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Archaeological remains as sea level change markers: A review

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ABSTRACT

The Mediterranean Sea constitutes a unique basin from an historical and archaeological point of view, as it has been a privileged way of communication for thousands of years for the people that dwelled on its shores. Their passage has left many traces on the seabeds in the areas where the ancient commercial routes passed, and remains of structures where moorings, havens or dwellings existed. Some of these structures, nowadays submerged, offer interesting indications aiding the reconstruction of the ancient coastlines. This contribution aims to examine recent work in coastal geo-archaeology, targeting both (1) gathering and discussion of the data, particularly those pertaining to the Italian coasts; and (2) commentary on the methodological debate and verification of the possibility of a protocol that may contain unequivocal referring elements.

To investigate the archaeological evidence currently underwater because of the relative sea level variations (harbour infrastructures, fishponds, *villae maritimae*, caves – *nymphaei*, private or public buildings or town quarters, pre- and protohistorical villages, quarries, caves, etc.), a clear and more coherent methodological assumption may be needed. The archaeological interpretation must initially establish the maritime and/or harbour nature and vocation of the site, determine its typology and specific usage, analyze the elements of its building techniques (that reveal themselves as meaningful markers of height or depth at the time of building) and its "functional" elements (the measure of the emerged part with respect to the average sea level), and point out the time of construction, its chronological range of usage/frequentation, the dynamics of its abandonment/destruction/obliteration.

The evaluation of both the height and functional depth to the mean sea level depends on the typology of the archaeological evidence, its use and the local tide amplitudes. The surface of a pier surely has a functional elevation different from that of a haulage area or a *platea* or a pavement.

1. Introduction

The Mediterranean Sea (*Mare Nostrum*) is a unique basin throughout the world from a historical–archaeological point of view, since it was a privileged way of communication for the people living on its shores. This passage has left numerous evidence near the coasts, such as evidence of production structures, town structures, landing places, and ports. Some artefacts that are today submerged can provide interesting details to support the reconstruction of the ancient coastlines (Antonioli et al., 2007). To this day, no single text in the scientific literature clarifies the use of archaeological markers for studies of the variations regarding the sea and the coast. A pre-eminent previous contribution is the article by Antonioli and Leoni (1998, including references), an effective synthesis on the development of geo-archaeological studies.

This work is intended as a contribution to the use of a measurement methodology, to the correction of data, and to a clear interpretation that can be applied to most archaeological markers (Lambeck et al., 2004b). The review includes general and regional studies, as well as those of single sites, from a specifically archaeological aptitude, in the belief that only a close interaction between archaeologists, geomorphologists, and geophysicists can lead to persuasive results. The definition by Graeme Barker and John Bintcliff of geo-archaeology is particularly significant: "The only developed intellectual approach has to be a coherent sub-discipline of *human ecology*, neither a form of natural science nor a form of archaeology, but an integrated way of understanding humans in dynamic landscapes" (Barker and Bintcliff, 1999). This is the same aptitude informing the new archaeological research, rightfully referable to *landscape archaeology* and *global archaeology*.

This contribution aims to examine recent work in coastal geo-archaeology, targeting both

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1. gathering and discussion of the data, particularly those pertaining to the Italian coasts (Fig. 1): Northern Adriatic, Marche, Southern Puglia, Calabria, Campania, Lazio, Toscana, Sicilia, and Sardegna, but referring also to other significant works in other areas of the Mediterranean; and
2. commenting on the methodological debate and verify the possibility of a protocol that may contain unequivocal referring elements concerning the interpretation/exegesis of the archaeological data, the measurements of the archaeological markers, and the evaluation of errors.

2. Methods

The repertoire of the archaeological evidence currently underwater due to the variations of sea level is quite large. This includes harbour infrastructure (dry dock foundations, quays, piers, breakwater, equipped banks, haulage chutes, docks, dry docks, navy yards, etc.), fishponds, residential units – *villae maritimae*, caves – nymphaei, private and public buildings, or town quarters (foundations, floorings, roads and pavements, etc.), thermal baths, plumbing installations (wells, aqueducts, cisterns, sewers, drains, gullies), tombs, pre- and protohistorical settlements, quarries, caves, *beach rock*, beached wrecks, and anchorages.

In order to use this evidence, which has different degrees of reliability concerning the rendering of the ancient coastal landscape, a more coherent and explicit methodological assumption must be made: the archaeological interpretation/exegesis has to ensure the nature and maritime or harbour vocation of the site, and has to clarify the typology and its use. It moreover has to analyse the elements of building technique (which are important markers of height or depth at the time of the building), as well as the “functional” elements (namely, the size of the emerged part compared with the average sea level) (Fig. 2). Consequentially, it has to determine the period of construction, its chronological range of usage/frequentation, and the dynamics of its abandonment/destruction/obliteration. This is possible only after a series of surveys ranging from the prospecting of the area being studied to the sampling of the chronological indicators present (ceramic finds, etc.), and to the detection and (partial) excavation of part of a structure (sample). The retrieval and the transmission of archaeological data are not always unequivocal (even if strict), since it is based upon the current knowledge and upon the interpretation of the data.

Interdisciplinary work needs a tight link between archaeologists, geomorphologists and geophysicists, and hence the formulation of a pattern that provides

- measurement of archaeological markers already interpreted, as described above, repeated and conduced on the best preserved parts of the monument;
- 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 is different depending on the typology of the evidence, its use and the local tide amplitudes (the surface of a pier has a functional elevation different from that of a haulage or a *platea* (used surface) or a pavement; the depth of a fishpond is different from that of a cistern, etc.);
- error bars both for temporal values (when the archaeological study has not been able to determine the precise chronology

Fig. 1. Map with the location of the contemplate sites.

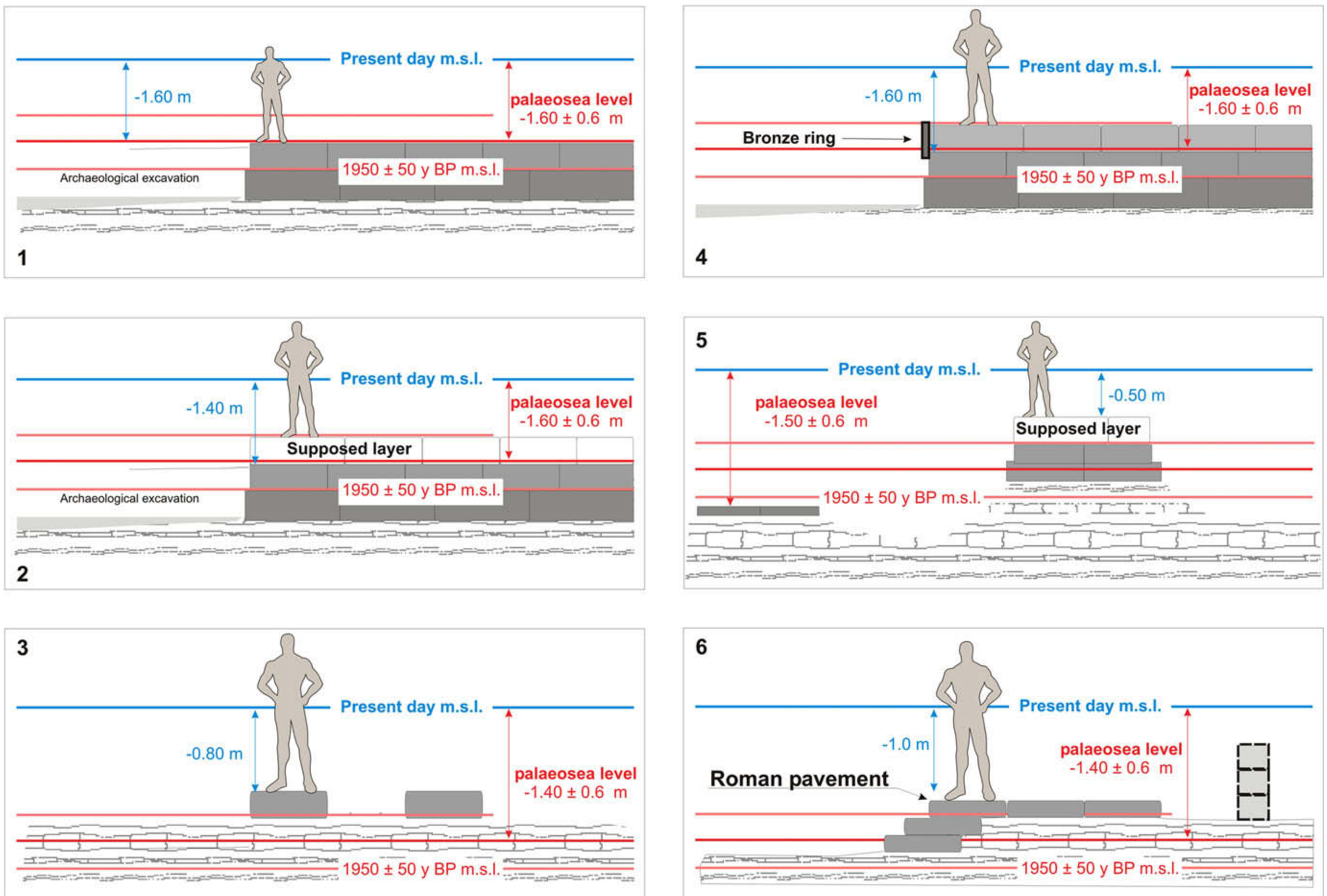


Fig. 2. Cross sections of some archaeological sites showing their functional height and relationship with the current and past sea level: (1) Stramare; (2) Punta Sottile; (3) San Bartolomeo; (4) San Simone; (5) Salvore; (6) Briunj (Antonioli et al., in press).

of the monument) and for elevation (linked to the measurements, the corrections and the estimate of the functional height);
- comparison, for the site studied, between the current theoretical model (Lambeck et al., 2004a,b) of the sea level variations and the values observed. Where curve and marker are the same, it is possible to hypothesize a stability of the area. Observed values differing from those of the model indicate tectonic subsidence.

For the first phase, a typological selection is convenient, a census of all those structures that are able to provide data on the variations of the sea level for that location due to their use, position, preservation, and geological placement. For architectural stone or concrete structures, the *condition sine qua non* is that they are based (or excavated) on bedrock. Remains built on unconsolidated material cannot be considered.

For the second phase, the measuring and correction of the obtained measurements, it is necessary to correct an analysis of the mareographic data in order to determine the heights at the time of the survey with respect to average sea level. It is also necessary to correct the measurements with tide, pressure and wind data. If a tide-gauge is not available within 50–100 km, it is essential to correct the measures with a portable mareograph installed at the site (Antonioli et al., 2007).

Both for the first and for the second phase, the following technical rules have to be considered: detailed topographical surveys of the studied structure (or expedited, in case of logistic difficulties when using the equipment), bathymetric surveys (to connect the studied structure with the bathymetry, e.g. *Punta Sottile* N, *Muggia* – Trieste, Fig. 7), and direct measurements of the "negative" heights made with the INVAR bar in shallow waters. In case of depths superior to 3 m, measurements must be carried out with a float with a lead weight ferrule and a metric drawstring.

A similar protocol was used during a project directed by INGV (Marco Anzidei), funded by the Italian National Research Council (CNR) in 2001–2003, by this group in the study of the Tyrrhenian Sea fishponds and in the Interreg Project Italia – Slovenia "AltoAdriatico", thanks to the partnership among the Department of Scienze dell'Antichità and the Department of Scienze Geologiche, Ambientali e Marine of the University of Trieste, and ENEA (Antonioli et al., 2007).

3. Archaeological features and data

3.1. Fishponds

Fishponds are the most reliable class of monuments for the study of these variations, as they have had a very accurate relationship with the sea level and with the tide variations at the time of their construction, i.e. between 1st century B.C. and 1st century A.D.

3.1.1. Tyrrhenian Sea fishponds (piscinae)

Exemplary works on the Tyrrhenian Sea fishponds include Anzidei et al. (2004) and Lambeck et al. (2004a,b). The analysis of the sources and the recognition carried out at sea allowed a restrictive selection of significant markers compared to previous studies, i.e. the exclusion of the external perimeter walls (which cannot provide reliable data on the ancient sea level). Analysis was confined to the reference heights gathered from

(1) *crepidines* running along the inner basins, i.e. the narrow paths (sometimes paved) which enabled maintenance (probably without getting wet). In some fishponds, several levels of *crepidines* were found. The top of the sluice gate (*cataracta*) corresponds to the level of the lower grid. The upper *crepido* always had to be emerged in order to guarantee maintenance;
(2) captation 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 part, even during low tide, to guarantee water supply;
(3) closing gates (*cataractae*): only some are still *in situ*. The access of the canal into the basin or the communication passage between each basin is characterised by a horizontal element for the lower level flanked by two piers. These three elements all have a groove – rack rail to insert the grid. Another horizontal element is the upper trim size, which has a fissure to extract the sluice gate. At the time of its construction, the sea level (for functioning) could not go over the top of the grid (to avoid the leakage of water and loss of fish), nor underneath the base of the grid, to guarantee an uninterrupted influx of water;
(4) carvings for the *trop-plein* at the top of the dividing walls were useful for the communication between the internal basins, so they had to be somewhere near the average sea level or a few centimetres above, in order to be put into action only during high tide.

Considering that the maximum tidal amplitude in the Tyrrhenian Sea is approximately 0.4–0.45 m, the sea level had to be within this range with the present height of the grid. The thickness of the upper element (about 0.2 m) guaranteed a security limit. Considering that the average height of the grid was 0.6–0.7 m (except in particular cases), and that it never had to emerge completely with respect to the sea level, the old sea level is easily identifiable. In the fishpond at *Ventotene* (Latina), the sea level rose about 1.5 ± 0.2 m (Fig. 3). Relating this datum to the harbour, the quay (currently submerged) emerged 0.4 ± 0.2 m. Along the western part of the quay, a submerged bollard at -0.57 cm was found, providing a further datum on the current submersion level. The fishpond in *La Banca* near *Torre Astura*, missed by previous surveys (Schmiedt, 1972; Pirazzoli, 1976; Leoni and Dai Pra, 1997) and discovered under the beach sediments by Marco Anzidei, provides useful datum points, having the *cataractae* which allow measurement of the relative rise of the sea level as 114 ± 22 cm. Various examples of fishponds indicate lowering of some parts of the Phlaegraean coast to 4.5 ± 0.5 m below current sea level, due mainly to bradyseismic movements (Benini, 2007).

The work carried out by this group in *Briatico* on *Scoglio Galera* (Vibo Valentia), where there is a *vivarium* (fishpond), is quite interesting. In the latter there are four communicating basins carved in the rock, and other structures (Fig. 4). Geo-archaeological investigations discovered that the hollow running horizontally along the internal perimeter of the basins was not provided as a socle or carved step to go down, but is a groove caused by the persistent location of sea level at the time of its construction.

One remark concerning the quoted study concerns the submerged structure in *Basiluzzo*, in the Isole Eolie (Messina). The difficulties in positioning this structure in the coastal landscape arrangement, and in defining its nature, function, and relation with the villa (even from the chronological point of view) make it impossible to use it as a marker for the estimation of sea level rise.

The results radically changed the evaluations of the study by Schmiedt (1972). This research is a starting point for all studies concerning this topic. From Toscana to southern Lazio, there is an average variation of the sea level of 1.25 m over the past 2000 years, caused by isostasy, eustatics and tectonics. In Calabria, based on the connection between the heights in the different archaeological and geo-morphological elements of the Briatico fishpond, sea level has not changed in relation to the functional height of the structure, because the combined isostatic and the glacio-hydrostatic effects have the same value as the tectonic uplift. Therefore, the total rise (both sea level and tectonic uplift) is 1.4 m in the last 1806 years (the year of construction ascertained from ^{14}C AMS of a wooden fragment belonging to the original mould; Anzidei et al., 2004).

3.1.2. Adriatic Sea fishponds

The Adriatic fishponds (Fig. 5a–e) are less significant as they do not have such evident structural elements connected to sea level. The construction technique (*gettata di pietre sciolte o pietre perse*) consists of single stones thrown into the sea, used to delimit large overlapping basins (Auriemma, in press). However, there are parts that can be recognized as piers or a walking plane: this is the case for the fishpond of *San Bartolomeo* or the one in *Fisine* (Gaspari et al., 2006), which were both measured (Antonioli et al., 2007).

Fig. 3. Ventotene fishpond: the fixed sluice gate (Lambeck et al., 2004b).

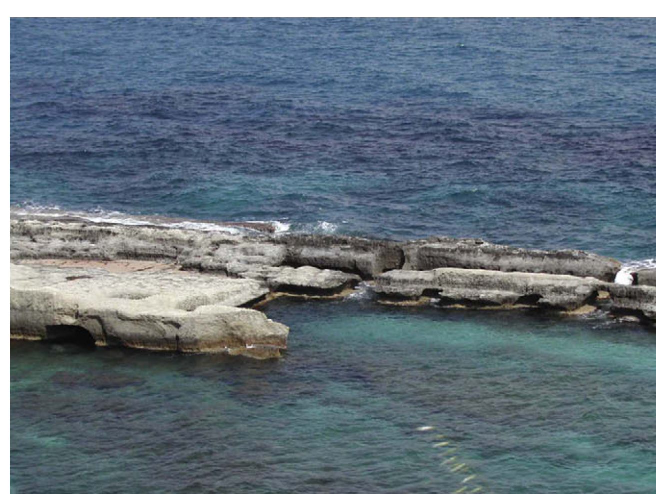


Fig. 4. Briatico, Scoglio Galera: fishpond.

Fig. 5. Adriatic fishponds: (a) S. Bartolomeo/Jernejeva draga, Ankaran (Slovenia); (b) Fizine, Portorose (Slovenia); (c) Catoro, Umag (Croatia); (d) Kupanja, Poreč (Croatia); (e) Svršata, Kornati Island (Croatia).

An interesting remark can be made concerning the presumed fishpond belonging to the villa of *Val Catena/Verige bay* on the island of Brioni (Fig. 6) (Jurišič, 1997; Schrunk and Begović, 2000). The base of the presumed fishpond is at −1.20 m (corrected with tide and pressure data), at the same depth as the walking plane (quay) of the nearby pier (−1 m). Therefore, it is impossible to presuppose a basin function for a structure that surely was emerged and had different usages (avant-corps of the villa?; Antonioli et al., 2007).

3.2. Harbour structures

The harbour (port) structures have a greater margin of error, both for the state of preservation and due to the limited knowledge on the ancient heights (or for the variability degree of the ancient height) of the quay level compared to the sea level. The significant markers are represented by

(1) walkways of the piers or coastal embankments in comparison with the sea level;
(2) evidence of carpentry, such as the *catenae*, i.e. the horizontal beams to which the bulkheads of the wooden caisson were hooked. The *catenae* were put into action just above the sea level at the time of construction. The moulds of these wooden structures have been preserved in the cement, which "flooded" the caisson;
(3) the bollards and the clinch rings, if preserved;
(4) string-courses between building techniques or different coverings: the foundation of the cement quays (with hydraulic grout containing pozzuolana), with or without a cover (depending whether the jet occurred in a watertight caisson (with a double gap, which enabled the emptying and work inside, or was flooded), and a slope from sea level or just above (with a brick covering, for instance; see *Neronian harbour* in Anzio: Felici, 1993, 2002).

Fig. 6. Brioni, Villa of Val Catena (Croatia): the presumed fishpond.

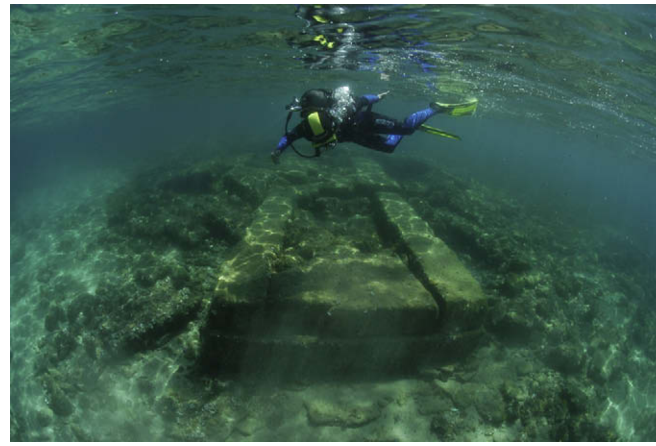


Fig. 7. Punta Sottile, Muggia (Trieste): the pier.

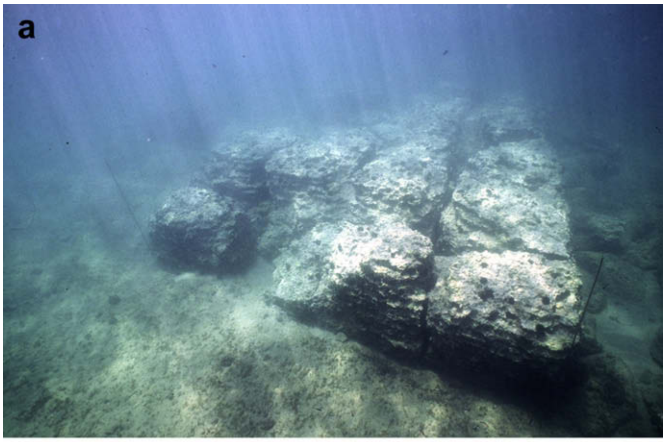
3.2.1. Piers and quays

The height of the pier surfaces depended on

(a) the draught of the ancient ships, which was smaller than the modern ones. Fishing boats or the small or medium tonnage *oneraria* ships (up to 20–22 m length) had a draught ranging from 0.5 m to 1.5 m, as suggested by some examples dating to the Middle Ages: e.g., the ship of the Late-Roman "Parco di Teodorico" wreck (V century A.D.): draught about 0.5 m (Medas, 2003); Fiumicino 1: 1–1.5 m depending on the load (Boetto, 2003); Grado 1: 0.8–1.2 m (Beltrame and Gaddi, 2007); Jules-Verne 7: 0.7–1.1 m (Pomey, 2003); Kinneret boat: 0.6–0.8 m (Steffy, 1990); Anse des Laurons 2: 1–1.5 m (Gassend et al., 1994); Serçe Limani: 1.2–1.6 m (Steffy, 1982); La Chrètienne C: 1–1.2 m (Joncheray, 1975); Cavaliére: 0.5–1.2 m (Charlin et al., 1978).
(b) the tidal range, which is obviously changeable, according to the coastal area under consideration;
(c) the use and the kind of receptiveness that change from the outer pier, in service of an urban centre or terminal of important sea routes (assigned to the mooring of big merchant ships with bigger draught and bulwark height), to the small landing stage/loader belonging to a residential or productive unit (that received small boats used along the redistribution routes);
(d) the limits to the navigation season in the Roman age, from October to March: the period when navigation was forbidden (*mare clausum*: Janni, 1996). Some piers, mostly the smaller ones, were inactive in some periods because of very high or low tides, especially in the northern Adriatic, where the tidal range is very wide.

The exposure (especially the piers) to the energy of the wave action sometimes prevents the preservation of the original working surface, whose height can be estimated through archaeological survey. This is the case for the small pier in *Punta Sottile*, *Muggia* (Trieste) where the presence of a third missing row was deducted from the conditions of the nearby collapsing blocks, in addition to the relation between the height of the platform (*platea*) at the back, which is partially made up of rocks (Fig. 7). *Punta Sottile* is one of the sites, in addition to *Salvore*, *S. Simone*, *S. Bartolomeo*, *Stramare*, *Grignano*, etc. studied in the Interreg Project AltoAdriatico" Italy–Slovenia (Antonioli et al., 2007, in press; Auriemma et al., in press), where the application of the protocols related to the docking structures, piers and quays belonging to harbour structures or simple landing stages/loaders, assigned to the goods loading more than to the ships stop (*carigador*) of the Northern Adriatic were tested. A functional height of 0.60 m was suggested for the piers, with an estimated relative sea level change value of 1.60 ± 0.60 m (0.60 m as a margin of error, due to the large tidal range, which reaches 1.20 m). The inconsistency between the data and the Lambeck curve indicates active tectonics in the two past millenniums, in contrast to what was previously supposed (Antonioli et al., 2007). The same protocol has been suggested for the Greek structure of *Megara Hyblaea* (Catania), the so-called "banchinamento Orsi", identified as a quay. It is not clear, however, how it is possible to estimate a height of the paleo sea level at 1.48 m (Scicchitano et al., 2008). In *Egnazia* (Brindisi), the revision of the submerged evidence and the clarification of uses, functions and building technology identified these as harbour structures made of cement, and to date them to the third quarter of the 1st century B.C. (Auriemma, 2004). In the southern part of the pier, which is made of pozzuolanic cement, the prints of the *catenae* and moulds from horizontal beams are perfectly clear. The beams were placed just above the sea level to wind brace the wooden chest together with the vertical poles and the perimeter supports. The *catenae* in Egnazia are currently at −3 m m.s.l. (Fig. 8a and b).

This example illustrates an incorrect assumption of the archaeological datum, noticed in Marriner and Morhange (2007), where the value of the sea level rise doubles, i.e. from 3 to 6 m! A "distortion" in the use of the archaeological datum is also found in Stiros (1998), also see Papageorgiou et al. (1993), on the *opus caementicium* structures of *Mavra Litharia*, in the Gulf of Corinth. The part of the pier above the sea level should be more than 2 m high (from 3.90 to 6 m above the current sea level). Which ancient ship could have docked at a 2-m high pier? The "functionality" problem of this structure was not considered. Maybe this height referred to an external wall, which protected the boarding/disembarking operations, although Stiros (1998) does not supply a plan of the presumed piers. These building techniques (the cement "bag-shaped" basement or foundation and the elevation with covering) also characterize interior and harbour structures (for example, sub-structures and the elevation, foundations and elevations). Therefore, it is not the building technique in the case of *Mavra Litharia* (at least as described by Stiros, 1998) that demonstrates the nature of the buildings and indicates the tectonic rise, but the opposite. It is rather the observation of the lower strata, undoubtedly marine, together with the observation of the rising movement affecting the Gulf of Corinth that indicates port structures (even though the perplexities concerning height remain).



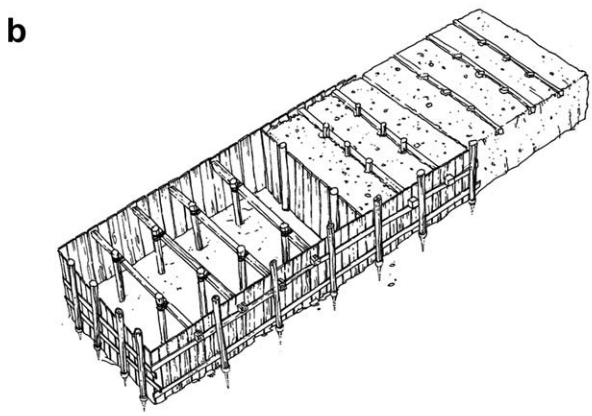


Fig. 8. Egnazia (Brindisi). (a) Southern pier. (b) Reconstruction hypothesis scheme.

3.2.2. Breakwaters

Breakwaters are less important and indicative as markers except for two cases:

(1) when their elements, i.e. carved blocks, have tilted or collapsed, can be referred to their original position;
(2) when they are associated with other elements.

There are some examples in the Salento region, in *Torre S. Gregorio* (Lecce) and in *Saturo* (Taranto), both built with the typical technique of "throwing single rocks" (*gettata di pietre sciolte o pietre perse*: Auriemma, 2004; Felici, 2007) (Fig. 9). These breakwaters were originally above sea level. Currently, the tops of these breakwaters are between −2.30 and −2.5 m. On the surface of the breakwaters in *Saturo* were found the remains of a load of bricks, probably sunk between the end of the 2nd and 1st century B.C., because the ship shattered against the breakwater. Archaeological material supplies an important chronological reference. At the time of the shipwreck, the seawall was probably just above or just under the sea level (Auriemma, 2004; Colucci, in press).

In Sardinia, near the mouth of the inlet in *Capo Malfatano* (Teulada – Cagliari), two large breakwaters have been studied, and their function seems to be to protect the internal landing place which has been identified with the Ptolemaic *Portus Herculis* (La Marmora, 1921; Barreca, 1965) or more recently with *Bithia Portus* (Mastino et al., 2005). The top blocks coming from the coastal quarry in *Piscinnì* are about 0.5 m $\times$ 0.7 wide and about 2-m long (Fig. 10). Because of the lack of excavation surveys, the dating of the breakwaters is based upon the information taken from the sources, and from the finds from the nearby area, which allows dating the structures to the Roman–Punic Ages. Considering that tidal range for the Tyrrhenian Sea is 0.45 m, a functional height of 0.70 m above the sea level at the time of construction was estimated, resulting in a paleo level of -2.26 ± 0.23 m dating between the 4nd and 1st century B.C. (Antonioli et al., 2007).

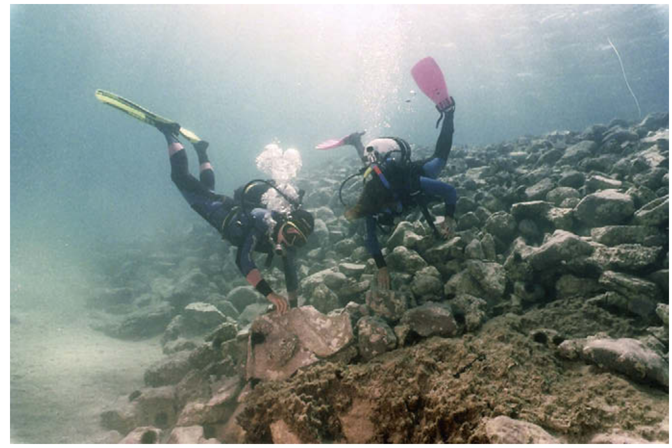


Fig. 9. Saturo (Taranto). The breakwater.

Fig. 10. Capo Malfatano (Teulada – Cagliati). The breakwater.

The same criteria have been used to date the breakwater in the western inlet of *Nora* (Pula – Cagliari) (Fig. 11), which had been already indicated as a pier (Schmiedt, 1965). It was built with sandstone blocks with a subrectangular section from the nearby quarry of *Is Fradis Minoris*, and resting upon an elevation made up of weak volcanic rocks. In this case a 0.60 m functional height was estimated, indicating a sea level rise of 1.58 $\pm$ 0.23 m (Antonioli et al., 2007). In both cases, the presence of regular blocks (which composed the top) resting upon an irregular elevation enabled the reconstruction of the original position of the base.

3.3. Private and public buildings

Private and public buildings, town quarters, political and religious buildings, and residential units can also be important, even though they cannot give precise height values in comparison with the sea level. Compared to the sea, at what height should a floor or a walking plane have been constructed? More than one answer is possible. Sivan et al. (2001) believed that "the living floors of underwater sites provide only upper bounds of palaeo sea level, and under the assumption that the living quarters were above the sea spray level, the sea level is assumed to have stood at least 2 m below these floor levels"; currently, the walking/living floors could have been more than 2 m.a.s.l. However, these monuments can easily be identified and dated. This is the case of the basilica built in the 4th century in *Nora* (Pula – Cagliari), which lies in front of the western inlet (Bejor, 2000). The interior is divided into three aisles leading to an apse, which is now submerged, with the remnants of the foundations visible. The variation has been estimated at larger than 1.18 $\pm$ 0.23 m, assuming as a minimum the same functional height (0.60 m), and considering that the floor of the basilica had to be above the maximum high tide.

An excellent case is that of the great archaeological heritage of the *Campi Flegrei* (*Phlaegrean Fields*), especially of *Baia*. A recent study, which discusses the post-Roman history of the bradyseismic movements along the Phlaegrean coast (Morhange et al., 1999, 2006; Pappalardo and Russo, 2001) is an accurate analysis of the geo-morphological, archaeological and historiographic data (literary and archive sources, such as The Apocryphal Acts of the Apostles). However, it is rather restricted from the methodological point of view. This study illustrates the post-Roman sedimentary sequences in geo-archaeological contexts: the Granaries in *Pozzuoli*, the Nymphaeum in *Baia*, the underwater remains near *Castel dell'Ovo*, in *Posilippo*, *Marechiaro*, *Nisida*, *Pozzuoli*, *Portus Iulius* (whose remains are certified up to various metres below sea level), and along Ripa Puteolana, the submerged town area in *Baia*, the submerged structures in *Bacoli*, *Miseno* and *Torre Gaveta*, and the stratigraphic survey in the town centre of Naples (Anzidei et al., 2004; Benini, 2007; Benini, in press; Benini and Giacobelli, in press).

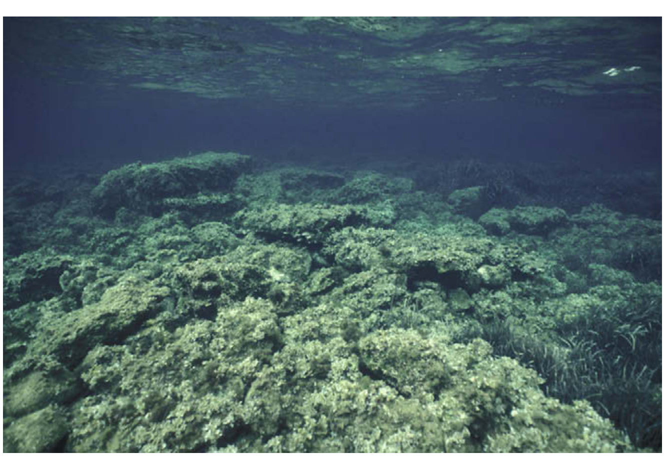


Fig. 11. Nora (Pula – Cagliari). The breakwater.

Thus, the "Puteolan Curve of the bradyseism" (Parascandola, 1947) has been updated, as it was based on the data coming from the Serapeo in *Pozzuoli* (*macellum*). A very well-structured analysis of the situation on the geo-morphological events in this active volcanic area includes

(a) the sinking of the Phlaegrean coast caused by the bradyseismic subsidence took place during three fundamental periods: between the end of the 4th and 5th centuries; between the 7th and 8th centuries, and between the 14th and 16th centuries. Each was preceded and was followed by an inversion of the phenomenon, which led to a rise with a partial or total emersion of the areas;
(b) the total extent of the sinking estimates is about 17 m, of which only 6–7 are retrieved by the rising bradyseismism (Pappalardo and Russo, 2001; Morhange et al., 2006).

The use of private and public buildings as markers of variations concerning sea level is limited to a few cases. In the majority of the cases, the metric values of the current submersion are no considered. Several contributions regarding the structures in the peninsula of *Vižula*, *Medulin*, near Pula do not mention at which depth the piers, quays/equipped banks, the fishponds (?), or the sewers are, nor have they published graphics allowing retrieval of this information (Jurišić, 2006; Miholjek, 2006).

3.4. Coastal quarries

The coastal quarries (see examples from the Salento region: Auriemma, 2004; Auriemma et al., 2004, 2005) are interesting, although the height of the surface of the detachment/mining of the blocks involves a higher margin of error. Moreover, it is not always possible to date them with accuracy, even if the territorial context, the blocks module or the relative metrological system (Punic, Greek, Roman) and architectonical elements left *in situ* are significant archaeological indicators. There are two assumptions:

(a) these quarries, today partially underwater, completely emerged in order to enable mining;
(b) the blocks were embarked near their original place and shipped to the destination, which was not too far away, in the case of simple rocks.

The evaluation on the relationship between the mining place and loading place has never been realized due to the difficulties that it causes: little is known about these kinds of ships or barges. In addition, little is known about the way they were loaded, probably with derricks. Thanks to the quarry in *Ventotene*, Marco Anzidei (in Lambeck et al., 2004b) suggested an estimation of the functional height of the quarry level, on the strength of the relationship between the height of this same level and those of the fishpond and pier that are in close proximity (the data of this site offers a precise estimate of the relative emersion of the different Roman markers). This functional height is 0.30 m. The value was also applied to the quarry in *Capo Testa* (Palau – Olbia/Tempio) and to other Sardinian examples (-1.16 ± 0.30 m). A different value ($\geq$0.60 m) has been considered for the quarry in *Punta della Mola*, Maddalena Peninsula, assuming a minimum elevation at 0.30 m above high tide (Scicchitano et al., 2008).

The holes in the quarry of *Piscinnì* (Teulada – Cagliari), next to Capo Malfatano Bay, can be interpreted as the places where loading derricks were (Fig. 12a and b). If block loading and shipment *via* sea are not called into question, in the case of the use of the peninsula of *Is Fradis Minoris*, in the western inlet of *Nora* (Pula – Cagliari) the situation is more complicated. The quarry was situated along a palaeo sandbank once partly protecting a lagoon, which has been several times indicated as the principal harbour area of the ancient town (Bartoloni, 1979; Finocchi, 1999). The part overlooking the inlet blocked the approaching boats and protected the mining from the ground-swells, thanks to a non-excavated belt. It is likely that the loading of the stone materials only took place on the side overlooking the lagoon. It is possible to date the mining activities to the same period of time supposed for the breakwaters.

The coastal quarry in *Perde e'Sali* (Antonioli et al., 2007), located not far from Nora along the coast along which are remains of Roman villas, can be dated to the Roman period. An open-air quarry, today partly underwater, shows grooves chiselled by the miners, some of which are deep and outline different-sized square blocks.

The sandstone quarry locally known as *Sala'e Ballu* to the north of the San Giovanni beach, next to the Phoenician – Punic and subsequently Roman village of *Tharros* (Cabras – Oristano), was exploited since the Punic Ages. Dating was possible thanks to the presence *in situ* of an Egyptian gorget, a typical feature of the Punic civilization.

The quarry in *Punta S'Achivoni* (Marina di Arbus – Medio Campidano) could date back to the Punic–Roman ages. The quarry may be related to the village of *Neapolis* (Solinas, 1992), the only large urban centre in the neighbourhood. The quarry faces the sea side of the Capo Frasca headland, which flanks the Golfo di Oristano, whereas the urban centre of *Neapolis* rises on the far southern side of the "pond" in Marceddì – San Giovanni (Zucca, 1987; Solinas et al., in press).

In *Egnazia* (Brindisi) open-pit quarries with the step system are present. Hollows representing the positions of extracted blocks, and *in situ* ready but not removed blocks are present. The floor level of these quarries stands currently between −0.5 m and −1.00 to 1.50 m. The dating is still debated, but in some cases, pseudo-sarcophagus shaped tombs (datable between the 5th and 4th centuries B.C.) cut at the bottom of the quarries are a useful *terminus ante quem* for the intervention of the rock exploitation. Furthermore, the blocks that were abandoned before being removed are rather large, giving a further clue of antiquity (Auriemma et al., 2004).

In *Torre S. Sabina* (Brindisi), where the surveys highlighted a landing place from the end of the 2nd millennium B.C. to the Middle Ages, evidence of exploitation is visible on the surfaces of the rocks of the inlet (Auriemma, 2004; Auriemma et al., 2004, 2005). The western quarry has its bottom, i.e. its living floor, at −0.50 m to −1 m. Unfortunately dating is not possible, even though the blocks at the bottom of the inlet are large and are datable back to the Roman or Hellenistic Age. In the area between *Egnazia* and *Torre Canne* (Brindisi) are quarries with large blocks, which eluded erosion, whose living floor is 2 cm from the surface of water.

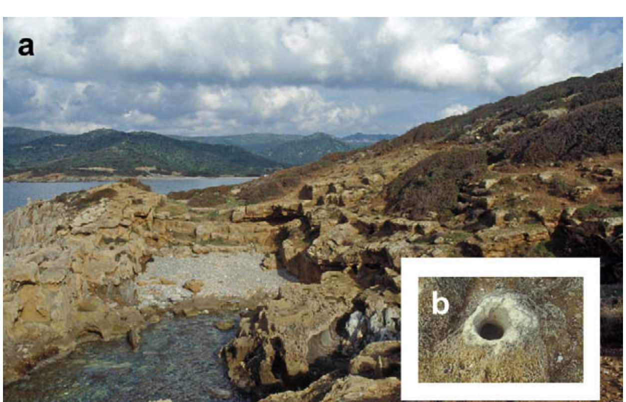


Fig. 12. Piscinnì (Teulada – Cagliari). (a) The quarry; (b) The hole.

3.5. Hydraulic systems

Hydraulic systems presuppose a close link to the coeval sea level. In *Egnazia*, *Torre S. Sabina* in the Mezzaluna inlet, *S. Vito di Polignano* (Bari), are canals whose bed is currently at about −0.80 m under sea level, whereas they should have been above in order to guarantee the disposal of the town waters. In *Egnazia*, a cistern, internally lined with *cocciopesto*, has its bottom at least −0.36 m below the current sea level (Auriemma et al., 2004).

3.5.1. Wells

Even the wells, which were fed by ground water, which are currently underwater or situated along the coast up to 150–200 m from the seashore, are important markers of sea level variations. A particular contribution is given by an important data set, 64 near-coastal wells in *Caesarea Maritima*, dating from the early Roman period (the oldest occurring in the 1st century A.D.) up to the end of the Crusader period, mid-13th century A.D. (Sivan et al., 2004). Thanks to several measurements, it is possible to estimate a 0.80 m height of the water table above the mean sea level. There are two assumptions: first, the relationship between the two levels has remained constant over time. Second, the bottom of these wells must have been at least 0.30–0.40 m below the water table, in order to easily reach the water with containers, under all conditions, as is the case for modern wells in the area. The bottom could not have been deeper, to avoid the salinization of the water. The reductions used are well bottom + 30 cm = past water table; past water table − 80 cm = paleo sea level. The idea that the bottom of the wells was only 30–40 cm below the water table is rather binding. The height of the potable water column in modern wells can be noted, but the methods of drawing water have changed. In any case the results are quite interesting, especially for the Byzantine and Moslem periods, indicating that sea levels at Caesarea were at or above present level. Furthermore, the well data is consistent with an absence of significant vertical tectonic movements of the coast over about 2000 years, as the preservation of an effective gradient in the Roman aqueduct across the coastal plain indicates.

In Italy, near the port of *Pyrgi*, the port of the Etruscan city Caere, today named Cerveteri (RM), were found some wells which were in use, according to filling material, between the 6th and 3rd century B.C. The interior of the wells is now situated at −2.30 to −2.60 m (Enei, 2008). The structures are 1.5 m in diameter and have a height of 0.30–0.40 m. They rest on clay at −2.7 m, indicating a significant rise in relation with an increase in sea level.

3.6. Pre–protohistorical settlements

Several pre–protohistorical settlements are partially submerged. Unlike the historical settlements, the functional height of the living floors cannot be evaluated, unless they are associated with other elements.

The area around *Torre Guaceto* (Brindisi), an extensive settlement dating back to the Bronze Age, symbolizes very well the destructive action of sea modelling. The natural obstruction of a water branch has been partly destroyed by the last sea level rise, and fragmented to a series of headlands, islets, rocks of Apani, where the "stubs" of a presumed formerly continuous wall are situated. Round pole holes are located in the rocks at variable

Fig. 13. Santa Gilla (Cagliari). Commercial amphorae.

depths, between 0.50 m and 2.5 m, with diameters ranging from 25 to 50 cm, some in a row. Many others are along the northern coast, along the inlets, and along the perimeter of the islets. In some cases, the ridges at the bottom of the inlet have holes for timbers of huts, originally above sea level, very close to one another, seeming to close the lowered part, which is currently invaded by the sea with a depth of −0.50 m to −1.00 m. The bottom of the current inlets corresponds to an ancient internal living floor belonging to living and/or producing units or huts (Scarano et al., 2003).

Extremely interesting for their richness and variety of evidence (paved floors, stone wall foundations, wooden fences, hearths, pits, burials, potsherds, flint artefacts, charcoal plaint remains, animal bones, etc.) are the pre- and protohistorical settlements dating back from the Late Pottery Neolithic to the Late Bronze Age. These are situated along the Israeli coast at more than 15-m depth. Although they have nothing to do with the geographical area, they are an important reference from the methodological point of view (Sivan et al., 2001). Some of the evidence can be easily dated thanks to ^{14}C analysis of organic remains, and to the data taken from the archaeological stratigraphy. The bottoms of the wells are lined with layers of earthenware, which act as guide fossils. They were useful to cleanse the ground water.

3.7. Pre–protohistorical caves

Another class of archaeological sites showing a different sea level at the time of their occupation are pre–protohistorical caves and necropoli. The geo-archaeological surveys in many caves of the Sicilian coast – *Grotta del Genovese* (Levanzo, Isole Egadi), *Grotta dell'Uzzo* and *Grotta della Ficarella* (S. Vito Lo Capo – Trapani), *Grotta dell'Arco* (Capo Zafferano – Palermo) suggest a sea level 40–50 m less than the current in the Mesolithic period (Antonioli et al., 1996).

The *Gotta Verde* (Alghero – Sassari), reachable only by sea, is situated in the Eastern slope of Capo Caccia Peninsula, overlooking the Golfo di Porto Conte (Antonioli and Leoni, 1998). Its name (Green Cave) originates from the colour of the green moss and lichen that covers the stalagmite columns, 20 m high, situated in front of the wide entry at a level of 75/80 m above sea level. The first part of the cave resembles a large pothole with a 45° slope ending in a salty-water pond. Here, a tunnel (at a height of −10 m) flows into a dome-shaped vast salon, which is partly flooded. At −8.5 m were found various burial places, situated in natural niches, or partly excavated in the rocks containing bodies with ceramics dating back to a cultural facies of the late Neolithic (Atzeni, 1981), datable to the 6th–5th millennium B.C. (5300–4700 B.C.). Tectonic stability around Capo Caccia defined the sea level during the late Neolithic at a depth lower than −10 m, which corresponds to a well window in the lower part of the sepulchral room (Antonioli et al., 1996).

During a dive at −37 m in September 1985, Henri Cosquer discovered a narrow opening in the rocky wall. A 175-m long tunnel lead him to a wide cave partly underwater, whose walls showed many paintings and incisions depicting animals and several hands. The archaeological survey determined that this place was a prehistorical sanctuary dating back to 25000–17000 B.C. (www.culture.gouv.fr/fr/archeosm/fr/fr-cosqu1.htm). At that time, the entry to the cave was completely emerged, and the animals and the Palaeolithic hunters that depicted the walls lived in the lower level.

Along the Eastern coast of Sicily (*Thapsos* and *Ognina*) there are important tombs dating back to the Bronze Age, excavated in the rock. They have a *dromos* (narrow entry corridor), a small artificial cave with one or more sub-circular chambers with domed ceilings, that can be assimilated to the Aegean *tholos*. Some of them are presently underwater. The functional height of the ground plan in with respect to the sea has been estimated at ≥0.60 m, as for the caves, 0.30 m above high tide to be always dry (Scicchitano et al., 2008).

3.8. Paleo-beaches

A special category of markers is that of paleo-beaches, as they are natural geological markers with ceramic materials contributing

Fig. 14. Golfo di Palmas (Sant'Antioco – Carbonia/Iglesias). Ceramic fragments.

Fig. 15. Torre S. Sabina (Brindisi). The wreck.

to the dating of the fossils. An interesting example of the first category is that of the bottom of the Laguna in Santa Gilla (Cagliari), on whose shore was the town of *Krly* (Nieddu, 1988; Stiglitz, 2002). Many Phoenician and Punic artefacts were found there, such as figured pottery and commercial amphorae (Spano, 1869; Vivanet, 1892, 1893; Zucca, 1988) (Fig. 13). The finding of culturally and chronologically homogenous contexts (Solinas, 1997), such as amphorae still preserving the original contents, especially butchered bovine and goat bones (Fonzo, 2005), that lay on a shell bed under a metre of mud (at an average of −1.60 m a.s.l.), suggested the hypothesis of an existing beach at the end of the lagoon. The slight slope (elevation 0 ± 1 m) was suitable for the beaching of small boats, which had a little draught (Solinas and Orrù, 2006). Goods were unloaded from vessels drawn up on the ramping coastline overlooking the mouth. The presence of these finds enabled the delineation of the margins of the lagoon during the Punic age between the 5th and 4th centuries B.C.

Similar contexts have been also found in the lagoon of Santa Giusta (Oristano), where the excavation, which is still in progress (Del Vais and Sanna, 2007) highlighted amphorae dating back to a period between the 6th and 4th centuries B.C. The amphorae were used to carry butchered meat.

The use of pierced stones as markers for the paleo-shores (Sivan et al., 2001) is perplexing. The identification of the pierced stones as anchors is still debated. Many are weights for fishing nets, especially if many are found in a long row. Small stones could have rested on the sea floor, either as fishing line weights for single or multiple fish-hooks, or ballasts for wickerwork fish traps or similar traps.

The identification of a ceramic fragment in *Ponti – Golfo di Palmas* (Sant'Antioco – Carbonia/Iglesias) enabled precise dating of the surface level of a coastal beach rock (Orrù et al., in press). This is a rather complex beach rock composed of two levels with several diagenetic and sedimentary features. The first level, the base, was found in the submerged beach at a distance of 4–10 m from the shore, at a height between −0.5 and −0.8 m. The second level, the top, is present in the submerged beach at a height of −0.5 m, elevated towards the coastline at −0.15 m. At this level were found remains of meals, butchered materials, and ceramic fragments that are linked to the nearby town, the Phoenician – Punic and then Roman centre of *Sulci* (Bartoloni, 1989) (Fig. 14). An interesting fragment is from a cup, very common among the thin-walled potteries of the first Imperial age, and already existing in several specimens in the funerary and living contexts in *Sulci* (Frau, 1999). The cup is datable to the Tiberian or Claudian ages (second quarter of a 1st century A.D.) based on the kind of clay and the treatment of its surfaces. This specifies the period of development of the beach rock top level.

3.9. Beached wrecks

Most shipwrecks are spread along all the southern Apulian wave dominated sedimentary coasts, as is pointed out by different archaeological studies, at depths between the present sea level and

Table 1

Type of evidences	Significant markers	Functional height (m)	Range of chronological error (years)	Reliability
1.1. Tyrrhenian Sea fishponds	(1) the closing shutters (2) the captation canals (3) the carvings for the trop-plein	0 a.m.s.l. (Anzidei et al., 2004)	≤100	High
1.1. Adriatic fishponds	Parts that can be recognized as: Piers Walking plane	0.60 a.m.s.l. (Antonioli et al., 2007)	≤100	Medium–low
2.1. Piers and quays	(1) Walkways (2) Missing carpentry (3) Bollards and the mooring rings (4) String-courses between building techniques or different coverings	0.60–1.00 a.m.s.l. (Antonioli et al., 2007)	≤100	High
2.2. Breakwaters	(1) Carved blocks, referable to an original breakwater dock (2) Other referential elements associated	0.60 a.m.s.l. (Antonioli et al., 2007) >0.70 a.m.s.l (Antonioli et al., 2007)	>100	Medium–low
3. Private and public buildings	(1) Pavements (2) Walking planes (3) Use surfaces	≥0.60 a.m.s.l. (Antonioli et al., 2007)	<100	Low
4. Coastal quarries	Mining plane Piano di distacco/cava/estrazione	0.30 (Lambeck et al., 2004b) 0.30 above high tide (Antonioli et al., 2007; Scicchitano et al., 2008)	>100	Medium
5. Hydraulic systems	(1) Cistern bottom (2) Canal basis	Above high tide (Auriemma et al., 2004)	>100	Medium–low
5a. Wells	Well bottom	0.30–0.40 under the water table (Sivan et al., 2004; Enei, 2008)	<100	Medium
6. Pre–protohistorical settlements	(1) Post holes (2) Hut floors (3) Stone-wall foundations	Above high tide (Scarano et al., 2003)	≤100	Low
7. Pre–protohistorical caves	(1) Cave floor (2) Sepulchral room/burials floor (3) Pits	0.30 above high tide (Antonioli et al., 2007)	<100	Medium–low
8. Paleo-beaches	Beach rock top level	Above high tide (Antonioli et al., 2007)	<100	Medium–low
9. Beached wrecks	Keel basis	−0.50/1.50 a.m.s.l.	≤100 (C14)	High

The reliability depends on the accuracy of the chronology and the degree of the functional height approximation. The error within the tide amplitudes should be considered (±0.23 m for the Tyrrhenian Sea and ± 0.60 m for the Adriatic Sea).

the −5 m isobath (Auriemma, 2004, in press; Auriemma et al., 2004, 2005; Auriemma and Mastronuzzi, in press). They are represented by complete or partial hulls of different ages, from the Roman age to the mediaeval. Their features are different: some have been destroyed by waves and only a few parts of their hulls are preserved; on the other hand, some of them are characterised by the preservation of the entire keel placed parallel or orthogonal to the shoreline. These different features correspond to different types of beached wrecks caused by storms and/or abandonment by sailors in harbour areas. In all cases, each represents a potential marker of past mean sea level (Sivan et al., 2001). The range of error of these indicators changes from case to case, depending on a mix of factors: the exactness of dating, the storm wave heights, and the type and tonnage of the vessel. In particular, the survey of the wrecks in the archaeological sites of *Santa Sabina* (Fig. 15) and *Canale Giancola* (Brindisi), *Torre Chianca*, *Torre Rinalda* (Lecce) and *Torre Saturo* (Taranto) related to the hydrodynamic features of both Ionian and Adriatic sea, permitted reconstruction of the sea level curve of the last 3000 years in relation to the most recent eustatic model (Lambeck et al., 2004a).

4. Conclusion

Many archaeological remains have been found along the Mediterranean Sea coasts. Archaeology deals with interpreting and dating the evidence, which can offer important clues on the sea/coast evolutions. Nevertheless, in order to use these archaeological markers without great margin of error, some aspects must be considered:

(1) an artefact has different reliability degrees, depending on (Table 1):
  (a) its "functional features": the sluice gate of a fishpond gives more accurate clues, compared with a walking plane or living floors of a private or public building;
  (b) the accuracy of the chronology. Private or public buildings can be dated by their intrinsic and distinctive features with more precision than can quarries or breakwaters, whose typology remained unchanged for centuries. The chronology of a well can be given by its filling (pottery sherds);
  (c) the degree of the functional height approximation. The Tyrrhenian Sea fishponds approximation is the highest, thanks to the architectonical components which had to be at sea level at the time of construction. That for pavements or use surfaces is the lowest, for which it is not possible to determine the "high" value of the emersion range (how much above high tide?).

A typological selection of the most significant markers, including a hierarchical classification as well as different issues concerning their correct interpretation is presented in Table 1;

(2) the measuring, the correction, and evaluation of the heights in respect to an artefact not only has to account for specific methodologies, but they require an interdisciplinary discussion between archaeologists, geomorphologists and geophysicists for the interpretation. The protocols used on the Tyrrhenian Sea fishponds (Lambeck et al., 2004b), on the emergencies that were studied in the Interreg Project "AltoAdriatico" Italy–Slovenia, and lately in Sardinia, supplied extremely interesting data. Among the studied markers, the intent was not only to conduct a census of only the artefacts, but to also consider the coastal quarries, modifications that humans made to the coastal landscape, natural pits, such as caves, and fossil beaches where the presence of ceramic material certifies the emersion and determines the dating of frequentation and use.

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