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Holocene palaeoenvironmental changes in Agia Paraskevi prehistoric settlement, Lamia, Central Greece

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ABSTRACT

Holocene palaeoenvironmental changes in the area of the prehistoric settlement of Megali Vrysi close to the village of Agia Paraskevi in Central Greece, 5 km east of Lamia City, were investigated. The area is situated in the low flat alluvial plain on the outskirts of Sperchios Valley that is bordered NNW to ENE by a rocky, hilly ridge of the Othrys Mountain foothills, 5.5 km away from the present coastline.

The Megali Vrysi site is considered to be an important Mediterranean prehistoric commercial centre. Reconstruction of the palaeoenvironmental changes of the broader area adds new information concerning the general palaeogeographical setting of the settlement. Multidisciplinary research involved a detailed geomorphological survey combined with stratigraphical, palaeontological, and geophysical studies.

The penetrated strata differentiated into 4 units from top to bottom. The first represents the archaeological strata. The second consists of the freshwater marshy sediments, while the third is the transition layer between the second and the deeper fourth group of marine – lagoonal sediments. The Holocene stratigraphy data was combined with the ^{14}C-AMS dating results and showed a marine palaeoenvironment (~ 5500 BC) gradually having shifted to a coastal – lagoonal one (~3500 BC) and finally changed to a freshwater marshy environment (~2500 BC).

The comparison between ages and depths of the relative sea level points allowed the estimation of the sea level rise rate for the Agia Paraskevi area which is considerably lower than the one proposed for the Aegean Sea in the same time period. This considerable offset is attributed to the intensive tectonic uplift of the study area due to the tectonic deformation of the Sperchios Valley and this is probably why the prehistoric coastal settlement remained on the surface and unaffected from the sea transgression for more than 7000 yrs during Holocene.

1. Introduction

The human habitation in the coastal areas of the Aegean Sea is highly related to the changing environmental conditions and the shoreline migration through time. Many famous ancient Aegean coastal cities such as Pella, Ephesus and Troy, had been commercial centers of antiquity. Archaeological and geoarchaeological research showed that ships were able to approach large harbors for trading purposes because these cities were close to the sea. However, the delta prolongation of Axios and Aliakmon Rivers is responsible for the siltation of the ancient Pella harbor in the Thessaloniki plain (Albanakis et al., 1993; Ghilardi, 2007; Fouache et al., 2008; Ghilardi et al., 2008). The siltation of the seaport Ephesus (W Turkey) was associated with the progressive delta and floodplain growth of the Küçük Menderes (Kaystros) and its tributaries (Kraft et al., 2000, 2001; Brückner, 2005) while ancient Troy (W Turkey) faced the advancing Karamenderes (Scamander) and Dümrek (Simois) river deltas (Kayan, 1995, 2001; Kraft et al., 2003a, 2003b).

This study focuses on the area of Agia Paraskevi, a village 5 km east of the city of Lamia in the northern part of Sperchios Valley (Fig. 1). The area studied is situated next to one of the most important and long-lasting ancient settlements in Central Greece,

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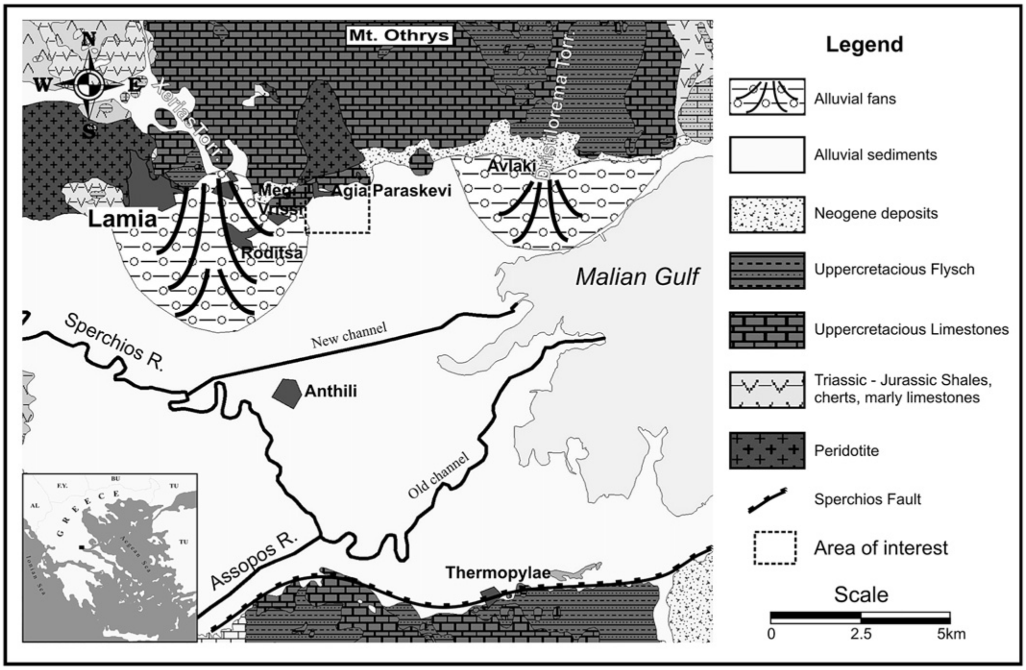

Fig. 1. Geological and geomorphological setting of the Sperchios River deltaic plain, including the study area.

Halos. Its relation to the sea (Maliakos or Malian Gulf) as well as the Sperchios River delta prolongation has been direct and long-term. Today, the area studied is located 5.5 km from the present coastline. The depositional process of the Sperchios River has filled a considerable part of the basin with alluvial sediments (Zamani and Maroukian, 1980), resulting in the delta's prolongation and the transformation of the plain's geography. Moreover, Sperchios Valley is a fault bounded valley (Kilias et al., 2008) highly influenced by tectonic deformation. Due to this constant tectonic activity it was difficult to use and evaluate all the known data from other deltaic systems of the Aegean Sea (Kraft et al., 1977; Fouache, 1999, 2003; Vött et al., 2003; Brückner, 2005; Vött, 2007; Ghilardi et al, 2008) in order to establish the palaeoenvironmental conditions and the mean base level in the Maliakos Gulf – Sperchios Basin and specifically in the area of the settlement.

In the site area, close to the ancient settlement, there was a coastal marsh until the last decades of the 20th century. The Holocene sea level and climate changes and the anthropogenic effects are recorded in the sediments of coastal marshes and wetlands (Cole and Liu, 1994; Clave et al., 2001; Pavlopoulos et al., 2006, 2007). In particular, coastal marshes are sensitive to local paleoenvironmental changes and can provide useful proxy data for studying coastal changes over the last thousands of years. The main scope of this work is the determination of the Holocene palaeoenvironmental changes in Agia Paraskevi area, close to one of the most important prehistoric settlements of Central Greece, that are representative for the northern coastal margins of the Sperchios deltaic plain.

2. Description of the study area

2.1. Archaeological information

The study area includes the remains of a prehistoric settlement situated at the Platania location near the village of Agia Paraskevi. The settlement appears today as a low mound and is considered to be of great archaeological importance (Hope-Simpson and. Dickinson, 1979). The place has been related to the Homeric topography of Phthiotis, namely Halos (Hope-Simpson and Lazenby, 1959).

The inhabitation of the site dates back to the Neolithic period (6500–3300/3000 B.C.). Surface investigation has yielded Neolithic material of most classes, including the earliest, some Early Helladic shards (3rd millennium B.C.) and an amount of Middle Helladic (2000/1900–1600 B.C.) and Mycenaean ones (1600–1050 B.C.). A trial trench 3.90 m deep opened near the summit of the mound, brought to light four successive cultural strata (Hourmouziadis, 1973): the Mycenaean stratum (0.00–0.30 m depth) which was disturbed by modern agricultural activities; the Middle-Helladic stratum (0.30–2.40 m depth), which yielded abundant shards of the characteristic ceramic categories of Sperchios Valley (Grey Minyan and Δ1β ware); the Early Helladic (2.40–3.60 m depth) and, finally, the Late Neolithic stratum (3.60–3.90 m depth) whose excavation has not yet been completed.

During the last three years, the systematic investigation of the Middle-Helladic phase of the settlement has uncovered domestic architectural remains of rectangular and apsidal houses (Papakonstantinou, 2006, 2007, 2008). Excavation is in progress.

2.2. Geological setting

The Sperchios Valley is a fault bounded valley running in an E-W direction. The main normal fault system, shaping the local topography is situated in the southern part of the basin and can be subdivided into two individual parts: (a) the Sperchios-Ipati Fault Zone in the west, which borders to the south the valley of the Sperchios River and (b) the Kamena Vourla-Arkitsa Fault Zone in the east that borders to the south the Maliakos Basin (Eliet and Gawthorpe, 1995; Kilias et al., 2008). The tectonic deformation started at the end of the Pliocene and beginning of the Pleistocene, and persists today with earthquakes and neotectonic movements. Due to these movements the Pliocene deposits, located to the south of the Maliakos Gulf, have been uplifted by more than 500 m (Maroukian and Lagios, 1987; Gartzos and Stamatis, 1996). The Sperchios fault system and the

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Atalanti fault (Pavlides et al., 2004; Karastathis et al., 2007) are active faults which generated many strong earthquakes (Papazachos, 1990), such as those in 426 B.C. and 1894 A.D. and resulted in major disasters in the broader area (Pirazzoli et al., 1999; Albini and Pantosti, 2004; Pantosti et al., 2004; Ganas et al., 2006).

The geological setting of the N and NE parts of the Sperchios basin, including the area of interest, consists of an ophiolithic complex in a shale-chert formation composed of shale, chert and limestone with ultra-basic and basic igneous rocks belonging to the Malian (Subpelagonian) Zone (Ferrière, 1977). More specifically, the area of interest is located in the low flat alluvial plain in the Northern margins of Sperchios Valley (Fig. 1) that is bordered NNW to ENE by a rocky, hilly ridge of the Othrys Mountain foothills consisting of karstified Mesozoic limestones.

2.3. Geomorphological background

The tectonic basin is occupied and shaped by the Sperchios River. The drainage basin of the Sperchios covers an area of 1780 km^2, is approximately 60–80 km long and 20–30 km wide (Psomiadis et al, 2004). The main channel of the Sperchios River flows west to east. Many times in the past, the river's main channel shifted course (Fig. 1) due to hydrological changes or tectonic deformation of the basin. These directional changes on the river's main channel created several deltaic prolongations in the Maliakos Gulf and formed an extensive deltaic plain due to the high rates of sedimentation. The total annual sediment load of the Sperchios River has been estimated to be in excess of 1.5×10^6 tonnes/year (Poulos et al., 1997), and the mean annual growth of the delta is estimated at 0.04 km^2/yr within the last 2.5 millennia (Zamani and Maroukian, 1980).

The specific study area (Fig. 1) is situated in the northern part of the Sperchios basin, between the city of Lamia and the coastline of the Maliakos Gulf, close to the small villages of Agia Paraskevi on the east and Megali Vrissi on the west. The area is located between the Sperchios low flat alluvial plain and the rocky hilly ridge of the Othrys Mountain foothills. The prehistoric settlement of Megali Vrysi is situated in the western part of the area, forming a very low, almost flat tell with an altitude of about 7.5 m above sea level (a.s.l.) (Fig. 2).

The lithological background of the Othrys Mt. foothills (limestones) in combination with the karstification of the area created a hilly relief with gentle slopes. The limestone solution created a depression covered with alluvial sediments, and formed an embayment on this marginal terrain (Figs. 1 and 2). The eastern side is the rocky hill of Sfagia, while the west is the anthropogenic prolongation of the flat tell. The contiguity of the karstified carbonate rocks (limestone) with the impermeable fine-grained alluvial sediments of the basin margins caused the overflow of the aquifer, as a large karstic spring, on an elevation very close to sea level (Fig. 2). The large freshwater discharge from the spring is the main reason for the freshwater marsh formation in the area.

The study area is hydrographically isolated. The intense karstification of the limestones favoured underground flow, resulting in the absence of major segments of the drainage network in the region. Thus, in the interior of the marsh the sedimentation is owed to the very small transport of sediments originating from the overland flow. In the plain area, between the hilly terrain and the present coastline, the main sedimentation process derives from the sediment load transport and deposition, both of which are regulated by coastal wave action, in the Sperchios River mouth. For this reason, the altitudes in this section of the alluvial plain are very low with substantial drainage problems in the agricultural land.

The study area is located between the large alluvial fans of the two major torrents coming from Mount Othrys. Xerias torrent is situated 3 km in the west, close to the city of Lamia, and the Dristilorema torrent 5.5 km east, near the village of Avlaki (Fig. 1). Their relatively long distance from the study area prevented the rapid alluviation with coarse-grained materials and contributed to progressive alluviation with low sedimentation rates controlled by the rise in sea level.

3. Materials and methods

Vibracoring was used as the main tool for delineating subsurface stratigraphy. Seven (7) vibracores (PAR-1, 2, 3, 4, 5 and MAG-1, 2) were drilled in total, and their location is depicted in Fig. 2. Five (PAR-1,2,3,4,5) were drilled in the flat plain area south of the village in order to investigate the Holocene stratigraphy. The other two (MAG-1,2) were drilled on the prehistoric settlement: MAG-1 traced the thickness of archaeological strata in the centre of the settlement, while MAG-2 investigated the interface between anthropogenic and natural strata at the northern settlement margin.

The sediment cores were obtained by using an Atlas Copco vibracoring device (Cobra MK 1). The corer used (1 m in length) was equipped with a 40 mm in diameter core cutter and basket type core catcher. The inner sampling was achieved through the use of plastic PVC tubes (with a 40 mm outer diameter) sealed, marked and stored properly for further analysis. The maximum recovery depth for the drilling procedure in Agia Paraskevi was 10 m below surface. Splitting of the core samples in the lab allowed stratigraphic description and photographic record.

Selective samples containing molluscs were taken from the vibracores. They were treated with water containing ~10% diluted hydrogene peroxide and washed into a stainless steel sieve with 1 mm wire mesh. Residue was dried up and mollusc shells and fragments were hand selected for further palaeontological study. The determination of sedimentary and environmental facies was based on the analysis of fossil molluscs such as gastropods, bivalves, and plant remains.

The chronostratigraphy of the cores was determined by a series of ten C^{14}-AMS radiocarbon determinations undertaken on in situ marine shells and organic deposits (Table 2). All the samples were submitted to CEDAD Laboratory, University of Salento, Lecce, Italy).

The conventional radiocarbon ages of the marine shells have been calibrated in calendar years by using the MARINE04 curve for marine data and a $\Delta R = 149 \pm 30$ years. Also the conventional radiocarbon ages for the samples of organic material and charcoal were converted into calendar years by using the software OxCal Ver. 3.5 based on the last atmospheric dataset (Reimer et al., 2004).

The topographical survey of the drilling sites and the field surveys in areas where the elevation data were not sufficient were done using of a Topcon FC100 differential GPS. The instrumentation accuracy was ≤ 1 cm in positioning and ≤ 2 cm in levelling. All the GPS measurements used the Greek grid and the mean sea level derived from Hellenic Military Geographical Service (H.M.G.S.) data.

Interpretation of remote sensing data such as Landsat ETM7 and Quickbird (Digital Globe, 2005, from GoogleEarth) were helpful tools in undertaking geomorphological analysis of the area as well as establishing the evolution of its landscape. For the 3D representation of the morphological relief, high resolution topographic data derived from SRTM (Shuttle Radar Topography Mission) surveys were used and superimposed on the satellite imagery in order to obtain hypsometric information of the different landforms identified in the northern part of Sperchios Valley. Previous works highlighted the sound accuracy of this data in northern Greece (Andritsanos et al., 2004; Ghilardi et al, 2007).

Geophysical measurements were carried out, by means of the Electrical Resistivity Tomography (ERT) technique, in an attempt to

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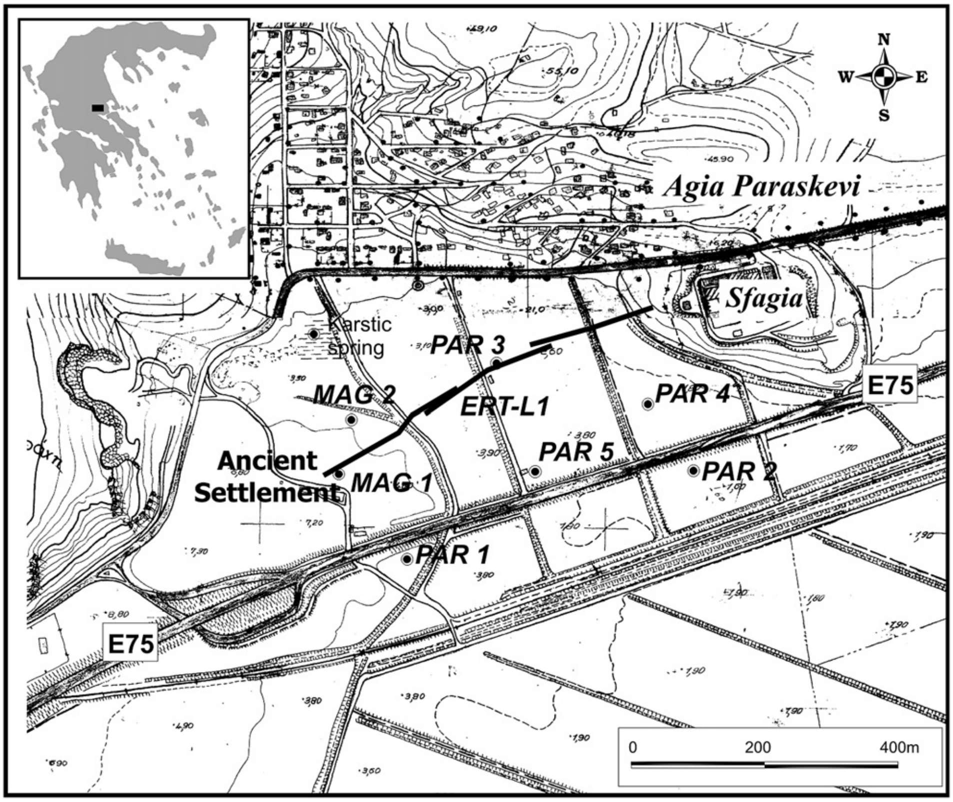

Fig. 2. Site map of Agia Paraskevi area, including the Prehistoric settlement, where the locations of the boreholes and the lines of the electrical resistivity tomography are shown. E75 is the Athens-Thessaloniki national highway.

obtain information regarding the deeper geometry and lithology of the subsurface at the area under study. ERT (Dahlin, 2001) is based on the development of the standard geoelectrical method, using fully automated measuring systems and advanced interpretation algorithms (Yi et al., 2003) which allow the collection of large amounts of data and the production of informative electrical resistivity images of the subsurface. The ability of ERT to provide fast and reliable shallow subsurface geoelectrical property images under various field conditions is particularly useful in studying sedimentary areas and thus ERT is considered an increasingly important imaging tool in various relevant research fields including geoarchaeological and paleoenvironmental studies (Smith and Sjogren, 2006).

Five overlapping Electrical Resistivity Tomography geophysical sections, obtained in a roll-along mode, were measured (for location see Fig. 2) aiming to produce 2D images of the subsurface resistivity properties and to provide indirect information concerning the deeper stratigraphy. The inter-electrode spacing (a) in every geo-electrical section was 5 m and the maximum electrode separation N was set to 8 (a, 2a) providing an estimated investigation depth of approximately 50 m. Data from individual lines were merged to produce a continuous, 550 m long, geoelectrical line having a WSW to ENE orientation. The pole-dipole array was used to collect the data since it is known to have good lateral and vertical resolution and adequate signal to noise ratio (Ward, 1989). Data were collected using a 10-channel resistivity meter (IRIS INSTRUMENTS) with a 48 cable multiplexing ability.

Geoelectrical section interpretations were obtained by inverting the unified data-set with a standard iterative smoothness constrain scheme based on a finite element forward solver (Tsourlos, 1995). Prior to inversion, data were corrected for the topography effect (Tsourlos et al., 1999). Inversion produced a low RMS error (3.4%) between measured and predicted data indicative of good data quality.

4. Results

4.1. Lithostratigraphy

Facies determination is mainly based on macro-faunal analyses from the core samples of the seven vibracores. In Table 1, data from selected samples of all vibracores are compiled, showing generic and species names of gastropods, bivalves, etc. in relation to sampling depth.

Vibracore profile PAR-1 (+3.08 m a.s.l., 6.50 m depth) is located ~150 m SSE from the margins of the prehistoric settlement (Fig. 2). At the base (1.52–3.42 m b.s.l.) a coastal marine (Mc) gravelly sand with rounded marine molluscs was found (Fig. 3). Some pebbles are bored by Clionid sponges. Above this (0.82–1.52 m b.s.l.), silty sands with thin shelled bivalves (*Abra*) indicate a shallow to lagoonal marine (Ms-l) environment. At 1.52 m b.s.l. a subangular pottery fragment indicates proximal human activity. The marine sediments are overlain by thin layered marshy clayey silts (0.52–0.82 m b.s.l.), followed by terrestrial (Ts) sediments mainly brown soils (+3.08 m a.s.l. – 0.82 m b.s.l.). Intercalations of sands (1.18 – 1.48 m a.s.l.) and sands with fine gravel (+0.22 m a.s.l. - 0.52 m b.s.l.) reflect fluvial (Fl) action.

Vibracore profile PAR-2 (+1.32 m a.s.l., 7.00 m depth) is located ~150 m SSW from the hill of Sfagia (Fig. 2). The lower and middle parts (1.48–5.68 m b.s.l.) of the profile show dark grey, clayey silts to silty fine sandy sediments of the littoral facies of a calm, restricted, shallow marine to lagoonal (Ms-l) environment (Fig. 3). A few thin shelled molluscs are scattered into these muddy sediments, while at 3.83 – 4.18 m b.s.l. numerous thin shelled molluscs

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Table 1
Mollusc fauna from selected samples of Agia Paraskevi vibracores in relation to sampling depth (*) = articulated valves.

Samples			Gastrodods							Bivalves										
Bore hole	sampling depth	absolute depth	*Planorbis*	*Alvania*	Trochidae	*Cerithium vulgatum*	*Bittium*	*Murex*	*Cyclope neritea*	*Nuculana*	*Cerastoderma glaucum*	*Abra*	*Tapes*	*Venus verucosa*	Veneridae	*Ostrea*	*Loripes lacteus*	*Solen*	*Cladocora* coral	Clionid boring on pebbles
PAR-1	3.95	0.87										*								
	4.20	1.12										*								
	4.65	1.57										*								
	4.75	1.67										*					*			
	4.95	1.87				*	*	*			*	*								
	5.35	2.27															*			
	5.55	2.47										*								
	5.60	2.52										*								
	5.95	2.87		*							*	*	*	*		*			*	
	6.35	3.27				*	*									*				
	6.45	3.37		*	*	*				*	*			*		*			*	*
PAR-2	2.45	1.13				*	*				*	*					*			
	3.15	1.83									*									
	3.65	2.33										*								
	4.25	2.93										*			*					
	4.35	3.03										*								
	5.20	3.88		*			*				*		*		*		*			
	5.70	4.38				*														
	5.90	4.58													(*)					
	6.30	4.98										*								
PAR-3	3.35	1.10					*					*					(*)			
	3.45	1.20					*					*						(*)		
	3.70	1.45					*					*								
	3.95	1.70					*					*								
	4.20	1.95					*					*								
	4.40	2.15		*			*				*	*								
	4.55	2.30					*													
	5.59	3.34				*														
	6.20	3.95									*									
	6.30	4.05									(*)									
	7.05	4.80					*					*								
	7.30	5.05					*					*								
	7.55	5.25																		
	8.40	6.15										*								
	8.55	6.30							*											
	8.75	6.50										*								
	9.25	7.00										(*)								
	9.70	7.45							*											
PAR-4	2.70	0.79					*					*					*			
	2.80	0.89					*					*								
	3.05	1.14										(*)						(*)		
	3.50	1.59										*								
	4.20	2.29															*			*
	4.45	2.54				*														
	4.80	2.89										(*)								
	4.90	2.99										*								
	5.40	3.49										*								
	5.90	3.99										*								
	6.10	4.19																	*	
	6.45	4.54				*														
	6.80	4.89													*					
	7.05	5.14													*					

(*continued on next page*)

Table 1 (*continued*)

Samples			Gastrodods							Bivalves										
Bore hole	sampling depth	absolute depth	*Planorbis*	*Alvania*	Trochidae	*Cerithium vulgatum*	*Bittium*	*Murex*	*Cyclope neritea*	*Nuculana*	*Cerastoderma glaucum*	*Abra*	*Tapes*	*Venus verucosa*	Veneridae	*Ostrea*	*Loripes lacteus*	*Solen*	*Cladocora* coral	Clionid boring on pebbles
	7.40	5.49					*													
	7.65	5.74									*									
	7.90	5.99					*					*								
	9.24	7.33													*					
	9.35	7.44					*								*					
	9.80	7.89													*					
PAR-5	3.36	0.54	*																	
	3.55	0.73			*															
	3.70	0.88																		*
	3.80	0.98				*									*					
	4.24	1.42										*								
	4.50	1.68																		
	4.90	2.08			*								*							
	5.65	2.83			*															
	5.80	2.98										*								
	6.70	3.88										*								
MAG-2	4.70	1.56		*			*								*					*
	4.80	1.66						*						*	*				*	*
	6.65	3.51					*				*									

(*Abra, Cerastoderma, Bittium, Loripes*) appear in a fine sandy matrix. At 1.08–1.48 m b.s.l. a silty-sandy layer with *Cerastoderma, Abra, Cerithium, Bittium* shells indicates a typical lagoonal environment. It is followed (0.00 - 1.08 m b.s.l.) by grey - brown thin bedded silty marshy deposits. Brownish marshy soils appear in the upper 1.30 m of the profile.

Vibracore profile PAR-3 (+2.25 m a.s.l., 10.00 m depth) is located halfway between the prehistoric settlement and Sfagia Hill (Fig. 2). The lower and middle parts (1.05–7.75 m b.s.l.) of the profile include dark grey silty to fine sandy sediments of a restricted calm shallow marine palaeoenvironment with some scattered mollusc shells (Fig. 3). Few intercalations of sand with pebbles and mollusc fragments at 3.05–3.35 m b.s.l., 6.00–6.20 m b.s.l., and silt with charcoal fragments and angular pebbles at 7.05–7.25 m b.s.l., indicate a very shallow marine to lagoonal – marshy environment. Thin layers of organic matter at 2.25 m b.s.l. indicate stagnant water. At 1.05–1.55 m b.s.l. many mollusc shells (*Abra, Cerastoderma, Bittium*) and articulated valves of *Solen, Loripes*, indicate a shallow marine - lagoonal environment. Above this (0.70–1.05 m b.s.l.) are dark brown to blackish silty marshy sediments, rich in organic matter. Brownish marshy soils appear in the uppermost 2.50 m of the profile.

Vibracore profile PAR-4 (+1.91 m a.s.l., 10.00 m depth) is located 60 m SW of Sfagia Hill (Figs. 2 and 3). The lower and middle parts (0.70–8.10 m b.s.l.) of the profile include alternating beds of dark grey silty-clayey sands with scattered mollusc shells deposited into shallow marine to lagoonal environments and gravelly sands containing mollusc fragments. Gravelly sands with mollusc fragments were found at 0.70–1.10 m, 2.05–2.60 m, 5.40–5.70 m, 7.80–7.10 m b.s.l., indicating successive coastal environments. The upper 2 m are brownish terrestrial clastic sediments, soils, sands and calcareous cobbles, representing colluvial material.

Vibracore profile PAR-5 (+2.82 m a.s.l., 7.00 m depth) is located halfway between the prehistoric settlement and Sfagia Hill (Figs. 2 and 3).The base of the profile shows silty fine sands with thin shelled molluscs of a shallow marine calm environment (2.90–4.20 m b.s.l.), followed by coastal gravelly sand with shell fragments and pebbles with clionid borings (1.93–2.90 m b.s.l.). Above (1.20–1.93 m b.s.l.) are fine bedded grey - blackish clayey silts to silty sands with *Tapes*. Marine sediments terminate upwards in a coastal gravelly sand containing mollusc fragments. Silty sands and loam with *Planorbis* are deposited above (0.00–0.63 m b.s.l.) in a freshwater marshy environment. The top 1.70 m are brownish marshy loams with sandy intercalations ending in brown loamy soil.

Vibracore profile MAG-1 (+5.89 m a.s.l., 7.00 m depth) is located in the centre of the prehistoric settlement (Figs. 2 and 3). Only anthropogenic strata are found through the 7 m core.

Vibracore profile MAG-2 (+3.14 m a.s.l., 6.90 m depth) is located at the northern margins of the prehistoric settlement (Figs 2 and 3). The lower part of the profile (1.30 m-3.76 m b.s.l.) is characterized by sandy gravel containing shell fragments and pebbles with clionid borings. It is coastal marine sediment that also contains rounded pottery fragments of the proximal settlement and reflects the shoreline along the northern side of the settlement. Upwards, marshy sediments with freshwater gastropods (*Planorbis*), land snails and relics of human activity (pottery fragments, food litter) follow. Younger anthropogenic sediments ~3.5 m thick from the settlement cover the sequence.

The collected data indicate that the penetrated strata can be distinguished into 4 informal sedimentary units (Fig. 3), from the youngest to oldest:

- *Unit A* consists of anthropogenic sediments which include all the archaeological strata of the settlement. It exceeds 7 m in thickness in MAG 1 (no “natural ground” reached) whereas in

Table 2
Radiocarbon ages for dated samples from the cores of Agia Paraskevi, calibrated after INTCAL 04 (Reimer et al. 2004). (CEDAD).

Sample code/Lab. number	Depth below m.s.l. (m)	Material	$\delta^{13}C$ (‰)	Conventional R/C age (yrs BP) ($^{13}C/^{12}C$ corr.)	2 σ Calibrated age
PAR 1 – 4.95-5.00 LTL2632A	1.87–1.92	Marine shell fragments	-0.5 ± 0.5	5821 ± 55	Cal BC 4280–3960 (6230–5910 Cal. BP)
PAR 2 – 4.23-4.27 LTL2627A	2.91–2.95	Marine shell (*Abra)*	-6.3 ± 0.6	5035 ± 50	Cal BC 3400–3020 (5350–4970 Cal. BP)
PAR 4 – 4.83-4.87 LTL2633A	2.92–2.96	Marine shell fragments	-9.9 ± 0.7	6703 ± 65	Cal BC 5290–4940 (7240–6890 Cal. BP)
PAR 1 – 6.45-6.50 LTL2631A	3.37–3.42	Marine shell fragments	-0.1 ± 0.1	6132 ± 55	Cal BC 4600–4320 (6550–6270 Cal. BP)
PAR 2 – 5.90-5.92 LTL2628A	4.58–4.60	Marine shell (Veneridae)	-3.2 ± 0.7	6888 ± 45	Cal BC 5440–5200 (7390–7150 Cal. BP)
PAR 3 – 8.56 LTL2629A	6.31	Marine shell *(Cyclope neritea)*	-3.5 ± 0.5	8209 ± 60	Cal BC 6760–6420 (8710–8370 Cal. BP)
PAR 4 – 9.23-9.25 LTL2635A	7.32–7.34	Marine shell *(Tapes)*	-3.2 ± 0.4	7527 ± 50	Cal BC 6010–5750 (7960–7700 Cal. BP)
PAR 3 – 4.55 LTL2630A	2.30	Organic matter	-23.4 ± 0.3	5970 ± 55	Cal BC 4990–4720 (6940–6670 Cal. BP)
PAR 5 – 4.35 LTL2634A	2.16	Organic matter	-2.3 ± 0.5	4654 ± 35	Cal BC 3520–3360 (5470–5310 Cal. BP)
PAR 3 – 9.43 LTL2636A	7.18	Charcoal	-18.8 ± 0.4	7299 ± 45	Cal BC 6240–6060 (8190–8010 Cal. BP)

MAG 2 it is 3 m thick and overlies sediments of Unit 2. Sediments of this unit are located and restricted only to the prehistoric settlement area.

- Unit 1 includes the youngest and uppermost part of the natural sediments. It consists of brownish soils, relics of marshy sediments, and in places sandy-gravelly thin layers. It includes all the sediments from soil surface to 1.5 m and in places to 3 m depth.
- Unit 2 conformably overlies Unit 3 and is overlain by Unit 1. It consists of fine grained sands, silts and clays that contain freshwater fauna (*Planorbis* sp.) and represents marshes and shallow ponds. The thickness of this unit ranges between 0.5 m and 1.5 m. In some boreholes, this unit represents the transition between Unit 1 and Unit 3 sediments.
- Unit 3 is the oldest and lowermost of the natural sediments. It consists mainly of fine grained clastic sediments (sand, silt, clay), and locally (PAR 1, 4, MAG 2) of coarse-grained sands and gravels. The sediments contain rich mollusc fauna (*Cerastoderma glaucum, Bittium, Abra, Cerithium, Alvania, Cyclope, Venus, Tapes,* etc.), indicating a shallow marine to lagoonal depositional palaeoenvironment. In some places (PAR 1, 4, MAG 2), coarse coastal sands with gravel and mollusc fragments were located. The thickness of the penetrated strata ranges from 2.5 m in PAR1 to 7.5 m in PAR4. The top of the sediments in this unit is located approximately at a depth of 1 m b.s.l.

All the above described units include sediments that were deposited between various transitional environments such as terrestrial-fluvial, freshwater marshes, coastal lagoons, shallow marine and gravelly marine coast, as a result of the Holocene sea level rise and the diachronic evolution of the area.

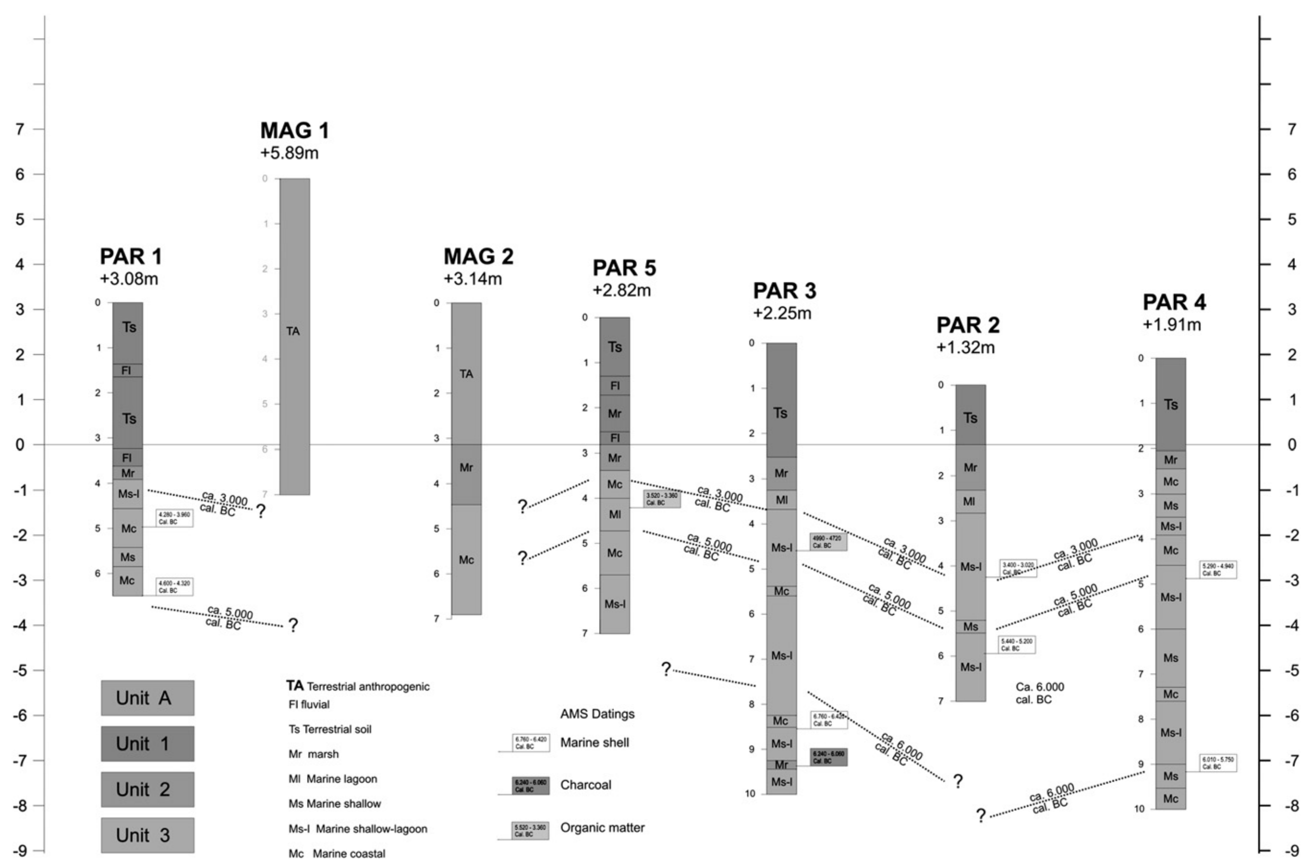

Fig. 3. Schematic presentation of the sedimentological characteristics of the selected sediment cores (for location see Fig. 2) and their stratigraphic interpretation.

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4.2. ^{14}C dating

Ten samples of marine shells, organic material and charcoal, from the boreholes PAR-1, PAR-2, PAR-3 and PAR-4 were dated with the ^{14}C-AMS method. The type of dated materials is given in Table 2, as well as their depth below present sea level and their calibrated age.

Chronological incoherence was absent from all samples, with the exception of sample PAR-3 9.43 at −7.18 m below mean sea level (charcoal), which has a younger age than the overlying sample PAR-3 8.56 (marine shell) at −6.31 m below mean sea level. The inversion is attributed to contamination or bioturbation.

4.3. Electrical resistivity tomography

The aim of the electrical resistivity tomography (ERT) investigation was to provide complementary information regarding the deeper structure of the studied area given the fact that no deeper coring information was available. In this framework, and although the ERT measuring lines were designed to cross over some of the existing shallow drilling holes, only limited correlation was possible between drilling and geophysical data as the need for a larger investigation depth resulted in a relatively lower resolving ability of the geoelectrical images compared to the existing drilling information.

The inverted results of the ERT section are depicted in Fig. 4a in grayscale and illustrate the subsurface geoelectrical image to a depth of 45 m below sea level. Based on the resistivity image and the correlation of the resistivities with the coring information, it was possible to produce a lithological interpretation section, depicted in Fig. 4b.

The geophysical image (Fig. 4) clearly depicts a stratigraphic sequence of a top low resistivity layer dominating the centre of the section (from 160 to 370 m) having a maximum thickness of 2–3 m, and corresponds to clayey soils and marshy sediments. This is followed by a more resistive layer of varying thickness (5–10 m), which corresponds to marine deposits of clay-sand composition. The above is verified by the coring of drill MAG-3 situated at 310 m of the ERT section.

Below this layer, a low resistivity formation probably corresponding to older clay soils can be seen. Finally a resistive formation, possibly limestone, can be seen at a depth of 40 m below sea level between 160 m to the end of the section. As expected, the high resistivity limestone is also apparent on the surface in the easternmost part of the section (at 470–550 m).

The western part of the section (0–160 m) exhibits a stratigraphic sequence which clearly differentiates itself from the remaining section. Furthermore, at that part of the section no high resistivity formation (limestone) is detected within the investigation depth limits.

5. Discussion and synthesis

5.1. Holocene palaeoenvironmental changes: palaeogeography

Evaluations of stratigraphic palaeontological chronological and geophysical data allow determination of palaeoenvironmental changes in Agia Paraskevi. According to this scenario, the area was flooded by the sea due to the Holocene sea level rise, and a shallow marine bay was formed in the area between the prehistoric settlement and Sfagia Hill, just south of the present village of Agia Paraskevi (Fig. 5a). The bay was part of the northern coastline of the Maliakos Gulf. This ancient coastline should extend parallel to the margins of the hilly terrain. Diachronically, the coastline can be traced (Fig. 5a) from the southern margins of the settlement (PAR-1) along the south-east to north margins of the settlement (MAG-2), and east between PAR-3 and the village to the western side of Sfagia Hill (PAR-4). Coastal gravelly sediments were confirmed in PAR-1, 3, 4, MAG-2 vibracores, while in PAR-1 coastal sediments are thicker. This shallow marine gulf may have played a critical role (sheltered

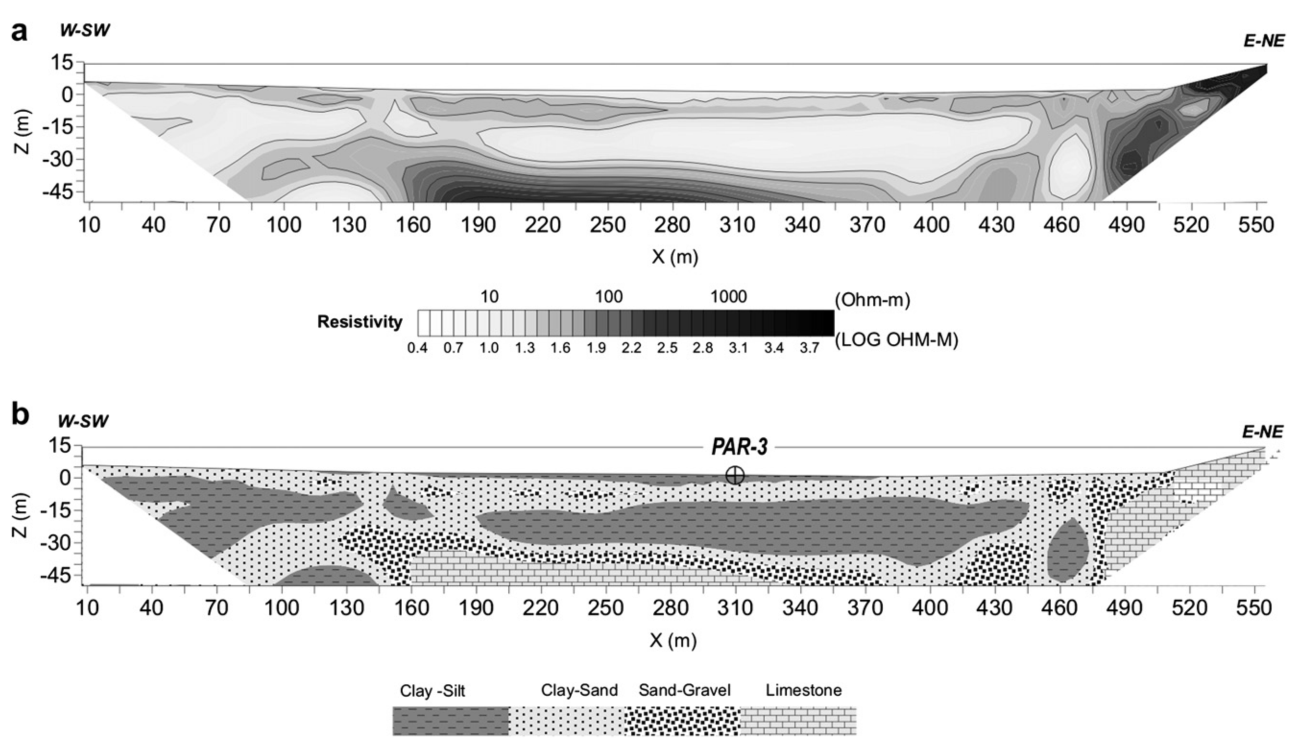

Fig. 4. (a) Image of the Geoelectrical subsurface properties along ERT section 1 (for location see Fig. 2); and (b) the stratigraphical/lithological interpretation.

area) in the prehistoric settlement as it co-exists with the human presence indicated by the pottery shards found in the marine sediments (PAR-1 1.52 m b.s.l., and MAG-2 1.30 m-3.76 m b.s.l.).

The shallow marine bay gradually became silted up and evolved into a very shallow area with lagoons and saltwater marshes. Freshwater supply from large karstic springs that already existed along the hilly margins affected the area. Initially, a gradual slow silting up of the inner part of the bay caused a slow coastline migration to the south. A small freshwater marsh was formed around the karst spring (Fig. 5b) that gradually expanded up to the northern side of the settlement (Fig. 5c). Pottery shards embedded into the marshy deposits in the northern outskirts of the settlement (MAG-2 0.00–1.30 m b.s.l.) indicate human activity in the vicinity. Thereafter, the marshy regime dominated the area (Fig. 5b) until the beginning of the previous century. Present-day morphology is the result of extensive reclamations during the last decades.

5.2. Sea level changes

Sea level is one of the most important parameters controlling the progradation of a deltaic system. The sea level is defined by the position of the sea surface relative to the coast, whilst sea-level change is a measure of the relative shift in position of these two surfaces (Lambeck, 1995) which coincides with the vertical and horizontal displacement of the associated coastline (Lambeck and Purcell, 2005, Poulos et al., 2009). Over the last three decades, many researchers proposed several different sea level curves (Kayan 1991; Kelletat, 1975, Van Andel, 1989, 1990; 2005; Vouvalidis et al., 2005) for sites around the Aegean Sea. Despite the abundance of sea level data scattered around the Aegean Sea, it is very difficult to unify these into a single sea level curve as, although the glacio-hydro-isostatic model for the Eastern Mediterranean Sea have been successfully defined (Lambeck, 1995), the accuracy of the result is questioned due to different or undefined local tectonic control (Thommeret et al., 1981, Pirazzoli et al., 1982; Pirazzoli, 2005).

Sperchios basin and Maliakos Gulf, its prolongation seawards, are located in the centre of the Aegean Sea and are highly controlled by active tectonic deformation. This undefined tectonic control is the main reason why the sea level data derived from the geo-archaeological research in Eretria and Chalkis (Kambouroglou et al., 1988) and Skyros Island (Pavlopoulos et al., 2007) cannot be used as a reference for the study of the Sperchios delta evolution. In this paper the sea level curves proposed by Lambeck and Purcell (2005) and Vouvalidis et al. (2005) are used for the correlation of the sea level changes in Maliakos Gulf (Fig. 6). The first is based on the eustatic and glacio-hydro-isostatic model for the Aegean Sea, and it is representative for the sea level changes in the central Aegean Sea without any tectonic influence. The second curve proposed for the Thermaikos Gulf it is considered by the authors as representative sea level curve for the North Aegean plateau.

The corresponding sea level graph in Fig. 6 contains relative sea level points and their associated error ranges, based on the reasoning described subsequently. From the dated samples, seven (7) are marine shells, two (2) are organic matter, and one (1) is charcoal. The marine shell samples are benthic shallow dwellers, originate from sediments deposited into a very shallow marine coastal environment as indicated by lithostratigraphy, lithology, and synthesis of the mollusc fauna; and can be considered as near sea level indicators (vertical error is estimated at $\sim$0.5 m). The organic matter samples originate from deposition into a very shallow calm water environment (possibly a very shallow lagoon), and the vertical error is $\sim$1 m. The charcoal fragment was collected from a small silty - sandy layer that contained also some small pebbles, and a vertical error of $\sim$1 m is acceptable.

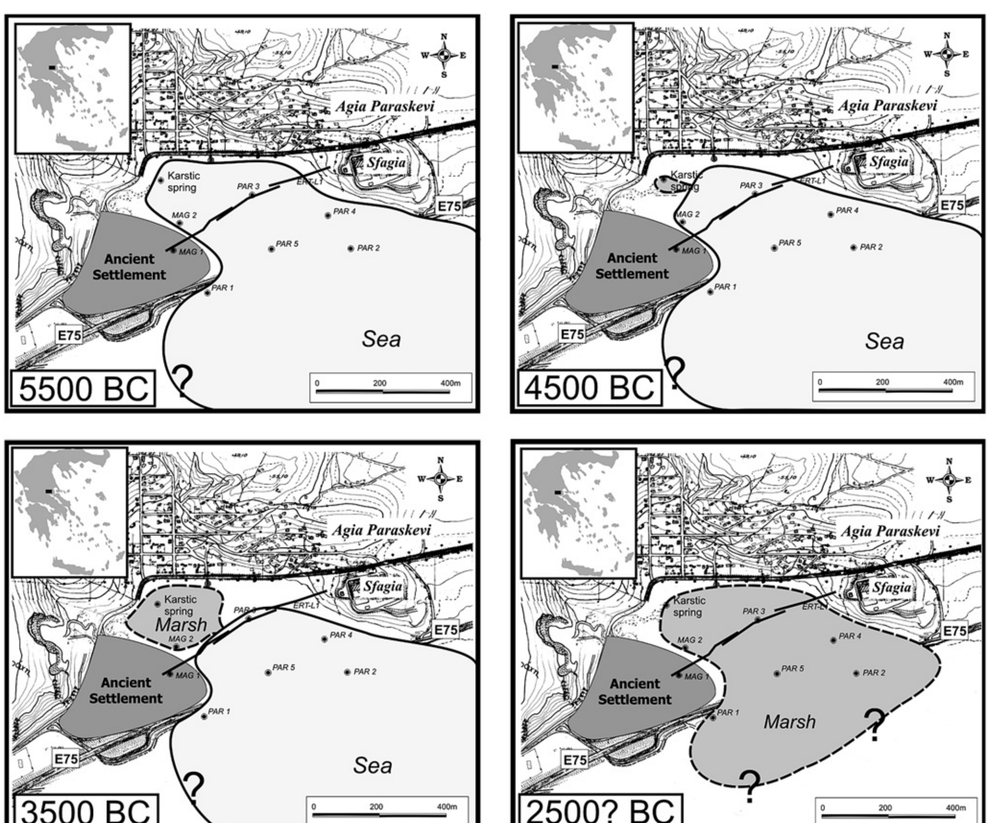

Fig. 5. Palaeogeographic reconstruction of the area in between the Agia Parascevi and the ancient settlement from 5500 BC to 2500 BC.

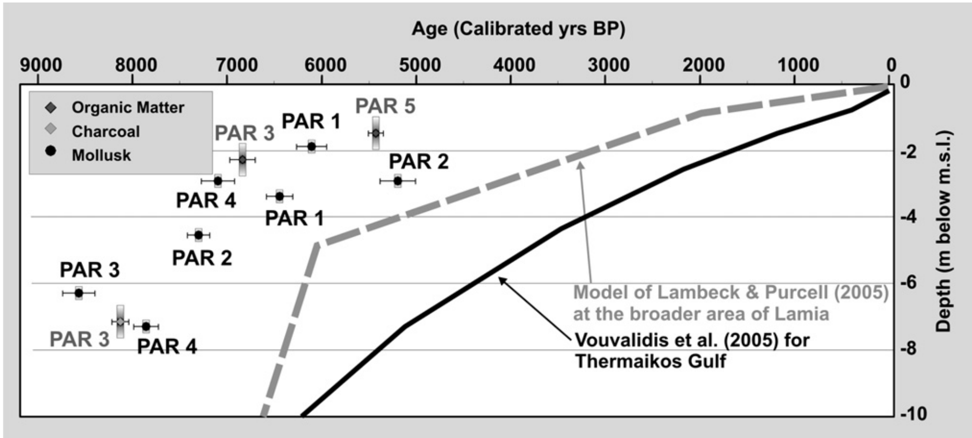

Fig. 6. Schematic presentation of the ^{14}C dating samples against Holocene sea-level curves of Lambeck and Purcell (2005) and Vouvalidis et al. (2005).

A comparison between ages and depths (Table 2) allows estimation at the rate of the rise in sea level. For the time span between 7390 and 5350 cal BP, a sea level rise rate of 0.8 mm/a is estimated, while for the previous time interval between 8710 and 7390 cal BP, the sea level rise rate is estimated at 1.3 mm/a. These rates are considerably lower than the sea level rise rates proposed by Lambeck and Purcell (2005) and Vouvalidis et al. (2005) for the same time period (Fig. 6). It is very possible that this significant rate difference is the result of the intensive tectonic uplift of the study area due to the tectonic deformation of Sperchios Valley.

6. Conclusions

The multidisciplinary study presented in this work revealed a shallow marine palaeoenvironment, gradually shifting to a coastal – lagoonal one and finally changing to a freshwater marshy environment. The inhabitation of the area remained constant in a changing environment. More specifically, during the Neolithic period ($\sim$6000 BC) in the area of Agia Paraskevi, a prehistoric settlement was founded on a headland extending into a shallow marine gulf. The presence of this sheltered gulf as well as a large freshwater karstic spring in the north of the headland may have been the pivotal reasons that attracted prehistoric man to this area.

Sedimentation in this shallow gulf was low due to restricted overland transport from the surrounding calcareous karstic hilly terrain. Until that time, the area was slowly but constantly silting up to a shallow marine – lagoonal environment (4500–3500 BC, late Neolithic period). This is directly connected with a probable deltaic progression of the Sperchios River along the northern margins of Maliakos Gulf. The area was restricted and gradually turned into a freshwater marsh ($\sim$2500 BC, Helladic period). Marshes extended along the whole area until the previous century. Continuous occupation of the site for a long period ($\sim$6000–1000 BC) indicates the diachronic importance of this area for prehistoric humans.

As far as the sea level changes are concerned plot of the ages/depths, of the dated samples, in comparison with the sea level rise curves for the Aegean Sea/Maliakos Gulf reveals a considerable offset above the curve which is attributed to a possible tectonic deformation of the Sperchios Valley. This tectonic uplift is probably the reason why a coastal settlement remained on the surface and unaffected from the sea transgression the last 7000 years.

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