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UPPER QUATERNARY EVOLUTION OF THE NORTHERN ARGOLIS GULF, NAFPLIO AREA

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Abstract

The recent palaeogeographic history of the Gulf of Argolis was studied by means of marine geophysical surveys and sediment sampling for subsequent laboratory analyses. Data interpretation suggests a relatively smooth seafloor gradient, characterized by an amphitheatrical pattern of the sea bottom. Prominent beetling features comprise the Bourtzi islet near Nafplio coast, small ridges in the southern margin of the studied area, and several conical ridges in the central part of the gulf. Four unconformities were identified, defining four different sedimentary units. Granulometry measurements allowed the mapping of present-day seafloor sediment distribution, where fine sediments prevail; the only exception was observed at the eastern coastal areas, where sand con-tent reaches 70%. Contouring of granulometry statistical parameters highlights a NW towards SE transfer of fine-grain sediments. Finally, taking into account the results of the present study and all available information for the broader area, a model for the Upper Quaternary palaeogeographic evolution of the Argolis Gulf was constructed.

Key words: *Upper Quaternary, marine geophysics, seismic profiles, bathymetry, stratigraphy, Aegean Sea, Argolis Gulf*

1. Introduction

The Institute of Geology and Mineral Exploration (I.G.M.E.) of Greece, in the frame of "Community Support Framework 2000 – 2006", Operational Program "Competitiveness", implemented the project called "Collection, codification and documentation of geothematic information for urban and suburban areas in Greece. Pilot studies". In the framework of subproject 3 "Integrated geological, geotechnical, hydrogeological, geochemical, geophysical and marine studies of the urban and suburban pilot area of Nafplio, Argolis municipality", marine geology research was carried out at the Gulf around the broader Nafplio area (Andrinopoulos et al., 2008). This paper presents the Upper Quaternary stratigraphy and paleogeographic evolution during the same period of the northern Argolis Gulf (Fig. 1) using high-resolution seismic-reflection profiles and surface sediment sampling.

2. Geological setting

The Argolis Gulf is a located off the east coast of Peloponnese, opening into the Aegean Sea. It is surrounded by two prefectures, Arcadia and Argolis. At the head of the gulf we find its principal port, Nafplio, and the mouth of the Inakhos River. Just north of the head of the gulf is the

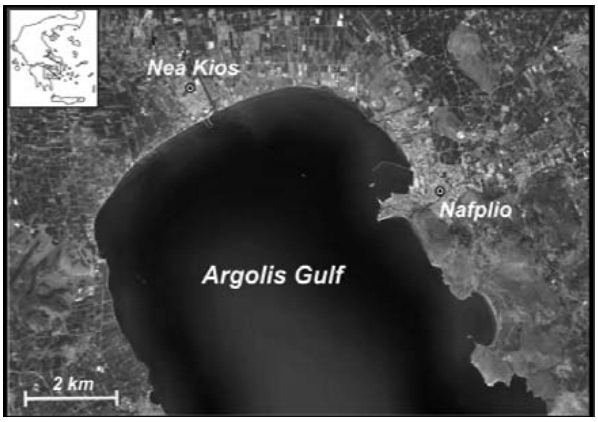

Fig. 1: Satellite image – taken from Google Earth – showing the location of the Argolis Gulf and main topographic features of the broader Nafplion area.

city of Argos, an important Mycenaean and Dorian centre. The prominent topographic features of the gulf are: Bourtzi, a small island in shallow waters with the homonymous castle, and Akronafplia peninsula, bounding from the north Nafplion seaport. The inclination of the slopes surrounding the gulf vary, affected mainly by tectonics, while the wider studied area is characterized by the existence of active and potentially active faults (Georgiou & Galanakis, 2009).

The Argolis peninsula geotectonically belongs to the Pelagonian isopic zone of the Internal Hellenides. It comprises a composite nappe pile (Bortolotti et al., 2003 and references therein) of several imbricated pre-Neogene tectonic units, tectonically assembled in two major distinct tectonic phases, one in the late Jurassic and the other in the late Eocene (Photiades & Skourtsis-Coroneou, 1994). A detailed geological survey in scale 1:5.000 of the greater Nafplion area was carried out by Photiades (2008).

3. Data acquisition

Geophysical data from the Argolis Gulf were collected during a single cruise by the vessel *Agni 3*, in September 2006. The acquisition area covers a rectangular area of 3 km×4.5 km (Fig. 2), with 22 parallel lines in E–W direction, track spacing of 200m, and 4 profiles in N–S direction, track spacing of 500m (for a total of 100 km).

A Geoacoustics 3.5 kHz 10KW high-resolution shallow seismic system (Fig. 3) was used with a resolution of 20-50 cm and an average penetration of 30-40 m. Data were recorded in analogue format with a EPC 9800 graphic recorder. Recording sweep rata and triggering of acoustic waves was set to □ and ¼ of a sec respectively. An assumed sound velocity of 1500 m/s was used to derive the water depths and the thickness of subbottom layers (Houtz, 1973). Bathymetric data were collected with a KNUDSEN LED 320M precision depth recorder (12 and 200 kHz), with increased resolution, 10-20 cm, and satisfactory penetration, 30m.

The recognition of seismic sequences and their interpretation are based on the seismic stratigraphic analysis methods outlined by Mitchum and Vail (1977), Sangree and Widmier (1979) and Brown and Fisher (1980). Processing and plotting of the seismic data was carried out at IGME using Surfer software (Golden Software); kriging interpolation was applied. Our knowledge of the oceans from geophysics depends heavily on positioning observations accurately. In the present study a GPS Magellan sportrak map system was used for navigation giving an accuracy of about 5m, which is adequate for sea geophysical studies. To avoid interpretation er-

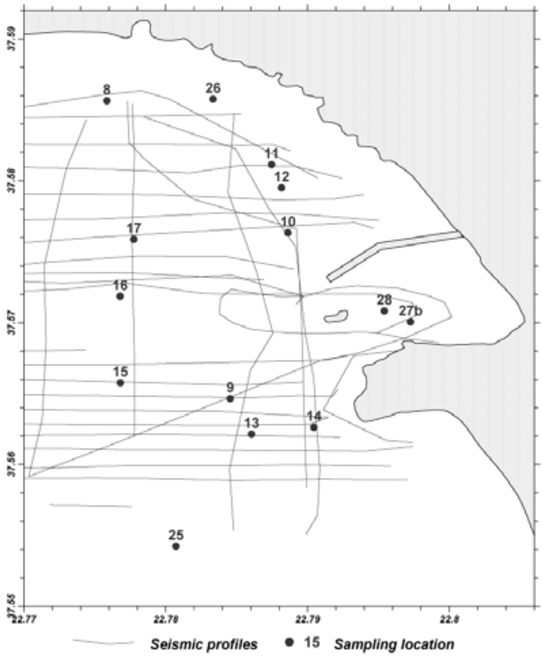

Fig. 2: Index map showing the location of seismic-reflection profiles and numbered surface samples collected from the Argolis Gulf.

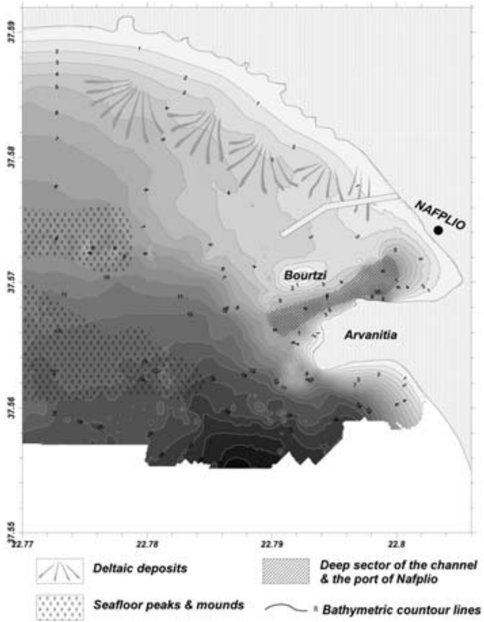

Fig. 3: Present-day bathymetry of the study area, obtained from marine geophysical data. Bathymetric contour lines every 1m.

rors, acoustic response data should be complemented with sedimentological data from surface samples. Thus, 14 samples (Fig. 2), of both fine- and coarse-grained material, from the sea-bottom surface were gathered, using a Dietz la Font and a Van Veen bottom grab samplers.

4. Results

4.1 Bathymetry

Seismic data is generally of good quality and allowed the elaboration of a high resolution, scale 1:5.000, bathymetric map of the northern Argolis Gulf. Bathymetric contour lines are drawn every 1m (Fig. 3). The Argolis gulf is characterized by regular seafloor morphology with an amphitheatric pattern. A maximum depth of 22m, below sea level, is measured, while the steeper inclinations are observed in the southeastern sector of the study area. Prominent feature of the gulf is the mound forming Bourtzi islet, off the coast of Nafplio; it is a ENE-WSW trending elliptically shaped mound, defined by the 2m bathymetric contour line. In the central part of the gulf small underwater conical peaks, of 20-50m diameter and 2m height, are present (Figs. 3 and 4). Another element, worth noting, is the morphology observed throughout the channel between Bourtzi island and Cape Arvanitia, at Akronafplia peninsula. It constitutes a deepening corridor of the channel and the port of Nafplio, with approximately 1200m length, 200m width and 8m depth.

4.2 Sub-bottom structure

Seismic reflection data comprise the most obvious and directly analysed seismic parameter and show the gross stratification patterns from which depositional processes, erosion and palaeoto-

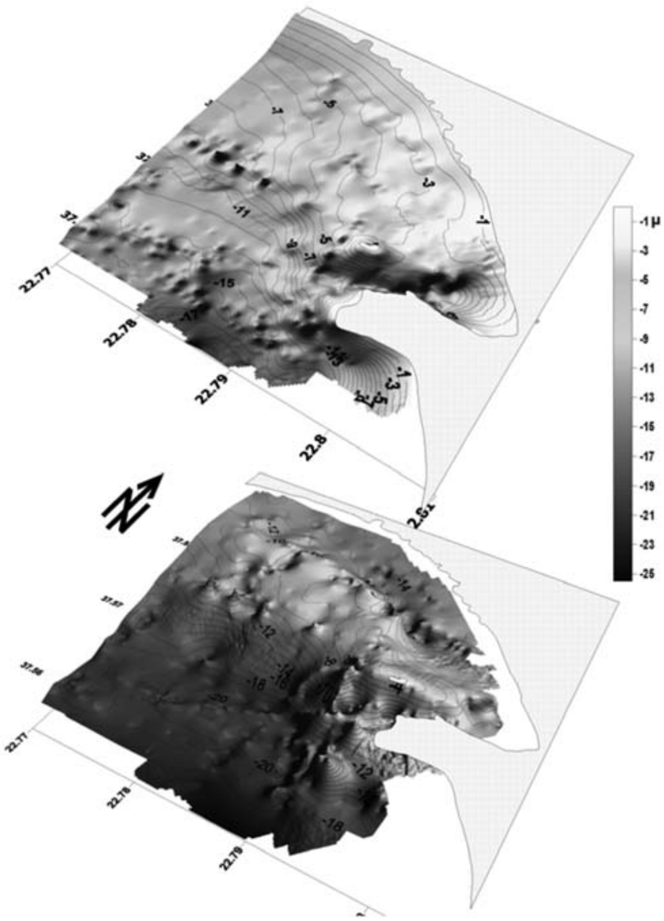

Fig. 4: 3D view of the present-day seafloor morphology (top) and horizon B (bottom).

pography can be determined (Mitchum et al., 1977). Three main seismic reflectors, that define three unconformities (horizons a-c), bounding four seismic units (A-D), are observed in the study area (Figs. 5 & 6). Two examples of seismic profiles are shown in Figures 5 and 6, where the interpreted profiles illustrate the primary seismic stratigraphic and geomorphic elements discussed in the text. The unconformities observed are, from top to bottom the following: Horizon a: The upper unconformity appears as a strong reflector, extending almost everywhere in the study area. It is found at depths varying from 1-6m below present-day sea bottom level, while in places it is wedge-shaped towards the seafloor. This horizon is regular, in general, with erosional features, e.g. old channels, only locally present. Horizon b: A second unconformity is detected in the seismic profiles as a very strong reflector, irregularly shaped, spanning all over the studied area. It is found at varying depths, 1-10m, below the present-day sea bottom surface. This horizon is a very irregular surface, characterized by the presence of old channels and stream beds, dipping 1-8m. The morphological differences between unconformity *b* and the present-day seafloor can be seen in Figure 4. Seismic horizons a and b converge and wedge into the seafloor around the Bourtzi mound. Horizon c: The lower unconformity is detected only around the Bourtzi islet; as we move away from this mound it is steeply dipping, soon exceeding depth penetration of our equipment.

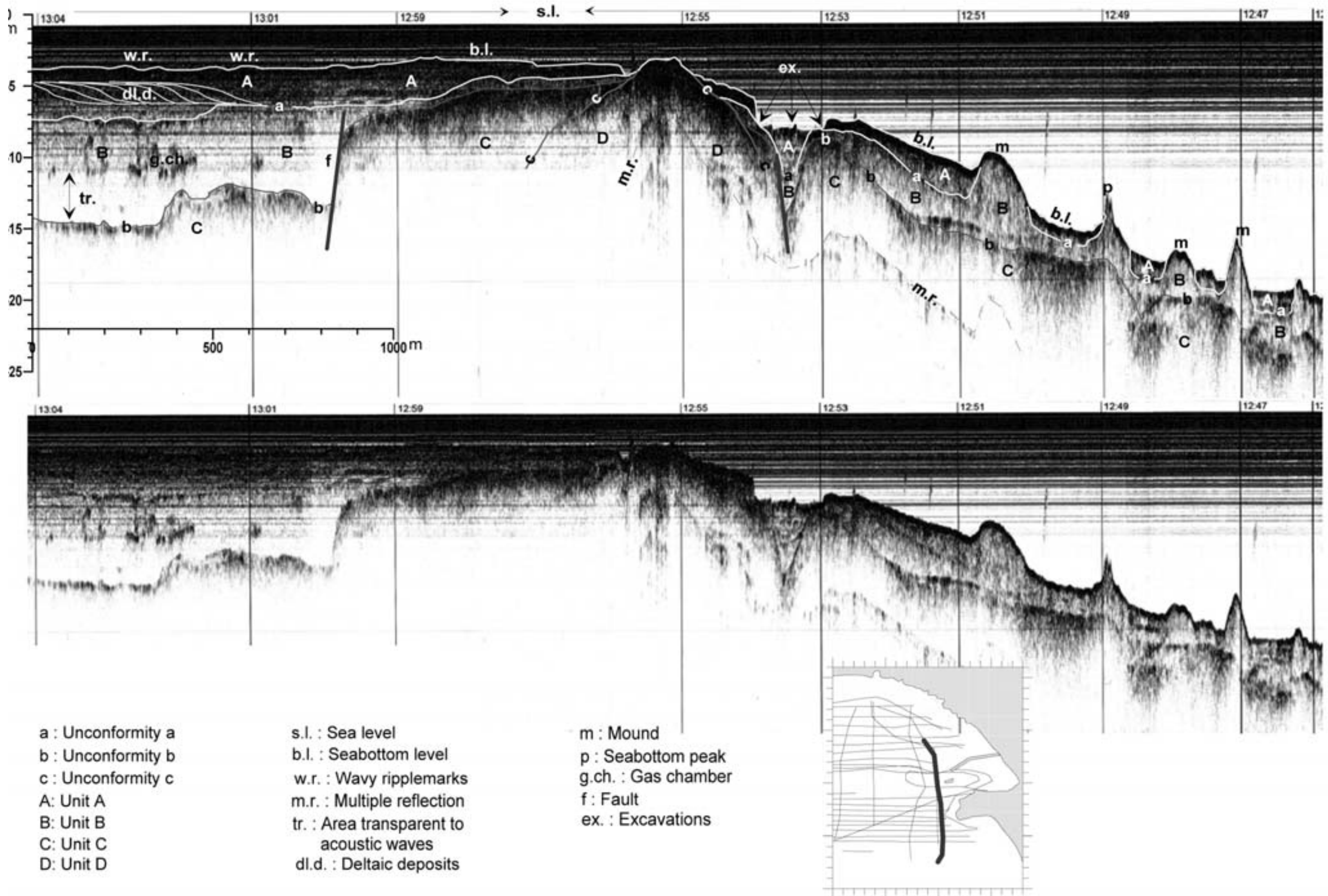

Fig. 5: Interpreted (top) and uninterpreted (bottom) 3,5 kHz seismic reflection profile (SN-12).

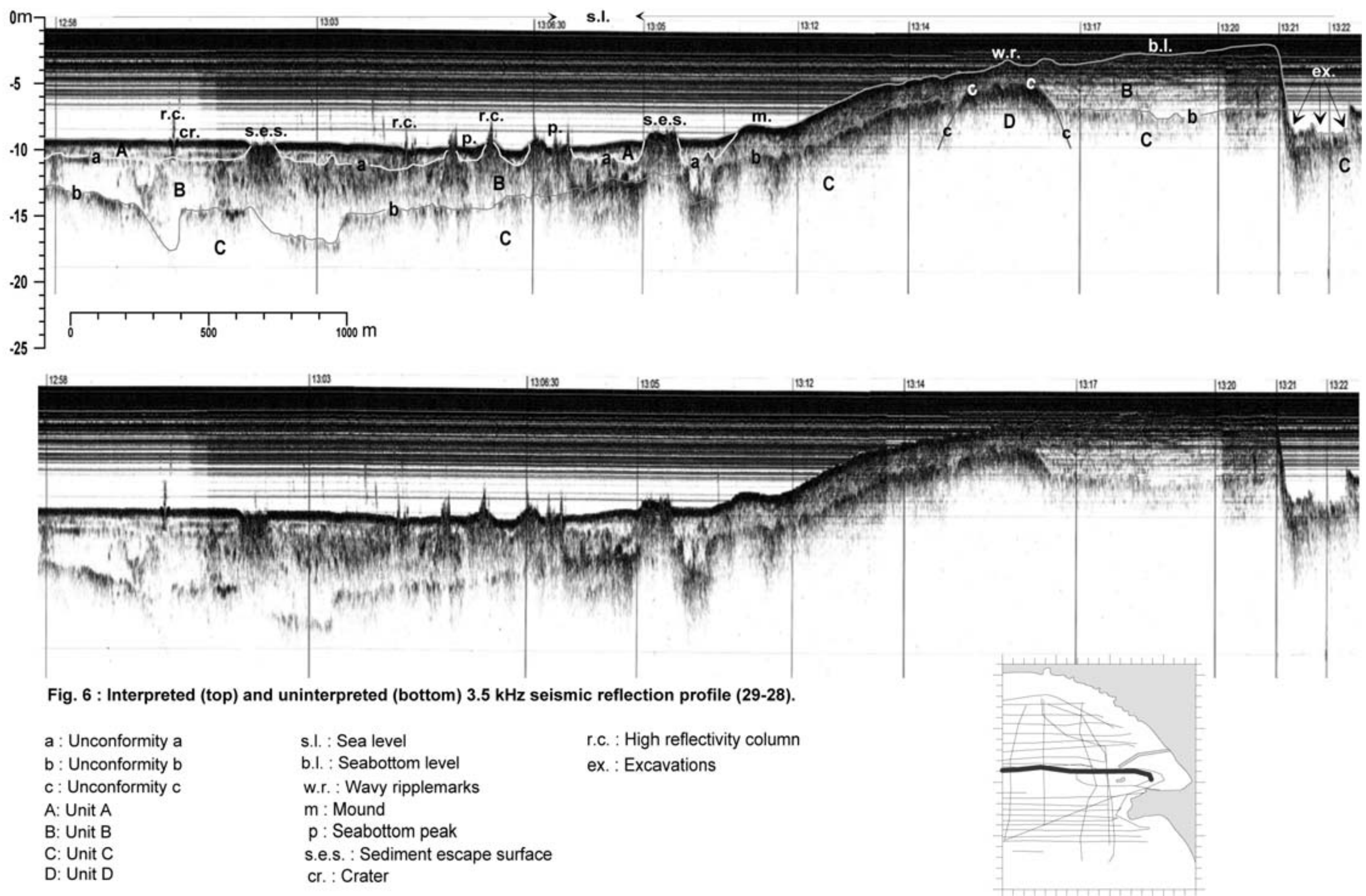

Fig. 6 : Interpreted (top) and uninterpreted (bottom) 3.5 kHz seismic reflection profile (29-28).

Fig. 6: Interpreted (top) and uninterpreted (bottom) 3,5 kHz seismic reflection profile (29-28).

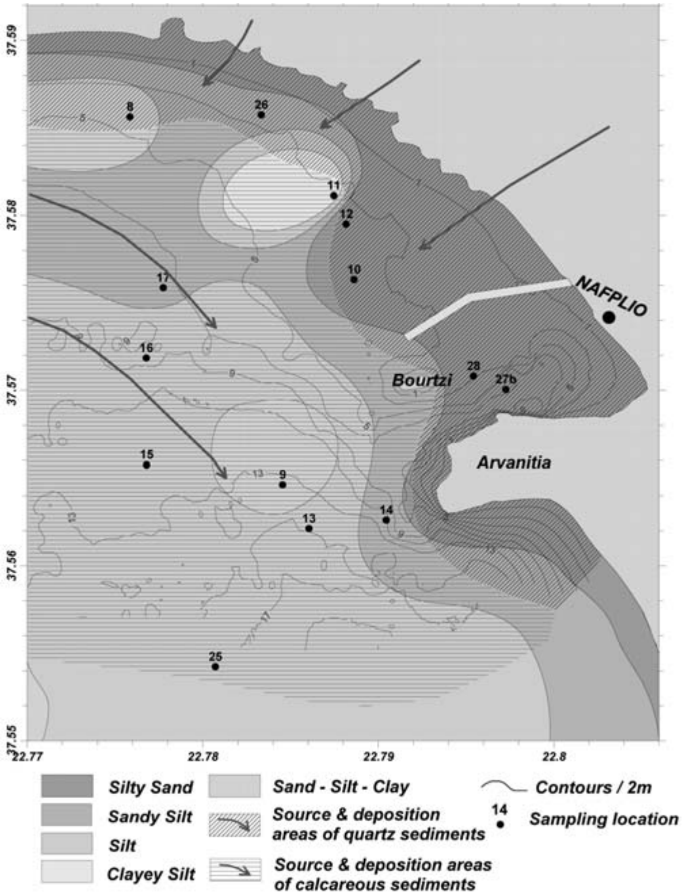

Fig. 7: Sediment distribution over the seafloor surface.

The sedimentary units determined from seismic data are, from top to bottom, the following: Unit A: The upper unit comprises mostly fine-grained sediments (silt and clay), while in the coastal areas a gradual transition to more coarse-grained materials is observed. This unit extends over the whole study area, with thickness varying from 0-6m. Its upper limit, which constitutes the present-day seafloor, exhibits locally at 4-7m depth, wavy ripplemarks formed during rough sea periods. At the northeastern part of the gulf, over the base of unit A, well-developed deltaic deposits are observed, with prograding delta characteristics. Unit B: Reflectors a and b define a sequence of intercalating coarse- and fine-grained sedimentary layers. This unit, spanning all over the study area, varies in thickness from 0-13m; the smaller values are observed along a zone northwest of Bourtzi mound, while at both sides of this area the thickness is increased abruptly, reaching 12m. In the interior of unit B seismic data indicate the presence of numerous secondary unconformities, old channels and watercourses of rivers filled by younger sediments that are often re-eroded and refilled. In the central and southern regions the emersion of this unit creates small elevations at the seafloor; from the top of these peaks an escape of fluid material into the sea water is observed, while at the regions where this unit is overlain by thin sedimentary layers perforation of unit A and creation of small craters on the sea bottom takes place. The nature of these fluids was not possible to be precisely determined from the existing data. However, from the seismic characteristics it can be deduced that they are probably due to the escape of freshwater that circulates within unit B. Finally, in the interior of this unit there

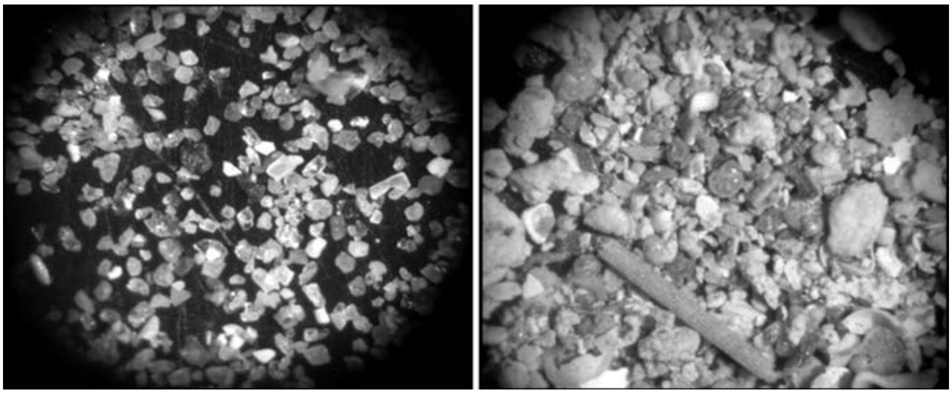

Fig. 8: Representative sediment samples with predominance of quartz crystalloclasts (left) and calcareous rocks lithoclasts (right). Photos from stereoscopic microscope (x20).

are obvious signs of sapropelic deposits and biogenic gases. Unit C: This seismic layer extends almost throughout the gulf, with intense characteristics of erosion over its surface. The thickness was not possible to be thoroughly mapped because it appears opaque to acoustic waves. This unit comprises a cohesive sandstone formation, rich in marine shells. At the eastern part it appears affected by a NW-SE directed fault system, which caused the development of a horst and a graben, both NW-SE trending. Unit D: This seismic unit is only locally detected, around the Bourtzi mound and the Arvanitia coastline, up to 18m depth. It constitutes an extension of the Mesozoic limestones from these regions beneath Unit C.

4.3 . Sediment texture

Granulometry analyses allowed the compilation of a distribution map for sediments of the seafloor (Fig. 7). In this map we can observe the predominance of fine-grain sediments (silts, sandy silts, clayey silts), with the exception of the coastal – and mainly the eastern – areas where sand content increases up to 70%. Examining the statistical parameters (Table 1) derived, using the formulas of Folk (1974), from the granulometry analyses data it is obvious that for the majority of sediments the mean size is less than 4Φ (0.0625mm). The values of skewness, which for all samples exceeds 1Φ, characterizes poorly sorted sediments. Finally, the spatial distribution of statistical parameters indicates a trend for transportation of fine-grained sediments from NW towards SE.

From the microscopic examination of the sand fraction of each sample it is evident that the sediments of the gulf can be divided in two categories, based on their qualitative and quantitative composition. The first group includes coastal sediments, which comprise quartz crystalloclasts and biogenic components in a fraction up to 95% of the total sand content; the second is made up by sediments from the central and southern areas that are characterized by the presence of calcareous rocks lithoclasts and biogenic components up to 95% (Fig. 8). This fact leads to the conclusion that sediments of the first category emanate mainly from erosion of flysch formations from the east and northeastern areas of the Argolis gulf, while the second are mostly products of erosion from calcareous rocks around the northwestern coasts of the gulf. In both cases biogenic material consistes of shells and fragments of benthic foraminifera, lamellibranchii, bryozoa, porifera, gastropods, brachiopods, biogenic structures and aggregates.

Table 1. Statistics derived from granulometry analyses, using the formulas of Folk (1974). Depth (in meters) measured from sea level; Mean size Mz=(Φ16+Φ50+Φ84)/3; Standard deviation σI=(Φ84-Φ16)/4+(Φ95-Φ5)/66; Skewness SK1=(Φ16+Φ84-2Φ50)/2(Φ84-Φ16); Kurtosis KG=(Φ95-Φ5)/2.44(Φ75-Φ25)

Sample	*Depth (m)*	*Mean Size (Φ)*	*Standard Deviation (Φ)*	*Skewness (Φ)*	*Kurtosis (Φ)*
08	3.5	5.47	3.08	-0.05	0.95
09	10.5	5.84	3.46	-0.29	0.76
10	3.0	4.08	1.75	0.40	1.97
11	3.0	6.80	2.80	-0.27	1.53
12	4.5	2.88	1.00	0.36	0.69
13	11.1	6.64	1.86	-0.23	1.68
14	9.2	5.20	2.45	-0.12	0.95
15	15.0	7.12	1.05	-0.15	1.49
16	6.5	6.60	2.04	-0.38	1.92
17	6.8	5.24	3.18	-0.53	1.44
25	2.5	5.68	2.73	0.17	1.13
26	2.9	5.17	2.27	0.35	1.21
28	3.3	3.88	3.29	0.15	0.73
27b	6.5	0.76	2.75	0.93	1.20

5. Conclusions - Palaeogeographic evolution

Based on all data and published information (Finke, 1988; Perissoratis & Van Andel, 1988; Perissoratis et al., 2000; Stanley & Vitaliano, 1987; Stanley et al. 1990; Van Andel & Perissoratis, 2006) the palaeogeographic evolution of the Argolis gulf during the Upper Quaternary can be determined:

During the last glacial period, that took place 18,000 years ago, sea level reached a minimum of 120m below the present datum (Fig.9) and thus dry land extended down to this depth. Subsequent melting of ice and important growth of the local hydrographic network resulted in intense erosion of the area and collection of significant amount of sediment from the same area; thus, the sandstones of Unit C were revealed, through a much eroded surface, namely unconformity b.

The presence of a horst, NW-SE directed and dipping towards the NW, played a decisive role in the palaeogeography of the Argolis gulf. After sea regression this horst acted as a barrier and did not allow the total drainage of the adjacent tectonic ditch, resulting in the creation of lakes at the level of -13m down to -15m approximately. These lakes most probably extended northern from the present-day coastline (Fig.10) and linked at the time the northeastern hydrographic network to the northwestern one. The fine-grained sediments deposited by both networks constitute Unit B.

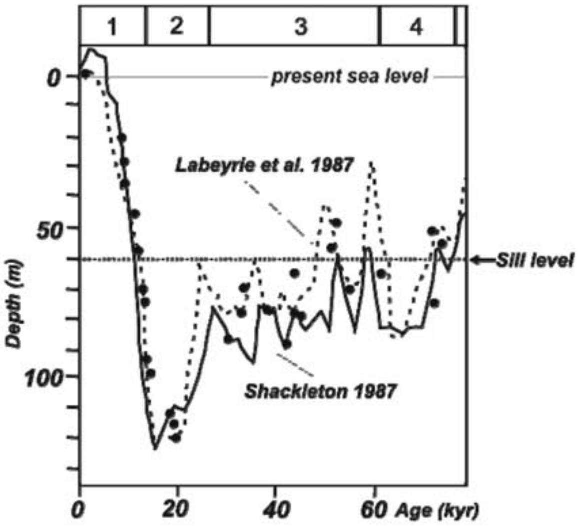

Fig. 9: Global eustatic sea level change during the last 80,000 years (Van Andel & Perisoratis, 2006).

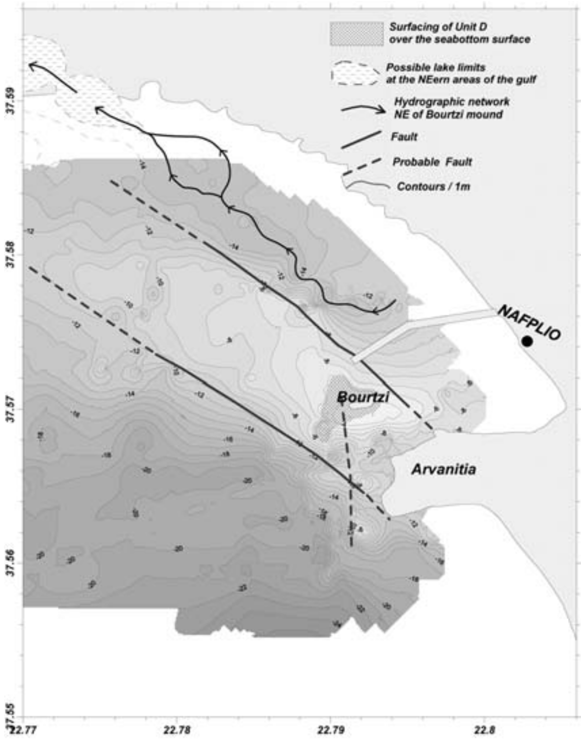

Fig. 10: Topographic and morphologic map of unconformity b.

The continuing melt of glaciers resulted in a rapid rise of the sea level that gradually covered Unit B, which was unconformly overlain – originally at the deeper regions and successively at the shallower ones – by the more recent marine sediments of Unit A.

When the sea level reached the level of the lakes, the latter had been completely filled by the ultrafine-grain material of Unit B. The continuous sea transgression caused a rise in the sea level up to -5m, covering the whole region of the lakes, creating a lagoon area. In this new environment sediments, transported by the hydrographic network, were deposited as deltaic thrusts over a long period.

Finally, 6,000 years ago the level of the sea reached its present-day status, submerging the lower dry land up to the fringes of the ancient Tiryns mounds. At that time the growth of delta deposits seizes and they are covered by the more recent Holocene marine sediments of Unit A. The constant infill of material resulted in the repletion of shallow lagoons, moving thus the coastline to its current position.

The uninterrupted sedimentation, on-going even today, will result in the continuous expansion of land against the sea. However, at present this phenomenon appears to have slowed down considerably, due to a decrease in rainfalls over the last years and to anthropogenic intervention (e.g. overpumping of the aquifers, interventions in the hydrographic network).

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