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determination of a marine Plio/Pleistocene  
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# Biostratigraphical and paleoenvironmental determination of a marine Plio/Pleistocene outcrop in Cefallinia Island (Greece)

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## ABSTRACT

Lofos section is located in the southern part of Paliki peninsula in southwest Cefallinia island. It consists of 15-20 m of homogenous bluish marls with macrofossils and coarse grained alternations, followed by almost 10 m of sandy marls.

The data from the quantitative biostratigraphic analysis based on calcareous nannofossils of the studied material allow the correlation of the lower part of Lofos section with MNN19a biozone which chronostratigraphically points to an uppermost Pliocene. At about 16 m from the base of the section, it is possible to recognize the MNN19a/MNN19b biozones boundary which points to the Pliocene/Pleistocene boundary. The rest of the section can be assigned to Pleistocene.

Finally, a paleoenvironmental reconstruction and determination of the paleoenvironmental parameters is attempted based on the quantitative, paleoecological analysis of the benthic foraminifera. The paleoecological data indicate that the lower part of the studied sequence have been deposited in waters with lowered oxygen levels. Stagnant conditions became less severe in the course of deposition.

## RÉSUMÉ

Caractérisation biostratigraphique et paléoenvironnementale des affleurements marins Plio/Pleistocènes dans l'île de Cefallinia (Grèce). La coupe de Lofos est située dans le Sud de la péninsule de Paliki, au Sud-Ouest de l'île de Cefallinia. Elle est constituée par 15-20 mètres de marnes bleuâtres homogènes avec macrofossiles et alternances à grains grossiers ; elle se termine par presque 10 m de marnes sableuses.

**KEY-WORDS :** Cefallinia, Calcareous nannofossils, Plio/Pleistocene boundary, Benthic foraminifera, Paleoenvironment.

**MOTS-CLÉS :** Cefallinia, Nannofossiles calcaires, Limite Plio/Pleistocène, Foraminifères benthiques, Paléoenvironnement.

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Les données de l'analyse biostratigraphique basée sur les nannofossiles calcaires, permettent de corréler la partie inférieure de la coupe avec la biozone MNN19a chronostratigraphiquement située dans le Pliocène terminal. A environ 16 m de la base il est possible de reconnaître la limite entre les biozones MNN19a et MNN19b qui correspond à la limite Pliocène/Pleistocène. La suite de la coupe est attribuée au Pleistocène.

Un essai de reconstitution paléoenvironnementale et de détermination des paramètres paléoenvironnementaux, basé sur l'analyse paléocécologique quantitative des foraminifères benthiques est proposé : la partie inférieure de la séquence étudiée s'est déposée dans des eaux peu oxygénées ; les conditions de stagnation devenant moins sévères au cours du dépôt.

## I - INTRODUCTION

Cefallinia island is found in the Ionian Sea (Western Greece) which geographically is located opposite of the Gulf of Patras (Fig. 1). The evolution of this region, in terms of stratigraphy, micropaleontology, hydrogeology and geodynamics, has been studied by many authors (HAMILTON & STRICKLAND, 1847 ; PARTSCH, 1890 ; RENZ, 1955 ; MULLER-MINY, 1957 ; 1958, 1965 ; HAGN, 1958 ; AUBOUIN, 1959, 1965 ; GEORGIADIS-DIKEOULIA, 1967 ; BLANCVERNET & KERAUDREN, 1970 ; HUG 1970 ; SYMEONIDIS & SCHULTZ, 1970 ; BRAUNE & FABRICIUS, 1970 ; BRAUNE, 1973 ; BRITISH PETROLEUM co, 1971 ; DE MULDER, 1975 ; SOREL, 1976 ; HEIMANN, 1977 ; NIKOLAOU, 1986 ; UNNDERHILL, 1988, 1989 ; BROOKS *et al.*, 1988 ; KAHLE *et al.*, 1993 ; HATZFELD *et al.*, 1990 ; TRIANTAPHYLLOU, 1993 ; STIROS *et al.*, 1994).

The Oligocene and Miocene sedimentation area of Cefallinia island is situated in the external part of the

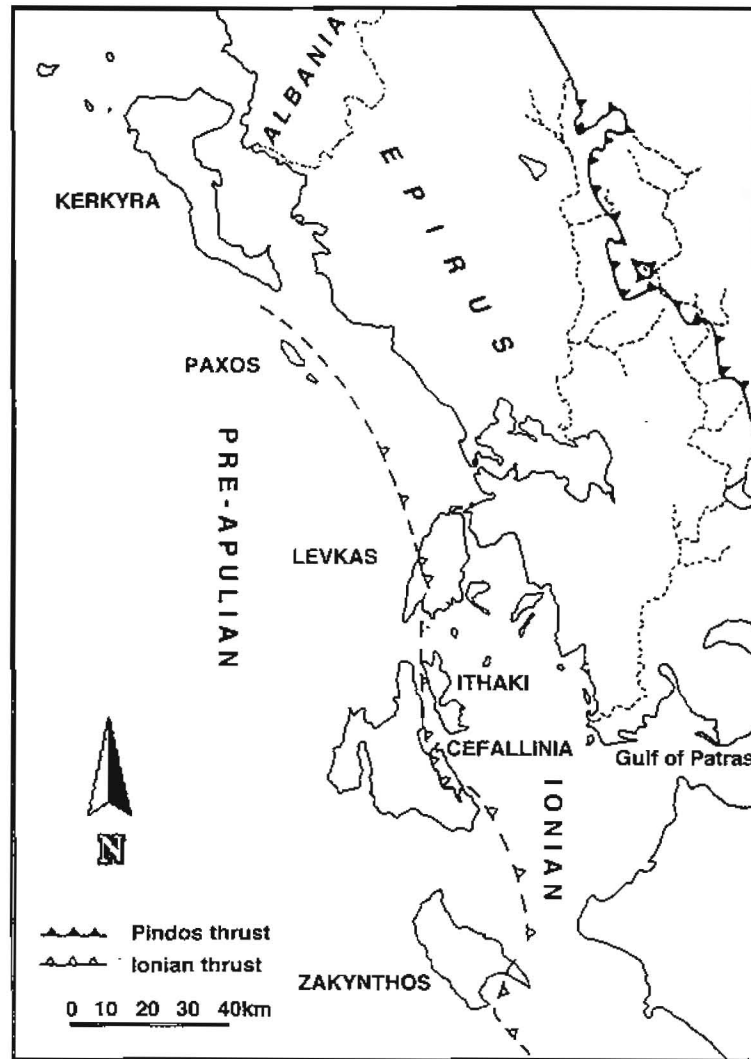


Figure 1 - Schematic map of NW Greece. The position of the major thrusts is approximate (after BIZON, 1967).

Carte schématique du N.W. de la Grèce. La position des chevauchements majeurs est approximative (d'après BIZON, 1967).

Hellenides, a NNW-SSE trending orogenic belt. In the concept of AUBOUIN (1959, 1965), the Alpine framework on which the Neogene basins of Cefallinia island are developed consists of the two zones of isopics in the External Hellenides: the Ionian and Pre-Apulian zones (Fig. 1). Most of the part of the island belongs to the Pre-Apulian zone, while only a small part in its southeast side comprises the Ionian zone (RENZ, 1913, 1940, 1955; AUBOUIN, 1959). The Pre-Apulian zone is separated from the Ionian zone by a major thrust fault, crossing the islands of Zakynthos, Cefallinia and Levkas.

Flysch-like sediments are absent from the Lower Miocene of the Pre-Apulian zone and the carbonate-dominated sequences of Cefallinia form part of a

progressive westward thinning with associated facies change.

Thickness variations and sedimentary patterns in the Serravallian-Tortonian of Cefallinia, including the presence of olistoliths indicate extensional faulting (UNDERHILL, 1989).

In Cefallinia, a major unconformity separates Messinian sequences from those of the Middle Pliocene. Sedimentation persists in well-defined basins in the Pre-Apulian zone during the late Pliocene. Thick Pliocene-Pleistocene delta-fan conglomerates in western Cefallinia were shed westwards and southwestwards (UNDERHILL, 1985).

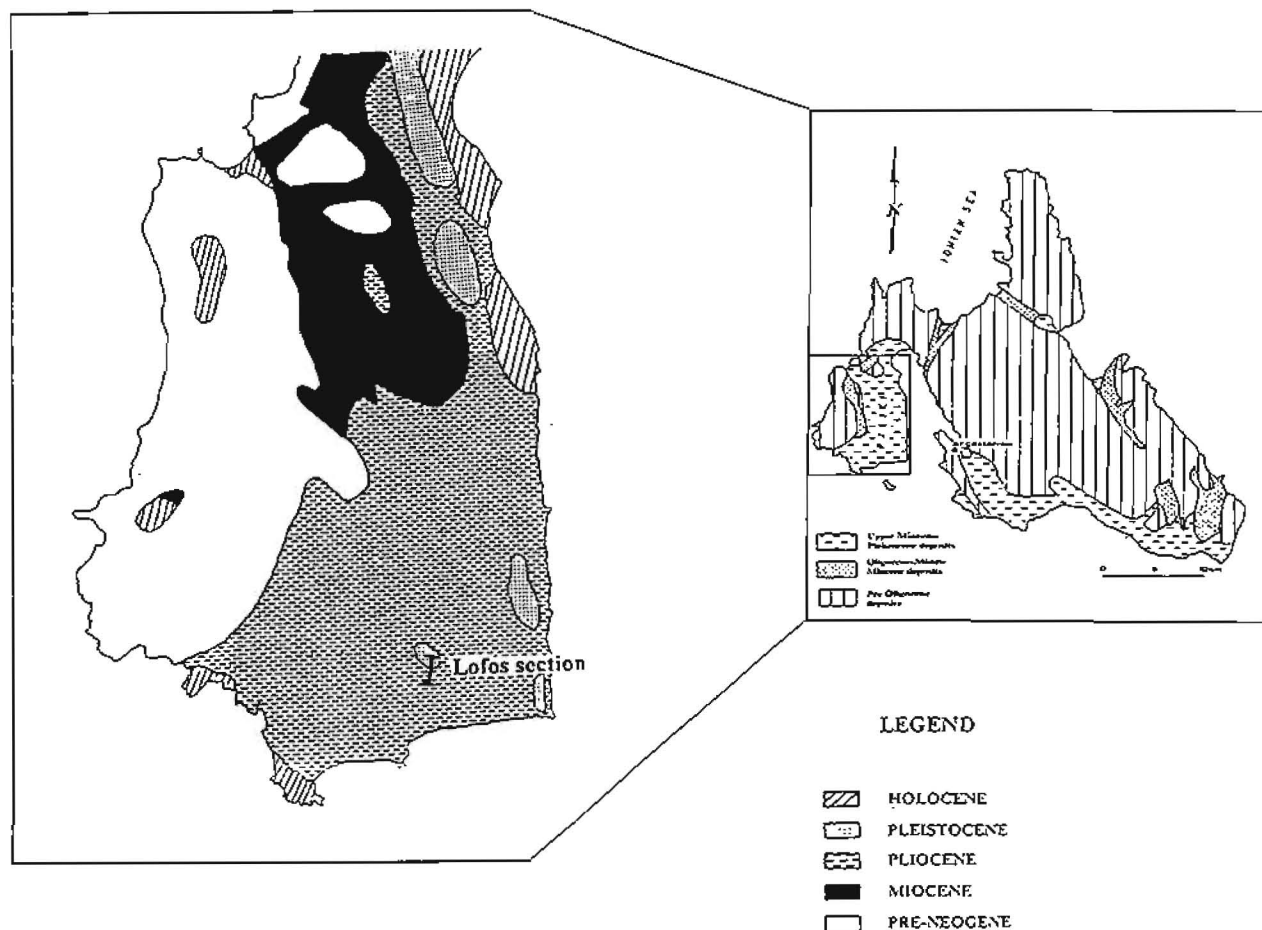


Figure 2 - Geological map of the study area (after de MULDER, 1975, modified by TRIANTAPHYLLOU, 1993).  
 Carte géologique du secteur étudié (d'après de MULDER, 1975, modifié par TRIANTAPHYLLOU, 1993).

The main goal of the present study is the paleoenvironmental reconstruction and the determination of the paleoenvironmental parameters which controlled the deposition of the Pliocene/Pleistocene sediments in the Paliki Peninsula in the southwest side of Cefallinia island. For this purpose a detailed biostratigraphical and paleoecological study has been carried out in a representative section exposed in that area, the Lofos section.

## II - LOCATION AND LITHOLOGICAL DESCRIPTION OF THE STUDY AREA

The study area is located in the southwest side of the island, in the Paliki Peninsula (Fig. 2).

Late Miocene to Pleistocene age sediments of south-western Cefallinia consist of predominantly clays and marls, which seem to have been affected by normal faulting only. These Upper Neogene and Pleistocene sediments are well exposed in coastal cliffs along the south coast and cover vast areas of the Paliki peninsula in the west (Fig. 2). DREMEL (1968) who studied the southern part of Cefallinia, assumed two successive transgressions in the Early Miocene. The first transgression started in the Aquitanian and continued into the Early Burdigalian, The second transgression took place later in the Burdigalian and marine sedimentation continued throughout the Middle and Late Miocene. DREMEL concluded that Cefallinia emerged during the Oligocene, but the authors of the Institut Français du Pétrole (1966) and BIZON (1967) reported a fairly continuous Oligocene to Upper Miocene biostratigraphic record from the northern side of the isthmus

connecting the Paliki peninsula with the main part of Cefallinia.

According to GEORGIADES-DIKEOULIA (1967), Paliki peninsula is the only area of Cefallinia island where the Miocene is exposed. Miocene deposits comprise marly limestones with characteristic macrofauna. As far as the Pliocene is concerned, this is extended along the east and south part of Paliki peninsula as well as along the south coast of Cefallinia. These deposits are composed of marls, silts and sandstones containing Lamellibranches, Gastropods (*Ostrea*, Pectinidae, *Natica*), Scaphopods, Echinoids and corals.

In addition, BLANC-VERNET & KERAUDREN (1970) recognized Calabrian marly sediments in Paliki peninsula by determining the benthic foraminifer *Hyalinea balthica* and TRIANTAPHYLLOU (1993) determined marly deposits of Early Pleistocene age by means of calcareous nanofossils, in the south part of Paliki peninsula and along the south coasts of Cefallinia.

The studied section is located at the side of a small hill (40 m height) in the southern part of Paliki peninsula (Fig. 2). It consists of 15-20 m of homogeneous bluish marls and scarce coarse grained alternations, followed by almost 10 m of coarser marly sediments (Unit 1). Massive calcarenite beds of Unit II are unconformably overlying and cover the top of the small hill (Fig. 3).

### III - MATERIAL AND METHODS

The distribution of calcareous nanofossil taxa was determined by light microscope techniques (plate 1). Preparation of smear slides for light microscope examinations followed standard procedures.

The calcareous nanofossil taxonomy and zonation are after RAFFI & RIO (1979); RIO (1982); RIO *et al.*, (1990); RAFFI *et al.*, (1993); TRIANTAPHYLLOU (1993); TRIANTAPHYLLOU *et al.*, (1997), to which the reader may be referred.

The quantitative methods of biostratigraphic analysis being used in the present study are those proposed by RIO *et al.*, (1990) and TRIANTAPHYLLOU (1993):

- counting of the index species versus the total nanofossil assemblage e. g. medium sized gephyrocapsids (counts in 300 placoliths > 3 µm).
- counting of the index species versus a fixed number of taxonomically related forms, e. g. *Helicosphaera*

*sellii* (counts in 50 specimens of the genus), *Calcidiscus macintyreii* > 10 µm (counts in 100 specimens of the genus), discoasterids (counts in 50 specimens of the genus).

The extraction of considered biostratigraphic information from the samples required these methods to be reproducible (RAFFI *et al.*, 1993).

The determination of the biostratigraphic events and the evaluation of the relative abundances of the index species, have been estimated on the philosophical basis of RIO *et al.* (1990) with minor changes due to the nature of the studied sediments.

Additionally, semiquantitative analyses (presence of the species in 40 fields of view under 1250X magnification), have been used for the estimation of very small forms (small *Gephyrocapsa* spp. ),

A paleoenvironmental interpretation of the studied sediments based on benthic foraminiferal associations is also attempted. The benthic foraminifera were identified at species level and counted as such.

This qualitative analysis was followed by a number of quantitative analyses. For the quantitative computer analyses we entered the species scores of some selected species or groups of species. Generally the most frequent categories were chosen for the statistical analyses. The relative frequencies are all based on 200-counts in the >125 µ size fraction. The Plankton/Benthos (P/B) ratio, expressed as the ratio of the number of planktonics per 200 counted benthonic specimens is also estimated,

In addition, the general relationship between Depth and %P ( $\%P = P/P+B \times 100$ ) is described according to :  $\text{Depth} = e^{(3.58718 + (0.03534 \times \%P))}$  (v. d. ZWAAN *et al.*, 1990).

The diversity of the species per sample is measured by using the SHANNON-WIENER formula (MARGALEF, 1968) which is :

$$H = \sum_{i=1}^M p_i \log_2 p_i$$

where  $p_i = n_i/N$  ( $n_i$  = being the number of individuals of the  $i^{\text{th}}$  species and  $N$  the total number of individuals) and  $M$  is the total number of species.

Finally the index of Evenness ( $J$ ) is defined by the formula  $J = H/H_{\text{max}}$  (MARGALEF, 1968) where  $H$  = diversity and  $H_{\text{max}} = \log_2 M$ .

Moreover, according to their reactions to environmental changes expressed in terms of food abundance-competition for food and salinity, the determined benthic foraminifera have been grouped in three categories (after v. d. ZWAAN, 1982).

**Group A** : comprises the species which show an indifferent reaction to any environmental change, which means that they are greatly tolerant to physical/chemical changes. These species are mostly epiphytes or vegetation bound or they show a positive correlation with the epiphytes. These are the following : *Cibicides lobatulus*, *C. refulgens*, *Discorbis* spp., *Asterigerina rhodiensis*, *Elphidium* spp., *Bolivina pseudoplicata*, Miliolids, *Ammonia beccarii*, *Bolivina antiqua*, *Planulina ariminensis*, *Neonorbina* sp., *Cibicides* sp., *Fursenkoina acuta*.

**Group B** : is composed of species which inhabit in stable marine conditions. They show intolerance to oxygen deficiency and increased salinity and they never proliferate during times of nutrient abundance. These are usually open marine species which inhabit a considerable depth range, living mainly on muddy substrates. These species are : *Cibicides dutemplei*, *Hanzawia boueana*, *Siphonina reticulata*, *Höglundina elegans*, *Melonis pompiloides*, *Melonis dutemplei*, *Melonis* sp., Agglutinants.

**Group C** : is represented by species which tolerate a great deal of environmental change and are tolerant to oxygen deficiency and salinity increase. They proliferate during periods of nutrient abundance (stressed and nutrient-rich environments) These are : *Bolivina spathulata*, *Bulimina aculeata neocarinata*, *Bulimina marginata*, *Bulimina costata*, *Cassidulina neocarinata*, *Bolivina alata*, *Gyroidinoides* sp., *Globocassidulina subglobosa*, *Gyroidinoides soldanii*, *Oridorsalis umbonatus*, *Uvigerina peregrina*, *Valvulineria bradyana*, *Uvigerina mediterranea*.

The above grouping has been attempted taking into consideration the fact that in Late Pliocene-Pleistocene times a considerable modification of the ecological patterns took place, which is shown by a rather systematic change of the species arrangement. Thus, a number of species which were formerly restricted to the group of stable marine species moved to the stress tolerant group. Under this statement, if *Uvigerina peregrina* is followed through time, one notes that this species was negatively correlated with oxygen deficiency during the Miocene but it becomes the dominant *Uvigerina* species in oxygen deficient waters, during the Plio-Pleistocene. Other examples are *Cassidulina neocarinata* and *Oridorsalis umbonatus* which are only minor constituents in Miocene associations that are indicative of oxygen deficient waters. These shifts coincided with and were probably related to the Late Pliocene event.

The nature of the Late Pliocene event, according to ZACHARIASSE & SPAAK, (1983) ; KEIGWIN & THUNELL (1979) ; THUNELL (1979 a, b) ; ZAGWIJN & SUC (1983) ; THUNELL & WILLIAMS (1983), is that cool-temperature surface waters from the

Atlantic entered the Mediterranean 2.3 Ma before. The benthic associations started to react clearly only from *Globorotalia inflata* Zone upwards. Therefore, the net effect of the Late Pliocene event was an increase in the bottom productivity. This might imply that the entrance into the Mediterranean of cool-surface waters and possible lowering of the surface water temperature resulted in a better vertical mixing of the water and, as far as the benthic foraminifera were concerned, ultimately higher productive systems.

#### IV - BIOSTRATIGRAPHY

For the biostratigraphic determination of Lofos section sediments, six samples have been analysed. The distribution patterns of three species and taxonomical groups (medium sized geophyrocapsids, *C. macintyreii*, *H. sellii*) have been established by applying the before-mentioned counting methods on the samples of Lofos section (Fig. 3).

In the lower part of the section the quantitative biostratigraphic analysis of the studied material revealed the total absence of discoasterids.

The species *Pseudoemiliana lacunosa* appears with nicely developed forms. Moreover, *H. sellii* is present with high percentages whereas *C. macintyreii* shows low abundances.

Semiquantitative analyses pointed to an intense presence of transitional forms (almost 3,5 µm in size) of the genus *Gephyrocapsa*.

As far as the planktonic foraminifera are concerned, *Gt. inflata* has been found along with *Gt. scitula* specimens and transitional forms to *Gt. bononiensis*, especially to the lower parts of the section.

However, the total absence of discoasterids, the good development of *P. lacunosa* specimens, the increased presence of transitional forms (almost 3,5 µm in size) of the genus *Gephyrocapsa* and the presence of the planktonic foraminifer *Gt. inflata* may allow the correlation of the lower part of Lofos section (till 16 m of the base) with MNN19a biozone (RIO *et al.*, 1990), NN19 (MARTINI, 1971), (Fig. 4).

Concerning the 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 an uppermost Pliocene age.

The first appearance of *Gephyrocapsa* specimens

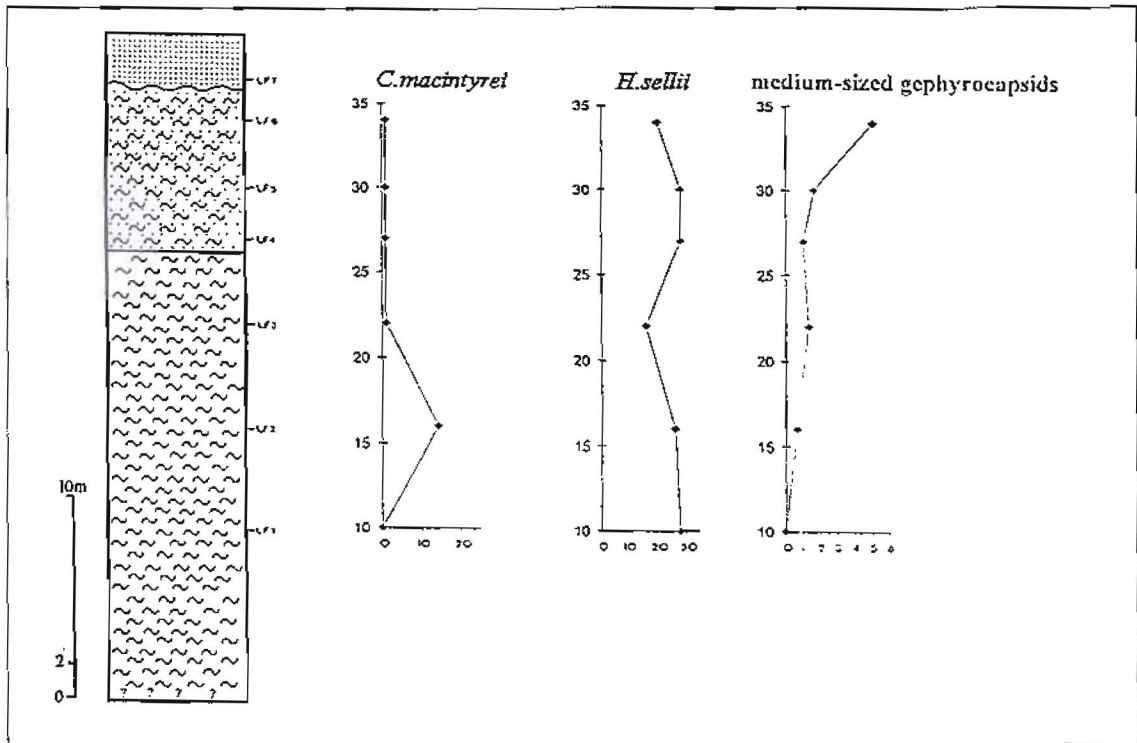


Figure 3 - Lithostratigraphic column for the Lofos section and relative abundances of the main calcareous nannofossil representatives. Note the different scale used for expressing the percentage of medium-sized gephyrocapsids. Colonne stratigraphique de la coupe de Lofos et abondance relative des principaux nannofossiles calcaires. Notez les échelles différentes utilisées pour exprimer le pourcentage des gephyrocapsides de taille moyenne.

TIME (Ma)	CHRONOS	POLARITY	EPOCH	AGE	FORAMINIFERA		NANNOFOSSILS				
					CITA 1975 (emend)	SPAAR 1983	RIO et al. 1990				
1	C1n	■	PLEISTOCENE	LATE	<i>Globorotalia truncatulinoides excelsa</i>	IX	MNN 20b	<i>E. huxleyi acme</i>			
				MIDDLE			MNN 21a	<i>Emiliania huxleyi</i>			
							MNN 20	<i>Gephyrocapsa oceanica</i>			
	C1r	■	EARLY	CALABRIAN			MNN 19i	<i>Pseudoemiliania lacunosa</i>			
							MNN 19e	Small <i>Gephyrocapsa</i>			
							MNN 19d	Large <i>Gephyrocapsa</i>			
2	C2n	■	PLIOCENE	LATE	<i>G. cariacensis</i>	VII	MNN 19c	<i>H. sellii</i>			
							MNN 19b	<i>C. macintyreii</i>			
	C2r	■		GELASIAN			MPL 6	MNN 19a	<i>Dictyococcites productus</i>		
							MPL 5	VIII	MNN 18	<i>Discoaster brouweri</i>	
	C2An	■		PIACENZIAN				LATE	MPL 5	VI	MNN 16b
							MNN 17				

Figure 4 - Biostratigraphic location of the studied Lofos section based on calcareous plankton stratigraphy in the Mediterranean. Magnetostratigraphy is based on BERGGREN et al. (1995a, b). Position biostratigraphique de la coupe de Lofos, basée sur le plancton calcaire de Méditerranée. La magnétostratigraphie est basée sur BERGGREN et al. (1995 a-b).

with the features of the taxonomical group of medium sized gephyrocapsids - ranging in size between 4  $\mu\text{m}$  up to 5.5  $\mu\text{m}$  - with a bar and a relatively open central area (RAFFI *et al.* 1993), is located at the interval between samples LF2 and LF3, about 16 m above the base of the section. Data derived from all major ocean basins (western and equatorial Pacific, northwestern North Atlantic) as well as marginal seas (Caribbean, western Mediterranean) clearly depict the sharpness by which  $> 4 \mu\text{m}$  forms first appear (RAFFI *et al.* 1993). This event has also clearly recognised in the eastern Mediterranean / Ionian islands (TRANTAPHYLLOU, 1993, TRIANTAPHYLLOU *et al.*, 1997),

The first appearance datum of medium sized gephyrocapsids, which corresponds to an evolutionary appearance, has been calibrated to the new GPTS and has proved to be a reliable, distinct and easily recognised biochronologic datum (BERGGREN *et al.* 1995b). This datum event represents the first of a set of Pleistocene calibrated bioevents, providing a high degree of stratigraphic resolution.

The appearance of medium sized gephyrocapsids in combination with the intense presence of transitional gephyrocapsid types (with an approximate size of 3.5  $\mu\text{m}$ ) allows the recognition of MNN19a/MNN19b biozones boundary (RIO *et al.* 1990) suggesting an age of 1.71 Ma (LOURENS *et al.*, 1996) for the stratigraphic interval between the samples LF2 and LF3. Therefore it is possible to define the Pliocene/Pleistocene boundary at the specific point, based on biostratigraphic events.

The rest of the sequence, till the unconformity surface can be assigned to MNN19b biozone (RIO *et al.*

1990) and NN19 (MARTINI 1971), CN13a (OKADA & BUKRY 1980). Concerning planktonic foraminifera, these biozones can be correlated with the lower parts of the *Globorotalia cariacensis* zone (CITA 1975 emend.) and the biostratigraphic interval IX (SPAARK 1983). This points to Lower Pleistocene age.

The unconformably overlying massive calcarenitic beds can be generally assigned to Pleistocene.

## V - PALEOENVIRONMENTAL ANALYSIS

### 1 - Surface water conditions

Coccolith distribution patterns indicate environmental preferences. They are sensitive indicators of surface water temperature and to a lesser degree of surface water fertility (ROTH & BERGER 1975 ; ROTH & COULBOURN 1982). It is well established that patterns of accumulation of coccoliths in the sediment reflect environments of production in the overlying surface waters (ROTH & BERGER 1975).

Therefore calcareous nanofossils can be useful markers of surface water paleoenvironmental changes at the investigated Plio-Pleistocene sediments in Cefallinia island. For this purpose, a quantitative analysis has been carried out for the nanofossil group of *Helicosphaera* spp., and for the species *Coccolithus pelagicus* (Fig. 5).

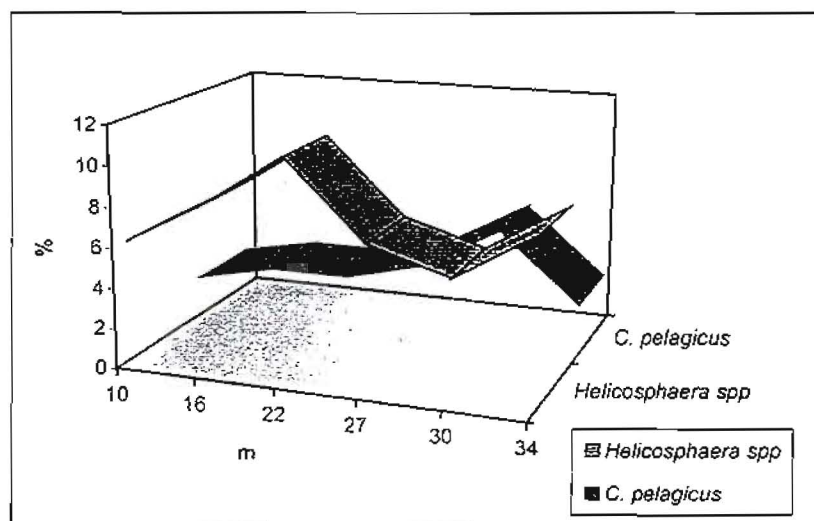


Figure 5 - Frequency curves of *Helicosphaera* spp. and *C. pelagicus* from the studied deposits.  
 Courbes de fréquences de *Helicosphaera* spp. et *C. pelagicus* dans les dépôts analysés.



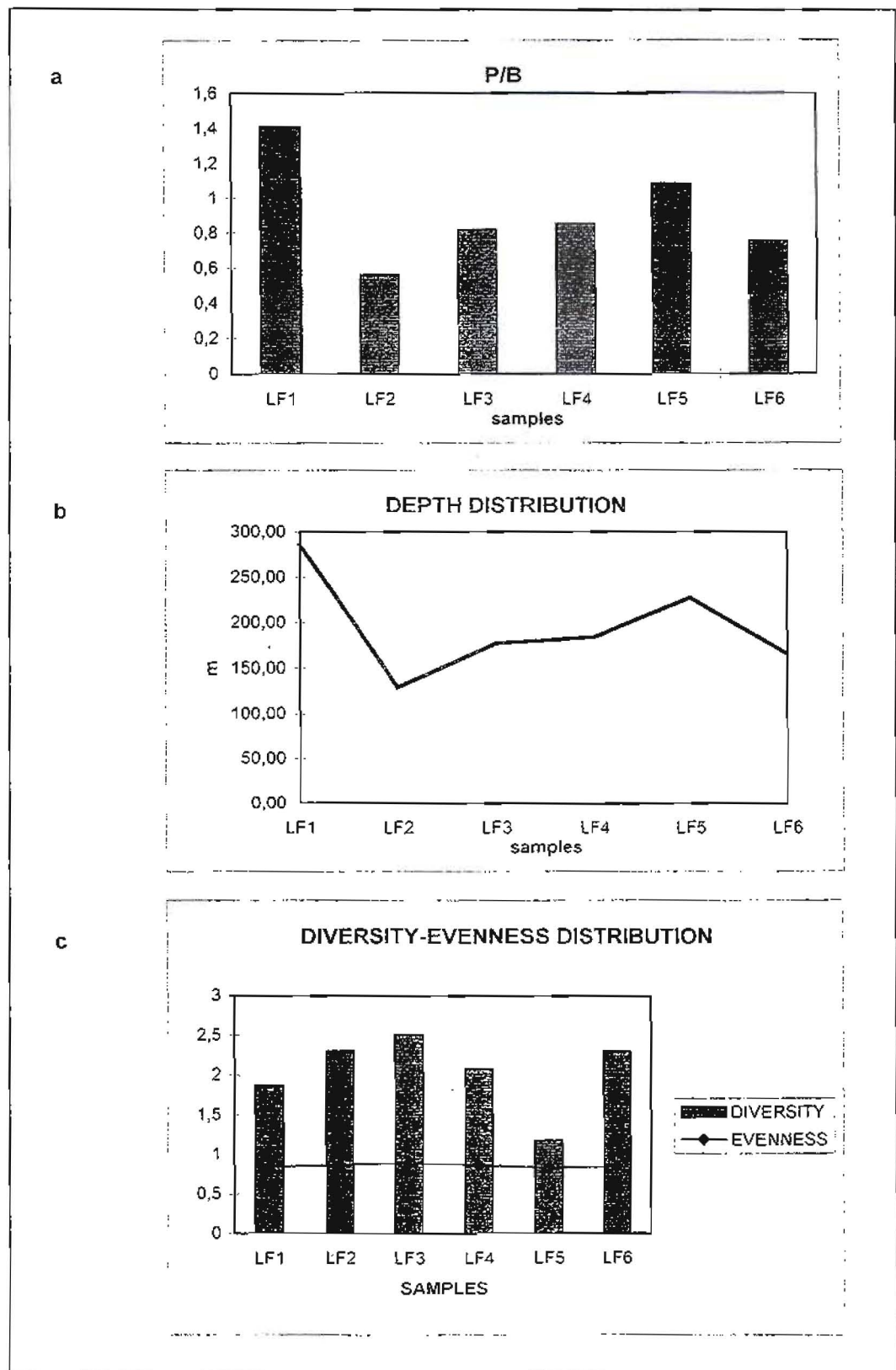


Figure 6 - a : relation of the estimated planktonik/benthic ratios in the studied samples ; b : depth distribution ; c : distribution of the Diversity and Evenness indices in the studied samples.  
 a : rapports planctoniques / benthiques dans les échantillons étudiés ; b : distribution en fonction de la profondeur ; c : diversité et indices de similitude dans les échantillons étudiés.

• *Helicosphaera* spp. is varying throughout the whole Unit I of Lofos section with low frequencies ranging from 5-10 %. The genus *Helicosphaera* generally represents relatively warm environments (20-28° C) (ROTH & BERGER, 1975) and is associated with upwelling regimes (PERCH-NIELSEN, 1985).

• The frequencies of *C. pelagicus* do not exceed 8 %. The species *C. pelagicus* has a narrow and disjunct distribution. It is found only in the North Atlantic and the North Pacific. Its temperature range is 6-14° C and its highest concentrations recorded to date occur between 9 and 12° 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 to medium sized gephyrocapsids appearance, near the Pliocene/Pleistocene boundary, the abundance of *C. pelagicus* drops drastically and, in the basal Lower Pleistocene, it completely disappears.

• Small *Gephyrocapsa* spp. (< 3.5 µ) are abundant along with transitional gephyrocapsid forms with an approximate size of 3.5-4 µ.

• Medium sized gephyrocapsids > 4µ are present from the middle part of Unit I. *G. oceanica*, which belongs to these forms, is an important component of coccolith assemblages found to be frequent in or under warm waters of high to moderate fertility (ROTH & COULBOURN, 1982). It prefers marginal seas with

normal to high salinity (OKADA & HONJO, 1975) and even resists up to 45-51 ‰ (WINTER, 1982). Generally, gephyrocapsids characterise transitional nanoplankton associations in the Atlantic Ocean (MCINTYRE & BE, 1967 ; OKADA & MCINTYRE, 1979).

It must be noted that the open sea records indicate that the Pliocene/Pleistocene boundary was not marked by any significant climatic change. The Mediterranean appears to be an exception to this situation in that a regional cooling event does occur across this interval. (RIO *et al.* 1990). LOURENS *et al.* (1992) showed that short-term variations in surface water temperature of Late Pliocene to Early Pleistocene Mediterranean sediments are controlled both by precession and obliquity, whereas similar variations in surface water productivity are almost exclusively controlled by precession.

Conclusively, the combination of the above mentioned data from the studied Plio/Pleistocene deposits in Cefallinia island, suggests cold environmental conditions with increase of primary productivity (absence of discoasters, abundance of small *Gephyrocapsa* spp. and *Goborotalia inflata*, low frequencies of helicoliths), and a tendency to higher surface temperatures, indicated by the presence of medium sized gephyrocapsids.

## B - Bottom-water conditions

The study of the benthic microfauna has allowed the following qualitative analysis of Lofos section :

<i>Ammonia beccarii</i> ( LINNE )	<i>Hantzawaia boueana</i> ( d' ORB. )
<i>Angulogerina angulosa</i> ( WILLIAM. )	<i>Hoeglundina elongans</i> ( d' ORB. )
<i>Asterigerina rhodiensis</i> TERQUEM	<i>Logena sulcata</i> ( WAL. & JAC. )
<i>Astrononion</i> sp.	<i>Lenticulina</i> sp.
<i>Bolivina alata</i> ( SEQUENZA )	<i>Massilina milleti</i> ( WIESNER )
<i>Bolivina antiqua</i> d' ORB.	<i>Melonis pombillioides</i> ( FIC. & MOL. )
<i>Bolivina midwayensis</i> CUSHMAN	<i>Melonis</i> sp.
<i>Bolivina pseudoplicata</i> HER.- AL. & EAR.	<i>Neoconorbina</i> sp.
<i>Bolivina spatulata</i> ( WILLIAM. )	<i>Nodosaria scalaris</i> ( BATSCHE )
<i>Bolivina striatula</i> CUSHMAN	<i>Oolina</i> sp.
<i>Bulimina aculeata</i> ( d' ORB. )	<i>Oridorsalis umbonatus</i> ( REUSS )
<i>Bulimina costata</i> d' ORB.	<i>Planulina ariminensis</i> ( d' ORB. )
<i>Bulimina marginata</i> ( d' ORB. )	<i>Praeglobulimina pyrula</i> ( d' ORB. )
<i>Cassidulina carinata</i> SILVESTRI	<i>Pyrgo carinata</i> d' ORB.
<i>Cibicides duempei</i> ( d' ORB. )	<i>Quinqueloculina bicarinata</i> d' ORB.
<i>Cibicides lobatulus</i> ( WAL. & JAC. )	<i>Quinqueloculina</i> sp.
<i>Cibicides</i> trans. type <i>refulgens</i>	<i>Quinqueloculina triangularis</i> d' ORB.
<i>Cribrononion</i> sp.	<i>Scutulopsis</i> sp.
<i>Cyclagyra</i> sp.	<i>Sigmaitopsis schlumbergeri</i> ( SILV. )
<i>Discorbis pateriformis</i> BELLER	<i>Siphonina reticulata</i> CZIZEK
<i>Discorbis</i> sp.	<i>Spiroplectanumina carinata</i> d' ORB.
<i>Dorothia</i> sp.	<i>Spirosignollina tenuis</i> ( CZIZEK )
<i>Elphidium aculeatum</i> ( d' ORB. )	<i>Sitostomella challengeriana</i> ( THAL. )
<i>Elphidium crispum</i> ( LINNE )	<i>Sitostomella adolphina</i> ( d' ORB. )
<i>Elphidium fichtellianum</i> ( d' ORB. )	<i>Sitostomella gracilis</i> ( PAL. & BER. )
<i>Elphidium granosum</i> ( d' ORB. )	<i>Textularia agglutinans</i> d' ORB.
<i>Fissurina</i> sp.	<i>Textularia candellana</i> d' ORB.
<i>Fursenkoina acuta</i> ( d' ORB. )	<i>Uvigerina mediterranea</i> HOFKER
<i>Globocassidulina subglobosa</i> ( BRAD. )	<i>Uvigerina peregrina</i> CUSHMAN
<i>Gyrogonoides soldanii</i> ( d' ORB. )	<i>Valvulineria bradyana</i> FORNASINI

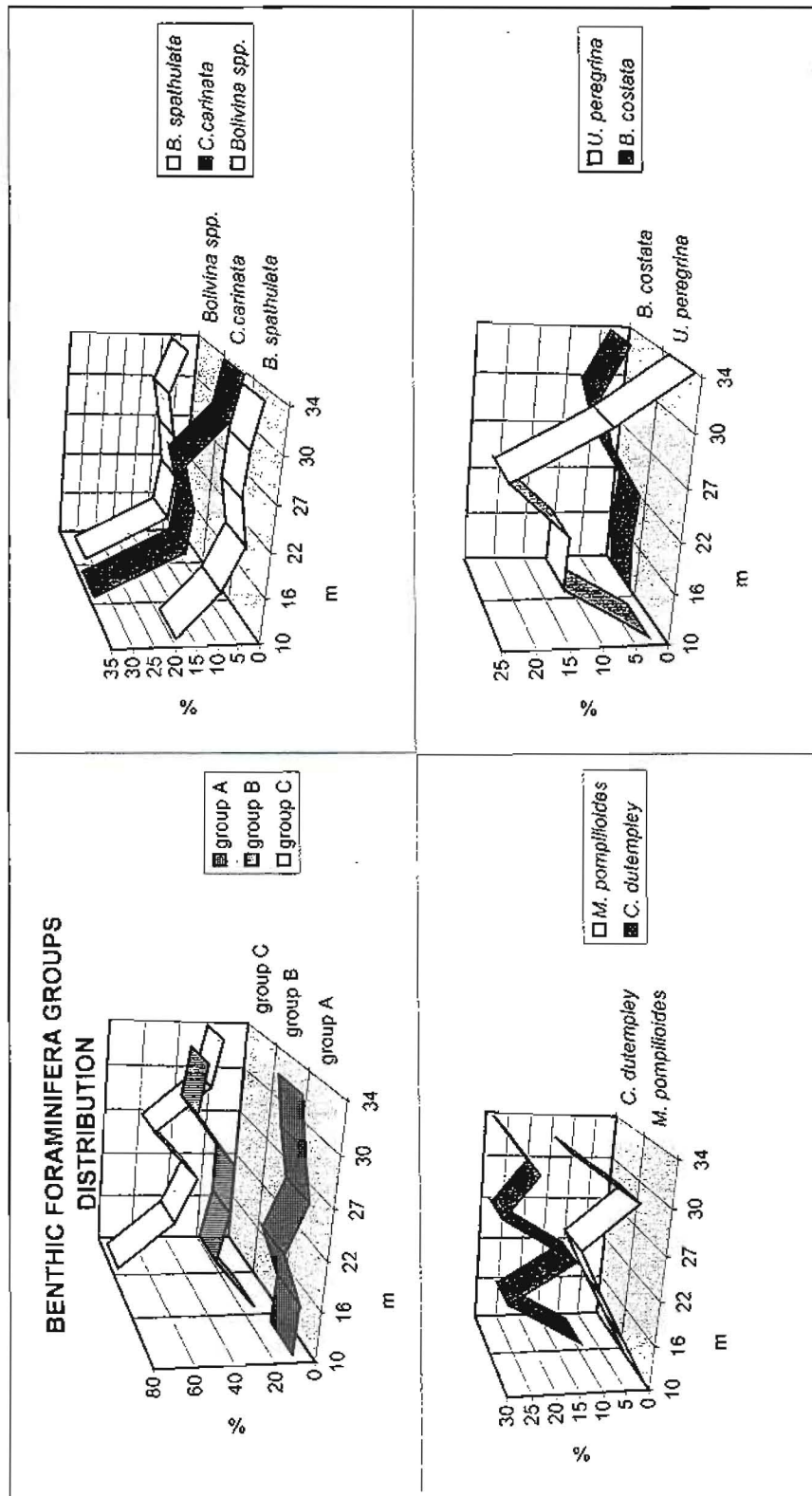


Figure 7 - Frequency curves of the benthic foraminifera in the studied samples.  
 Courbes de fréquence des foraminifères benthiques dans les échantillons étudiés.

From the quantitative data and the plotted diagrams the following have been concluded :

The Plankton/Benthos ratio (P/B) (Fig. 6a), varies between 0,5 and 1,4 ; the relatively high values is confined to the lower part of the section. It must be noted that the relative P/B ratios which dominate during Lofos section deposition, indicate a rather shallow-marine environment (~ 250 m). Moreover, the P/B ratio which is correlated with depth (GRIMSDALE & VAN MORKHOVEN, 1955 ; STEHLI, 1966 ; HALLAM, 1967), is also known to be sensitive to productivity (PHLEGER, 1960 ; DIESTER-HAASS, 1978 ; LUTZE, 1980). Therefore, when interpreting P/B ratios, then, three environmental factors—depth, food supply and partial dissolution of carbonate must be considered. In addition, BERGER & DIESTER-HAASS (1988) used the P/B ratio as a productivity index. Under this respect, the elevated percentage of the planktonic foraminifers in LF1 and LF5 samples may be due to an increase to the flux of primary produced organic matter (ZACHARIASSE *et al.*, 1990, ZIJDERVELD *et al.*, 1991) or a shortage in terrigenous clastic material influx.

The depth of deposition as this has been reconstructed using the relevant formula ranges from 128,95 to 285,86 m (Fig. 6b).

As far as the Diversity-Evenness indices are concerned, apart from LF5 sample, these remain rather constant with small scale changes (Fig. 6c). The low diversity index H of LF5 (~1) goes with the predominance of one species which is *Uvigerina peregrina*. The Evenness Index (J) remains constant for the six samples ranging from 0,7 to 0,95 indicating a trend for predominance of one species.

Overall, the studied sequence is characterized by low percentage values of the representative taxa of Group A (epiphytes) which may indicate the absence of well-vegetated areas in the proximity of the deposition area of the sequence or deposition below the photic zone.

From the frequency diagrams (Fig. 7) it may be inferred that *Bolivina spathulata* reaches its highest relative frequencies in the lower part of the section while *Bulimina costata* has high percentage values in the middle part of the section. *Cassidulina carinata* seems to display an decrease from the bottom to the top of the section. The same trend is followed by *Bolivina* spp.

The high number of planktonic foraminifers in the lower part of the section (sample LF1) may be interpreted in terms of high (selective) productivity. The relative low diversity may be caused by the high relative abundance of species of the genus *Bolivina* especially of *Bolivina spathulata*. High relative and total abundances of *Bolivina* species are known to occur in areas

where the bottom waters are deficient in oxygen, and the sediments are rich in organic matter (BOLTOVSKOY & WRIGHT, 1976 ; THOMAS, 1986). Such circumstances exist in basins or shelf-slope areas with sluggish circulation, Oxygen deficiencies in bottom waters also exist in shelf and slope areas in the oxygen-minimum zone (generally between 200 and 1 500 m depth), and are caused by accumulation of large amounts of organic matter in zones of high surface productivity (upwelling) (BOLTOVSKOY & WRIGHT, 1976 ; SEN GUPTA *et al.*, 1981 ; POAG & LOW, 1985). Upwelling phenomena may have played a role, but it may as well be argued that these high productivities were caused by a nutrient supply that was related to fresh-water input. If this interpretation is correct then a density stratification between the upper, slightly less saline part of the water column and a lower, denser, more or less stagnant lower water mass will be created. The more or less stagnant lower part of the water column ultimately resulted in oxygen deficiency at the bottom which affected bottom life. In the benthonic foraminifera, these bottom conditions are expressed by high percentage values of some more tolerant species like *Bolivina spathulata* and *Cassidulina neocarinata*. As far as *Cassidulina neocarinata* is concerned, from the literature it is known that *Cassidulina* species can be found in a variety of habitats. Evidently, depth does not seem to be a major controlling factor for the distribution of this taxon. Data from the fossil record of Plio-Pleistocene sediments in Peloponnese show that *C. neocarinata* reaches its highest value in sediments which were deposited in the most marine of the shallow environments (HAGEMAN 1979). The decrease of bottom life is reflected by the high P/B value. Bottom conditions, however, never became so extreme that only a few taxa could survive. In particular, *Bolivina spathulata* may be regarded as a very productive species under low oxygen/high food conditions. Abundance of food, the absence of "predators" and low competition were thought to be responsible.

The environmental conditions must have changed during the deposition in shallower waters of the sample LF2. From the relative low percentages of planktonic foraminifera one may infer that the conditions favouring high selective productivity came to an end. Moreover, representatives of the *Cibicides dulemplei*, *Bulimina costata* and *U. peregrina* show high percentage values. The conditions that led to the high numbers of representatives of *U. peregrina* are not understood. It is possible that an increase of the salinity played a role in the shallow seas at the time. Representatives of this group are probably tolerant to high salinities.

During deposition of LF3 sample, bottom conditions were slightly more favourable as this is indicated by the higher percentage values of Group A and the decrease of Group C. This fact is also supported by the

absence of *Bulimina costata* species, and the decrease in percentage value of *Cibicides dutemplei*. The relatively high occurrence of representative species of Group A suggest that these shallow living species were all transported basin-inwards by plant-rafting and should therefore be considered as allochthonous in deeper mud-environments.

During the deposition of LF4 sample the environmental conditions have changed. Unfavourable bottom conditions are indicated by the peak occurrences of *Uvigerina peregrina* and *Bulimina costata*, which are intermediate species between groups B and C, and the relatively high percentage values of *Cassidulina neocarinata*.

LOHMAN (1978) concluded that with decreasing oxygen content the abundance of *U. peregrina* increases. Stronger evidence of oxygen and nutrient dependence of this benthic species is provided by the data of CITA & ZOCCHI (1978) concerning the distribution of benthic foraminifera in the deeper parts of the Mediterranean. In addition, SEIGLIE (1968) found *U. peregrina* to be correlated with sediments rich in organic matter. Furthermore, the high percentage value of *Bulimina costata* which is an open marine, mud-dweller species proliferating in oxygen-depleted environments supports the above environmental conditions. However, the low percentage values of *Bolivina spathulata* and *Bolivina* spp. indicate that the *Uvigerina-Bulimina* association dominated in an environment with lesser stress and less enriched in nutrients. *Bulimina costata-Uvigerina* s. s. indicate bottom conditions less strongly affected by oxygen deficiency.

The coexistence of the highly abundant *Cibicides dutemplei* and *Melonis pompilioides* (representative taxa of Group B), which are deep water epifaunal forms (indicative of relatively favourable conditions, CORLISS & CHEN, 1988), with the frequent *Uvigerina peregrina* probably indicates high salinity conditions.

The last two samples of the section, LF5 and LF6 are characterised by the predominance of Group B. Group B is regarded by v.d. ZWAAN (1982) as characteristic for stable, deep-marine conditions, not greatly affected by changes of salinity, oxygen content or nutrient amount. LF6 sample contains a rather rich and diversified benthic fauna which points to a stable marine environment; shallow marine elements or epiphytes are scarce pointing to a depth of deposition well below the photic zone.

In conclusion, the paleoenvironmental data indicate that the upper part of the studied sequence has been deposited in well oxygenated waters. The sediments of the lower part of the section are inhabited by low diverse faunas, consisting mostly of *Bolivina* species, indicating

an oxygen-poor area. Thus, the specific compositions of benthonic faunas in moderately to extremely oxygen-poor environments seem to confirm the stagnation gradient. Stagnant conditions became less severe in the course of deposition. Along with an increase in oxygen content of the bottom waters, the amount of organic matter may in turn have decreased, due to a higher degree of oxydation and possibly to nonenhanced production in the surface waters. As conditions become more favourable (more oxygen available), species with somewhat different environmental tolerances survive.

## VI - CONCLUSIONS

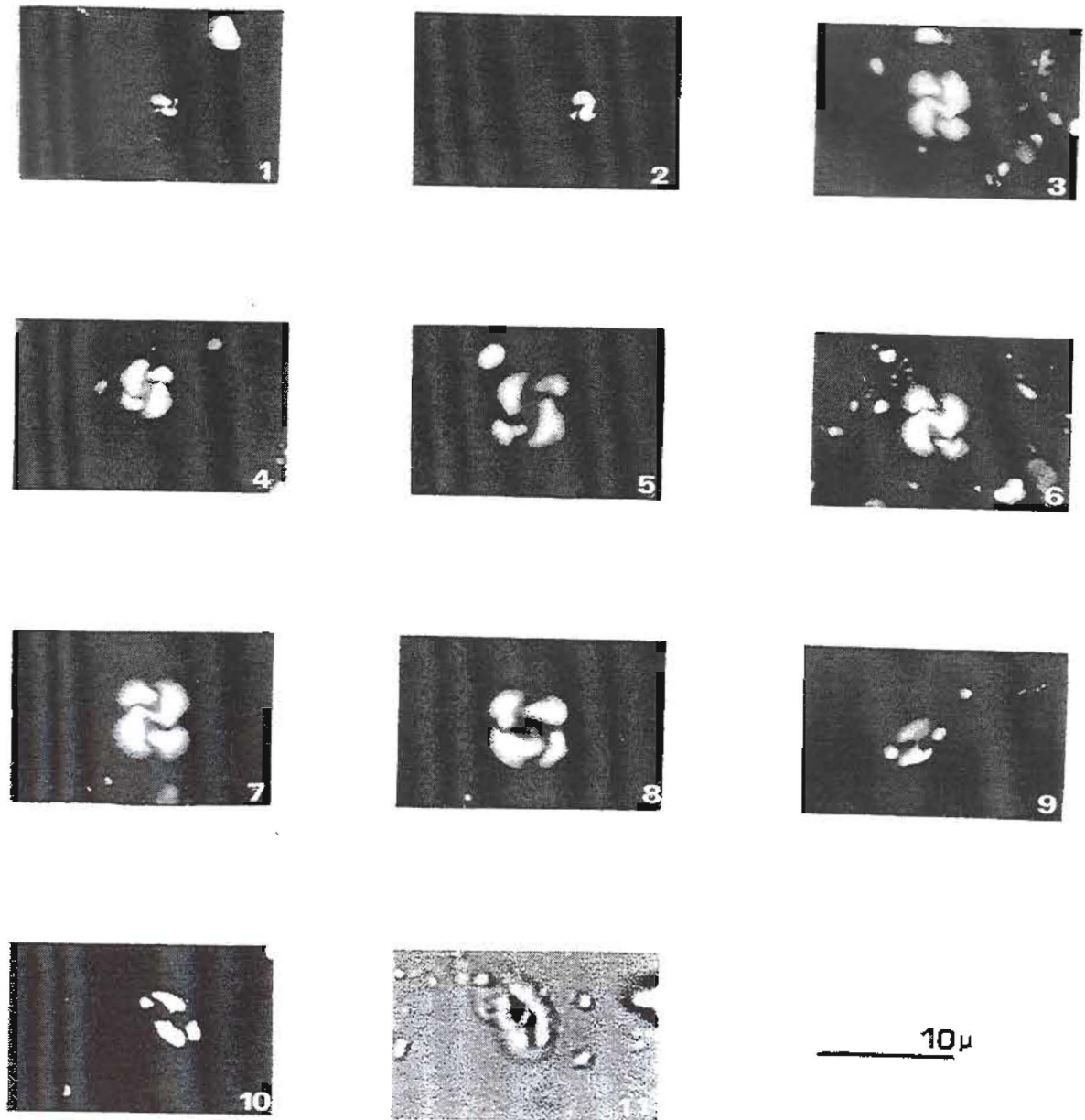
The biostratigraphic and paleoecological analysis of the deposits of Lofos section (Paliki peninsula, SW Cefallinia) led to the following conclusions:

- The total absence of discoasterids, the abundance of transitional forms (almost 3.5  $\mu\text{m}$  in size) of the genus *Gephyrocapsa*, the good development of *P. lacunosa* specimens and the presence of the planktonic foraminifer *Gl. inflata* allow the correlation of the lower part of Lofos sections with MNN19a biozone, which chronostratigraphically points to the uppermost Pliocene.
- The first appearance of *Gephyrocapsa* specimens at about 16 m from the base of the section with the features of medium sized *gephyrocapsids* in combination with the intense presence of transitional types of *gephyrocapsids* allows the recognition of the base of zone MNN19b.
- The rest of the section, including also the unconformably overlying calcarenitic beds, can be assigned to Pleistocene.
- The depth of deposition as this can be estimated by the P/B ratio and calculated by the relevant formula corresponds to shallow-marine environment (~ 250 m), well below the photic zone. The low percentage values of the representative benthic taxa of Group A further support this conclusion.
- The lower part of the studied sequence have been deposited in waters with lowered oxygen levels. Stagnant conditions became less severe in the course of deposition.
- The studied Plio/Pleistocene deposits in Cefallinia island, suggest cold environmental conditions with increase of primary productivity, and a tendency to higher surface temperatures

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## PLANCHE 1

1. Small *Gephyrocapsa* spp. Sample LF3.
2. Small *Gephyrocapsa* spp. Sample LF5.
- 3, 4. Medium-sized *gephyrocapsids*. Sample LF3.
5. Medium-sized *gephyrocapsids*. Sample LF5.
- 6, 7, 8. Medium-sized *gephyrocapsids*. Sample LF6.
9. *Helicosphaera setti* (BUKRY & BRAMLETTE) JAFAR & MARTINI. Sample LF3.
- 10, 11. *Helicosphaera setti* (BUKRY & BRAMLETTE) JAFAR & MARTINI. Sample LF5.