DEPENDENCE OF LATE QUATERNARY COCCOLITH ASSOCIATIONS TO THE IMPACT OF CLIMATIC CHANGES: PRELIMINARY REPORT FROM THE IONIAN SEA.

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ABSTRACT

The impact of climatic fluctuations on the marine Mediterranean paleoenvironment (paleoproductivity, deep water formations) during the late Quaternary is herein quantified utilizing coccolith associations of the piston corer M25/4-KL13, located in the Ionian Sea between southern Italy and Greece and consisting of the "heavy" and "light" groups (enriched or diminished in ^{18}O relative to equilibrium respectively). The former group includes species as *Emiliania huxleyi*, *Gephyrocapsa caribbeanica*, *G. oceanica* and small gephyrocapsids dominated by *G. ericsonii* and *G. muellerae*, while the latter group includes the *Calcidiscus leptoporus*, *Helicosphaera carteri* var. *carteri*, *H. carteri* var. *wallichii*, *H. hyalina*, *Syracosphaera pulchra* and *Umbilicosphaera sibogae*. The investigated sediments reach down up to isotope stage 9 (about 330 ka) and include the sapropel formations S1 to S10. Data interpretation suggests the existence of eight climatic related intervals (coded I-VIII) along the core.

KEY WORDS: Calcareous nannofossils, Coccoliths, Late Quaternary, paleoclimatology, palaeoecology, Ionian Sea.

INTRODUCTION

Oxygen or carbon isotope equilibrium with ambient water is rarely recorded in biogenic carbonate precipitation. Some physiological control is usually imposed by the organism. The magnitude of this "vital effect" is different for each group of organism and often for each different species within a group (Hemleben et al. 1989). Isotopic variations within the oceans mainly occur due to the interaction with the hydrologic cycle (evaporation, precipitation, runoff), freezing effects and the mixing of water masses. The "glacial effect" resulting from the preferential removal of ^{16}O from the ocean during glacial episodes and its deposition as isotopically light ice on land, has a marked effect on the oxygen isotopic composition of the world ocean (Anderson and Arthur 1983). The impetus to examine the stable isotopic composition of calcareous marine microfossils originally derives from the classic paper of Emiliani (1955). Due to the fact that "Coccoliths are good indicators for palaeoenvironmental change" and their utility has been successfully applied in the Alboran Sea, western Mediterranean Sea (Weaver and Pujol 1988), in the present work it was attempted for the first time determination of the eastern Mediterranean Sea surface temperature fluctuations of the Late Quaternary, utilizing quantified coccolith associations calibrated to the isotopic record of the planktonic foraminifer *Globigerina bulloides* (Schmiedl et al. 1998). Moreover, as it was very recently delineated by Negri & Giunta (2001), though nannofossils are very useful paleoceanographic tools, papers related to their study under a paleoenvironmental view are relatively rare.

For that purpose, material of the piston corer M25/4-KL13 has been examined both in smear-slides under the light microscope and in SEM). The core has a 11,20m length and was recovered at a water depth of 2,533m from the Ionian Sea. Its location is situated between the central and eastern Mediterranean Sea (position 37°33,2′ N, 17°49,2′ E –Calabrian Rise) (fig. 1). Detailed sampling was made spaced at 10cm intervals in average. After determination of the foraminifera, a stable isotopic curve for the *Globigerina bulloides* was constructed. Isotope measurements have been completed at the Univ. of Bremen, Faculty of Geosciences (Dr. M. Segl in Schmiedl et al. 1998). The sediment core was then stratigraphically compared through the graphical correlation method of the ^{18}O-curve with the SPECMAP –standard isotope curve (Imbrie et al. 1984). Accordingly, the examined core reaches down from isotope stage 1 until stage 9 (with an age of 330ka approximately) and includes the sapropel formations S1 to S10 (fig. 2). Exceptionally light values of ^{13}C and ^{18}O were determined in

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foraminifera tests at the stratigraphic levels of the sapropel layers (SCHMIEDL et al., 1998). These records are probably related to an intensive input of fresh water masses (THUNELL and WILLIAMS 1989, ROHLING and HILGEN 1991, VERGNAUD-GRAZZINI and PIERRE 1991, TANG and STOTT 1993, AKSU et al., 1995, GERAGA et al., 2000).

The so-called ”heavy” group of coccoliths consisting of *Emiliania huxleyi*, *Gephyrocapsa oceanica* and small *Gephyrocapsa* spp. is proved to be about 1‰ heavy (enriched in ^{18}O relative to equalibrium) and reflects a significant temperature dependence of the selected species in oxygen isotopic composition. The relationship between temperature and isotopic composition of the three prementioned taxa was similar and with no significant differences among them at warmer temperatures (STEINMETZ 1994).

Main goal of the present paper, is to identify the ”heavy” and ”light” groups of the calcareous nannofossils outlined above and to apply and connect their compositional alternations along the core sediments, in relation to oxygen isotope stratigraphy and simultaneously to the known isotope stages. This is made in order, a) to recognize how climatic changes affected the coccolith associations the last 330ka in the eastern Mediterranean and b) to investigate if, utilizing the latter quantification, it is realizable to establish climatic intervals/zones representative for these changes. Nannofossil analyses were primarily performed on the piston core M25/4, Station KL13.

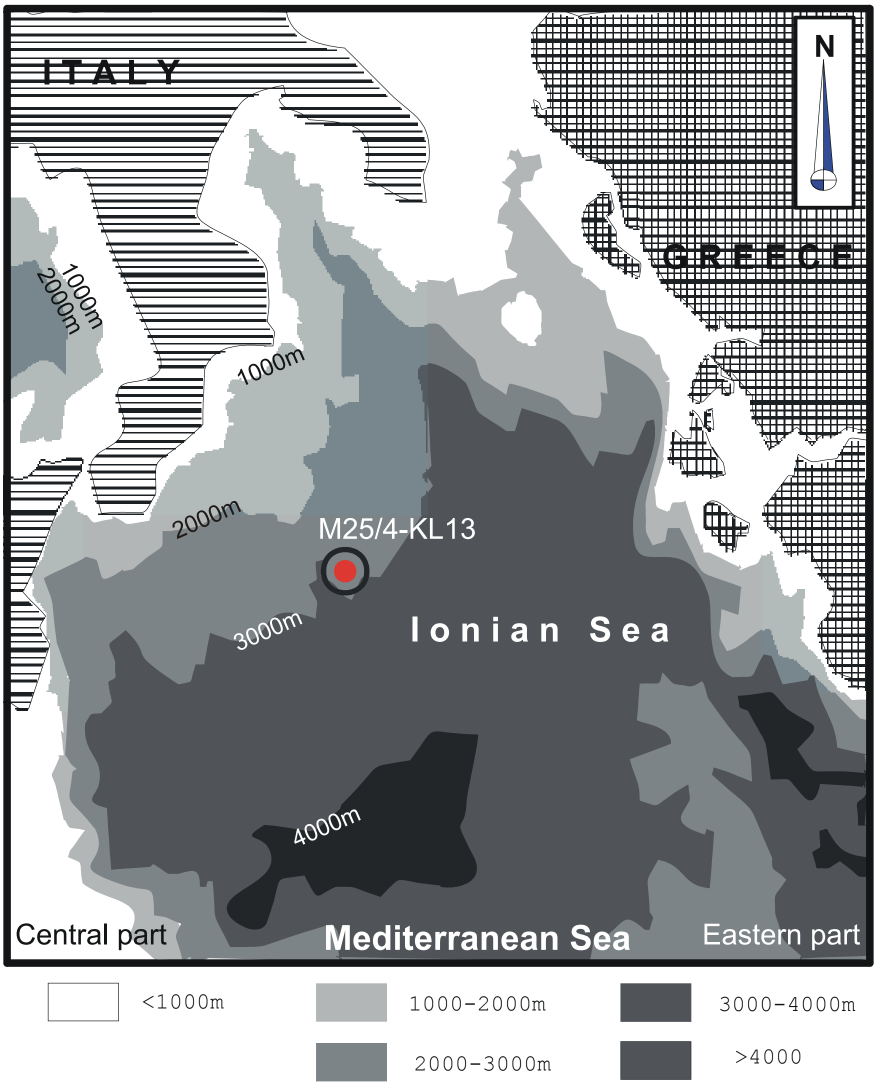

Figure 1. Location of the studied piston core M25/4, Station KL13 in the Ionian Sea (between southern Italy and Greece). It was recovered by the R/V METEOR in January 1998. Paleobathymetry is given in 1000 of meters and it is indicated by the scale in grey-colour grade.

COCCOLITH ASSOCIATIONS AND PALAEOCLIMATE

According to the quantification of paleoecologically important recorded species in the different coccolith asssociations and their correlation and calibration to the known isotope stages 1 to 9 (by means of oxygen isotope stratigraphy adopted from the *Globigerina bulloides* d^{18}O data), eight climatic-related zones were distinguished dated from Late Quaternary to Recent along the investigated piston core sediments (see right part of fig. 2: coded I to VIII). These zonal boundaries or intervals are defined by: a) dominance, b) first appearance, c) recurrences (or re-occurrences) of species, and d) in dominance between two closely related species. Such criteria used to define datum levels are well known to biostratigraphers. A datum defined on the basis of a change in dominance of two coccolith species was firstly reported by THIERSTEIN et al. (1977). The use of a recurrence, falls in the same category of bioevents as changes in coiling direction which are for long broadly and successfully applicated in planktonic foraminifera. The rational for using the reappearance of a species as a useful datum level follows the fact, that within each recurrence interval, the composition of the nannofloral associations is always somewhat different. Thus, for example, the recurrence of *G. oceanica* in the upper part of the isotope stage 7 (at ca. 210ka) which corresponds to the climatic zone VII of the present work, can be differentiated from the occurrence of the same species situated just below the first appearance of *E. huxleyi* (at ca. 270ka), because the former coexists with *Helicosphaera carteri* (WALLICH) KAMPTNER var. *carteri* emend. THEODORIDIS, *Helicosphaera hyalina* GAARDER and *Helicosphaera carteri* var. *wallichii* (LOHMANN) BOUDREAUX & HAY emend. THEODORIDIS, while the latter occurs together with small *Gephyrocapsa* spp. These data for each zone are referred in the text-summary explanation of figure 2.

Given the above considerations, quantification of the calcareous nannoflora along the studied core, permitted establishment of eight coccolith associations and correspondent calcareous nannofossil bioevents in relation to the isotope stages 1 to 9. Each of them is interpreted to represent a climatic-related zone or interval. The eight associations are identified and described as follows below (in the order of youngest to oldest):

1) Dominance of *E. huxleyi* with a participation of more than 20% in abundance until isotope substage 1,1 (core interval 0-46cm, warm climatic zone I);

2) Less than 20% of *E. huxleyi* from the isotope substage 1,1 up to the substage 3,1, which corresponds to the core interval from 46 to 102cm (cold climatic zone II);

3) A significant increase in the abundances of the warm surface-water species *Calcidiscus leptoporus* and helicosphaerids like *H. carteri* var. *carteri*, *H. hyalina* and *H. carteri* var. *wallichii* is observed between the 3,1 and 3,3 isotope substages, core material interval of 102 to 222cm (warm climatic zone III). Isotope stages 1 and 3 are considered interglacial intervals, whereas isotope stage 2 is a glacial one;

4) A change in dominance between *E. huxleyi* and *Gephyrocapsa muellerae* BOUDREAUX & HAY, a cold water species, was observed below the isotope substage 3,3 (core sample 25, situated at 298cm depth). An age estimation for this bioevent can place it at about 75ka (relative to the left column of fig. 2). The climatic zone IV corresponds to the interval from 222 to 322cm (cold zone). Isotope stage 4 is considered a glacial interval. Climatic zones I to IV correspond to the subzone MNN21b (Acme of *Emiliania huxleyi*) of RIO et al. (1990) approximately. Biostratigraphic assignments of the later authors were based on study of DSDP (Site 132) and ODP (Sites 652 and 653) cores recovered from the Tyrrhenian Sea in western Mediterranean Sea.

5) Recurrence of *E. huxleyi* below the isotope substage 5,2 together with the "light" group of coccoliths such as *C. leptoporus*, *H. carteri*, *Syracosphaera pulchra*. It lasts up to the isotope substage 5,5 and corresponds to the core stratigraphic interval between 322 and 511cm (warm climatic zone V). Isotope stage 5 is an interglacial interval. If one considers the rich in siliceous microfossils (including diatoms and radiolarians) sapropel layer S5 from the eastern Mediterranean sites 969 and 971 (co. DANELIAN and FRYDAS 1998, ODP Leg 160), this could be equivalent to the lower part of the present core interval (relative to isotope substage 5,5) with an estimated age of 125ka approximately;

6) Dominance of small *Gephyrocapsa* spp. like *G. muellerae* and *Gephyrocapsa ericsonii* below isotope substage 5,5. It lasts up to the isotope substage 7,1 (compare end of dominance for the small *Gephyrocapsa* spp. in fig. 2). This bioevent represents the core interval between 511 and 720cm (cold climatic zone VI). This zone corresponds to the isotope stage 6 and partly to stage 7. Isotope stage 6 is considered a glacial interval.

7) A recurrence of *Gephyrocapsa oceanica* KAMPTNER with helicosphaerids starts from isotope substage 7,2 and continuous downcore up to the first occurrence (FO) of *E. huxleyi* at approximately 266ka (sample 86: 987 to 988cm). It is located directly above the isotope substage 8,4. This nannofossil association is representative of the interval between 720 and 987cm and the correspondent warm climatic zone VII is partly related to the isotope stage 7, an interglacial interval. The lowermost part of the zone VII correlates with the upper part of isotope stage 8, considered a glacial interval. Therefore, the FO of *E. huxleyi* is to be found within the latter interval. Biostratigraphically, the climatic zones V to VII broadly correspond to the MNN21a subzone (*Emiliania huxleyi*) of Rio et al. (1990).

8) Finally, a dominance of *G. oceanica* together with small *Gephyrocapsa* spp. is observed. It starts directly below the isotope substage 8,4 and is running further down to the upper part of the isotope stage 9. This association record corresponds to the core stratigraphic interval from 927 to 1120cm depth (base of the core) and represents the deepest presently established cold climatic zone VIII. Considering a biostratigraphic interpretation within the Mediterranean area, this interval corresponds to the biozone MNN20 (*Gephyrocapsa oceanica*) of RIO et al. (1990).

RESULTS AND DISCUSSION

Summarizing, the investigated core-material spans a period of sedimentation of 330ka approximately. Biostratigraphy utilizing the calcareous nannofossils and their associated events proves the presence of three subzones, namely the MNN20 (refered to the climatic zones I to IV), MNN21a (includes the climatic zones V to VII) and MNN21b (represented partly by the climatic zone VIII to the core bottm), according to the scheme of RIO et al. (1990) established from data of the Tyrrhenean Sea in western Mediterranean.

The "heavy" group of coccoliths consisting of an association with *E. huxleyi* and *Gephyrocapsa caribbeanica* shows a preferential occurrence in the glacial stages 2 and 4 with moderate fluctuations in frequency, while the small *Gephyrocapsa* spp. association with *G. muellerae* and *G. ericsonii* predominantly, appears with a significant participation frequency in the glacial stage 6 (our climatic zone VI). The abundance ratio of *G. oceanica* to *G. muellerae* is thought to give a good estimation relative to paleotemperature, with higher values of *G. muellerae* indicating lower temperatures (co. WEAVER and PUJOL 1988). The *G. oceanica* association occurs solely with strong fluctuations with depth, in both interglacial and glacial stages (dominant in the isotope stages 7 and 8, less frequent in stage 2 of the latest Pleistocene; fig. 2). Higher frequencies of this species in the glacial stages 8 and 2, could be interpreted as to relative increase of temperature (fluctuations) within the same glacial isotope stage.

The so-called "light" group of coccoliths (STEINMETZ 1994) consisting of nannofloral associations like *C. leptoporus*, various helicosphaerids, *S. pulchra* and *Umbilicosphaera sibogae* has a maximum in appearance in the interglacial isotope stages 3 and 5 (fig. 2: warm climatic zones III and V). Studies from the European North Sea have shown that *S. pulchra* and *H. carteri* are species with occurrences within interglacial periods (BAUMANN 1990). Recent data on the composition, distribution and seasonal variation of coccolithophore communities from the north Atlantic (45° to 75° N), although latitudinally not directly related to the present study area (Mediterranean, 37° N), have also included *C. leptoporus* and *S. pulchra* in the same "North Atlantic group", while *G. muellerae* was placed in the "Norwegian Sea group", the latter correlated to colder water temperatures than the former group (SAMTLEBEN et al. 1995).

Present results are in well agreement with data from the existing paleo-ceanographical researches based on foraminifera. They show that the variations in climate during the Late Quaternary to Recent time in the whole Mediterranean are distinctly reflected in the bio- and fossil-content of the sediments, particularly in the organic rich, sapropel formations S1 to S9 (AKSU et al., 1995; HEMLEBEN et al. 1999). Further, the impact of thermohaline circulation and its role in controlling production and oxygenation of deep waters in the eastern Mediterranean Sea, producing formation of sapropels was recently introduced by a new model of STRATFORD et al. (2000). Such or similar fluctuations related probably to re-circulation or periodical circulation can be reconstructed and back-traced through the determination, quantification of the participated species and the stable isotope composition of benthic and planktonic foraminifera as well as that of the coccolith flora.

The diversity of benthic foraminifera for example is marked through extreme fluctuations which are in relation to the 23,000 years precession cycle and it is going back on zero values in the sapropel layers. This probably explains the

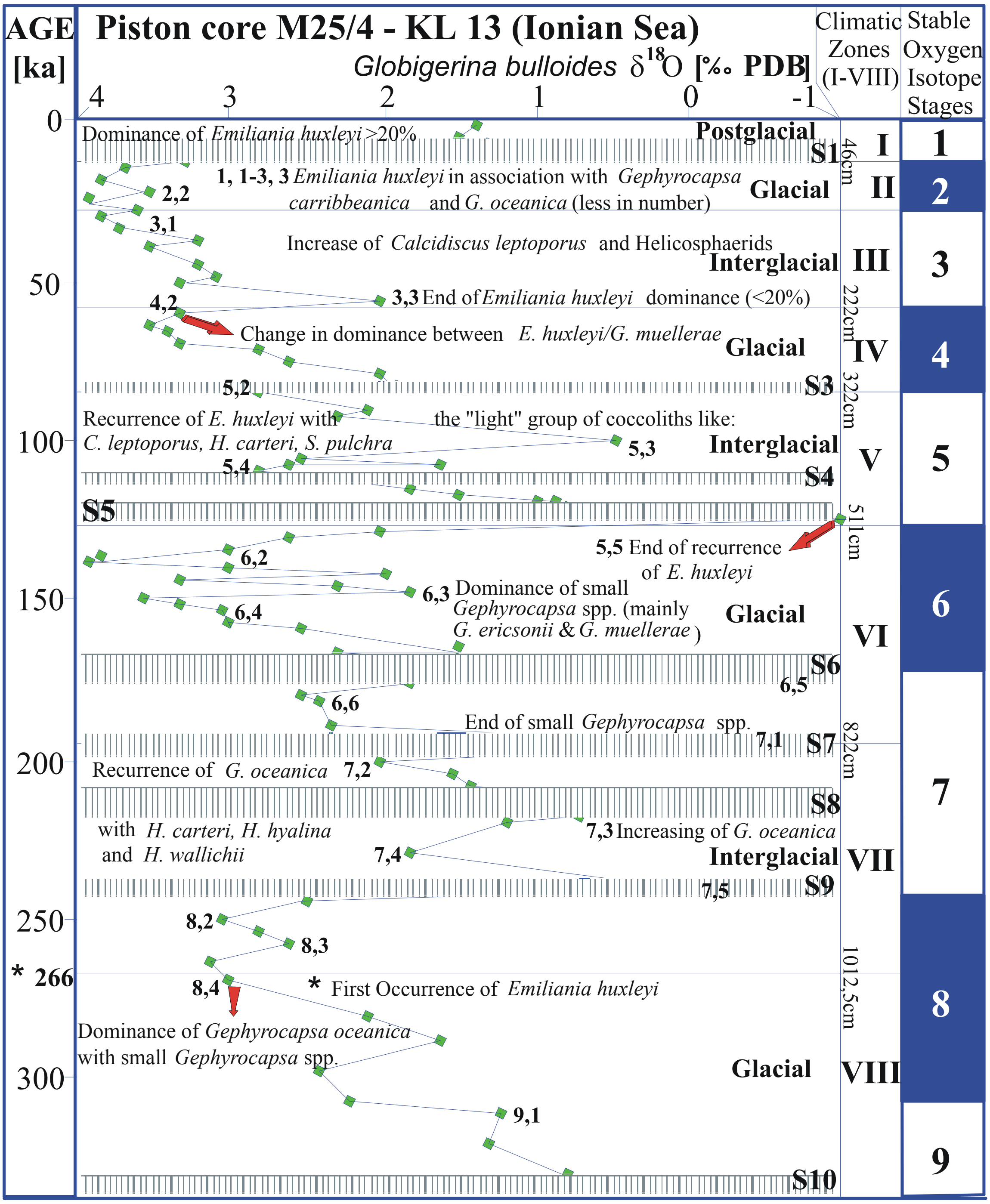

Figure 2. The eight coccolith associations presently recognized (organized in alternations of events based on the "light" and "heavy" groups schema), each indicating a climatic zone interval (labeled I to VIII). Zones I, III, V and VII are generally indicative of warm, interglacial periods ("light" group of coccolith flora), while, zones II, IV, VI & VIII are indicative of cold or glacial periods ("heavy" group of coccolith flora). Calibration of the bioevents was made relative to the stable oxygen isotope stages (OIS) 1 to 9. Calcareous nannofossil data are plotted against $\delta^{18}O$ values of *Gl. bulloides* curve obtained by SCHMIEDL et al., (1998). The left column shows absolute age estimations (the bottom-core dates to 330kyrs). Numbers in bold delineate isotope substages (e.g. 1,1; 3,3;etc.). Star in bold points to the *E. huxleyi* FO (OIS 8, climatic zone VIII to VII: 266ka). Note the heavy arrows indicating significant changes in the composition of the coccolith associations (dominances of species, etc.). S1 to S10 refer to the recorded sapropel formations included in the investigated core material. Numbers included in the column of the climatic zones represent thicknesses of the core (in cm); Total recovered core thickness is 1,120cm.

recent poverty of species and individual fauna in the abyssal part of the Ionian Sea (MULLINEAUX and LOHMANN 1981, ROSSIGNOL-STRICK et al. 1982, CASTRADORI 1993, ROSSIGNOL-STRICK 1995, CHEDDARDI and ROSSIGNOL-STRICK 1995).

Like in the foraminifera mentioned above, in our study the most extreme environmental conditions occur during times of sapropel formation as well, when coccolith diversities markedly decrease and become very low in number or even the whole calcareous nannoflora seems to disappear. Such negative fluctuations in the abundance of calcareous nannofossils were also reported for the S1 stratigraphic level of the eastern Ionian Sea by NEGRI & GIUNTA (2001). In contrast to the benthic foraminifera fauna recovered from the present core (in SCHMIEDL et al. 1998), where the diversities remained very low some thousand years after cessation of anoxic conditions (directly above sapropels S5 and S1), the coccolith associations seem to "recolonize" this area within a short time interval before or after sapropel formation. It is also important to note, that within sapropel S6, being considered a composite multi-layer formation predominantly characterizing glacial conditions, a high participation of the dissolution-resistant helicosphaerid-group was observed, although they usually represent the ”light” group of calcareous nannofossils. But this fact is probably according to the situation of sapropel S6 (at least of the basal part of it), at the isotope stages 6 to 7 boundary approximately, thus, making possible physical components supply of either glacial or interglacial origin, depending on the sapropel sublayer.

Furthermore, two questions are raised through the present study: Firstly, if the climatic fluctuations described herein are isochronous over the broad area of eastern Mediterranean or at least in the Ionian Sea, and secondly to what degree does climate, as reflected in the oxygen and carbon isotope record, arbitrate the first and last appearance events of individual coccolith species? Such variations in the climatic and oceanographic conditions during deposition of the first, younger sapropel layer S1 have been also suggested for the Aegean Sea by GERAGA et al. (2000). Further, within the Late Pleistocene, the oxygen isotope record is considered a high precision correlation tool and allows for fine resolution in the order of ±2000 years (THIERSTEIN et al. 1977). Therefore, it is of paricular interest a correlation of this record with the calcareous nannofossil signal under the present approach of establishing climatic intervals or zones.

Additionally, in order a) to better understand and avaluate the changes in the central-eastern Mediterranean Sea past water-masses circulation and paleoceanography and b) to test the accuracy of significant bioevents or boundaries of climatic zones established relative to coccolith associations, current biostratigraphic and paleoecologic research is at the moment undertaken including study of three new piston cores recovered from the adjacent area of the Ionian Sea and south of Crete island.

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