.

Scrinari. V. (1971). Il "Portus Plaudii" e i piu recenti ritrovamenti nella zona di Fiumicino. Atti del III Congresso Internazionale di Arch. Sottomarina, Barcelona 1961, 215–224.

Segre, A.G. (1986). Considerazioni sul Tevere e sull'Aniene nel Quaternario. In Il Tevere e le altre vie d'acqua del Lazio Antico. Quaderni del Centro di Studio per l'Archeologia etrusco-italica, 12, 9–17. Consiglio Nazionale delle Ricerche, Roma.

Testaguzza, O. (1970). Portus: Illustrazione dei porti di Claudio e Traiano e della città di Porto a Fiumicino. Roma: Julia Editrice.

Received 25 March 2008
Accepted for publication 1 November 2008
Scientific editing by Rolfe Mandel