DISTRIBUTION OF CALCAREOUS NANNOFOSSILS IN THE SAPROPEL LAYERS OF HOLE 69-2SL, *METEOR* CRUISE 40/4, EASTERN MEDITERRANEAN SEA

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Abstract: Calcareous nannoplankton associations from the sapropel layers of the gravity core M40/4, Station 69-2L, south-eastern Mediterranean Sea, have been examined. The investigated core mainly consists of nannofossil-/foraminifera-bearing mud, sapropel layers S1 to S5/6 (except S2), and tephra layers. A subtropical coccolith association was recognised in sapropels S1, S4, S5, S5/6, while a temperate one characterises S3. A reversal in dominance between *Gephyrocapsa muellerae* and *Emiliania huxleyi* was observed in sapropel S3 at 256cm subdepth. A significantly lower coccolith diversity was observed in the sapropel and tephra layers themselves, as in the foraminiferal mud, probably because of the influence of anoxic conditions, including bacterial activity, or ash-falls on the coccolith assemblages. In addition, a moderate to intensive corrosion characterises the nannofossils in the bioturbated upper part of some sapropels.

Introduction

The Mediterranean Sea is a marginal basin that is almost entirely surrounded by continents. Therefore, both hydrography and sedimentation processes are controlled by the regional climate and topography of the adjacent land-masses. High evaporation rates and deep winter convection initiate the formation of warm and oxygen–rich deep and intermediate water-masses in the southern Adriatic Sea, the Levantine Sea, the south-western Aegean Sea and the northwestern Mediterranean Sea (Pickard & Emery, 1990). The primary production in the surface-water that controls the flux of organic matter to the sea-floor exhibits a strong seasonal and spatial variability. While primary productivity rates are generally low from summer through winter, deep convection of the water-column and nutrient input by rivers cause a pronounced increase in phytoplankton activity during spring, particularly along the coastal areas (Amone, 1994). The deep parts of the eastern Mediterranean can presently be regarded as a food-limited environment, and exhibit oligotrophic and well-oxygenated conditions (Miller *et al.*, 1970; Pickard & Emery, 1990).

One of the main sedimentological characteristics of the eastern Mediterranean is the cyclic deposition of sapropels that point to drastic changes in the marine environment. Previous studies on the origin of these anoxic events discuss both severe decrease in the ventilation of the subsurface waters (Thunell & Williams, 1989; Rossignol-Strick *et al.*, 1982; Fontugne *et al.*, 1989; Thunell *et al.*, 1983; Tang & Stott, 1993) and increased palaeoproductivity, followed by high organic-carbon flux rates to the sea-floor (Castradori, 1993; Sancetta, 1994). A temporal correlation has been observed between the accumulation of sapropels and the precessional cycle of Earth's orbit (Schmiedl *et al* ., 1998). Furthermore, a link has been established between the sapropels and: (1)

intensifications of the Asia-Africa transverse monsoons (Rossignol-Strick, 1985; Kleijne, 1990); and (2) increased activity of Mediterranean depressions followed by enhanced humidity in the northern borderlands of the eastern Mediterranean (Rohling, 1994, 1999; Rohling & Gieskes, 1989). Geochemical evidence indicates that sapropel formation has been promoted either by increased productivity (Calvert *et al.*, 1992; Howell & Thunell, 1992) or by a model combining both higher productivity and better preservation persisting during precession minima (Nijenhuis *et al.*, 2001).

The Late Quaternary climate of the Mediterranean region is generally characterised by humid interglacials accompanied by low $?^{18}O$ values, and arid glacials defined by high $?^{18}O$ values (Rossignol-Strick, 1985; Vergnaud-Grazzini *et al.*, 1977, 1986). Schmiedl *et al.* (1998) reported changes in the benthic foraminifera fauna of the Ionian Sea in the last 330kyr, while Aksu *et al.* (1995a, b) and Geraga *et al.* (2000) evaluated various microfossil data from short cores of the Aegean Sea for palaeoenvironmental changes in the last 18kyr (including only sapropel S1). Phytoplankton associations concerning the geographic, as well as stratigraphic, distribution of Holocene to Upper Pliocene coccoliths, silicoflagellates and diatoms in the eastern Mediterranean area were reported by Schrader & Matherne (1981), Danelian & Frydas (1998), Pearce *et al.* (1998), Frydas (1999), Negri *et al.* (1999) and Negri & Giunta (2001).

In this paper, we mainly report on the calcareous nannofloral content of five successive sapropel layers, S1, S3, S4, S5 and S5/6, from a gravity-core in the eastern Mediterranean Sea. Both a quantitative study of selectively important species through the core, and a semiquantitative presentation of the whole assemblages in each sapropel, have been performed. Based on this diversity data, and correlations between the individual sapropels, specific
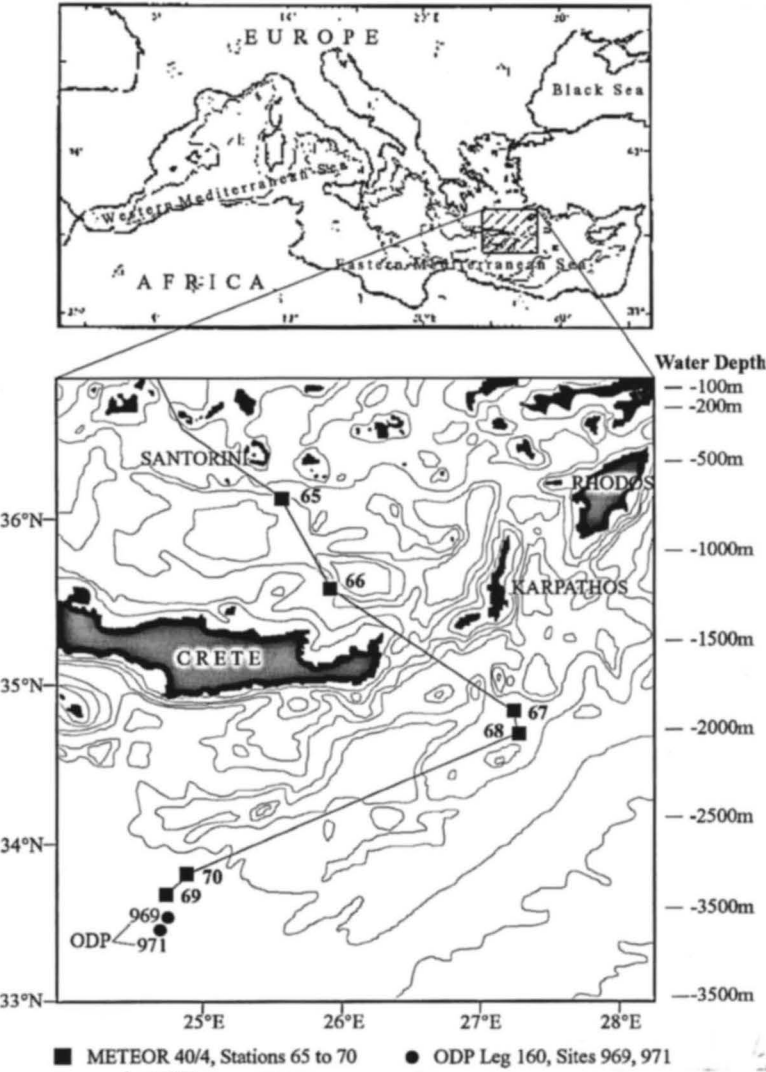
Figure 1: Bathymetric map of the eastern Mediterranean Sea, with location of the core site, M40/4-69, S of Crete Island, and regional map of the Mediterranean Sea and investigated area in the inlet

Several dark grey to brown-brownish yellow tephra interlayers were observed as well.

A total of 63 samples were analysed for calcareous nannofossils. At least 300 coccoliths were identified per sample, using a Leitz DIALUX 20 EB photomicroscope at a magnification of 1250x (normal and polarised light). The development of the eight most important species abundances through the studied core is presented in Figure 3. Preparation of smear-slides for light-microscope examination followed standard procedures (Bown & Young, 1998). Additionally, several samples of the sapropel layers were examined at the Free University of Berlin, Institute of Palaeontology, under a Cambridge Instruments scanning electron microscope (SEM: Plate 1) to facilitate fine taxonomic identifications. Generally, all of the nannofloral assemblages are moderately to well preserved. *Emiliania huxleyi* preservation seems to suffer most, or alternatively the ultrastructure could be more delicate and more easily corroded than that of the other species, as it is shown in Plate 1 (Figures 11 and 12). All the studied smear-slides (SMR), as well as the negatives (NG), are stored in the Laboratory of Micropalaeontology, University of Patras (Series *Meteor* 40/4, SMR-1998/1 to -63, NG-SMR-1998/1 to -6, x36).

Below (Table 1) is the identification scheme used for differentiating between the various gephyrocapsids, based on morphometric measurement of various parameters.

distributions related to sapropel level, as well as quantitative differences between the assemblages from sapropel and non-sapropel sediments, are described. It is postulated that such variabilities are most probably related to palaeoecological and palaeoceanographic circulation changes during the Late Pleistocene to Recent.

Material and methods

The gravity core, 69-2SL, logged on board the research vessel *Meteor* (Federal Republic Germany), was recovered from the Levantine Basin (eastern Mediterranean Sea) and deposited at the University of Tübingen, Institute of Palaeontology. The site of Core 69-2SL is located at 33°51.57'N, 24°41.45'E, at a present water-depth of 2154m (Figure 1). Sampling took place at 5cm intervals through the sapropel formations and at 10cm intervals (approximately) through the grey-yellowish to brownish-grey, nannoplankton- and foraminiferal-pteropod-bearing muds, which are moderately bioturbated in their upper parts (Figure 2). The most significant characteristic of this core are here considered to be the easily-recognisable sapropel formations, S1, S3, S4, S5 and S5/6 (Hemleben *et al.*, 1999).

Species	Angle (a°)	Length (μm)	B/L (%)	P/L (%)
G. caribbeanica	45	4.0	88	46
G. ericsonii	26	2.7	76	54
G. margerelii	39	2.2	73	58
G. muellerae	24	3.6	75	51
G. oceanica	54	3.9	83	42

Table 1: Mean values of the measured morphological elements of the gephyrocapsids: a° = bridge angle; Length of coccolith; B/L = relative roundness = B/Lx100 (B = coccolith breadth; L = coccolith length); P/L = relative pore width = P/Lx100, (P = pore size)

Stratigraphic framework

Sapropel layers represent a first-class stratigraphic tool for the interval covered by the studied core and, moreover, for intra-Mediterranean correlations. According to recent high-resolution data from the adjacent Ionian Sea, published by Schmiedl *et al.* (1998), the following age-assignments have been made for the recovered sapropels (kyr BP): 78 to 80kyr for S3, 105 to 108kyr for S4, 119 to 124kyr for S5 (at *c.*520-540cm depth), and 163 to 167kyr for the upper (younger) part of S6, which was located at *c.*770cm core-depth. Since our S5 sapropel is placed at a
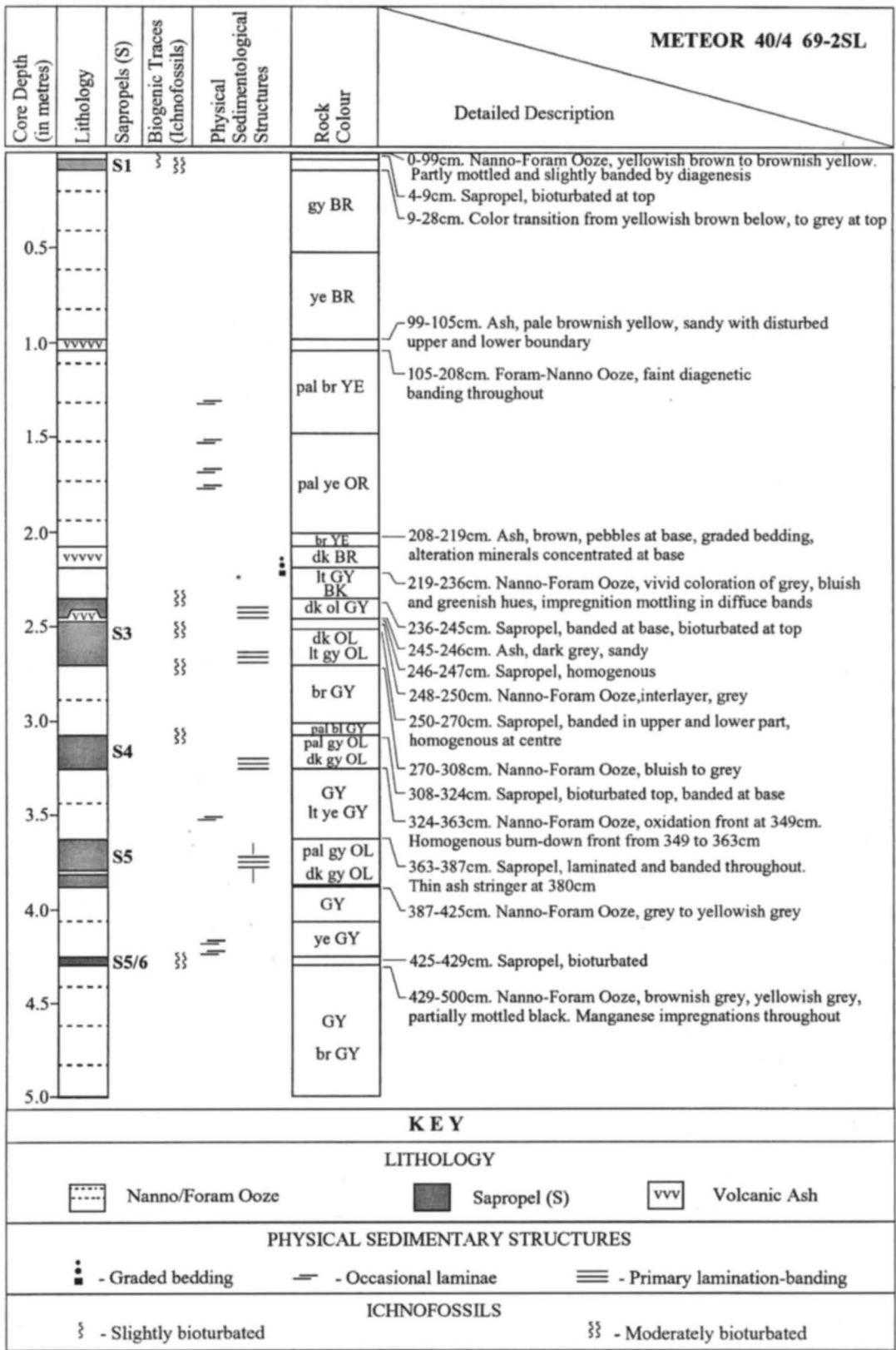
Figure 2: Lithology, sedimentary structures and stratigraphy of the studied gravity-core, 2SL (Station 69), from the SE Mediterranean Sea

depth of between 363 and 387cm, it is obvious that much lower sedimentation rates (3.00 to 3.35cm/kyr) dominated in our core location compared to those in Core M25/4-KL13 of Schmiedl *et al.* (1998).

In a biostratigraphic context, a few to common occurrence of *E. huxleyi* places the assemblage in the homonymous zone, NN21, of Martini (1971) and CN15 of Okada & Bukry (1980). The high abundance of *E. huxleyi* (>20%) in the upper part of the core (above 52cm) makes an assignment of this core-interval (0 to 52cm) to the *E. huxleyi* Acme Subzone, coded MNN21b by Rio *et al.* (1990), possible. The lower core interval (53 to 500cm), with
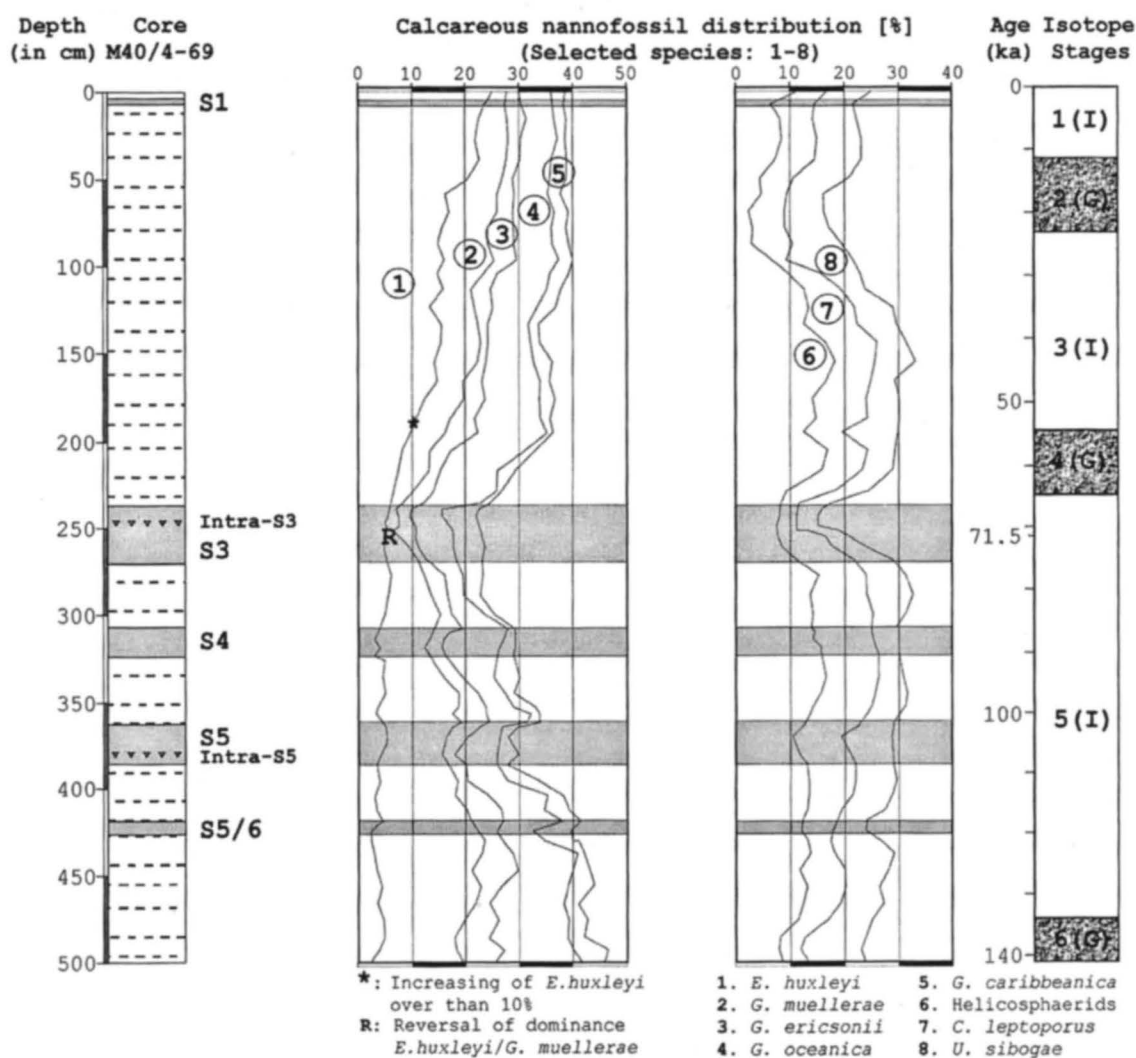
Figure 3: Quantitative percentage cumulative distribution of the eight most important calcareous nannofossil species. *Left*: Core 69-2SL, *Meteor* Cruise M40/4, Station 69, S of eastern Crete; *right*: correlation to Isotope Stages 1 to 6

predominating *Gephyrocapsa oceanica, Gephyrocapsa muellerae* and fewer *E. huxleyi*, is simply referred to as the *E. huxleyi* Zone (MNN21a).

Results

After the morphometrical analysis of 300 gephyrocapsid specimens under the SEM, two groups of small coccolith associations could be determined (work in preparation, see Table 1, above): (1) coccoliths that have a mean bridge-angle of 26° and 24° and a mean length of 2.7 and 3.6μm. *Gephyrocapsa ericsonii* and *G. muellerae*, belong to this group, respectively. They correspond to the transitional to sub-Arctic associations of Bollmann (1997); (2) coccoliths with a mean bridge-angle of 45° and 54°, and a mean length of about 4.0μm. This group includes large gephyrocapsids, such as *Gephyrocapsa caribbeanica* and *G. oceanica*, and corresponds to Bollmann's (1997) subtropical coccolith association.

Moving downcore, from the top of the core (0cm) to the sample at 251cm, the main components of the nannofloras in S1 and S3 are *E. huxleyi* and *G. oceanica* together with various helicosphaerids, *Calcidiscus*

leptoporus and *Umbilicosphaera sibogae* found as free coccoliths (see Table 2, Figure 3). In general, the specimens of *E. huxleyi* in this interval belong to the genotype variation C of Young & Westbroek (1991). A small overall and central-area size, and a delicate appearance of the distal-shield elements, generally characterise variety C. The central-area elements may be entirely or partly absent, as in our case (Plate 1, Figures 24 and 16, respectively).

E. huxleyi distinctly dominates (values up to 26%) from 0cm down to the samples interval between 251 and 256cm (abundant, Table 2), though in reducing percentages, particularly towards S3 (falls to under 10% below star in Figure 3). Within the same stratigraphic interval, *G. muellerae* is few to common (Table 2, Figure 3). Below 251cm, *G. muellerae* frequency increases to abundant, and consistently dominates the assemblage down to the bottom of the core, while *E. huxleyi* is common down to 323cm, and then decreases to few (2-5%) to the bottom of the core. *G. oceanica* shows the same behaviour as *G. muellerae* below S3 down to the bottom. It can be assumed that the assemblages in the interval between 251 and 256cm represent the so-called 'reversal in dominance

Sapropels	Samples (subdepth in cm)	Emiliania huxleyi var. huxleyi	Gephyrocapsa muellerae	Gephyrocapsa ericsonii	Umbilicosphaera sibogae v. s.	Gephyrocapsa oceanica	Gephyrocapsa caribbeanica	Calcidiscus leptoporus f. lept.	Helicosphaera carteri v. cart.	Helicosphaera carteri v. hyal.	Helicosphaera carteri v. wall.	Syracosphaera pulchra	Rhabdosphaera clavigera v. c.	Cricolithus jonesii	Florisphaera profunda var. pr.	Calciosolenia murrayi	Umbilicosphaera maceria	Crenalithus sessilis	Acanthoica acanthos	Ceratolithus cristatus var. cr.	G. ericsonii/G. protohuxleyi	Triquetrorhabdulus sp.
S1	9	A	F	F	C	C	F	C	C			C	C	F					R			
	236	A	C	F	F	C	F	C	C	C	C	C	C									
	241	A	C	F	F	C	F	C	C	C	C	C	C									
	245	A	C	F	F	C	F	C	C	C	C				F				R			
S3	251	A	C	F	F	C	F	C	C	C	C				F	F			R			
	256	C	A	F	F	C	F	C	C	C	C	F	F				R	F				
	261	C	A	F	F	C	F	C	C	C	C	F					R					
	267	C	A	F	F	C	F	C	C	C	C	F				F	R					
	308	C	A	F	F	A	F	C	A	C	C	C	C	F								
S4	313	C	A	F	F	A	F	C	A	C	C	C	C		F							
	318	C	A	F	F	A	F	C	A	C	C	F			F	R	F	R				r
	323	C	A	F	F	A	F	C	A	C	C	F	C				R					
	363	F	A	F	C	C	F	A	A	F	C	F	C									
	368	F	A	F	C	C	F	A	A	F	C	F										
S5	373	F	A	F	C	A	F	A	A	F	C			C								
	378	F	A	F	C	A	F	A	A	F	C	C	F					F			r	
	383	F	A	F	C	A	F	A	A	F	C	C	F				F	F				
	387	F	A	F	C	A	F	A	A	F	C	C	F				F					
S5/S6	425	F	A	F	C	C	F	F	A	F	C	C					F		R		R	
	429	F	A	F	C	C	F	F	A	F	C	C										

Table 2: Distribution of calcareous nannofossils in sapropels, gravity-core 2SL (Station 69). A = abundant (>10%); C = common (5-10%); F = frequent (2-5%); R - rare (1-2%); r = reworked

between *E. huxleyi* and *G. muellerae*', a significant biostratigraphic event previously reported by other authors from Mediterranean Sea cores (*e.g.* Thierstein *et al.*, 1977, and see discussion below).

Generally, it appears that all coccoliths observed in S3 occur in lower frequencies, or present negative peaks or lows, than within the other layers above S3 to the top. Normally, each species is represented by <10% frequency in S3. This is also the case for the nannofloras in the youngest sapropel, S1, with the exception of *E. huxleyi*, which is abundant and which increases within S1 to 24% (Figure 3).

Moving further downcore, the deeper sapropels, S4, S5 and S5/6, are characterised by an increased abundance of helicosphaerids, such as *Helicosphaera carteri, H. hyalina* and *H. wallichii*, with a mean abundance usually ranging between 12% and 16% (Figure 3). The latter sapropels are associated with well-represented gephyrocapsids, consisting mainly of *G. muellerae* (ranging between 10% and 20% on average) and *G. oceanica* (up to 15%). Both these species' frequencies increase downwards. Subordinately, *G. caribbeanica* (~3-5%), *G. ericsonii* (~5-8%), and very small *Gephyrocapsa* sp. (L<2μm) were observed. *C. leptoporus* ranges from between 12%, (value recorded directly below S3) and 4% (below the S5/6 down to the core-bottom). Similarly to S3, within the S5/6 this latter taxon reaches its minimal values (~6%). *E. huxleyi* shows values varying between 4% and 8%. Sediment layers other than sapropels are enriched in

U. sibogae and *Syracosphaera pulchra*, having averages ranging between 10 and 15% in the total assemblage. In S4, S5 and S5/6 particularly, *U. sibogae* clearly decreases, and ranges between 5% and 9% (Figure 3), while *S. pulchra*, though not consistently present, shows few to common abundances (Table 2).

Considering the cumulative distributions in the sapropels (Figure 3), the absolute frequencies of some species, such as *G. caribbeanica, G. ericsonii* and *U. sibogae*, remain almost constant through the whole core with minor fluctuations of the order of 1 to 2%. It is also interesting to observe that *G. caribbeanica* presents its abundance minima directly above (or, alternatively, directly after) sapropel deposition (S3, S4 and S5).

The distinctive decrease, or low trend, in the representative values of nearly all the species is clearly demonstrated, from the selected calcareous nannofossil cumulative distribution through Core M40/4-69 (Figure 3), and particularly from the development of their frequencies at the levels of the sapropel layers. *E. huxleyi* is the only taxon which decreases consistently, downcore to the level of S3, coded R (negative correlation with depth), then becoming more stable (~5%). Comparing semiquantitative and quantitative frequency distribution data of all the sapropels in Table 2 and Figure 3, the most pronounced and longest-duration values decrease is recorded within the thick S3 between 236 and 267cm. Negative peaks, or lows, in the selected nannoflora values determined for S5 are also important, but not in the order recorded for S3.

Discussion

The euphotic zone is a well-known common habitat for calcareous nannoplankton, with minor exceptions. Additionally, their being primary producers makes them a first class, sensitive group for monitoring surface-water changes and fluctuations related to recent or past environmental variations.

As previously reported, *G. oceanica* is one of the main components of the calcareous nannoflora through the studied core from the eastern Mediterranean. In recent seas (Indonesian Archipelago), the dominance of *G. oceanica* (February-March), followed by occurrences of *Umbellosphaera irregularis* and *E. huxleyi* have also been observed. In warm August water-samples, *G. oceanica* and *E. huxleyi* are the most frequently-occurring species, followed by *C. leptoporus* (Kleijne, 1990). In the Mediterranean Sea particularly, *G. oceanica* increases in abundance in lower salinity samples than in surrounding ones, where it drops in abundance (Knappertsbusch, 1993). According to recent oceanographic data obtained from the western coast of Australia (Takahashi & Okada 2000)

the occurrence of *G. oceanica*-enriched floras, though rather sporadic, correlates with high water-temperature, low salinity and low water-density in the upper photic zone community. Common to abundant *G. oceanica* in the sapropel layers of Core M40/4-69 could have, therefore, been caused by reducing of surface-water salinity during deposition of the S1 and S3, S4 to S5/6. This could, in turn, have caused shoaling of the pycnocline into the lower euphotic zone, and maintenance of a Deep Chlorophyll Maximum (DCM), a highly productive layer of enhanced production which might have caused high accumulation of organic matter, leading to formation of sapropels, a composite procedure also suggested by Castradori (1993) for the origin of the eastern Mediterranean sapropels.

Florisphaera profunda contributes <2% to 3% to these nannofloras. It is sporadically present in all the studied sapropels, except S1. Probably, its occurrence is limited by the oligotrophic surface-water conditions of the south-eastern Mediterranean Sea, in contrast to the north-western Pacific Ocean and the northern South China Sea, where a bloom of *F. profunda*, caused by high surface-water fertility, has been observed (Ahagon *et al.*, 1993; Wei *et al.*, 1997). This taxon is considered to be a good palaeoproductivity proxy, and its abundances can be used for monitoring the depth of the nutricline, which controls nutrient availability (Molfino & McIntyre, 1990; Castradori, 1993). It represents a main component of the deep-water assemblages developed at depths between approximately 60 and 180m (Reid, 1980). Recently, *F. profunda* seasonal fluxes in the deep-photic layer were studied off Morocco and the Canary Islands, where abundance-peaks were recorded between January and March and in November (Sprengel *et al.*, 2000). *F. profunda*'s sporadic occurrences in the sapropels studied here could possibly indicate such seasonal fluxes.

The reversal in dominance between *E. huxleyi* and *G. muellerae* has been reported by Flores *et al.* (1997) in the western Mediterranean Sea at about 73kyr, while Violanti *et al.* (1987) estimated this event at 85kyr from the Tyrrhenian Sea. In an earlier work, Thierstein *et al.* (1977, pp.403-404) recorded, in transitional waters, the "reversal in dominance between *Emiliania huxleyi* and *Gephyrocapsa caribbeanica*", and dated it at approximately 73kyr. According to our data, the reversal (coded R in the cumulative distribution diagram, Figure 3) falls within S3, below Glacial Isotope Stage 4 and should have an age of 71.5kyr, approximately.

Warm interglacial periods are characterised by a higher phytoplankton percentage than glacial (cold) periods. Although S1, S4, S5 and S5/6 are considered to have been deposited within warm interglacial intervals, it is here shown that sapropel associations are represented by low calcareous nannofossil diversities, and show significant dissolution. The elements of *E. huxleyi* and *Ceratolithus* sp. are partly corroded or dissolved (Plate 1, Figures 11, 12, 14). In contrast, *C. leptoporus, Rhabdosphaera clavigera, U. sibogae* and the helicosphaerids are proved to be more solution-resistant in the sapropel layers, as shown by their good state of preservation and consistent abundances (Figure 3).

Progressive alteration, due to processes such as dissolution, of the coccoliths of *E. huxleyi* is probably responsible for the significant drop in abundance downcore of this taxon, particularly below S3. This might be indicative of long periods of suspension, or low sinking speed in the water-column (Broerse *et al.*, 2000), a fact which in turn points to low sedimentation rates for the lower part of the studied core (251 to 500cm), perhaps due to strong subbottom oceanographic currents. Another synergetic role might have been the great depositional palaeodepth that these coccoliths were deposited at.

Moreover, bacterial activity and populations were studied from the upper sediment and sapropel layers (down to S5) by Overmann *et al.* (1999). The main sites were KL51-Station 69 (Figure 1) and the anoxic Urania Basin at Station 76, SW of Crete. Significant microbial cell numbers and intense activity were recorded, even in the deepest samples of S5, which might have provided favourable conditions for the growth and survival of carbonate chemotrophic bacteria. Total numbers of bacterial cells reached values of about 10^8 per cm^3 in all sapropel layers of Gravity-core M40/4-69. Additionally, the water in the anoxic brine from the Urania Basin below 3470m was found to contain enormous concentrations (up to 24mM) of free sulphide (H_2S), while the concentration in the underlying sediment was only 3mM (Overmann *et al.*, 1999).

It seems, therefore, that the most extreme environmental conditions occurred during sapropel formation and deposition. Thus, either coccoliths were prevented from settling, or their preservation potential was minimised, or both processes worked together, as in the case presented here. As a consequence, coccolith diversities become very low, or even the whole nannoflora disappears. This is due probably to the influence of anoxia, including intensive bacterial activity (Overmann *et al.*, 1999), or to additional ash-falls on the coccolith assemblages (Thunell *et al.*, 1983; Keller, 1994; Keller *et al.*, 1978; see ash-layers in the present core, Figure 2). But, in contrast to the benthic foraminifera fauna from the Ionian Sea to the west, where the diversities remained very low some thousand years after the cessation of anoxic conditions, especially after deposition of S1 and S5 (Schmiedl *et al.*, 1998), coccolith associations restabilised within a short interval after sapropel formation was terminated. This is clearly shown particularly directly above S3, where the increase in abundance of some taxa is in the order of 10 to 20%.

Additionally, and in contrast to the impoverished calcareous nannoplankton, well-preserved opal phytoplankton and zooplankton assemblages, containing diatoms, silicoflagellates and radiolarians, have been found, described and illustrated from S5 by Danelian & Frydas (1998) and Pearce *et al.* (1998), close to Station 69 (ODP Sites 969 and 971: Figure 1). Opal phytoplankton were not affected by carbonate chemotrophic bacteria, and therefore present a high preservational potential.

Conclusions

1.   The reversal in dominance between *E. huxleyi* and *G. muellerae* was recognised in Core M40/4-69 and was

placed at *c.*71.5kyr, thus pointing to a slightly younger age than in other, similar studies of the Mediterranean Sea.

2. Generally, a quantitative decrease was recorded in the percentage distributions of the eight selected calcareous nannofossil species evaluated in the sapropels, relative to the non-sapropel sediments of the studied core.

3. The most prominent percentage decrease was observed in S3, but it must be noted that this was the thickest sapropel recovered (among the five sapropels studied).

4. A decrease in the quantitative composition of the whole assemblages in the individual sapropels was clearly observed.

5. Despite this decrease (point 4) in the sapropels, a few species, such as *C. leptoporus* and the various helicosphaerids, are still well-represented (seem not really to be affected).

6. Recovering rates of the coccoliths above the sapropel layers, immediately after the anoxic events, are quite quick (rapid rejuvenation) in relation to published data from foraminifera.

7. *F. profunda* is, surprisingly, found in only rare to few frequencies, in relation to other Mediterranean studies.

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Plate 1

Calcareous nannofossils recovered from gravity-core 2SL, eastern Mediterranean Sea (*Meteor* cruise M40/4, Station 69). Depths from top of core. All distal coccolith views except Fig.17 (proximal view). Bars = 1µm

1 — *Gephyrocapsa muellerae*: warm form, 378cm, S5

2 — *Gephyrocapsa muellerae*: warm form, 378cm, S5

3 — *Gephyrocapsa muellerae*: temperate form, 245cm, S3

4 — *Gephyrocapsa muellerae*: temperate form, 245cm, S3

5 — *Gephyrocapsa ericsonii*: S3

6 — *Gephyrocapsa ericsonii*: 323cm

7 — *Gephyrocapsa ericsonii*: 323cm, S4

8 — *Gephyrocapsa caribbeanica*: 267cm, S3

9 — *Gephyrocapsa oceanica*: 323cm, S4

10 — *G. ericsonii-G. protohuxleyi* transitional form: 378cm, S5

11 — *Emiliana huxleyi*: 323cm, S4

12 — *Emiliania huxleyi*: 425cm, S5/6

13 — *Calcidiscus leptoporus*: 323cm, S4

14 — *Ceratolithus* cf. *C. cristatus*: 425cm, S5/6

15 — *Rhabdosphaera clavigera*: 378cm, S5

16 — *Florisphaera profunda*: 425cm, S5/6 (bioturbated)

17 — *Helicosphaera carteri* var. *carteri*: 378cm, S5

18 — *Helicosphaera carteri* var. *hyalina*: 323cm, S4

19 — *Scapholithus fossilis*: 323cm, S4

20 — *Acanthoica acanthos*: 9cm, S1

21 — *Cricolithus* cf. *C. jonesii*: 9cm, S1

22 — *Syracosphaera pulchra*: 378cm, S5