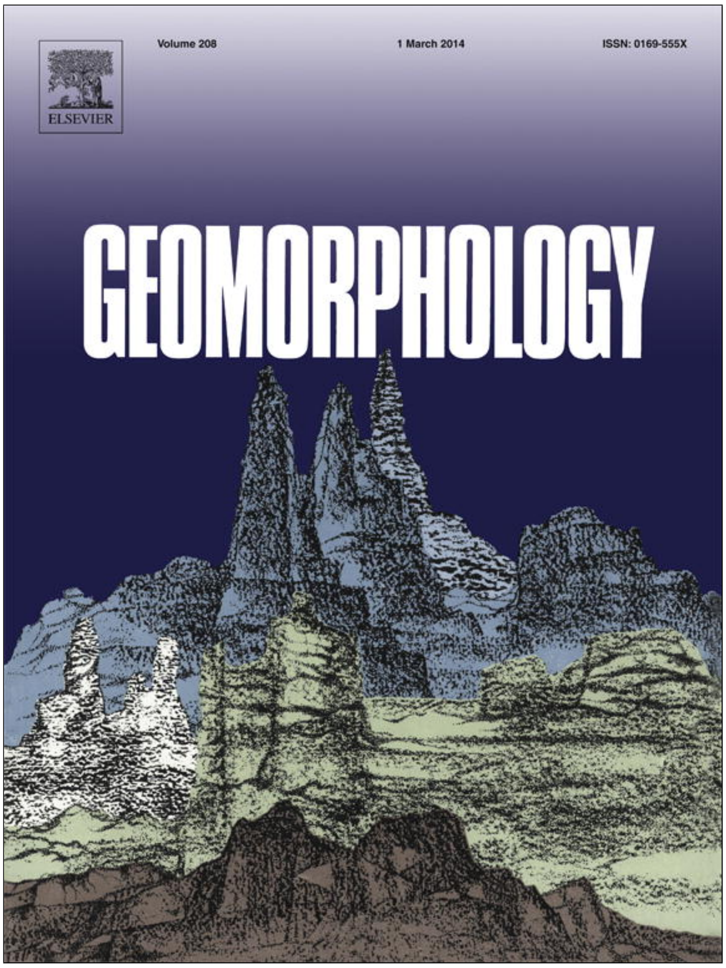
Volume 208
1 March 2014
ISSN: 0169-555X
ELSEVIER
GEOMORPHOLOGY

Geomorphology 208 (2014) 225–237

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Mid- to Late Holocene shoreline reconstruction and human occupation in Ancient Eretria (South Central Euboea, Greece)

Matthieu Ghilardi [a,*], David Psomiadis [a,b], Kosmas Pavlopoulos [c], Sylvie Müller Çelka [d,e], Sylvian Fachard [d,f], Thierry Theurillat [d,g], Samuel Verdan [d,g], Alex R. Knodell [f], Tatiana Theodoropoulou [h], Andrew Bicket [i], Amandine Bonneau [a], Doriane Delanghe-Sabatier [a]

[a] CEREGE (UMR 7330 CNRS), Europôle de l'Arbois BP 80, 13545 Aix-en-Provence CEDEX 04, France
[b] Imprint Analytics GmbH, Technologiezentrum Mittelburgenland, Werner von Siemens Straße 1, 7343 Neutal, Austria
[c] Harokopeio University of Athens, Department of Geography, Eleftheros Venizelou Street 70, 176-71 Kallithea-Athens, Greece
[d] Swiss School of Archaeology in Greece, Skaramanga Str., Athens, Greece
[e] Archéorient (UMR 5133 CNRS), Maison de l'Orient et de la Méditerranée Jean Pouilloux, 7 rue Raulin, 69365 Lyon CEDEX 7, France
[f] Joukowsky Institute for Archaeology and the Ancient World, Brown University, Box 1837/60 George Street, Providence, RI 02912, USA
[g] University of Lausanne, Institut d'archéologie et des sciences de l'Antiquité, Lausanne, Switzerland
[h] The American School of Classical Studies at Athens, 54 Souidias Street, GR-106 76 Athens, Greece
[i] Wessex Archaeology, Coastal and Marine, 7-9 North Saint David St., Edinburgh EH2 1AW, Scotland, UK

A R T I C L E I N F O

Article history:
Received 21 June 2013
Received in revised form 3 December 2013
Accepted 8 December 2013
Available online 14 December 2013

Keywords:
Eretria
Greece
Coastal stratigraphy
Mid- to Late Holocene
Shoreline reconstruction

A B S T R A C T

Few studies have aimed to reconstruct landscape change in the area of Eretria (South Central Euboea, Greece) during the last 6000 years. The aim of this paper is to partially fill in this gap by examining the interaction between Mid- to Late Holocene shoreline evolution and human occupation, which is documented in the area from the Late Neolithic to the Late Roman period (with discontinuities). Evidence of shoreline displacements is derived from the study of five boreholes (maximum depth of 5.25 m below the surface) drilled in the lowlands of Eretria. Based on sedimentological analyses and micro/macrofaunal identifications, different facies have been identified in the cores and which reveal typical features of deltaic progradation with marine, lagoonal, fluvio-deltaic and fluvial environments. In addition, a chronostratigraphy has been obtained based on 20 AMS ^{14}C radiocarbon dates performed on samples of plant remains and marine/lagoonal shells found in situ. The main sequences of landscape reconstruction in the plain of Eretria can be summarized as follows: a marine environment predominated from ca. 4000 to 3200 cal. BC and a gradual transition to shallow marine conditions is observed ca. 3200–3000 cal. BC due to the general context of deltaic progradation west of the ancient city. Subsequently, from ca. 3000 to 2000 cal. BC, a lagoon occupied the area in the vicinity of the Temple of Apollo and the settlement's development was restricted to several fluvio-deltaic levees, thus severely limiting human activities in the plain. From ca. 2000 to 800 cal. BC, a phase of shallow marine presence prevailed and constrained settlement on higher ground, forcing abandonment of the major part of the plain. Finally, since the eighth century BC, the sea has regressed southward and created the modern landscape.

1. Introduction

Much geoarcheological work in Greece has focused on the interaction between Holocene landscape changes and human occupation (e.g. Fouache et al., 2010; Ghilardi and Tristant; 2012; Tourloukis and Karkanas, 2012). Reconstructing shoreline evolution in areas of archeological interest is a well-developed topic on both the Ionian (Vött, 2007) and Aegean coasts (Kraft et al., 1977; Ghilardi et al., 2008; Pavlopoulos et al., 2012; Tourloukis and Karkanas, 2012). Facies identification and chronostratigraphies both contribute to the reconstruction of coastal evolution and sea-level rise during the Late Holocene (Pavlopoulos et al., 2006; Vött, 2007; Pavlopoulos, 2010; Pavlopoulos et al., 2010, 2012) as well as to the study of human settlement patterns in a given region (Mourtzas and Marinos, 1994; Baika, 2008). In Euboea, several attempts have been made to reconstruct the post-Glacial maximum sea-level rise and to estimate the local influence of tectonics (Philip, 1974; Stiros et al., 1992; Pirazzoli et al., 1999; Gaki-Papanastassiou et al., 2001; Evelpidou et al., 2012). However, relatively little geoarcheological research has been conducted along the island's coastline. To date, work has concentrated in Amarynthos (situated 10 km eastward of Eretria) where deltaic progradation is attested and well described for the last 4500 years (Ghilardi et al., 2013a). The consequences of these major landscape changes on the human occupation have been also studied. At Eretria (Fig. 1), the

* Corresponding author. Tel.: +33 4 42 97 17 78.
E-mail address: ghilardi@cerege.fr (M. Ghilardi).

0169-555X/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.geomorph.2013.12.006

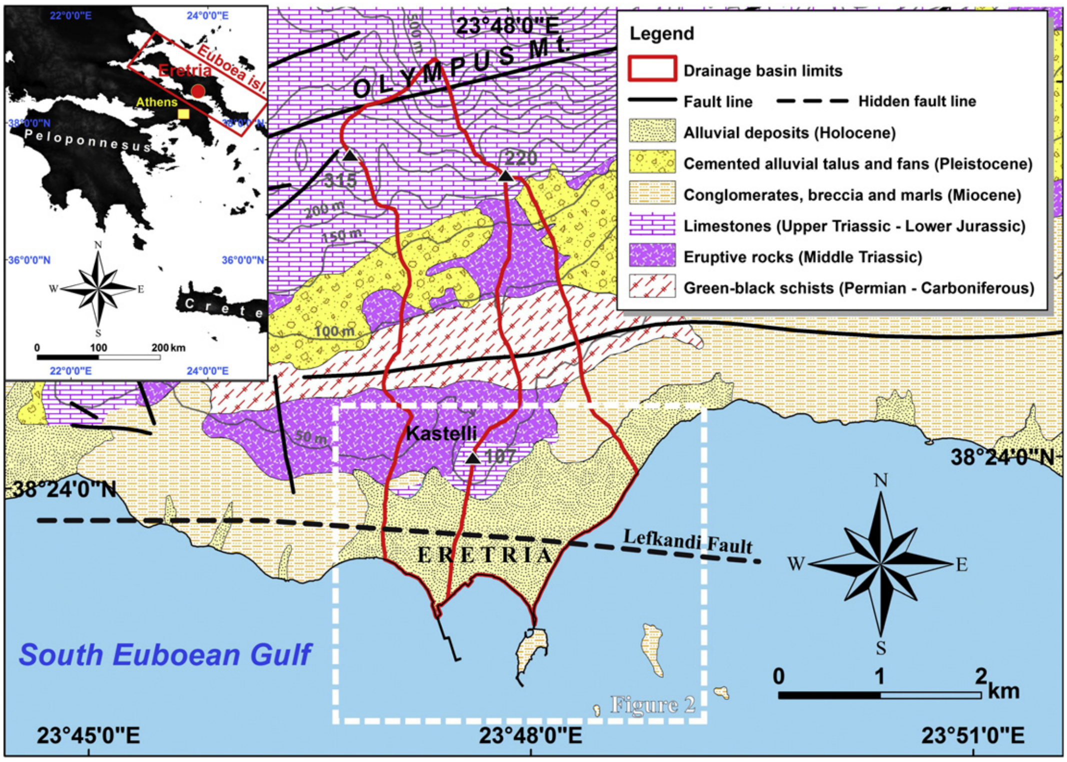

Fig. 1. Location and geological maps of the study area.

microfaunal identification of sediments from boreholes revealed the presence of marine environments in the subsoil of the modern city (Pavlopoulos et al., 1985; Kambouroglou et al., 1988;Kambouroglou, 1989). Unfortunately, the lack of radiocarbon dating precluded the development of a robust chronostratigraphy. At the same time, archeologists have also tried to decipher changes of the coastal landscape, relying on archeological remains (Krause, 1985). However, due to the lack of paleoenvironmental evidence, several questions related to landscape and shoreline evolution from the Neolithic to Late Roman times (fifth millennium BC to the fifth century AD) remain unanswered. The present study aims to fill this gap.

2. Geological and geomorphological settings

Euboea is the second largest island of Greece (ca. 3685 km^2), located just off the east coast of the mainland (Fig. 1). Rocky coasts prevail along the Euboean shoreline and the largest deltaic areas are only located in the north and central parts of the island: the Kalas and Lilas estuaries,

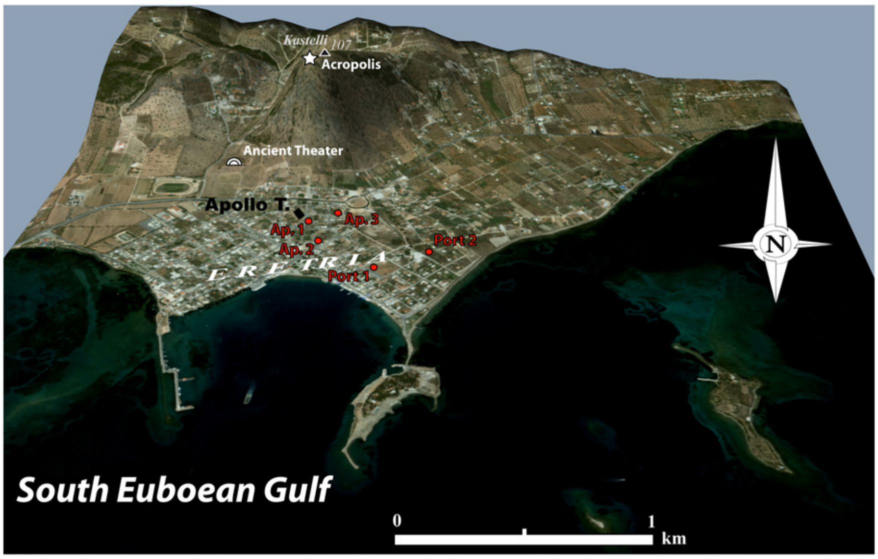

Fig. 2. Location map of the boreholes drilled in the easternmost part of the modern town of Eretria. Aerial photography dated from July 4th, 2005 was superimposed on a Digital Elevation Model where elevation information is derived from the Shuttle Radar Topography Mission data (SRTM version 3).

respectively (Genre, 1989; Ghilardi et al., 2013b). The ancient city of Eretria is located on the northern shore of the southern Euboean Gulf; the latter is representative of the early stages of the Quaternary tectonism that formed the marginal Aegean basins. The ancient site is situated within the drainage basins of two ephemeral streams which cover an area of ca. 4.9 km^2 and 3.5 km^2, respectively (Fig. 1). The wider region consists of geological formations of the Pelagonian zone, mainly Mesozoic limestones and some clayey sandstones with basic eruptive rock beds (Fig. 1). The carbonate layers are partly or totally composed of dolomites or dolomitic limestones. Lacustrine deposits of conglomerates, breccia and marls of Upper Miocene age cover the western lowlands (Malakonta area). Paleozoic bedrock emerges north of the acropolis (a limestone outcrop 107 m asl, also called Kastelli, Figs. 1, 2) in the foothills of Mt. Olympus as a clastic series (shales, schists, phyllites, graywackes) with carbonate intercalations (Middle Carboniferous–Permian). The relation between the formations of this series and the overlying Mesozoic formations is usually one of stratigraphic unconformity. Pleistocene screes and talus cones overlie the foothills of Mt. Olympus, while Holocene alluvial deposits cover the southernmost lowlands, near the coastline. The western part of the coastal plain consists mainly of torrential and floodplain deposits, while marine deposits – muds and sands – cover the central and eastern part of the coastal plain (Kambouroglou, 1989). Eretria (ancient and modern) was built upon these alluvial sediments.

The southern Euboean Gulf is an area of mild tectonic activity and moderate seismicity (Drakopoulos et al., 1984). There are no large tectonic structures in the vicinity of the central Euboean Gulf, and earthquakes are usually of low magnitude. Earthquakes were recorded in 1853, 1894, 1914 and 1938; although they affected Chalkis and its immediate surroundings, most of them had little wider impact (Galanopoulos, 1955; Papazachos and Papazachou, 1997; Gaki-Papanastassiou et al., 2011; Roumelioti et al., 2011). The Olympus massif consists of an intensely tectonized reversed synclinal megafold, on an E–W axis plunging northeastwards. The neopaleozoic formations between Eretria and Olympus form a great, anticlinal fold, following an E–W axis. The main faults that affect the pre-Neogene and recent geological formations of the study area are normal, oriented WSW–ENE to W–E. Two antithetic normal faults with a WNW–ESE direction are found in the south and north coastlines of the southern Euboean Gulf (Rondoyanni et al., 2007). The combination of both uplifted notches and quasi-submerged ancient sites has long led archeologists to believe that Central Euboea is tilting to the southwest on its long axis (Sackett et al., 1966). The Lefkandi fault, dipping to the south, continues offshore for a total length of 25 km, south of the modern towns of Eretria and Amarynthos (Perisoratis and van Andel, 1991); it forms the northern margin of the southern Euboean Gulf's graben (Fig. 1). Neotectonic activity affected the area (Aubouin, 1963), resulting in subsidence in coastal areas. These vertical movements seem to have influenced the pre-Holocene sediments while Holocene deposits overlie the coastal areas, which remain mostly unaffected (Voreadis, 1952). However, recent tectonism, including earthquakes recorded in 365 AD and 511 AD (Ducrey et al., 2004), indicates the continuation of subsidence at minor rates during the Holocene. Evelpidou et al. (2012) conclude that the coastal geomorphology of Euboea was tectonically influenced during the Late Holocene, with tilting that probably affected part of the island. Another possibility is that the uplift is related to strike–slip events of magnitude larger than 7.0; these are known to occur offshore, in and around the North Aegean Trough, which is not far from the study area (Stiros et al., 1992). Recent studies have documented evident uplift in tectonic blocks north and south of the North Aegean Trough (Syrides et al., 2009; Pavlopoulos et al. 2012; Vacchi et al., 2012, in press).

Tidal range at the Euripus, the narrowest point in the Euboean Gulf, has been accurately measured for the last fifty years and shows its maximum amplitude in North Chalkis of 0.56 m with an error of $\pm$0.05 m (Tsimplis and Blackman, 1997; Cundy et al., 2000). Some authors consider it to be the largest tide recorded along the Greek Aegean coastline (Tsimplis and Blackman, 1997), though Tsimplis (1997) records a distinction between North Chalkis, where daily tide is around 0.5 m, and South Chalkis where values are closer to 0.2 m.

3. Regional and local relative sea-level contexts

Holocene sea-level changes in the Aegean Sea have been studied and illustrated in several sea-level curves (Van Andel, 1989; Pirazzoli, 1991, 1997, 2005; Vouvalidis et al., 2005; Desruelles et al., 2007; Goodman et al., 2009; Poulos et al., 2009; Syrides et al., 2009; Pavlopoulos et al., 2012). They reflect global eustatic changes, regional glacio-hydro-isostatic adjustments, vertical displacements and sedimentary processes (Pavlopoulos et al., 2011). The local effect of tectonism prevents the establishment of a unique sea-level curve for the Aegean Sea and, therefore, only regional curves have been published up to this point. The Mediterranean glacio-hydro-isostatic model of Lambeck and Purcell (2005), calibrated by a variety of geomorphological, biological and archeological indicators, predicts a valid sea-level change pattern since the Last Glacial Maximum. In the past, the prevailing view was that the Holocene paleo-shorelines around Euboea were formed during the Versilian sea-level highstand (~5500 years BP) or eustatic sea-level peaks (3000 and 1500 years BP). Kambouroglou (1989) attempted to draw a relative sea-level curve of the last ca. 9000 years in the area of Eretria by plotting together archeological indicators, radiocarbon data, and sedimentary formations (beachrocks). He suggested a sea-level highstand (at a higher position than the present-day sea-level) at 6000 years BP, an abrupt lowering in the next 1000 years, and a gradual increase from −3.8 m at ca. 5000 years BP until today. However, more recent investigations of Greek coasts do not determine any Holocene sea-level highstand event that exceeded present-day sea level, and suggest a continuous sea-level rise throughout the Holocene, although at different rates (Vött, 2007; Vouvalidis et al., 2010). In addition, Stiros et al. (1992) and Pirazzoli et al. (1999) found that most uplift in the North Euboean Gulf and the Aegean coast of Euboea itself is episodic and coseismic; consequently, they cannot be related to climatic events; nor can they be coeval.

4. The human occupation of Ancient Eretria: long-term history of abandonment and resettlement

The earliest traces of a human occupation at Eretria are found on the top of the acropolis and date to ca. 3500 BC (Late Neolithic, Fig. 3A, Müller Çelka, 2010b). Little is known about the extent and the early environment of the settlement, which may have been established on a coastal barrier or protruding headland and likely moved periodically (Müller Çelka, 2010a, 2010b). Evidence of a village, dated to the end of Early Helladic I (3000/2800 cal. BC), is attested in the center of what is now the modern city of Eretria (Fig. 3B) and some structures have been identified in several locations, such as Bouratsa (Tuor, 1981, 1982, Fig. 3), Roussos (Themelis, 1969), Alexandri (Psalti, 2003), as well as in the vicinity of the later sanctuary of Apollo (Verdan, 2002). Around 2000 BC (beginning of Middle Helladic I), the site is abandoned and only sparse traces of human occupation (Fig. 3C) have been identified in the surroundings (Themelis, 1969). Subsequently, after a four-century interruption of human occupation, a new village was built on top of the acropolis (Fig. 3C) around 1600 BC (end of Middle Helladic). Contemporary pottery has also been found in the plain, suggesting an extension of the settlement or a seasonal occupation of the modern coastline. The hill site was sporadically occupied during the Mycenaean period, ca. 1600–1050 BC (Müller Çelka, 2010a, 2010b; Müller Çelka et al., 2013).

The lack of archeological remains dated between the 11th and the 9th centuries BC (Protogeometric period) suggests that the site was probably abandoned during that time, although a sparse occupation leaving no visible material record cannot be excluded (Lemos, 2002; Blandin, 2007). This situation is in contrast to the flourishing of Lefkandi,

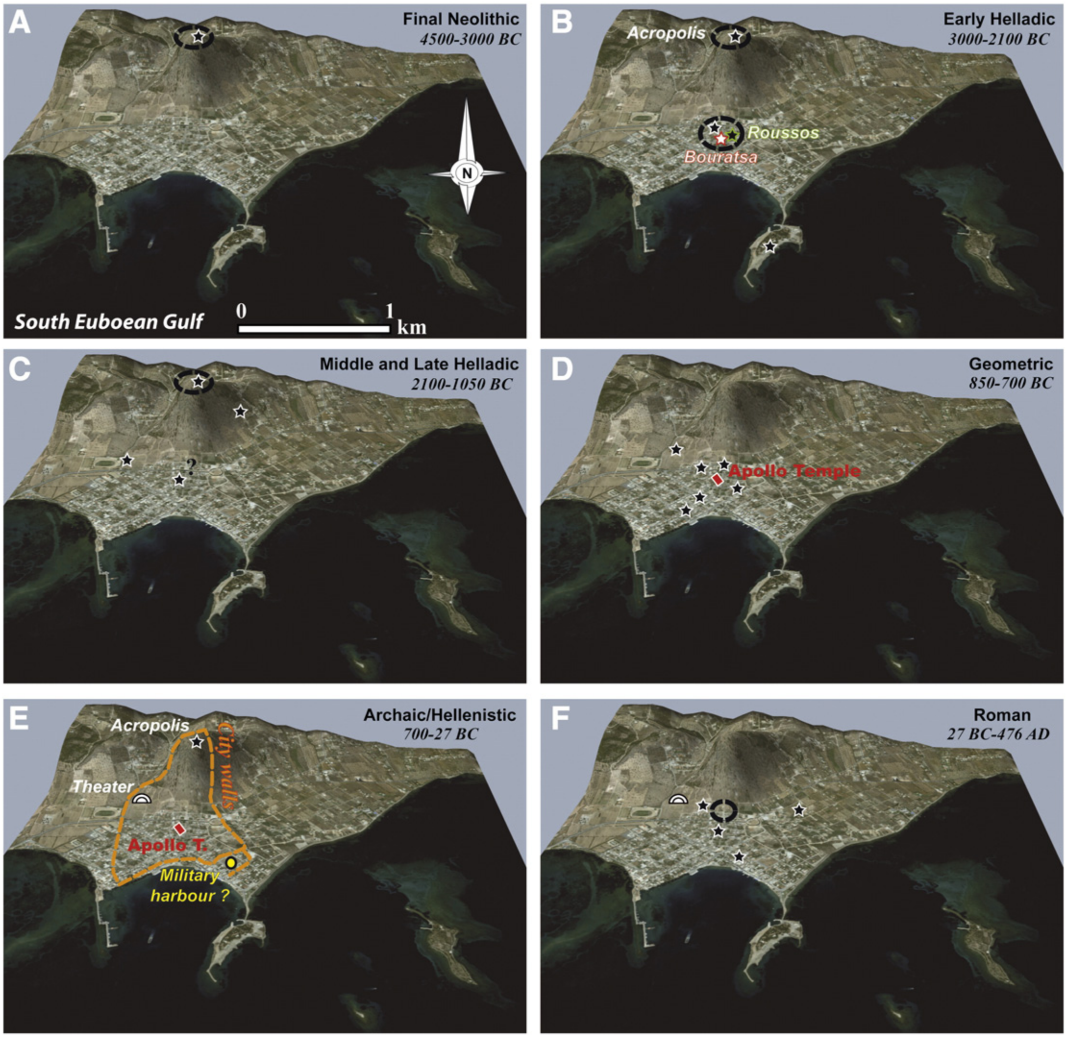

Fig. 3. Sketches showing the location of human settlements in Ancient Eretria for the last 5000 years. The black dashed line indicates an important site development and the stars reveal the presence of structures (walls) and abundant pottery remains.

located just 15 km westward. Eretria was resettled during the middle of the 9th century BC (Sub-Protogeometric II) and rapidly expanded in the course of the 8th century BC (Middle Geometric II–Late Geometric). The first evidence of communal architecture comes from the last quarter of the 8th century BC, with the building of a temple probably dedicated to Apollo Daphnephoros (Fig. 3D; Verdan, 2002, 2010, 2013). During the second half of the 6th century BC (Archaic times), a series of large-scale construction projects were undertaken in the city. First, the main stream was channeled from the foothill of the acropolis down to the sea, following a straight line; east of this new limit, some of the former tributaries of the river were conveniently transformed into streets (Krause, 1981). Second, perhaps more importantly, the settlement was surrounded by a city wall (Fig. 3E). Its exact shape remains unclear, but it probably included the acropolis and the lower town in a single fortified area (Fachard, 2004). The 4th century BC opens an era of renewed prosperity: fortifications were rebuilt, the city center was renovated, and luxurious private houses were erected (Ducrey, 1993; Reber, 1998). The city now reached its maximum extension. The southeastern trace of city wall was erected in a marshy environment that limited the spread of the settlement towards the south-east (Fachard, 2004, Fig. 6F). The city was sacked by the Romans in 86 BC (Knoepfler, 2004), but it recovered and eventually enjoyed a period of economic prosperity in the 2nd and 3rd centuries AD. A small community was still inhabiting Eretria in the 5th and 6th centuries AD, as attested by burials. The plain and acropolis were then largely unoccupied during most of the Byzantine and Ottoman periods. The site was only resettled in the late 19th century when a new town was founded above the ruins of the ancient city, following the initiative of the young Greek State (Pajor, 2006). The proximity of swamps long hindered the expansion of the settlement until the completion of their drainage only a few decades ago.

On the whole, this part of the Euboean shoreline was very attractive to humans from the Late Neolithic period onward but the paleoenvironment changed rapidly and forced local people to adapt to the frequent modifications of the shoreline and salinity influxes. The region's major morphological changes during the Late Holocene must thus be analyzed through a geoarcheological and interdisciplinary approach combining paleoenvironmental coring and analysis with archeological records.

5. Methods of paleoenvironmental reconstruction

Five 50-mm diameter vibracores were drilled between the present-day shoreline and the Temple of Apollo, reaching a maximum depth of 5.25 m (Fig. 2). Each borehole was precisely mapped and subsequently leveled with theodolite measurements (Table 1). The field research and laboratory research were conducted with the permission of the Hellenic Ministry of Culture and the 11th Ephorate for Prehistoric and Classical Antiquities and laboratory analysis was undertaken at CEREGE in Aix-en-Provence (France).

Table 1
Borehole locations. Leveling was achieved using a theodolite and all measurements were reported on the Greek leveling model EGSA 87. Vertical (closing) error is due to the technique employed for measuring the elevation.

Core ID	Latitude (UTM —WGS84)	Longitude (UTM —WGS84)	Depth (m)	Elevation above mean sea-level (m)	Error (m)
Apollo 1	N 38°23′42.42″	E 23°47′42.65″	5.25	2.05	0.05
Apollo 2	N 38°23′36.52″	E 23°47′45.51″	4.20	1.60	0.1
Apollo 3	N 38°23′44.13″	E 23°47′48.12″	5.25	1.71	0.05
Port 1	N 38°23′30.09″	E 23°47′55.89″	5.25	1.52	0.05
Port 2	N 38°23′35.06″	E 23°48′4.74″	3.15	0.95	0.2

5.1. Microfaunal/mollusc identification and AMS dating

All samples were wet-sieved through a wire screen (0.40 mm mesh) and air dried at room temperature. The residue was examined under a binocular microscope (magnification: ×10) and all identifiable shells and characteristic fragments were selected and placed in separate plastic tubes. In general, cores Apollo 1 and Port 2 contain few molluscs, while Apollo 2, Apollo 3, and Port 1 are richer in fossils. Based on the molluscan classification system that assigns Mediterranean species to well-defined ecological groups (Péres and Picard, 1964; Péres, 1982), bio-sedimentary units were then distinguished for the present study.

The chronostratigraphy of the cores was established by a series of 20 AMS radiocarbon dates taken from marine/lagoonal shell and plant remain samples (Table 2). The dating analyses were performed at the Poznan Laboratory for Radiocarbon (Poland). Marine samples were corrected for the local marine reservoir effect according to Siani et al. (2000) and Reimer and McCormac (2002), where regional ΔR is 113 (±23), although it must be emphasized that the real (paleo) reservoir effect—still unknown—varies widely in different marine environments such as lagoons, coastal swamps or littoral zones (Vött, 2007). ^{14}C ages were subsequently calibrated using the IntCal09 curve (Reimer et al., 2009) and Calib 6.0 software.

5.2. Grain-size analyses

Samples were taken at 5 cm intervals. Many exhibited coarse particles (gravels to pebbles) above 2 mm; wet-sieving by hand was then used to isolate the total fractions of coarse (>2 mm) and fine sediments (<2 mm). Percentages were subsequently estimated and are reported on the core profiles (Figs. 4 and 5). For the layers which contained exclusively fine particles (below 2 mm), laser diffraction grain-size analyses were undertaken (Ghilardi et al., 2008). The grain-size distribution was measured using a Beckman Coulter LS 13 320 laser granulometer with a range of 0.04 to 2000 μm, in 116 fractions detected from 132 detectors (126 detectors for the scattering pattern and 6 detectors for the PIDS (Polarization Intensity Differential Scattering) technology which is sensitive to sub-micron sized particles). The calculation model (software version 5.01) uses Fraunhöfer and Mie theory. For the calculation model, we used water as the medium (RI = 1.33 at 20 °C) and a refractive index in the range of that of kaolinite for the solid phase (RI = 1.56; Buurman et al., 1996). Samples containing fine particles were diluted, so we measured between 8 and 12% of obscuration and between 45 and 70% PIDS obscuration.

6. Results: general stratigraphy

Facies identification of the five boreholes provided clear lithostratigraphical sequences and allowed us to distinguish seven bio-sedimentary units, which can be described as follows (Figs. 4. 5):

6.1. Unit A: a basal marine unit

This first unit is found in the lowermost part of boreholes Apollo 1, 2 and 3 (Fig. 4) but is not clearly recognized for Port 1 and Port 2 (Fig. 5). For the three Apollo cores, the unit is found at ca. 3.15 m below the surface (the top of the sequence is situated ca. 1.20 m to 1.50 m below mean sea-level); the base of the unit was not reached. The total depth is thus unknown, but cores Apollo 1 and 3 indicate an approximately 2 m deposit of coarse material, consisting of well rounded pebbles and gravels with intercalated beds of fine sediments (mainly medium to coarse sands). The main sedimentological feature of this unit is the variation in size of particles above 2 mm. Mollusc identification revealed the prevalence of hard and sandy substrate assemblages (within the infralittoral zone) and the abundant presence of gastropods such

Table 2
Radiocarbon dating results. The * indicates that material was certainly reworked; depths above/below mean sea level were calculated after Table 1.

Order	Sample name	Borehole ID	Depth (m)	Elevation (below mean sea-level)	Material	BP	Error±	Cal. 2σ	Laboratory reference
1	Apollo-1_200	Apollo 1	2.00	+0.05	Shell (*Rissoa ventricosa*)	5470	40	3939–3630 BC	Poz-49040*
2	Apollo-1_235	Apollo 1	2.35	−0.30	Shell (*Nassarius reticulatus*)	5935	35	4449–4097 BC	Poz-49041*
3	Apollo-1_256	Apollo 1	2.56	−0.51	Plant remains (*Posidonia*)	3250	35	1613–1445 BC	Poz-49053
4	Apollo-1_290	Apollo 1	2.90	−0.85	Plant remains (*Posidonia*)	3365	35	1743–1535 BC	Poz-49622
5	Apollo-1_308	Apollo 1	3.08	−1.03	Plant remains	4230	35	2911–2695 BC	Poz-49623
6	Apollo-2_140	Apollo 2	1.40	+0.20	Shell (*Nassarius reticulatus*)	4145	30	2312–1892 BC	Poz-49042*
7	Apollo-2_260	Apollo 2	2.60	−1.00	Shell (*Nassarius reticulatus*)	4065	35	2198–1771 BC	Poz-49044
8	Apollo-2_295	Apollo 2	2.95	−1.35	Shell (*Cerithium vulgatum*)	4840	40	3281–2863 BC	Poz-49045
9	Apollo-3_200	Apollo 3	2.00	−0.30	Plant remains	3375	35	1750–1605 BC	Poz-49617
10	Apollo-3_245	Apollo 3	2.45	−0.75	Plant remains	3260	30	1616–1454 BC	Poz-49621
11	Apollo-3_288	Apollo 3	2.88	−1.18	Plant remains	4050	35	2677–2473 BC	Poz-49618
12	Apollo-3_294	Apollo 3	2.94	−1.24	Plant remains	3935	35	2496–2299 BC	Poz-49619
13	Apollo-3_303	Apollo 3	3.03	−1.33	Plant remains	4410	35	3115–2915 BC	Poz-49620
14	Apollo-3_311	Apollo 3	3.11	−1.41	Shell (*Cerithium vulgatum*)	5615	35	4137–3746 BC	Poz-49049*
15	Apollo-3_360	Apollo 3	3.60	−1.90	Shell (*Tricolia speciosa*)	5400	40	3897–3536 BC	Poz-49050
16	Apollo-3_525	Apollo 3	5.25	−3.55	Shell (*Donacilla* sp.)	5660	35	4194–3791 BC	Poz-49051
17	Port-1_177	Port 1	1.77	−0.25	Plant remains	335	30	1474–1641 AD	Poz-49054
18	Port-1_183	Port 1	1.83	−0.31	Plant remains	255	30	1521–1675 AD	Poz-49055
19	Port-1_349	Port 1	3.49	−1.98	Shell (*Conus mediterraneus*)	3315	35	1270–856 BC	Poz-49057
20	Port-2_210	Port 2	2.10	−1.15	Shell (*Bittium reticulatum*)	3290	35	1238–832 BC	Poz-49056

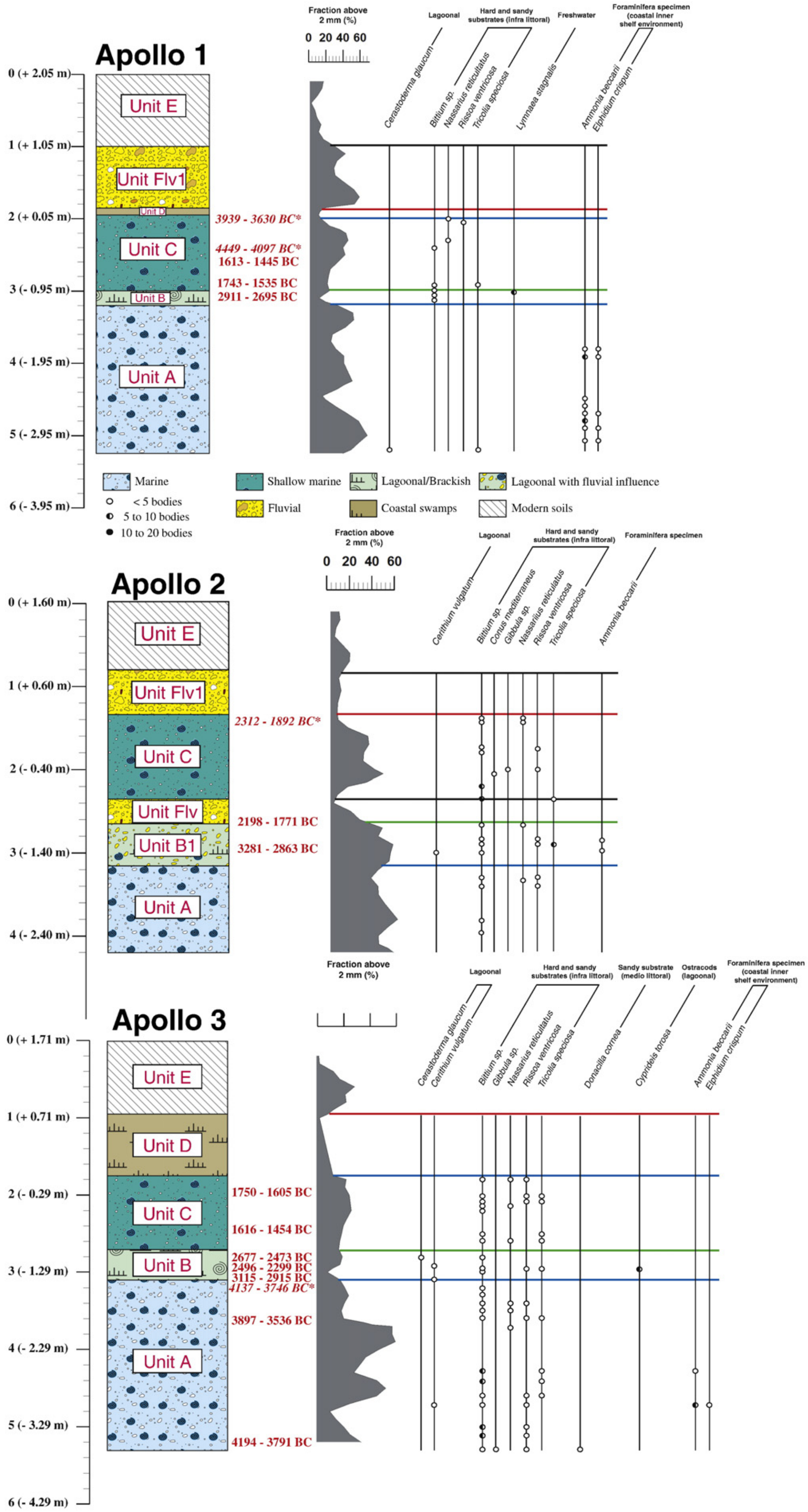

Fig. 4. Core profiles of Apollo 1, 2 and 3 associated together with paleontological and macrofaunal results.

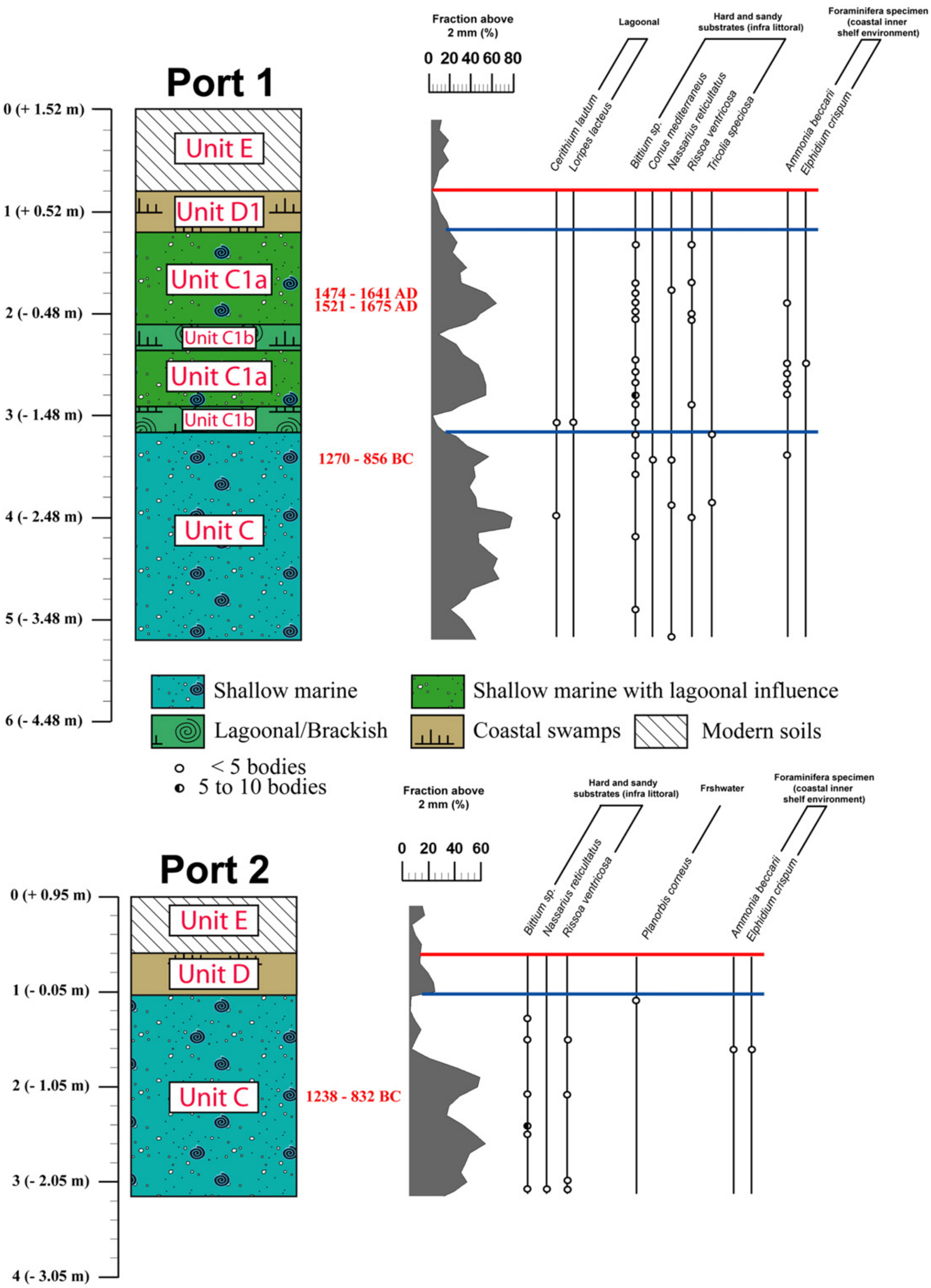

Fig. 5. Core profiles of Port 1 and 2 associated together with paleontological and macrofaunal results.

Bittium reticulatum, *Gibbula* sp., *Tricolia speciosa*, *Nassarius reticulatus*, *Rissoa ventricosa* and *Conus mediterraneus*. Microfaunal identification confirms the existence of a marine to shallow marine environment; a range of foraminifera specimens belonging to the coastal inner shelf zone were identified, including *Ammonia beccarii* and *Elphidium crispum*.

The age of this sequence has been determined through two radiocarbon dates on in situ marine shells from Apollo 3 (Table 2). They indicate an age of ca. 4194–3791 cal. BC in the lowermost part of Unit A (5.20 m below the surface) and an age of 3897–3536 cal. BC in the uppermost part of the sequence. The transition from Unit A to Unit B (above it) has been dated ca. 3115–2915 cal. BC. In summary, Unit A is characteristic of a marine environment of high energy of deposition and rapid vertical accretion. This sequence is dated from ca. 4200 to ca. 3000 cal. BC (corresponding to the Mid-Holocene).

6.2. Units B and B1: a lagoonal environment with local fluvial influence

Overlying the marine unit (Unit A), there is a thin layer of very fine material, with sediments ranging from clays to fine sands (Fig. 4) recorded only in the Apollo cores. In Unit B, abundant plant remains are found together with a typical lagoonal mollusc assemblage: gastropods such as *Cerithium vulgatum* and bivalves such as *Cerastoderma glaucum* (Fig. 4). In addition, characteristic lagoonal/brackish ostracods *Cyprideis torosa* (Pérès and Picard, 1964; Heip, 1976) are found in core Apollo 3 together with the aforementioned lagoonal gastropods (Fig. 4). However, we also find the presence of marine gastropods such as *B. reticulatum*, *N. reticulatus* and *R. ventricosa*, indicating persistent connection with the sea. The macrofaunal evidence from Apollo 1 indicates an abundant presence of freshwater gastropods *Lymnaea stagnalis* in the uppermost part of Unit B. These freshwater gastropods could indicate the development of coastal swamps and a freshwater input from a local stream west of Eretria.

Unit B1 is only identified in core Apollo 2 where we have a mixture of fine gray clays and sands with gravels and angular to rounded yellowish pebbles. Mollusc identification indicates the presence of lagoonal species such as *C. vulgatum* and of an infra-littoral zone with the abundant presence of *T. speciosa* and sparse occurrence of *B. reticulatum* and *N. reticulatus*. *A. beccarii* foraminifera are also recorded within Unit B1. The difference with Unit B is a clear input of very coarse material, probably brought in by a local stream.

The chronology of Unit B is determined by four radiocarbon dates on plant remains found embedded within the clay material and on a typical lagoonal gastropod (*C. vulgatum*). Dates for the lowest point of unit B and B1 range from 3281–2863 cal. BC to 3115–2915 cal. BC. The middle part is dated to ca. 2911–2695 cal. BC and the uppermost part of the sequence is dated, for Apollo 3, from 2677–2483 cal. BC to 2499–2296 cal. BC. Unfortunately we have no dates for the transition from unit B to the overlaying unit (Unit C). For unit B1, only recognized in Apollo 2, the lagoonal environment is affected by strong input of fluvial material, and the transition with the overlaying unit (Unit Flv) is dated to ca. 2198–1771 cal. BC. In general, Units B and B1 are characteristic of a lagoonal environment with low energy of deposition, except for Apollo 2 where a fluvial/stream influence can be observed. Vertical sediment accretion is generally very low, where less than 40 cm was accumulated from ca. 3000 to 2100 cal. BC.

6.3. Unit Flv: a fluvial input

Overlying unit B1 in core Apollo 2 there is a thin layer of approximately 20 cm composed of coarse material (mainly pebbles, gravels, and coarse sands), which was already identified in the middle to uppermost parts of unit B1. It is important to note that no micro/macrofauna have been found within the yellowish sediments. It is thus obvious that a local stream/river influence had deposited these sediments within the lagoon (Unit B1) and gradually contributed to create a fluvial levee due to rapid vertical sediment accretion. The lowest part of this stratum is precisely dated to ca. 2198–1771 cal. BC. Unfortunately there was no material for dating its uppermost part and the transition with the overlying unit (Unit C).

6.4. Units C and C1: a second marine unit recorded in all boreholes

A unit of 0.8 to 1 m thick, composed of coarse material (ranging from gravels to well rounded pebbles), overlies the fluvial deposits (Unit Flv) in Apollo 2, and is found above the lagoonal/brackish sediments (Unit B) from Apollo 1 and 3 cores. In general, 30 to 40% of the material is fine grained (below 2 mm), consisting mainly of fine to medium sands.

Macrofaunal identification reveals a prevalence of hard and sandy substrates (molluscs from the infra-littoral assemblages): we mainly found gastropods such as *B. reticulatum* (abundant representation in the lower part of the unit for Apollo 2), *R. ventricosa*, *T. speciosa*, *N. reticulatus*, *Gibbula* sp. and *C. mediterraneus*. Unit C is also found in the lowermost part of the other cores, Port 1 and Port 2 (Fig. 5), where it exhibits the same mollusc assemblage; in addition, we have the presence of some foraminifera typical of an inner shelf environment in the upper part of the unit. *A. beccarii* and *E. crispum* were the best represented specimens. Unit C is very similar to Unit A in terms of sediment characteristics and macro/microfaunal assemblages. We can thus infer that Unit C is characteristic of a marine environment.

Radiocarbon dates of different marine plants (*Posidonia*) reveal an age of ca. 1743–1535 cal. BC (Apollo 1) in the lowermost part of Unit C and ca. 1615–1450 cal. BC (Apollo 1 and 3 cores) for its middle part. Dating the upper part of the sequence has been difficult in all cores situated in the vicinity of the Apollo Temple since the dated material shows a Mid-Holocene age of ca. 4000 to 2000 cal. BC (Table 2; Fig. 4). This difficulty might be attributed to natural processes (reworked material) or human intervention, which will be discussed later. However, the upper part of Unit C is well dated for Port 1 and the transition with the above unit (C1b) gives an age of 1270–856 cal. BC. For Port 2 we have a similar age (Fig. 5) but it is found in the middle part of the Unit C; thus, it could indicate that the area surrounding Port 2 core remained under marine conditions during ancient times, while the area of Port 1 was already affected by terrestrial dynamics.

Units C1a and C1b are only found in Port 1 and record an alternation of thin, silty layers (Unit C1a) and a layer composed of coarse materials (Unit C1b). In Unit C1a lagoonal molluscs (*Cerithium lautum* and *Loripes lacteus*) are encountered. Unit C1b consists of coarse material (gravels to pebbles) where marine gastropods and foraminifera were found, similar to the ones identified in Units A and C. To summarize, phases of marine (to shallow marine) (Unit C1b) environments alternate with lagoonal conditions (Unit C1a). Dating of the Unit C1a and C1b sequences indicates a wide age range, from 1270 to 856 cal. BC for its lower part and from 1474 to 1641 cal. AD (Ottoman period) for its upper part. Therefore, from the Geometric to Roman period, the area surrounding Port 1 (Fig. 2) was affected by frequent marine incursion and lagoonal developments.

6.4.1. Units D/D1: a coastal swamp environment

Unit D is observed in Apollo 1 and Apollo 3, where its depth increases towards the east. For Apollo 1 this stratum is only 10 cm thick, while for Apollo 3 it is 80 cm. It consists of very dark gray clays where fauna are poorly represented by fragments of freshwater gastropods (mainly *Helicidae* sp.). This unit is situated between Units C and Flv1 for Apollo 1. Unfortunately no precise dating of Unit D can be provided (though a rough estimate of early antiquity is discussed later). Unit D1 is found in Port 1 and Port 2 and is 40 cm thick, very few recognizable shells were found and fragments were chiefly of terrestrial and brackish species. According to the radiocarbon results (Fig. 4), the dating of Unit D1 is later than Unit D and seems to be quite recent, i.e. 19th to early 20th century AD.

6.4.2. Unit E: archeological layers and modern soils

Unit E is found in the upper part of all the cores and shows reworked material with recent cement bricks mixed with pottery sherds, dating from several different periods. This disturbance makes it of minimal paleoenvironmental interest.

7. Discussion

7.1. Paleogeographic reconstruction of the eastern Eretrian plain and human occupation from Neolithic to Roman times

The results derived from the boreholes drilled for the purposes of this study, combined with previously published data (Kambouroglou, 1989), offer new elements for reconstructing the main phases of shoreline development in the eastern part of ancient Eretria. A stratigraphic cross-section has been established, comprised of cores Apollo 1, 2 and 3 and Port 1 (Fig. 6). The goal of this cross-section is to link the different facies dated with ^{14}C dating.

From ca. 4200 to 3200/3000 cal. BC, what is now Eretria's coastal stretch is characterized as a high-energy marine environment (Fig. 7A). This is confirmed by the presence of well-rounded pebbles in the lowest

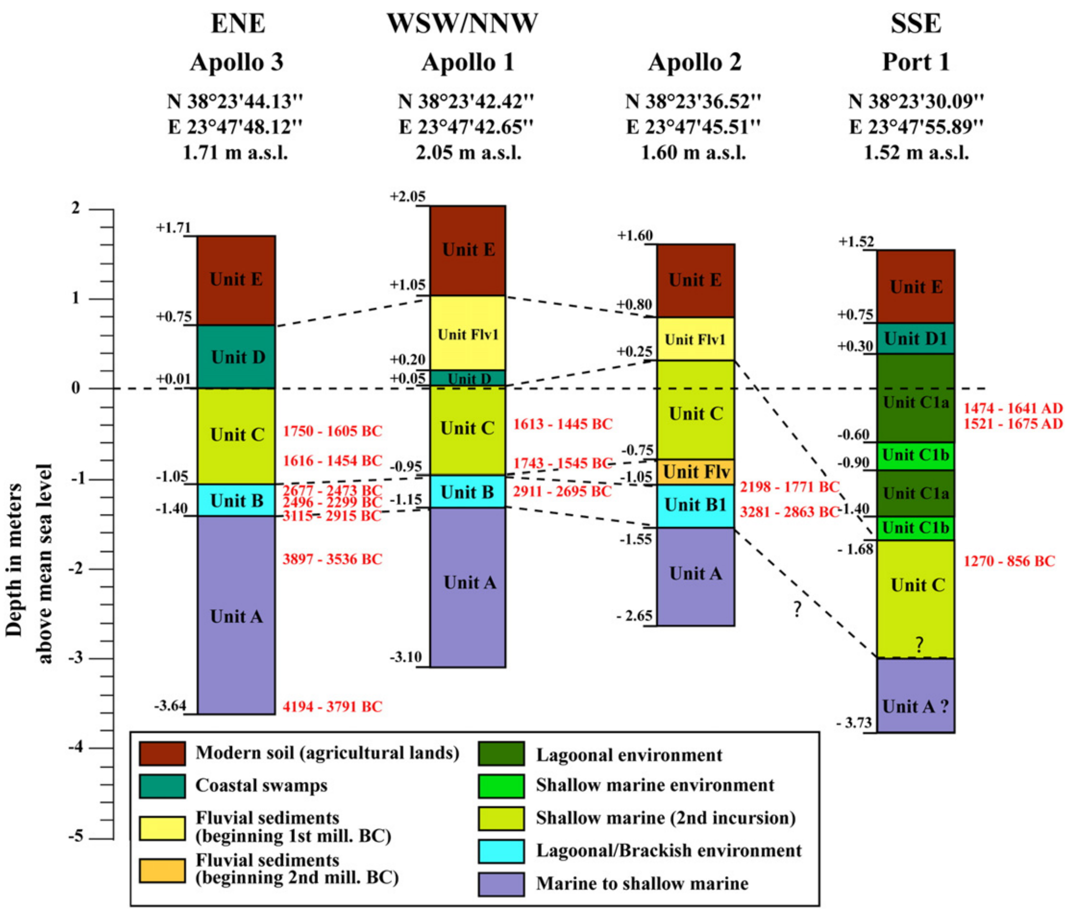

Fig. 6. Stratigraphic cross-section that includes cores Apollo 1, 2, 3 and Port 1.

part of the cores located in the vicinity of the temple of Apollo. Evaluation of the northern and western extensions of the marine incursion is somewhat difficult at this stage, since the area corresponding to the westernmost part of the ancient city is yet to be investigated through coring. However, it seems that the sea penetrated almost up to the foot of the acropolis (Fig. 7A), at the height of the modern Chalkis–Amarynthos road. Although the boreholes drilled for the present study did not reach the Pleistocene surface, Kambouroglou (1989) estimated that such levels are situated at a depth of ca. 5–6 m below the mean sea-level, so 1.5 to 2.5 m below the deepest levels where dates that were obtained for Apollo 3. A transgressive surface could be locally dated to ca. 5500 cal. BC (Ghilardi et al., 2013b). In terms of human occupation, Neolithic evidence is located only on the top of the hill (Fig. 3) and dates to ca. 3500 cal. BC. This pattern is obviously explained by the fact that the coastline was situated at the foot of the hill during this time (Fig. 7A).

Following the marine environments, the development of a lagoon is observed in the eastern part of ancient Eretria from ca. 3200 to 2100 cal. BC (Fig. 7B). Very low-energy deposition is inferred from the sedimentological results, with an estimated sediment accumulation rate of 0.03 m per century. A possible explanation of this lagoonal development may be found in the deltaic progradation of the local stream, running west of the ancient city. The rapid outbuilding of an alluvial plain to the west facilitated the construction of several coastal barriers to the east that isolated brackish/lagoonal depressions. However, some distinction must be made between the boreholes where freshwater influence is more important in the zone surrounding Apollo 1 and Apollo 2. Apparently, the lagoon was almost continuously affected by sporadic yet significant detrital input only in the vicinity of Apollo 2, suggesting the presence of a river/deltaic channel that could locally build levees in the very shallow depth of the lagoon.

During the Early Helladic period (3000–2100 cal. BC), site occupation is only attested in a specific location of the plain, where the sites of Bouratsa, Roussos and Alexandri are located, close to Apollo 2. During the second half of the 3rd millennium BC, lagoonal environments were strongly altered in this area by repeated fluvial influxes that locally created levees surrounding the lagoon to the east, and the deltaic plain to the west. An influx of freshwater is also confirmed in Apollo 1, as freshwater gastropods are found in the uppermost part of the lagoonal unit, dating from the end of the 3rd millennium BC. This influx indicates a reduction of the lagoon, combined with the development of an alluvial fan within the lagoon towards the southeast (Fig. 7B).

The results of this study show that a new marine incursion affected the easternmost part of the Eretrian coastline from ca. 1800 to 1000/900 cal. BC (Fig. 7C). It is important to stress that this process is recorded in all studied boreholes. In terms of human occupation, this period seems to coincide with an abandonment of the plain, where no sites from the Middle to the Late Helladic period have yet been identified. In his paleogeographic reconstruction of the Eretrian plain, Kambouroglou (1989) does not mention this phenomenon or suggest a shoreline position for this period.

During the Protogeometric period (950–850 cal. BC), an important detrital influx is observed in the area surrounding the cores Apollo 1 and 2 while cores Port 1 and 2 are not affected by any river alluviation and remained under shallow marine to lagoonal conditions. Apollo 3 records the development of coastal marshes without direct terrestrial sediment flux. Obviously, a new phase of deltaic progradation controlled the shoreline migration towards the southeast and several fluvial

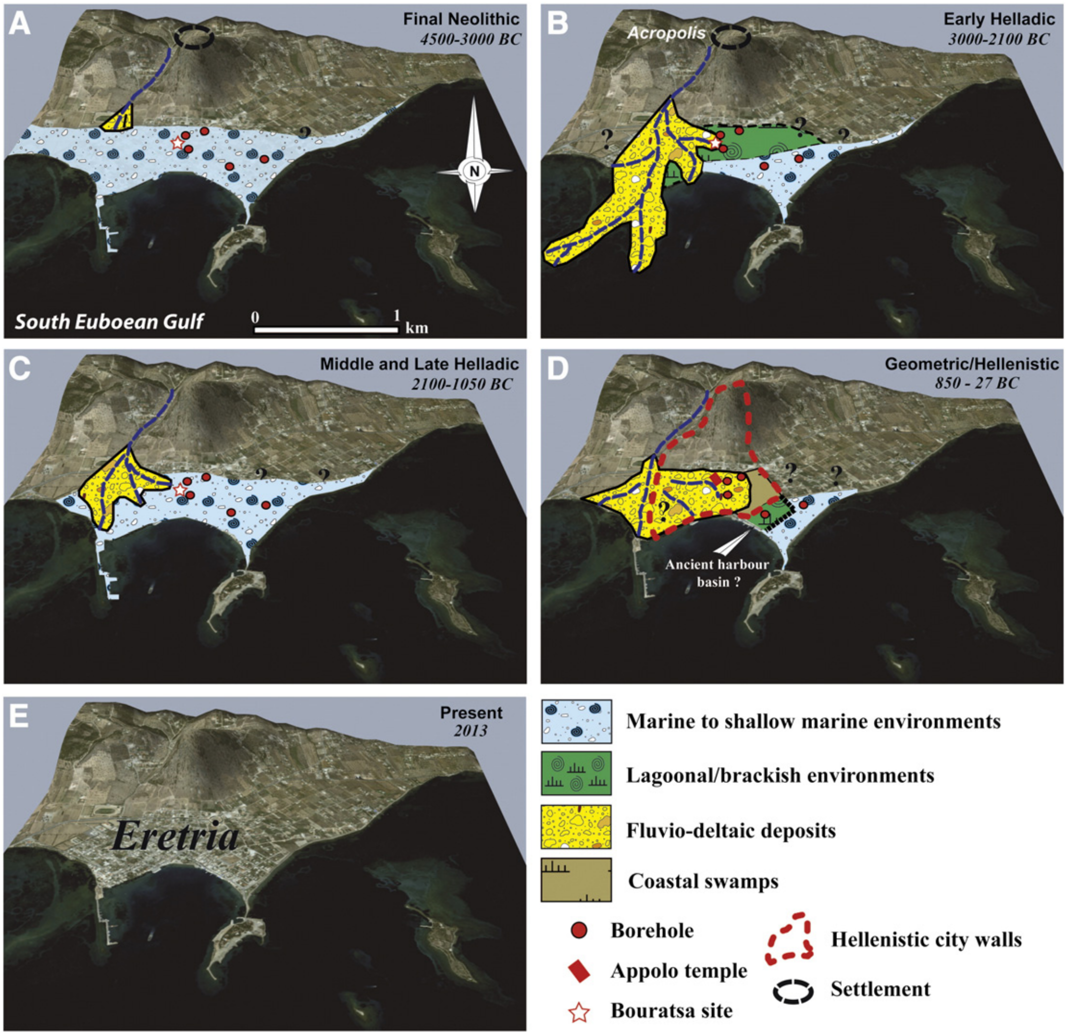

Fig. 7. Paleogeographic reconstruction of the south Euboean gulf along the Mid to Late Holocene in the vicinity of ancient Eretria (see Section 7.1 for details.) Borehole data from Kambouroglou (1989) were included to improve the scenario for the westernmost part of Eretria.

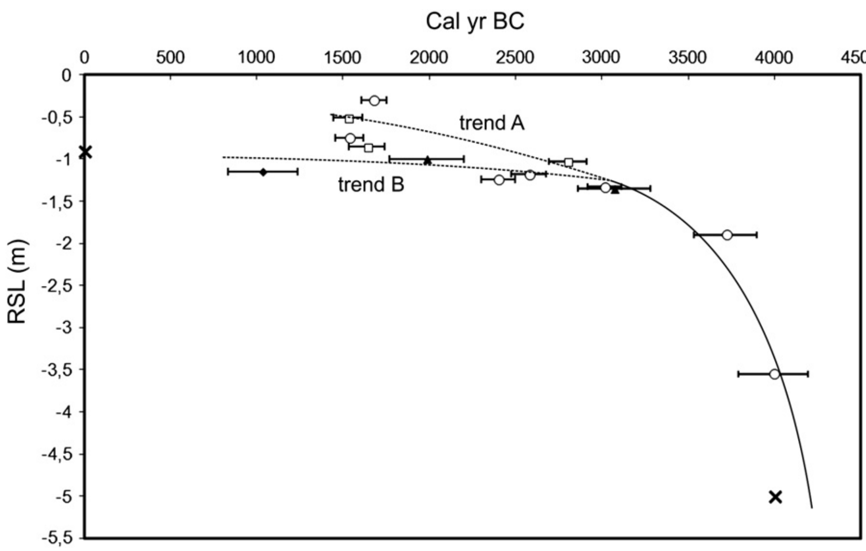

Fig. 8. Proposed sea-level reconstruction for the South Euboean Gulf in the area of Eretria. For radiocarbon ages and samples, see Table 2. Squares: Apollo 1; Triangles: Apollo 2; Circles: Apollo 3; Diamond: Port 2; x: Predicted sea-level positions for the study area are from the model of Lambeck and Purcell (2005). Solid line: Single sea-level rise trend. Dashed-lines: Two observed trends of sea-level change in South Euboean Gulf after ca. 3000 BC.

levees (identified and mentioned by Krause, 1985) were built to support archeological structures. Indeed, the sanctuary of Apollo (dated to the Geometric period) was built upon coarse yellow detrital material that formed a levee and probably emerged from coastal marshes. The important development of the city between the Geometric and the Hellenistic periods in its central and western parts contrasts with the persistence of lagoonal/shallow marine conditions in the vicinity of the eastern (military) harbor (Fig. 7D). Full marine conditions still prevailed in the easternmost part of the plain (core Port 2) until the late Ottoman period (17th/18th century AD). Further coring in the eastern harbor, combined with excavations, would have great potential to investigate the existence of archeological remains that could have demarcated a harbor basin as suggested in Fig. 3.

7.2. Coastal evolution and local sea-level changes

The radiocarbon ages of plant and skeletal remains in this study (Table 2) provide a significant collection of data for the reconstruction of the coastal evolution and the relative sea-level fluctuations in the coastline of Eretria from ca. 4000 BC. As presented in Fig. 8, local sea-level was rising rapidly until ca. 3000 BC, following the global trend of the Early to the Mid-Holocene. After the decrease in the rate of sea-level rise at that point, two similar but distinct trends are observed for the study area. One (trend B, Fig. 8) represents a trend of stabilization (though still rising), with a maximum rise of ca. 30 cm during ca. 2000 years (until 1000 BC), whereas the second (trend A) exhibits a relatively greater rising trend, with a sea-level rise of more than 100 cm during 1500 years (a 5 times higher value). The two groups of samples (one group per trend) are distinguished by their composition: two littoral shells represent the first trend whereas four plants represent the second. Three plant samples can be included in both trends (between 3000 and 2500 BC). Moreover, the two trends are illustrated by different cores; the first is seen in cores Port 2 and Apollo 2, while the second is seen in Apollo 1 and Apollo 3. This core grouping is not random, since cores Port 2 and Apollo 2 include mostly the marine sequence for the area during the respective period. On the other hand, cores Apollo 1 and Apollo 3 are strongly influenced by fluvial activity during the period of the deposited, dated samples. While one might suggest a reservoir effect on the carbon of shell samples, in this case it seems that the depositional conditions could be responsible for the slight difference of the two trends. Furthermore, the two trends of sea-level rise do not cancel each other but rather delineate the relative fluctuations, depending on specific local factors.

Generally, the paleoenvironmental reconstruction follows the model for the relative sea-level changes in the wider area of the Eastern Mediterranean by Lambeck and Purcell (2005), which suggests a rapidly rising sea-level until 4000 BC (−5 m) and a slow-down afterwards (0.9 m at 0 BC/AD) (Fig. 8). Our data rely on regional sea-level curve reconstruction proposed for the South Aegean Sea over the last 20 years (Lambeck and Purcell, 2005; Poulos et al., 2009; Pavlopoulos et al., 2012) rather than the local scenario around Eretria (Kambouroglou, 1989). The data of this study supplement the model of Lambeck and Purcell (2005), including local tectonic, human, and fluvial influences on the coast, and present a reconstruction of the coastal area of Eretria from the Neolithic period onward. The effects of tectonics on the sea-level changes in the South Euboean Gulf must also be reconsidered in comparison with the situation observed in northern Euboea where major coseismic uplifts were highlighted and accurately dated. Clearly, further research must be aimed at depicting the tectonic impacts on the Holocene sea-level history for the entire island. The combination of bio-markers, coring data and archeological evidence should be integrated in a multi-proxy model, rather than being separated, in order to reconstruct the vertical trend of sea-level rise during the last 6000 years.

8. Conclusions and perspectives

Based on a robust chronostratigraphy (20 radiocarbon dates) from five boreholes, our results show for the first time important morphological changes in the easternmost part of ancient Eretria during the Mid- to Late Holocene. The long-term settlement history of Eretria appears to have been influenced by natural factors, namely the advances and retreats of the coastal plain. The different steps of shoreline migration at Eretria follow the general pattern of both regional and local studies (Kambouroglou, 1989; Ghilardi et al., 2013a, 2013b) but show some important differences, in particular for the Helladic period (Bronze Age). First, the shoreline displacements indicate that two main phases of marine sedimentation were separated by a lagoonal stage. The latter is probably due to the general phenomenon of deltaic progradation which occurred in the westernmost part of the area ca. 3500–3000 cal. BC, when the southern slopes of Mount Olympus and Kastelli hill were first occupied. Settlement location was obviously linked to landscape evolution. Consequently, there is a lack of human occupation in the coastal plain before 3000 cal. BC and during the 2nd millennium BC because the area was then under seawater. The lagoonal phase, dated to the 3rd millennium BC, corresponds to important changes in the western part of the study area, while the very easternmost part (the area of the Port cores) remained under marine conditions. The lagoonal development was induced by deltaic progradation, combined with deceleration of the rate of sea-level rise. Fluvio-torrential levees turned into coastal barriers isolating some lagoons that were still connected to the sea. Such levees could potentially host local sites, as it is the case of Bouratsa.

Finally, the sea-level curve derived from the coring data presented here indicates a continuous sea-level rise since the Mid-Holocene without any highstand during the Neolithic, as assumed by previous authors for the same area (Kambouroglou, 1989).

In the near future, a coring program could be undertaken in the westernmost part of Ancient Eretria in order to precisely reconstruct the different phases of the deltaic progradation. The results, coupled with studies of vegetation history (pollen analyses), could help us determine whether anthropogenic factors (such as forest clearance, site development in the uplands) had an impact on sudden alluviation of the local streams along the shoreline, or if natural processes (such as erosion induced by climate changes) should be invoked as the main trigger.

Acknowledgments

This paper is part of the *Fonds Incitatifs de Recherche* research program (period 2010–2012), led by Matthieu Ghilardi (CNRS) and Christophe Morhange (University of Aix-Marseille, France), which is directed toward reconstructing the past landscapes of eastern Mediterranean islands (Cyprus, Crete, and Euboea). It is funded by the University of Provence (Aix-en-Provence, France) and the Swiss School of Archaeology in Greece (Dir. Karl Reber). We are very grateful to Dimitris Vandarakis and Stamatis Katsiadramis for their help during fieldwork in September 2011. Finally, Jan Bloemendal is warmly thanked for polishing the English and improving the manuscript.

References

Aubouin, J., 1963. Sur la stratigraphie et la tectonique de l'Eubée moyenne (Grèce). Bull. Soc. Geol. Fr. 7 (V), 821–827.

Baika, K., 2008. Archaeological indicators of relative sea-level changes in the Attico–Cycladic massif: preliminary results. Bulletin of the Geological Society of Greece, vol. XLII/II 33–48.

Blandin, B., 2007. Les pratiques funéraires d'époque géométrique à Erétrie. Eretria XVII, 2 vols. Gollion.

Buurman, P., Pape, T., Muggler, C.C., 1996. Laser grain-size determination in soil genetic studies: practical problems. Soil Sci. 162 (3), 211–218.

Cundy, A.B., Kortekaas, S., Dewez, T., Stewart, I.S., Collins, P.E.F., Croudace, I.W., Maroukian, H., Papanastassiou, D., Gaki-Papanastassiou, P., Pavlopoulos, K., Dawson, A., 2000. Coastal wetlands as recorders of earthquake subsidence in the Aegean: a case study of the 1894 Gulf of Atalanti earthquakes, central Greece. Mar. Geol. 170, 3–26.

Desruelles, S., Fouache, É., Dalongeville, R., Pavlopoulos, K., Peulvast, J.-P., Coquinot, Y., Potdevin, J.-L., Hasenohr, C., Brunet, M., Mathieu, R., Nicot, É., 2007. Sea-level changes and shoreline reconstruction in the ancient city of Delos (Cyclades, Greece). Geodinamica Acta 20 (4), 231–239.
Drakopoulos, I., Makropoulos, K., Stavrakakis, G., 1984. Junction of Evia–Beotia and Chalkida diversion. Seismological study. Report for the Greek Ministry of Public Works. 58 (in Greek).
Ducrey, P., 1993. Le Quartier de la Maison aux mosaïques. Eretria VIII, Lausanne.
Ducrey, P., Fachard, S., Knoepfler, D., Theurillat, T., Wagner, D., Zannis, A., 2004. Eretria. Guide of the ancient city. Ecole Suisse d'archéologie en Grèce.Gollion, Switzerland 314.
Evelpidou, N., Vassilopoulos, A., Pirazzoli, P., 2012. Holocene emergence in Euboea island (Greece). Mar. Geol. 295–298, 14–19. http://dx.doi.org/10.1016/j.margeo.2011.11.010.
Fachard, S., 2004. L'enceinte urbaine d'Erétrie: un état de la question. Antike Kunst 47, 91–109.
Landscape Evolution and Geoarchaeology. In: Fouache, E., Pavlopoulos, K., Stiros, S. (Eds.), Quat. Int. 216, 162.
Gaki-Papanastassiou, K., Maroukian, H., Papanastassiou, D., Palyvos, N., Lemeille, F., 2001. Geomorphological study in the Lokrian coast of northern Evoikos Gulf (central Greece) and evidence of palaeoseismic destructions. Rapports et Procès-verbaux des Réunions, Commission Internationale pour l'Exploration Scientifique de la Mer Méditerranée, 36 25.
Gaki-Papanastassiou, K., Cundy, A.B., Maroukian, H., 2011. Fluvial versus tectonic controls on the late Holocene geomorphic and sedimentary evolution of a small Mediterranean fan delta system. J. Geol. 119 (2), 221–234.
Galanopoulos, A., 1955. Σεισμική γεωγραφία της Ελλάδος. Ann. Géol. Pays Hellén. VI, 83–121.
Genre, C., 1989. Variations de la ligne de rivage depuis l'Antiquité en Egée centre-occidentale. Cahiers du centre de géomorphologie de Caen 36, 247–250.
Ghilardi, M., Tristant, Y., 2012. Geoarchaeology of Egypt and the Mediterranean: reconstructing Holocene landscapes and human occupation history. Quat. Int. 266, 1–3. http://dx.doi.org/10.1016/j.quaint.2012.03.019.
Ghilardi, M., Fouache, E., Queyrel, F., Syrides, G., Vouvalidis, K., Kunesch, S., Styllas, M., Stiros, S., 2008. Human occupation and geomorphological evolution of the Thessaloniki Plain (Greece) since Mid Holocene. J. Archaeol. Sci. 35 (1), 111–125. http://dx.doi.org/10.1016/j.jas.2007.02.017.
Ghilardi, M., Fachard, S., Pavlopoulos, K., Psomiadis, D., Collana, C., Bicket, A., Crest, Y., Bonneau, A., Delanghe-Sabatier, D., Knodell, A., Theurillat, T., 2013a. Reconstructing mid- to recent Holocene paleoenvironments in the vicinity of Ancient Amarynthos (Euboea Island, Greece). Geodin. Acta (Online version. http://dx.doi.org/10.1080/09853111.2013.838064) (in press).
Ghilardi, M., Colleu, M., Pavlopoulos, K., Fachard, S., Psomiadis, D., Rochette, P., Demory, F., Knodell, A., Triantaphyllou, M., Delanghe-Sabatier, D., Bicket, A., Fleury, J., 2013b. Geoarchaeology of Ancient Aulis (Boeotia, Central Greece): human occupation and Holocene landscape changes. J. Archaeol. Sci. 40, 2071–2083. http://dx.doi.org/10.1016/j.jas.2012.12.009.
Goodman, B., Reinhardt, E., Boyce, J., Dey, H., Sahoglu, V., Erkanal, H., Artzy, M., 2009. Multi-proxy geoarchaeological study redefines understanding of the Palaeocoastlines and ancient harbours of Liman Tepe (Iskele, Turkey). Terra Nova 21, 97–104.
Heip, C., 1976. The life-cycle of *Cyprideis* torosa (Crustaceae, Ostracoda). Oecologia 24, 229–245.
Kambouroglou, E., 1989. Eretria. Paleo-geographical and geomorphological evolution during the Holocene. (PhD Thesis) Department of Geology, National and Kapodistrian University of Athens, Athens 234 (in Greek).
Kambouroglou, E., Maroukian, H., Sampson, A., 1988. Coastal evolution and archaeology north and south of Khalkis (Euboea) in the last 5000 years. In: Raban, A. (Ed.), Archaeology of Coastal Changes. BAR International Series 404. British Archaeological Reports, Oxford, pp. 71–79.
Knoepfler, D., 2004. From the Macedonian occupation to the Roman conquest. In: Ducrey, P., et al. (Eds.), Eretria, A Guide to the Ancient City. Gollion, pp. 31–45.
Kraft, J.C., Aschenbrenner, S.E., Rapp Jr., G., 1977. Palaeogeographic reconstructions of coastal Aegean archaeological sites. Science 195, 941–947.
Krause, C., 1981. Eretria, Ausgrabungen 1979–80. Antike Kunst 24, 70–71.
Krause, C., 1985. Naissance et formation d'une ville. Hist. archéologie 94, 17–25.
Lambeck, K., Purcell, A., 2005. Sea-level change in the Mediterranean Sea since the LGM: model predictions for tectonically stable areas. Quat. Sci. Rev. 24, 1969–1988.
Lemos, I.S., 2002. The Protogeometric Aegean: The Archaeology of the Late Eleventh and Tenth Centuries BC. Oxford.
Mourtzas, N.D., Marinos, P.G., 1994. Upper Holocene sea-level changes: palaeogeographic evolution and its impact on coastal archaeological sites and monuments. Environ. Geol. 23, 1–13.
Müller Çelka, S., 2010a. L'occupation d'Érétrie (Eubée) à l'Helladique Moyen. In: Philippa-Touchais, A., Touchais, G., Voutsaki, S., Wright, J. (Eds.), Mesohelladika. La Grèce continentale au Bronze moyen. Actes du colloque international (Athènes, 8–12 mars 2006). Bulletin de Correspondance Hellénique, Suppl. 52, pp. 269–279.
Müller Çelka, S., 2010b. Avant la cité. In: Martin Pruvot, Ch., Reber, K., Theurillat (dir), T. (Eds.), Gollion (50–55 and 86–88).
Müller Çelka, S., Krapf, T., Verdan, S., 2013. La céramique helladique du sanctuaire d''Apollon Daphnéphoros à Érétrie (Eubée). Bulletin de Correspondance Hellénique 135/1, 21–61.
Pajor, F., 2006. Eretria - Nea Psara. Eine klassizistische Stadtanlage über der Antiken Polis. Eretria, XV. Gollion.
Papazachos, B., Papazachou, C., 1997. The Earthquakes of Greece. Ziti editions, Thessaloniki.
Pavlopoulos, K., 2010. Relative sea level fluctuations in Aegean coastal areas from middle to late Holocene. Geodin. Acta 23 (5–6), 225–232.
Pavlopoulos, K., Mpompolos, C., Papadopoulos, K., Sympardis, K., Tzormbatzoglou, G., Charalambakis, A., 1985. Oceanographical Researches in the Coastal Area Between Malakonta and Eretria, South Euboic Gulf.Department of Geology, University of Athens 63 (in Greek).
Pavlopoulos, K., Karkanas, P., Triantaphyllou, M., Karymbalis, E., Tsourou, T., Palyvos, K., 2006. Paleoenvironmental evolution of the coastal plain of Marathon, Greece, during the Late Holocene: depositional environment, climate, and sea level changes. J. Coast. Res. 22 (2), 424–438.
Pavlopoulos, K., Triantaphyllou, M., Karkanas, P., Kouli, K., Syrides, G., Vouvalidis, K., Palyvos, K., Tsourou, T., 2010. Paleoenvironmental evolution and prehistoric human environment, in the embayment of Palamari (Skyros Island, Greece) during Middle–Late Holocene. Quat. Int. 216, 41–53.
Pavlopoulos, K., Kapsimalis, V., Theodorakopoulou, K., Panagiotopoulos, I.P., 2011. Vertical displacement trends in the Aegean coastal zone (NE Mediterranean) during the Holocene assessed by geo-archaeological data. The Holocene 22 (6), 717–728.
Pavlopoulos, K., Kaspimalis, V., Theodorakopoulou, K., Panagiopoulos, I.P., 2012. Vertical displacement trends in the Aegean coastal zone (NE Mediterranean) during the Holocene assessed by geo-archaeological data. The Holocene 22 (6), 717–728.
Péres, J.M., 1982. Major benthic assemblages. In: Kinne, O. (Ed.), Marine Ecology, Part 1, vol. 5. Wiley, Chichester, pp. 373–522.
Péres, J.M., Picard, J., 1964. Nouveau manuel de Bionomie benthique de la Mer Méditerranée. Recueil des Travaux de la station Marine d'Endoume 47–31, 3–137.
Perisoratis, C., Van Andel, T.H., 1991. Sea-level changes and tectonics in the Quaternary extensional basin of the South Evoikos Gulf, Greece. Terra Nova 3, 294–302.
Philip, H., 1974. Etude néotectonique des rivages égéens en Locride et en Eubée nord occidentale (Grèce centrale). (PhD thesis) University of Montpellier (France) 90.
Pirazzoli, P.A., 1991. Oceanography Series, 58. Elsevier, Amsterdam (300 pp.).
Pirazzoli, P.A., 1997. Sea-level changes in the Mediterranean. In: Tooley, M.J., Shennan, I. (Eds.), Sea-Level Changes. Institute of British Geographers, Special Publications Series, Page Bros (Norwich) Ltd., pp. 152–181.
Pirazzoli, P.A., 2005. A review of possible eustatic, isostatic and tectonic contributions in eight late-Holocene relative sea-level histories from the Mediterranean area. Quat. Sci. Rev. 24, 1989–2001.
Pirazzoli, P., Stiros, S.C., Arnold, M., Laborel, J., Laborel-Deguen, F., 1999. Late coseismic vertical displacements and tsunamis deposits near Kynos, Gulf of Euboea, Central Greece. Phys. Chem. Earth 24 (4), 361–367.
Poulos, S., Ghionis, G., Maroukian, H., 2009. Sea-level rise trends in the Attico–Cycladic region (Aegean Sea) during the last 5000 years. Geomorphology 107, 10–17.
Psalti, A., 2003. Δύο νέοι τάφοι αυτοκρατορικών χρόνων από την Ερέτρια. Πρακτικά Ημερίδας, Μνήμη Άγγελου Χωρέμη, 22 Ιουνίου 2003. Chalcis, pp. 17–20.
Reber, K., 1998. Die klassischen und hellenistischen Wohnhäuser im Westquartier. Eretria X, Lausanne.
Reimer, P.J., McCormac, F.G., 2002. Marine radiocarbon reservoir corrections for the Mediterranean and Aegean Seas. Radiocarbon 44, 159–166.
Reimer, M.J., Baillie, M.G.L., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Bronk Ramsey, C., Buck, C.E., Burr, G.S., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Hajdas, I., Heaton, T.J., Hogg, A.G., Hughen, K.A., Kaiser, K.F., Kromer, B., McCormac, F.G., Manning, S.W., Reimer, R.W., Richards, D.A., Southon, J.R., Talamo, S., Turney, C.S.M., Van der Plicht, J., Weyhenmeyer, C.E., 2009. INTCAL09 and MARINE09 radiocarbon age calibration curves, 0–50,000 years cal BP. Radiocarbon 51 (4), 1111–1150.
Rondoyanni, Th., Galanakis, D., Georgiou, C., Baskoutas, I., 2007. Identifying fault activity in the Central Evoikos Gulf (Greece). Bull. Geol. Soc. Greece XXXX, 439–450.
Roumelioti, Z., Kiratzi, A., Benetatos, C., 2011. Time domain moment tensors of earthquakes in the broader Aegean Sea for the years 2006–2007: the database of the Aristotle University of Thessaloniki. J. Geodyn. 51, 179–189.
Sackett, L., Hankey, V., Howell, R., Jacoben, T., Popham, R., 1966. Prehistoric Euboea: contribution towards a survey. The Annual of the British School at Athens, London, 61, pp. 31–112.
Siani, G., Paterne, M., Arnold, M., Bard, E., Metivie, B., Tisnerat, N., Bassinot, F., 2000. Radiocarbon reservoir ages in the Mediterranean Sea and Black Sea. Radiocarbon 42, 271–280.
Stiros, S.C., Arnold, M., Pirazzoli, P.A., Laborel, J., Laborel, F., Papageorgiou, S., 1992. Historical coseismic uplift on Euboea Island, Greece. Earth Planet. Sci. Lett. 108, 109–117.
Syrides, G., Vouvalidis, K., Albanakis, K., Tsourlos, P., Matsas, D., 2009. Palaeogeographical evolution and sea-level changes during Holocene in the Prehistoric settlement of Mikro Vouni (Samothrace Island, Greece). Z. Geomorphol. 53 (Suppl. 1), 39–54.
Themelis, P.G., 1969. Eretriaka. Archaiologiki Ephemer. 143–178 (In Greek).
Tourloukis, V., Karkanas, P., 2012. Geoarchaeology in Greece: a review. J. Virtual Explor. 42, 4.
Tsimplis, M.N., 1997. Tides and sea-level variability at the strait of Euripus. Estuar. Coast. Shelf Sci. 44, 91–101.
Tsimplis, M.N., Blackman, D., 1997. Extreme sea level distribution and return periods in the Aegean and Ionian Seas. Estuar. Coast. Shelf Sci. 44, 79–89.
Tuor, A., 1981. Eretria. Ausgrabungen 1979–1980. Die prähistorische Grabung in G/10. Antike Kunst 24, 83–84.
Tuor, A., 1982. Zur bronze zeitlichen Siedlung in G 10. Antike Kunst 25, 158–160.
Vacchi, M., Rovere, A., Zouros, N., Desruelles, S., Caron, V., Firpo, M., 2012. Spatial distribution of sea-level markers on Lesvos Island (NE Aegean Sea): evidence of differential sea-level changes and the neotectonic implications. Geomorphology 159–160, 50–62.
Vacchi, M., Rovere, A., Chatzipetros, A., Zouros, N., Firpo, N., 2013. An updated database of Holocene relative sea level changes in NE Aegean Sea. Quat. Int. (in press).
Van Andel, T.H., 1989. Late Quaternary sea-level changes and archaeology. Antiquity 63, 733–745.
Verdan, S., 2002. Fouilles dans le sanctuaire d'Apollon Daphnéphoros. Antike Kunst 45, 131–132.

Verdan, S., 2010. La naissance de la cité. In: Martin Pruvot, Ch., Reber, K., Theurillat (dir), T. (Eds.), Cité sous terre. Des archéologues suisses explorent la cité grecque d'Érétrie. Gollion (64–68 and 92–101).
Verdan, S., 2013. Le Sanctuaire d'Apollon Daphnéphoros à l'époque géométrique. Eretria XXII, 2 vols. Gollion.
Voreadis, G., 1952. The carboniferous Tertiary basin of Malakasa–Oropos. Geological and mineralogical study by geological mapping. Geol. Geophys. Stud., IGEY 141–180 (in Greek).
Vött, A., 2007. Relative sea level changes and regional tectonic evolution of seven coastal areas in NW Greece since the mid-Holocene. Quat. Sci. Rev. 26, 894–919.
Vouvalidis, K., Syrides, G., Albanakis, K., 2005. Holocene morphology of the Thessaloniki Bay: impact of sea level rise. Zeitschrift für Geomorphologie. Supp. 137, 147–158.
Vouvalidis, K., Syrides, G., Pavlopoulos, K., Pechlivanidou, S., Tsourlos, P., Papakonstantinou, M., 2010. Palaeogeographical reconstruction of the battle terrain in Ancient Thermopylae, Greece. Geodinamica Acta 23 (5–6), 241–253.