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Relative sea level change at the archaeological site of Pyrgi (Santa Severa, Rome) during the last seven millennia

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ABSTRACT

New data are presented for late Holocene relative sea level change for one of the older harbors of the Mediterranean Sea. Data are based on measurements of submerged archaeological remains, indicating past sea level and shoreline positions. The study has been carried out at Pyrgi (Santa Severa), an important Etruscan archaeological site located in central Italy, 52 km north of Rome. Underwater geomorphological features (a large shore platform) and archaeological remains (a Roman dock, two fishtanks, and wells of Etruscan age) connected to relative sea level and to the shoreline during the last 7 millennia have been measured and compared with current glacio-hydro-isostatic theoretical models in order to reconstruct the long-term shoreline evolution and to evaluate coastal tectonic vertical movements, so far derived for this area only from Last Interglacial (125 ka) sea level markers.

1. Introduction

Sea level change is the sum of eustatic, glacio-hydro-isostatic and tectonic factors (Waelbroek et al., 2002; Lambeck et al., 2004a). While data derived from of oxygen isotopes and geophysical models (Lambeck and Purcell, 2005) are largely used to predict the first two, field data are particularly useful to assess the third one, once the elevation of the sea level marker measured in the field is compared to the predicted sea level elevation (Antonioli et al., 2009).

Different kinds of sea level markers exist: biological (Laborel and Laborel-Deguen, 1996; Stirling and Andersen, 2009), sedimentological (e.g. Andreucci et al., 2009), geomorphological (Pirazzoli, 1996; Kershaw and Guo, 2001) and archaeological (Auriemma and Solinas, 2009). In particular, the use of the latter is more effective when archaeological remains can be directly related to the position of the ancient sea level, such as in fishtanks (Lambeck et al., 2004b), which were built with elements related to tides (e.g. sluice gates, Auriemma and Solinas, 2009). Some archaeological remains can be indirectly related to sea level, and can be used as sea level marker after an accurate reconstruction of their functionality and associated error (harbor structures, wells, hydraulic systems; Auriemma and Solinas, 2009).

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The aims of this multidisciplinary research were to: *i)* measure geomorphological and archaeological sea level and paleoshoreline markers; *ii)* compare them to the predicted sea level curves (Lambeck et al., in this volume); *iii)* evaluate the vertical tectonic behaviors and the long-term shoreline evolution of the Pyrgi area, located in central Italy.

2. Study area

2.1. Archaeological setting

The study area is located in the Lazio administrative Region, between the towns of Santa Severa and Cerveteri, 52 km north of Rome. The area is presently occupied by a Middle Age castle, which was built on the remnants of the former Etruscan settlement named Pyrgi (Colonna, 2000; Enei, 2008 and references therein).

The archaeological findings indicate the presence of a human settlement in the area since the middle Neolithic, with traces of human occupation in the Bronze and Iron Ages. The favorable natural conditions and the prehistoric occupation contributed to the development of the first harbor settlements between the late Iron Age and the beginning of the VII century BC. In the same period, the Etruscan town of Caere (today Cerveteri), together with the other Etruscan coastal cities, controlled the Tyrrhenian Sea. For this reason, Pyrgi was defined by Strabo as an "*epineion*", i.e. an equipped harbor (Strabone V, 2, 8).

In the archaic period, Pyrgi was one of the most important harbors of the ancient Cerveteri, open to commerce through the Mediterranean, and particularly frequented by Greek and Phoenician sailors and merchants. The settlement, with a regular urban plan, was developed around the harbor and was bordered by a large sanctuary. Archaeological studies revealed that the area of the sanctuary is characterized by two temples with long rectangular buildings divided in cells, and a monumental entry opening on the street. The street was a 10 m wide road extending for 13 km and linking Pyrgi to Caere. Inside the temples were found three gold-leaves, two inscribed in the Etruscan language, and the other reporting the same text in Phoenician. Pyrgi is famous in the world as a source of knowledge of Aetruscan–Phoenician languages.

In the first years of the III century BC (2.7 ka BP), Romanization of the coastal area of the Caere territory started. Pyrgi passed under Roman control and the town was converted in a Roman *castrum*. The Roman settlement was built partially on the Etruscan one, and was given control of the littoral, of the port and of the strategic and commercial interests linked to it. In the II century BC, the sanctuary was definitively abandoned and destroyed.

Pyrgi was, for the entire Rome Republican age, a Roman naval base. During the Imperial epoch, due to the decline of the strategic-military importance of the *castrum*, the area was occupied by maritime villas, property of rich Roman families. During the II century AD *Pyrgi* was governed, together with Caere, by a *curator rei publicae* (i.e. a functionary officer named by the emperor). The two ancient Etruscan settlements were still linked from a political and administrative point of view. In this period the port hosted (Ateneo VI, 224c) a rich fishing fleet, which served the Roman market.

It was probably the continuity of life in what was once the Roman colony that allowed the development of *castellum Sanctae Severae* in the medieval age (VII–IX century A.D., 1.2 ka BP). A recent excavation discovered the remains of the palaeo-Christian church of Santa Severa, dated to the V century, 1.5 ka BP, found near the fortress. In the IX century the "Saracen Tower" was constructed in order to control the port and coast. Afterwards, the castle and related village were built, with two churches, dedicated to Santa Severa and Santa Lucia (1594), restored in 1700. During the Renaissance era, the town of Santa Severa was economically self-sufficient owing to its advanced agriculture and marine development. Santa Severa Castle has changed hands several times over the years until it became part of the property of the Ospedale del Santo Spirito in 1482 and was an intermediate port of call between Roma and Civitavecchia. Today, the monument site belongs to the Santa Marinella Municipality.

2.2. Geomorphological setting

The bedrock in the study area (Fig. 1b) belongs to the allochthonous Outer Ligurids (Sestini et al., 1986), represented by a Late Cretaceous to Palaeogene unit known either as the Tolfa Formation (Abbate and Sagri, 1970), or the Pietraforte and "comprehensive succession" (Alberti et al., 1970). The latter is represented by a series of thick to very thick marly limestone and grey marl beds exposed between Rome and Civitavecchia and underlying the Pietraforte unit. A small strip of biogenic sandstone in some areas overlies the Pietraforte, and it has been attributed to the Early-Middle Pleistocene Panchina Formation (Alberti et al., 1970). In the western part of the area (Fig. 1b) the products of the Plio-Pleistocene volcanic activity of the area outcrop. The covering Holocene deposits are represented by travertines, slope debris, alluvial deposits and weathering deposits. Gravels and sands characterise the beaches (Chiocchini et al., 1997).

Concerning the neotectonic setting of the area, between Livorno and the Roman volcanic complex the MIS 5.5 marker elevation indicates tectonic stability (Ferranti et al., 2006). Under the Roman volcanic complex (Vulsini, Sabatini and Albani, Fig. 1a) MIS 5.5 markers are indicative of a 150 km wavelength bulge which was related to magmatic injection beneath the 420 ka vents (Bordoni and Valensise, 1998; Karner et al., 2001; Nisi et al., 2003). Between Punta della Vipera and Anzio, the MIS 5.5 shoreline reaches 30–35 m asl at Punta Della Vipera (Hearty and Dai Pra, 1986; Carrara et al., 1994; Giordano et al., 2003) and Cerveteri. Recent studies (Lambeck et al., 2004a,b) indicated that at the sites of Punta Della Vipera, Santa Marinella Odescalchi and Le Grottacce (all located near Pyrgi, Figs. 1 and 2), "the uplift rate based on the elevation of the MIS 5.5 shoreline, may not be appropriate for the shorter time interval … these sites may actually have been subject to some subsidence over the past 2000 years" (Lambeck et al., 2004a,b, p. 572).

3. Methods

For the topographic reconstruction of the of the study area, bathymetric charts were developed from the raw data of the Istituto Idrografico della Marina through geostatistical analysis. Direct surveys were then carried out in order to identify and measure the depth of the significant archaeological elements, which were successively corrected using mareographic tables of the nearby Civitavecchia harbor.

In general, the approach suggested by Auriemma and Solinas (2009) has been adopted:

- measurement of new and previously reported archaeological markers repeated and conduced on the best preserved parts of the monument using an invar rod;
- correction of the measurements for tide and atmospheric pressure values at the time of the surveys;
- evaluation of the height and functional depth to the average sea level, which differs depending on the typology of the evidence, its use and the local tide amplitudes.
- error bars both for temporal values (where the archaeological study has not been able to determine the precise chronology of the monument) and for elevation (linked to the measurements, the corrections and the estimate of the functional height);
- comparison between the current theoretical model (Lambeck model, in this issue) of the sea level variations and the values observed.

4. Results

4.1. Prehistory

Prehistoric frequentation of the study area is documented by archaeological findings (Colonna, 1981; Belardelli et al., 2007) indicating the presence of a Neolithic (6500–7300 BP) human settlement in the area successively occupied by the Etruscan Temples.

To reconstruct the gross coastal morphology at 7300 BP, the shoreline has been shifted to the depth indicated by the glacio-hydro-isostatic model for this age, i.e. 10 m below present sea level (Fig. 2a).

Even though the reconstruction does not take into account the possible effects of erosion and tectonic displacement, and is therefore only indicative, it shows that the 7300 BP was located approximately 500–1500 m seaward with respect to the present-day one. The study area ("Santa Severa Castle") was located in an embayment between two large promontories in front of the present "Santa Severa" and "Macchiatonda", the latter faced by two large islands. Direct surveys carried out in one of these (presently submerged) islands (Fig. 2b) identified that, morphologically, they

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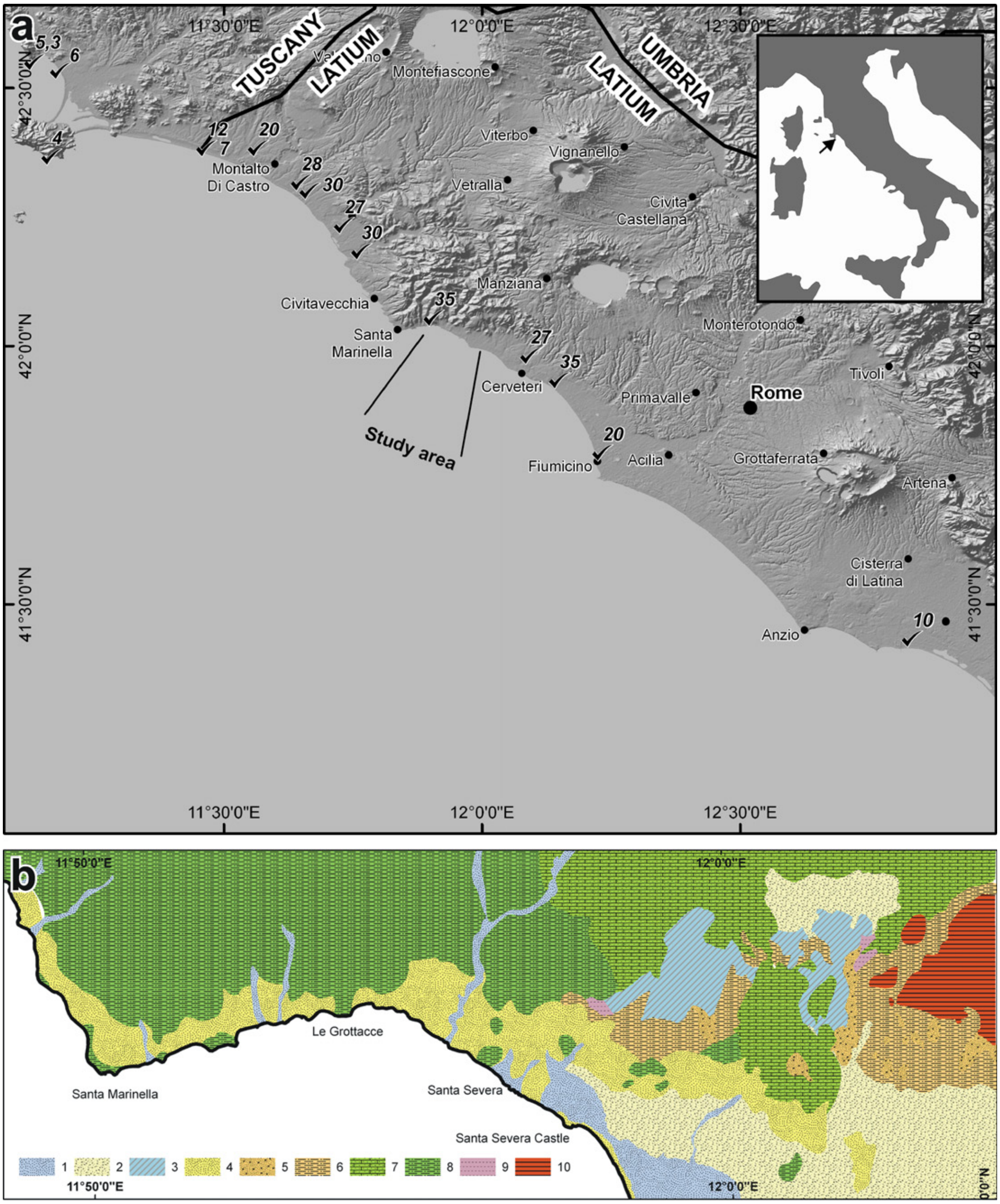

Fig. 1. a) DEM (Digital Elevation Model SRTM shaded relief (http://srtm.csi.cgiar.org)) of Southern Tuscany-Northern Latium showing the elevation of the MIS 5.5 markers (black ticks, numbers indicate the elevation of the marker in meters as reported by Ferranti et al., 2006); b) Geological sketch map (redrawn from Alberti et al., 1970) of the study area. Legend: 1-Recent and actual alluvial deposits (Holocene); 2-Ancient alluvial deposits and marsh clays (Holocene); 3-Recent and ancient travertine (Holocene); 4-Sands and conglomerates (Late Pleistocene); 5-Polygenic conglomerates and sands (Pleistocene); 6-Marls and grey clays (Miocene); 7-marly calcareous units (Palaeogene); 8-Sandstones (Cretaceous); 9-Ignimbrite (Late Pleistocene); 10-Acid lavas from Neck (Late Pliocene).

are characterized by a surface gently dipping seaward located at 9–12 m depth, interrupted at −12 m by a sub-vertical calcarenite cliff. The cliff foot is covered by rockfall deposits starting at 15–18 m depth and ending in fine sediments at 24–26 m. The planar surface identified has been interpreted as an inactive shore platform, produced by sea erosion near the sea surface. Therefore, on this surface no Neolithic remains were found to support for this depth attribution of the former shoreline.

4.2. Etruscan and Roman periods

The archaeological markers revealed in this study (Fig. 3) comprise different Etruscan and Roman elements.

4.2.1. Etruscan wells

The bases of three wells (n.1 in Fig. 3) excavated into a clayey bottom have been measured at 2.13, 2.47 and 2.64 m below sea level (Fig. 4a). These measures correspond to the lower part of the well, and in the third well (−2.64 m) the measure corresponds to the real bottom of the well, as the remnants lay directly on the clayey bottom.

The wells have been archaeologically dated at 2400 ± 150 BP (Enei, 2008). Comparison with their modern counterparts, described in Coccolino and Follieri (1980), still in place about 150 m landward (in the area of the Etruscan temples) and penetrating into the terrain down to the clayey bottom for 4 m, allowed reconstruction of the erosional dynamics in the study area (Fig. 4b).

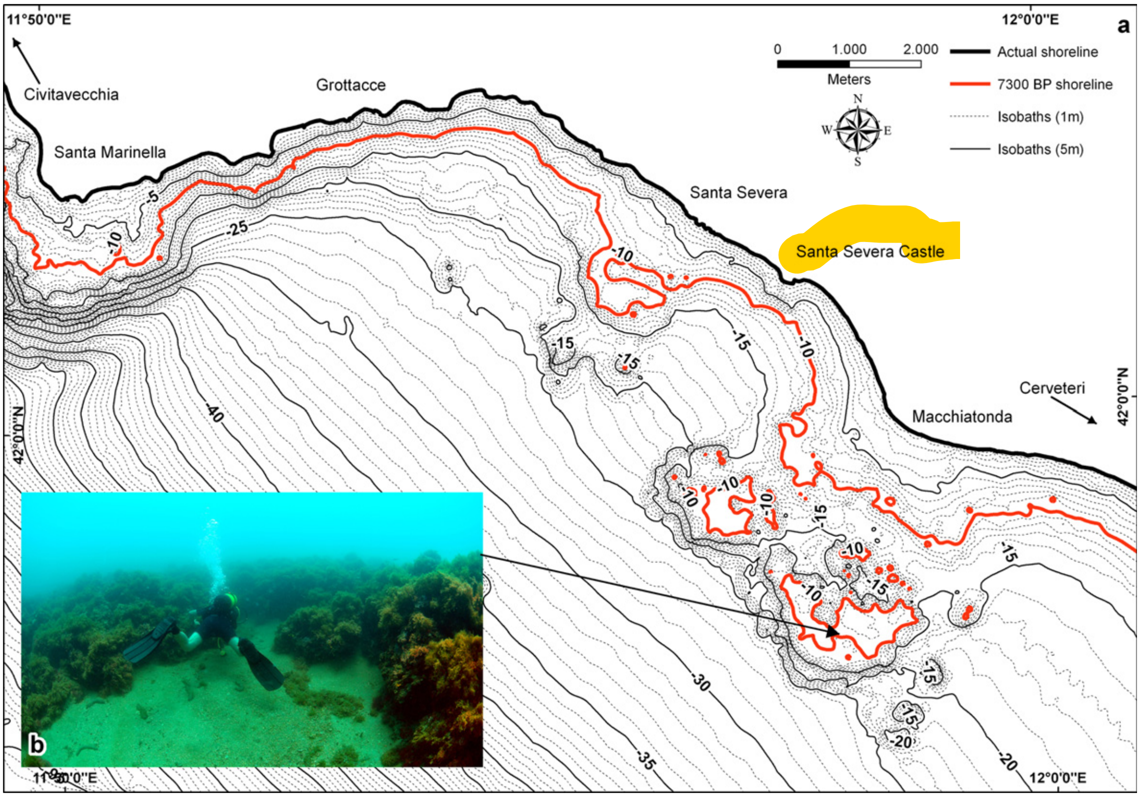

Fig. 2. a) Reconstruction of the coastline paleomorphology in the study area. The reconstruction has been made shifting the shoreline (red line) at the depth indicated by the glacio-hydro isostatic model of Fig. 9 for 7300 years BP, (−10 m below present sea level). The reconstruction does not take into account the effects of erosion and tectonic displacement, and is therefore only indicative (Bathymetry obtained from raw data of the Istituto Idrografico della Marina, Genoa, prot. SRE/4653). b) Survey on the submerged island (position of the photo indicated in the map) cut into sandstone. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

4.2.2. Pierced stones

The finding of pierced stones (n.2 in Fig. 3) sizing in diameter about 40–50 cm has been attributed by Enei (2008) to the Etruscan epoch, although these manufactures have been in use since the third millennium BC to contemporary age. As the use of pierced stones as markers of paleoshorelines is perplexing due to difficulties in chronological attribution and real function of the stones (Auriemma and Solinas, 2009), the reconstruction of the

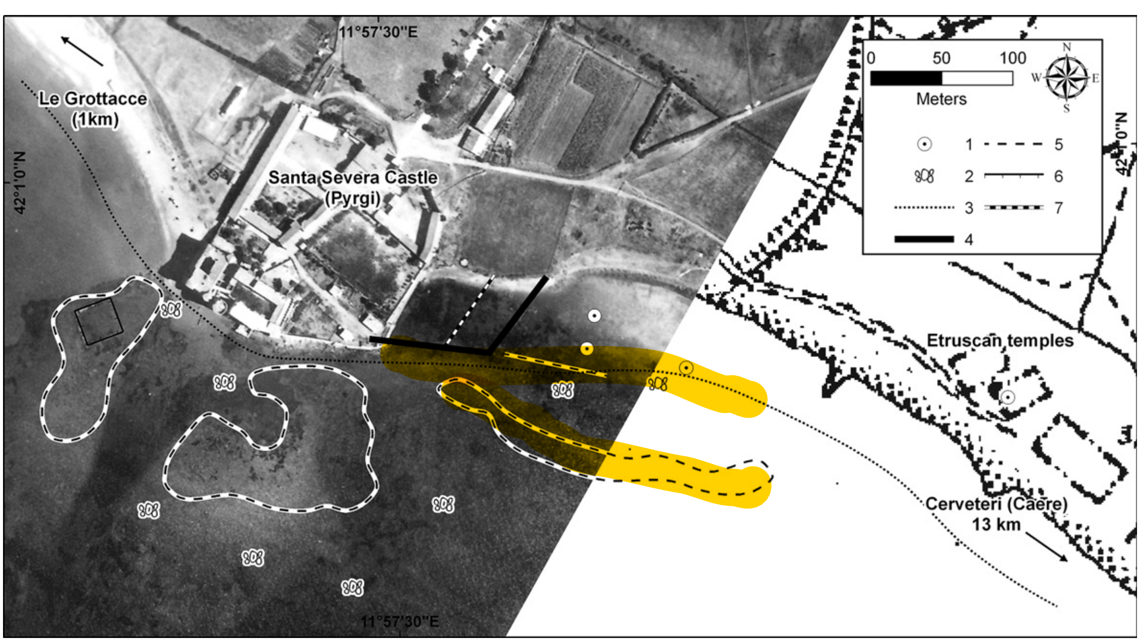

Fig. 3. Main elements measured in this study. Legend: 1-Etruscan wells; 2-Lithic anchors; 3-Reconstructed Etruscan shoreline; 4-*Castrum* walls destroyed by wave action; 5-Harbor structures; 6-*Pyrgi* fishtank; 7-Reconstruction of the sewer pipe.

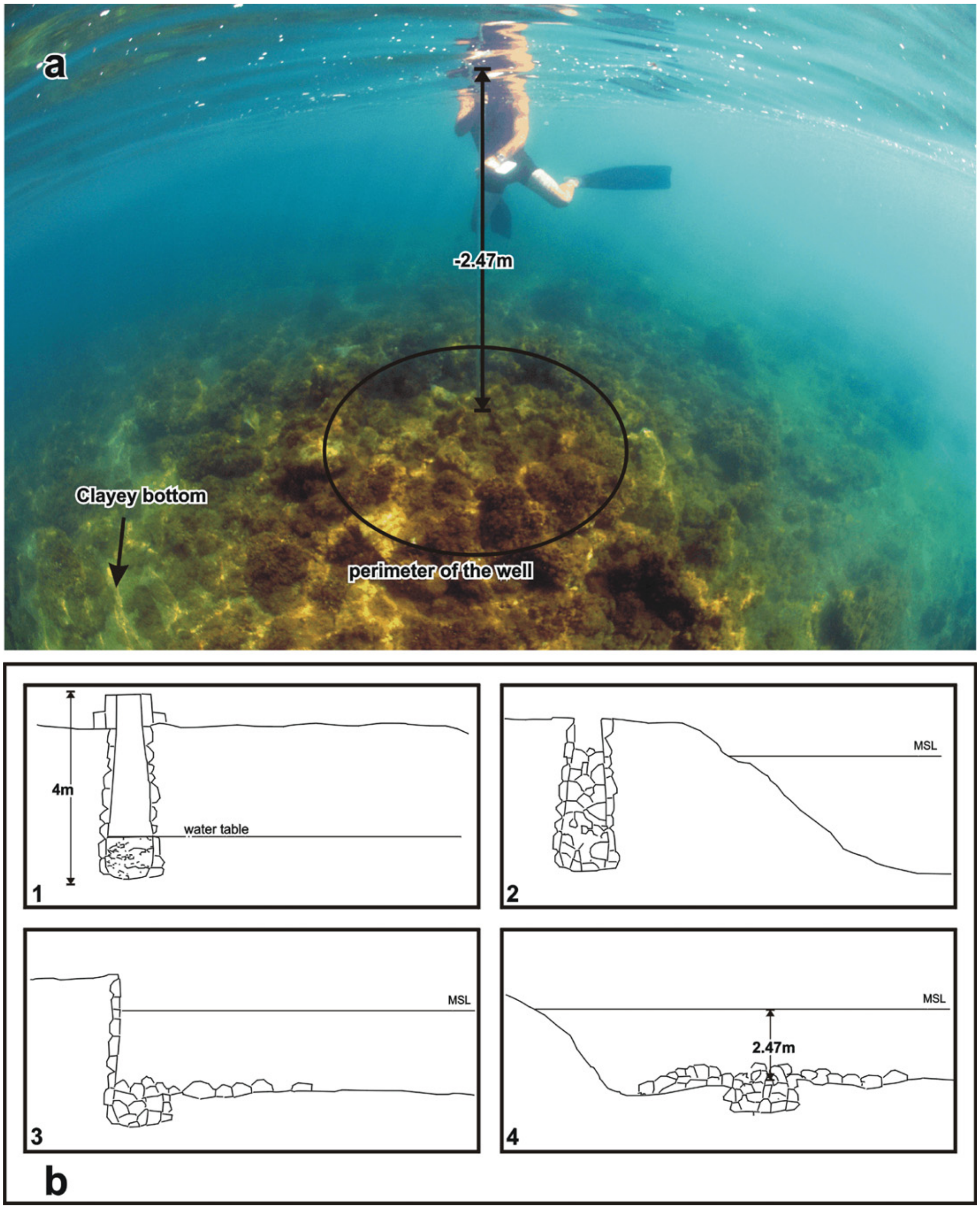

Fig. 4. a) Photo of one of the Etruscan wells during surveys; b) Erosion dynamics of the presently submerged spring-wells (redrawn from Enei, 2008). 1-Active phase: the well is fed by ground water; 2-Due to coastal erosion and/or variation in relative sea level, processes of salinization of the freshwater begins and the well is closed with raw materials; 3-Shoreline erosion processes destroy the well; 4-Modern situation: due to coastal erosion and relative sea level changes, the well bases are found underwater.

paleoshoreline of Etruscan age (n.3 in Fig. 3) relies more on the position of the Etruscan wells described above and on the indications from the literature (Colonna, 1985, 2000; Belelli Marchesini, 2001) that both the Roman *castrum* where the Santa Severa Castle is located and the Roman harbor were yet Etruscan settlements (n.4 in Fig. 3).

4.2.3. Harbor structures

Several architectonical elements (Enei, 2008) indicate that the seaward side of the modern Santa Severa Castle lies along the ancient Roman harbor, with its foundations upon the ancient docks. Underwater surveys identified at least four different elements related to the ancient harbor.

The first two, described in Oleson (1977), are contiguous with the Santa Severa Castle, and represent two foundation jetties attributed to Etruscan age (500 ± 200 BC–2450 ± 200 BP) by Enei (2008). They are built of large boulders piled on two sandstone shoals (still visible from the aerial photo, n.5 in Fig. 3), and their base and their top are at respectively 2 m and 0.75 m bsl.

East of the Santa Severa Castle, two other elements have been surveyed and related to the ancient Roman harbor. These elements are remnants of structures built with hydraulic grout. The first, located in proximity of the ancient perimeter wall of the *castrum* (identified in Oleson (1977) and Enei (2008)), consists of remnants of harbor structures, which have been dislocated by wave action and are dispersed on the bottom from 1.50 to 2.60 m bsl (Fig. 5).

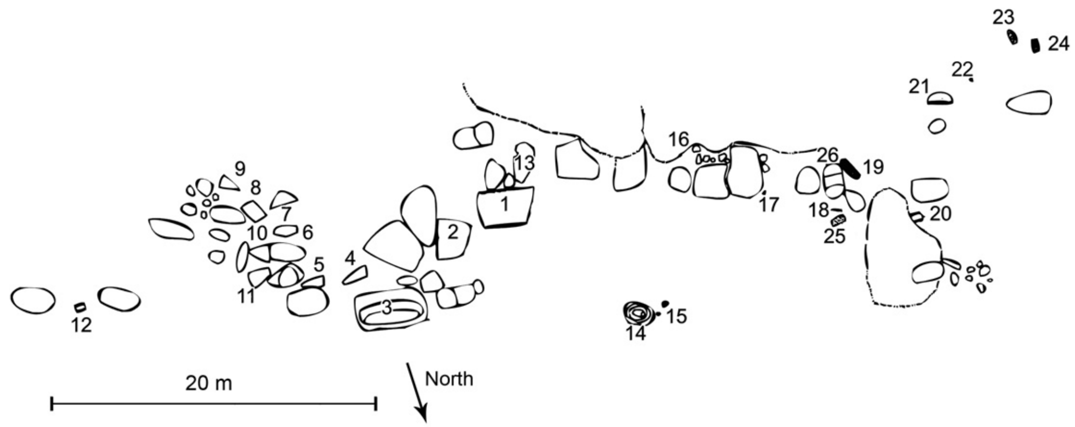

Fig. 5. Remnants of harbor structures dislocated by wave action at depths between 1.50 and 2.60 m bsl (redrawn from Enei, 2008). Legend: 1–3) 2.10–2.50 m wall remnants; 4–11) Squared stone blocks coming from the Roman *castrum*: 12, 15–25) Parts of smaller (30–40 cm thick) walls in some case associated to pavements (23,25), limestone *cubilia* (18,22) and roof-ceramics (16,17); 13, 14, 26) Parts of walls with remnants of wooden forms used as foundations.

This elements have been attributed by Enei (2008) to upper-mean Imperial Roman age (200 ± 200 BC–2150 ± 150 BP). The second, located seaward of the first (n.5 in Fig. 3), consists of a breakwater partially destroyed by wave action, whose top and bottom are located respectively at 1.50 m and 3.80 m bsl. Among the blocks of which this breakwater was made, two displaced bollards can be recognised. These remnants have been attributed (Enei, 2008) to the Adrian age or generally, to the Imperial age (150 ± 150 BC–2100 ± 150 BP).

4.2.4. Roman sewer pipe

Along the shoreline, east of the Santa Severa Castle, the remnants of a sewer pipe (n.7 in Fig. 3) and of a cistern are both archaeologically dated 2025 ± 175 BP (Fig. 6a). A reconstruction

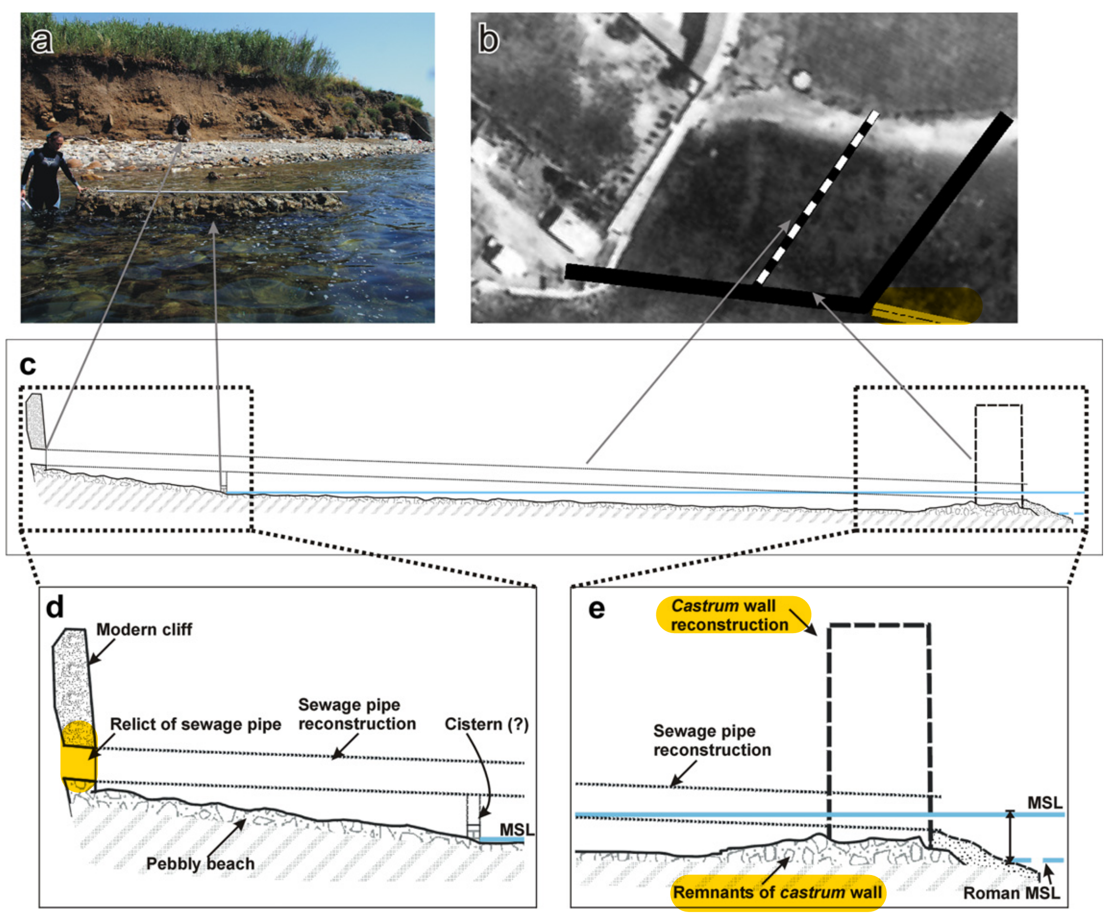

Fig. 6. a) Roman sewer pipe and remnants interpreted as a cistern (in the foreground). In the background, the cliff of non-cohesive materials has been eroding since at least the Etruscan epoch; b) Particulars of Fig. 3, showing the reconstruction of the castrum walls (made by Enei, 2008 on the basis of underwater surveys) and of the pipe; c) Schematic cross section of the cliff-castrum walls profile, showing the hypothetical reconstruction; d) Landward part of the reconstruction; e) Seaward part of the reconstruction.

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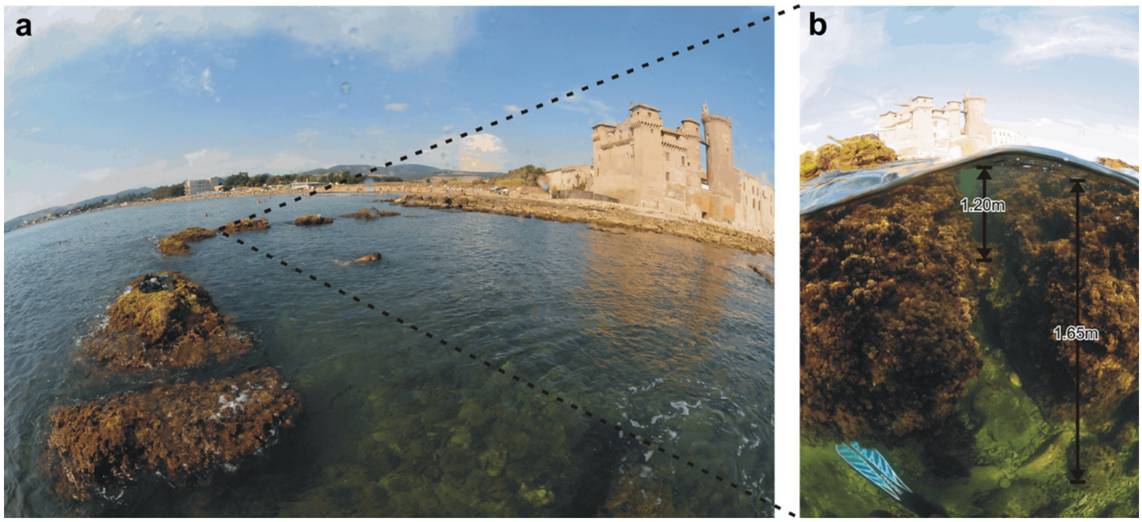

Fig. 7. a) Perimeter walls of the Pyrgi fishtank; b) particulars and measurements of the channel in the northern part of the fishtank.

(Fig. 6b,c) of the sewer pipe original size has been made following two assumptions. The seaward inclination of the pipe is assumed to be as measured, at 3°. The second assumption is that the pipe is related to the *castrum* walls, which are older (III century BC, 2.3 ka BP).

4.2.5. Pyrgi fishtank

The Pyrgi fishtank (n.6 in Fig. 3) was built on the northernmost jetty in front of the Santa Severa Castle, and has been previously described by Oleson (1977), Enei (2008) and Pellandra (1997). The structure consists of a square foundation formed by a concrete wall

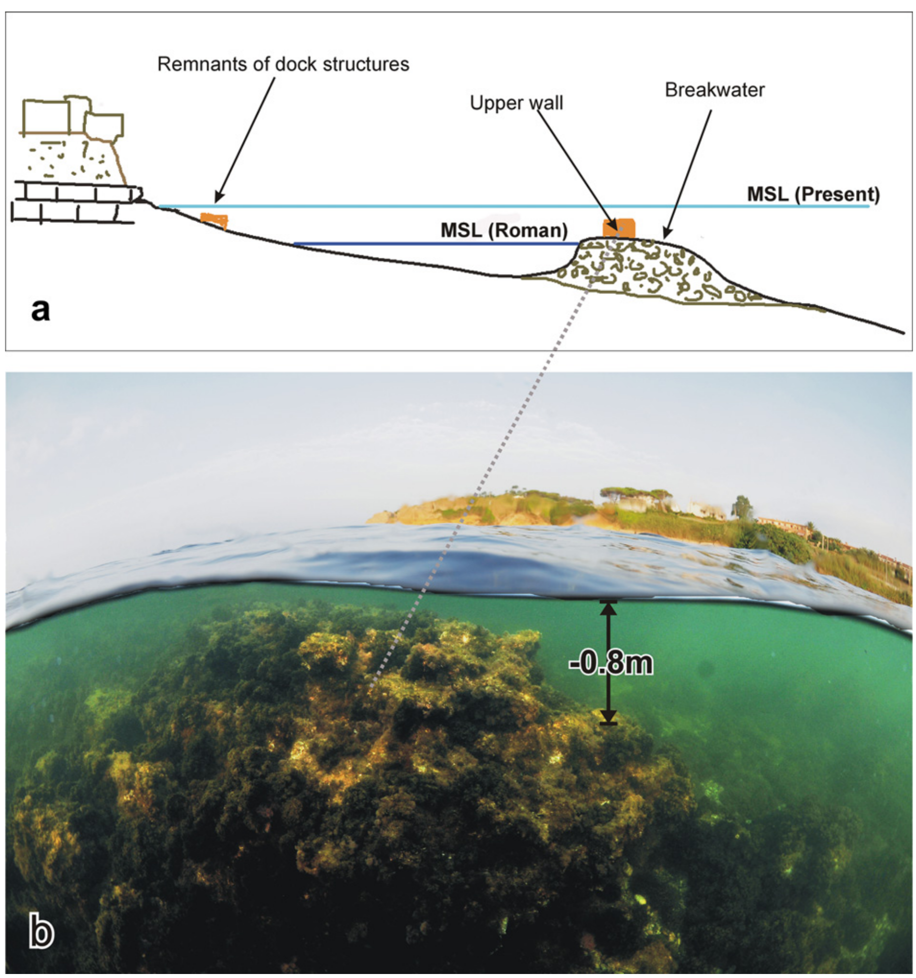

Fig. 8. a) Cross section of Le Grottacce Site, showing the location of the fishtank with respect to the breakwater and the upper wall; b) Upper wall.

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Table 1
Depth and age of the elements found in this study.

Element	Depth (Mean) (m)	Age (Historical)	Age (BP)	Age attribution
Planar surfaces	−10 ± 2	Ancient Neolithic	7300	Model results
Wells	−2.40 ± 0.25	Etruscan	2450 ± 100	Archaeological
Fishpond (Pyrgi)	−1.20 ± 0.3	Roman imperial	2070 ± 50	^{14}C
Fishpond (Le Grottacce) (Lambeck et al., 2004a,b)	−1.37 ± 0.2	Roman imperial	1950 ± 50	Archaeological
Upper wall (Le Grottacce)	−0.80 ± 0.2	Roman imperial	1950 ± 50	Archaeological
Foundation jetties	−0.75 ± 0.05	Roman imperial	2050 ± 100	Archaeological
Sewer pipe[a]	−1.20 ± 0.5	Roman imperial	2025 ± 175	Archaeological

[a] The depth of the sewer pipe is the result of a geometrical reconstruction: therefore, also the associated error is estimated.

approximately 2.50 m thick (Fig. 7a) and traces of internal subdivisions. Despite modification of the structure by wave action, at least two channels can be identified at 1.20 m bsl (Fig. 7b), while its base is at 1.60–1.65 m bsl. The channels could represent canals: "the bases of the canals, which guaranteed the refill of water from the exterior or among the basins, in most cases correspond with the lower level of the grid. The canals had to be always submerged in the lower parts, even during low tide, to guarantee water supply" (Auriemma and Solinas, 2009). The structure has been dated to 120 ± 50 B.C. (2070 ± 50 BP) through ^{14}C radiometric ages obtained from the still partially preserved wooden forms into which it was founded.

4.2.6. Le Grottacce site

Le Grottacce site is located 2 km from the Santa Severa Castle, and consists of a Roman villa built on the coast. Directly in front of the villa are different remains connected with the sea: a fishtank, described in Lambeck et al. (2004b), remnants of a dock, and, seaward, a large breakwater with a 1.60 m wide wall at the top (Fig. 8b), probably representing a walkway. The altitude of this walking surface was measured at −0.8 m. The age of these features has been archaeologically set at 1950 ± 50 BP.

5. Discussion

The depth and age of the elements described in this study (Table 1) allow some consideration on the paleogeography of the area and on the relative sea level changes throughout the last seven millennia (Fig. 9).

i) Based on the assumptions made on the functionality of the measured remains (Auriemma and Solinas, 2009), the base of the foundation jetties in front of the Santa Severa castle at Pyrgi should have been below sea level at the time of their use (Etruscan age). Conversely, the upper wall of Le Grottacce should lie above sea level at the time of its use (Roman age). Considering error bars, measured data are in agreement with the predicted sea level curve for both elements. For the Roman harbor structures, the intense modification due to wave action do not allow a precise location of the Roman sea level with respect to the present one.

ii) More precise assumption on the Roman sea level position can be made on the basis of data from the two fishtanks of Pyrgi and Le Grottacce (respectively −1.20 ± 0.3 m and −1.37 ± 0.2 m, the latter described in Lambeck et al., 2004b),

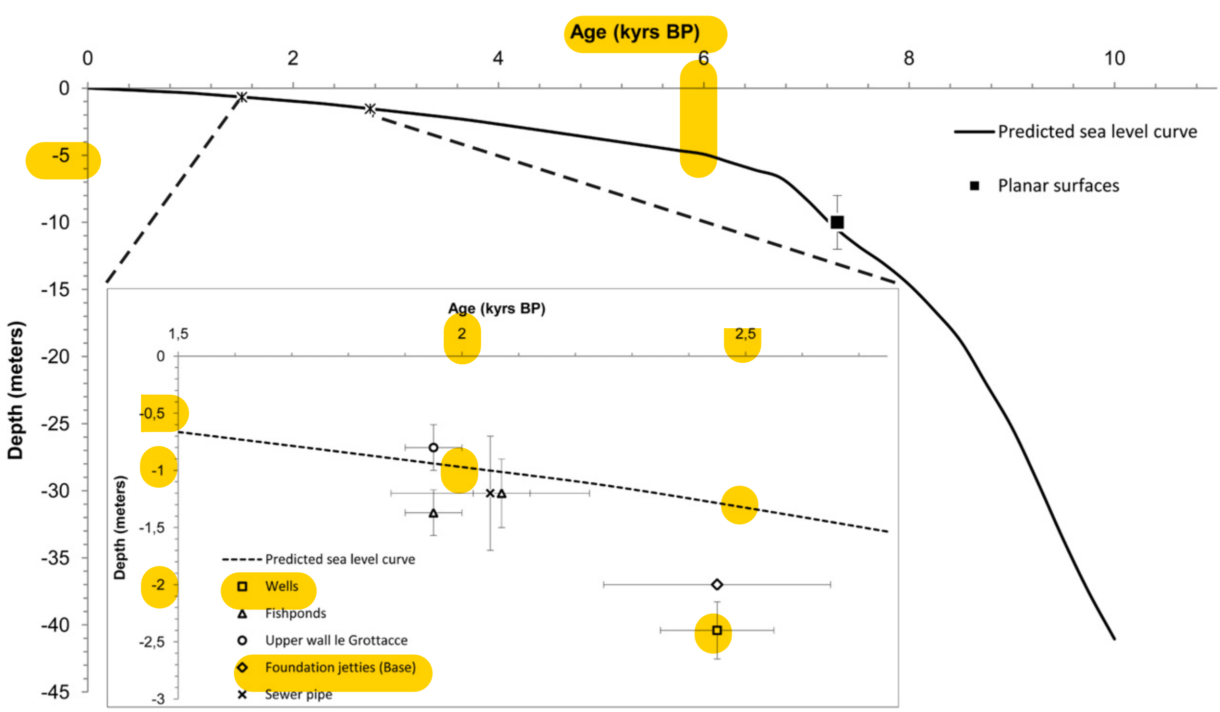

Fig. 9. Comparison between the data obtained in this study and the predicted sea level curve of Lambeck et al. (in this volume).

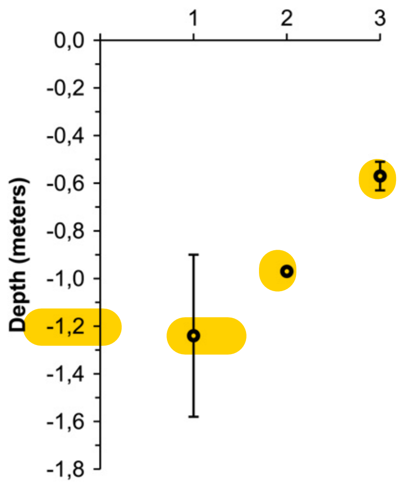

Fig. 10. Location of the Roman shoreline according to: 1) field observation; 2) predicted datum (Lambeck model, in this issue); 3) predicted datum from the theoretical model, added with the tectonic contribution calculated assuming a constant uplift of 0.17–0.25 mm/y calculated from the MIS 5.5 markers in the area, derived by Ferranti et al. (2006).

which are more reliable sea level markers. The average datum of these two fishtanks sets the observed Roman sea level (about 2000 BP) at 1.24 ± 0.34 m below present.

iii) This datum is in accord to that obtained from the geometrical reconstruction of the Roman sewer pipe, indicating a Roman sea level at 1.20 ± 0.5 m below present. The predicted value of the sea level in Roman time from the theoretical model is about −1 m, slightly higher than the observed one. Correcting this value for the tectonic uplift calculated on the basis of the altitude of the MIS 5.5 shoreline in the study area (0.17–0.25 mm/y), the Roman shoreline should be located at −0.57 ± 0.06 m (Fig. 10). Despite the uncertainty linked with the sea level predictions (discussed in Lambeck and Purcell, 2005) and with the reliability of the markers, the data presented in this study suggest that the uplift trend calculated on the basis of the MIS 5.5 markers is not representative of the Late Holocene tectonic behavior of the study area, which can be considered as stable to slowly subsiding in this time span. This is in agreement with previous geo-archaeological studies carried out in the proximity of the study area (Lambeck et al., 2004b). Without excluding a component of regional tectonic uplift, this suggests a major role of volcano-tectonic processes in the elevation of the MIS 5.5 shoreline.

The position of the Etruscan wells in the area provides an insight of long-term coastal erosion rate. According to the confrontation of the results with the glacio-hydro isostatic model, the bottom of the wells should lie, at the time of their use, at least 1 m below sea level. This is not in contradiction with the use of the wells as source of freshwater, as some unpublished cores (Soprintendenza dei beni Archeologici, Roma) reveal a particular geological conformation of the clayey impermeable layers, which preserved the wells from saltwater even if their bases were lower than sea level during Etruscan time (for a detailed methodology on the use of wells as sea level indicators see Sivan et al., 2001, 2004). By comparison with their counterparts, still preserved in the on-land part of the study area (Coccolino and Follieri, 1980), the top of the wells should lie at least at 3 m asl. The minimum coastal erosion rate since Etruscan time can be calculated dividing the distance of the wells from the modern shoreline (62 m), by the age of the wells (around 2450 BP). Hypothesizing that the wells were at least 20 m from the coastline (in order to avoid direct salinization due to swells), the mean coastal erosion rate since 2450 BP would be 3.3 cm/year. This value is a yearly average, estimated over a long-term basis. More likely, erosion and the consequent retreat of the soft cliffs characterizing part of the Pyrgi coastline occurred and still occurs mostly during low-frequency, high energy events.

6. Conclusions

Archaeological indicators have been surveyed and measured in order to obtain data on both sea level and the position of the Etruscan shoreline in the area of Santa Severa, known in the past with the Latin name of Pyrgi. While the position of three Etruscan wells allowed determination of an average rate of coastal erosion in the area, the position of Roman and Etruscan structures in relation to sea level gave a value of Roman sea level that (considering error bars) is in agreement with glacio-hydro-isostatic models, but is lower than the value expected following the uplifting pattern indicated by the MIS 5.5 shoreline elevation. The results suggest that the uplift rate inferred using the MIS 5.5 shoreline markers could be overestimated. Tectonic uplift may have ceased between the Last Interglacial and Holocene. In general, the results obtained in this study stress the importance of considering different time spans when attempting to define the vertical behavior of coastal areas. This assumes significance not only from a geomorphological point of view, but also from a coastal management perspective.

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