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LATE MIOCENE CALCAREOUS NANNOFOSSIL STRATIGRAPHY AND BIOEVENTS CORRELATION: KALIDONIA CASE SECTION (NW CRETE, GREECE)

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Abstract

Calcareous nannofossils are widely used for biostratigraphic correlations. Quantitative approaches enable better understanding of reliability of bioevents. In order to refine the late Miocene stratigraphy of NW Crete, the deposits of Kalidonia basin along its type section are here investigated. It was possible to distinguish the Tortonian/Messinian boundary by NN11a & NN11b, CN9a & CN9b, MNN11a & MNN11b biozones. Reticulofenestra pseudoumbilicus PB (Paracme Beginning) and R. rotaria FO (First Occurrence) proved to act as additional significant biohorizons improving the stratigraphic evolution of the studied paleobasin and providing a tight biochronologic framework. The Kalidonia section fully covers an undisturbed marine depositional cycle from the upper Tortonian to upper Messinian, where a predominant deep water facies (DWF) is followed by transitional sediments (TF) and the sequence closes at the top by a reefal-bioclastic facies (RF) relative to the 'Calcare di Base' in Italy indicating the 'Messinian Salinity Crisis Event'.

Key words: *Calcareous nannoplankton, biostratigraphic correlations, Tortonian, Messinian.*

Περίληψη

Τα ασβεστολιθικά ναννοαπολιθώματα χρησιμοποιούνται ευρέως για βιοστρωματογραφικούς συσχετισμούς. Η καλύτερη κατανόηση των βιογεγονότων βελτιώνεται με τη χρήση ποσοτικών δεδομένων. Μελετήθηκαν οι αποθέσεις της ιζηματογενούς λεκάνης Καλυδώνια στην τυπική της τομή, με σκοπό τη λεπτομερέστερη στρωματογραφία του ανώτερου Μειόκαινου της ΒΔ Κρήτης. Προσδιορίστηκε το όριο του Τορτονίου/Μεσσηνίου με τη χρήση των βιοζωνών NN11α & NN11β, CN9a & CN9b. MNN11a & MNN11b. Επιπρόσθετα σημαντικοί βιοορίζοντες που βελτιώνουν τη στρωματογραφική εξέλιξη της μελετηθείσας παλαιολεκάνης και παρέχουν ένα ισχυρό βιοχρονολογικό πλαίσιο, αποδείχθηκαν η αρχή της παρακμής της Reticulofenestra pseudoumbilicus (PB) και η πρώτη παρουσία της R. rotaria (FO). Η τυπική τομή Καλυδώνια περιλαμβάνει θαλάσσια ιζήματα ενός αδιατάρακτου ιζηματογενούς κύκλου που καλύπτει απόθεση από το ανώτερο Τορτόνιο έως και το ανώτερο Μεσσήνιο, όπου κύρια φάσεις βαθιάς θάλασσας, ακολουθούνται από μεταβατικές φάσεις ιζημάτων, ενώ η ακολουθία ολοκληρώνεται στην κορυφή της τομής με υφαλογόνες-βιοκλαστικές

φάσεις που σχετίζονται με τους επονομαζόμενους 'Ασβεστολίθους Βάσης' της Ιταλίας και προσδιορίζουν και την έναρξη της 'Κρίσης Αλμυρότητας του Μεσσηνίου'.
Λέξεις κλειδιά: *Ασβεστολιθικό ναννοπλαγκτό, βιοστρωματογραφία, συσχετισμοί, Τορτόνιο, Μεσσήνιο.*

1. Introduction

The Hellenic Arc System, has been since long the subject of intensive research (McKenzie 1970, Makris 1978, Angelier 1979 Dewey and Sengör 1979 Mascle *et al.* 1982, Dixon and Robertson 1984). Generally it is believed, that southward retreat of the trench system induced migration of the arc itself, and gave birth and shape to the present-day Hellenic Arc System configuration (Wortel and Spakman 1992). The extension in the Aegean Sea (especially at the southern part of it) and the southward movement of Crete Island was caused by the rollback effect of the slab and the broad subduction zone (Le Pichon 1982, Meulenkamp *et al.* 1988, 1994). This rollback process of the Hellenic subduction zone started about 12 my ago (Meulenkamp *et al.* 1994). Furthermore, the active tectonics deformation of the Aegean region itself is dominated not only by extensional but by combined strike-slip motions and compressional tectonics as well (Jackson 1994, Meulenkamp *et al.* 1988). The concentration of slab pull forces causes a pattern of subsidence (combined with depocenters development) and uplift migrating along strike. Subsequently prevailed a maximnm crustal thinning and subsidence in the region of Cretan Sea produced the back-arc basin(s) at the north of Crete as it was firstly suggested by studies of Makris (1978) and Angelier *et al.* (1982) and recently by Wortel and Spakman (2000).

The Neogene basins of northwestern Crete are generally considered the result of the prementioned subsidence. NNE- and WNW- trending fault systems, which were developed during the middle Miocene, represent the dominant structural feature controlling the configuration of these basins. Sedimentary deposition commenced at most if not at all of them during either the middle or the early late Miocene interval, usually at the Serravallian or the lower Tortonian respectively (Freudenthal 1969, Menlenkamp *et al.* 1979, Keupp and Bellas in collab. with Frydas and Bartholdy 2000).

Based on recently published integrated bio-, cyclo- and magnetostratigraphic schemes dealing with the late Miocene deposits of Mediterranean, this work aims firstly to present a tight biostratigraphy of the Kalidonia section located between Kolymbari and Kastelli town at the northwestern Crete Island. A refinement of the existing biostratigraphy will be further discussed. The Kalidonia section is considered the "type section" of Kalidonia basin (Keupp and Bellas in collab. with Frydas and Bartholdy 2000, this work). In addition to the Potamida section ("representative section" of Kissamou Formation after Freudenthal 1969) and dne to the good material quality, exposure possibilities (easy access, undisturbed sequences) and preservation of the microfossils and nannoflora, Kalidonia is also considered as a subtypus locality for the Deep Water Facies (DWF), former "Kissamou Formation". The variability of paleodepositional environmental conditions prevailed in Kalidonia basin during the late Tortonian to late Messinian time span is lithostratigraphically demonstrated. Furthermore, the reliability of some known biohorizons of calcareous nannofossils has been evaluated along the studied section and their applicability concerning the biochronological correlation in the eastern Mediterranean Sea has been discussed and commented. For this purpose, we have used semiquantitative data of calcareous nannofossils.

2. The study area in the Neogene

The Kalidonia Basin is a small sedimentary basin (or subbasin), located on the NW Crete and situated directly on the foot of Rodopou peninsula (Fig. 1). Geologically, the Kastelli and Maleme (or Voukolies) Basins bound this basin to the west and to the east respectively (Keupp and Bellas in collab. with Frydas and Bartholdy 2000). Pre-Neogene strata, mostly represented by the P-Q

Group (Phyllites-Quartzites) separate the neogene successions of Kalidonia Basin, by those of the other basins. Remnants of neogene littoral deposits of Kalidonia have been mapped along the Rodopou peninsula at various altitudes. It has been postulated that syngenetic formation of horst (uplifted blocks where erosion predominates) and graben structures (downfaulted areas where sediments accumulate) modified an initially rather uniform depositional area of NW Crete (Frydas *et al.* 1999). Despite this isolation and the small size, the Kalidonia basin and its Neogene strata present a similar to the other Cretan basins lithostratigraphic facies and biostratigraphic history (i.e. Meulenkamp *et al.* 1979), pointing to a rather common development of them all.

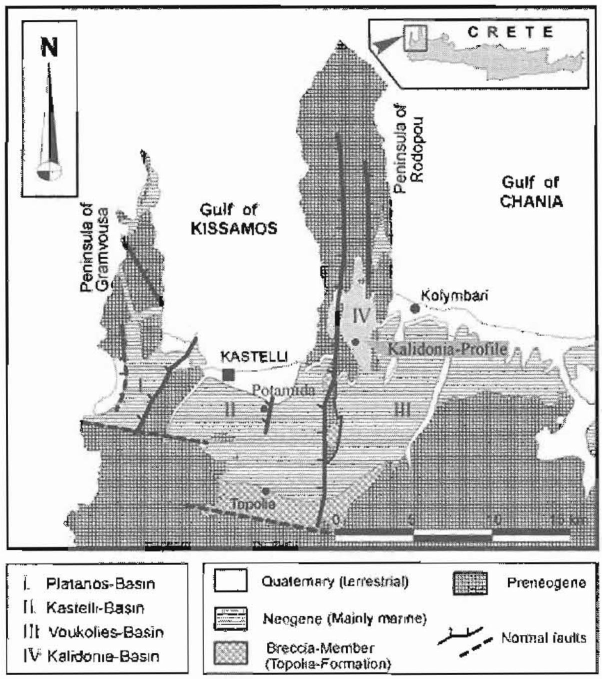

Figure 1 - Location of the studied Kalidonia section in NW Crete Island

Four sedimentary formations of Neogene age have been recognized in the broader area of Plakalona, namely the Mesonisi, Roka, Cherethiana and Kissamou (*sensu* Freudenthal 1969). In general the Neogene strata have been distinguished into two major groups based on their depositional environment, a) the non-marine and b) the marine facies. The Mesonisi Formation belongs to the terrestrial-fluviatile facies, which was not encountered in the studied section. Miocene and Pliocene age deposits firstly recognized in NW Crete by means of foraminifera by Christodoulou (1963) and later on were studied by Dermitzakis and Markopoulou-Diakantoni (1979), Meulenkamp *et al.* (1979) and Schmidt (1979). According to Kontopoulos *et al.* (1996) the Neogene strata of NW Crete were distinguished in two depositional sequences, the Miocene Sequence A and the Pliocene Sequence B, or the so-called First Miocenic Cycle and the Second Pliocenic Cycle (Frydas and Keupp 1996). The present study allows us to affirm that the sediments of the Kalidonia basin belong to the first and older depositional sequence (i.e. the Miocenic Cycle).

3. Material and Methods

Kalidonia section is located on the new national road connecting Kolymbari village and Kastelli town (Fig. 1). Samples of soft sediment were collected for biostratigraphic analyses at an average distance of 0.90 meters. In other studies of ODP for similar purposes, considering biostratigraphy and palaeoecology, resolution of ca. 1.0-1.5m was judged good enough. In our case decompaction was not taken into account. Micropaleontology was mainly based on the calcareous nannofossils identification under both the normal light (at magnifications of ca. 1000x) and the scanning electron microscope (SEM.). Smear slides preparation followed standard techniques. In a preliminary publication, the planktonic foraminifera of Kalidonia section were also studied and some of the key species were reported and illustrated, but as subordinates to the nannoflora (compare Plate 2 in Frydas *et al.* 1999). The biostratigraphic schemes used are the "standard" zones of Martini (1971) and Okada and Bukry (1980). Additional useful bioevents and their biochronological calibration are based on Theodoridis (1984), Martini and Müller (1986), Young *et al.* (1994), Raffi and Flores (1995), Fornaciari (2000), Lourens *et al.* (2004) and Raffi *et al.* (2003, 2006). A quantitative and subsequently semiquantitative study using the calcareous nannoplankton has been also performed. Quantification of species presented in Table 1, based on the following pattern: **A** (Abundant)= >20 individuals (measuring 100 specimens), **C** (Common)= 11-20, **F** (Few)= 6-10, **R** (Rare)= 2-5 and **P** (Present)= 1 individual/smear slide.

4. Results

4.1. Lithostratigraphy and biofacies

In the last years, a new concept concerning facies and sedimentary architecture for the neogene deposits of NW Crete has been developed. Therefore, facies terminology of the present work and their subdivision in broad follows that of Frydas and Keupp (1996), Bellas *et al.* (1998, 2000) and Keupp and Bellas in collab. with Frydas and Bartholdy (2000).

According to this concept three mainly depositional lithofacies, which compose the ca. 32 meters thick Kalidonia section, are recognized in the studied section (Fig. 2):

Unit-1. (Deep Water Facies or **–DWF-**). At the base, grey, amorphous, homogenous, slightly sandy marls about 17 meters thick, are overlain by 8 meters of slightly laminated marls and claystones of middle/outer shelf to slope or mesopelagic environment. When alternate, the former marls are generally considered to correspond to insolation minima, while the later one to insolation maxima (Krijgsman, *et al.* 1999). This facies is correlated to the former "Kissamou Formation" after Freudenthal (1969). It is followed upwards by:

Unit-2. (Transitional Facies or –**TF**-). Yellowish sandy marls (~2 meters thick) and a sandstone bank (1 meter thick), point to the transition from shelf sediments to shallow-water, neritic environment. The **TF** is correlated to the former "Cherethiana Formation" after Freudenthal (1969).

Lithofacies of Unit-2 exhibits important fossil elements, like Brachiopods of the Genus *Terebratula* sp., abundant Pectenidae and a significant biohorizon of the benthic foraminifer *Heterostegina* sp.. Freudenthal (1969) firstly reported on the *Heterostegina* massive banks of the former "Roka Formation". However, the later occurrences are referred to the transgressive littoral facies **LF-A (LF-At, t** for transgressive**)** and characterize the basal neogene sediments (in our case of Tortonian age) deposited in the NW Crete basins, while the frequent occurrences of *Heterostegina* bioevent recorded in Unit-2 of Kalidonia section, are referred to the regressive littoral facies **LF-A (LF-Ar, r** for regressive) or to the **TF** of the above basins and depict a pre-commence of the so-called "Messinian Event" of middle-upper Messinian age.

Unit-3. (Reefal-bioclastic Facies or **–RF-**). The section closes at the top with a caprock consisting of the recently described reefal-bioclastic limestones facies, which is placed in the upper, regressive, littoral facies Type A (part of **LF-A**, in Bellas *et al.* 1998).

The **RF** in Kalidonia (Unit-3) is about 3.5m thick and it is partly correlated to the former "Roka Formation" after Freudenthal (1969). It is rich in macrofossils like Corallinaceae (*Lithothamnium*), scleractinian Corals (*Tarbellastraea* sp., *Porites* sp.), Tentaculats (cyclostome Bryozoa, *Terebratula sinuosa*), Cirripeds (*Pyrgomma* sp.), Molluscs (*Glycimeris* sp., *Lithophaga* sp., diverse pectinids and molds of gastropods), and Echinoids (*Schizechinus* sp., *Clypeaster* sp.). The **RF** is characteristic for deposition during onset of the well-known Mediterranean Messinian Salinity Crisis, which mainly affected the margins and the highly uplifted blocks (Plakalona case) of the basins in the studied area. Similar marine algal limestones were reported from the marginal Late Messinian Sea in Spain, Tunisia, western Sinai and central Crete (Sonnenfeld 1985, our unpublished data).

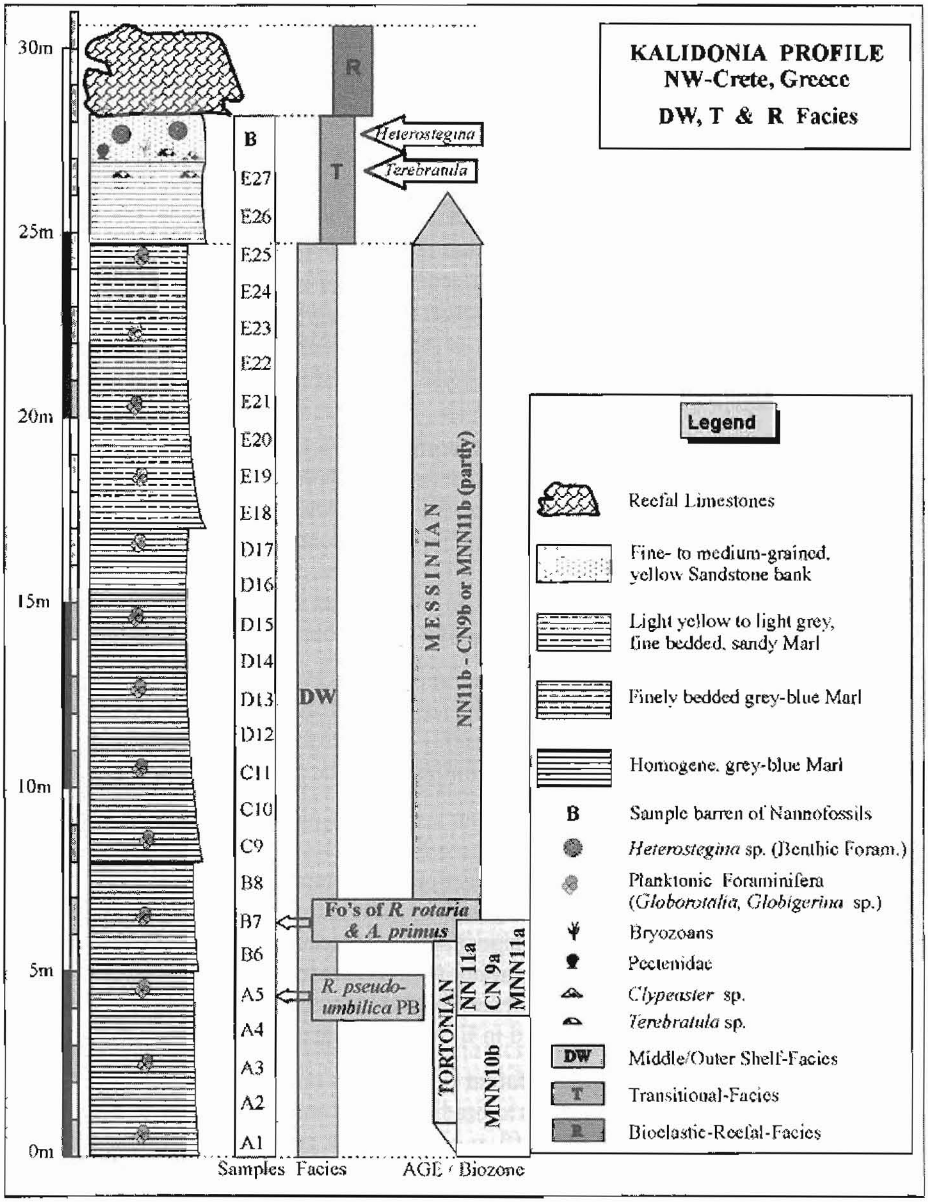

Figure 2 – Lithostratigraphy, facies and key biostratigraphic events of calcareous nannofossils along Kalidonia section

The whole succession of the three above-mentioned litho-biofacies generally points to a regressive sequence, developed from deep marine at the base (Unit-1), to shallow-water (Unit-2) and further to pure littoral deposits at the top (Unit-3). It belongs to the first sedimentation cycle (A) of Late Miocene age (Frydas and Keupp, 1996; Kontopoulos *et al.* 1996).

4.2. Calcareous nannofossils biostratigraphy

4.2.1. Late Miocene calcareous nannofossil biozones

According to the preliminary study (based on a first set of five samples) of the calcareous nannofossils of Kalidonia section (Frydas *et al.* 1999, Keupp and Bellas in collab. with Frydas and

Bartholdy 2000), their association was placed in the **CN9** biozone (= *Discoaster quinqueramus*) sensu Okada and Bukry (1980) "Low-latitude biostratigraphic zonation", or to the equivalent and homonymous of it **NN11** zone of "Standard Nannofossil Zonation" (Martini 1971). The latter zone was primary defined on the basis of the total range of *D. quinqueramus*.

Okada and Bukry (1980) subdivided the CN9 Zone in CN9a and CN9b by use of *Discoaster berggrenii* and/or *Discoaster surculus* occurrences. Martini and Müller (1986) also subdivided the NN11 in NN11a and NN11b, by the presence of *Amaurolithus delicatus* at the base of the last subzone. Theodoridis (1984) developed another biozonation scheme for the Mediterranean Miocene CN9 Zone, where three zones (*Coccolithus pelagicus*, *Amaurolithus primus* and *Reticulofenestra rotaria*) and one subzone (*Calcidiscus leptoporus* Zone MA) were distinguished. First Occurrence of *A. primus* defined the base of the homonymous species Zone, while a small interval (that of *R. rotaria* Zone) was introduced by presence/disappearance of this species (base/top of homonymous Zone).

A further attempt to biostratigraphically refine the important stratigraphic period of Late Miocene was made by Raffi and Flores (1995). They subdivided the CN9b into three parts; CN9bA, CN9bB and CN9bC, by using the FO and LO of *Amaurolithus amplificus* (now *Nicklithus amplificus* sensu Raffi *et al*., 1998) as defining the base and top of CN9bB. According to recent studies by Hilgen *et al.* (2000), the *Amaurolithus amplificus* s.s. FO postdates the Tortonian/ Messinian (T/M) boundary. Since this species was not identified in the studied samples (compare also Fornaciari, 2000), the above tripartite subdivision of CN9b is not applicable in this paper.

Recently, Raffi *et al.* (2003) proposed for the upper Miocene five out of seventeen selected biohorizons of calcareous nannofossils as easily reproduced in the Mediterranean and out of it, which as they stated, were also considered useful for correlations to worldwide stratigraphy. Among them, four could be incorporated and commented in the present study.

4.2.2. Biostratigraphic results

The calcareous nannofossils of the Kalidonia section are generally well preserved, comprising a total of 47 different species, but are represented in low abundances. In the upper part of the section, due to the littoral character of the deposits (TF; samples E25-E27), the assemblage is not considered original. Late Miocene most important taxa have been identified and reported in Table 1. In the following it will be commented on key biohorizons of selected species from Kalidonia section, as they have been mainly recognized in E. Mediterranean by Raffi *et al.* (2003, 2006).

Discoaster pentaradiatus is exceptionally found common in only one sample by the base of the Kalidonia section; otherwise, this species is sporadically present and generally occurs in very low abundances. Therefore, the proposed by Raffi *et al.* (2003) *D. pentaradiatus* FCO (First Common Occurrence), defining the base of Zone MNN10b, is not recognized in the present work.

Both, *D. berggrenii* and *D. quinqueramus*, the key species of CN9 Zone, are present along the section (samples A1 to E24) although inconsistently.

The *Reticulofenestra pseudoumbilicus* PB is easily recognizable and can be placed at the stratigraphic level of samples interval A4 to A5, where the species after a constant presence from the base of the section upwards (samples A1 to A5), disappears or after a small recover in samples B7 and B8, is simply present as rare specimens to the top of the section.

In Kalidonia section, first *Amaurolithus*, although rare, together with *R. rotaria*, have been both recorded at the level of sample B7 onward (Table 1), therefore indicating the CN9a/CN9b, NN11a/NN11b and MNN11a/ MNN11b subzonal boundary and subsequently the T/M boundary.

These nannofossil events make possible an important assignment of the lower part of Kalidonia section (samples A1-B6) at the upper Tortonian zones NN11a/CN9a, while the sediments which bound sample B7 to the Tortonian/ Messinian boundary and the rest of the succession is placed to the lower Messinian zone NN11b/CN9b (samples B7 to E24). *R. pseudoumbilicus* size ranged from greater than 8 μm at the base, to less than 7 μm at the top and the scarcity of it upsection, are additional bioevents that also support our previous results (co. also Young 1990, Huang 1997). The T/M boundary coincides with sample level B7. Lithostratigraphically, above sample E24 sedimentation firstly changes to littoral type and later commences a transition (TF) to the RF deposition, pointing to the onset of the salinity crisis Messinian event in the Mediterranean. The RF facies relatively corresponds to the base of the 'Calcare di Base' dated at 5.95 Ma by Hilgen *et al.* (1995) or at 5.96±0.02 Ma by Krijgsman *et al.* (1999).

Summarizing, the following bioevents of calcareous nannofossils are well documented and provide a useful and reliable stratigraphical framework applicable to the Kalidonia section. They are listed from the base of the section onwards below. **a)** Occurrence of both *D. berggrenii* and *D. quinqueramus* (NN11a, CN9a), **b)** common occurrence of *R. pseudoumbilicus*, followed by **c)** PB (paracme beginning) of it (base of MNN11a), **d)** Common FO's at the same stratigraphic level of both *A. primus* and *R. rotaria* (~T/M boundary and NN11b, CN9b, MNN11b) and **e)** almost consistent presence of *D. quinqueramus* to the section upward and possible top occurrences of both *D. berggrenii* and *D. quinqueramus* (E24 sample). It follows an almost barren interval of calcareous nannofossils, prior to the Reefal Facies (RF) development at the top of the section.

5. Discussion

Considering the Kalidonia section, *D. berggrenii* was observed in low abundances at the base of the Kalidonia section and *D. quinqueramus* was simply present in the samples of the section upwards to the top. As Wei (2003) pointed out, major disagreements exist on the taxonomical concepts used by various authors for these species. Both of them characterize the NN11/CN9 zone of calcareous nannofossils. The ages of 8.5 Ma and of 8.2 Ma were assigned to the FO datums of *D. quinqueramus* and *D. berggrenii berggrenii* respectively (EXXON core in the Gulf of Mexico, Wei, 2003). The datum of the top of *D. berggrenii* roughly calibrated at ~6.2 Ma by the previous author. The *D. quinqueramus-berggrenii* intergrade appears slightly later (is relatively younger in age). It is reported by Rio *et al.* (1990) to have gradationally evolved from *Discoaster bellus* (Young *et al.* 1994). The *D. bellus* is inconsistently represented in low abundances along the section. Based on the specimens' rarity and preservation state, we consider at least the uppermost two occurrences of them to be reworked (samples E24 & E25).

Since *D. pentaradiatus* occurs sporadically and in very low abundances along Kalidonia section, its FCO (calibrated at 9.37 Ma by astronomically induced sedimentary cycles by Raffi *et al.* 2003) cannot be identified. Obviously this event stratigraphically predates commence of deposition of the section basal layers in Kalidonia basin.

According to Raffi *et al.* (2003, 2006) and Lourens *et al.* (2004), the event of *R. pseudoumbilicus* PB (Paracme Beginning) characterizes the base of Zone MNN11a, with an absolute age of 8.76 or 8.71 Ma respectively. Young (1998), Fornaciari (2000), Kameo and Bralower (2000) and Marino and Flores (2002) report on this event too. According to the latter, this paracme interval incorporates the base of NN11b, although others place it to the upper part or only the base of CN8b (Fornaciari 2000, Kameo and Bralower 2000). We have also identified the paracme interval of *R. pseudoumbilicus* in the Potamidha section of NW Crete (Schmidt 1979: fig. 1, p. 169, 188), where it is obvious that the abundance of this species dramatically reduces at the upper stratigraphic intervals to the top of the section (late part of II, III and IV). This is well correlated with the interval starting with the so-called *R. pseudoumbilicus* PB by Raffi *et al.* (2003).

The reliability of events related to the genus *Amaurolithus* was confirmed by Negri and Villa (2000) for Cretan sections, as well as by Raffi *et al.* (2003, 2006) on a combined study of various sections and holes. *Amaurolithus* spp. and/or *A. primus* FO (First Occurrence) biohorizon is equivalent to the base of Subzone MNN11b and it is calibrated at 7.46-7.47 Ma (Qued Akrech section of Morocco; Hilgen *et al.* 2000), at 7.430-7.435 Ma (Faneromeni section of SE Crete; Negri and Villa 2000), or somewhat younger at 7.424 Ma (E. Mediterranean; Raffi *et al.* 2006). These species FO's slightly predate the Tortonian/Messinian (T/M) boundary in Mediterranean Neogene. They are the closest nannofossil bioevents corresponding to the T/M boundary, which is defined by the FAD of the foraminifera grouped as *Globorotalia conomiozea*. The T/M boundary level in Morocco was astronomically dated at 7.251 Ma, found in the middle of the reversed Subchron C3Br.1r (Hilgen *et al.* 2000). According to these authors, all above *Amaurolithus* group events (including the *A. delicatus* FO, not mentioned here), predate the T/M boundary and are considered "extremely useful" to delimit it on a global scale. The T/M datum in the Mediterranean was initially placed at 7.24 or at 7.12 Ma by Hilgen *et al.* (1995) and Krijgsman *et al.* (1995) respectively, but recently it has been dated at 7.246 Ma (Lourens *et al.* 2004, Raffi *et al.* 2006).

Raffi *et al.* (2003) stated that the *R. rotaria* FO and FCO are not reliable events, not improving the biostratigraphic resolution by calcareous nannofossils. Despite that, Negri and Villa (2000) had pointed out the usefulness of this event, especially in onland sections, like that of Faneromeni in SE Crete and considering the nannofossil events across the Tortonian/Messinian boundary. *R. rotaria* is a circular but distinctive variant of *R. pseudoumbilicus*, relatively easy to identify and it is reported from CN9b subzone by many authors like Theodoridis (1984), Flores *et al.* (1992), Young (1994), Bellas *et al.* (1998, 2000), Siesser and Kaenel (1999), Duermeijer *et al.*, (1999), Hilgen *et al.* (2000), Keupp and Bellas, in collab. with Frydas and Bartholdy (2000) and Raffi *et al.* (2003, 2006). It is true that *R. rotaria* may not be always present (or better identified) in all studied sections in the Mediterranean till now, however if it is recognized once, then is very important as biohorizon (proved both in Faneromeni and in present case of NW Crete onland sections). Notably, the FO and the FCO of *R. rotaria* are differently dated at 7.421 and 7.264 Ma respectively (Negri and Villa 2000) or recently at 7.41 and 7.24 Ma (Lourens *et al.* 2004). Therefore, *A. primus* FO predates the occurrence of *R. rotaria* by a difference of ~0.01 Ma. In our samples set, *A. primus* and *R. rotaria* occur both at the same stratigraphic level (sample B7). It seems that the samples resolution interval along Kalidonia section (ca. 0.90 m) was low and not enough to distinguish these events from one another. Hilgen *et al.* (2000) study of the classic Messinian Moroccan Oued Akrech section (Atlantic Morocco), correlated *A. primus* FO with an age ranging between 7.470 and 7.466 Ma, dates which are obviously older than those obtained from eastern Mediterranean (7.424 Ma according to Raffi *et al.* 2006). According to Theodoridis (1984: 48, fig. 44), the occurrence of *R. rotaria* can be in part correlated to the lowermost part of the CN9b subzone of Okada and Bukry (1980), a fact further supporting our data.

6. Conclusions

The Kalidonia section, a type profile of the Neogene Kalidonia sedimentary basin was used for a biostratigraphic study of late Miocene deposits in the eastern Mediterranean Sea. New nannofossil data and development of the science (integration of magneto-, cyclo-, and biostratigraphy) make easier the age calibration of Kalidonia as well as correlations with assignments of bioevents from the Mediterranean and the Atlantic Morocco where major disturbance took place at the entrance of the ocean water to the Mediterranean during most of the upper Messinian.

The calcareous nannofossil distribution pattern is well documented. It shows a high paleo-biodiversity and good preservation but scarcity of the key species in the Deep Water Facies (DWF, Unit-1). Presence from the base upwards of *D. berggrenii* and *D. quinqueramus* defines the NN11 or the equivalent of it CN9 Zones of Upper Miocene age for the studied section. Both species range almost to the top, where due to factors of sensitivity to carbonate dissolution in shallow-waters they disappear (Transitional and Reefal Facies, TF & RF, Units -2, -3).

Table 1 – Semiquantitative distribution and biozones of calcareous nannofossils in Kalidonia section

Samples Number - Species	*Amaurolithus primus*	*Braarudosphaera bigelowii*	*Calcidiscus leptoporus*	*Calcidiscus macintyrei*	*Coccolithus pelagicus*	*Coccolithus miopelagicus*	*Cryptococcolithus takayamae*	*Dictyococcites antarcticus*	*Dictyococcites productus*	*Discoaster adamanteus*	*Discoaster asymmetricus*	*Discoaster bellus*	*Discoaster berggrenii*	*Discoaster brouweri*	*Discoaster calcaris*	*Discoaster challengeri*	*Discoaster intercalaris*	*Discoaster moorei*	*Discoaster pansus*	*Discoaster pentaradiatus*	*Discoaster quinqueramus*	*Discoaster quinqueramus-berggrenii*	*Discoaster surculus*	*Discoaster variabilis*	*Geminilithella jafari*	*Geminilithella rotula*	*Hayaster perplexus*	*Helicosphaera carteri*	*Helicosphaera orientalis*	*Helicosphaera pacifica*	*Helicosphaera stalis ovata*	*Helicosphaera stalis stalis*	*Helicosphaera sellii*	*Holodiscolithus macroporus*	*Pontosphaera* spp.	*Reticulofenestra minutula*	*Reticulofenestra pseudoumbilicus*	*Reticulofenestra rotaria*	*Rhabdosphaera clavigera*	*Rhabdosphaera procera*	*Scapholithus fossilis*	*Scyphosphaera spp.*	*Sphenolithus abies*	*Sphenolithus moriformis*	*Sphenolithus verensis*	*Syracosphaera pulchra*	*Syracosphaera* sp.	BIOZONES
E27			R	R	P	P		P	A																A	P		R		P									R				F			P	R	
E26			F	P	C			C	A																A	F		C							P				P				C				P	
E25			C	R	R			F	A	P		P		P										R	A	C		A	P	P					R				R		R	P	F				P	
E24			R	F	P			R	A	P	P	P	P	R				P	P	P	P	P	P	R	A	F		C	P	R				P	R		R		C		F		C	P		R	F	NN11b or CN9b or MNN11b (partly)
E23	P		C	R				R	A	P			P	P		P			P	P	P	P		R	A	A		C						R	P				C		F		F		P		P	
E22			F	R	R	P		F	A	P			P	P		P			R	P		P	P	R	A	A	P	C		R		P			R		P		C				C		P		F	
E21			F	R	R			F	A																A	C		C		R					R		R		C				C				R	
E20			F	F	R			C	A	P	P			R		P			P	P	P			P	A	C		F	P					P	R		R		F		F		F				F	
E19		P	F	F	R		R	C	A	P	P			P		P					P			P	A	F	R	C		P					R		R		F		R	P	C			P	R	
E18	P		F	R					A	P			P				P		P	P	P	P	P	P	A	C	P	A	R	R					P				C			P	C				R	
D17			R	F	R			C	A	R			P	R		P			P	P	P			P	A	F		C		P				P	R		R		F		R		F	P	P	R	R	
D16	R		R	C	F			R	A	P				P		P					R	P	P	P	A	F		F	P					R	P				F		R	R	C		P	P	R	
D15			P	F	C			F	A	P						P								P	A	F	P	C	P					P	R				C			R	F				F	
D14			P	F	R			A	A	P				R		P		P	P	P			P	P	A	F		F						F	R		P		F		R	P	F				F	
D13			R	R	R		P	A	A	P			P	R		P			P	P				P	A	F	R	C							P				F			R	C				F	
D12		P	R	F	R				A	P				R	P				P	P	P	P		P	A	C		C	R		P		P		P				C		R	R	C				F	
C11			F	F	R			R	A	P				R		P			P	P	P		P	P	A	C		C		P			P				P		R		R		F	R			R	
C10			R	F	P	P		R	A	P			P	R		P	P		P	P	P		P	P	A	F		C	R	P					P				C		F	P	C	P		P	R	
C9	P		R	C	R				A	P				P		P			R	R				R	A	C		C						R	R				F		C		C			P	R	
B8	P		R	R	F		P	F	A	P	P					P			P	P			P	P	A	F		C	P						R	P	C		C		R		C				R	
B7	P		R	F	R		P	F	A	P			P	P		P		R	P	P		P		R	A	R		C							R		C	P	R		R	R	C		P	P	P	NN11a - CN9a - MNN11a
B6			R	P	R			P	A	P			P	P		P			P	P	P			R	A	C	P	F	P	P				P	R		R		F		F	R	C		R	P	F	
A5			F	R	R			R	A	P			P			P			P	P	P			R	A	R	P	C		R					R		F		F		R	P	C	P	P	R	R	
A4			R	F	F			A	A	P			P	P		P			R	R			P	R	A	R		F							R		C		R		F	R	F			P	R	MNN10b
A3			R	F	F	P	P	F	A	P				P		R			R	R			P	P	A	F		F	R		P	P		P	R		F		C		R	P	A		P	R	R	
A2			F	R	R			R	A	R		P	P	P		P		P	R					R	A	F		C							R		A		F		P		C			P	R	
A1			P	R	P	P		R	A	P		P	P	P		P	P		P	C	P		P	P	A	C		A							R		C		F	P	R	P	C			P	R	

In Kalidonia section the interval starting with the *R. pseudoumbilicus* PB bioevent (Paracme Beginning) is easily recognizable and can be placed at the stratigraphic interval between samples (s.) A4 and A5 (located at ca. 4-5 meters from the base of the section upwards). This event marks the base of MNN11a subzone. It is dated and astronomically calibrated at 8.761 Ma, well correlated with that proposed by Raffi *et al.* (2003, 2006) for the Mediterranean Sea. Large *Reticulofenestra* (>7 μ) specimens were never fully recovered. Reappearance of this species was rare and inconsistent up to the top of the section (Table 1).

Integrated biostratigraphy correlate the FO of *A. primus* (including the *Amaurolithus* spp.) and that of *R. rotaria*. It is possible to find both events at the same stratigraphic level together, due to close ages of both biohorizons (7.42 and 7.41 Ma respectively, Lourens *et al.* 2004, Raffi *et al.* 2006) if sampling resolution is low as in our case. In the above context, the lowermost part of Unit-1 (s. A1-A4) is placed in the upper part of MNN10b subzone. The calcareous nannofossil assemblage of s. A5 to B6 is biostratigraphically placed in the CN9a (or the equivalent NN11a, MNN11a) subzones, while the upper part of Unit-1 (s. B7 to E24) is placed in the CN9b (or the NN11b, MNN11b) subzones.

The commencement of sedimentation in Kalidonia basin cannot be exactly evaluated but it can be placed in the time interval between 9.37 Ma (*D. pentaradiatus* FCO) and 8.761 Ma (*R. pseudo-umbilicus* PB), being closest to the latter datum. Deep water sedimentation in the basin lasted to about 6.1-6.2 Ma (*D. berggrenii berggrenii* top or LO datum, located at level of sample E24).

The caprock of Kalidonia section consists of bioclastic, karstified limestones and coral-reef remnants. Considering the base of this reefal facies (RF), which characterizes the synchronous onset of the Messinian salinity crisis (Krijgsman *et al.* 1999), relatively equivalent to the 'Calcare di Base' in Italy, an age of ca. 5.960±0.02 Ma can be inferred. Subsequently the Uuits-1 and -2 of Kalidonia section (measuring 28 meters in thickness, including compaction) cover deposition between 3.41 and 2.80 Ma, plus the unknown time demand for development of the RF (regressive Unit-3). An average sedimentation rate of ca. 1.11 cm/kyr is calculated for the deposition of the lower two lithostratigraphic units in Kalidonia basin during the Late Miocene.

7. Aknowledgments

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