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CALCAREOUS NANNOFOSSIL BIOSTRATIGRAPHY AND BIOCHRONOLOGY IN EASTERN MEDITERRANEAN DEEP-SEA CORES

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Riassunto. E' stato condotto uno studio al microscopio ottico delle associazioni a Nannofossili calcarei in carote di mare profondo provenienti dal Mediterraneo orientale. La maggior parte delle carote sono state prelevate nel corso della crociera MD69, organizzata all'interno del progetto europeo MAST-Marflux.

Il lavoro ha un duplice scopo: a) la stratigrafia preliminare dei sapropels "antichi" (ovvero quei sapropels mai recuperati in carota prima della crociera MD69); b) il riconoscimento su base quantitativa di eventi biostratigrafici e la loro calibrazione rispetto alla magnetostratigrafia e agli stadi isotopici e faunistici.

La stratigrafia a Nannofossili qui presentata indica che i sapropels sono presenti nella Zona a *Pseudoemiliania lacunosa* e anche nella sottostante Zona a small *Gephyrocapsa*. Questi risultati sono assai importanti per collegare il record di mare profondo con quello delle sezioni su terra (Calabria e Sicilia), ove livelli sapropelitici sono presenti fino al limite tra le zone a large *Gephyrocapsa* e small *Gephyrocapsa*.

L'inizio dell'Acme di *Emiliania huxleyi* viene calibrato allo stadio isotopico/faunistico 4. Sulla base dell'età "astronomica" dei sapropels S1 (8 ka) e S3 (79 ka), viene proposta un'età di 51 ± 2 ka (carota Ban88-11GC) o 54 ± 5 ka (carota Ban82-15PC) per questo evento biostratigrafico. L'evento di prima comparsa di *E. huxleyi* è di difficile identificazione al microscopio ottico.

L'estinzione di *Pseudoemiliania lacunosa* è datata a 468 ka sulla base dell'interpolazione tra il limite paleomagnetico Brunhes/Matuyama (780 ka) e il sapropel S9 (238 ka). Con lo stesso procedimento, l'uscita dal Mediterraneo di *Gephyrocapsa* sp. 3 (sensu Rio, 1982) è datata a 584 ka.

La prima comparsa di *Gephyrocapsa* sp. 3 e il "rientro" nel record stratigrafico delle medium sized *Gephyrocapsa* definiscono il tetto della Zona a small *Gephyrocapsa*. Viene qui dimostrato, per la prima volta nell'area mediterranea, che questo limite zonale corrisponde a un intervallo stratigrafico di poco successivo al tetto dell'evento paleomagnetico Jaramillo con un'età di 944 ka. Un evento di acme delle small *Gephyrocapsa*, la cui base è prossima al sapropel S9, è correlato con lo stadio isotopico 8 e datato a 265 ka.

Abstract. A study of calcareous nannofossils was carried out, using an optical microscope, on a set of eastern Mediterranean deep-sea cores. These cores were mainly collected during cruise MD69, organized within the framework of the MAST-Marflux project. The main purposes of this paper are the assessment of a preliminary stratigraphy of "old" sapropels (i.e. never recovered in piston cores prior to cruise MD69), the quantitative recognition of biostratigraphic events and their calibration with respect to magnetostratigraphy and isotope/faunal stages.

Nannofossil biostratigraphy demonstrates that sapropels are present in the *Pseudoemiliana lacunosa* and in the underlying small *Gephyrocapsa* nannofossil zones. These findings are of key importance to link the deep-sea record to that of land sections (Calabria and Sicily, Southern Italy), where sapropelitic layers are present up to the large *Gephyrocapsa*/small *Gephyrocapsa* zonal boundary.

The beginning of the *E. huxleyi* Acme is calibrated with isotope/faunal stage 4. Based on astronomical dating of sapropels S1 (8 ka) and S3 (79 ka), this event is estimated to 51 ± 2 ka (core Ban88-11GC) or 54 ± 5 ka (core Ban82-15PC). The *E. huxleyi* FAD cannot be confidently detected using the optical microscope technique.

The LAD of *P. lacunosa* is estimated to 468 ka, based on interpolation between the Brunhes/Matuyama magnetic boundary (780 ka) and sapropel S9 (238 ka). With the same procedure the disappearance of *Gephyrocapsa* sp. 3 (sensu Rio, 1982) from the Mediterranean is estimated to 584 ka.

The FAD of *Gephyrocapsa* sp. 3 and the "re-entrance" of medium sized *Gephyrocapsa* define the top of the small *Gephyrocapsa* Zone, which is demonstrated to occur shortly after the end of the Jaramillo magnetic event in the Mediterranean area, with an interpolated age of 944 ka. An "acme" event of small *Gephyrocapsa*, beginning close to sapropel S9, is correlated with isotope stage 8 and dated as 265 ka.

Introduction.

In the last decades calcareous nannofossil biostratigraphy of Mesozoic and Cenozoic sediments has been continuously improved and now constitutes one of the most important tools in the stratigraphy of this time interval. In the Quaternary, calcareous nannofossils are even more important due to diminished resolution of other fossil groups, particularly of planktonic foraminifera (see Bolli & Saunders, 1985, for further information). Siliceous microfossils, which provide a good biostratigraphy of this time interval in many open oceanic areas, cannot be used in the eastern Mediterranean due to their low and scattered abundance throughout the Quaternary sedimentary sequence.

This paper deals with the nannofossil biostratigraphy of a set of deep-sea cores raised from the eastern Mediterranean during various oceanographic cruises (MD69, Ban88, Ban82). Cruise MD69 was organized in the framework of the European scientific program MAST-Marflux. The aim of the project is the reconstruction of biogeochemical fluxes in the Mediterranean sea and in the eastern North Atlantic Ocean, within a high resolution biostratigraphic framework.

In the first part of this paper the qualitative biostratigraphy of nine long piston cores, forming a W-E transect in the eastern Mediterranean (Fig. 1, Tab. 1), is reported together with the preliminary characterization of the recovered sapropel sequence. Sapropels are organic rich layers interlayered in the normal pelagic sequence of the eastern Mediterranean. Particularly famous are those recovered, since 1947-48 (see Kulenberg, 1952; Olausson, 1961), in dozens of piston cores (see e.g. Ryan, 1972; Vergnaud-Grazzini et al., 1977; Cita et al., 1977).

The oldest sapropel recovered before cruise MD69 was sapropel S12 with an estimated age of about 480-500 ka, within the uppermost part of the *Pseudoemiliana lacunosa* Zone (Vergnaud-Grazzini et al., 1977, core RC9-181). Onland sections exposed in Calabria and Sicily (Southern Italy) contain many sapropelitic layers, the youngest of which is attributed to the boundary between the small *Gephyrocapsa* and

the large *Gephyrocapsa* nannofossil zones (approximately 1,200 ka) (see Hilgen, 1991a, for a review). Legs 13 and 42A of the Deep Sea Drilling Project (DSDP) failed to recover a continuous section through the interval ranging from the oldest sapropel of deep-sea cores to the youngest of onland sections (see Kidd et al., 1978 for a review). The stratigraphic sequence of the MD69 cores presented here allows to decrease the middle-early Pleistocene "gap" in the Mediterranean sapropel stratigraphy.

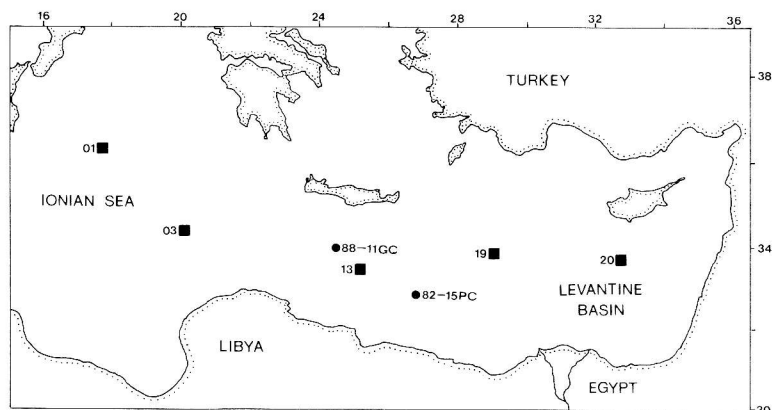


Fig. 1 - Location map of the deep-sea cores studied in this paper. Black squares refer to cores collected during cruise MD69, organized within the MAST-Marflux project; black circles refer to cores collected during various oceanographic cruises of the Italian R/V Bannock.

Core	latitude N	longitude E	Water depth (m)	Core length (m)
KC01	36°15.25'	17°44.34'	3643	25.93
KC01B	36°15.25'	17°44.34'	3643	37.04
KC03	34°16.07'	19°49.88'	3250	25.23
SP03	34°16.07'	19°49.88'	3250	16.62
KC13	33°19.38'	25°00.75'	2181	16.22
KC19B	33°47.85'	28°36.50'	2750	21.71
KC19C	33°47.85'	28°36.50'	2750	19.63
KC20	33°40.56'	32°42.59'	882	10.23
KC20B	33°40.56'	32°42.59'	882	12.04
Total (m)				184.65

Ban88-11GC	33°49.10'	24°24.71'	1900	5.62
Ban82-15PC	32°42.60'	26°44.61'	2915	10.50

Tab. 1 - Main characteristics of the MD69 cores (upper part of the table) and of the other two cores studied in this paper.

The second part of the paper describes the results of a quantitative biostratigraphic study carried out on three cores (KC01B, one of those recovered during cruise MD69, Ban88-11GC and Ban82-15PC, recovered during two cruises of the Italian R/V *Bannock*) selected along a NW-SE transect from the Calabrian Ridge to the western Levantine basin (Fig. 1, Tab. 1). This quantitative biostratigraphy allows: a) to demonstrate the applicability of the most recent biozonation, based on quantitative definitions, proposed for the Mediterranean area (Rio et al., 1990; Fig. 2), b) to propose secondary events for further subdivisions of this time interval, and c) to obtain absolute ages (biochronology) for some of the bioevents through correlation with the magnetic stratigraphy and isotope/faunal stages.

Previous studies on nannofossil biostratigraphy and biochronology.

The first formal nannofossil zones for the Quaternary were proposed by Boudreaux & Hay (in Hay et al., 1967). Gartner (1969) partially modified the definitions of the latter authors and introduced a few new biozones. The widely known standard zonation proposed by Martini & Worsley (1970) and Martini (1971) simply incorporates Gartner's (1969) zonation for the Quaternary interval. Through the studies of Bukry (1973, 1975) and Okada & Bukry (1980), another zonation for the entire Cenozoic was defined. They subdivided the Quaternary interval into three zones comprising a total of five subzones. Gartner (1977) proposed the most detailed Quaternary zonation for oceanic areas, consisting of seven zones.

In the last century, the Mediterranean area has been always considered suitable for the location of appropriate stratotypes for Neogene and Quaternary stages (see Rio et al., 1991 for a review). That is why in the last fifteen years particular attention has been paid to the calcareous nannofossil biostratigraphy of this area. Raffi & Rio (1979) and Rio et al. (1990) defined a calcareous nannofossil zonation for the Mediterranean (Fig. 2) that is applied in the present paper. For the upper part of the Quaternary (i.e. the interval studied here) they introduced quantitative definitions of the zonal boundaries of Gartner's (1977) zonation (see "Material and methods").

Biochronology is the organization of geologic time according to the irreversible process of evolution in the organic continuum (Berggren & Van Couvering, 1978). Many attempts have been performed in the past decades in order to obtain a reliable nannofossil biochronology. Age estimates are primarily based, directly or indirectly, on the magnetic polarity time scale which rests, in turn, upon the radiometric dating of terrestrial lavas (Berggren et al., 1980). In particular, the biochronologic calibration proposed for the Quaternary nannofossil events are linked to the age of the Brunhes/Matuyama magnetic boundary, usually estimated to 700-730 ka (e.g. Berggren et al., 1985). Absolute ages of nannofossil events occurring in the time interval investigated here are listed in Tab. 2.

Astronomical calibrations of the Neogene paleomagnetic events were recently proposed by Shackleton et al. (1990) and Hilgen (1991 a, b). This calibration, which is

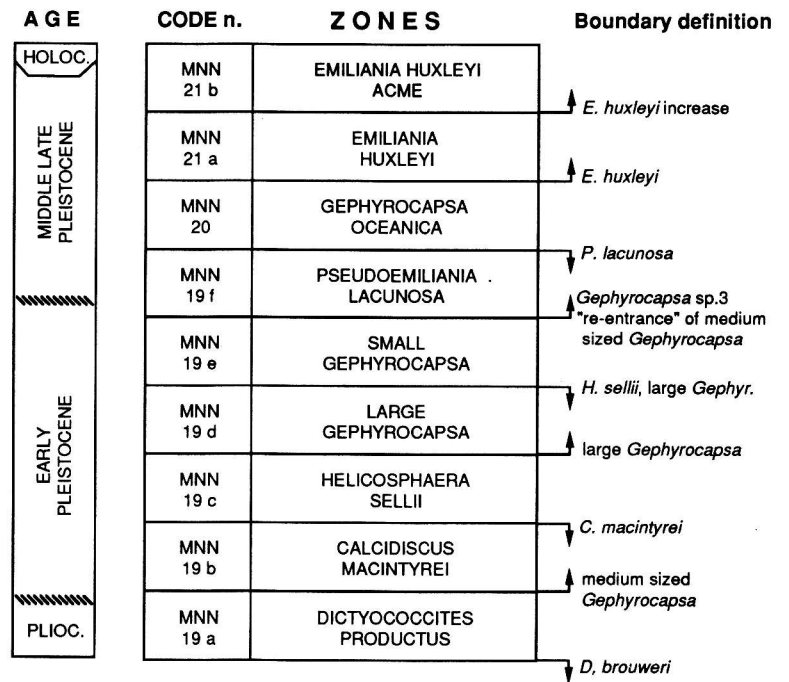


Fig. 2 - The nannofossil biostratigraphic scheme of Rio et al. (1990) applied in this study; for quantitative definitions of bioevents, see text.

	base <i>E. huxleyi</i> Acme	<i>E. huxleyi</i> FAD	<i>P. lacunosa</i> LAD	top of small <i>Gephyrocapsa</i> Zone
Bukry 1975		200	300	
Gartner 1977	70	270	440	920
Thierstein et al. 1977	73 (transitional)* 85 (tropical)*	268	458	
Berggren et al. 1980	73 (transitional)* 85 (tropical)*	275	474	900
Hills & Thierstein 1989		230	350	
Rio et al. 1990				950

* dominance inversion *G. caribbeanica*/*E. huxleyi*

Tab. 2 - Biochronology of some nannofossil events in the time interval studied in this paper (ages in thousands of years).

completely independent from the traditional radiometric dating method, resulted in ages of 780, 990 and 1070 ka for the Brunhes/Matuyama, the top and the base of the Jaramillo event, respectively (Shackleton et al., 1990). Very recently, Cande & Kent (1992) accepted the astronomical age calibration of 780 ka for the Brunhes/Matuyama boundary and included this datum in their new geomagnetic polarity time scale.

Based on the astronomical calibrations of magnetic events by Shackleton et al. (1990), revised ages of nannofossil events were then proposed (Raffi et al., in press). Of the bioevents recognized in the present study, only the top of the small *Gephyrocapsa* Zone is included in the paper by Raffi et al. (in press). These authors proposed an age of 1028 ka (low latitudes) or 957 ka (middle-high latitudes) for this nannofossil event.

With the exception of the first occurrence of *E. huxleyi* (discussed below), the calibration of the middle and upper Pleistocene events in the Mediterranean area are as follows:

- a) beginning of the *E. huxleyi* Acme dated as 85 ka by Rio et al. (1990) on the basis of the correlation with isotope stage 5b (Thunell et al., 1990);
- b) last occurrence of *P. lacunosa* correlated with isotope stage 12 by Rio et al. (1990) and Vergnaud-Grazzini et al. (1977); this event can thus be considered synchronous with respect to oceanic areas and estimated to 460 ka (Rio et al., 1990);
- c) top of the small *Gephyrocapsa* Zone: in the Mediterranean area, it was never directly calibrated to magnetostratigraphic and isotopic stratigraphy before the present study.

Material and methods.

All cores studied are from the eastern Mediterranean and contain hemipelagic sediments with sapropel and tephra layers as minor lithologies. Thin sandy-silty turbidites are seldom present, but are rather abundant in cores raised from the Calabrian ridge (Fig. 3). A relatively thick Nile turbidite (Parisi, 1987a, b) is present between sapropel S6 and S8 in core Ban82-15PC (Fig. 4 to 6).

The nine cores investigated qualitatively were chosen within a set of 25 piston cores collected during cruise MD69 (Fig. 1, Tab. 1). One of these latter (KC01B) was studied also quantitatively, together with other two cores (listed in the lower part of Tab. 1).

Core KC01B was the subject of paleomagnetic analyses by Langereis and Dekkers (unpublished data) at the Paleomagnetic Laboratory of Utrecht University (The Netherlands). These analyses (whose preliminary results are here shown under the authors' permission) pointed out the presence of the Brunhes/Matuyama boundary and the top and base of the Jaramillo magnetic event (see below). Since core KC01B has been chosen as the reference core for the Ionian Sea by the participants to the MAST-Marflux project, much more information will be available in the near future concerning stable isotopes, climatic curves, clay minerals, etc.

Stable isotopes of core Ban82-15PC were studied by Parisi (1987 a, b). A planktonic foraminifera climatic curve was developed by Violanti et al. (1991) on core Ban88-11GC.

For each sample analyzed (about 200 for the qualitative and 659 for the quantitative analyses) a smear slide was mounted with Canada Balsam. No specific techniques were applied to clean or concentrate the biogenic fraction, in order to retain the original composition of the nannofossil assemblages. All smear slides were analyzed with an optical microscope at 1250 x magnification. This methodology was chosen because it allows a simple and fast sample preparation and can be carried out in all situations, even onboard a ship. This imposes some limitations on the taxonomic approach that can be applied, the most important of which concerns the genus *Gephyrocapsa*. On the basis of the classifications proposed by Gartner (1977), Raffi & Rio (1979), Rio (1982), and Rio et al. (1990), among the others, *Gephyrocapsa* spp. were subdivided as follows:

a) *G. oceanica* s.l. has an open central area and a maximum length between 3.5 and 5.5 μm ; b) *G. caribbeanica* is similar to *G. oceanica* but has a smaller central area; c) the "small" *Gephyrocapsa* group comprises specimens with a maximum length shorter than 3.5 μm ; d) *Gephyrocapsa* sp. 3 (sensu Rio, 1982) (syn. *G. parallela*, see Raffi et al., in press, for discussion), usually 4 to 6 μm in size, is characterized by a bridge nearly parallel to the short axis of the ellipse; e) the "large" *Gephyrocapsa* group consists of specimens with an open central area and maximum length longer than 5.5 μm (this morphotype is virtually absent in the time interval investigated). The sum of *G. oceanica* s.l., *G. caribbeanica* and *Gephyrocapsa* sp. 3 (when present) will be referred to as "medium sized" *Gephyrocapsa*.

The quantitative biostratigraphic analysis was performed in subsequent counting phases. The first phase consisted of counting 300 specimens belonging to the whole assemblage. Secondly, counts were devoted to the minor species (i.e. all the species except the *Gephyrocapsa* group and *E. huxleyi*) in order to assess their relative abundance on a larger number of specimens (500-1000). The extinction of *P. lacunosa* has been detected in a counts of 500 specimens (see Thierstein et al., 1977, and Rio et al., 1990) and the abundance of *Gephyrocapsa* sp. 3 was monitored with respect to 100 specimens of medium sized *Gephyrocapsa* (see Rio et al., 1990). Finally, a specific semi-quantitative estimate was carried out on the species *Florisphaera profunda*; the reasons for this separate count and its results are described by Castradori (submitted).

The quantitative definition of zonal boundaries introduced by Rio et al. (1990) and applied in the present study are the following: 1) the base of the *Emiliana huxleyi* Acme Zone is defined as the midpoint between frequency values straddling the 20% level in a count of 300 nannofossil specimens; 2) the top of the *P. lacunosa* Zone is defined as the midpoint of the decrease of the index species from 1% to 0% in a count of 500 coccoliths (for original definition see Thierstein et al., 1977); 3) the top of the small *Gephyrocapsa* Zone is marked by the "re-entrance" of medium sized *Gephyrocapsa* among which a large amount of *Gephyrocapsa* sp. 3.

The base of the *Emiliana huxleyi* Zone was defined by Thierstein et al. (1977) as the midpoint of the initial increase of this taxon in a count of more than 300 nanofossils with a transmission electron microscope. The present work was carried out by using an optical microscope which prevents a confident recognition of the small and rare specimens of *E. huxleyi* present in the lowermost range of this species. Therefore, the base of the *E. huxleyi* Zone, as shown in Fig. 3, 4 and 7, is placed where the first specimens of this species were observed with the optical microscope. The question of a possible later entrance of this species in the eastern Mediterranean (i.e. stage 7, Sigl & Muller, 1975; Blechschmidt et al., 1982; Erba et al., 1987 among others) with respect to oceanic areas (stage 8, Thierstein et al., 1977) and even to the nearby Tyrrhenian sea (stage 8, Rio et al., 1990; Thunell et al., 1990), will not be addressed here.

Results and discussion.

Preliminary stratigraphy of sapropel layers.

The results of the qualitative biostratigraphic analysis of nine long deep-sea cores are shown in Fig. 3 (for core location see Fig. 1). The biostratigraphic scheme adopted (Rio et al., 1990) is shown on the right side of Fig. 3 (see also Fig. 2). The relationships between sapropel layers and biostratigraphic boundaries are as follows (from top to bottom):

a) only sapropel S1 occurs between core tops and the base of the *E. huxleyi* Acme Zone. Sapropel S2, the true existence of which is questionable, is absent in all cores under consideration;

b) all sapropels from S3 to S9 were recognized on the basis of planktonic foraminifera assemblages (determinations by F. Lottaroli and M.B. Cita). The FAD of *E. huxleyi* cannot be precisely located with an optical microscope (see above);

c) sapropels S10 and S11 were recognized by Vergnaud-Grazzini et al. (1977) between sapropel S9 and the base of the *Gephyrocapsa oceanica* Zone (marked by the extinction of *P. lacunosa*). Sapropels S10 and S11 were here tentatively identified only in two cores (KC19B and KC19C). In the other cores, either one or both sapropels are absent. This finding is not surprising, because the sapropel sequence is often incomplete in various areas of the eastern Mediterranean;

d) before cruise MD69, the oldest sapropel recovered in piston cores was sapropel S12 (see Vergnaud-Grazzini et al., 1977; Cita et al., 1977). This latter is here identified based on the nannofossil biostratigraphy. In fact, S12 is the first sapropel lying below the extinction of *P. lacunosa* (according to Vergnaud-Grazzini et al., 1977). Unfortunately, not enough data have been recorded so far on planktonic foraminifera assemblages to help in recognizing sapropels below S8. Using the biostratigraphic criterion described above, sapropel S12 has been tentatively identified in cores KC01, KC01B, KC03, SP03, KC19B, KC19C, and KC20B;

e) the stratigraphic position of sapropels older than S12 is now briefly described:

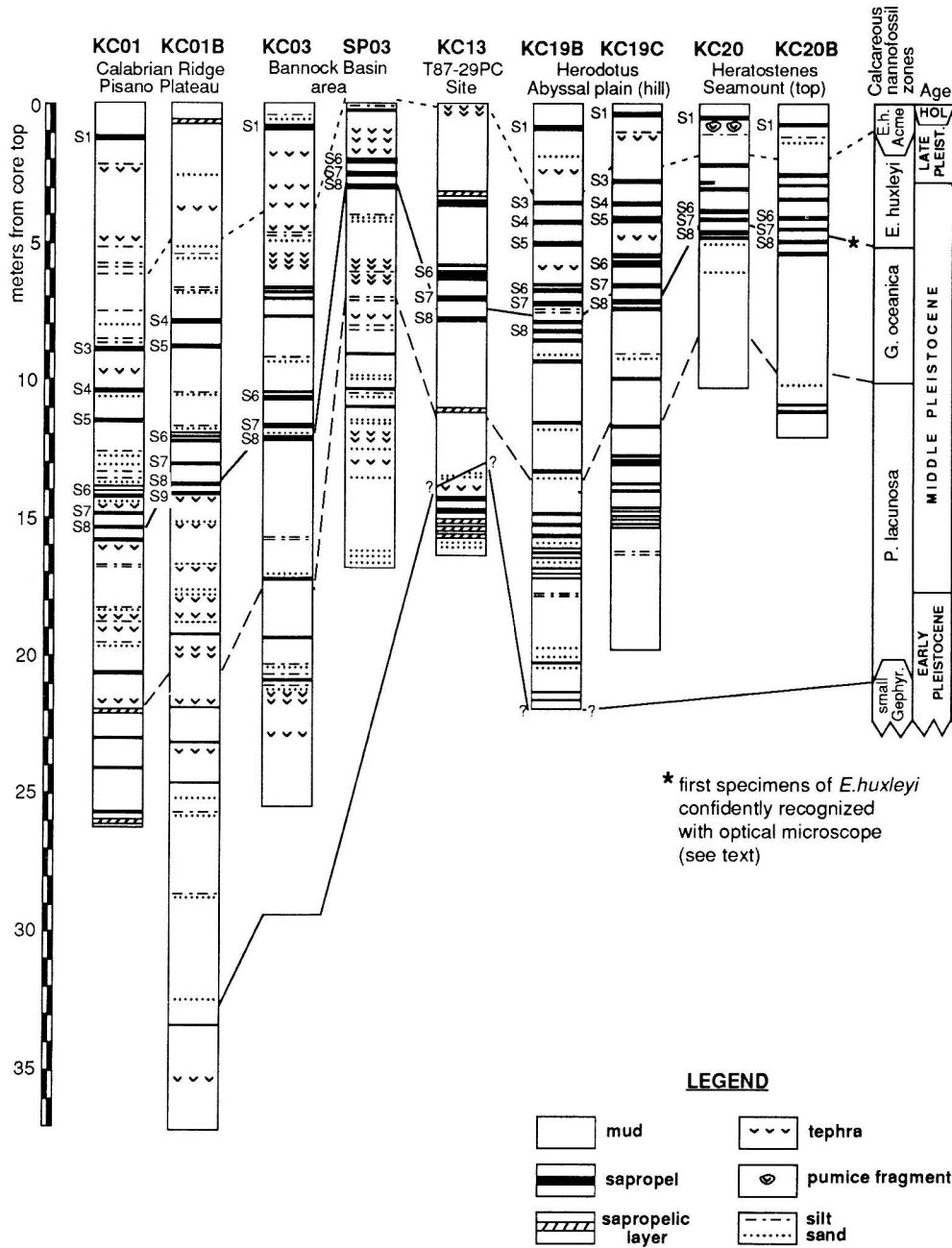


Fig. 3 - Lithologic logs and qualitative nannofossil biostratigraphy of the nine pelagic reference cores collected during cruise MD69 by the French R/V Marion Dufresne. Only sapropels confidently identified through their planktonic foraminiferal assemblage have been numbered (see text).

- at least two other sapropels are present in the *P. lacunosa* Zone (see, for example, cores KC01B and SP03). In cores KC19B and KC19C a higher number of sapropel layers has been identified in the same stratigraphic interval. This can be due to the occurrence of turbiditic episodes which subdivide single sapropels into separate layers or to the intermittence of conditions leading to sapropel formation (anoxia or primary production?) in this part of the Levantine Basin;

- cores KC01B and KC13 contain sapropel layers also in the underlying small *Gephyrocapsa* Zone. These are the oldest sapropels ever recorded in a piston core.

Much work remains to be done (ODP drilling, hopefully) before a satisfying knowledge of "old" sapropel stratigraphy can be reached; however, the long piston cores of cruise MD69 mark an important first step in this direction.

Quantitative biostratigraphy.

The results on quantitative biostratigraphy and biochronology of the three selected cores will be presented starting from the most recent bioevent (the *E. huxleyi* Acme). Biochronologic assignments were based on interpolation between sapropels and/or paleomagnetic events. Astronomical ages of sapropels and magnetic boundaries were applied according to Hilgen (1991a) and Shackleton et al. (1990), respectively.

a) The beginning of the *E. huxleyi* Acme is younger than sapropel S3 (Fig. 4, see also qualitative studies shown in Fig. 3). Sapropel S3 has been correlated with isotope substage 5a by Vergnaud-Grazzini et al. (1977), Parisi (1987 a, b), and many others. Therefore, the *E. huxleyi* Acme event is younger than substage 5a. Fig. 4 shows the correlation of this event with the isotopic curve of Parisi (1987 a, b) for core Ban82-15PC and with the faunal climatic curve of Violanti et al. (1991) for core Ban88-11GC. The climatic faunal curve can be considered coincident with the isotopic curve, at least over the time interval considered here (i.e. from 125 ka to the present) (Vergnaud-Grazzini et al., 1977; Cita et al., 1977; Parisi, 1987a). A discussion of isotope stage assignments in core Ban82-15PC compared with other eastern Mediterranean deep-sea cores can be found in Parisi (1987b).

In Fig. 4, the 2 samples below and above the threshold value of 20% are plotted. The resulting intervals in the two cores overlap in the "coldest" peak of isotope/faunal stage 4, which is thus assumed as the best calibration for this bioevent. A calibration of this event with isotope stage 4 is similar to the one proposed by Thierstein et al. (1977) for the transitional oceanic areas.

In the Tyrrhenian sea (ODP Leg 107, Site 653), the beginning of the *E. huxleyi* Acme was correlated with isotope substage 5b by Rio et al. (1990) and Thunell et al. (1990). A critical check of these two companion papers suggests a few comments. Plotting the depth interval defined by the two samples below and above the threshold value of 20% (see tab. 2 of Rio et al., 1990) on the isotopic curve (fig. 7 of Thunell et al., 1990; see also their tab. 2) one can note that the beginning of the acme is actually correlatable with the interval between the transition 5a-5b and stage 4. The interpretation of these data is complicated by the presence of a core break in that stratigraphic

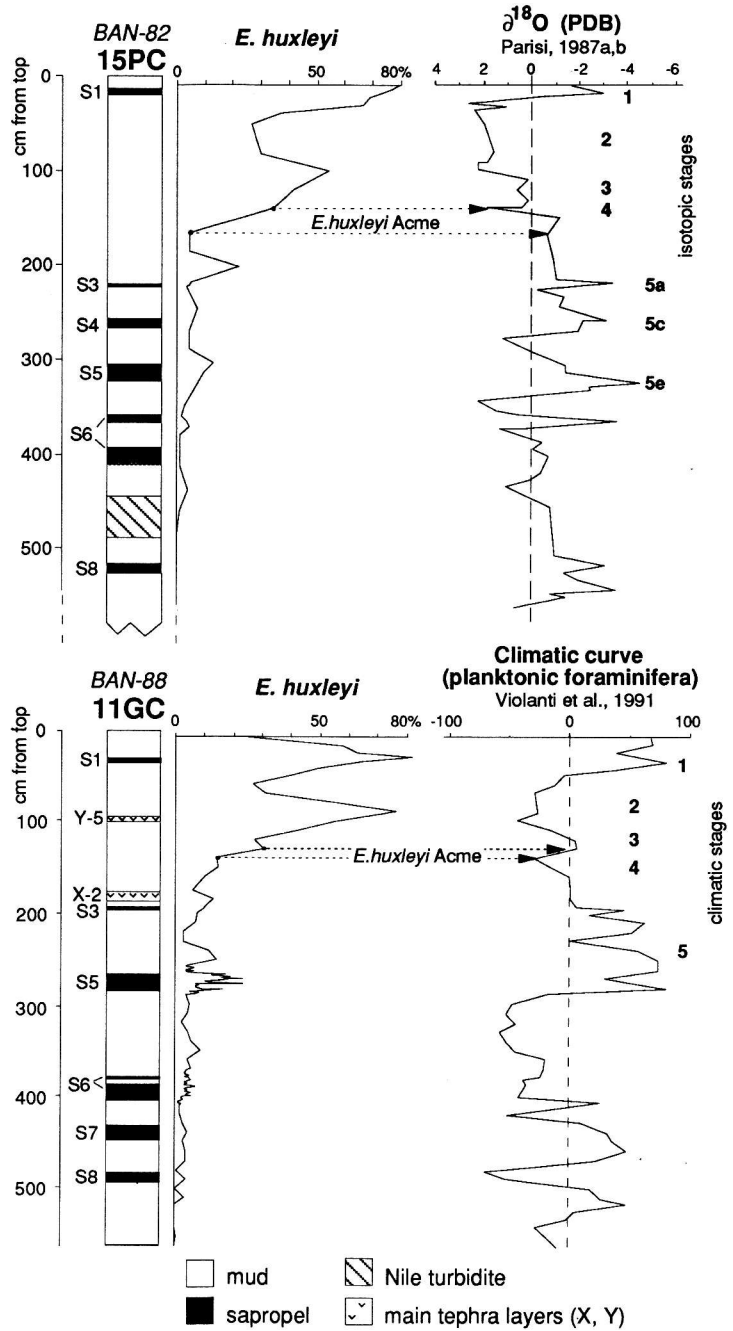


Fig. 4 - Abundance plot of *Emiliana huxleyi* compared with the isotopic curve of Parisi (1987a,b) for core Ban82-15PC and with the faunal climatic curve of Violanti et al. (1991) for core Ban88-11GC. Note that the beginning of *E. huxleyi* Acme is correlatable with isotope/faunal stage 4 (for isotope stage assignments see Parisi, 1987b).

interval and by the low sampling rate applied. The data of Site 653 are similar to those of core Ban82-15PC, pointing to a possible synchronicity of this bioevent in the Tyrrhenian and eastern Mediterranean seas. However, for the time being, a diachroneity between these two adjacent areas cannot be completely ruled out.

Linear interpolation between sapropel S1 (8 ka, Hilgen, 1991a) and S3 (79 ka, same author) results in ages of 51 ± 2 ka (core Ban88-11GC) or 54 ± 5 ka (core Ban82-15PC) for the base of the *E. huxleyi* Acme Zone (Fig. 5). These ages are slightly younger than the calibration of oxygen isotope stage 4 (about 60 ka) proposed by Shackleton et al. (1990). Since oxygen isotope stratigraphy is not available for all cores studied, ages derived from sapropel calibrations are here used as shown in Fig. 5.

b) Below sapropel S8 and close to sapropel S9 (when present) an abundance event in the *Gephyrocapsa* group was identified, consisting of a distinct increase in small, with respect to medium sized, *Gephyrocapsa*. In Fig. 6, the beginning of this acme is shown for two, out of the 3 cores studied: core Ban88-11GC was excluded since its base is coincident with this abundance event. In the Pleistocene, several other intervals with very abundant small *Gephyrocapsa* have already been identified (Rio et al., 1990). However, the analysis of core KC01B (see Fig. 7), clearly demonstrates the distinctiveness of this interval within the stratigraphic record of the last 500 ka (i.e. from below the *P. lacunosa* Last Appearance Datum to the present). This abundance event can, thus, be considered useful for the biostratigraphy of this time interval, particularly of those cores in which sapropels S6 to S9 are lacking (Castradori in Violanti et al., 1991; E. Erba, pers. comm. 1988).

Fig. 6 shows the correlation of this abundance event with isotope stage 8 in core Ban82-15PC (for isotope stage assignments see Parisi, 1987b). The present lack of isotopic data prevents a similar correlation in core KC01B. A correlation with isotope stage 8 was proposed for the *E. huxleyi* First Appearance Datum (FAD) by Thierstein et al. (1977) in the oceans. As already pointed out, the FAD of *E. huxleyi* in eastern Mediterranean is possibly diachronous with respect to oceanic areas, occurring in isotope stage 7 (Sigl & Muller, 1975; Blechschmidt et al., 1982; Erba et al., 1987). Therefore, the abundance event of small *Gephyrocapsa* in the eastern Mediterranean might be synchronous with the *E. huxleyi* FAD in oceanic areas.

Fig. 8 shows the calibration of the base of the acme of small *Gephyrocapsa* based on the astronomical ages of the Brunhes/Matuyama boundary (780 ka, Shackleton et al., 1990) and sapropel S9 (238 ka, Hilgen, 1991a) in core KC01B. This procedure results in an age of 265 ka for this event. The absence of sapropel S9 prevents the application of this procedure for the biochronologic calibration of this event in core Ban82-15PC.

The relatively low sampling rate applied, in this stratigraphic interval, for the qualitative biostratigraphy of the MD69 cores (first part of this paper) does not allow for a precise location of the acme event of small *Gephyrocapsa*, which was thus excluded from Fig. 3.

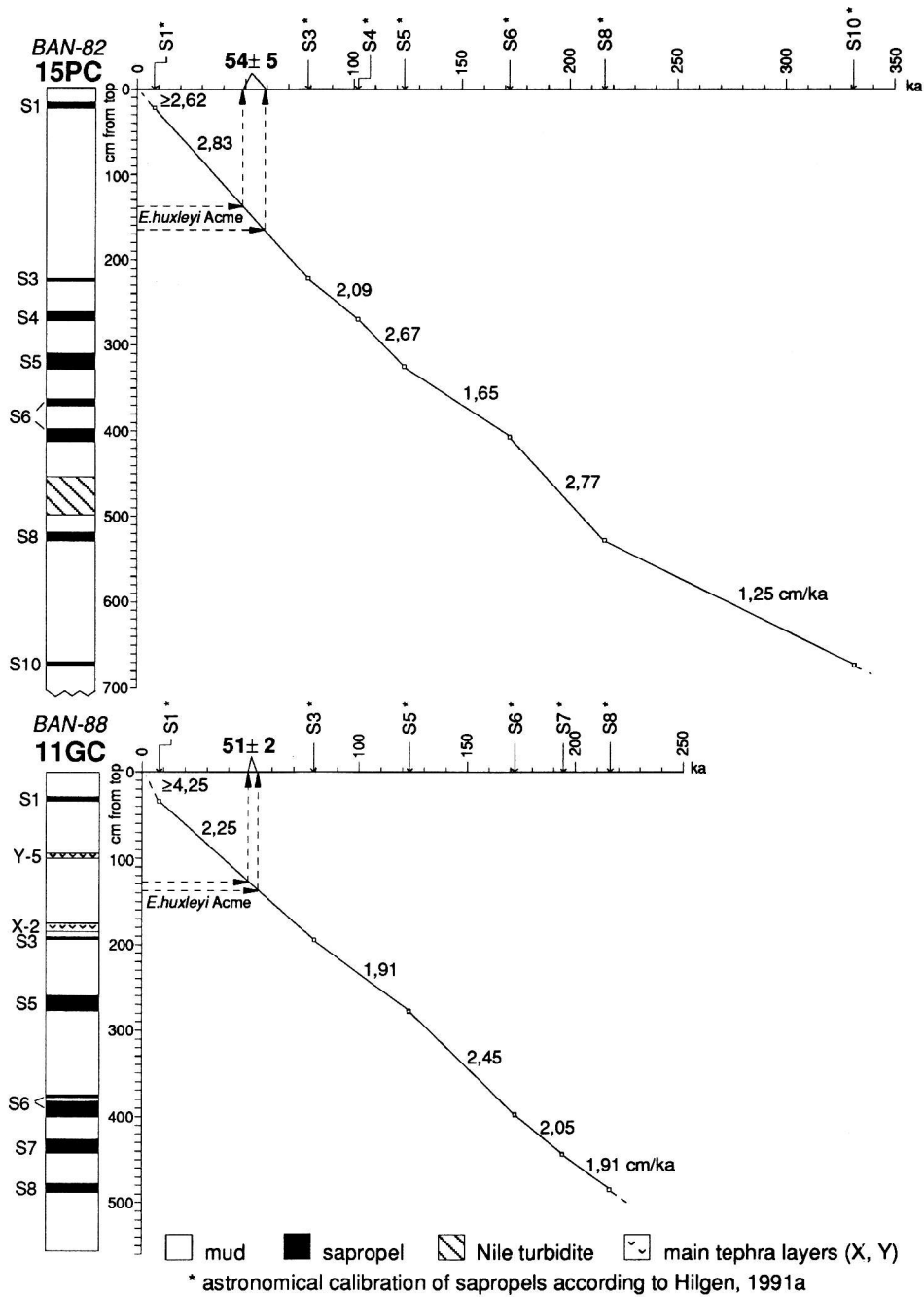
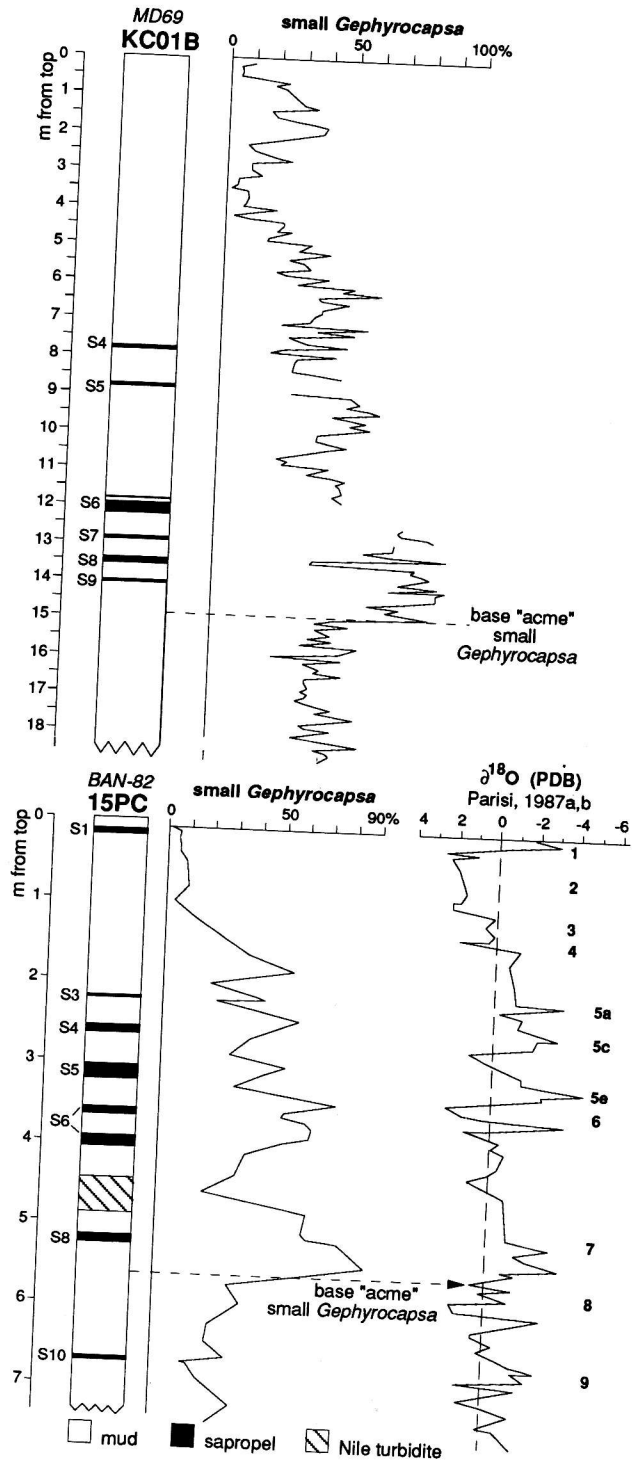


Fig. 5 - Dating the *E. huxleyi* Acme event with respect to the "astronomical" calibration of sapropel layers by Hilgen (1991a); the resulting ages are 51 ± 2 and 54 ± 5 ka in cores Ban88-11GC and Ban82-15PC, respectively (see text for comments on isotope stage chronology).



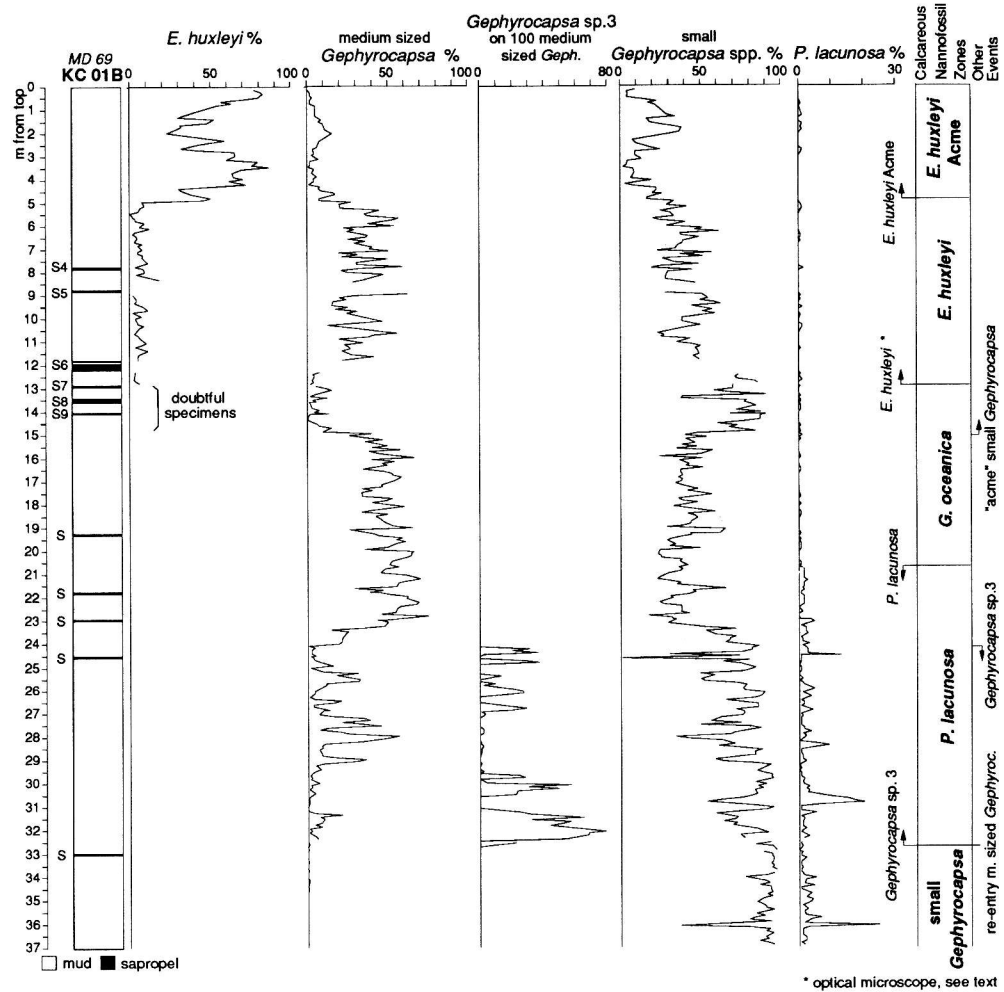


Fig. 7 - Abundance percentages of the biostratigraphic important species recognized in core KC01B. Particularly important are the FAD and LAD of *Gephyrocapsa* sp. 3 (sensu Rio, 1982) and the LAD of *P. lacunosa* (see Fig. 8 for age calibrations). Note that sapropels below S9 are not numbered.

The interval with very abundant small *Gephyrocapsa* ends near the top of sapropel S6, with the exception of core Ban82-15PC, where the presence of a turbiditic layer disturbs the interpretation of the primary signal.

c) The *P. lacunosa* LAD (as well as the underlying events) was identified only in core KC01B. This event occurs half-way between two sapropel layers (Fig. 7) that can

Fig. 6 - Abundance percentages of small *Gephyrocapsa* in cores KC01B and Ban82-15PC. The distinctive increase detected at the optical microscope occurs just below sapropel S9 (KC01B) or between sapropels S8 and S10 (Ban82-15PC). In the latter core, a correlation with isotope stage 8 (isotopic curve by Parisi, 1987a,b) is pointed out (for isotope stage assignments see Parisi, 1987b).

thus be tentatively identified as S11 and S12 (according to the stratigraphy proposed by Vergnaud-Grazzini et al., 1977). As stated above, no isotopic data are available from core KC01B. Therefore, the calibration of the *P. lacunosa* LAD with isotope stage 12 (Thierstein et al., 1977; Rio et al., 1990) cannot be confirmed in the present study.

An age calibration of 468 ka is here proposed for the *P. lacunosa* LAD (Fig. 8) by interpolating between the Brunhes/Matuyama magnetic boundary (780 ka, Shackleton et al., 1990) and sapropel S9 (238 ka, Hilgen, 1991a). The use, as calibration point, of sapropel S9 instead of sapropel S11 (the closest to the *P. lacunosa* LAD) has been

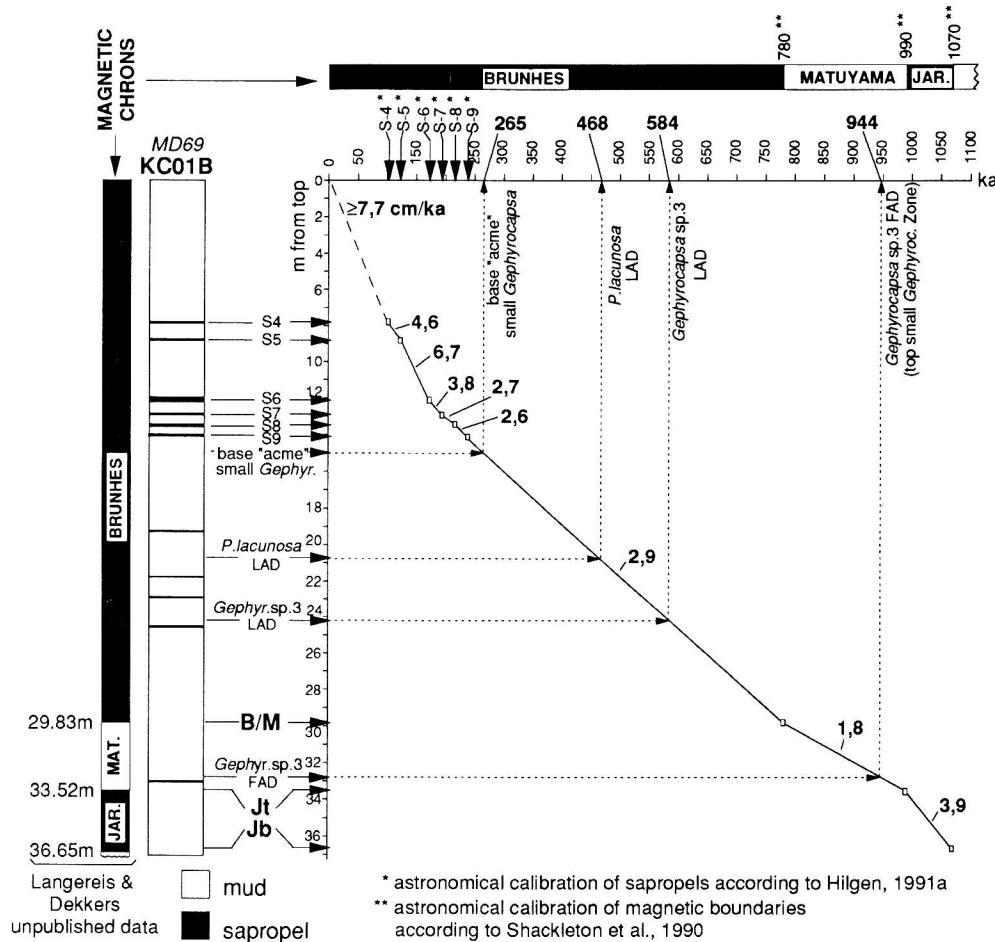


Fig. 8 - Biochronology of some calcareous nannofossil events in core KC01B based on astronomical ages of sapropels and magnetostratigraphic boundaries. Magnetostratigraphy of core KC01B developed by Langereis and Dekkers (unpublished data) at the Utrecht Paleomagnetic Laboratory (The Netherlands) within the framework of the MAST-Marflux project.

preferred because of the more confident identification of the former.

d) *Gephyrocapsa* sp. 3 was not observed above 24.14 m from the top of core KC01B (Fig. 7). This bioevent actually represents the disappearance of this morphotype from the Mediterranean area, in contrast to open ocean areas in which it is present until today. The possible usefulness of this event in the nannofossil biostratigraphy of the Mediterranean area, already pointed out by Rio et al. (1990), is confirmed here. The age of this intramediterranean bioevent is estimated to 584 ka (Fig. 8) on the basis of interpolation between sapropel S9 and the Brunhes/Matuyama boundary.

e) At 32.71 m from the top of core KC01B, the FAD of *Gephyrocapsa* sp. 3 was detected together with the "re-entrance" of medium sized *Gephyrocapsa* (Fig. 7). These events define the top of the small *Gephyrocapsa* Zone of Rio et al. (1990). The top of this biozone has been shown to be diachronous in the oceanic realm by Raffi et al. (in press), occurring within the Jaramillo magnetic event (isotope stages 29-30) in low latitudes environments and just above it (isotope stage 25) in middle and high latitudes of the Atlantic ocean.

In core KC01B this event was detected 81 cm above the Jaramillo. Thus, as for the base of the *E. huxleyi* Acme Zone, the Mediterranean area seems to be correlatable with the middle and high latitudes in the oceans. The top of the small *Gephyrocapsa* Zone in core KC01B can be estimated to 944 ka (Fig. 8) through interpolation between the top of the Jaramillo (990 ka, Shackleton et al., 1990) and the Brunhes/Matuyama boundary (780 ka, Shackleton et al., 1990).

Conclusions.

The qualitative and quantitative analyses of nannofloras from eastern Mediterranean deep-sea cores described in the present paper resulted in the following conclusions.

1) At least two more sapropel layers are present within the *P. lacunosa* Zone below sapropel S12 (the oldest sapropel recovered in piston cores before cruise MD69). Cores KC01B and KC13 witness about the presence of sapropels also in the underlying small *Gephyrocapsa* Zone. The youngest sapropel in outcropping sequences (e.g. the Vrica section, southern Italy) occurs close to the large *Gephyrocapsa*/small *Gephyrocapsa* zonal boundary (see Hilgen, 1991a, and Rio et al., 1991, for review). Thus, this paper represents a first step toward the closure of the "gap" between the onland and deep-sea sapropel record.

2) The base of the *E. huxleyi* Acme is calibrated with the "coldest" peak of isotope/faunal stage 4 (synchronous with oceanic middle and high latitudes). Interpolation between sapropel S1 and S3 resulted in ages of 51 ± 2 ka (core Ban88-11GC) or 54 ± 5 ka (core Ban82-15PC) for this bioevent. These ages are slightly younger than the calibration of stage 4 (about 60 ka) proposed by Shackleton et al. (1990).

The reliability of the *E. huxleyi* FAD is low when only the optical microscope is applied.

An interpolated age of 468 ka has been proposed for the LAD of *P. lacunosa*. The LAD of *Gephyrocapsa* sp. 3 (sensu Rio, 1982) has been estimated to 584 ka. The FAD of this latter and the "re-entrance" of medium sized *Gephyrocapsa* define the top of the small *Gephyrocapsa* Zone which is calibrated here, for the first time in the Mediterranean area, with the interval immediately above the Jaramillo magnetic event (correlatable with middle and high latitudes in the world ocean), with an age of 944 ka. The base of an "acme" event of small *Gephyrocapsa*, occurring in the stratigraphic interval close to sapropel S8-S9, is calibrated with isotope stage 8 with an interpolated age of 265 ka.

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