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Palaeogeographies of the Magra Valley coastal plain to constrain the location of the Roman harbour of *Luna* (NW Italy)

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ABSTRACT

The Roman city of *Luna* founded in 177 BC (2127 BP) and located in NW Italy was famed for its port, from which the prized "marble of Carrara" was shipped. Despite decades of archaeological surveys, the exact location of this harbour is unknown to date. Progress in the palaeogeographic reconstruction of the Magra Valley coastal plain surrounding the ruins of *Luna* has been possible thanks to the collection and analysis of six cores, supported by radiocarbon dates and microfauna analyses. The late Holocene evolution of the *Luna* surroundings was reconstructed starting from the maximum Holocene transgression. The latter was identified from lagoonal sediments which are chronologically connected with the most landward position attained by the shoreline after the Last Glacial Maximum (LGM). Lagoon sediments are topped by swamp and floodplain deposits. A climate fluctuation was identified in the stratigraphic record, which correlates with the first Neoglacial cooling episode. The coastal plain underwent major landscape changes over the last three millennia. A few centuries before the colony was founded, the territory was characterized by a complex delta architecture, made of swamps and marshes limited by dune ridges and fluvial sand bars. The positions of these morphological features were not fixed; they shifted, depending on the spatial interaction between the coastline and the drainage network of the plain. In this paper, we present new data to improve our understanding of the environmental constraints determining the position and setting of the ancient harbour of *Luna*. We suggest that its location could be searched for in the water basin once present west of the city, at a distance of more than 0.25 km.

1. Introduction

Due to the various archaeological findings and historical sources, the coasts of the Mediterranean represent an ideal study area to investigate the interactions between changing natural settings and evolving human societies (Grove and Rackham, 2003).

During the past few decades, geoarchaeological research along the Mediterranean coasts has dealt with a variety of topics. Many authors have studied former seaports that had lost their function due to siltation, relative sea level rise/fall, coastal subsidence/uplift, and strandline displacements induced by prograding river deltas (Stanley, 1988, 1997, 2005; Sivan et al., 2004; Galili et al., 2005; Marriner et al., 2005, 2006; Marriner and Morhange, 2007; Fouache et al., 2010; Goiran et al., 2010; Algan et al., 2011; Bony et al., 2011). Examples of seaports lying at former marine embayments which were closed off by delta progradation are reported by Kraft et al. (2003), who reconstructed the palaeogeographies around ancient Troy, by Brückner (2003, 2005), Brückner et al. (2005, 2006), Müllenhoff (2005) and Kraft et al. (2007), who detected how the harbours of the ancient cities Ephesus, Miletus, Priene, and Myous lost their access to the sea, as well as by Vött et al. (2006a,b) who showed how the shipsheds of Oiniadai (NW Greece) gradually silted up.

In Italy, although many archaeological sites are situated in coastal areas, a geoarchaeological approach to this kind of research has seldom been used. Indeed, geoarchaeological studies have mainly focused on archaeological sites as markers of sea level change (Schmiedt, 1972; Pirazzoli, 1976, 1987; Cinque et al., 1991; Leoni and Dai Pra, 1997; Antonioli and Leoni, 1998; Lambeck et al., 2004; Sivan et al., 2004; Chelli et al., 2005; Morhange et al., 2006a,b; Antonioli et al., 2009; Auriemma and Solinas, 2009; Bini et al., 2009a,b). However, the subjects of harbour silting and shifts in the shoreline during the past millennia have been less studied using a geoarchaeological approach (Marriner and Morhange, 2007).

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The relevant works dealing with the Italian Peninsula addressed particularly the ancient harbours of Rome (Giraudi et al., 2006, 2007, 2009; Goiran et al., 2008; 2009; 2010), and those of Ravenna (Veggiani, 1976; Bondesan et al., 1995), Coppa Nevigata (Caldara et al., 2002, 2003), and Egnazia (Auriemma et al., 2004) located on the Adriatic Sea, as well as Pozzuoli (Gianfrotta, 1996; Morhange et al., 1999, 2006b), Naples (Cinque et al., 1991) and Cuma (Stefaniuk et al., 2003) located on the Tyrrhenian Sea (Fig. 1). Nevertheless, there is a paucity of data for the coastal plains of the northern Tyrrhenian Sea, although strategic ancient (Roman and Etruscan) harbours were present in the Apuo-Versilia plain (Pasquinucci et al., 2004). For instance, *Portus Pisanus* (Pasquinucci, 2003) and *Portus Lunae* (Delano Smith et al., 1986; Bini et al., 2006, 2009a,b; Bisson and Bini, 2011) are documented in ancient texts and historical maps (Table 1). Among these harbours, the *Portus Lanae* in the northern Apuo Versilia coastal plain was of strategic relevance due to its geographical position in relation to the commercial routes in this region (Pesavento Mattioli, 1985). Its history was greatly conditioned by the evolution of the coastal plain, and today there are still doubts about the position of the harbour structures of the city.

This study is aimed at reconstructing the main steps of the northernmost Apuo Versilia coastal plain evolution, since 6000 BP ca. In this context, the main focus was to improve our knowledge about the landscape in the environs of Luna at Roman times (2000 BP ca.) and to constrain the area where an archaeological survey could be implemented in order to discover the ancient harbour(s).

2. Geological setting

The *Luna* archaeological site is located at the boundary between the lower Magra Valley and the Apuo-Versilia plain (Figs. 2, 3). The Magra Valley represents the south-eastern portion of the River Magra graben system (Federici, 1973; Raggi, 1988; Bernini, 1991) displaying NW–SE-striking normal faults formed during the extensional tectonic phase that thinned the western side of the Northern Apennines. The Apuo-Versilian coastal plain is considered to be a subsiding basin (Mazzanti, 1983; Pascucci, 2005). The progradation of the Apuo-Versilian and Pisa plains has been controlled by sediment input supplied not only from the major streams, i.e. Magra and Arno rivers flowing, respectively, at the northern- and southernmost edge of the coastal plain, but also from the minor streams descending from the Tyrrhenian side of the Apuan Alps (Fig. 2).

During the Last Glacial Maximum, the sea-level drop caused the major rivers to incise wide and deep valleys (Amorosi et al., 2011). About 8000 yr BP, the coastline in this part of the Mediterranean Sea had reached −15 m with respect to its present position, while 3000 yr BP it is reported to have been at about −2.5/−1.7 m (Lambeck et al., 2004), testifying its fast shift.

The Apuo Versilia Plain hosts the type site of the so-called “Versilian”, i.e. the Holocene transgression which followed the LGM (Blanc, 1942; Federici, 1993). This unit has been radiocarbon dated in different cores; ages range from 10.15 ka cal BP at −34 m (Antonioli et al., 1999) to 5280 ± 50 BP using a wood fragment (*Pinus silvestris*) at −

Fig. 1. Map of the main ancient harbours located in the Italian Peninsula.

Table 1
List of the historical maps used for palaeogeographic reconstruction.

Map name	Author	Year	Source
Parte della Lunigiana	E. Spina	1592	Genoa National Archive
Territorio tra Sarzana e la Giurisdizione di Carrara	Unknown	1610	Torino National Archive
Copia di pianta del 1610 dell'area di Luni da Ameglia ad Avenza	M. Vinzoni	1610	Genoa National Archive
Territorio tra Sarzana e Avenza	Unknown	1626	Genoa National Archive
Territorio tra Sarzana e l'Avenza	Unknown	1628	Genoa National Archive
Pianta per l'informazione dell'acqua e letto della Parmignola fatta l'anno 1638 quando si andò nel fatto col Signor Marchese di Carrara, figlio del Signor Prencipe di Massa et si andò a vedere tutto il dano, che faceva in quello del Signor Prencipe	M. Vinzoni	1638	Genoa National Archive
Il corso del corrente Parmignola	Unknown	1639	Genoa National Archive
Disegno e pianta delle muraglie ed alvio nuovi	Unknown	1672	Genoa National Archive
Contorni di Luni di Sarzana e del golfo della Spezia descritta da Hercole Spina, sarzanese	F.M. Accinelli	1724	Biblioteca Civica Mazzini, La Spezia
La Marinella	M. Vinzoni	1753	Genoa National Archive
Pianta della città di Luni	M. & P. Vinzoni	1752–1779	Quaini (1986)
Pianta dell'antica città di Luni	M. Vinzoni	1773	Biblioteca Civica Berio, Genova
Il corso del Parmignola	P. Vinzoni	1777	Genoa National Archive
La Marinella (Rilievi per la carta topografica degli stati sardi)	IGM	1816	IGM
Stato delle Rovine dell'Antica città di Luni al principio del XVIII	Promis	1857	Bernieri et al. (1983)
La presente pianta del confine tra Serenissima Repubblica di Genova e Principato di Massa	E. Spina	unknown	Genoa National Archive

15 m (Federici, 1993). The uppermost part of the sequence, above the marine sands, is represented by a continental environment with episodic brackish and freshwater intercalations. A great number of borehole data with chronological constraints clustered in the above mentioned time range are available for the southern part of this coastal area, e.g. near Lake Massaciuccoli (Amorosi et al., 2011). For the northern part, instead, the sedimentary record is still to be investigated and chronologically constrained.

3. Geoarchaeological setting

At least since ca. 2500 BP, evidence of human settlement in the area exists, but this became more relevant as the Roman colony of *Luna* was founded in 177 BC (2127 BP) at the foothills of the Apuan Alps (Gervasini, 2007) (Fig. 2). 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 quarried in the Apuan Alps (Baroni et al., 2010) and 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 been detected as yet. Some authors (Pesavento Mattioli, 1985; Raffellini, 2000), based on literary and historical sources, suggest that the city had two harbours: the first one, located west of the city walls, used for food trading and military purposes, and the second one, located further south, used specifically for marble trading.

A first geoarchaeological approach was attempted by Delano Smith et al. (1986), in order to reconstruct the palaeogeography of the *Luna* area during Roman Times (ca. 2000 BP) and the subsequent environmental evolution after the city declines. The authors used stratigraphic data from cores drilled inside the city settlement and in its surroundings but, unfortunately, no chronological constraints supported their results.

Several other studies and different palaeogeographic scenarios of the landscape features near *Luna* have been provided by different Authors (Bernieri et al., 1983; Raggi and Sansoni, 1993; Raffellini, 2000) through time (for the main results of these works see the review in Bini et al., 2009b). Nevertheless, none of these scenarios is complete or sufficiently supported by sedimentologic evidence. In addition, none of them enabled the identification of the ancient harbour(s) of *Luna*. All these authors agree that a wide water basin occupied the area between the present coastline and the foothills. A harbour could have been located in this basin. They also recognize that a wide basin of lagoonal/continental nature was present west of the city (in the area identified on modern maps with the name "*Seccagna*") (Fig. 3), that was supposed to have hosted the other harbour of the *Portus Lunae* system.

In the last six years Bini et al. (2006, 2009a) have reconsidered the issue of the palaeoenvironment of *Luna* plain. They performed a geomorphologic survey that allowed to identify the main key features of the plain (Fig. 3): the Parmignola Stream alluvial fan, the sand bar projecting westwards from the *Luna* settlement, two wetlands, some dune ridges and the Magra alluvial deposits (Fig. 3). A general revision of stratigraphic data was carried out by Bini et al. (2009b) that created a database containing the descriptions of 29 sediment cores drilled in the area for various purposes and at different times, providing some new preliminary data on the palaeogeography of the area. In Table 2, a list of the cores discussed in Bini et al. (2009b) and used in this work is provided (see Fig. 4 for core locations).

4. Methods

The geoarchaeological approach applies the geological stratigraphic method to sedimentary sequences that are partly natural and partly human-induced (Marriner and Morhange, 2006; Brückner and Gerlach, 2007). In this research, six cores were studied (Fig. 4). The field survey was carried out between the summer 2006 and the autumn 2009. The core Orto 06, already described by Bini et al. (2009a), was drilled by a machine-operated drill rig. The other five cores (Luni 1, 2, 3, 4, 5) were drilled with a hand-operated vibracorer (Cobra mk1 of Atlas Copco Co.; diameter of the augerheads: 6 cm for the first 5 m of depth, and 5 cm for the deeper portion of the core). The elevation of each core was calculated by the interpolation of spot heights based on the regional technical map of Liguria at the scale of 1:10,000. Digital photographs were taken of every sediment core. The selection of the coring sites was based on the results of previous studies, in particular on the recognition of the major geomorphological units of the area (Bini et al., 2006) and on stratigraphic data (Bini et al., 2009a,b).

In fact, coring sites were selected to validate and implement the palaeogeographic evidence derived from the analysis of some cores from the lithostratigraphic database created for the area. In details, the new core Luni 1 was carried out in the same place as the old core 5/04, the new core Luni 3 about 100 m south of the old core ACAM2. In a broad sense, the stratigraphic units recognized in the corings from the database are consistent with the corresponding cores of the new dataset. Facies interpretation, though, was refined thanks to the analysis of the faunal content, and minor discontinuities (e.g. palaeochannels) were identified.

The stratigraphy of each core was determined in the field according to texture, grain size, colour (with Munsell Soil Color Charts) and

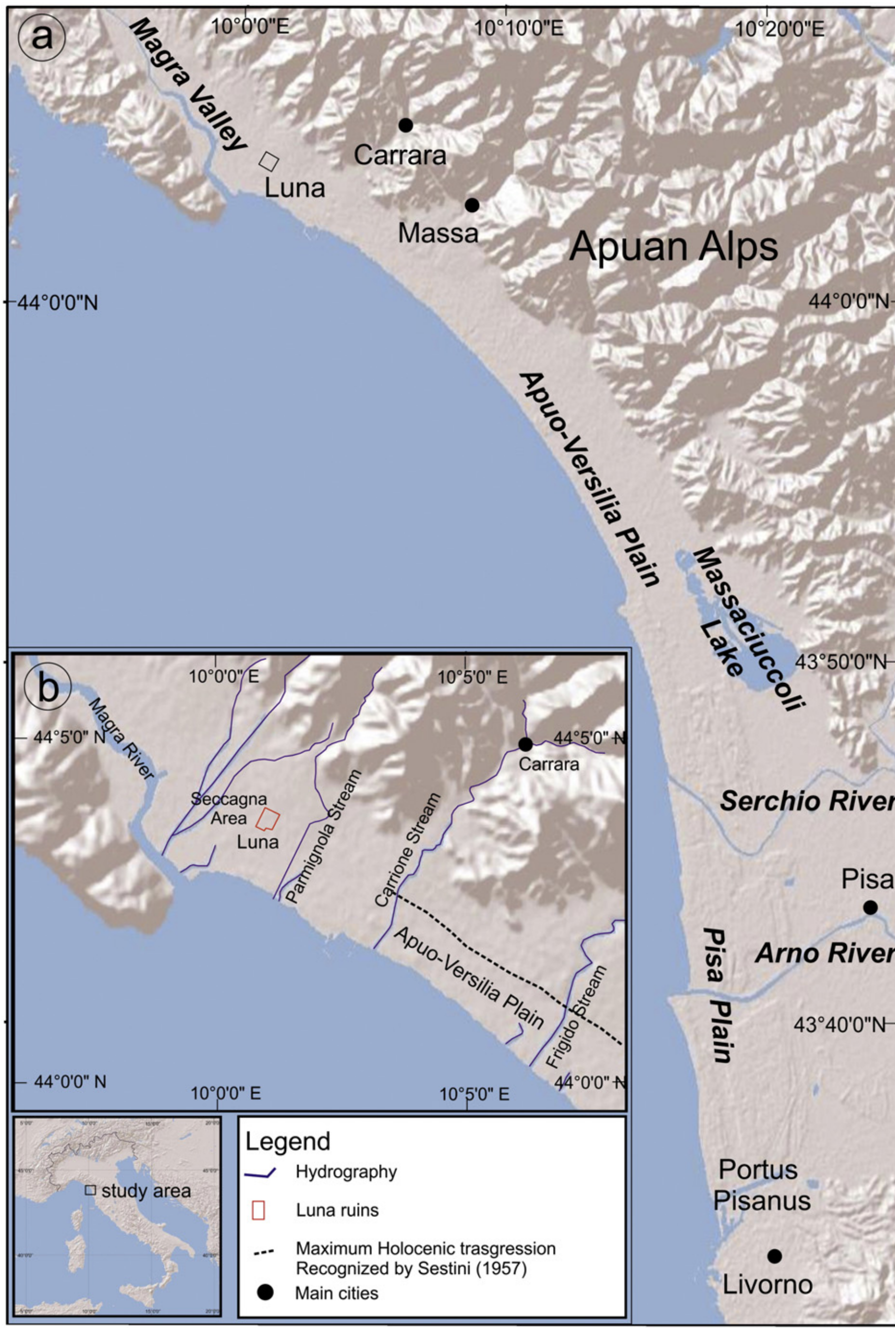

Fig. 2. Location map of the ancient *Luna* ruins in the framework of the Apuo-Versilia and lower Magra Valley plains (a), and zoom of the study area (b).

macrofossil content. Sediment samples were taken for further analyses in the laboratory.

In the laboratory, the sand fraction (0.063–2 mm) was sieved and examined under a binocular microscope. For selected samples, the complete grain size distribution was determined. Micropalaeontological analyses were carried out on a selected set of about fifty samples which were considered representative of the main environments. The weight of each processed sample was usually about 100 g. The total picking of ostracods and foraminifera was accomplished from the washed residues >125 µm. A list of the species identified is provided in Table 3. Ostracods are excellent palaeoenvironmental indicators (Carbonel, 1988; Holmes and Horne, 1999; Griffiths and Holmes, 2000; Boomer, 2002; Frenzel and Boomer, 2004). They have been used successfully in geoarchaeological studies (e.g., Vött et al., 2006a,b; Marriner and Morhange, 2007; Marriner et al., 2008; Bates et al., 2011). Selected microfauna individuals were also analysed using Scanning Electron Microscopy (SEM) technique.

The geochronological framework is provided by AMS-^{14}C-dated organic material (wood, peat, plant remains etc.) and by ceramic fragments. All ^{14}C ages were calibrated using OxCal (Version 3.10); they are quoted at the 2σ range. The results are summarized in Table 4.

For each core, the temporal succession of different environments was illustrated identifying the sedimentary facies. The stratigraphies showing the palaeoenvironmental interpretation were arranged in two different cross profiles, both aligned from north to south. The first cross profile (*Seccagna* area), west of the *Luna* city walls, is based on the cores Luni 4, Orto06 and Luni5; the second profile for the area south of the *Luna* city walls comprises the cores Luni 2, Luni 1 and Luni 3. The profiles cross the areas that previous authors described as possible ancient harbour sites.

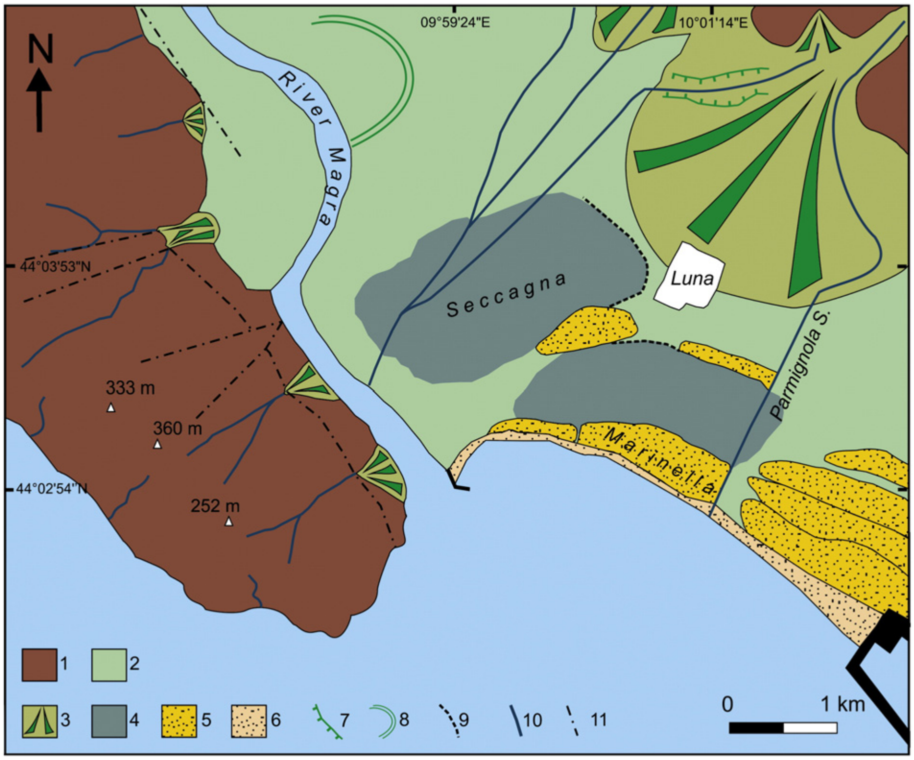

Fig. 3. Geomorphological setting of the study area: (1) bedrock; (2) alluvial plain; (3) alluvial fan; (4)wetland (remains of water basins representing possible harbours locations); (5) beach ridge; (6) present-day beach; (7) torrent scarp; (8) palaeochannel; (9) innermost penetration of the Holocene transgression; (10) main stream and/or channel; (11) main fault.

The correlation of the different profiles allowed us to trace approximate time lines based on ^{14}C datings (Fig. 5). They show synchronous lateral facies distribution.

5. Results

An interpretative description of the six logs is provided in the following.

5.1. Luni 1

Luni 1 was cored, approximately 1.5 km inland from the present coastline (Fig. 4). The ground surface is at 1.6 m asl (above present mean sea level) and the depth of 10.4 m bsl (below present mean sea level) was reached. From 10.4 to 10.3 bsl (Fig. 5) is a sandy unit with pebbles, void of fauna. It can be interpreted as the Parmignola Stream alluvial fan, which represents the basal unit in the surroundings of the ancient city (Bini et al., 2009b). In the upper part of this unit a very dark greyish-brown palaeosol is developed. Then a sharp contact marks the boundary to a dark grey level of fine silty sand. Organic matter from this layer was ^{14}C-dated to 5390 ± 40 yr BP (6290–6020 yr cal BP; sample Luni 1/31, Table 3). Between 10.3 and 8.2 m bsl there is an alternation of medium and fine sand, with many faunal and a few floral remains. The microfauna is characterized by *Cyprideis torosa* with *Neocytherideis* sp., *Pontocythere turbida*, *Carinocythereis* sp., *Leptocythere* sp. and *Quinqueloculina oblonga* (Fig. 5, Table 3): this association is indicative of a coastal lagoon interacting with the marine environment.

Between 8.2 and 6.9 m bsl the sediment type is similar to that previously described, but the ostracod and foraminifera content (*Ammonia*

Table 2
List of the cores from the database Bini et al. (2009b) cited in this work. The depth of the boundaries between Parmignola Stream alluvial fan and the lagoon deposit and between lagoon and alluvial plain is indicated.

Core	g.s.[a] height (m asl)	b.c.[b] depth (m bsl)	P.a.f.[c]/l.[d] depth (m bsl)	l./a. p.[e] depth (m bsl)	Age ^{14}C yr BP	2σ max; min (cal BC)
5/04	1.50	40 (m bgs[f])	10	6		
ACAM2	1.50	8.50	//	//		
3/04	1.50	9.50	//	6.50	l./a.p. ≈ 2310 ± 60	500; 460 430; 340 320; 210

[a] Ground surface.
[b] Bottom of the core.
[c] Parmignola Stream alluvial fan.
[d] Lagoon.
[e] Alluvial plain.
[f] Below ground surface.

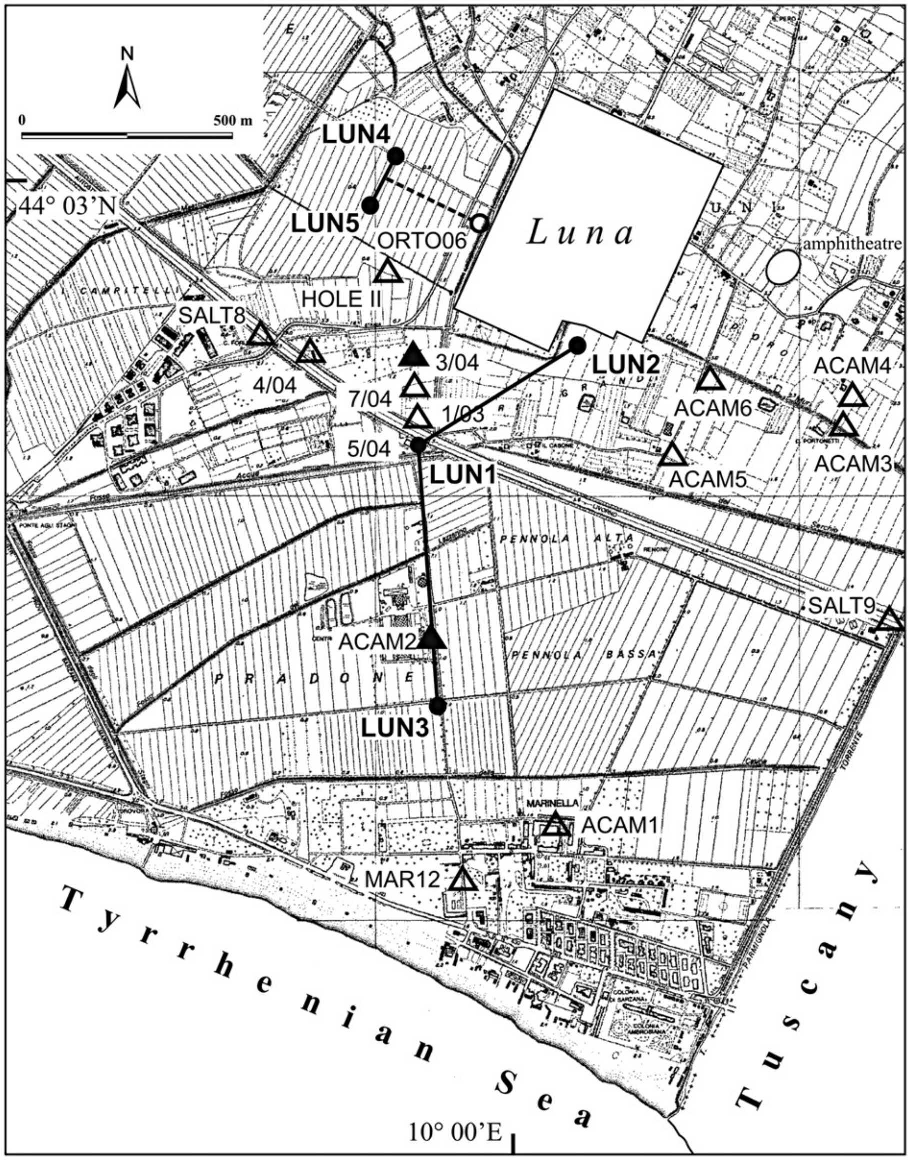

Fig. 4. Location map of the cores existing for the studied area; filled circle: new core; empty circle: new core already employed in Bini et al. (2009a); filled triangle: core from the database (Bini et al., 2009b) cited in this work; empty triangle: core from the database (Bini et al., 2009b) not used/cited in this work. The solid time lines connect the cores employed in the two transects.

tepida, *Candona* sp., *Cyprideis torosa*; Fig. 6, Table 3) suggests the increasing isolation of the lagoon. Plant remains at 7.9 m bsl yielded ^{14}C-ages of 3440 ± 40 yr BP (3830–3600 yr cal BP; sample Luni 1/20, Table 4).

The unit between 6.9 and 5.4 m bsl comprises homogeneous, slightly silty clay with an abundance of plant remains. From a sedimentological point of view, it could be consistent with a coastal swamp; however, it is void of ostracods and foraminifera. At 5.4 m bsl a large angular gravel may be an indicator of a man-made passage over the swamp.

A sharp border at 5.3 m bsl marks the change to the fluvial environment. Between 5.3 m bsl and 0.6 m asl the sequence is characterized by an alternation of olive brown medium and fine sands; several rounded pebbles (1–2 cm of diameter) are present. At 1.3 m bsl, a sharp border marks the contact to a fining-upwards layer of medium to coarse sand that represents a palaeochannel. Some basalt pebbles suggest a provenance from the Magra River.

Between 0.6 and 1 m asl the grain size is finer than before (sandy silt), and signs of oxidation appear. This is consistent with the evolution of a floodplain towards its mature stage. The plough horizon is developed in the uppermost part of the profile.

5.2. Luni 2

Luni 2 was cored 24 m south of the southern city wall (Fig. 4). The ground surface lies at 1 m asl, and a total depth of 6 m bsl was reached. From 6 to 5.6 m bsl, the sedimentary record (Fig. 5) shows a yellowish brown medium sand with angular clasts. It is the alluvial fan deposit (Parmignola Stream) on which – as in Luni 1 – a palaeosol is developed. Between 5.6 and 4.75 m bsl medium to fine sand occurs with some yellowish brown stains of iron and manganese. At 4.75 m bsl, a 15 cm thick layer of limestone pebbles starts with an erosional disconformity. The interval between 4.6 and 3.5 m bsl is occupied by dark brown medium sand. A thin organic layer with plant remains is intercalated at 3.5–3.3 m bsl. Between 3.3 and 2.7 m bsl the medium to fine sand unit continues with the same characteristics as before. Between 2.7 and 2.5 m bsl the dark brown sand becomes coarser and contains some pebbles.

From 2.5 to 0.5 m bsl there is a dark brown medium to coarse sand. Two levels of rounded pebbles are within this layer: the first one at 1.5–1.2 m bsl, the second one at 0.7–0.5 m bsl, both are very dark greyish-brown. They may represent the bottom of two palaeochannels as part of the forming floodplain. The upper part of this core (0.5 m bsl to 1 m asl) is characterized by homogeneous medium-fine sand, well sorted and dark grey in colour. Some dark yellowish brown oxidation spots are present (starting from 0.5 m asl). All units of this core are void of macro- and microfossils. These sediments represent a fluvial environment.

5.3. Luni 3

Luni 3 was cored 0.5 km landward from today's coastline and 0.8 km south of the city wall (Fig. 4). Ground surface is at 1.1 m asl and the depth of 8.9 m bsl was reached. The sedimentary record (Fig. 5) shows a basal unit between 8.9 m and 7.2 m bsl, containing an olive grey fine silty sand with several plant remains. Ostracofauna is characterized by frequent specimens of *Cyprideis torosa* and *Loxoconcha elliptica* with common *Pontocythere turbida* and *Semicytherura* cf. *rarecostata* (Fig. 6, Table 3). As regards foraminifera, scattered individuals of *Ammonia* sp. are present. This association is indicative of mesohaline water; the presence of *Pontocythere turbida* and *Semicytherura* cf. *rarecostata* testifies the marine influence. These characteristics are well-matched with an open lagoon environment. Between 7.2 and 7.1 m bsl (sample Luni 3/20a, Table 3) a layer of peat with olive grey clayey silt occurs, characterized by immature specimens of *Candona neglecta* and *Iliocyprys gibba*, associated with badly preserved mature specimens of *Loxoconcha elliptica*. The absence of *Pontocythere turbida* and *Semicytherura* cf. *rarecostata* is indicative of a reduced interaction with the sea, consistent with a decrease in grain size with respect to the previous unit (8.9–7.2 m bsl). This layer may represent a closed lagoon.

The stratum between 7.1 and 6.6 m bsl (sample Luni 3/20, Table 3) is made up of dark reddish brown fine silty sand with several plant remains and the same faunal association as the previous one, with the exception of *Semicytherura* cf. *rarecostata*. This evidence is indicative of recurrent interaction with the sea and/or variable lagoon salinity and an opening up of the environment. A dark grey layer of medium clayey silt, rich in muscovite and with abundant plant remains, is between 6.6 and 6.4 m bsl (sample Luni 3/19, Table 3). Ostracods are represented by several specimens of *Loxoconcha elliptica* and *Candona compressa*, *Limnocythere* sp., *Prionocypris zenkeri*. These characteristics are indicative of a continental meso- to oligohaline environment, with a low-energy sedimentation (closed lagoon).

An olive grey fine silty sand, follows from 6.4 to 4.7 m bsl (sample Luni 3/18, Table 3). Macro remains of molluscs and a microfossil content of *Pontocythere turbida* and *Loxoconcha elliptica* with some specimens of *Quinqueloculina* sp. indicate a marine influence.

The stratum at 4.7–4.5 m bsl (samples Luni 3/17, Luni 3/12, Table 3) is made up of fine to medium sand with small rounded and flat pebbles (among other rock types chert was found, suggesting a provenance from the River Magra). From 4.5 to 3.4 m bsl a dark grey, mica-rich clayey silt occurs, void of fauna but with organic matter. It may represent a swamp which was still in existence around ~5000 yr BP (5040–4850 yr cal BP; ^{14}C age estimate performed on organic matter at 3.75 m bsl; sample Luni 3/14, Table 4).

The unit at 3.4–0.8 m bsl (samples Luni 3/11–Luni 3/5, Table 3) is characterized by very dark grey fine silty sand, fining upwards, with several plant remains. The ostracofauna is represented by frequent specimens of *Loxoconcha elliptica* with common specimens of *Cyprideis torosa* and rare *Candona* sp. Juvenile *Ammonia* spp. were found with high frequency. This is indicative of a mesohaline environment. In general, this unit represents a transitional environment in which the direct influence of the sea is lacking: it may represent a lagoon characterized by an occasional intrusion of sea water.

The upper part of the core (0.8 m bsl–1.1 asl) (Luni 3/2 and 1) is characterized by a plastic dark grey medium clayey silt, with several Fe–Mn oxide nodules. This part of the layer is capped by a few centimetres of fine silty sand. A monospecific association of gastropods (*Hydrobia* sp.) is present while the ostracoda association is represented by common specimens of *Cyprideis torosa*, which can adapt to nearly any aquatic environment. This unit represents the floodplain. The layer ends with 40 cm of agricultural soil/land reclamation.

5.4. Luni 4

Luni 4 was cored about 250 m west of the city wall (Fig. 4), the ground surface has an altitude of 0.9 m asl.

This core reached a depth of 4.1 m bsl (Fig. 7). The lowermost unit (4.1–2.1 m bsl) represents the alluvial fan of the Parmignola Stream. It is made up of sandstone pebbles in a yellowish brown, very oxidized matrix of silty sand. Between 2.1 and 0.3 m bsl a clayey silt occurs, very dark greyish brown, barren of ostracods and foraminifera, but with many plant remains and peat lenses. This represents a swamp, developed on the alluvial fan. The top of this swamp was dated to 280 ± 40 BP (460–160 yr cal BP; sample Luni 4/4, Table 4).

Between 0.3 m bsl and 0.5 m asl a layer of clayey silts with many roots represents the modern alluvial plain. The uppermost part of this core (0.5–0.9 m asl) shows the modern Ap horizon.

5.6. Luni 5

Luni 5 (ground surface at 0.8 m asl) was cored 150 m SW of Luni 4 (Fig. 4). The sedimentary record (Fig. 7) encountered at a depth of 7.3 m bsl corresponds to the Parmignola alluvial fan. Its facies is the same as previously described for Luni 1, 2, and 4: sand and gravel with angular grains of green metamorphic stones, void of microfossils. The top of this unit shows a transgressive surface.

From 7.3 to 3.35 m bsl a clayey silt occurs; it contains several thin lenses of peat, plant remains and pieces of wood. The bottom of this layer (7.3 m bsl) dates to 5840 ± 50 yr BP (6750–6500 yr cal BP); sample Luni 5/21, Table 4), and a piece of wood at 6 m bsl dates to 4630 ± 40 yr BP (5460–5300 yr cal BP; sample Luni 5/15, Table 4). At 5.3–5.4 m bsl there is a stratum of very dark grey clayey silt. The ostracofauna is composed of many specimens of *Cyprideis torosa* and rare *Loxoconcha elliptica*; there are also common specimens of the foraminifera *Ammonia* spp. and fragments of the brackish bivalve *Cerastoderma* sp. (sample Luni 5/12, Table 3; Fig. 6). This faunal association is indicative of the mesohaline, low energy environment of a partially-closed lagoon.

From 3.35 to 1.45 m bsl follows a very dark greyish brown, slightly silty clay. The contact at 3.35 m bsl is very sharp. According to dated plant remains it is 2800 BP yr old (2860–2740 yr cal BP; sample Luni 5/9, Table 4). This unit, barren of ostracods and foraminifera, is characterized by many plant remains and peat layers, typical of a swampy environment.

A sharp border at 1.45 m bsl marks the transition to the stratum above, composed of dark greenish grey silty clay with organic layers. It is characterized by a mono-specific fauna of *Candona* sp., indicative of a continental aquatic environment with oligohaline water, interpreted as an alluvial plain. The top 30 cm is land reclamation material.

5.7. Orto 06

The Orto 06 was drilled 25 m west of the western city wall and 200 m south of the *decumanus maximus* of the ancient Roman city of Luna (Fig. 4). Surface elevation is 2.0 m asl, and the core bottom lies at 26 m bsl. Most of this profile is composed of fine-grained sand with rounded pebbles. Thin layers of fine-grained sand and silt

Table 3
Distribution of the Ostracods, Foraminifera, Molluscs and Plants taxa collected in the boreholes. FF very frequent: over 10 valves; F frequent: 5–10 valves; C common: 3–5 valves; R rare: 1–2 valves; X occurrence; T peat; O oogons.

Samples	Depth bsl	Depth	Ostracods								
			Fresh-water					Brackish		Marine	
			Candona compressa	*Candona* sp.	*Iliocypris decipiens*	*Limnocythere inopinata*	*Prionocypris zenkeri*	*Cyprideis torosa*	*Loxoconcha elliptica*	*Carinocythereis* sp.	*Cytheretta subradiosa*
LUNI1/4	−19	141									
LUNI1/9	205	365									
LUNI1/10	−15	145									
LUNI1/11	315	475									
LUNI1/12	400	560									
LUNI1/13	490	650									
LUNI1/14	534	694									
LUNI1/15	580	740		F							
LUNI1/16	625	785									
LUNI1/18	700	860									
LUNI1/21	820	980						**C**			
LUNI1/22	890	1050						**F**			**R**
LUNI1/25	925	1085									
LUNI1/26	937	1097						**C**		**C**	
LUNI1/27	981	1141		**C**							
LUNI1/28	1000	1160						**C**			
LUNI2/9	251	371									
LUNI3/1	−65	45						**C**			
LUNI3/2	−45	65						**C**			
LUNI3/3	−30	80									
LUNI3/4	30	140									
LUNI3/5	65	175		**C**				**CF**	**F**		
LUNI3/6	80	190									
LUNI3/8	140	250						**C**	**FF**		
LUNI3/9	150	260		**C**				**F**	**F**		
LUNI3/10	175	285						**C**	**C**		
LUNI3/11	250	360		**C**	**C**		**R**		**F**		
LUNI3/12	270	380									
LUNI3/13	350	460									
LUNI3/15	425	535		**C**	**C**						
LUNI3/16	455	565									
LUNI3/17	475	585									
LUNI3/18	560	670							**C**		
LUNI3/19	653	763	**C**		**C**	**C**	**C**		**FF**		
LUNI3/20	675	785						**C**	**F**		
LUNI3/X	715	825	**F**		**F**				**C**		
LUNI3/21	745	855		**C**					**C**		
LUNI3/22	775	885						**F**	**FF**		
LUNI3/23	840	950						**F**	**C**		
LUNI 4/5	50	140									
LUNI 4/6	165	255									
LUNI 4/7	177	267									
LUNI 5/1	−20	60		**C**							
LUNI 5/2	64	144									
LUNI 5/3	100	180									
LUNI 5/6	202	282									
LUNI 5/8	260	340									
LUNI 5/10	360	440									
LUNI 5/11	390	470									
LUNI 5/12	450	530						**F**	**F**		
LUNI 5/13	480	560									
LUNI 5/19	675	755									
LUNI 5/21	693	773									
LUNI 5/22	737	817									

are intercalated (at 3.7–3.2 m bsl). The analyzed samples were barren of microfossils.

The lower deposits represent the alluvial fan of the Parmignola Stream from the bottom up to 2.25 m bsl. It is covered by a dark clay, very rich in organic matter (at 2.25–1.75 m bsl; note that in Fig. 7 only the uppermost part of the log is shown). This unit is void of microfauna, but it contains many plant remains. Therefore, it can be interpreted as a swamp. The bottom of this unit was dated to 2350–2130 yr cal BP (sample Orto 06/1, Table 3). Pottery recovered from the same layer in an archaeological section close by indicates dates of 2nd–1st centuries BC (Bini et al., 2009a). On top of the swamp, between 1.75 m bsl and 0.5 m asl are floodplain deposits: mainly clayey silts, with some roots. A plant remain at 0.67 m bsl was dated to 1410–1300 yr cal BP (sample Orto 06/2, Table 4). The

				Forams					Molluscs		Plant remains
Hiltermannicythere turbida	*Leptocythere multipunctata*	*Neocytherideis fasciata*	*Pontocythere turbida*	*Nonion* sp.	*Elphidium* sp.	*Ammonia* spp.	*Triloculina* sp.	*Quinqueloculina seminulum*	Bivalva	Gasteropoda	
						C					
						C					
						C	**C**	**C**	**X**	**X**	
R									**X**	**X**	
						C			**X**		**X**
	C	**C**	**C**						**X**		**X**
						F				**X**	
						C				**X**	
						C			**X**		
									X		
				F							
						F			**X**		
						C					
					C						
			F					**C**			
			C			**F**					
			C								**O**
			R								
											T
											T
											T
											X
						R					
											T
									X		**X**
									F		
						R			**X**	**X**	
									X		
									X		

analysed samples are void of fauna. The uppermost 1.5 m of the profile contains material from land reclamation.

6. Reconstruction of palaeogeography

The cross profile represented in Fig. 7 shows new evidence and timing about the palaeogeographic evolution of the basin near the western city wall (*Seccagna*) (Fig. 3). In particular, it enables us to outline its history since the Mid-Holocene and to refine our knowledge about its extension and nature around 2000 BP. In the cross profile of Fig. 5, cores are arranged in order to investigate the nature and evolution of the basin already recognized south of the city walls, of which new chronological constraints are provided.

The Parmignola alluvial fan was reached in each core, except for Luni 3. No evidence of an erosive phase is detectable at the top of it. For our study this fan can be considered, at least for the more landward part of

Table 4
AMS ^{14}C results mentioned in the text. Ages-calibrated by means OxCal (Version 3.10), probability of occurrence according to the 2σ range (95.4%). NA = not available.

Sample name (code)	Depth (m bs)	Depth (m bsl)	Sample description	Conventional ^{14}C age (BP)	2σ max; min (cal BP)	2σ max; min (cal BC)	$\delta^{13}C$ (‰)
Luni 1/20 (Beta−255400)	9.5	7.9	Peat	3440 ± 40	3830; 3600	1880; 1650	−26.0
Luni 1/31 (Beta−255401)	11.9	10.3	Wood	5390 ± 40	6290; 6170	4340; 4220	−24.0
					6150; 6110	4200; 4160	
					6070; 6060	4120; 4110	
					6050; 6020	4100; 4070	
Luni 3/14 (Beta−255396)	4.85	3.75	Organic matter	4370 ± 40	5040; 4850	3090; 2900	−25.1
Luni 4/4 (Beta−255403)	1.30	0.30	Plant remain	280 ± 40	460; 280	1490; 1670 AD	−25.4
					160; 160	1780; 1790 AD	
Orto 06(1) (CEDAD LTL2130A)	4.25	2.25	Organic mud	NA	2350; 2130	400; 180	−24.1 ± 0.5
Orto 06(2) (CEDAD NA)	2.57	0.67	Plant remain	NA	1410; 1300	540; 650 AD	NA
Luni 5/9 (Beta−255399)	4.15	3,35	Plant remain	2680 ± 40	2860; 2740	910; 790	NA
Luni 5/15 (Beta−255397)	6.80	6.00	Wood	4630 ± 40	5460; 5300	3510; 3350	−25.8
Luni 5/21 (Beta−255398)	8.10	7.30	Peat	5840 ± 50	6750; 6500	4800; 4550	−29.3

the investigated plain, as the "basement" of the late Holocene sedimentary sequence. Alluvial fans with similar sedimentary and textural characteristics were reported for the Apuo-Versilia plain as the base of the Holocene transgressive sequence by Federici (1993) who considers them as Pleistocene in age. The bottom topography on which the Holocene sequence rests can be outlined thanks to the new corings presented in this paper.

The top of the alluvial fan deepens from Luni 4 via Orto06 to Luni 5 (Fig. 7) and it continues to deepen towards the west–southwest where, in the subsurface of the area close to the present-day course of the Magra River, the depocenter of the western basin (*Seccagna*) probably existed. The western basin started to form as a lagoon on top of the fan at about 6000 yr BP as far as Luni 5 core, while landwards the fan remained exposed for a long time throughout the Holocene; at its boundaries in 2350–2130 BP a swamp formed (as Orto 06 core testifies) and even more landward the fan has been exposed up to a few centuries ago; in core Luni 4, in fact, the fan displays only a post-mediaeval, thin capping of swamp deposit.

Palaeotopography controls also the setting of the southern basin (Figs. 3 and 5). The alluvial fan surface deepens towards the south from Luni 2 to Luni 1 whereas, at the bottom of Luni 3, it was not reached, as the drilling was not continued deep enough. The stratigraphy of the northernmost core (Luni 2) shows that the southern basin never occupied the area in the proximity of the city walls. In fact, floodplain sediments directly onlap onto the alluvial fan of the Parmignola Stream. In Luni 1 a lagoon formed on top of the fan surface shortly before ca. 6000 yr BP6290–6020 yr cal BP, Table 4). The northern shore of the basin was located between Luni 2 and 1.

Both cross profiles record the effects of the innermost penetration of the Holocene transgression and the following progradational sequence. Our data demonstrate that the lagoon sediments onlapping on top of the Parmignola alluvial fan (cores Luni 1 and 5) are indicative of the development of lagoons related to the maximum innermost penetration of the Holocene transgression; in fact they yield basal ages consistent with those reported for the neighbouring Massaciuccoli Lake (Nisi et al., 2003). They represent the landward

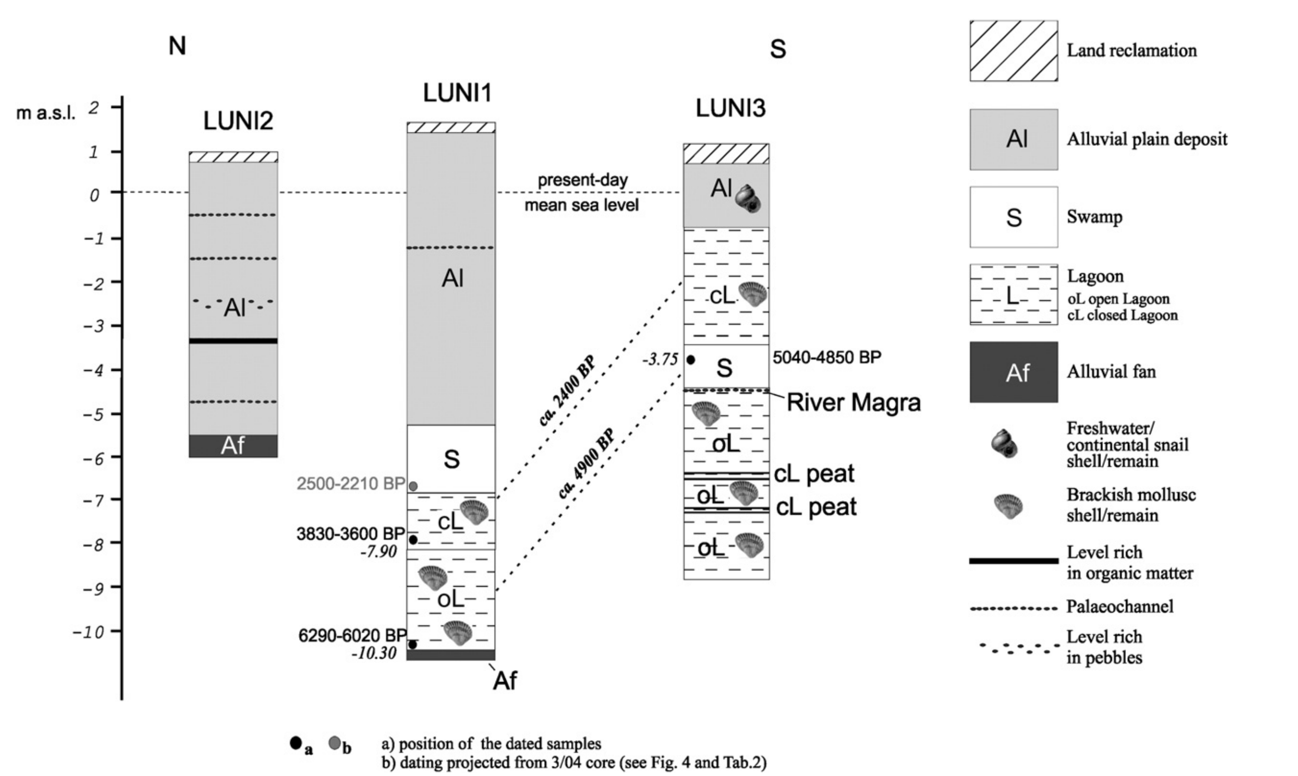

Fig. 5. Southern cross profile (see Fig. 4 for location). The logs are representative of the sedimentary facies detected through sedimentological and microfaunal analyses.

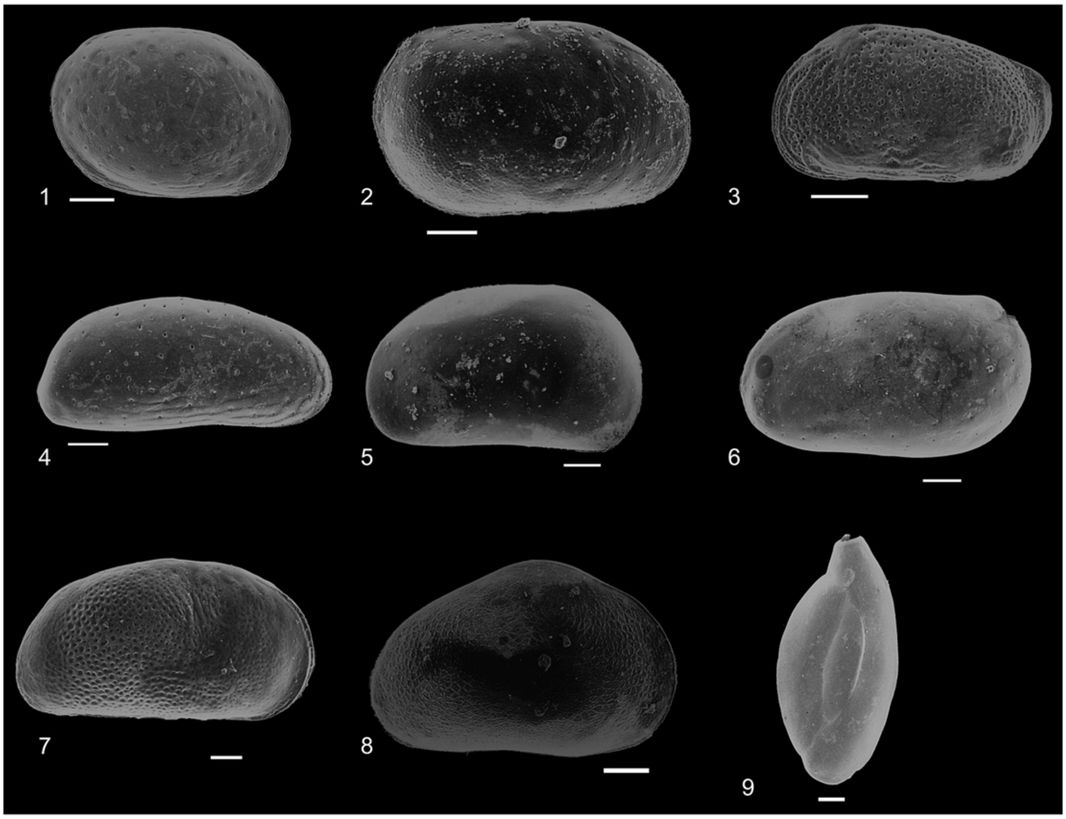

Fig. 6. Microphotographs of selected species. All views are external lateral (scale bars = 100 μm). 1. and 2. *Loxoconcha elliptica*; 3. *Leptocythere multipunctata*; 4. *Pontocythere turbida*; 5. *Candona compressa*; 6. *Cytheretta subradiosa*; 7. *Cyprideis torosa*; 8. *Heterocypris salina*; 9. *Quenqueloculina seminulum*.

equivalent of the littoral and shallow-marine deposits recorded in other coastal plains facing the Tyrrhenian sea, e.g. the southern Apuo-Versilia Plain (Bergamin et al., 2006) and the northern Pisa Plain (Carboni et al., 2010). In our study area, coastal marine sediments were not found on top of the piedmont alluvial fan. Anyway, they might be preserved below the bottom of the lagoon/floodplain sequence reached by our coring Luni3. This suggests that the Holocene transgression shoreline was located seaward of our drillings (possibly except

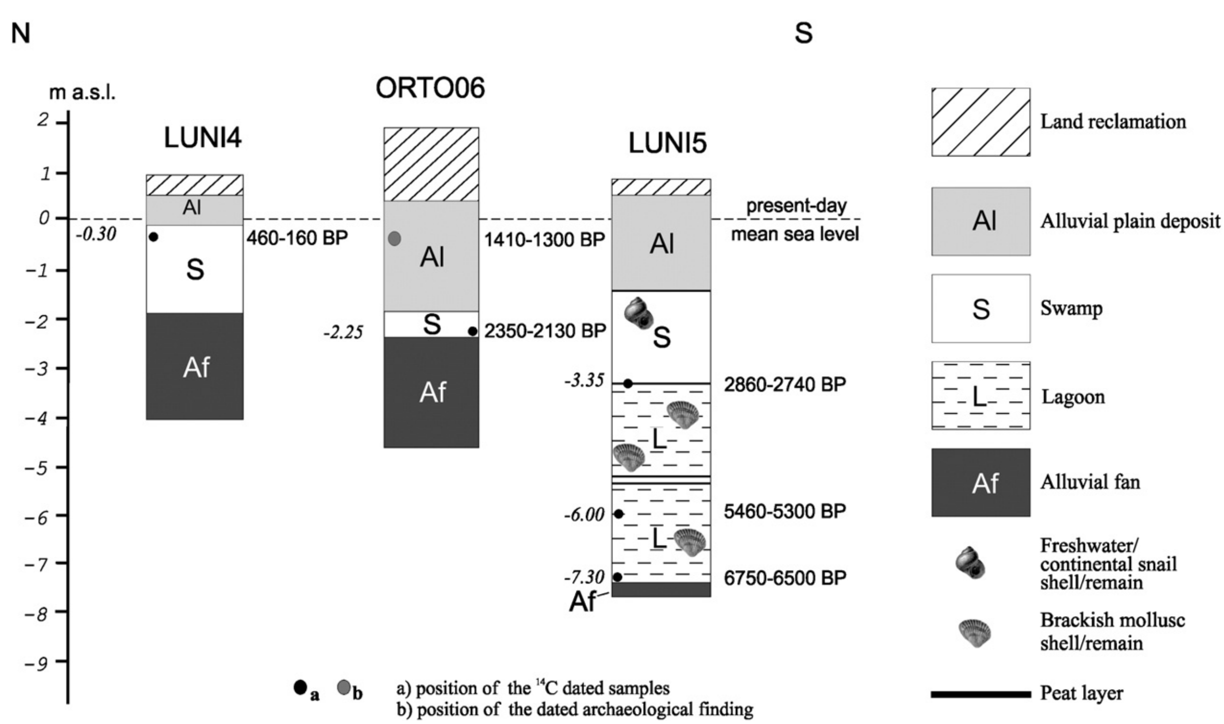

Fig. 7. Western transect (see Fig. 4 for location). The logs are representative of the sedimentary facies detected through sedimentological and microfaunal analyses.

Luni3). This is consistent with geomorphological evidence (Fig. 3). In fact the marine palaeocliff that marks the innermost penetration of the Holocene transgression can be traced along all of the Apuo-Versilia Plain in the distal part of the alluvial fans at the foothill of the Apuan Alps (Sestini, 1957). At the foot of the Parmignola alluvial fan, though, it is missing (Fig. 2b).

Since about 6500 yr BP (6750–6500 cal BP) a lagoon had started to evolve in Luni 5. Its faunal content is indicative of a mesohaline milieu and a low-energy wave climate. We can deduce that it was a nearly closed lagoon. The environment, that persisted for about three millennia, was characterized by alternating phases of minor and major interaction (connection) with the sea. The reasons were the major or minor relevance of the sand barrier separating the lagoon from the sea, the fluctuations in the sedimentary budget or in sea level, and the impact of extreme events (storms, tsunamis). The Luni 1 and 3 cores reveal the nature and the evolution of this lagoon south of the city. In fact, ostracods and foraminifera demonstrate that the basin, formed shortly before 6000 yr BP (6290–6170 yr cal BP, Table 4) was in connection with the sea, although it may occasionally have suffered from temporal or partial isolation, e.g. around 5000 yr BP (5040–4850 yr cal BP, Table 4), when it temporarily turned into a swamp.

Sediment ages yielded by the basal part of this lagoonal sequence suggest that it formed synchronously about 6000 yr BP. This lagoon development phase is accounted for also in other cores retrieved south of the study area, where it overlaps the Early-Holocene transgression littoral sediments, highlighting shoreline progradation (Bergamin et al., 2006; Carboni et al., 2010) or other, Early-Holocene lagoonal sediments (Mazzini et al., 1999; Rossi et al., 2011). In our cores these sediments represent the bottom of the sedimentary sequence of the Magra River delta displaying the same regressive trend highlighted for many Italian coastal plains. Apart from those already mentioned, in similar environments with the same age are reported e.g. for the Po (Amorosi et al., 1999; Amorosi and Milli, 2001), the Ombrone (Carboni et al., 2002; Bellotti et al., 2004) and the Tiber (Amorosi and Milli, 2001; Giraudi et al., 2009) deltas.

This almost isochronous phase of deltaic and coastal plain progradation after the Holocene peak of transgression is interpreted to reflect the deceleration in sea-level rise (Antonioli et al., 2009).

It is still unclear whether the lagoons west and south of the city were interconnected. Their evolution, though, displays similar pattern in both cross-profiles, bearing on top a late Holocene regressive succession of prograding deltaic and alluvial plain deposits of different thickness in the examined cores. A swamp began to develop 2860–2740 yr cal BP in Luni 5 (Fig. 7) and it ended after 460–180 yr cal BP (Table 4), according to the ^{14}C-dated top of the swamp in Luni 4 (Fig. 7). A continental facies (alluvium) covers the swamp unit in all of the three cores; it documents the complete siltation of the basin. Projecting on Luni 1 the age of the core 3/04 (Fig. 4; Table 2) available in the database (Bini et al., 2009a), one can infer that the lagoon changed into a swamp after 2310 yr BP (2450–2160 yr cal BP, Table 2), and then into a floodplain. For the alluvial unit overlapping the swamp no chronological data exist but the petrography of the sand grains suggests that in the lower part, up to 1.3 m bsl, it was originated from the Parmignola Stream. At 1.3 m bsl, a palaeochannel created an erosional disconformity and then fluvial sands of the Magra River have started to accumulate. Similar evidence is given by the layer of rounded pebbles identified in Luni 2, between 1.5 and 1.2 m bsl.

Our data show that a swampy environment is synchronous in Luni 1, Luni 5 and Orto06 around 2500 BP. This event may be attributed to the oscillating cold climate phase which is known to have occurred 2500 yr ago at the end of the Subboreal (first Neoglacial event, Orombelli and Pelfini, 1985). These climatic conditions may have forced the lagoon to a freshening of water due to a surplus of sediment supply (Nichols, 1989). In fact when sedimentary accretion overwhelms the rate of relative sea-level rise it fosters shoreline progradation. As suggested for many coastal areas all over the world (e.g., Vandenberghe, 1995; Bridgland and Westaway, 2008) sedimentary accretion in alluvial plains is favoured by cold climate conditions.

7. Possible locations of the *Luna* harbour

Stratigraphic and chronologic evidence from the examined cores testifies that around 2200 BP, when the city of *Luna* was founded, environmental conditions in the area close to the city walls were not favourable for a harbour. In fact, the sedimentary facies in those cores closest to the city walls is typical of a floodplain during that time. Our data confirm the preliminary scenario depicted by Bini et al. (2009a), according to which two water basins were present west and south of the city walls, but none of them was close to the settled area. Moreover new evidence is provided about the different nature of the two basins both displaying a thick fill of lagoonal sediments dating back to ca. 6000 BP. A lagoon, though, persisted southwest of core Luni 5. In fact stratigraphic evidence from the database (Bini et al., 2009a) suggests that in that area a thick lagoonal clay deposit was present extending upward until the land reclamation layer. A harbour, then, could have been hosted in the western basin but far away from the city walls, at least 250 m west of them.

The core Luni 2 demonstrates that the southern indentation in the city wall cannot be due to an articulation of the coastline, as suggested by previous authors (e.g., Frova, 1976). In fact the core represents a sedimentary sequence typical of an alluvial plain directly overlapping the alluvial fan deposit. A basin south of *Luna* was probably still present at the times of the city settlement, as confirmed by the cores Luni 3 and Luni 1. Its nature, proved to be lagoonal, and in the upper part of Luni 3 (coeval with the city settlement age), the faunal assemblage testifies that the connection with the open sea was extremely reduced. The features of this basin (its faunal content and its moderate extension) seem to be not consistent with those suitable for the location of one of *Luna*'s harbour system anchorages. In these scenarios the lagoon west of the city (*Seccagna*) seems the most promising location for a harbour, as the one described by ancient historical sources for *Luna*. The palaeogeography of this basin was closely linked to the evolution of the Magra River mouth in the framework of the general coastline progradation.

In the Mediterranean, several harbours are located in a similar prograding delta context (Marriner and Morhange, 2007), such as Medjerda in Tunisia (Oueslati et al., 1987; Chelby et al., 1995), Ostia in Italy (Bellotti et al., 2007, 2011; Giraudi et al., 2009), Troy (Kraft et al., 2003), Ephesos, Miletos and Kaunos etc. on the Turkish Aegean coast (Bousquet et al., 1987; Kayan, 1996; Brückner, 1998, 2005; Brückner et al., 2006). Due to this typical location, the major environmental problems that affected all these harbours were delta growth and siltation in historical times (Marriner and Morhange, 2007).

This seems to be one of the most probable natural causes of *Luna*'s decline, which occurred only a few centuries after its foundation.

8. Conclusions

In this paper, some fundamental issues concerning the evolution of the coastal plain surrounding the ancient Roman colony of *Luna* were addressed and clarified.

1) The Holocene transgression, never identified in this area, was chronologically and geographically constrained. The shoreline at the time of the transgressive peak (6000 yr BP ca.) was located about 400 m southward of the south city walls (more than 1 km inland with respect to the modern shoreline);
2) A regressive sequence developed in a highstand sea level context is represented by lagoonal sediments that gradually silted up and were replaced by swamps. These lagoons developed both with the progradation of the mouths of the Magra River and the Parmignola Stream that, finally, covered every past environment with their

alluvium. The environmental evolution outlined for the Lower Magra Valley coastal plain occurred after the peak of the Holocene transgression, displays many similarities with those highlighted for many other Italian coastal plains, reflecting the response of the coastal system to the deceleration in sea level rise (Antonioli et al., 2009);

3) An environmental fluctuation at 2500 yr BP ca. was highlighted in the stratigraphic record. Although our data are still insufficient to state a climatic control on it, it is worth noticing that one episode of drying up of the lagoonal environment is chronologically consistent with the first Neoglacial cooling episode.

Finally, the essential features of the palaeogeographic scenario for the Roman times were further refined. In particular, it was demonstrated that the indentation in the southern city wall, stated by the archaeologists and based upon the ancient cartography (Table 1), cannot be due to an articulation of the coastline, as suggested by some of the previous authors. In fact the shoreline never attained a far landward position, or at least a fringe of land of 20 m south of the city walls was occupied by a floodplain throughout the Holocene. The evolution of the southern and western basins was reconstructed in detail both stratigraphically and chronologically. If an important harbour, consistent with the evidence bequeathed by ancient historians, existed near the city of *Luna*, it probably lies in the western water basin but at least 250 m off the city walls, whereas the southern lagoon was too small and closed for hosting an important harbour. A further possibility which deserves to be investigated is that one of the anchorages of the *Luna* harbour system is located SE of the southern basin, along the coast of Versilia. During the late Holocene, the progradation of the lower Magra Valley coastal plain occurred through the progressive change of the environment, from paralic to alluvial. In this view, the progressive silting-up of the *Portus Lunae*, with its transition from lagoon to swamp, probably accompanied by environmental health concerns (e.g. malaria), and finally to an alluvial plain seems one of the most probable natural causes of *Luna*'s decline, which occurred only a few centuries after its foundation.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found in the online version, at doi:10.1016/j.palaeo.2012.03.024. These data include Google maps of the most important areas described in this article.

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