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PLANKTONIC FORAMINIFERAL BIOSTRATIGRAPHY AND PALAEOENVIRONMENTAL IMPLICATIONS OF A MIDDLE MIOCENE TRANSGRESSIVE SEQUENCE ON THE IONIAN ZONE OF LEVKAS ISLAND, IONIAN SEA, GREECE

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Abstract: Asprogerakata section, located in the northeast part of Levkas Island, Ionian Sea, consists of well-bedded grey-brown calcareous sandstones and silty to sandy marls and represents part of the Miocene transgressive cover of the Ionian zone. Biostratigraphic data and palaeoenvironmental conditions are inferred based upon the planktonic foraminifera. A rich, highly to moderately diverse and well preserved planktonic foraminiferal association enabled biostratigraphic zonation of the Lower-Middle Miocene deposits. On the basis of the composition of the foraminiferal assemblages, palaeoecological and palaeoclimatic interpretations have been made. Quantitative and qualitative analyses provide a detailed distribution of the identified taxa and defined a number of bioevents for the Middle Miocene. The recognition of the first Acme End (AaE) of *Paragloborotalia siakensis* proved that the neogene deposits in Levkas Island have an age of 15.435 Ma and belong to the MMi4 planktonic foraminiferal zone. The MMi4c-MMi4d boundary has been defined by the presence of *Praeorbulina glomerosa circularis* dated at 14.89 Ma. Planktonic foraminiferal assemblages identify a significant change in variability of climate system at around 15.2 Ma, probably corresponding to the global cooling events superimposed to the Middle Miocene Climatic Optimum. In particular, faunal composition suggests a warmth phase in the lower part of the section followed by a cooling phase.

Key words: planktonic foraminifera, Middle Miocene, Eastern Mediterranean

1. Introduction

Levkas Island belongs to the Ionian Islands, which are located in the west segment of the Hellenic Arc, the most active plate margin of the Mediterranean region. The tectonic setting of the wider area is determined by the continental collision between northwestern Greece in the east and the Apulian platform in the west, as well as by the subduction of the African plate under the Aegean microplate along the active Hellenic Arc in the southwest. The Ionian Islands are situated in a transitional zone between the northwestern end of this active subsidence and the continental collision in the north.

The Ionian Islands form part of the para-autochthonous Apulian foreland of the Hellenide orogen and include rocks of the Pre-Apulian (or Paxos) and Ionian isopic zones (Aubouin, 1965; Underhill, 1989).

The Ionian zone represents one of the major tectonic lineaments within Apulia (Adria), and was situated at the southern margin of Neo-Tethys Ocean during Mesozoic times. Palaeogeographically, the Ionian zone originated as a deep-water basin when a pre-existing carbonate platform collapsed during Early Jurassic crustal extension. Early Jurassic syn-sedimentary faulting gave rise to intrabasinal differentiation, which resulted in basinal successions with continuous sedimentation, and reduced sequences deposited on intrabasinal swells, punctuated by stratigraphic gaps (IGRS-IFP, 1966). Pelagic sediments (mainly carbonates, but also argillaceous and siliceous) with local intercalations of cherts and shales accumulated up to Eocene time in a depositional environment remote from any major siliciclastic input. The transition into flysch-type sedimentation took place during the Early Eocene already and ended in the Aquitanian, when the eastern part of Levkas emerged. Several local formations unconformably rest over the flysch of the Ionian zone that as a whole correspond to a Miocene transgressive cover, which is interesting both from the stratigraphic-palaeontological and the structural point of view.

However, Miocene sediments in Levkas Island have not yet been studied adequately palaeontologi-cally and furthermore a biostratigraphic framework has not yet been properly established.

The purpose of this study is to provide the first comprehensive account of the micropalaeontology of the Early to Middle Miocene in Levkas Island, by using a reference section (Asprogerakata section). Depending on the lithology, the biotic content changes remarkably and, consequently, its potential resolution. Although no formally established biozones have been generally used because of the rarity of species useful for biozone recognition, a biostratigraphic framework has been developed using plenty of age-diagnostic taxa recovered. Information derived from the planktonic foraminiferal assemblages and analogy with present day phylogenetically related taxa, have been also used for the palaeoenvironmental analysis.

2. Materials and methods

2.1. The studied section

The Asprogerakata section (Fig. 1) gives a representative picture of the Miocene sedimentary record of the Ionian zone, in Levkas Island. The section is located along a roadcut just south of the village Aprogerakata. A conspicuous steep fault separates white non-detrital limestones of Late Eocene age from approximately 65 m of grey marls and intensively burrowed, medium to fine-grained calcareous sands. Coarse intercalations were not observed in the succession.

The grey-brown, medium to fine-grained, calcareous sandstones, which predominate in the lower and middle parts of the section, are well bedded and generally ill-sorted. Primary sedimentary structures are obscured by the intense bioturbation (Fig. 1).

Beds are generally parallel sided, while the burrows (*Skolithos/Ophiomorpha*) are commonly vertical, penetrating downwards from the upper surface, and have hard, brown meniscoid sandy walls, filled with loose, clean white sand.

From bottom to top the sandstone beds are decreasing in number and thickness. Silty and sandy, burrowed marls with some intercalations of thin, calcareous sandstone beds are prevailing in the upper part of the section.

These facies are believed to have been deposited in both inner shoreface and middle to outer shelf settings below the fair-weather wave base by slow and semi-continuous fall-out from storm-generated suspension clouds, enabling infaunal reworking to keep pace with sediment accumulation. The sediment was supplied from the upper shoreface by relatively frequent and strong wave and storm reworking. During calm intervals, various organisms thoroughly reworked the sediments, obliterating the primary sedimentary structures.

2.2. Planktonic foraminifera

Planktonic foraminiferal analyses were carried out on a total of 58 samples collected from Asprogerakata section at a mean interval of 0.50 to 0.60 cm.

All the samples were washed with a 63μm sieve. Quantitative analysis was performed on the whole samples. For the biostratigraphy semi-quantitative and qualitative analyses have been carried out on survey of the >125 μm fraction. Distribution patterns have been reconstructed counting about 300 specimens of all planktonic species from splits of the total sample. The distribution of selected taxa and their estimated abundance, for the two sequences are expressed in percentages of the total planktonic fauna and are reported in Fig. 2.

The palaeoclimatic record was determined using biogeographic indicators as proxies of temperature. Therefore, a palaeoclimatic curve was constructed using the formula (w-c)/(w+c)x100 of Amore et al. (2004), where *w* represents the warm-water indicators and *c* the cold water indicators. *Paragloborotalia siakensis, Globoquadrina dehiscens, Globoturborotalita decorapeta, Dentoglobigerina altispira, Globigerinella obesa, Globigerinoides subquadratus., Globigerinoides quadrilobatus, Praeorbulina* spp. are considered warm water species (Hemleben et al., 1989; Rohling and Gieskes, 1989; Turco et al., 2002). *Globorotalia praescitula, Globigerina praebuloides, Catapsydrax parvulus,Globigerinita. glutinta*, and *Turborotalita quinqueloba* are considered cool water indicators (Hemleben et al., 1989; Pujol and Vergnaud-Grazzini, 1995).

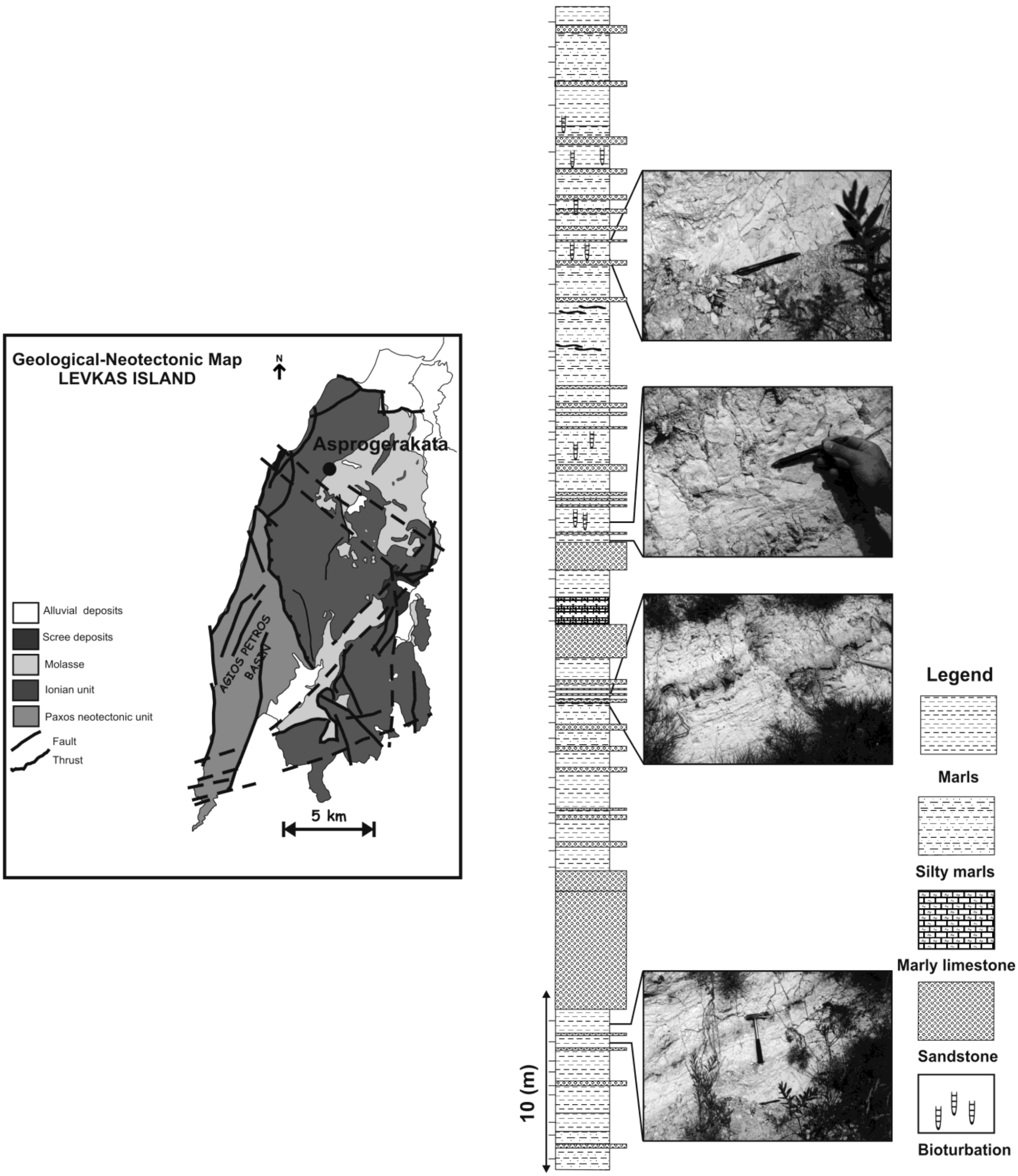

Fig.1. Geological and Neotectonic map of Levkas Island (after Lekkas et al., 2001, modified), depicting the location of the studied area. Lithology and position of samples of Asprogerakata section.

3. Results

3.1. Faunal changes

Planktonic foraminifera are abundant in the studied section, showing generally a moderate preservation. In spite of a minor resolution, planktonic foraminiferal bioevents are recorded as in the time equivalent Mediterranean sequences.

The quantitative distribution pattern of 20 planktonic foraminiferal categories are presented in fig. 2, showing biostratigraphic and/or abundance significance. Some categories represent different taxa linked by morphological or philetic affinities. *Globigerina praebulloides* group contains the species *G. praebulloides*, *G. falconesis* and *G. bollii*. *Glo-*

bigerina bollii has been considering as a synonym of *G. falconensis* (Blow, 1969), a characteristic species for the Medirerranean Middle Miocene (Foresi et al., 2002). In the studied section this species shows a limited distribution so it is included in the *G. praebulloides* group. In the *G. obesa* group specimens *of G. praesiphonifera, G. obesa* and *G. pseudobesa* are also included. *Globigerinoides quadrilobatus* group contains *G. quadrilobatus*, *G. trilobus* and *G. sacculifer*. *Dentoglobigerina* spp. is referred to the *D. baromoensis* and *D. langhiana* species, which have been considered by many authors as synonyms (Kennett and Srinivasan, 1983). Both species were recognised in the studied section, but because of their limited distribution we incorporated them in the same group. *Globigerinoides obliquus obliquus* specimens sporadically occur in the section and because of its low percentages in the assemblage it is not plotted.

tains the *G. praemenardii, G. miozea* and *G. archeomenardii*.

The taxa *T. quinqueloba, G. druryi. G. Decoraperta, C. parvulus, D. altispira, Dentoglogerina* spp., *G. obesa, G. quadrilobatus* are continuously present and show abundance fluctuations throughout the studied sections. The most abundant species are those of *G. praebulloides* group and *G. glutinata*. Among the species having discontinuous distribution *Glolobigerinoi-des subquadratus* and keeled globorotaliids, occasionally reach significant percentages.

In the following paragraphs we only consider the appearance/disappearance of marker species which are used as biohorizons. The results, as well as an adopted biozonal scheme, are presented in Fig. 3.

Paragloborotalia siakensis (Le Roy): In Asprogerakata section *Paragloborotalia siakensis* is

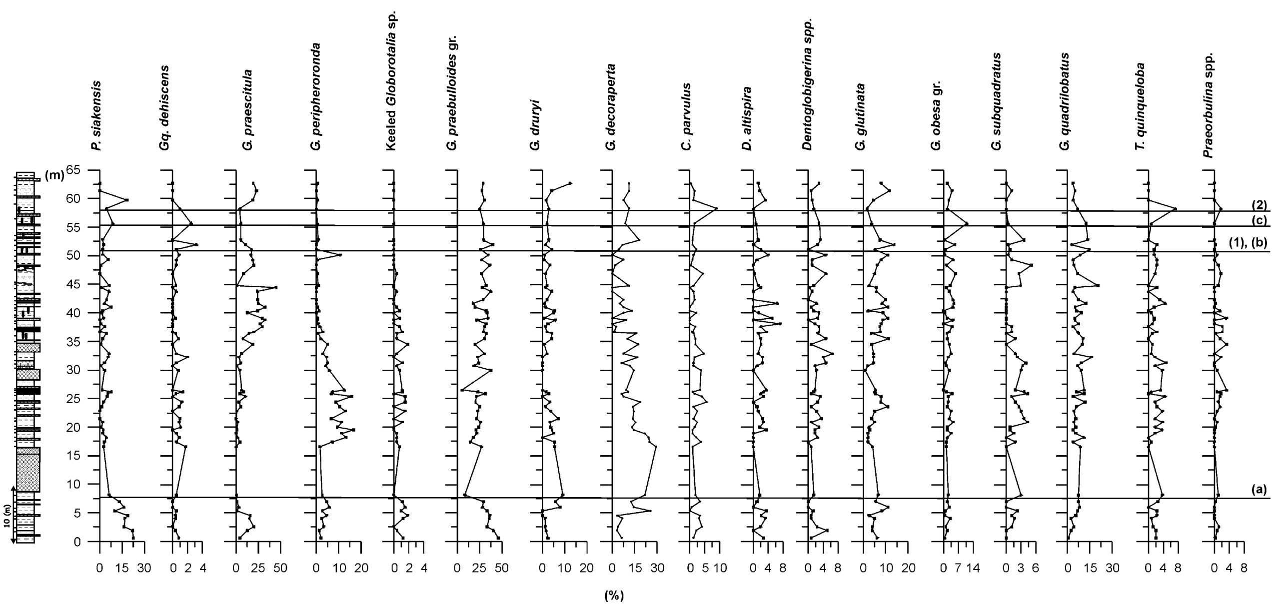

Fig.2. Quantitative distribution pattern of planktonic foraminiferal marker species and the position of the main bioevents: (a) AaE1 *P. siakensis*, (1) FAD *P. glomerosa glomerosa*, (b) high abundance of *G. dehiscens* (c) AbB2 *P. siakensis* (2) FAD *P.glomerosa circularis*.

The qualitative analysis reveals the occurrence of *Paragloborotalia birnageae* in some levels, but because of the small numbers of abundance this species was not plotted. This species was previously reported by Zachariasse, (1992) in N4 zone and in the N7 Zone by Kennett and Srinivasan (1983). Foresi et al. (2002) found this species in Tremiti Island in the *Praeorbulina gl. sicana* zone. *Praeorbulina* spp. consists of *P. transitoria, P. glomerosa sicana, P. glomerosa glomerosa* and *P. glomerosa circularis*. Keeled globororaliids con-

nearly absent from 10 to 55 m of the section, but is abundant in the lower part up to 10 m, where the Acme End (AaE) of this taxa is recorded for the investigated interval (Fig. 2). The percentages of its abundance are ranging between 21 to 45% of the total planktonic foraminiferal assemblage. After an interval of its near absence, *P. siakensis* appears in the top part in significant percentages. The coiling direction of *P. siakensis* is random from 0-10 m, while from 25 m and upwards seems that the sinistral coiling forms prevail. A second distinct interval of high abundance of *P. siakensis* is observed just below the FO of *P. gl. circularis,* up to the top of the section. The prevailed coiling direction of the taxon in this interval is sinistral. *P. siakensis* is a long ranging species displaying several distributional changes of biostratigraphic significance. The age of the Acme End (AaE) of *Paragloborotalia siakensis* has been magnetostratigraphically dated at 15.435 Ma (Abdul-Aziz et al., 2008).

The interval of the Acme End of *P. siakensis* in Levkas Island seems to be synchronous with the AaE in Site 372 and in Tremiti Island (Abdul-Aziz et al., 2008; Di Stefano et al., 2008) The reabundance of the species, at the top of the section (56 m), is recorded just below the first appearance of *P.gl. circularis* and can be compared with the AbB bioevent recorded in the previous sections (Di Stefano et al., 2008).

Praeorbulina spp. Olsson: Several specimens of *P.gl. sicana* were recognized in the middle part of the record, while the FO of *P. gl. glomerosa* occurs in the upper part (51 m) of the section. The topmost part of the studied record is characterized by the FO of *P. gl. circularis*, exactly at the 58 m of the section.

Globoquadrina dehiscens Chapman, Parr and Collins: Although this taxon occurs in small percentages, rather continuously, its distributional pattern reveals a distinct interval in which the species shows an elevated abundance between the first occurrences of *P. gl. glomerosa* and *P. gl. circularis*. The influx of *G. dehiscens* is associated with peak in abundance of *G. subquadratus* and *C. parvulus* and absence of *G. praescitula*. This event can be considered of secondary significance and has been recognised also at the same stratigraphic level in northern Italy (La Vedona section, Hüsing et al., 2010).

Globorotalia praescitula Blow: Dextral and sinistral specimens reveal two significant intervals of maximum abundance. The first interval is recorded at the base of the investigated section and the second in the middle part of the section, where the dextrally coiled specimens dominate the assemblage.

Globorotalia peripheroronda Blow and Banner: This species shows a discontinuous distribution pattern. It is present at the base and then it occurs in significant numbers at 17-35 m of the section. At 50 m of the investigated interval a remarkable peak in abundance of the sinistral coiled specimens is obvious. The species exists in the Mediterranean from the Aquitanian stage and ends within the lower part of the Serravallian (Foresi et al., 2002; Di Stefano et al., 2008).

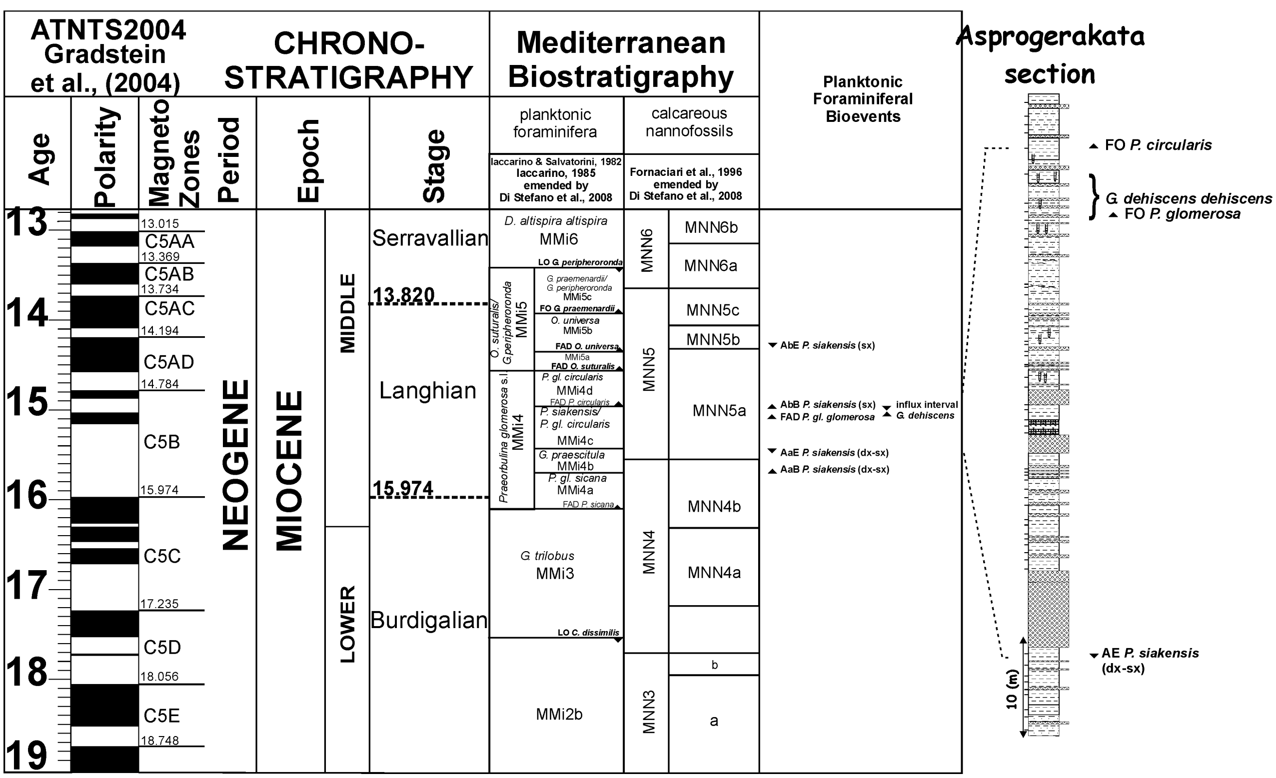

Fig. 3. Planktonic foraminiferal biostratigraphy of the Asprogerakata section.

3.2. Biostratigraphy

Several biostratigraphic schemes, based on planktonic foraminifera (Iaccarino and Salvatorini, 1982; Iaccarino 1985; Foresi et al. 1998; Sprovieri et al., 2002), have been proposed in the last decades for the Mediterranean Middle Miocene. Recently, Di Stefano et al. (2008) emended the biostratigraphic zonal scheme of Iaccarino & Salvatorini, 1982 and Iaccarino, 1985 by the addition of two subzones using the $Acme_a$ interval of *P. siakensis*. Following these pioneer works, as well as the abundance pattern of the taxa, the appearance of marker species and acme interval of selected taxa, which are used as biohorizons according to the integrated biostratigraphic scheme of Di Stefano et al. (2008), we are able to date the section.

The planktonic foraminifera which have been identified in the investigated succession characterize the Langhian interval. The main planktonic foraminifera events recorded in Asprogerakata section in stratigraphic order are: (1) the First Appearance Datum (FAD) of *Praeorbulina gl. glomerosa (*dated at 15.102 Ma, Abdul Aziz et al., 2008) and (2) the FAD of *P.gl. circularis* (14.89Ma, Abdul Aziz et al., 2008). In addition, the quantitative distribution patterns of planktonic foraminifera taxa reveal additional faunal changes of biostratigraphic significance, such as two acme intervals of *Paragloborotalia siakensis* (a, c, Fig. 2) and an interval of high abundance of *Globoquadrina dehiscens* (b, in Fig. 2). The AaE (Fig. 2, a) of *P. siakensis* has been dated at 15.435 Ma and the AbB (c) at 14.93 Ma (Abdul-Aziz et al., 2008; Di Stefano et al., 2008). The chronostratigraphic level of the observed high abundance of *G. dehiscens* is consistent with the one of FAD of *P. gl. glomerosa* and is followed by an Acme interval of sinistrally coiled *P. siakensis.* The influx of *G. dehiscens* is also defined in northern Italy (La Vedona section).and dated 14.915-15.098 Ma, which is in accordance with the studied chronostratigraphic record (Hüsing et al., 2010).

The bioevents listed above allow the identification of *P. siakensis-P.gl.circularis* subzone of MMi4 planktonic foraminiferal Zone for the Langhian of the Mediterranean region of Di Stefano et al. (2008). The first occurrence of *P .gl. circularis* defines the MMi4c/MMi4d boundary.

According to the astronomical ages derived from other astronomical tuning sections in the Mediterranean Sea the investigated section spans from 15.435 to 14.89 Ma, corresponding to Langhian.

3.3. Palaeoenvironmental-palaeoclimatic implications

The palaeoclimatic curve and the different abundance patterns of planktonic foraminifera allowed the recognition of four main intervals in the Middle Miocene sequence of the section (Fig. 4).

<u>*0-7.5m*</u>*:* The lower part of the section is characterized by *P. siakensis* random coiled, a warm species (Turco et al., 2002), *G. praebulloides* and *G. praescitula*. The last two species are closely related to the extant species *G. bulloides* and *G. scitula* respectively, which have the same environmental preferences (cool water indicators) (Hemleben et al., 1989).

<u>*7.5-20 m*</u>*:* Just after the acme end of *P. siakensis* the interval is characterized by the elevated percentages of *G. druryi*, *G. decoraperta*, and *G. quadrilobatus.* These taxa are relatively warm water forms, which are inhabited in warm subtropical environments (Pujol and Vergnaud-Grazzini, 1995).

<u>*20-32m*</u>*:* The palaeoclimatic fluctuations towards cool conditions are due to the dominance of cool water species such as *G. glutinata* and *G. praebulloides* (Pujol & Vergnaud-Grazzini, 1995), while

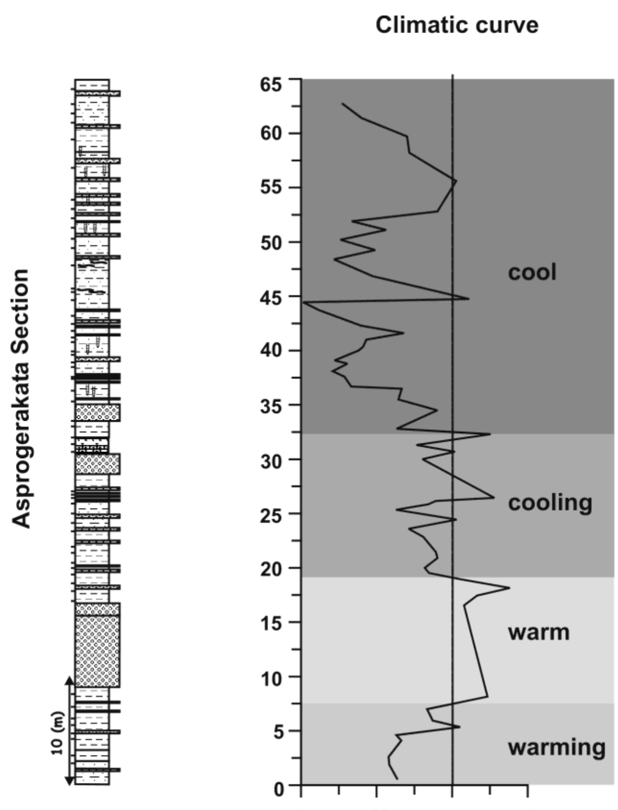

Fig. 4. Palaeoclimatic curve based on warm vs cold water plantkonic foraminiferal species.

warm water species display several peaks in abundance.

32-65 m: The palaeoclimatic curve implies that cool sea surface conditions prevailed in this period, due to the elevated percentages of the cool water indicators and the lack of warm water taxa. A major cooling step is recorded at 45 cm, whereas two warming steps are recorded within the cool interval. The first follows the significant cooling shift and the second is described between the first occurrence of *P. gl. glomerosa* and the first occurrence of *P. gl. circularis*. The latter event is characterised by a shift in abundance of *G. dehiscens* and reflects the warming (deepening) of the thermocline while surface temperatures are also warmed.
Planktonic foraminiferal abundance identify a significant change in variability of climate system prior to 14.89 Ma probably corresponding to the global cooling events superimposed to the Middle Miocene Climatic Optimum (D Event of Shevenell and Kennet, 2004 recorded at 14.8 Ma and/or affected by the Mi3a event of Miller et al., 1991).

In particular, the lower part of the section up to 20m seems to be subjected to more ameliorated conditions implied by the occurrence of *Paragloborotalia siakensis* (Turco et al., 2002). More deteriorated climatic conditions are evident for the middle–upper part of the sequence.

4. Discussion

Asprogerakata section was previously dated to the Lower Miocene (Burdigalian) on the basis of the presence of *G. trilobus, G. obliquus, G. subquadratus, G. praescitula* and the absence of *Orbulina* (de Mulder, 1975). According to Fornaciari et al. (1996) and Rio et al. (1997), the Langhian Epoch is defined by the FO of *Praeorbulina* and the LO of *Sphenolithus heteromorphus*.

The biostratigraphic data referred to this study, based on planktonic foraminifera, allowed us to characterise and date the beginning and the end part of the section.

In particular, at the lower part of the section the distribution pattern of *P. siakensis* led to the recognition of the AaE event, which has been dated at 15.435 Ma (Abdul-Aziz et al., 2008). Going upwards, the FAD of *P. gl. glomesa* recorded at 51 m and the FAD of *P. gl. circularis* at 58 m as well as the acme interval of *G. dehiscens* and the AbB of *P. siakensis* sinistrally coiled made our data comparable to that of Tremiti Island and other Mediterranean sites (Di Stefano et al., 2008; Hüsing et al., 2010), dating the top part at 14.89 Ma.
In the climate evolution of Cenozoic, this interval represents the Middle Miocene climatic transition from relative global warmth of the Late Oligocene-Early Miocene to the Neogene "ice-house" From the early-middle Miocene, global temperatures cooled dramatically through a series of major changes in climate, polar ice volume and ocean circulation (Roth et al., 2000; Mutti, 2000). Following the Miocene Climatic Optimum, between 16-14.5 Ma, the Middle Miocene is characterized by a major period of expansion of Antarctic ice. The major phase of East Antarctic ice sheet growth took place between 15 Ma and 13 or 12 Ma (Zachos et al., 2001; Billups and Schrag, 2002; Winkler et al., 2002). During this period the global climate changed to colder conditions with increased zonality (Flower and Kennett, 1993; Zachos et al., 2001). At this time, the ocean climate evolved into modern state conditions dominated by strong meridionality and vertical thermal gradients and dominance of high-latitude deep water source (Miller et al. 1987, 1991; Woodruff and Savin, 1989, 1991; Flower and Kennett, 1993; Roth et al., 2000). This long term climatic Cenozoic evolution was punctuated by several brief periods of glaciation based on the recognition of prominent isotope events (Mi1-6) (Miller et al., 1991) with potential for global correlations. The Mi-events have been recently correlated and dated in several Mediterranean sections (Turco et al., 2001; Abels et al., 2005) on the basis of magnetostratigraphic data integrated into orbitaly-derived timescales (Lourens et al., 2004).

In Asprogerakata section, palaeoclimatic curve identify a significant cooling phase above the 15.4 Ma at the middle-upper part of the record. This phase follows a warming phase recorded at the lower part of the section, which may correspond to the later phase of the MCO as this has been recorded in site 608 of North Atlantic. Indeed, the Mi3 event recorded in site 608 in North Atlantic reveal two peaks in oxygen isotope record dated at 14.9 and 13.6 Ma (Miller et al., 1991) and labeled Mi3a and Mi3b respectively.

The astronomical dates for the Mi3a and Mi3b events have estimated at 14.2 Ma and 13.8 Ma (Shevenell and Kennett, 2004) while a major isotope enrichment event in Mediterranean dated at 13.82 Ma has been interpreted as related to Mi3b event (Abels et al., 2005; Holbourn et al., 2005), which is influenced by the 100-kyr of eccentricity cycles and coincides with a period of minimum amplitudes in obliquity. This orbital configuration was also recognized by Holbourn et al., 2007 during the lond-term cooling phase II from 14.7 to 13.9 Ma bounded by oxygen isotope increases.

On this basis, the two major climatic pahses recorded in Asprogerakata section is interpreted to have been affected by the global climatic deterioration recorded from 15 to 14.5 Ma (Zachos et al., 2001; Holbourn et al., 2005; 2007), whereas the cooling phase is affected by the global climatic transition to colder mode conditions (Miller et al., 1991; Shevenell et al., 2004; Wright and Miller, 1992).

From Langhian time onwards the only connection between the Mediterranean and the world's ocean was via Atlantic. Our data further support the inflow of cold North Atlantic water in the Mediterranean. The entry of cold Atlantic water was made possible by deepening of "Gibraltar sill", so an estuarine circulation can be assume for Langhian time (Gebhardt, 1999)

5. Conclusions

This study refers to the early Middle Miocene palaeoclimatic evolution of eastern Mediterranean, based on the planktonic foraminiferal assemblage changes. The biostratigraphic analyses reveal that the investigated section spans from 15.435 -14.89 Ma. The interval from the base (15.435 Ma AaE of *P. siakensis*) to the top part is characterised by an overall warming trend which is mainly represented by warm-temperate water taxa.

The relatively warm period is followed by a gradually cooling resulted at a major cooling event at 45 m of the section.

The undertaken analyses indicate that climatic and oceanographic cooling occurred during 15-14.89 Ma in the Eastern Mediterranean area coincides closely with the end of the Middle Miocene Climatic optimum between 17 and 15 Ma (Zachos et al., 2001).

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