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QUANTITATIVE CALCAREOUS NANNOFOSSIL BIOSTRATIGRAPHY OF BAY AKROTIRI SECTION (CEFALLINIA ISLAND, W.GREECE). TRACING THE GEPHYROCAPSID SIZE - TREND IN AN EARLY PLEISTOCENE TERRIGENOUS SEQUENCE

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ABSTRACT

Bay Akrotiri section represents a thick terrigenous sequence laying along the southern part of Paliki peninsula (southwest Cefallinia). The data of the calcareous nannofossil quantitative analysis indicate that the studied sediments are ranging in terms of age between 1.95 Ma and 1.238 Ma approximately. The provided distribution patterns clearly depict an apparent evolutionary lineage close to the Plio/Pleistocene boundary, from small *Gephyrocapsa* placoliths to larger forms of gephyrocapsids.

KEY WORDS: biostratigraphy, calcareous nannofossils, Plio/Pleistocene, gephyrocapsids

1. INTRODUCTION

The quantitative study of nannofossil assemblages has proven to be necessary in order to obtain precise age assignments for the terrigenous sediments (Triantaphyllou 1993,1998, Frydas *et al.,* 1995, Marino 1996).

The Late Miocene to Pleistocene age sediments of southwestern Cefallinia are mainly composed of marls, silts, silty clays, sandstones and calcarenites. These Upper Neogene and Pleistocene sediments are well exposed in coastal cliffs along the southwestern (Paliki peninsula) and southern part of the island (Georgiades-Dikeoulia (1967), Symeonidis & Schultz (1970), etc).

The main goal of the present study is to perform calcareous nannofossil analyses in order to obtain a more precise determination of biozones, improve the biostratigraphic resolution and provide new chronostratigraphic data on the sedimentary evolution of the Plio/Pleistocene of the Paliki peninsula on Cefallinia island.

Additionally this paper presents the gephyrocapsid size-trend in the terrigenous sequences of Bay Akrotiri, through a biometrically defined classification scheme –dealing with the morphologically most distinct features, which are (Fig.2) the mean bridge angle (a^0) and the mean placolith length (L), Rio(1982), Raffi *et al.* (1993), Bollmann (1997)- that can be applied with light microscope techniques. Is is well known that the gephyrocapsids increased progressively in overall size throughout the Early Pleistocene (Rio 1982, Raffi *et al.*1993). We used the Early Pleistocene deposits from Cephallinia island in order to reinforce the statement that this genuine evolutionary trend seems to have been developed simultaneously in all major ocean basins and marginal seas. Frydas *et al.* (1995) have also used gephyrocapsid representatives for the biostratigraphic subdivision of Middle-Late Pleistocene deposits of W. Peloponnesus, managing to distinguish four different species of the genus *Gephyrocapsa,* with biometric criteria.

It must be noted that we do not intend to distinguish species among the small representatives of gephyrocapsids, which are certainly difficult to be identified confidently under the light microscope. Moreover Bollmann (1997) showed that the morphology of the genus *Gephyrocapsa* assemblages correlates significantly with environmental gradients and questioned their assignment in formalized species. On the contrary, the only bioevents that have been used for biostratigraphic purposes are these which have already been calibrated versus the GPTS and stable isotope stratigraphy (Berggren *et al.,* 1995b), and therefore commonly used and widely accepted (Table 1).

2. PREVIOUS STUDIES, SELECTED MATERIAL AND METHODS

In Cefallinia island (Ionian Sea, western Greece), 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 west-

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wards and southwestwards (Underhill, 1989). Blanc-Vernet & Keraudren (1970) recognized Calavrian marly sediments in Paliki peninsula by determining the benthic foraminifer *Hyalinea balthica*, Triantaphyllou (1993) determined marly deposits of Early Pleistocene age by means of calcareous nannofossils, in the south part of Paliki peninsula and along the south coasts of Cefallinia, and Triantaphyllou *et al.*,(1999) studied the paleoenvironmental reconstruction of the Pliocene/Pleistocene sediments in the Paliki Peninsula.

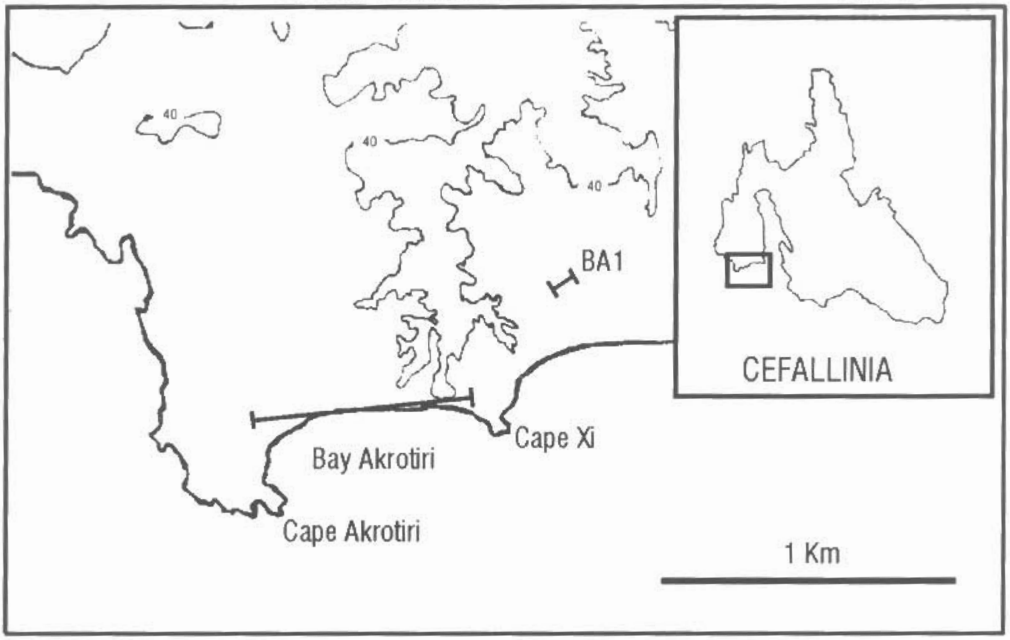

Fig.1. Location map of Bay Akrotiri and BA1 sections along the south coast of Paliki peninsula

The study area is located in the southwest side of the island. A sequence of almost 100m thick marly sediments outcrops along the Bay Akrotiri at the south coast of Paliki peninsula (Fig.1) The Bay Akrotiri section is mainly characterized by thick bedded marly sediments, which are occasionally intercalated by thin (less than 0.5m) sandy horizons, alternating with thinner marly beds (Fig.2). Three relative short unexposed parts are met across the section. A bioclastic limestone bed is occurring at the uppermost part of the section, which is covered by coastal calcarenite beds with distinct groove marks.

A total number of 28 samples were collected with an average spacing of 2m. Evidently the sample resolution is low, but it is capable to provide satisfying biostratigraphic results.

Four additional samples were collected from a small outcrop (section BA1), located almost 1km to the north of Bay Akrotiri (Fig.1).

Light microscope techniques were used for the examination of the smear slides, which were prepared using standard methods.

The calcareous nannofossil taxonomy and zonation are after Raffi & Rio (1979), Rio (1982), Rio *et al.* (1990) and Raffi *et al.* (1993), to which the reader is referred. The quantitative methods of biostratigraphic analysis being used in the present study are those proposed by Rio *et al.* (1990), Triantaphyllou (1993): a) counting of the index species versus the total nannofossil assemblage (counts in 300 placoliths, L>3μm). This method was applied in order to estimate the relative abundance of three size classes of gephyrocapsids (3<L<4μm, 4<L<4.5μm, 4.5<L<5μm), b)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 macintyrei*, L>10μm (counts in 100 specimens of the genus), discoasterids (counts in 50 specimens of the genus). Moreover this method was applied for evaluating the relative abundance of two gephyrocapsid size classes (5<L<5.5μm, L>5.5μm) in a count of at least 100 gephyrocapsid specimens.

A qualitatitave planktonic foraminifera analysis was performed at selected samples from various levels of

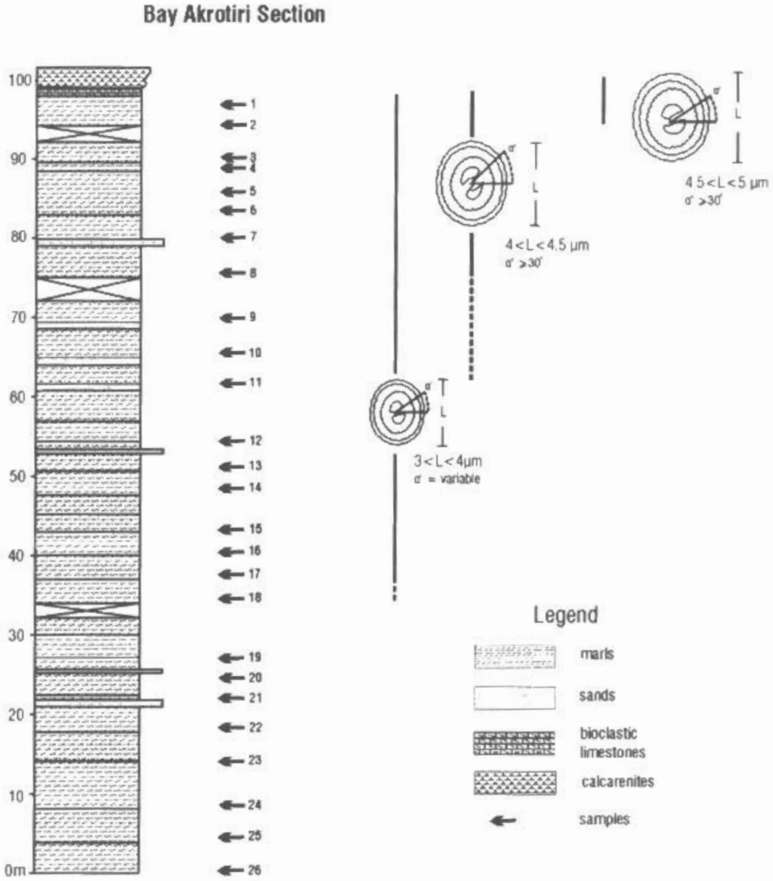

Fig.2. Bay Acrotiri section: Lithology and stratigraphic occurrences of three different size-classes of gephyrocapsids

the section, in order to confirm the calcareous nannofossil biozonation.

3. BIOSTRATIGRAPHIC RESULTS

The studied material is generally characterised by abundant nannofossil content, in a good state of preservation. An increase in terrigenous material is observed at the lower 10-15m of the section, accompanied by poor nannofossil assemblages. Abundant Pliocene to Oligocene reworked specimens were easily recognized.

The quantitative calcareous nannofossil analysis of 26 samples from Bay Akrotiri section led to the establishment of the distribution patterns of two species (*Helicosphaera selli, Calcidiscus macintyrei*) and three size-classes of gephyrocapsids (3<L<4μm, 4<L<4.5μm, 4.5<L<5μm), (Fig. 3). The abundance patterns of discoasterids have been evaluated at the lower 20m of the section. Discoasterid species are generally absent from the rest part of the section.

The quantitative analysis of Pliocene discoasterid species -which are extremely rare and in a bad state of preservation- led to the conclusion that these have been reworked, as different species with different stratigraphic intervals were found co-existing. On the contrary *Discoaster brouweri* exhibits relatively increased presence (very well preserved specimens) at the lower samples. Concerning *D.triradiatus*, the presence of two specimens of the species have been detected ,at around 20m from the base of the section (sample 21), but it is more difficult to judge whether or not they are indigenous.

The percentage abundance of *C.macintyrei* varies from 20% up to 35% in a count of 100 specimens of the genus (distal shields at parallel nicols). Along the upper 20m of the section *C.macintyrei* abundance declines considerably, showing percentages below 2%.

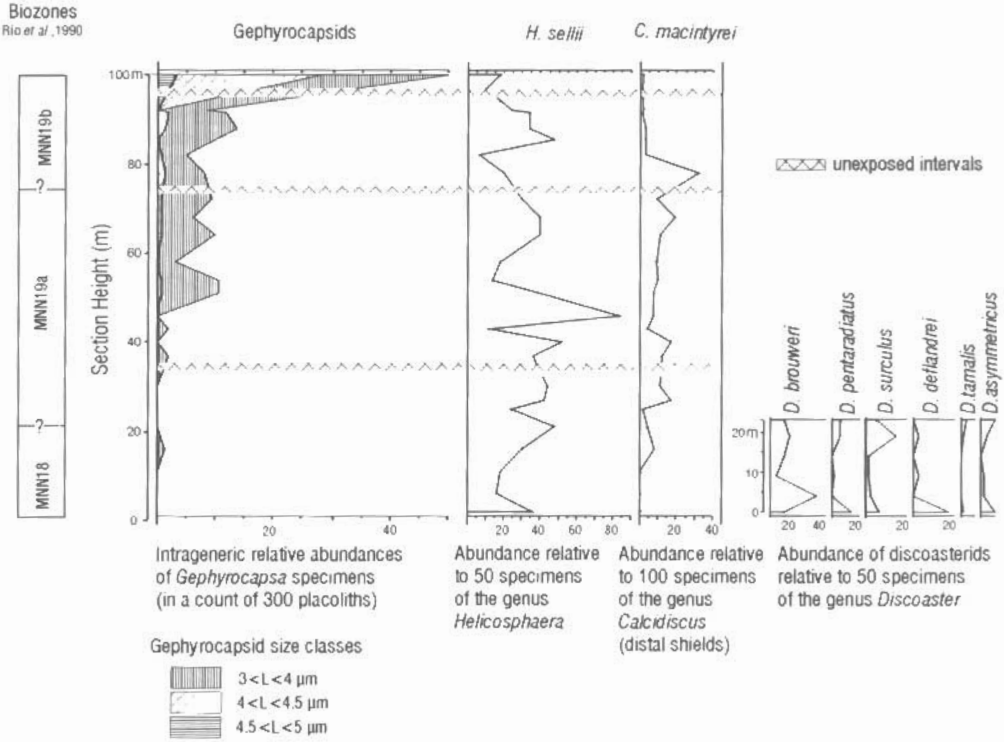

Fig.3. Calcareus nannofossil abundance and biostratigraphic correlation of Bay Acrotiri Section.

Helicosphaera sellii dominates the nannoflora assemblages, with percentages reaching 80%, but shows the same pattern with *C.macintyrei*, during the upper 20m of the section reaching in abundance 20%.

Pseudoemiliania lacunosa specimens are abundant and very well developed. Their shape changes only during the lower 10m of the section (samples 24,25,26), where more typical Pliocene forms (smaller and rather elliptical) can be observed.

The abundance patterns of gephyrocapsids clearly depict the sharpness by which forms with an overall placolith length ranging between $4<L<4.5\mu m$ first appear, although the clear lowest occurrence of these forms must be placed at about 75m from the bottom of the section (probably in the second unexposed part). This pattern has already been recognized on Cefallinia island (Triantaphyllou 1993, Triantaphyllou *et al.,* 1999), indicating the MNN19a/MNN19b biozones boundary, which points to the Plio/Pleistocene boundary.

The qualitative analysis of foraminifera assemblages showed that planktonic foraminifera are in excellent state of preservation, especially in the upper parts of the section, whereas *Globorotalia inflata* almost dominates the assemblages, accompanied by increased number of left-coiled Neogloboquadrinids.

On the contrary the lower part of the section is characterized by the dominance of benthic foraminifera, whereas the planktonic microfauna contains specimens of *Globorotalia puncticulata* (probably reworked) and rare specimens of *Gl.inflata*. The higher rate of benthic foraminifera at this stratigraphic level is accompanied by the intense presence of the calcareous nannofossil specimens of *Rhabdosphaera* spp.,*Scyphospaera* spp. and *Braarudosphaera* spp, followed by a distinct increase in terrigenous material, which has been recorded in the performed nannofossil analyses.

The intervals of low abundance or absence of discoasterids could indicate variations in productivity in the Early Miocene of the Mediterranean (Hilgen *et al.*, 2000). The abundance of discoasterids is considered to be influenced by productivity (Chepstow-Lusty *et al.* 1989, Chepstow-Lusty *et al.* 1992). Low abundance or absence of discoasterids are associated with high productivity as observed in Pliocene sections in the Atlantic ocean (Chepstow-Lusty *et al.* 1989, Chepstow-Lusty *et al.* 1992), and in the Late Miocene of the eastern equatorial Pacific (Raffi & Flores, 1995). High productivity at the lower part of Bay Akrotiri section, is indicated by the increased presence of *Rhabdosphaera* spp. Negri *et al.* (1999a,b) discussed the meaning of both *Rhabdospaera* spp. and *Helicosphaera* spp. in the Quaternary and Miocene sediments of the Mediterranean area, concluding that the behavior of the two taxa could support a mechanism of sapropel deposition triggered by both increased primary productivity and water stratification.

The frequencies of discoasterids in the lower part of the section (if we consider the presence of *D.brouweri* as indigenous) supported by the rare presence of *Gl.inflata*, suggest that the lower 20m of the section could be assigned to MNN18 biozone (Rio *et al.*, 1990).

The part of the section ranging from 20m to 75m can be assigned to MNN19a biozone and is characterized by the intense presence of gephyrocapsids with an overall placolith length between $3<L<4\mu m$, along with the absence of discoasters and the intense presence of well-developed specimens of *P.lacunosa*. The abundance of gephyrocapsids ranging between $3.5<L<4\mu m$ in size, with a relatively central opening and a clear central bar, is the major diagnostic element to recognize MNN19a biozone (Triantaphyllou 1993, Triantaphyllou *et al.* 1997,1999, Marino 1996).

The last 25 m of the section are characterized by the clear presence of gephyrocapsid forms with maximum placolith length $L>4\mu m$, and thus can be correlated with MNN19b biozone.

The lowest occurrence (LO) of placoliths with the features of the taxonomical group of medium sized gephyrocapsids –ranging in size between 4μm up to 4.5μm with a bar and a relatively open central area (Raffi *et al.*, 1993) must be placed at the level of the second unexposed part of the section.

The presence of gephyrocapsids ranging in size between $4.5<L<5\mu m$ has been detected during the last 10m of the section (samples 1,2) and can probably be associated with the apparent decline in *C.macintyrei* abundance, and the considerable increase in the abundance of the other two gephyrocapsid size-classes ($3<L<4\mu m$, $4<L<4.5\mu m$).Raffi *et al.* (1993) showed that the extinction level of *C.macintyrei* occurs shortly after the increasing appearance of gephyrocapsid forms ranging between $4.5<L<5\mu m$.

Therefore the uppermost part of the section must be correlated with MNN19b, and in particularly can be placed near the top of this biozone, close to the extinction level of *C.macintyrei*.

Subsequently Bay Akrotiri section deposits are in terms of time older than 1.95 Ma (LAD of *D.brouweri* and *D.triradiatus*, Rio *et al.* 1990) and younger than 1.710 Ma (FAD of normal sized gephyrocapsids, Rio *et al.* 1997).

The biostratigraphic analysis of the rest four samples (collected from a small outcrop to the north of Bay Akrotiri section), showed relatively high frequencies of gephyrocapsid forms $L>5.5\mu m$ (large *Gephyrocapsa* spp.), accompanied by high frequencies of forms ranging between $5<L<5.5\mu m$. The provided data allow the correlation of these sediments with MNN19d biozone (Fig.4). Large *Gephyrocapsa* forms show an abrupt decline at the level of the upper sample (the fourth of this set of samples). Normal sized gephyrocapsids are also missing, but there can be observed an intense presence of small *Gephyrocapsa* spp. in the assemblages. Therefore the stratigraphic level of this last sample may be correlated with MNN19e biozone (Rio *et al.*, 1990).

Subsequently BA1 outcrop deposits are in terms of time younger than 1.608 Ma (FAD of large *Gephyrocapsa*,

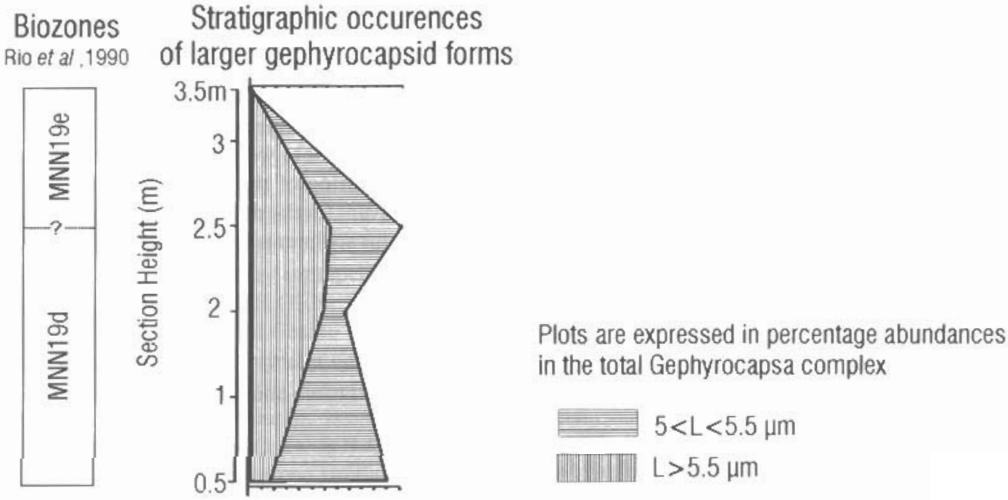

Fig.4. Gephyrocapsid abundance patterns and biostratigraphic correlation of BA1 outcrop.

Rio *et al. 1997*) and slightly younger than 1.238 Ma (LAD of large *Gephyrocapsa,* Rio *et al.* 1997)

4. THE PLIO/PLEISTOCENE SIZE-TREND OF GEPHYROCAPSIDS IN BAY AKROTIRI SECTION

The gephyrocapsid size-defined morphogroups have been proven to provide biostratigraphically useful results (Rio *et al.*1990, Raffi *et al.* 1993, Matsuoka & Okada 1990). Rio (1982) observed that gephyrocapsids increased progressively in overall size throughout the early Peistocene, and that this increase occurred over wide geographic and latitudinal distances.

We have performed countings of five different size-classes of gephyrocapsids ($3<L<4\mu m$, $4<L<4.5m$, $4.5<L<5\mu m$, $5<L<5.5\mu m$, $L>5.5\mu m$), in order to trace the gephyrocapsid size-trend in the terrigenous sequence of Bay Akrotiri section.

The provided distribution patterns (Fig.3,4) clearly depict an apparent evolutionary lineage from the small *Gephyrocapsa* to larger forms of gephyrocapsids near the Plio/Pleistocene boundary. These patterns are virtually identical to those observed by Raffi *et al.* (1993) from western and eastern equatorial Pacific, Caribbean sea, western Mediterranean sea and northern Atlantic ocean.

Gephyrocapsids ranging in size between $3<L<4\mu m$ are present with very low frequencies at almost 20m from the base of the section (Fig.3). Their abundance increases gradually and reaches almost 50% at the uppermost part of the section. This pattern is accompanied by a similar one, concerning forms ranging between $4<L<4.5\mu m$. These forms make their presence clear at about 75m from the base of the section, with very low frequencies that finally reach almost 20%. The presence of gephyrocapsid types with an overall size ranging between $4.5<L<5\mu m$ and percentages reaching 5%, is observed a few meters above the first occurrence of the normal-sized gephyrocapsids.

This is the first time that this trend towards larger size in the Late Pliocene/Pleistocene interval has been quantitatively traced in a Greek terrigenous sequence, indicating that stratigraphic changes in the *Gephyrocapsa* complex occurred in a similar mode between the terrigenous sequences of the Mediterranean (Greece, Italy) and the deep oceanic environments, during the Quaternary.

5. CONLUSIONS - DISCUSSION

In conclusion Bay Akrotiri section can possibly be correlated -on the basis of a quantitative calcareous nannofossil analysis- with MNN18, MNN19a, MNN19b biozones (Rio *et al.*, 1990), or NN18, lower NN19 (Martini, 1971) and CN12d, CN13a (Okada & Bukry, 1981) which are pointing to Late Pliocene/Early Pleistocene time interval (Berggren *et al.* 1995a,199b). Additional biostratigraphic data from the small outcrop BA1 (presence of MNN19d and MNN19e biozones, Rio *et al.*, 1990) prove that the marly deposits of Paliki peninsula clearly range in the middle Early Pleistocene.

The abundance of forms ranging between $3<L<4\mu m$ characterises the stratigraphic range of MNN19a biozone. Moreover the biostratigraphical importance of morphotypes with length $>4\mu m$ has been well defined, pointing the base of the Pleistocene (MNN19a/MNN19b biozones boundary).

We believe that the distribution patterns of forms with an overall size between $4.5<L<5\mu m$ should be useful in order to determine the MNN19b/MNN19c boundary. In particularly there must be a close relation between the increase in abundance of these forms and the decline of *C.macintyrei* frequencies.

We cannot provide enough data for this suggestion in this work -as there were few available samples from the certain biostratigraphic interval- but we consider that the monitoring of the abundance patterns of such gephyrocapsid morphotypes ($4.5<L<5\mu m$) may provide a sound bioevent for the definition of the top of MNN19b biozone as the highest occurrence (HO) of *C.macintyrei* in terrigenous sediments is very difficult to be evaluated due to strong reworking phaenomena.

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Table 1. Chronostratigraphic control for Bay Akrotiri section and BA1 outcrop

Stratigraphic event	Section/samples	Age (Ma)	Comments for Age
D.brouweri/ D.triradiatus HO	BA / 21	1.95	LAD: Rio *et al.*(1997)
Normal sized Gephyrocapsids LO	BA/8-9	1.710	FAD: Rio *et al.*(1990)
Large *Gephyrocapsa* LO		1.608	FAD: Rio *et al.*(1997)
Large *Gephyrocapsa* HO	BA1/3-4	1.238	LAD: Rio *et al.*(1997)

HO: Highest Occurrence, LO: Lowest Occurrence

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