COASTAL EVOLUTION OF THE INNER LACONIC GULF IN THE LATE PLEISTOCENE-HOLOCENE PERIOD

G.TSARTSIDOU[1], K.GAKI-PAPANASTASIOU[2], AND H. MAROUKIAN[2]

ABSTRACT

Geomorphological and archaeological data have been used to reconstruct the paleoenvironment of the inner Laconic gulf. Two emerged marine terraces (Eu- and Neo-Tyrrhenian) have been traced along both the east and west coasts of the gulf. The terraces contain characteristic fossils (*Strombus bubonius Lmk.*) and archaeological finds (Paleolithic). Marine notches and beachrocks have also been located in the study area. Some of them are related with archaeological remains (Roman). The level of the above indicators suggests similar tectonic movements (of the order of 0.1-0.2mm/year) for the two coasts in Late Pleistocene-Holocene. Eustasy was the main factor for the coastal evolution of the region, while tectonic and isostatic movements of the crust have played a minor role. The above data as well as core profiles from the plain of Eurotas river were used in order to reconstruct the paleoshorelines of 125000 and 6000 years ago.

KEYWORDS: Coastal geomorphology, archaeology, palaeoenvironment, sea level changes, Late Pleistocene-Holocene, Laconic gulf, Peloponnesus.

ΠΕΡΙΛΗΨΗ

Γεωμορφολογικά και αρχαιολογικά δεδομένα από τις ακτές του βόρειου Λακωνικού κόλπου επιτρέπουν την ανασύνθεση του παλαιοπεριβάλλοντος κατά το Ανώτερο Πλειστόκαινο-Ολόκαινο. Εντοπίστηκαν δύο ειδών αναβαθμίδες (Ευ- και Νέο-Τυρρήνιες), που φέρουν χαρακτηριστικά απολιθώματα (*Strombus bubonius Lmk.*) και αρχαιολογικά ευρήματα (Παλαιολιθικά). Εντοπίστηκαν επίσης θαλάσσιες εγκοπές και ακτόλιθοι, μερικοί από τους οποίους σχετίζονται με αρχαιολογικά κατάλοιπα (Ρωμαϊκά). Το επίπεδο στο οποίο εντοπίστηκαν τα παραπάνω γεωμορφολογικά και αρχαιολογικά δεδομένα παραπέμπει σε παρόμοιες τεκτονικές κινήσεις (της τάξης του 0,1-0,2χιλ/χρόνο) και για τις δύο ακτές (ανατολικές και δυτικές) του κόλπου κατά το Ανώτερο Πλειστόκαινο-Ολόκαινο. Ο ευστατισμός είναι ο βασικός παράγοντας που ευθύνεται για τη διαμόρφωση των ακτών του βόρειου Λακωνικού κόλπου, ενώ μικρότερο ρόλο έπαιξαν η τεκτονική και οι ισοστατικές κινήσεις του φλοιού. Τέλος, η μελέτη στρωματογραφικών τομών από το Λακωνικό πεδίο σε συνδυασμό με τα παραπάνω δεδομένα οδήγησε στη χάραξη των παλαιοακτών του 125000Π.Σ. και του 6000Π.Σ.

INTRODUCTION

Coastal evolution is dependent on: a) global eustatic changes (Pirazzoli, 1996; Bird, 2000) b) regional isostatic adjustments of the crust to the changing ice and ocean volumes (Inman, 1983; Pirazzoli, 1996, Lambeck 1996) or to the fluvial sedimentation (Bloom 1998) and c) tectonically controlled crustal movements (Nakiboglou et al., 1983). These three factors have played a significant role on the coastal evolution of the inner Laconic gulf especially in Late Pleistocene and Holocene period. The indicators of their impact are the geomorphological and archaeological data of the region. The data come from coastal and underwater research and they consist in: a) Pleistocene and Holocene marine terraces, beachrocks and marine notches, and b) submerged ancient ports or harbor structures, waterfront man-made structures, palaeolithic sites, ancient settlements or vilas, which reflect human exploitation of the coast. Finally, of great help in reconstructing the coastal environment was the study of the subsurface topography of the Helos plain (the plain of Eurotas river).

1:Ephory of Palaeoanthropology-Speleology, Ardittou 34B, Athens.
2:Athens University, Faculty of Geology, Department of Geography-Climatology.

GEOMORPHOLOGICAL OBSERVATIONS/INDICATORS

Marine terraces

Previous studies that have been carried out along the east coasts of the gulf (Dufaure, 1970; Kowalczyk *et al.*, 1992) refer to five outcrops of two marine terraces (Fig. 1). Their deposits are very fossiliferous, containing

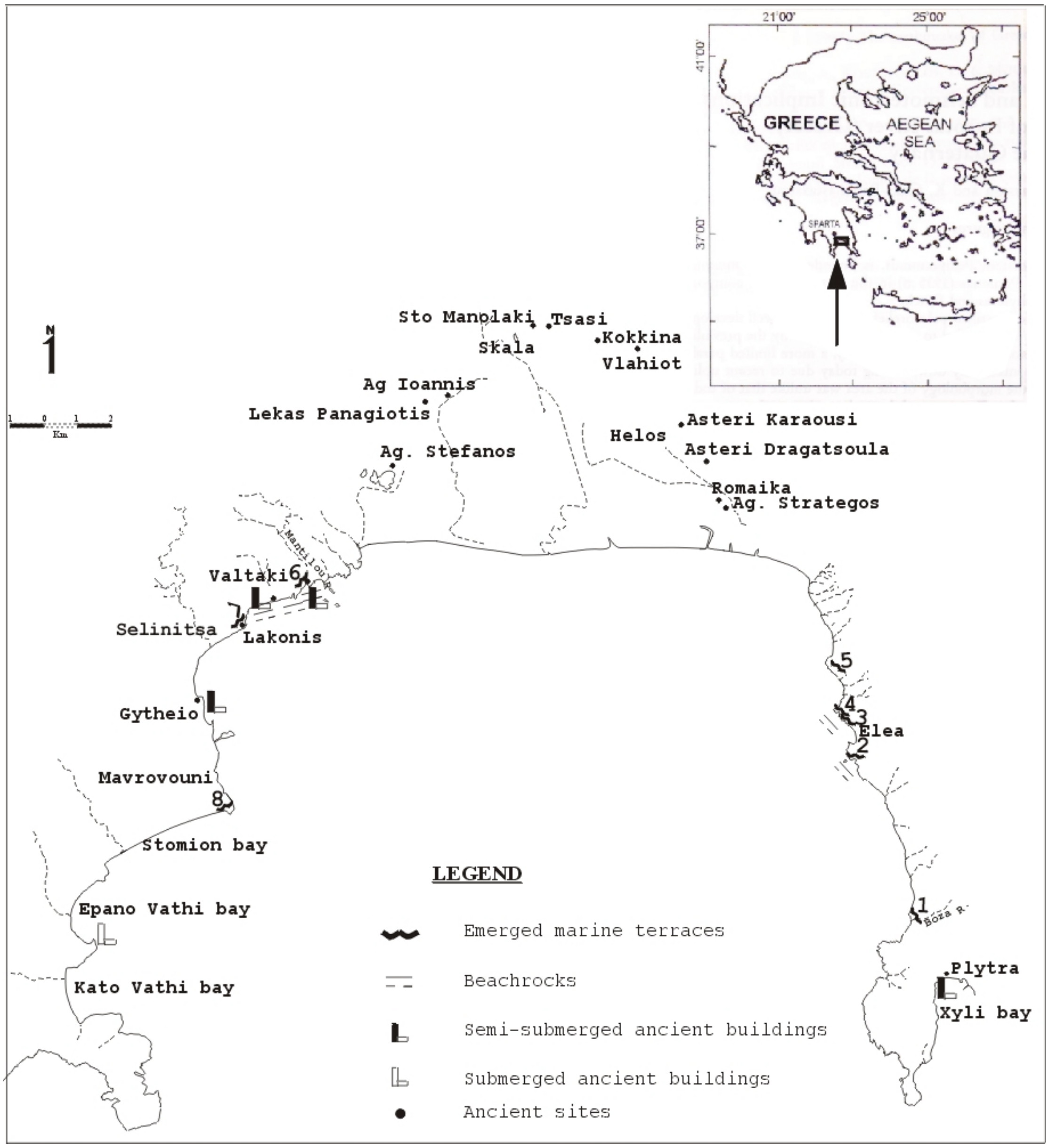

Fig. 1. Coastal landforms and archaeological sites in the study area (black arrow in the small square).

among others the characteristic fossil *Strombus bubonius Lmk*. They also contain palaeolithic artefacts. Two of the terraces are defined as Eu-Tyrrhenian and the other three as Neo-Tyrrhenian. The first Eu-Tyrrhenian terrace (1), at 16-18m above sea level, is located 5.5 km south of Elea at the mouth of Boza river. During fieldwork we traced the continuation of this terrace for another 500m south of the mouth of the river. The second Eu-Tyrrhenian terrace (5) is traced 2.5km north of Elea and it is also 16-18m above sea level. The sequences of both terraces are capped with aeolian sands.

Apart from the two referred Eu-Tyrrhenian terraces, two new sites, which must be the continuation of the others, have been traced at 20m above sea level. The first is located next to the main street from Elea to Elos, just 1km from Elea, and the second is traced at the rocky cliff below the Medieval tower of

Elea. They both contain marine sediments and fossils. The three Neo-Tyrrhenian terraces (1-4m above sea-level) are located in the region of Elea: two of them 1-1.5km north of it (3, 4) and a third one at the rocky cliff below the tower of Elea, where the Eu-Tyrrhenian terrace (at 20m) is also located. Holocene terraces have also been found at the same sites, where the Neo-Tyrrhenian terraces 2 and 3 are traced, e.g. 1-1.5km north of Elea. They are located at the present sea level.

Three new Neo-Tyrrhenian terraces have been traced along the west coasts of the Lakonic gulf (Fig.1): the first at the inlet, where the river Mantilou flows into (6), the second at the archaeological site Lakonis (7), just at the northeast end of Selinitsa bay, and the third at the north end of Stomio bay (8). All of them are 1-3m above sea level. The deposits of the third one (8) contain characteristic fossils (*Strombus bubonius Lmk*). The beach conglomerate in the second terrace (7) is covered by travertine, which is underlying a 7m sequence of terrestrial strata with archaeological finds. An excavation is taking place there under the supervision of E. Panagopoulou (Ephory of Palaeoanthropology-Speleology). Within the context of the excavation several dates have been obtained. U-series measurements on the travertine that covers the beach conglomerate yielded an age of 94ka±14.000, while some ^{14}C dates from the uppermost terrestrial strata are between 35-40ka (Panagopoloulou *et al.* in preparation).

Marine notches

An emerged notch, 3m above sea level, has been traced at the cliff where the Medieval tower of Elea is located, and it is accompanied by *lithophaga* boreholes. In the same location, there are two submerged notches: one at 0.50m and the other at 2m below sea level. Three submerged notches have been found along the west coasts, at the rocky coast between Valtaki and Selinitsa: one at 0,50m, also accompanied with *lithophaga* boreholes, a second one at 1m and a third one at 2m below sea level.

Beachrocks

They have been located (Fig. 1) at: a) the inlet south of the tower of Elea at 1.80-2m below sea level, b) the inlet of Mantilou river, where there are two beachrocks belonging to different periods. The first, at 0.10-0.90m below sea-level, covers Roman buildings and therefore it is of post Roman age and the second, at 1.50-1.90m below sea-level, older than the former and therefore ante-Roman c) Valtaki bay, where a beachrock at 0.10-0.90m below sea-level also covers Roman buildings.

ARCHAEOLOGICAL INDICATORS

The archaeological remains of the region (Fig. 1) range from Prehistory (even from the Middle Palaeolithic period 120000BP-30000BP) to the Middle ages. All the Palaeolithic finds come from caves (Elea, Lakonis) and the Tyrrhenian terraces of two coasts. They are made of local material (metamorphosed volcanic rocks), quartz and flint. The technology of the finds from the Eu-Tyrrhenian terraces points to an older phase of the Middle Palaeolithic (before 100000BP). On the contrary, the technology (thin debitage of the Levallois technique) of the finds from the Neo-Tyrrhenian terraces attributes them to younger than 100000BP. The finds of the Upper Palaeolithic (30000BP-10000BP) are scant, while there are no secure finds of Mesolithic (10000BP-8000BP) period. Neolithic pottery (8000-5000BP) comes from the lower strata of some sites (Ag. Stefanos, Asteri, Ag. Strategos) but it is also scant. Thus, we are unable to determine with certainty human activities in the period ranging from Upper Palaeolithic to Neolithic. Conversely, the Mycenean period (1580-1100BC) seems to be of great importance for the region. Some important Mycenean settlements have been discovered in the plain (Ag. Stefanos, Asteri, Ag. Strategos, Vlahiotis, Kokkinada, Tsasi, Ag. Ioannis, Xeronisi, L. Panagiotis). It is worth noting the horseshoe arrangement of the settlements, which characterizes them even through the later periods, ancient and Roman. From the Roman period until the Early Middle ages (2^{nd}-6^{th}A.D) there are buildings and structures on the coast (Cavanagh et al., 1996) such as: i) a flushing channel at Valtaki, which ends inland at a building, probably an aqueduct, ii) at the inlet of Mantilou there are traces of an ancient port, iii) in Gytheio there are baths and harbor structures iv) at the south end of Epano Vathi bay there is a long harbor structure (quay?) and finally v) at Plytra in Xyli gulf there are Roman baths and other buildings. All the above Roman structures are 0.1-1m below sea-level. Middle ages are represented mainly by Skala where five Byzantine churches have been found, while there is no sign of former life at the site. Finally, Medieval and younger towers can be seen at both the coasts, east and west of the gulf (Lakonis, Elea).

SUBSURFACE TOPOGRAPHY OF THE HELOS PLAIN

The data come from the core profiles supplied to us by the Greek Service of Land Improvement {Yperesia Eggeion Veltioseon (YEB)}. The horizontal and vertical study of the cores (Fig. 2) gave us the opportunity to reconstruct the evolution of the plain in the Late Pleistocene-Holocene. The marine sediments of the lower strata (So1, So2, So3, So4) point to the Neogene sea, which had been covered and eroded by the Pleistocene rivers. The fluvial sediments are overlain by coastal sediments pointing to the Pleistocene history of the plain, which is characterized by the alternation of river progradation and sea transgression. In the inner part of the plain, the deposits of Eurotas' delta are thicker, suggesting the aggradation of the river.

At -112m there is a stratum of peat (So2), which suggests the lagoonal marsh that was there probably just after the Last Glacial Maximum. The latest studies about the sea level after the LGM (Lambeck *et al.*, 2002) refer to a rapid rise of 15m between 19500BP and 19000BP (calibrated years BP) and a slow rise (3.3mm/year) from 19000calBP to 16000calBP. Accepting that the sea level during LGM at the region was 125m below present sea-level (Lambeck, 1996), then the peat of -112m points to the next period of 19000-16000BP. After 16000BP the sea rise was also fast (16.7mm/year) until 10000BP –with a small cold period during 12500-11500calBP, the Younger Dryas (Lambeck *et al.*, 2002). Therefore the stratum of peat at the level of –30 to -40m (So4, So6, S11 and perhaps So2 and So3) could point to the marshes of 10000BP. The lack of peat at the intermediate strata can be explained by the faster sea rise between 16000-10000BP. Finally the last stratum of peat is at –5 to -25m (So6, So8, S8) and this must represent the end of the last great sea transgression at 6000BP. It is worth noting the case of a core profile (S11) from the west end of the plain with a thick stratum of peat from -8 to -42m. This may point to a marsh for most of the Holocene. Again the rapid sea rise between 11500calBP and 7500calBP (Lambeck *et al.*, 2002) explain the lack of peat. These conclusions are compatible to an analogous study of Kraft et al. (1977), who refer that the peat of –40m points to 8905±150BP and the peat of 16m is assigned to 5270±100BP. Their conclusions are supported by ^{14}C dates of the peat deposits and they point respectively to 10000 and 6000 calibrated years BP.

At the inner part of the plain (S12) there are terra rosa soils, which refer to a pause of sedimentation at the plain. These strata are at analogous depth (-14-42m) to the peat strata, taking under consideration the topography. The sand from the upper strata of the cores is attributed to the barriers or dunes that existed in front of the marshes and the lagoons. Finally, the uppermost strata of all the core profiles are assigned to the recent deltaic sediments of Eurotas. An east to west shift of the channel of the river is obvious.

DISCUSSION-CONCLUSIONS

The level at which the Eu-Tyrrhenian terraces are traced (16-20m above sea-level) suggests that the tectonic uplift of the region is minor. The age of the terraces is attributed to the isotopic stage 5e (125ka), so it comes that the rate was about 0.1mm/year. If we apply this rate to the younger terrace, we will see that it is more compatible with the 5c (105ka) than with the 5a (80ka).

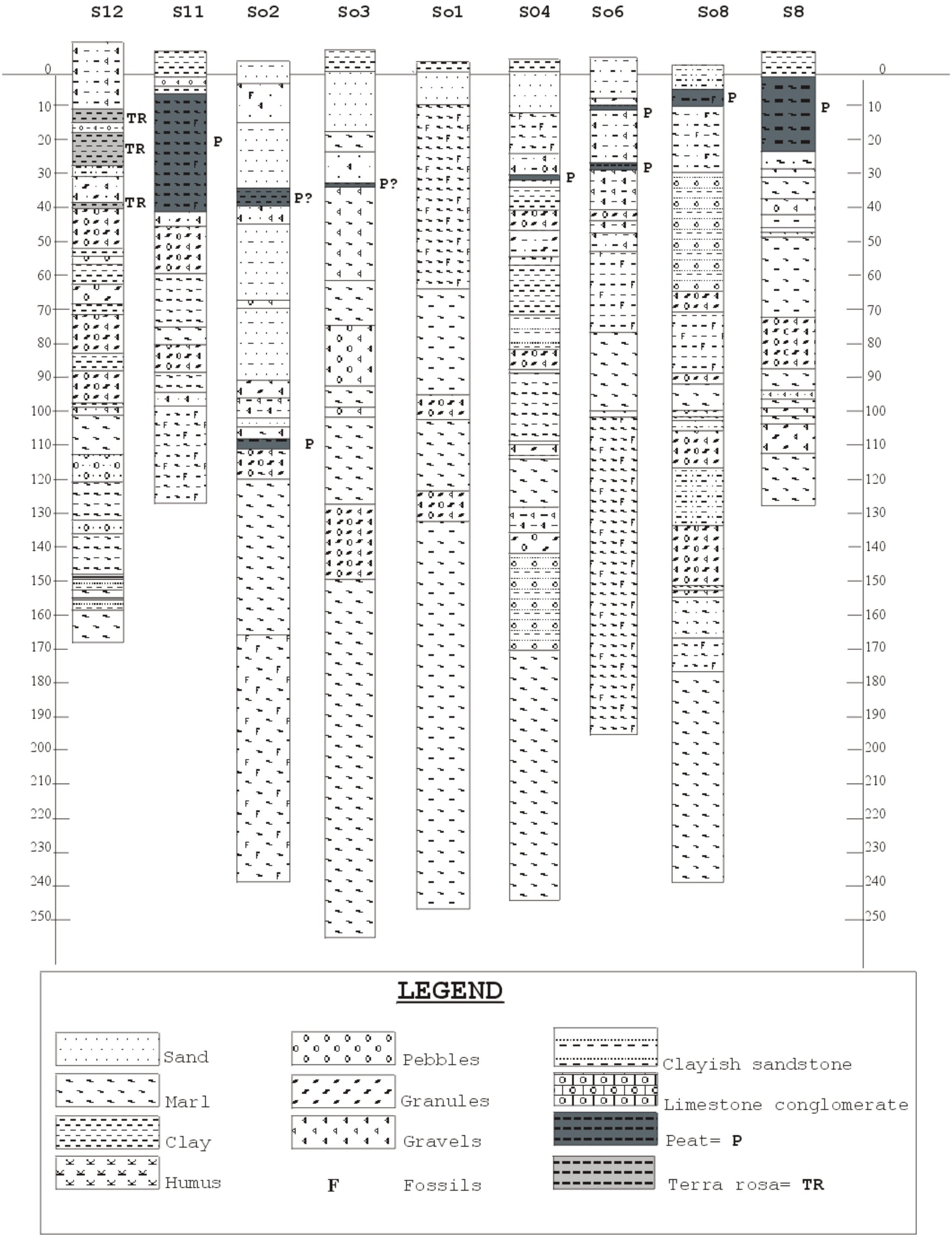

Fig. 2. Core profiles from the Helos plain.

The date also from the travertine that covers the beach conglomerate from Lakonis seems to agree with this view. If the terrace was attributed to 5a, then the travertine should be younger than 80ka, something incompatible with the obtained date. Therefore, the most plausible interpretation is that the Neo-Tyrrhenian terraces of the region belong to the isotopic stage 5c (105ka), although more dates from the deposits of the Neo-Tyrrhenian terraces of the region, could determine with confidence the correct isotopic stage. Unfortunately, the dates from west and east Mediterranean are not in agreement on the isotopic stage of the Neo-Tyrrhenian terraces (Ozer & Vita Finzi, 1986; Belluomini *et al.*, 2002).

The application of the tectonic rate to younger times, e.g. Roman period (2000BP) shows that the rate has not changed substantially through time. Roman buildings stand 0.10-1m below sea-level. Lambeck's curve (1996) of sea level for the region is 1.30m below present sea level. Therefore if we subtract the 0.20-0.40m attributed to the tectonic uplift we conclude that the sea level was 0.90-1.10m lower than today. That is compatible with the depth that the port facilities are found. It is also in agreement with the theory of Flemming (1972) that the ancient coastal waterline structures must have been built within 0.25-1m of mean water-level.

From the above we conclude that vertical tectonic movements of the Late Pleistocene-Holocene played a minor role in comparison to eustatic and isostatic movements of the crust. The latter is assigned to the glacio-hydro-isostasy that affected the Mediterranean during the Holocene (Lambeck, 1996). Glacio-isostasy results in a slowly rising sea-level due primarily to the crustal subsidence as the mantle material flows back beneath the formally glaciated region of Scandinavia. The hydro-isostatic contribution is one of falling sea level because of the loading of the Mediterranean by the meltwater and the flow of material beneath the continental lithosphere (Lambeck, 1995). An analogous model has been succesfully used along the Israeli coast (Sivan et al., 2001). Given the fact that the emerged Neo-Tyrrhenian terraces, as well as the submerged marine notches and the beachrocks are found at the same level on both the east and west coasts of the gulf, we also conclude that the tectonic movements were similar.

The location of the Eu-Tyrrhenian terraces next to the present coast refer to an environment analogous to the present one during the Last Interglacial (Fig. 3), while the plain must have been much reduced in size, overlooking to a larger gulf. On the contrary, during the LGM a coastal plain extended in front of the present coasts (Fig. 3), forming an ideal environment for human habitation. There were rivers that were crossing the plain and flowing to the sea and many springs that attracted animals and consequently the hunters. The caves that were away from the sea provided a shelter to the humans. These were benefits that attracted the hunter-gatherers of those times to exploit the region. Unfortunately, the next transgression of the sea must have covered their traces. The slow sea rise that followed is responsible for the lagoons and marshes that were created on the plain and in some of the bays of the west coasts (Gaki *et al.,* 2001*)*. After 10000BP during Mesolithic and Neolithic period and perhaps even until the Late Bronze age (10000BP-1200BC) the Helos plain was much smaller and the gulf extended up to the region of Skala with lagoons and marshes in the edges (Fig. 4). Especially at the west end of the plain a narrow cove must have existed for all the above period, as is suggested by the core profiles. This should be the reason for the horseshoe arrangement of the human settlements, which lasted until the draining of the marshes. Some traces of them still exist on both the east and west end of the Helos plain. For the region of Skala, where five Byzantine churches have been found, the life seems to begin during the Middle ages. The reason may be the development of the alluvial plain, which made the place fertile and habitable.

It is concluded that:

The older terraces of the inner Lakonic gulf (16-20m above sea-level) belong to the isotopic stage 5e (125ka).

The younger terraces of the gulf (1-5m above sea level) belong probably to the isotopic stage 5c (105ka).

The vertical tectonic movements are of the order of 0.1-0.2mm/year) for the two coasts from Upper Pleistocene to Late Holocene.

Isostatic movements played a minor role at the region during Holocene.

Eustasy were the main factor that affected the coastal evolution of the inner Lakonic gulf.

Humans have exploited the coastal area since Middle Palaeolithic to time.

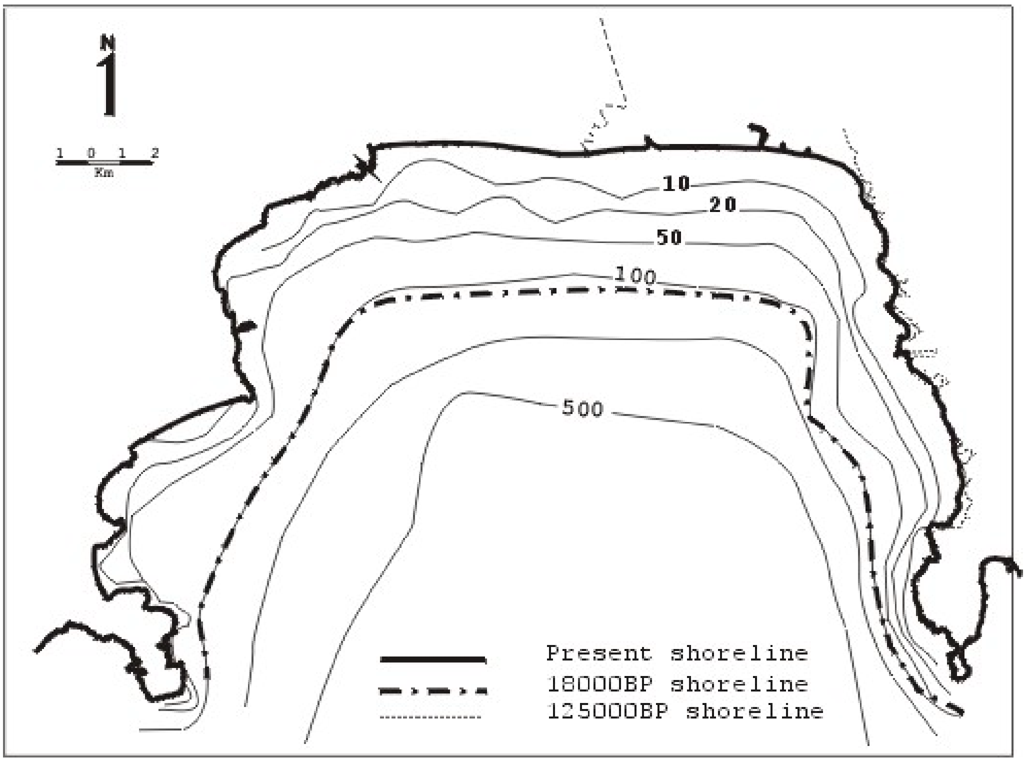

Fig. 3. Schematic reconstruction of the shorelines during 18000BP and 125000BP.

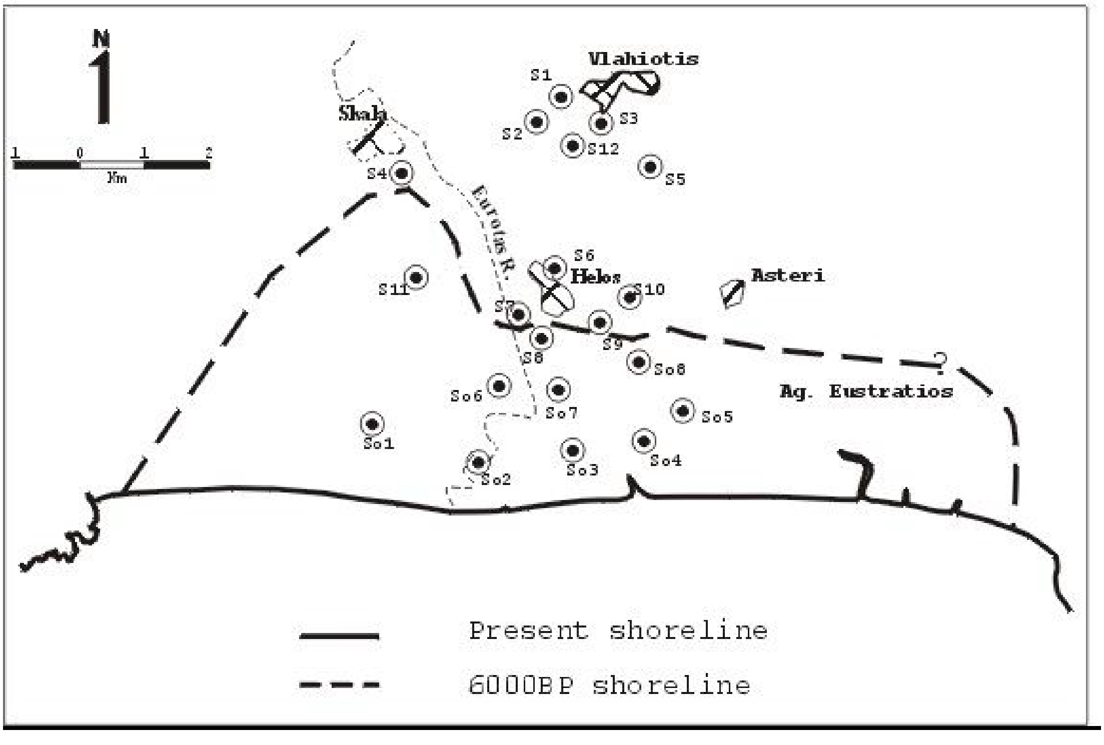

Fig. 4. Helos plain. Schematic reconstruction of the palaeoshoreline during 6000BP and at least 3000BP. Drill holes are shown with circles.

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