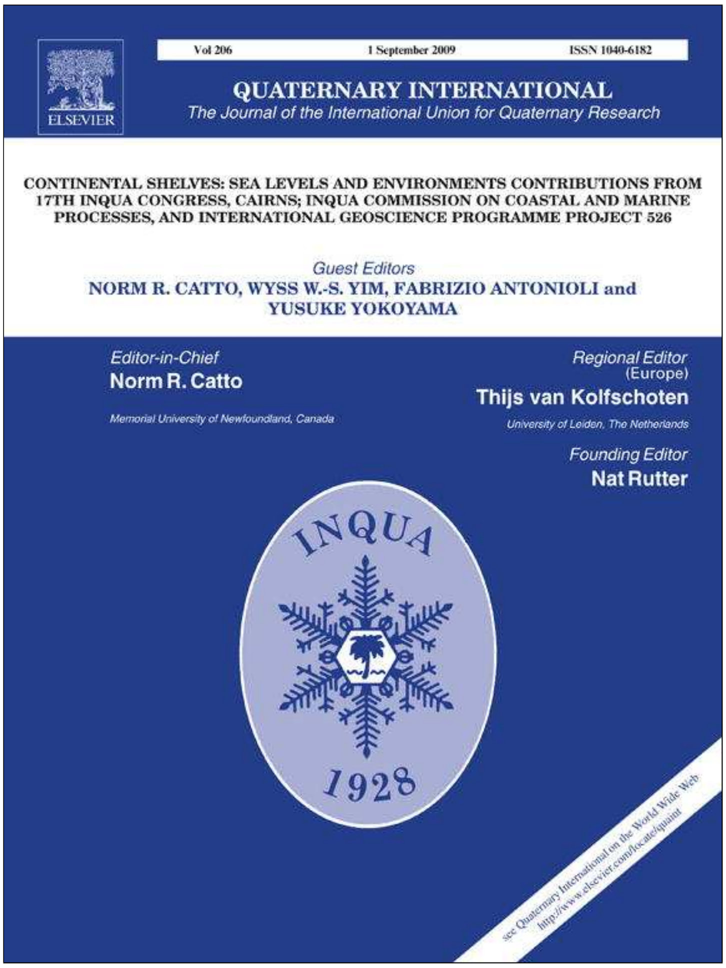
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Geoarchaeological sea-level proxies from a silted up harbour: A case study of the Roman colony of Luni (northern Tyrrhenian Sea, Italy)

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ABSTRACT

The Luni Plain, which faces the northern Tyrrhenian Sea, underwent major landscape changes over the last 3000 years. The coastline shifted south and west, separating the ruins of the ancient Roman colony of Luni (founded in 177 BC) from the sea by means of a new coastal plain. The precise location of the coastline during the main settlement phase as well as during the city's decline has never been established, although partial and qualitative scenarios have been suggested by various authors. According to these authors, an indentation of the coastline west of the city formed a major water basin, along the shores of which traces of pre-Roman settlements exist; near the city, two minor basins were present, suitable for hosting harbour structures. The city of Luni was famed for its harbour (Portus Lunae), from which the marbles quarried in the Apuan Alps, used to build many of the monuments in Rome, were delivered. The traces of its port, however, are scattered and uncertain.

Newly available subsurface data are presented, associated with a revision of unpublished archaeological evidence of the ancient city topography. Progress in palaeoenvironmental reconstructions at Luni has been possible thanks to the collection and analysis of ancient and recent cores, supported by radiocarbon dates, as well as the interpretation of archaeological findings suitable as markers for sea-level recognition. The main environmental changes in the area have been refined: since a few centuries before the colony was founded, the Luni plain had been characterized by a complex architecture of swamps and marshes limited by dune ridges and fluvial sand bars. The positions of these landforms were not fixed, but shifted, mainly depending on the spatial relationship between the coastline and the river mouths.

Determining the precise position of the Roman coastline is useful to constrain the area in which archaeological surveys should be concentrated in order to identify the harbour location. Moreover, some of these results have been used to infer altitude constraints on the sea-level position in Roman times: preliminary data are shown for constructing a Late Holocene local sea-level curve in the area.

1. Introduction

Geoarchaeological research in coastal areas provides excellent proxies for past sea levels, as it is possible to relate some coastal structures (e.g., fish tanks, docks) to sea level through their requirements for successful functioning (Schmiedt, 1972; Faivre and Fouache, 2003; Auriemma et al., 2004; Lambeck et al., 2004a; Sivan et al., 2004; Morhange et al., 2006). The presence of sedimentary archives, however, greatly improves the quality of reconstructions of palaeo-environments associated with ancient settlements (Vött, 2007). The potential of geoarchaeological research in coastal plains that have been prograding throughout the Holocene has been recognized for a long time (Pirazzoli, 1991; Kraft, 1994); in recent years, many papers have been published on this topic (among them Fouache et al., 2001; Brückner et al., 2006; Vött et al., 2006; Kraft et al., 2007). In Italy, some coastal sites associated with geo- and bio-archives have helped provide a continuous record of the environmental evolution of the last millennia (Pagliarulo, 2006; Goethals et al., 2006). Only some of these, however, display good sedimentological or geoarchaeological sea-level markers. Some archaeological remains are ambiguously related to sea level or are associated with sediments with clear marine facies that are deeper than suggested by archaeology (e.g., Benvenuti et al., 2006).

The Holocene sea-level curve for Italy is relatively well known (Lambeck et al., 2004b). Local differences are accounted for, due mainly to differential subsidence or uplift rates. In the area neighbouring the study site in this paper, the ancient city of Luna, there

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are two constrained sea-level altitudes for Roman times, deriving from dated sediments in the Versilia Plain (Antonioli et al., 2000) and from a Roman harbour dock at Varignano (Chelli et al., 2005).

The archaeological site of Luna (presently Luni), in the coastal plain formed in the lowermost tract of the Magra River course (Fig. 1), was already considered a potential source of archaeological sea-level markers (Schmiedt, 1972), and geoarchaeological research has been carried out on it with a stratigraphic approach (Delano Smith, 1986). Results of these studies, however, are not fully satisfactory. Both the sea-level altitude and the coastline position and displacement at the time of city settlement must be considered as unknown (Bini et al., 2006).

Newly available subsurface data associated with the revision of unpublished archaeological evidence are presented in this work. They permit improved knowledge of the palaeoenvironmental conditions of the site, broadly outlining its evolution around Roman times. Progress in palaeoenvironmental reconstructions at Luni has been possible thanks to the collection and analysis of ancient and recent cores, supported by some radiocarbon dates, as well as the interpretation of archaeological findings suitable as markers for sea-level recognition. The presented data are not exhaustive for the problem of sea-level position and coastline displacement in the area during Roman times; this would require further research, in particular in order to address archaeological surveys aimed at locating the city harbour. For this reason, an integrated study is being conducted of all physical environments associated with traces of ancient human settlement in the present-day Magra plain and its immediate surroundings.

2. Archaeological background of the lower Magra Valley coastal plain

Proof of human settlement since the Bronze Age in the area of the present-day coastal plain of the lower Magra Valley (Fig. 2) exists as scattered but meaningful findings. This proof becomes more widespread and consistent beginning with the Protostoric Age (6th to 3rd centuries BC) and then Roman times; it may contribute, from an archaeological point of view, to reconstructing the ancient shoreline.

Findings corresponding to the Protostoric Age consist of settlements and graveyards found mainly at the foothill of the slope of the western promontory bordering the coastal plain; they are attributable to ancient Ligurian people who lived on the western side of the marine gulf first named "Selene limen" by the Greeks and then "Portus Lunae" during Roman times (Gervasini, 2007).

The graveyard of Cafaggio (approx. 8 m a.s.l.), near Ameglia (Fig. 2), where 19 funerary monuments and 54 tombs were excavated in the 1970s (Durante, 2004), lies on a gentle slope at the foot of the western promontory of the lower Magra Valley. The grave goods found inside the tombs during archaeological surveys constrain the use of the site from the end of the 4th to the early 3rd century BC. Sporadic findings suggest a more ancient use of the site between the end of the 7th and the beginning of the 6th century BC. The graveyard was abandoned because it was buried by a landslide. Starting in the 1st century BC, the graveyard was used again by the Romans, as indicated by two tombs with floors at 8.00 and 6.98 m a.s.l.

Settling of the coastal plain probably became more relevant during Roman times (Gambaro and Gervasini, 2004) as the Roman colony of Luna was founded in 177 BC at the foothills of the Apuan Alps (Fig. 2). The city was located on the eastern side of Portus Lunae, already used by the Romans as a harbour for military expeditions towards Spain (3rd to 2nd centuries BC) against Carthaginian people. Literary sources report that the city was famed for its port, which was not merely of local importance (Strabo, Geogr. V 2.5). In particular, the "marble of Carrara," a prized type of white marble widely employed in the construction of most of the classical buildings of Rome, was shipped from this port. However, no reliable archaeological evidence of harbour structures has ever been found. Excavations have revealed a city with splendid buildings and an amphitheater that experienced a gradual decline after Roman times, probably due to both cultural and natural reasons (an

Fig. 1. Oblique aerial photograph of the Lower Magra Valley, with location of the archaeological area of Luni.

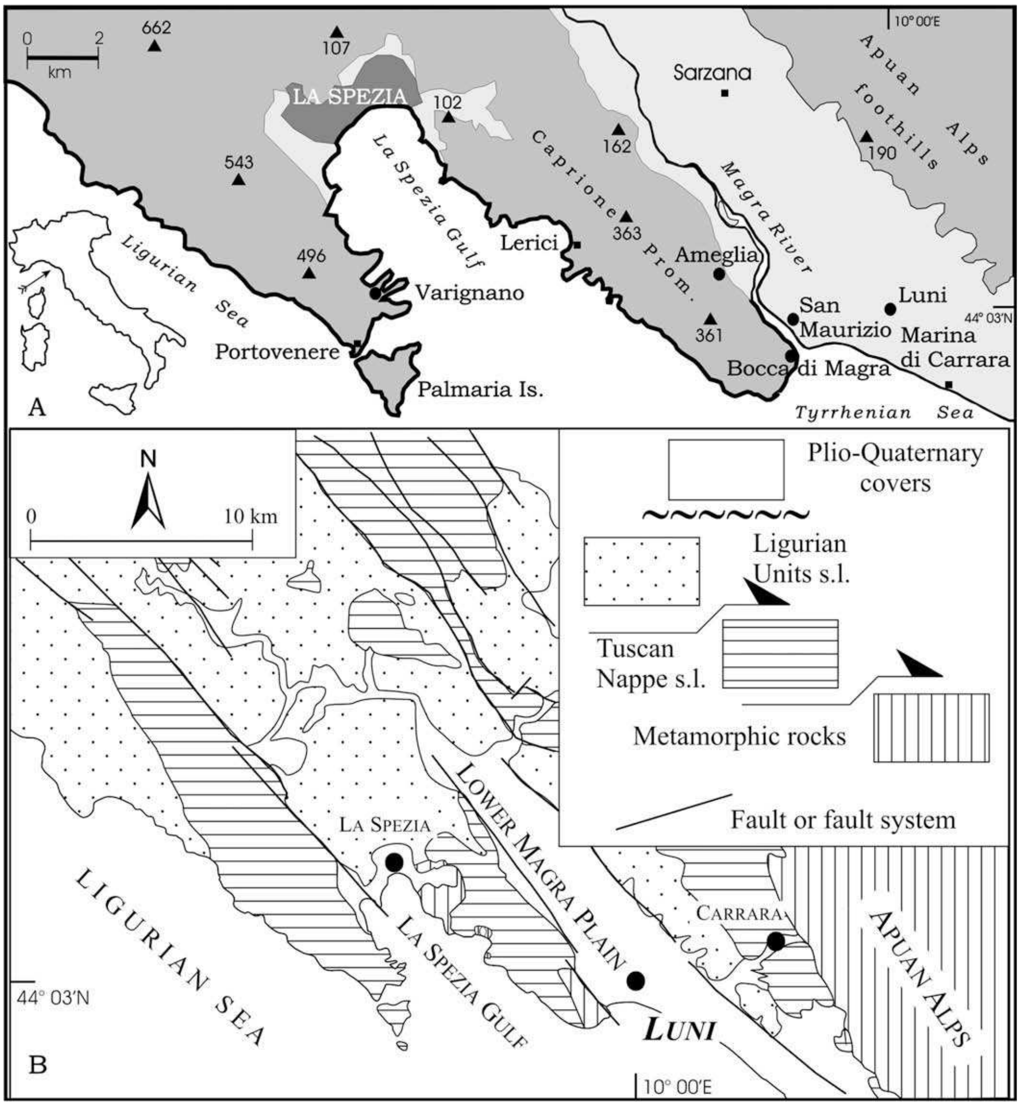

Fig. 2. Geographical (A) and geological (B) sketch maps of the lower Magra Valley and the surrounding area; redrawn after Del Tredici and Perilli (1998).

earthquake at the end of the 5th century AD, floods and gradual port silting up (Durante, 2001a)).

The urban plan of the city was defined within 25 years of its founding, before the final military triumph against the Ligurian people (155 BC); it was built with a network of streets, cardines and decumani, parallel to the directions of the two principal streets, oriented N–S (cardo maximus) and E–W (decumanus maximus) (Durante, 2001a). The city was built on terraces with surfaces at progressively descending heights from north to south towards the ancient shoreline (Fig. 3). Accurate instrumental measurements of elevation are available for the most relevant archaeological ground levels inside the city. During the Republican Age, the ground by the northern gate in the city walls reached an elevation of 7.16 m above present-day sea level; paving of the decumanus maximus in the middle of the urban area was at 2.83 m and a lower terrace (2.48 m a.s.l.) hosted the western tabernae buildings. South of the forum, another terrace 2–1.9 m a.s.l. can be recognized from the archaeological elevations of building (domus) ground floors and a square paving. Later, in the Imperial Age, the city was rebuilt and raised (Durante, 2001b; Durante, 2003), maintaining the same general stepped profile. The southernmost part of the cardo maximus, whose paving reaches the elevation of 1.37 m, is fairly well preserved in connection with the southern wall gate. This structure is potentially a good archaeological sea-level marker.

Many archaeological findings indicate settlement of the territory surrounding the colony (Ager Lunensis) during Roman times. On the western side of the Portus Lunae, the relics of a Roman villa (1st century BC) were found at Bocca di Magra (Fig. 2; Gambaro and Gervasini, 2004). This was built on different terraces descending towards the ancient western shoreline of the gulf. The uppermost terrace hosted the tank, with a floor at 5.76 m a.s.l., that supplied water to the villa and the belneum (bath), while the relic of the caldarium (area of thermae), with its floor at 0.62 m a.s.l., has been found in the lower terrace.

Archaeological relics of another maritime villa were found at 1.70–1.50 m a.s.l. near San Maurizio (Fig. 2), nowadays on the left bank of the Magra River but on the western side of the marine gulf in Roman times (Durante, 2008).

3. General setting

3.1. The lower Magra plain and previous palaeogeographic scenarios

The Lower Magra Valley is the south-eastern part of the Magra-Vara graben system and is characterized by NW–SE-striking faults that formed during the extensional tectonic phase that thinned the

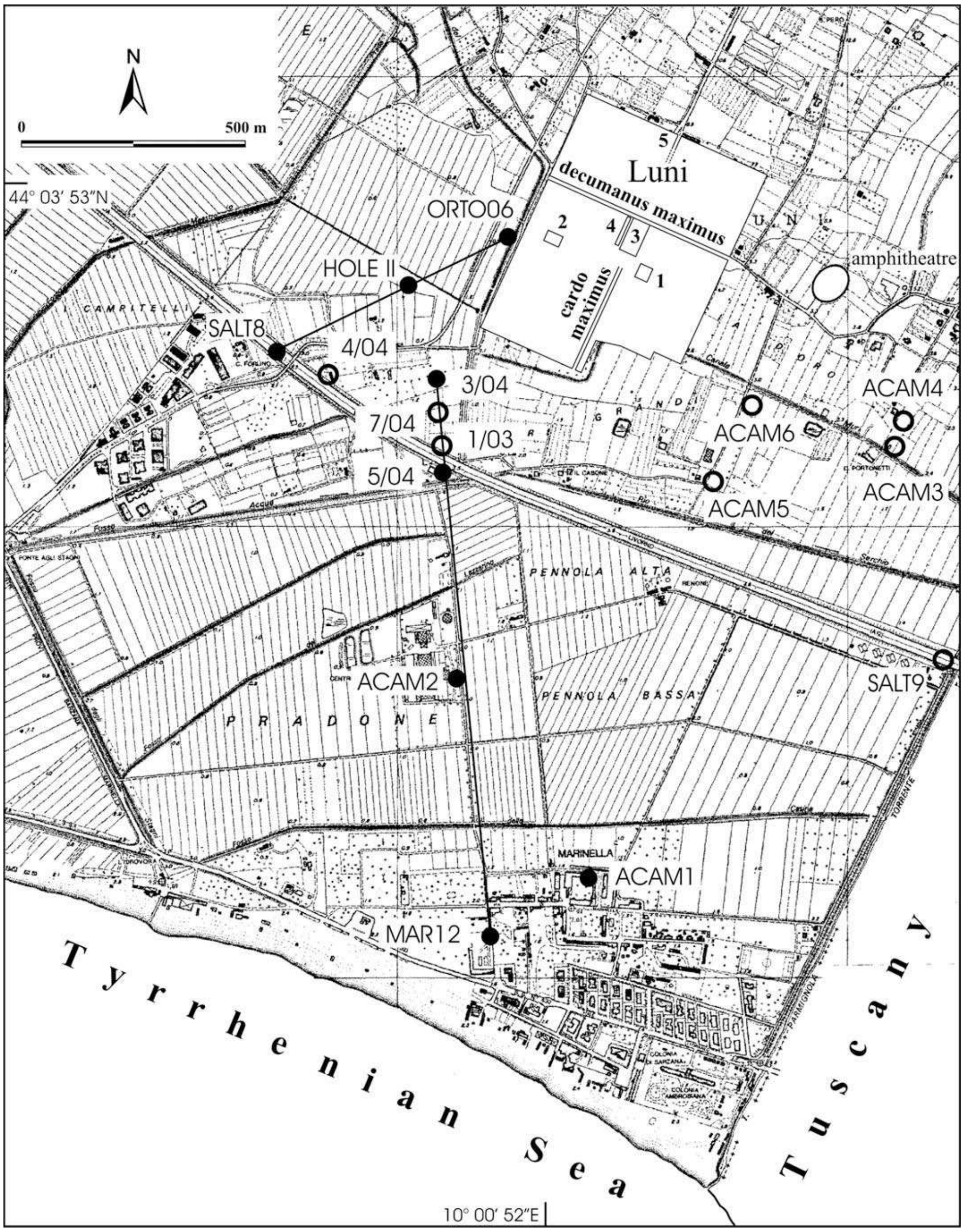

Fig. 3. The topographical features of the area surrounding the ancient colony of Luni (Regione Liguria Technical Map-scale 1:5000). The figure shows the archaeological elements of the town to which reference is made in the text: (1) domus degli affreschi, (2) domus di oceano, (3) forum, (4) tabernae, (5) northern gate of the town. The positions of the core profiles discussed in the text are also shown: filled circles represent the profiles included in the two transects (see Sections 5.1 and 5.2) while empty circles are the other profiles discussed in Section 5.3.

western side of the Northern Apennines. The main collapse of the Lower Magra graben occurred before the lower Pliocene as indicated by the age of lacustrine deposits present at its bottom (Bertoldi et al., 1994). The Pliocene lacustrine and fluvial deposits were tilted to the SSW and overlapped by a Pleistocene thick alluvial sequence developed as a consequence of the progressive aggradation of the coastal plain that nowadays extends between the lower tracts of the Magra River (W) and Parmignola Stream (E), 2 km wide and 5 km long (Fig. 2). Vertical movement along the graben probably never ceased; the region is at present seismically active.

Fig. 4 presents three different palaeogeographic scenarios of the landscape features near Luni in Roman times. In "a" Delano Smith (1986) starts from Roman times and depicts the different steps of the coastline positions up to the present day; "b" represents the view of Raffellini (2000), and "c" that of Raggi and Sansoni (1993).

None of these scenarios is complete or sufficiently supported by sedimentological evidence; although in the 1980s many profiles were mechanically drilled in the coastal plain down to a depth of 5–10 m by a team from Oxford University (Delano Smith, 1986), the stratigraphies of these are unpublished and unavailable. Moreover, none of these palaeogeographic reconstructions is considered satisfactory by archaeologists.

The most relevant feature in Delano Smith's reconstruction is the recognition of a sand bar, developed from the south-western corner of the city perimeter, which this author identified as a "spit." Raffellini agrees with this interpretation, and both indicate that the

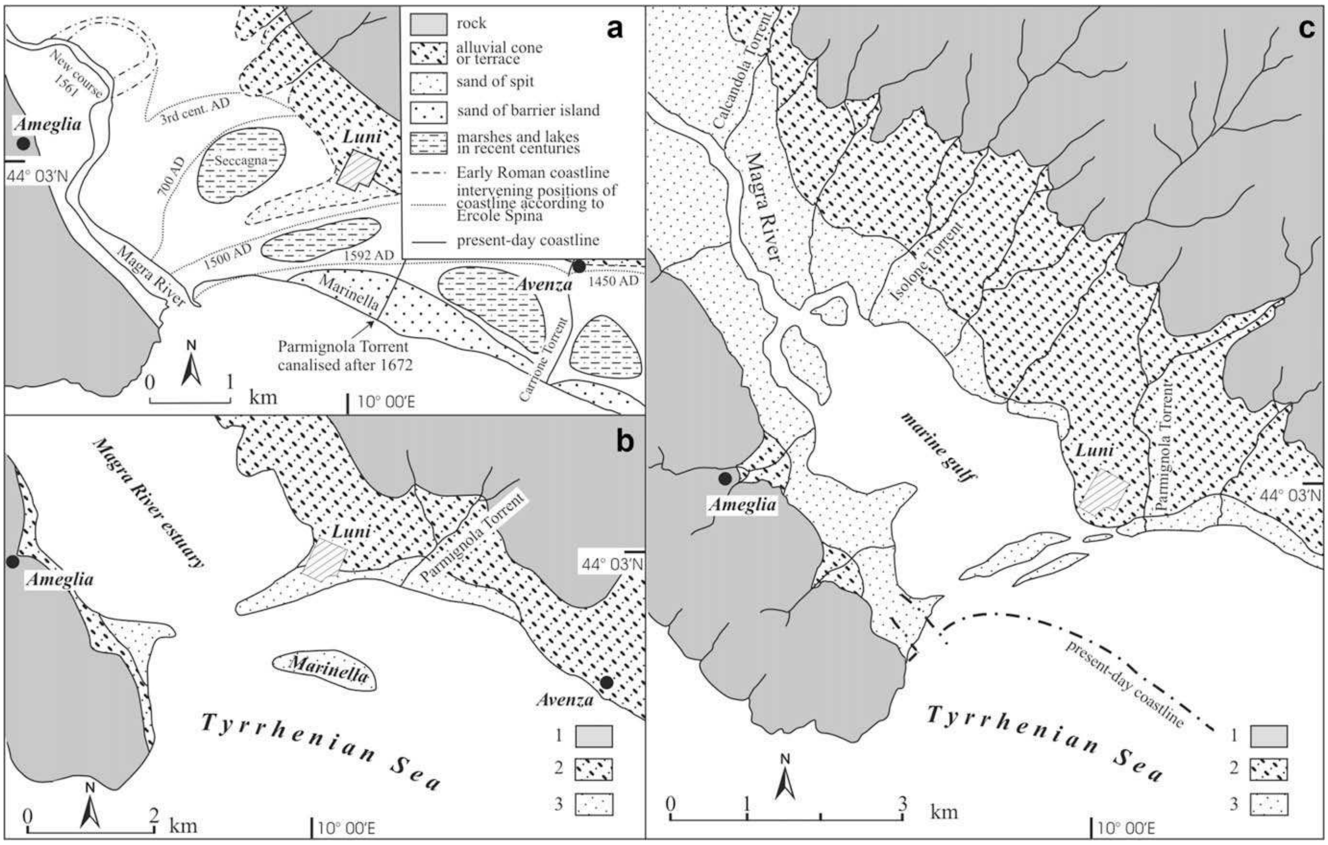

Fig. 4. Palaeogeographic scenarios of the landscape features in the area of Luni, redrawn and modified after (a) Delano Smith (1986), (b) Raffellini (2000) and (c) Raggi and Sansoni (1993). The sketches of Raffellini and Raggi and Sansoni represent the area at Roman times, while Delano starts from the same age and depicts the different steps of the coastline positions up to the present-day. For Delano's scenario the legend is inside frame (a). For the two sketches (b) and (c) the keys are: (1) rock; (2) alluvial deposits or alluvial cones; (3) alluvium from Magra River and littoral deposits. The area of Luni at Roman times in the view of a 16th century cartographer (Source: Ercole Spina, "Diverse piante", 1592, National Archive of Genoa, ms 423.).

city of Luni was built partly on the alluvial fan of Parmignola Stream and partly on this sand bar. The extent of the sand body along the southern side of the city walls is unclear. In particular, there is no evidence that it is connected to the dune ridge recognized in the Versilia Plain (from east of the present-day course of Parmignola Stream to Pisa) and identified as the morphological element closest to the Roman times coastline (Fabiani, 2006) on which the Roman street (Via Aurelia) was located. The position of Parmignola Stream along the fan is remarkably different in the three reconstructions but is consistently located east of the Luni settlement.

All the reconstructions put elongated sand bars facing the coastline. The extents and positions of these "islands," however, differ in Delano Smith's and Raffellini's views from Raggi and Sansoni's. According to Bernieri and Mannoni (1983), a shallow water body (saltwater lagoon, according to Delano Smith's definition) was present between the coastline and one of these islands that has now become a strip of the coastal plain on which the village of Marinella was built. Another basin was present in the area between the western side of the city walls and the sand bar linked to the coast (the "spit" of Delano Smith, 1986); the area, identified with the local name "Seccagna," is at present completely silted up and includes a peat bog in its central part. The two harbours of the *Portus Lunae* should have been located in these two water basins (Bernieri and Mannoni, 1983). This hypothesis is not supported by archaeological evidence; moreover it remains to be proven that these basins were deep enough to host ships suitable for marble trading and there are no radiometric dates as yet that support these palaeogeographic scenarios. Previous archeological interpretation of the presence of a dock (Frova, 1976) close to the southern city walls must, on the basis of geomorphological evidence, be rejected, as must palaeoenvironmental reconstructions based on it (Schmiedt, 1972).

3.2. Geomorphological outline

Geomorphological mapping (Fig. 5) permits five morphological units to be identified: the Parmignola Stream alluvial fan, a sand bar sub-parallel to the coastline, two swamps, some dune ridges and the Magra River alluviation deposits in the coastal floodplain (Bini et al., 2006).

1. The wide alluvial fan formed by the Parmignola Stream, on which the northern part of the city was built. This reaches an elevation of 80 m at the mountain foothills (apex) and decreases with a homogeneous and low gradient (2% of average dip) to an altitude of 4 m a.s.l. in its outer periphery. The stream probably changed its position along the fan from west to east in time, especially indicated by a bluff that is deeply incised along its western edge. Subsurface data available from a core by the fan's outer periphery indicate that this body is thicker than 25 m.
2. The sand body projecting west from Luni ("spit", sensu Delano Smith, 1986), on which the southern part of the city was founded. This sand body is at present hardly identifiable on a morphological basis due to the multiple land reclamations in the area after the Middle Ages. It can be detected through image interpretation in its western part, whereas towards the east its extent is unclear; its spatial relationship with the other morphologic units is particularly poorly known. Genetically, this body represents a sand bar that formed during an early

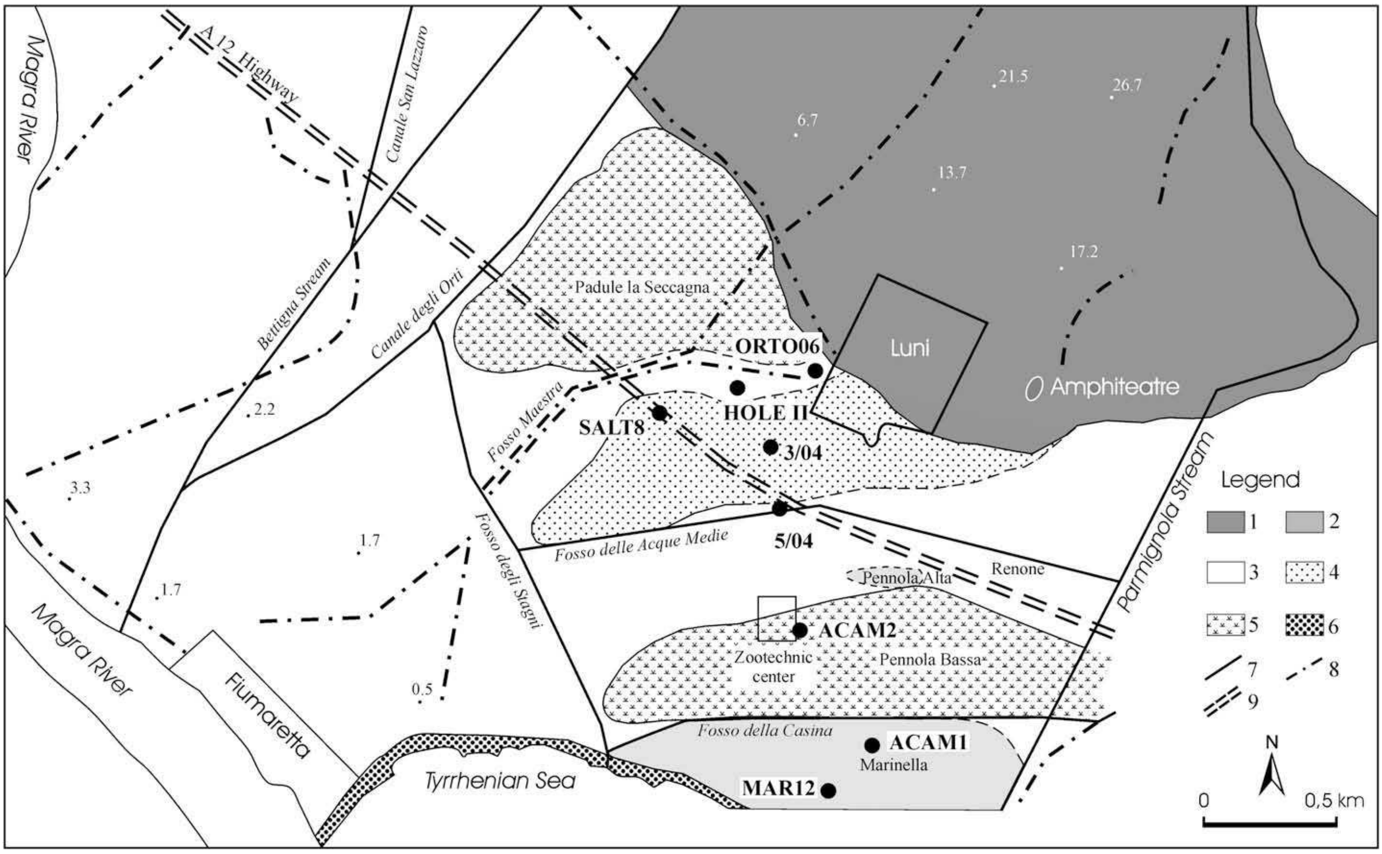

Fig. 5. Geomorphological sketch map of the Lunensis plain. Keys: (1) alluvial cone; (2) dune ridge; (3) alluvial deposits; (4) "spit" (sensu Delano Smith, 1986); (5) swamp; (6) present-day beach; (7) main streams and channels; (8) main traces of palaeochannels; (9) highway. The positions of the core profiles discussed in Sections 5.1 and 5.2 are indicated (see also Figs. 6 and 7).

stage of plain progradation and developed until late Roman times. Currently it is drowned by floodplain deposits, from which it can be hardly distinguished whenever it is not morphologically evident, and particularly from a sedimentological point of view. For this reason in the stratigraphy it is referred to here as fluvial/spit (e.g., Fig. 7). Preliminary grain size analyses of subsurface samples (Bini et al., 2006) suggest that the deposit grain size is more spread out than that of a dune, but more clustered than what is representative of alluvium. Delano Smith (1986) interpreted this body as a part of the Magra River mouth, a "spit" protruding into the sea towards the west.

3. The two swamps (locally called Seccagna and Pennola Bassa) are quite different from one another. The Seccagna is located west of the city; it is a wide sub-circular marsh 1 km in diameter, elevated from about 2 m a.s.l. at its outer perimeter down to 0.5 m in the middle. It is filled with a clay that is very rich in organic matter and becomes a peat bog in its central part, where the peat contains a great deal of pollen, as reported by Delano Smith (1986). It is considered as the evolution of the deep indentation of the coastline (or of the Magra estuary banks) flanking the western perimeter of the city. The Pennola Bassa swamp (bassa = low) is located south of the city, and is oriented with the present-day coastline (W–E); it is about 2 km long, 0.5 km wide, and 1 m elevated above present-day sea level, which is slightly lower than the areas surrounding it. The morphology and location of this latter swamp account for its origin as a backing swale.
4. The two dune ridges. The best preserved (Marinella) was detected between the Pennola Bassa swamp and the present-day coastline. The dune is a long (about 1.5 km) continuous ridge, sub-parallel to the present-day coastline, the maximum elevation of which exceeds the top of the Pennola Bassa swamp fill top of 0.5 m. The other dune (Pennola Alta-Renone) is undetectable from a morphological point of view, but grain size and morphoscopic analyses of subsurface deposits indicate the presence of dune deposits north of the Pennola Bassa swamp, now levelled and partly sheltered by recent deposits from alluviation and land reclamation. The place name (Renone, i.e., "Sand") also suggests the former presence of a dune ridge, which had never been recognized and included in previous palaeogeographic scenarios. The sediments of the Marinella and Pennola Alta-Renone dunes are very similar; both peak at the 0.315 mm grain size, and the grains are not very well rounded (Bini et al., 2006); these features are typical of the fossil as well as of the present-day dunes along the coast of the neighbouring Versilia Plain (SE of the Luni area), as stated by Baroni and Bini (2006).
5. The Magra floodplain alluvium. Historical data suggest coastline progradation and a simultaneous migration of the Magra River course to the west after Roman times, gradually reaching its present-day position close to the outer side of the eastern promontory of La Spezia Gulf. The Magra alluvium, well recognizable from its grain size and its petrographic features (Bini et al., 2006), partly overlaps the other and older morphologic units. Many palaeochannels have been recognized within this alluvium, partly cross-cutting those developed by Parmignola Stream during its migration along its own alluvial fan. Most of this alluvium should be considered younger than the morphologic units forming the city landscape at the moment of its foundation.

4. Materials and methods of the integrated research

Despite the fact that Italy is a country with a rich archaeological and cultural heritage, holistic geoarchaeological studies in coastal areas are still rare. Luni may serve as a case study, connecting archaeological and historical data with geological and palaeoenvironmental ones.

A joint project is being carried out to bring together archaeologists and earth scientists working in the area. The main result obtained so far is the construction of a database containing the stratigraphic descriptions of 29 sediment cores drilled in the area for various purposes. Some of these sediment cores were commissioned by the local Archaeological Heritage Office (Soprintendenza per i Beni Archeologici della Liguria), others were drilled in connection with building and pipeline construction. Each sediment core has been georeferenced, and all stratigraphic descriptions standardized using a specific legend. The elevation of the top of each core has been calculated with an error of ±0.5 m, interpolating the spot height derived from the Regional Technical Map of Liguria (scale 1:10,000) and referred to sea level.

Although the stratigraphies are inhomogeneous and have different degrees of resolution, they can be considered reliable enough to broadly identify the succession of sedimentary environments through time. Preliminary evaluation of this database, supported by a few radiocarbon dates, permitted construction of some profiles across the Luni plain, although isochron tracing and sedimentary environment determination is still approximate.

The geoarchaeological approach applied at Luni is inspired by successful studies carried out at several other ancient harbour cities, including Miletus and Ephesus, Turkey (Brückner, 2003; Brückner et al., 2006; Kraft et al., 2007), Tyre and Sidon, Lebanon (Marriner and Morhange, 2005, 2006; Marriner et al., 2006; Morhange et al., 2006) and Marseille (Morhange et al., 2003). This approach consists in applying the geological stratigraphic method to sedimentary sequences that are partly natural and partly conditioned by human activities.

5. Results

Study of sedimentary sequences from 11 boreholes that represent part of the wider database allowed reconstruction of some elements of the palaeogeography near the ancient Roman colony of *Luna*. Eight of these sedimentary logs were included along two different transects aligned E–W (three profiles) and N–S (five profiles) and, respectively, placed outside the western and southern walls of the city (Fig. 3).

5.1. Western transect

Three cores from the database were considered for the area west of the city walls, arranged in a transect showing a general WSW–ENE direction (Figs. 3 and 5). From west to east, these are SALT8, HOLE II and ORTO06 (Fig. 6).

Core SALT8 was drilled in 1966 by the company S.A.L.T S.p.A. for highway construction. It is located approx. 1.5 km inland from the present coast. The top of the core is at about 2.00 m a.s.l. and its bottom reaches 30.50 m below the ground surface.

The lower half of the profile (30.50–13.50 m below ground surface) is characterized by sand with clay and gravel made up of small rounded pebbles. The deposit is attributable to the alluvial fan of Parmignola Stream, showing several episodes of flood. From the top of the previous layer to 4.00 m below the ground surface (2 m b.s.l.), a deposit characterized by grey sand with gravel appears, containing fragments of marine macrofauna mixed with small pieces of organic matter (vegetal) and peat. The sedimentary facies of the deposit, the presence of marine molluscs and the vegetal matter indicate a saltwater lagoon environment that

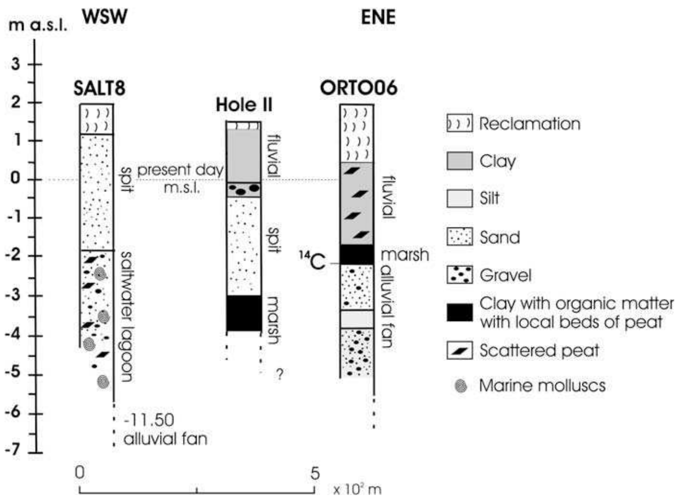

Fig. 6. Transect including three core profiles west of the ancient city walls.

sometimes underwent input from the stream (gravel). The uppermost layer of the core profile (4.00–1.00 m below ground surface) is the fine-grained sand deposit representing the spit (sensu Delano Smith, 1986).

HOLE II lies approx. 350 m ENE of SALT8, and the top of the core profile is at 1.50 m a.s.l. This is one of the core profiles retrieved by the team from Oxford University; it is shown in Fig. 6 with the depth of its bottom unknown, as presented by Delano Smith (1986).

The first layer (4.00–3.00 m b.s.l.) is made up of dark clay, very rich in organic matter, with local peat beds. From 3.00 to 0.50 m b.s.l., the sand deposit found in SALT8 appears. From 0.50 m b.s.l. to the top of the core profile, a layer of grey to brown clay represents fluvial deposits, which shows a level characterized by gravel (from 0.50 to 0.00 m b.s.l.), probably representing a flood event confined to a palaeochannel.

ORTO06 was commissioned in 2006 by the local archaeological authority; for this reason, some standard laboratory analyses could be carried out on sediment. It lies about 300 m ENE of HOLE II, and its top is at 2.00 m a.s.l. Most part of the core profile (bottom 26 m b.s.l.) is composed of fine-grained sand with rounded gravel. Locally, thin levels of fine-grained sand or silt were found (3.70–3.20 m b.s.l.). The deposit represents the alluvial fan of Parmignola Stream on which more than half of the city of Luni was founded. A layer about 0.50 m thick (2.25–1.75 m b.s.l.), composed of dark clay, very rich in organic matter, lies on top of the fan deposit. This represents the eastern margin of the marsh already found in HOLE II (4.00–3.00 m b.s.l.). An archaeological section was performed close to the drilling point down to the bottom of this marsh layer in order to investigate its possible relationship with archaeological structures. ^{14}C-dating (Table 1, ORTO06) of the organic matter at the bottom of the marsh layer suggests that the basin was present in the 4th to 3rd centuries BC. Pottery recovered from the same layer in the archaeological section dates to the late 2nd to 1st centuries BC. Combining the two chronological constrains, we can state that the Seccagna marsh where the ORTO06 core was drilled lasted from the 4th to the 1st centuries BC. The final portion (1.75 m b.s.l.–0.50 m a.s.l.) of the core profile is composed of fluvial deposits, mainly represented by clay, interbedded with thin silty clay layers and characterized by the presence of scattered organic matter and pieces of peat. The last 1.50 m of the core profiles contain material due to land reclamation.

5.2. Southern transect

The area south of the town walls was investigated by means of the five core profiles MAR12, ACAM1, ACAM2, 5/04 and 3/04

Table 1
Radiocarbon datings for samples from the lower Magra Valley coastal plain

Sample name and lab code	Depth (m b.s.l.)	Depth (m b.s.)	Sample description	δ ^{13}C (‰)	^{14}C yr BP	1σ max; min (cal BC)	2σ max; min (cal BC)
ORTO06(1) LTL2130A	2.25	4.25	Gyttja	−24.1 ± 0.5	2223 ± 45	370–340 320–200	400–180
3/04(1) Beta200989	6.90	8.40	Peat	–	2310 ± 60	400–370	500–460 430–340 320–210

Sample ORTO06(1) was dated by Lab. CEDAD-University of Lecce, Italy, calibrated with OxCal 3.1 based on data from IntCal04 (Reimer et al., 2004); sample 3/04(1) was dated by Beta Analytic, Inc., Miami, Florida, USA-calibrated with INTCAL98 (Stuiver et al., 1998).

(Fig. 7). These are arranged in a transect in a S–N direction (Fig. 3). ACAM1 is slightly offset with respect to the transect, but its distance from the transect is very small and it can be used to correlate with the others.

MAR12 was drilled by a coring firm for the company Marinella S.p.A., the owner of the farm located on a large portion of the territory between the ancient town of Luni and the coast. It lies about 250 m from the coastline (Fig. 5). The top of the core profile is at 2.00 m a.s.l. and its bottom reached 8.00 m b.s.l. (Fig. 7). The lowermost portion of the core (8.00–6.00 m b.s.l.) is made up of grey sand containing fragments of marine macrofauna, representing a beach deposit. On the top of the beach, the deposit changes into brownish sand reflecting a typical dune deposit; this is interrupted only at 0.80 m b.s.l. by a level of scattered organic matter.

ACAM1 lies about 150 m NNE of MAR12 (Fig. 5). It was drilled by the company ACAM S.p.A in 2005 during a survey aimed at adjusting and improving the sewer system of the Marinella settlement. The top of the core profile is at about 2.00 m a.s.l. while its bottom is at 8.00 m b.s.l. (Fig. 7). From the bottom of the core to 0.80 m b.s.l., a deposit of coarse- to fine-grained sand appears. Grainsize characteristics and sedimentary structures indicate a very thick beach deposit. Between 2.00 and 2.50 m b.s.l. and at 0.80 m b.s.l., two thin layers of clay occur, very rich in partly decomposed organic matter accumulated in backing swales.

ACAM2 is about 450 m north of MAR12 (Fig. 5) and, like the previous core profile, it was drilled by the company ACAM S.p.A. in 2005 for the same purpose. The top of ACAM2 lies at 1.50 m a.s.l. and it bottom is at 8.50 m b.s.l. (Fig. 7). The stratigraphy of the profile from the bottom to 0.50 m a.s.l. is represented by the same deposit. It is made up of medium- to fine-grained sand containing scattered pieces of organic matter (vegetal) and fragments of terrestrial gastropods. The sedimentological features and the presence of organic matter indicate a marsh facies. The only change in the stratigraphy of the profile is between 4.00 and 3.50 m b.s.l., where coarse- to medium-grained sands appear. The uppermost 1.00 m of the core is composed of material due to land reclamation.

The core profile 5/04 (Fig. 6) was retrieved by the company S.A.L.T. S.p.A. during a survey performed between 2004 and 2005 aimed at constructing buildings and a pedestrian route between the highway and the archaeological site of Luni. The top of the core, which lies approx. 650 m north of ACAM2, is at about 1.50 m a.s.l. (Fig. 7) and its bottom reached 40.00 m below the ground surface (not represented in the figure). From the bottom to 10.00 m b.s.l., the core is made up of silt and sandy silt with rounded gravel that represent the alluvial fan deposit of Parmignola Stream. On the top of the fan, a brackish lagoon deposit (10.00–6.00 m b.s.l.) appears, composed of fine-grained sand with scattered peat and fragments of marine molluscs. On the top of the lagoon environment, the fluvial/spit deposit develops between 6.00 and 1.00 m a.s.l., represented by fine-grained sand.

The core profile 3/04 is very close to the previous one (about 250 m north of 5/04; Fig. 5) and its top is at 1.50 m a.s.l. (Fig. 7). The core was retrieved by the company S.A.L.T. S.p.A. in 2004 for the same purposes as 5/04. The borehole reached 9.50 m b.s.l. The core profile 3/04 shows the same stratigraphy as 5/04, except for the alluvial fan deposit, which was not reached. From the bottom to 6.50 m b.s.l., the deposit is made up of grey to dark-grey sand, medium- to fine-grained, with scattered peat and fragments of marine molluscs representing the brackish lagoon deposit. From the top of this last deposit to 1.00 m a.s.l., the fine-grained sand of the fluvial/spit deposit appears. Just above the transition between the two layers (6.90–6.80 m b.s.l.), the sand contains scattered peat; ^{14}C-dating was performed here (400–370 cal BC; Table 1 and Fig. 7) that gives a minimum age for the complete silting up of the salt-water lagoon.

5.3. Scattered cores south of the city

A concentration of cores is available for the area constrained by the southern city wall (and its virtual prosecution towards the W and E) and the current location of the highway, between the southern perimeter of the city and the coastline (Fig. 3). All the

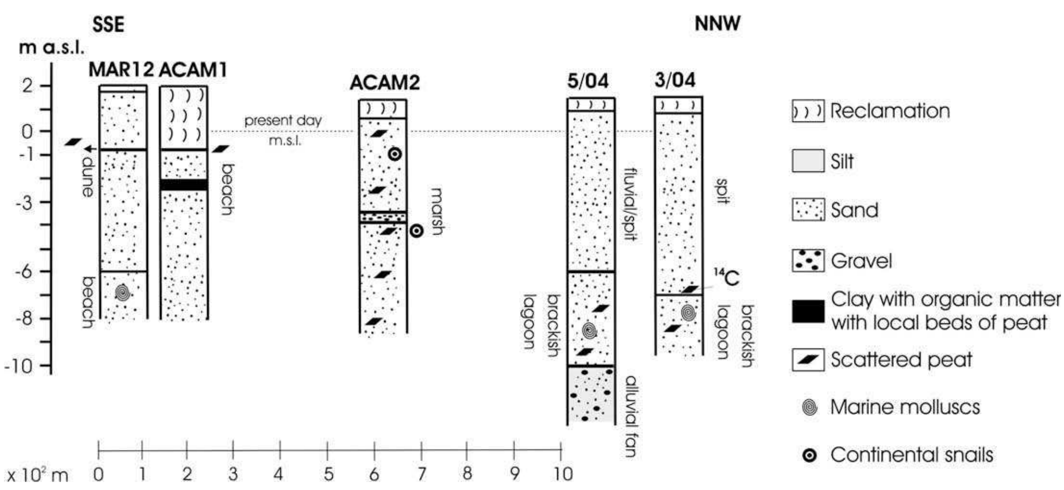

Fig. 7. Transect including five core profiles south of the ancient city walls.

stratigraphies of these cores display a similar distribution pattern, with fluvial sands overlapping a thick bedset of fine sands locally interbedded with coarse sands, silt and muds, containing vegetal debris and shell fragments, already described in cores 5/04 and 3/04.

The sedimentary evidence is described in detail, suggesting an interpretation of this lower unit as typical of a brackish environment, developed in a saltwater lagoon:

- marine shells and plant remains, more or less decomposed, are simultaneously present,
- the macrofaunal assemblage is characterized by a mixture of open sea, littoral and terrestrial environment species; among these both stenohaline and euryhaline species are present,
- shells are poorly preserved: they are mostly present in the form of fragments 0.5–2 mm in diameter, affected by mechanical abrasion and dissolution,
- grain size ranges from fine sand to fine gravel; grains are poorly sorted, rounded and flat, and
- petrography of sediments accounts for all the rock types present in the River Magra catchment, including ophiolites, which are distinctive of its solid load.

This sedimentary evidence indicates a depositional basin such as a sheltered inlet of the coast, quiet enough to permit sedimentation of organic matter but in communication with the open sea. Moreover, a high energy influence on the quiescent conditions (storm episodes) can be considered responsible for poor sorting and penetration of reworked fragments of macrofauna and rock grains from littoral drift.

The top of the sedimentary unit indicating a brackish environment can be found at elevations between 6.5 and 4.5 m below present-day sea level (Table 2); differences can be partly ascribed to the fact that cores were drilled at different times and with different equipment. A radiocarbon date performed on peat (core 3/04, Table 1) dates the transition from lagoon to floodplain between the second half of the 4th and the beginning of the 5th centuries BC (400–370 cal BC). However, the two westernmost cores, SALT8 (see previous paragraph) and 4/04 (Fig. 3) are characterized by a transition from lagoonal to continental deposits at higher elevations (2 m b.s.l.).

Other cores, located further east, display at least 10 m of continental deposits (medium to coarse sand with fine gravel) up to the core top (ACAM 3, ACAM 4 ACAM 5 and SALT 9, Fig. 3).

6. Discussion and conclusions

6.1. Palaeogeography of the area surrounding Luna

A lateral comparison of vertical facies changes along the two transects, chronologically constrained by the two available radiocarbon dates, allowed broad inference of the succession of palaeoenvironments between the 4th and the late 2nd centuries BC.

Table 2
Depth (m b.s.l.) of the top of the saltwater lagoon deposit in the different core profiles (for the position of core profiles see Figs. 3 and 5)

Core	Elevation of the top of the saltwater lagoon deposit (m below present-day sea level)
ACAM6	4.5
5/04	6
1/03	4.3
7/04	4.5
3/04	6.5
SALT8	2

The core profiles retrieved in the area west of the city walls (western transect, Fig. 6) show that a lagoon deposit (SALT8), containing fragments of marine macrofauna mixed with peat, lies on alluvial fan deposits of Parmignola Stream, whose top reached approx. 11.50 m b.s.l. On the lagoon deposit, a sand body corresponding to the so-called "spit" (sensu Delano Smith, 1986) up to 3 m thick in SALT8, was found. The sand body was also identified in HOLE II (Fig. 6), where it lies on marsh deposits attributable to the Seccagna. Even if the depths of the top and the bottom of the sand body are quite different in the two cores, the spit represents a stratigraphic marker connecting them. Before the appearance of the spit, two different environments, the saltwater lagoon and the marsh, were present very close to one another in the restricted area surrounding the south-western walls of the colony.

At present, the data do not provide the timing of the development of the sand body and the relation between the lagoon and the marsh. They were probably divided by a sand barrier, a kind of palaeo-spit, developed at the mouth of the marine gulf during the progradation of the coastal plain in the context of the Holocene sea-level rise. The lagoon and the marsh probably developed before the foundation of the colony and survived at least up to the 2nd century BC when, as indicated by the pottery found in ORTO06 from 2.25 to 1.75 m b.s.l., the eastern shoreline of the Seccagna was immediately west of the city walls. At that time, the palaeo-spit almost completely enclosed the marsh, which reached its maximum depth in the middle of Seccagna basin (Fig. 5) and slowly evolved towards progressive silting up. Progradation took place in most Italian floodplains facing the Tyrrhenian Sea during early Medieval times.

After the period characterized by moderate energy environments (lagoon and marsh), the spit (sensu Delano Smith, 1986) developed or, more generally, the sand body dividing the two basins experienced a phase of growth, expanding on top of the lagoon and part of the marsh. The spit development could be caused by an increase in solid load discharged by the Magra River, then redistributed by littoral processes (Bini et al., 2006), and/or by the approach of the mouth of the river to this area due to the general progradation of the coastal plain. Finally, the area was reached by the course of the Magra River, whose alluvial deposits were found in the upper portion of the cores HOLE II and ORTO06, under variable thicknesses of land reclamation.

South of the city walls, between these and the present-day coastline (Marinella), three of the core profiles compared along this transect (MAR12, 5/04, 3/04; Fig. 7) show evidence of a regression occurring almost at the same elevation (6.5–7 m below present-day sea level). In two cores (5/04, 3/04), the regression corresponds to silting up of the saltwater lagoon facing the southern city wall and is dated to the 4th century BC. The elongate form of this basin, parallel to the coastline and open to the west, suggests that from a geomorphological point of view it can be identified with a saltwater lagoon formed in a backing swale. South of it, a dune ridge was present in the area called Pennola Alta-Renone (Fig. 5; Bini et al., 2006). This scenario is consistent with the fact that in the westernmost cores the transition from lagoon to continental sediments occurred later; the easternmost ones display only a continental facies.

The other regression surface was found very close to the present-day shoreline (MAR12), suggesting the occurrence of an open-water littoral environment changing into a dune 6 m below the present-day sea level. This dune can be identified with the land, recognized in all the scenarios of Luni's palaeogeography and considered an island (Isola di Marinella, Fig. 4). Available data, however, are not conclusive about its insular or peninsular character.

Inland from the dune ridge (core ACAM1), continuous beach sediments interbedded in the uppermost part with layers of partly decomposed organic matter accumulated in a backing swale suggest that a water basin existed for a long time behind the evolving Marinella dune ridge, experiencing periodic isolation from the open sea with sedimentation of organic matter in the latest stages of its life. The persistence of littoral sands in core ACAM1 up to a depth of 1 m b.s.l. indicates progressive enlargement of the Marinella sand body.

Between the Marinella and Pennola Alta-Renone dune ridges, geomorphological analysis shows that a lowland (Pennola Bassa) occurs. This lowland hosted a marsh (core ACAM2), for which, unfortunately, there are no chronological constraints on its development. The sedimentary sequence filling the Pennola Bassa basin has a continental character, with organic material, peat and remains of terrestrial snails.

On the basis of the evidence above, in the early 4th century BC the palaeogeography between the colony and the present-day seacoast was characterized by different environments, as follows:

- a backing swale, in front of the city southern wall, for which the exact position of its northern shore is as yet undetected,
- the Pennola Alta-Renone dune ridge,
- a marsh (Pennola Bassa), not in direct connection with the sea,
- a dune ridge (of which there is, at the moment, neither morphological nor sedimentological evidence),
- a littoral environment, 300–600 m south of the Pennola Bassa marsh, a backing swale open to the sea in its western part, and
- an island or peninsula (Marinella), formed by the most seaward dune ridge of the prograding coastal plain.

The proposed palaeogeographic reconstruction implies that there must have been a dune ridge between the Pennola Bassa (core ACAM2) and the littoral (core ACAM1) that is still undetected; in fact, there is no morphological evidence for this ridge and no subsurface data are available for the area. It could be, however, from a geometrical point of view, the virtual continuation of a still recognizable dune ridge, stretching several km SE of the study area, along the Versilia coastal plain (Fabiani, 2006).

6.2. Potential indicators for the local relative sea-level curve

Although the Luni site has great potential as a source of sea-level proxies in Roman times, available data are not sufficient to fix points on the sea-level curve. Some indications can be inferred from the two radiocarbon-dated layers in cores ORTO06 and 3/04 (Table 3) and from archaeological evidence.

One radiocarbon-dated marker is a piece of organic matter at the base of a fluvial deposit overlapping a saltwater lagoon fill (core 3/04, 6.90–6.80 m b.s.l.). Due to the proximity of the sample to the top of the lagoon deposit, it can be considered a good sea-level marker (accuracy +0/−1 m). This datum points to a sea-level elevation of about −7 or −8 m with respect to the present day for the early 4th century BC, which is inconsistent with sea-level evidence obtained for Roman times along the Italian coast (Lambeck et al., 2004b). In the neighbouring Gulf of La Spezia in Varignano Cove (Fig. 2), according to Chelli et al. (2005), at the beginning of the 1st century BC sea level was lower than −0.415 m (ideal functioning of the archaeological marker in the paper would require a sea level around −1.5 m b.s.l.).

Reliability of the radiocarbon date obtained for the peat layer in core 3/04 can be argued and, in any case, would need to be supported by other dates. This anomaly could otherwise be explained by an elevated subsidence rate, which is to some extent consistent with the tectonic setting of the area. In fact, the current course of the Magra River coincides with an active extensional fault that displaces the rock basement such that the lower Magra Valley should be affected by high subsidence rates. In this case, however, a much higher subsidence rate should be admitted than that highlighted for any other site in Italy and in other areas (e.g., the eastern Mediterranean) of enhanced tectonic instability.

Table 3
Radiocarbon-dated palaeo-sea level markers

Core	Sample description (sedimentary context)	Palaeo-sea level (m) (with error bar)	Calibrated age (1σ max–min)
ORTO06	Organic clay (marsh)	−2.2 (±0.5)	370–340 BC 320–200 BC
3/04	Peat (transition from lagoon to fluvial)	−6.8 (+0/−1)	400–370 BC

One good archaeological sea-level proxy is the channel drain (cloaca) that underpasses the cardo maximus. This needed to flow out directly into the sea or a lagoon connected to it. At present the channel is visible inside the street down to the city southern perimeter and disappears below the plain. It would therefore be crucial to determine the physical seaward continuation of the channel; the position and elevation of its termination would be indicative of the position of the coastline and the sea level. Schmiedt (1972) provided a topographic section of the channel, finding that its bottom is 0.44 m below the cardo paving by the southern city wall. The presence of a wall identified inside the coastal plain close to the southern city walls and interpreted as a dock (Frova, 1976) allowed Schmiedt (1972) to infer the position of the coastline and the sea level (virtually projecting the channel down to the wall). Archaeological interpretation of the wall as a dock, however, must be rejected (Durante, 2001a).

As the channel termination is currently unknown, only a maximum value for sea level can be inferred. The cardo paving is 1.37 m a.s.l. in connection with the southern wall gate (part 2 of this paper) and the channel bottom is 0.44 m below the cardo paving (Schmiedt, 1972): sea level should have been surely lower than +0.93 m (1.37–0.44 m) for good channel functioning. Similar elevation constraints derive from the minimum altitudes of architectonic elements of the two villas of Bocca di Magra (0.62 m) and S. Maurizio (1.50 m).

The bottom of the organic clay that represents the marsh fill west of the city walls (core ORTO06) could be considered a sea-level marker. The water level in the Seccagna marsh should have been in equilibrium with sea level because of its proximity to the coast. Accuracy of this marker can be considered ±50 cm (according to Lambeck et al., 2004a and Vött, 2007). The sea, therefore, attained a level 2.2 m lower than the present day within the time interval 370–343 BC to 320–200 BC (1σ). This chronological attribution can be refined using the chronology of the pottery contained in the deposit and the limited thickness of the peat layer, to the end of the 2nd century, i.e., a few decades before the city was founded. The sea-level altitude obtained is consistent with that stated for the Varignano Villa's harbour (Chelli et al., 2005).

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