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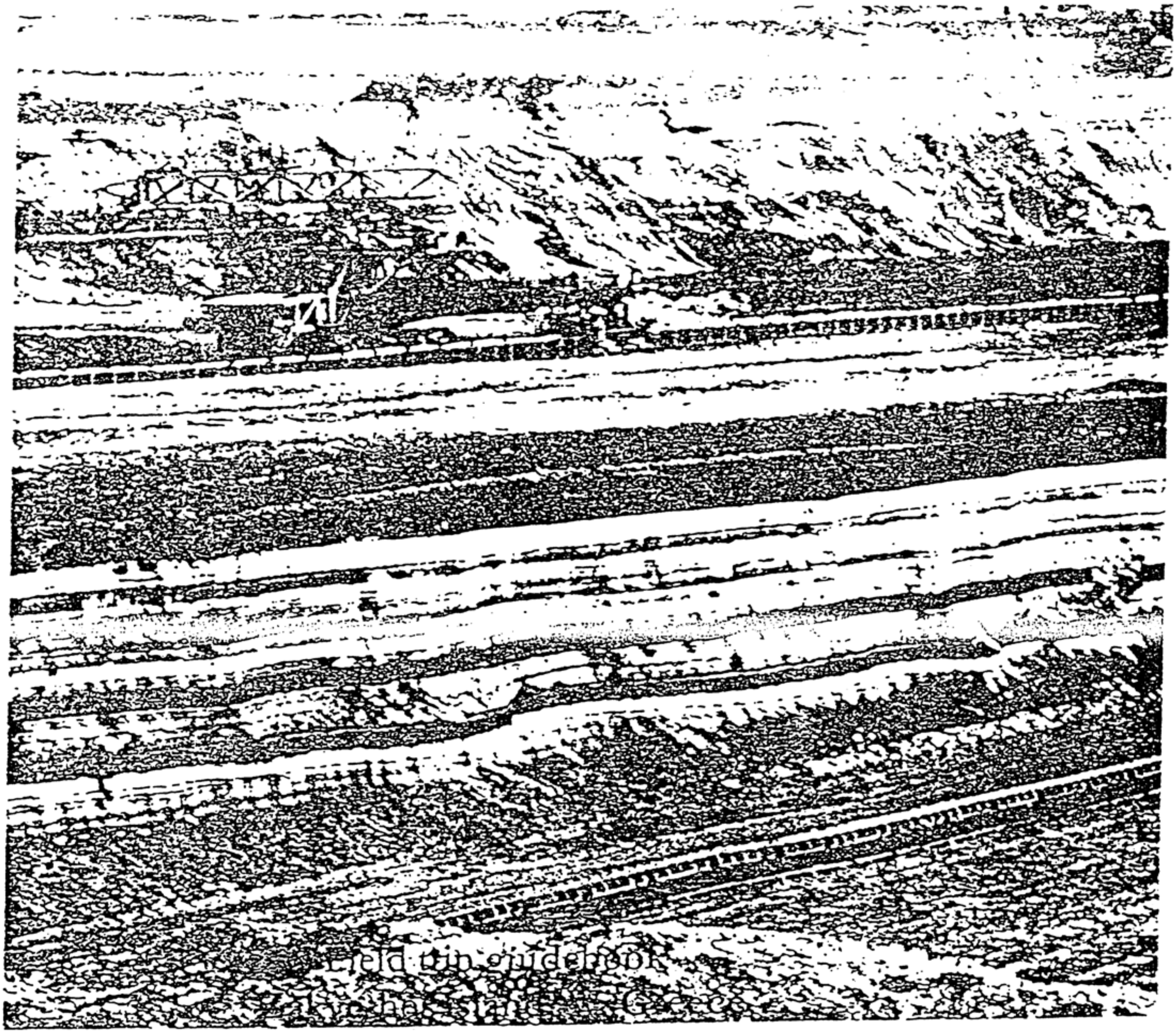

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The Plio-Pleistocene boundary in Gerakas section, Zakynthos (Ionian Islands). Biostratigraphic and paleoecological observations

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INTRODUCTION

Some uncertainties remain as the precise numerical age of Pleistocene stage boundaries, particularly at the transition from Tertiary to Quaternary. An earlier position was that the Pliocene-Pleistocene boundary is best positioned about 2.5 to 3.0 my ago, or at approximately 2.8 my ago (BEARD & LAMB 1969, LAMB & BEARD 1972, BEARD 1969, 1973, LAMB 1969, SMITH 1969, BEARD *et al.* 1976). Glass (fission-track) dates, combined with nannofossil dating, above the recently proposed Pliocene-Pleistocene boundary stratotype at Vrica, Italy (BASSETT 1985, AGUIRE & PASINI 1985), now render as untenable consideration of younger dates on the order of 1.81 my ago - coinciding almost with the top of the Olduvai (C2N) Magnetic Polarity Subchronozone - espoused by some authors (e.g. BERGGREN 1972, BERGGREN & VAN COUVERING 1974, HAQ *et al.* 1977, BERGGREN *et al.* 1985, BERGGREN *et al* 1995a,b).

The working group of International Geological Correlation Program (IGCP) Project 41 «Neogene - Quaternary Boundary» and the International union on study of the Quaternary (INQUA), as well as the Committee on Mediterranean Neogene stratigraphy (CMNS), are considering a section near Vrica, Italy, as a potential N/Q boundary stratotype. According to their results, a climatic implication - the appearance of cold water North Atlantic immigrants - can be considered in the definition of the boundary. However recent studies proved that the forementioned climatic event took place 2.6-2.4 my ago during Pliocene (BACKMAN 1979, SHACKLETON *et al.* 1984, RAYMO *et al.* 1989). Therefore the definition of the beginning of the Pleistocene has no longer a primary climatic implication, which, because of latitudinal and altitudinal effects on world climate, would be difficult to provide.

The main goal of the present study is the reconstruction of the Plio-Pleistocene paleoenvironment and the possible recognition of the Plio-Pleistocene boundary based on calcareous nannofossil biostratigraphic events, in Gerakas section in SE Zakynthos (Ionian islands).

GEOLOGICAL BACKGROUND

Zakynthos is one of the Ionian Islands off western Greece. It forms part of the external Hellenides - a NNW - SSE trending orogenic belt - and belongs to the Ionian and Preapulian zones (AUBOUIN 1959, AUBOUIN & DERCOURT, 1963). These two zones are separated by a major thrust fault, which runs across several Ionian Islands (Fig 1 in DERMITZAKIS & ALAFOUSOU, 1987).

The preneogene rocks of the Ionian zone on Zakynthos are represented by the predominantly evaporitic sediments which belong to the Triassic (BORNOVAS 1964). The Preapulian preneogene ranges from the Jurassic up into the Paleogene. The Cretaceous - Paleogene sequence is fairly continuous and mainly consisting of alternations of pelagic and detrital limestones.

The Neogene of central-southeastern Zakynthos forms a monoclinal succession which overlies the Cretacious - Paleogene limestones. According to DERMITZAKIS 1978, the Neogene can roughly be subdivided into two units: a lower unit, predominantly composed of calcareous sediments, and an upper unit, which consists of terrigenous-clastic deposits. Locally, evaporites occur in the upper part of the terrigenous-clastic succession (HEIMANN 1977).

The terrigenous-clastic sediments of Zakynthos island are mainly composed of marls, silts, silty clays, sandstones and calcarenites and are thought to be of Plio-Pleistocene age. These Neogene sediments are well exposed in the southeastern and eastern parts of the island and belong mainly to Gerakas Formation (DERMITZAKIS 1978, DERMITZAKIS *et al.*1979). DERMITZAKIS *et al.* (1979), DERMITZAKIS & GEORGIADES-DIKEOULIA (1987) and TRIANTAPHYLLOU (1993) recognised four lithostratigraphic units in SE Zakynthos: Seliniako Topio Unit, Gerakas Unit, Kalogera Unit and Ag.Nikolaos Unit.

LITHOSTRATIGRAPHY - SEDIMENTARY FACIES ANALYSIS

Gerakas section is located in the SE side of Zakynthos along the coast of Gerakas gulf (Fig.2). It consists of three depositional sequences each one bounded by angular unconformities. To the west, the section is in tectonic contact with the deposits of Pliocene which are mainly marls, coarse conglomerates and coral limestones. Planktonic and benthic foraminifera of the section have been studied by DERMITZAKIS (1978), DERMITZAKIS *et al.* (1979) and ostracodes by TSAPRALIS (1981).

Depositional Sequence I comprises «Seliniako Topio Unit» (Fig. 4,5) and covers the west edge of Gerakas coast. It is composed of 30m of laminated marls with occasional lenses or layers of fine to very fine grained siltstone and sandstone with dispersed macrofossils. The sandstone beds are very thin and, going upwards into the sequence, increase in abundance and thickness. The sandstone layers are usually massive but parallel lamination, ripple cross-lamination, lenticular and wavy bedding may also occur. This depositional sequence dominates mainly the basal part of the studied section.

Depositional Sequence I is likely to have been deposited in a quiet, shallow marine environment (shelf), where the deposition of marls and clays is dominant. The fossiliferous marls indicate deposition from suspension in a quiet environment, which has hardly been influenced by waves or other currents. The deposition of mud by suspension was occasionally interrupted by waning sand-laden traction currents (deposition of the sandstone beds).

Depositional sequence II is composed of «Gerakas Unit» (Fig. 3,6). The basal part of Depositional sequence II is characterised by the presence of a thin sandy conglomerate which is going upwards into 10 m of unlithified, rather massive brown sandstone with no indication of biogenic structures. The upper part of the sequence is exposed along the rest of the coast up to the cape Gerakas. This part is mainly composed of 60m of clays, silty clays and calcarenites with dispersed thin conglomeratic channels in between. The base of this part of the sequence consists of homogenised mostly massive clays which partly alternate with marly, mostly laminated beds, characterised by a variety of macro- and microfossils and trace fossils. The conglomeratic channels (max thickness 1.25m) are usually found in the middle part of the sequence, which is characterised by coarser-grained sediments. The clasts are usually composed of silty and sandy pebbles and cobbles, fractured mollusca, bryozoons, corals etc. Slumping structures are often observed in this part of the sequence. The topmost part of the sequence is becoming again fine-grained by the predominance of clayey sediments.

The basal thin sandy conglomerate and the unlithified brown sandstone show no indications of deposition in a marine environment. Their presence is thought to be due to the existence of the angular unconformity which separates Depositional Sequence II from Depositional Sequence I, and is indicative of processes of emergence.

The homogenized, partly marly clays of the lower part of the sequence have been deposited in a stable and quiet marine environment. The presence of macrofossils and trace fossils supports the above interpretation. The predominance of coarse-grained sediments in the middle part of the sequence is thought to be due to mass-flow processes which indicate unstable, high energy environments. The coarse-grained sediments are thought to have been transported through submarine channels. Finally, the topmost part of the sequence indicates deposition in a very stable and quiet environment.

Depositional Sequence II is unconformably overlain by Depositional Sequence III (Kalogeras Unit, Fig.3). The angular unconformity which bounds the two sequences is obvious along Gerakas coast, while to the NE it becomes less angular. This unconformity is mainly marked by the sudden arrival of coarse-grained calcareous sandstones over the pure blue marls of Depositional Sequence II.

Depositional Sequence III consists, at its base, of parallel-laminated calcareous sandstones alternating with yellow sandy marls which become more marly in a higher position. This transition to more marly sediments is marked by very impressive folds due to slumping phenomena, with fold axis direction to NE. Finally, at the top, the sequence becomes pure blue marly.

The sedimentary features observed in the basal part of Depositional Sequence III are indicative of deposition in a shallow-marine, coastal environment, where high energy processes prevailed. The transition to clays and marls indicates a deeper and quieter marine environment, which is separated from the coast by a slope.

BIOSTRATIGRAPHY - CHRONOSTRATIGRAPHY

The quantitative methods of biostratigraphic analysis being used in this study, are of RIO *et al.* (1990), TRIANTAPHYLLOU (1993).

Depositional Sequence I

Sequence I was studied concerning calcareous nannofossils using quantitative methods, especially for the species *D.brouweri*, *D.triradiatus*, *C.macintyrei*, *G.oceanica* s.l. or medium sized gephyrocapsids (RAFFI *et al.*, 1993). Semiquantitative analysis was carried for small *Gephyrocapsa* spp.

From the derived data (Fig.5), we can conclude that:

- the species *D.brouweri* is practically absent; the low abundances of certain samples may be due to reworking
- *D.triradiatus* is absent
- the presence of small *Gephyrocapsa* spp. is intense. Their size is increasing progressively and about 34m above the base of the sequence (samples C10, G11 etc.) reaches 3-3.5μ (transitional types to *G.oceanica* s.l.).
- the species *C.macintyrei* is present throughout the whole section, with high abundances
- inbetween samples G12 and G13 (at about 36m above the base of the sequence) the first appearance of *Gephyrocapsa* specimens -bearing the features of *Gephyrocapsa oceanica* s.l.- is observed. The specimens labeled as *G.oceanica* s.l. (RIO *et al.* 1990) or medium sized gephyrocapsids (RAFFI *et al.* 1993) are >4μ and <5.5μ in size with an open central area and clear diagonal bridge
- the species *P.lacunosa* was observed in high abundance and good development.

As far as the planktonic formaminifera are concerned, *Gl.inflata* has been found.

However, the total absence of discoasterids, the good development of *P.lacunosa* specimens, the increased presence of transitional forms (almost 3.5μ in size) of the genus *Gephyrocapsa* and the presence of the planktonic foraminifera *Gl.inflata*, may allow the correlation of the lower part of Sequence I (till 36m from the base of the sequence) with MNN19a biozone (RIO *et al.*, 1990), NN19 (MARTINI, 1971) and CN13a (OKADA & BUKRY, 1980).

Concerning planktonic foraminifera these biozones can be correlated with the upper part of MPL6 (CITA, 1975 emend.) and the lower part of biostratigraphic interval IX (SPAAK, 1983). This points to uppermost Pliocene in age (Fig.7).

The first appearance of *Gephyrocapsa* specimens - at about 36m from the base of the sequence - with features of *G.oceanica* s.l. in combination with the previous intense presence of transitional gephyrocapsid types, suggests an age 1.67-1.70 Ma for the stratigraphic interval between the samples G12/G13, allowing the recognition of MNN19a/MNN19b boundary (RIO *et al,* 1990). Therefore, it is possible to define the Pliocene/Pleistocene boundary at the specific point, based on biostratigraphic events.

The following 2-3m of the sequence, till the unconformity surface suggest the biostratigraphic correlation with MNN19b biozone (RIO *et al,* 1990) and NN19 (MARTINI, 1971), CN13a (OKADA & BUKRY, 1980). As far as planktonic foraminifera are concerned, these biozones can be correlated with the lower parts of *Gl.cariacoensis* zone (CITA, 1975 emend.) and biostratigraphic interval IX (SPAAK, 1983). This points to Lower Pleistocene .

No specific conlusion can be derived about the unconformably overlying sands (base of Depositional Sequence II), except that they are of Pleistocene age, because they lack of micropaleontological data.

Depositional Sequence II

Within the Depositional Sequence II sediments the following nannofossil bioevents can be recognised (Fig.3).:

- First occurrence (FAD) of *Gephyrocapsa* spp>5.5μ (large *Gephyrocapsa*)

- Last occurrence (LAD) of gephyrocapsids >5.5μ which occurs synchronously with a temporary disappearance of normal sized gephyrocapsids.

- Reentry of normal sized *Gephyrocapsa* in association with the first entrance of *Gephyrocapsa* sp3 (medium *Gephyrocapsa* spp with the bridge virtually parallel to the short axis of the placolith).

Concerning planktonic foraminifera, the presence of *Gl.inflata* and sinistral Neogloboquadrinds is obvious throughout the whole section. *Gl. truncatulinoides excelsa* is present at the uppermost part of the section. *Gl.puncticulata* and rare *Gl.margaritae* are sporadically present, mainly at the upper parts of the sequence - probably due to reworking. The benthic foraminifer *Hyalinea balthica* has been observed around 11m above the base of the sequence.

The lowest part of the sequence (nearly 11m from the base) can be correlated (Fig.7) with MNN19c biozone (RIO *et al.*, 1990) or NN19 (MARTINI, 1971) and CN13b (OKADA & BUKRY, 1980) due to the contemporaneous presence of *G.oceanica* sl and absence of the benthic foraminifer *H.balthica*. This species has been proved to be appeared near the FAD of large *Gephyrocapsa* (RAFFI & RIO 1980, RIO *et al* in press). Concerning planktonic foraminifera these biozones can be correlated with *Gl.cariacoensis* biozone (CITA, 1975 emend.) and biostratigraphic interval IX (SPAAK, 1983). Subsequently the interval between the samples Ger3-Ger7 can be assigned to MNN19d biozone (RIO *et al.*, 1990), as *Hyalinea balthica* is now present along with large *Gephyrocapsa* spp >5.5μ. Between samples Ger8-Ger15 the MNN19e biozone can be recognised as normal sized gephyrocapsids are missing. On the other hand the intense presence of the foraminifera *H.balthica* and *Gl.inflata* is remarkable.

Finally the uppermost part of the section -up to the unconformity surface- can be correlated with MNN19f biozone (RIO *et al.*, 1990) - correlated with NN19 (MARTINI, 1971), CN14a (OKADA & BUKRY, 1980) and concerning planktonic foraminifera *Gl. truncatulinoides excelsa* (CITA, 1975 emend.) and biostratigraphic interval IX (SPAAK, 1983) - on the basis of the contemporaneous presence of *Gephyrocapsa* sp3 forms along with the planktonic foraminifer *Gl.truncatulinoides*

The distribution of *H.sellii* and *C.macintyrei* in the Depositional Sequence II requires some discussion. *H.sellii* is found to be in situ till the level of sample Ger8, where it shows a sharp decline, as it occurs simultanuesly with large *Gephyrocapsa* specimens >5.5 μ. On the contrary *C.macintyrei* specimens are reworked throughout the whole section - as they are present uncontinously and in a bad state of preservation - together with reworked representatives of discoasterids, *R.pseudoumbilicus* and *Sphenolithus* spp and planktonic foraminifera *Gl.puncticulata* and *Gl.margaritae*. The possibility that *H.sellii* and *C.macintyrei* are reworked till the top of the section is encouraged also by the fact that they show similar frequency oscillations during that interval.

As far as the unconformabty ovetying calcarenites are concerned (base of Depositional Sequence III) no specific conclusion can be derived , as they lack of micropaleontological data.

PALEOECOLOGY. SURFACE WATER CONDITIONS DURING DEPOSITION OF THE GERAKAS SECTION

Depositional Sequence I

A quantitative analysis has been done for the paleoecological-ecostratigraphical study of depositional Sequence I sediments, concerning the following nannofossil groups: *Discoaster* spp., *Helicosphaera* spp., *Braarudosphaera* spp., *Scyphosphaera* spp and the species *Coccolithus pelagicus*.

The results (Fig.8) can be summarized into:

- Extremely low abundances of genus *Discoaster*
- *Helicosphaera* spp. is observed in high frequences (max>30%) at the upper part of Sequence I. At the lower and the upper part of the Sequence the same group is present with frequences ranging from 5-10%. The genus *Helicosphaera* generally represents relatively warm environments (20-28^{0}C), (ROTH & BERGER, 1975).
- A slight increase (til 1.5%) of *Braarudosphaera* spp. abundance is observed at the upper part of Sequence I, where at the rest part of the sequence this genus is absent.
- The species *C.pelagicus* is ranging throughout the whole sequence with frequences not higher than 5-6%. This species at present has a narrow disjunct distribution. It is found only in the North Atlantic and North Pacific. Its temperature range is 6-14^{0}C and its highest concetrations recorded to date occur between 9 and 12^{0}C (MCINTYRE *et al.*, 1970). *C.pelagicus* is a common species in the Cenozoic fossil record, but it does not show a clear temperature control all along its stratigraphic distribution, as expected (RAFFI & RIO, 1980). According to them just after the *D.brouweri* extinction and just prior the *G.oceanica* s.l. appearance, near the Pliocene/Pleistocene boundary, the abundance of *C.pelagicus* drops out, and in the Early Lower Pleistocene, it completely dissapears
- The presence of small *Gephyrocapsa* spp. is remarkable. These sediments are increasing in size towards the uppermost part of Sequence I
- *G.oceanica* s.l. which is found at the uppermost part of Sequence I, increasing gradually in size, is a species common in low nutritient content warm waters (temperature higher than 27^{0}C), (ROTH & COULBOURN, 1982). It prefers marginal seas with normal - high salinity (OKADA & HONJO, 1975) with maximum resistance 45-51$^0/_{00}$ (WINTER, 1982). Generally gephyrocapsids characterise transitional nannoplankton associations at the Atlantic ocean (MCINTYRE & BE 1967, OKADA & MCINTYRE 1979).

According to the above mentioned data the interval around the Plio/Pleistocene boundary can be characterised as a medium cold period of the Eastern Mediterranean surface waters, with increase of the primary producitvity elements (absence of discoasters, intense presence of small *Gephyrocapsa* spp. and *Gl.inflata*). However the increased content in helicoliths suggests upwelling conditions and higher temperatures. Additionaly the presence of *Braarudosphaera* specimens represents an indication of relatively low salinity coastal environments. Finally the presence of *G.oceanica* s.l. at the uppermost part of the sequence, which refers to the base of the Pleistocene, suggests higher surface water temperatures. According to DRIEVER (1988) the base of the Pleistocene at the typical Vrica section is placed in a relative warm interval, between two cold events.

Subsequently, we can resume that the surface water conditions during the uppermost Piacenzian/lowermost Pleistocene at Zakynthos island show a cold medium character with a tendency to higher temperatures.

Depositional Sequence II

The following nannofossil groups have been studied for the paleoenvironmental study of Depositional Sequence II sediments: *Helicosphaera* spp., *Braarudosphaera* spp. and the species *C.pelagicus*.

The results (Fig.9) can be summarised into the following:

- Helicolith abundances are increasing towards the upper parts of the sequence with max>15%.
- Specimens of *Braarudosphaera* spp. are present from the middle till the upper part of the sequence with frequences around 2%.
- The species *C.pelagicus* is present with relatively low frequences especially at the lower part of the sequence. This species is practically absent from the lowest Pleistocene and most of the middle Pleistocene, represented only by few reworked specimens (RAFFI & RIO, 1980). Although cold conditions were prevailing during most of the middle Pleistocene, *C.pelagicus* did not reappeared in the Mediterranean, probably due to paleobiographical thermal barriers or other factors (GARD, 1989).
- The presence of small *Gephyrocapsa* spp. is remarkable. Small gephyrocapsids are abundant in waters of high productivity (GARTNER *et al.* 1983, 1987).
- There is an absence of normal sized gephyrocapsids at the middle part of the sequence. During the interval of small *Gephyrocapsa* dominance, the water temperature at the euphotic zone was probably lower than today (15-20^0 C) and the nutrient content was two or three times higher (GARTNER, 1988).

Subsequently the lower part of Depositional Sequence II represents relatively warm waters (low abundance of *C.pelagicus*, presence of *Gl.inflata* and large gephyrocapsids, which characterise high productivity warm waters, GARTNER *et al.* 1983, 1987). At the middle-upper part of the Sequence there is evidence of surface waters temperature decrease (presence of small gephyrocapsids, *H.balthica*). The reappearance of normal sized gephyrocapsids at the upper parts of the Sequence suggests a slight temperature increase, as the presence of *C.pelagicus* specimens can be due to reworking. Finally it must be noted that the intense presence of *Braarudosphaera* spp. may suggest relatively shallow depositional environment.

CONCLUSIONS

The biostratigraphic and paleoecological analysis of the marly deposits of Depositional Sequences I,II of Gerakas Section (SE Zakynthos) lead to the following conclusions:

- The lower part of depositional Sequence I can be assigned to MNN19a biozone (RIO *et al.*, 1990). The first appearance of *Gephyrocapsa oceanica* s.l. specimens -at about 36m from the base of the Sequence- allows at the specific point the definition of the Pliocene/Pleistocene boundary, based on biostratigraphic events. The uppermost part of Depositional Sequence I can be correlated with MNN19b biozone. The derived data point to uppermost Pliocene/ lowermost Pleistocene.
- The following biozones can be recognised at the sediments of Depositional Sequence II: MNN19c, MNN19d, MNN19e, MNN19f (RIO *et al.*, 1990). This points to lower Pleistocene.
- During uppermost Piacenzian/ earliest Pleistocene the paleoecological data considering surface water conditions suggest cold-medium character waters with a tendecy to higher temperatures.
- For the interval of the lower Pleistocne the surface water conditions suggest low productivity relatively warm waters, showing a decrease and then again an increase of temperature, in a shallow coastal environment.

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