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CYCLOSTRATIGRAPHIC DETERMINATION OF THE REPLACEMENT OF *GLOBOROTALIA MENARDII* GROUP BY *GLOBOROTALIA MIOTUMIDA* GROUP - A SIGNIFICANT CLIMATIC CHANGE SIGNAL.

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This paper documents the periodicity in the relative abundance fluctuations of the *Globorotalia* species in the stratigraphic interval between the first occurrence of *Globorotalia menardii* form 4 and the first regular occurrence of *Globorotalia miotumida,* which marks the Tortonian/Messinian boundary. The objective of this work is to reconstruct the small-scale climatic changes recorded in the Late Miocene hemipelagic Metochia section (Gavdos Island).

The abundances of *Globorotalia* species reveal a distinct cyclic pattern. Spectral analysis was applied in order to identify the periodicity and astronomical forced variations and to correlate *Globorotalia* relative abundance fluctuations to solar insolation curve.

This analysis revealed that the relative abundance fluctuations of *Globorotalia* species are related to eccentricity, precession cycles and obliquity 41 kyr cycles.

The replacement of *G. menardii* group by the *G. miotumida* group is related to short-term climatic fluctuations (precession-controlled sedimentary cycles) superimposed by longer-term astronomically driven climate changes (eccentricity and obliquity glacio-eustatic cycles).

Keywords: astronomical cycles, Globorotaliids, Eastern Mediterranean, Late Miocene.

INTRODUCTION

The quantitative study of keeled globorotaliids in several Late Miocene sections in NE Atlantic, North Betic and South Rifian Gateways in western Mediterranean and in the Guadalquivir basin, revealed a sequence of planktonic foraminiferal events used for a high resolution correlation of the Mediterranean with the global ocean for the time interval prior to the Salinity Crisis (Sierro, 1985; Sierro and others, 1987; Sierro and others, 1993).

The most prominent change in the assemblages consists of the replacement of the *Globorotalia menardii* group by the *Globorotalia miotumida* group and the first appearance datum (FAD) of the *Globorotalia conomiozea.*

This change is well correlated with the Tortonian/Messinian boundary and is related to a widespread south migration of northern temperate faunas replacing the subtropical ones as the North Atlantic latitudinal thermal gradients increased (Sierro and others, 1993).

This event also coincides with the beginning of the Mediterranean Crisis recorded by isotope fluctuations in surface waters and immediately followed by the development of widespread anoxic conditions in the deep and intermediate waters (Sierro and others, 1993).

The occurrence of periods of bottom water anoxia in Neogene hemipelagic successions of the Eastern Mediterranean Basin is evident from rhythmic layering of sapropels separated by grey-blue, bioturbated and homogenized marl beds.

The origin of the rhythmic layering and consequently the environmental bottom water conditions is related to the orbital forced variations in climate (Hilgen and others, 1991; Lourens and others, 1992; Lourens, 1994; Krijgsman and others, 1995; Hilgen and others, 1995).

One of the very few complete hemipelagic successions of the Upper Miocene in the Mediterranean is found in Metochia section, Gavdos Island (SW Crete). The thickness of successive sapropel and marl beds varies such that distinct small and large-scale clusters can be distinguished.

The Neogene Mediterranean sedimentary cycles have been shown to be linked to variations in solar insolation (Hilgen, 1991) and an astronomically calibrated time scale for Metochia section has been established through correlation to the 65^{o}N summer insolation curve of solution La90$_{(1,1)}$ with present values for the dynamical ellipticity of the Earth and tidal dissipation of the moon (Laskar, 1990; Laskar and others, 1993; Hilgen and others, 1995; Lourens and others, 1996).

Individual sapropel-marl couplets are correlated to precession cycles with periodicities of 19 and 23 Kyr (average 21.7 Kyr), with the sapropels corresponding to the precession minima. Clusters of sapropelitic layers are, according to Krijgsman and others (1995), Hilgen and others (1995) and Antonarakou (2001), correlated to the 100-kyr and 400-kyr eccentricity cycles.

In this paper, we investigate the periodicity of the relative abundance fluctuations in the stratigraphic interval below the first occurrence of the *Globorotalia conomiozea*, in the Late Miocene hemipelagic section Metochia section (Gavdos island) in order to reconstruct small-scale climatic changes in the studied interval.

MATERIALS AND METHODS

Geological Setting-Stratigraphy

Metochia section is located west of the Metochia village at the northeast part of the Gavdos Island (Figure 1). It is a Late Miocene hemipelagic marl succession, which contains 96 rhythmic alternations of brown-grey, organic-rich laminated

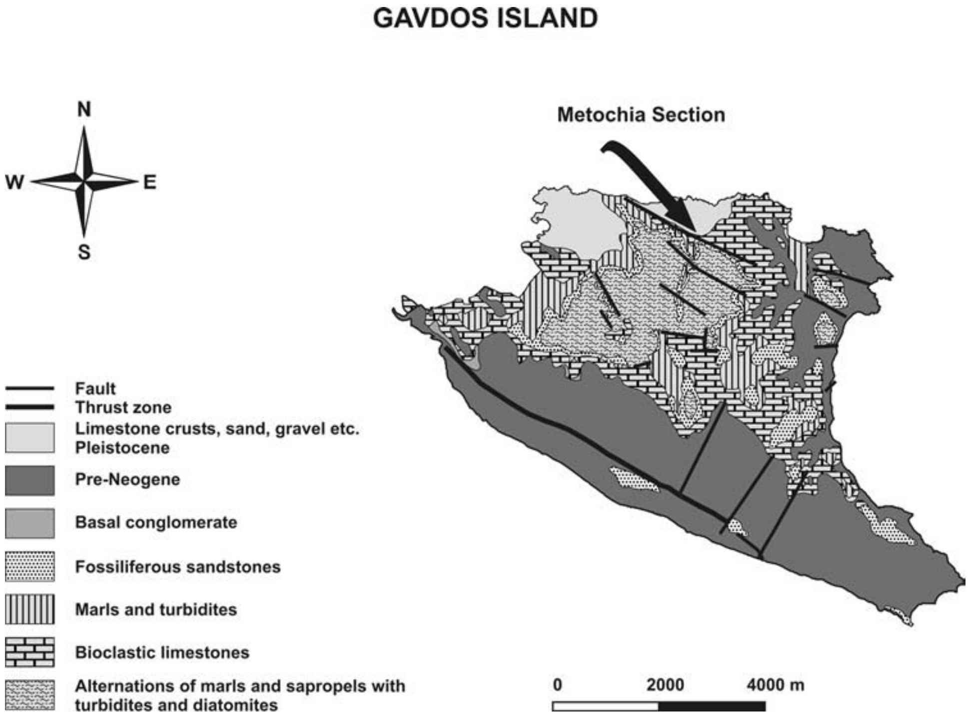

Figure 1. Location map of the studied area.

beds (the so called "sapropels") and bioturbated, light grey-blue, homogeneous, hemipelagic marl beds (Figure 2). The basal part of the approximately 100m thick section, consists of a paleosol, overlain by estuarine-type sediments with oyster banks. Strongly bioturbated shallow-marine sands with a high lateral continuity and many *Heterostegina* sp., Echinoderma*,* Pectinids and other gasteropods of shallow-marine origin overly the estuarine deposits. Above the fossiliferous sand bed, an alternation of laminites and marls occur. Plankton/benthos ratios from the pelagic marls at the first sapropel level indicate basin depths of the order of 850 m and more (Postma and others, 1993).

The stratigraphic position of the section is known from magnetostratigraphic, cyclostratigraphic and biostratigraphic data (Hilgen and others, 1995; Krijgsman and others, 1995; Raffi and others, 2003). The section covers the time span from 9.7 to 6.6 Ma, a period of substantial changes in the Mediterranean-Atlantic connections.

The planktonic foraminiferal biostratigraphy used in this paper (Table 1) is the one employed in earlier papers and consists of the following bioevents (Krijgsman and others, 1995), which are accurately dated using the astronomical calibrated time-scale.

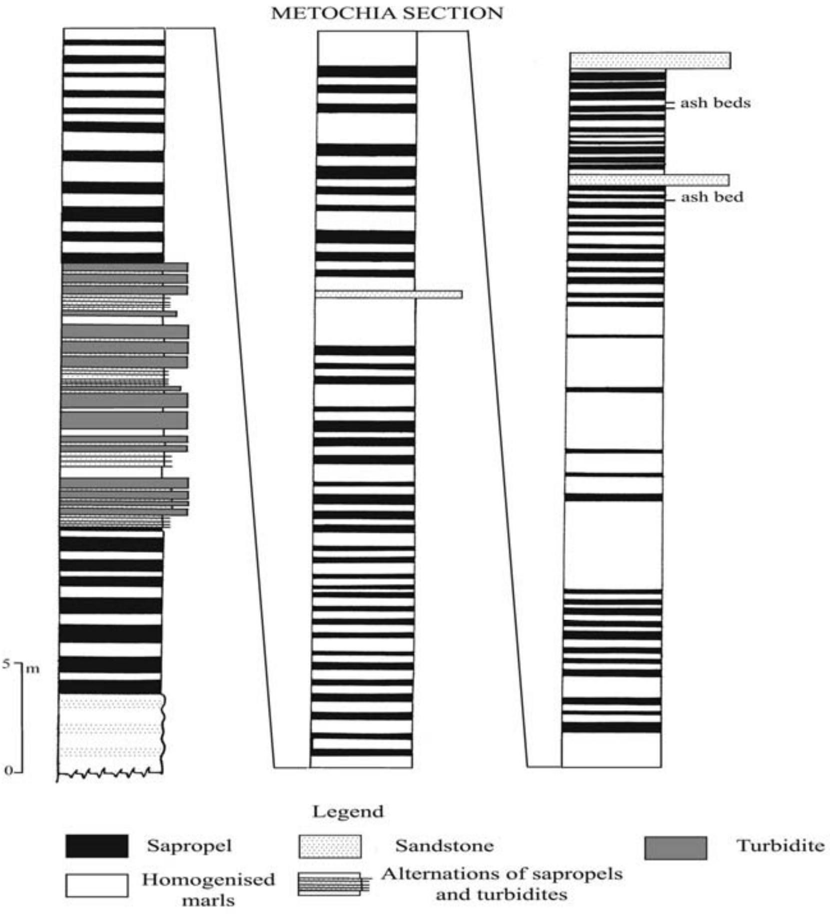

Figure 2. Lithostratigraphical column of the Metochia section.

The Tortonian/Messinian boundary is usually recognized at the First Regular Occurrence (FRO) of *Globorotalia miotumida* group at 7.24 Ma (Hilgen and others, 1995).

Micropaleontological Analysis

560 samples have been taken over a stratigraphic interval of approximately 100m, which corresponds to an average spacing of 20 cm. Sampling was aimed

Table 1. Planktonic foraminifera bioevents
(First Occurrence (FO), First Regular Occurrence (FRO), Last occurrence (LO), Last Common Occurrence (LCO), highest regular occurrence (hro), lowest regular occurrence (lro), frequency shift (fs)).

Bioevents		Stratigraphic level	Astronomical Age (Ma)
G. nicolae	FO	99.25 - 99.35 m	6.82 - 6.83
G. miotumida group	FRO	90.25 - 90.33 m	7.23 - 7.24
G. menardii 5	FO	87.90 - 87.97 m	7.35
G. falconarae	LO	85.20 - 85.69 m	7.44 - 7.46
G. menardii 4	LCO	84.12 - 84.24 m	7.50 - 7.51
S. seminulina	hro	79.06 - 79.31 m	7.72 - 7.73
S. seminulina	lro	74.44 - 74.60 m	7.91 - 7.92
G. falconarae	fs	57.31 - 57.84 m	8.42 - 8.44
G. falconarae	LCO	44.10 - 44.27 m	8.86
G. menardii 4	lco	29.35 - 29.76 m	9.31 - 9.32
N. acostaensis (dex)	hro	9.81 - 9.93 m	9.54

at a minimum of four levels per sedimentary cycle which corresponds to a resolution of 5 kyr. According to Schenau and others (1999), sapropels are characterized by a low sedimentation rate, 4cm/ky. Samples were dried at 60°C, and washed over a 63- and 125 µm sieve. Qualitative and quantitative analyses of planktonic foraminifera have been performed on the fraction larger than 63 µm. Samples showing abundant microfauna have been split; at least 300 specimens have been identified and counted. 19 different planktonic foraminifera species were determined which were lumped into 17 species-groups. Since the ecological characteristics of the taxa we lumped together are identical, these taxon groupings simplify the graphical representations, without fundamentally altering the quantitative analysis of the total foraminiferal data. Therefore, *Globoturborotalita apertura* and *Globigerinoides obliquus* are lumped under *G. apertura* group. The taxa *Globigerinoides trilobus* and *Globigerinoides sacculifer* are listed under *G. trilobus* group. In addition, the following species and species-groups have been determined: *Globigerina bulloides, Globigerina falconensis, Globigerina falconensis* intermediate, *Globoturborotalita nepenthes, Sphaeroidinellopsis seminulina, Globigerinella siphonifera, Orbulina universa, Neogloboquadrina acostaensis, Globorotalia scitula, Globorotalia menardii* group (including *G. menardii* form 4, *G. menardii* form 5 and *G. merotumida*), *Globorotalia miotumida* group (including *G. miotumida*, *G. conoidea*, *G. mediterranea* and *G. conomiozea*), *Turborotalita quinqueloba, Globigerinita glutinata, Globoquadrina dehiscens,* and *Globorotalia nicolae.*

The quantitative distribution pattern of the identified planktonic foraminiferal categories is expressed as the percentage of planktonics in the total foraminiferal assemblage and is presented in Figure 3, together with the biostratigraphic significance of the species.

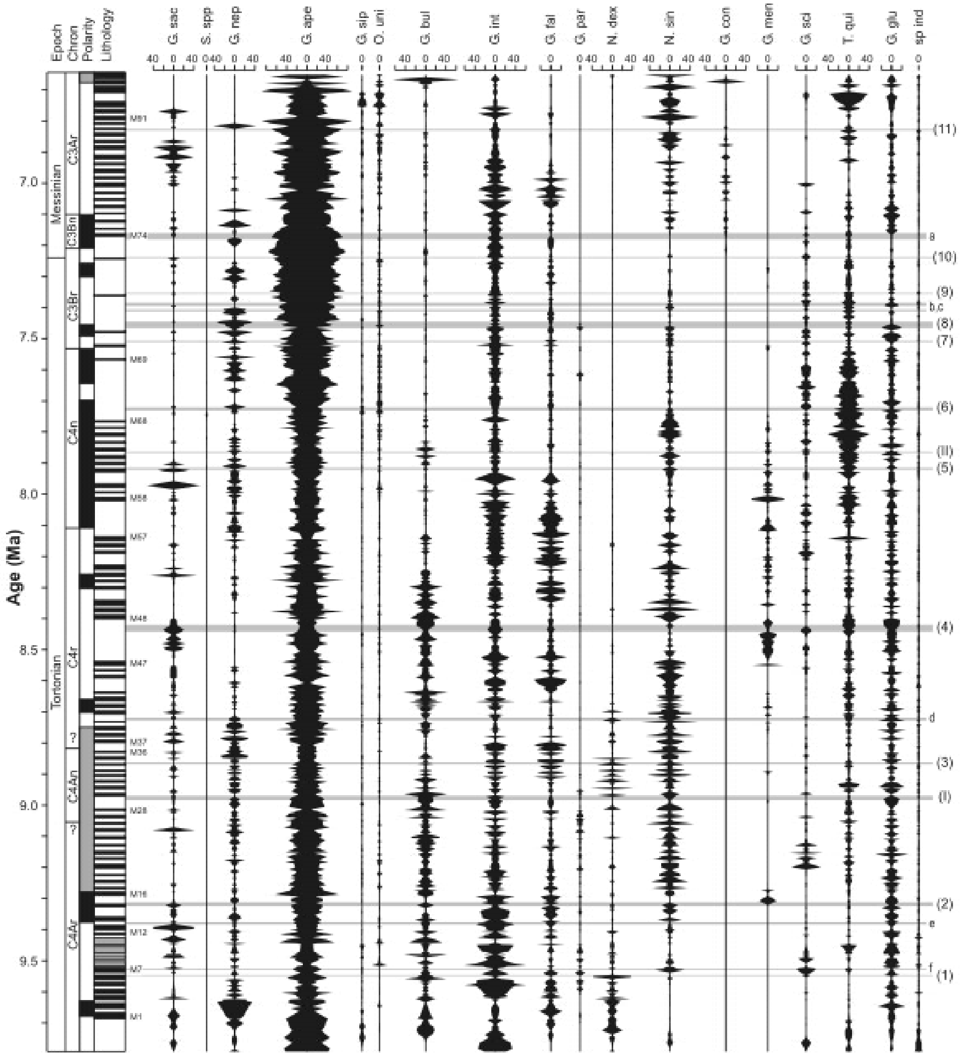

Figure 3. Abundance-curves of 17 planktonic foraminiferal species for the Metochia section.

In addition, a standardized Principal Component Analysis (PCA program of Davis [1973]) has been carried out to extract the most important factor in determining the overall faunal change. This program simplifies the matrix by combining species into a small number of independent variables or components. We also carried out spectral analysis and applied bandpass filtering in order to investigate the frequencies of variations recognized in the principal component analysis. We used a program in which the fourier transformation is applied to the autocorrelation function (Davis, 1973) of an equally spaced timeseries of the original record.

The quantitative data of *Globorotalia* species used in this paper and obtained by Antonarakou (2001) have been processed by spectral analysis using bandpass filter of 21 and 41 kyr components.

RESULTS

Faunal Pattern

The abundance pattern of the 17 counted planktonic foraminiferal categories versus time together with the chronostratigraphical position of the main bioevents are plotted in Figure 3. Among the taxa more or less continuously present, *G. bulloides, G. falconensis* and the dextrally coiling specimens of *N. acostaensis* show a (overall) decrease, whereas *G. apertura* and *O. universa* display an (overall) increase. All the other species do not display any particular trend, and show short-term recurrent variations (*G. nepenthes, G. trilobus, N. acostaensis*-sinistral, *T. quinqueloba*). The *Globorotalia menardii* group and the species *G. falconarae* display longer-term changes, whereas the species *G. glutinata, G. falconensis* intermediate – which are very abundant in all samples – and also *G. siphonifera* do not show significant variations.

Finally, the most abundant species are *G. trilobus, G. apertura, G. nepenthes, G. bulloides, G. falconensis* and *N. acostaensis* (sin.).

Globorotalia menardii group and *Globorotalia miotumida* group were identified throughout our record displaying periodic oscillations in abundance (Figure 4). Such a periodicity is most obvious for the sinistrally coiled *G. menardii* 4 in the lower part of the section (at 3-53m). This species occurs more regularly between 54-78m of the section, but then it vanishes until a short but prominent influx at the 82m of the section. The top of this brief reoccurrence is equated with the last common occurrence (LCO) of *G. menardii* 4 (Krijgsman and others, 1995). Keeled globorotaliids then become absent again up to the first occurrence (FO) level of the right coiling *G. menardii* 5, directly above the 88m level. At the upper part of the distribution range of the species *G. menardii* 5, *G. menardii* 4 shows a final and extremely brief but distinct influx. At about 90m, *G. menardii* 5 is definitively replaced by left-coiled assemblages of keeled globorotaliids characterized by a reniform chamber outline in spiral view. These assemblages are termed *Globorotalia conomiozea* group by Zachariasse (1979) and *Globorotalia miotumida* group by Sierro (1985) and Sierro and others, (1993). The earliest representatives of *G. conomiozea* group show flat tests typical of *G. miotumida* while the regular occurrence of the conical types (*G. conomiozea*) starts at the 92m of the section.

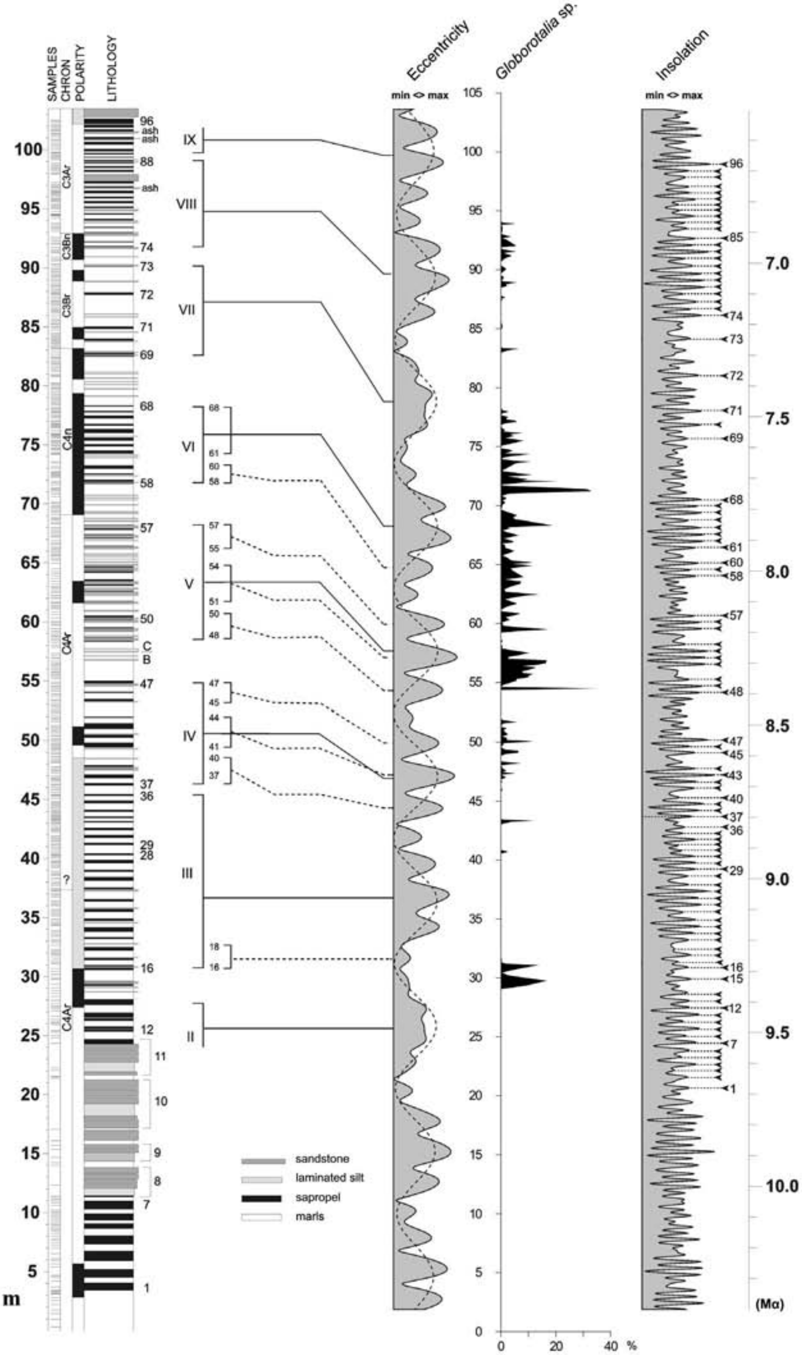

Figure 4. Abundance pattern of *Globorotalia menardii* group.

The characteristic pattern of these short incursions of *G. menardii* group is useful for biostratigraphic correlations.

The event of the LCO of *G. menardii* 4 was first recognized by Zachariasse (1975) and Langereis (1984) in Crete and coincides with the PF-Event I of Sierro and others (1993), in site 410 of Morocco and also in other sections of the Guadalquivir Basin. According to Sierro and others (1993), this interval is characterized by the sudden absence or decrease in abundance of *Globorotalia menardii* group 1 (*G. menardii* 4 in this paper). The brief reoccurrence of *G. menardii* 4 in the distribution range of *G. menardii* 5 was recognized also in the Potamidha and Faneromeni sections (Crete) and also in the Monte del Casino section of Italy and has been astronomically dated at 7.28 Ma while the LCO of the species, at 82m, has an age of 7.512 Ma (Krijgsman and others, 1995).

Multivariate and Spectral Analyses

A standardized Principal Component Analysis (PCA program of Davis (1973)) was carried out in the total data set using the varimax method in order to determine the impact of various environmental parameters on the planktonic foaraminifera distribution. The analysis yielded two statistically significant components accounting for 52.34% of the total variance. The interpretation of the two components is based on the loadings of the species on the first and second component and their microhabitat characteristics. Positive signs in scores indicate species with positive relationships, whereas negative values indicate inverse relationships.

The first principal component (PCA-1) describes the 33.28% of the total variance. Species yielding the highest positive loadings (Table 2) are *Globigerina falconensis-bulloides* intermediate, *Globigerina falconensis, Globigerinita glutinata, Globorotaloides falconarae* while the species *Globoturborotalita nepenthes, Turborotalita quinqueloba, Globorotalia scitula, Globigerina bulloides* and *Globorotalia menardii* display the lowest positive loadings. Taxa having negative loadings (Table 2) are *Globigerinoides trilobus, Neogloboquadrina acostaensis*, (d+s*), Orbulina universa, Globigerinella siphonifera* and *Sphaeroidinellopsis seminulina* (Bé and Hutson, 1977; Fairbanks and others, 1982; Thunell and Reynolds, 1984; Ravelo and others, 1990). Thus, PCA-1 seems to discriminate between an association made up of predominately cool-water species (having positive loadings) (Bé and others, 1971; Van Leeuwen, 1989; Malmgren and Kennett, 1977), and a mixed association of oligotrophic, warm water species and eutrophic species (species showing negative loadings).

The score plot of PCA-1 (Figure 5), however, reflects the long-term change in faunal composition and shows primarily variations in the sea surface temperature. The score plot of PCA-1 shows two major steps superimposed on the overall long-term trend. The first step occurs at around 8 Ma and corresponds to a warming period starting at that point and the second one corresponds to a cooling trend, which starts at Tortonian/ Messinian boundary and reflects the general cooling trend of the Messinian.

The second principal component PCA-2 (Table 2) describes the 19.06% of the total variance and is characterized by the positive loadings of *Sphaeroidinellopsis seminulina, Globigerinella siphonifera, Orbulina universa* which constitutes an association of oligotrophic, warm-water species (Bé and Hutson, 1977; Fairbanks and others, 1982; Thunell and Reynolds, 1984; Ravelo and others, 1990) and the positive loading of *Turborotalita quinqueloba*, a cool-water species (Bé and Hutson, 1977; Pujol, 1980). Negative loadings on the PCA-2 are recorded for *Globigerina bulloides* and *Neogloboquadrina acostaensis* (d+s).

Globigerina bulloides is often used as a good proxy for upwelling (Thiede, 1983; Prell and Curry, 1981; Wefer and others, 1983; Prell 1984). Reynolds and Thunell (1985) considered that *Globigerina bulloides* was controlled primarily by variations in primary production rather than by water temperature. *Neogloboquadrina acostaensis* thrives in cool water, in particular in oceanographic regions where a shallow nutricline favours the formation of a Deep Chlorofyll Maximum (DCM) (Bé and Toderlund, 1971; Fairbanks and Wiebe, 1980). Therefore, it is suggested that this assemblage reflects (seasonally) high food availability. Thus, it appears that PCA-2 discriminates between an association made up of oligotrophic, warm-water species and an association of predominately eutrophic species.

The score plot of PCA-2 (Figure 5) seems to reflect mainly variations in sea surface

Table 2. Loadings of the planktonic foraminiferal species on the first and second principal component.

Parameter-Species	PCA-1	PCA-2
G. apertura-obliquus	0	0
G. bulloides	0,05	-0,52
G. falconensis intet.	0,7	-0,19
G. falconensis	0,65	-0,24
G. trilobus	-0,03	-0,33
G. nepenthes	0,3	-0,01
G. falconarae	0,27	-0,16
G. conomiozea	-0,06	0,01
G. menardii	0,15	-0,03
G. scitula	0,08	0,02
N. acostaensis (dex.)	-0,04	-0,45
N. acostaensis (sin.)	-0,11	-0,44
T. quinqueloba	0,11	0,29
G. glutinata	0,45	0,02
O. universa	-0,08	0,42
G. siphonifera	-0,08	0,22
S. seminulina	-0,02	0,23
sp. indet.	0,07	0,04

productivity and shows the short-term changes in faunal composition which are related with the sedimentary cycles (Antonarakou, 2001).

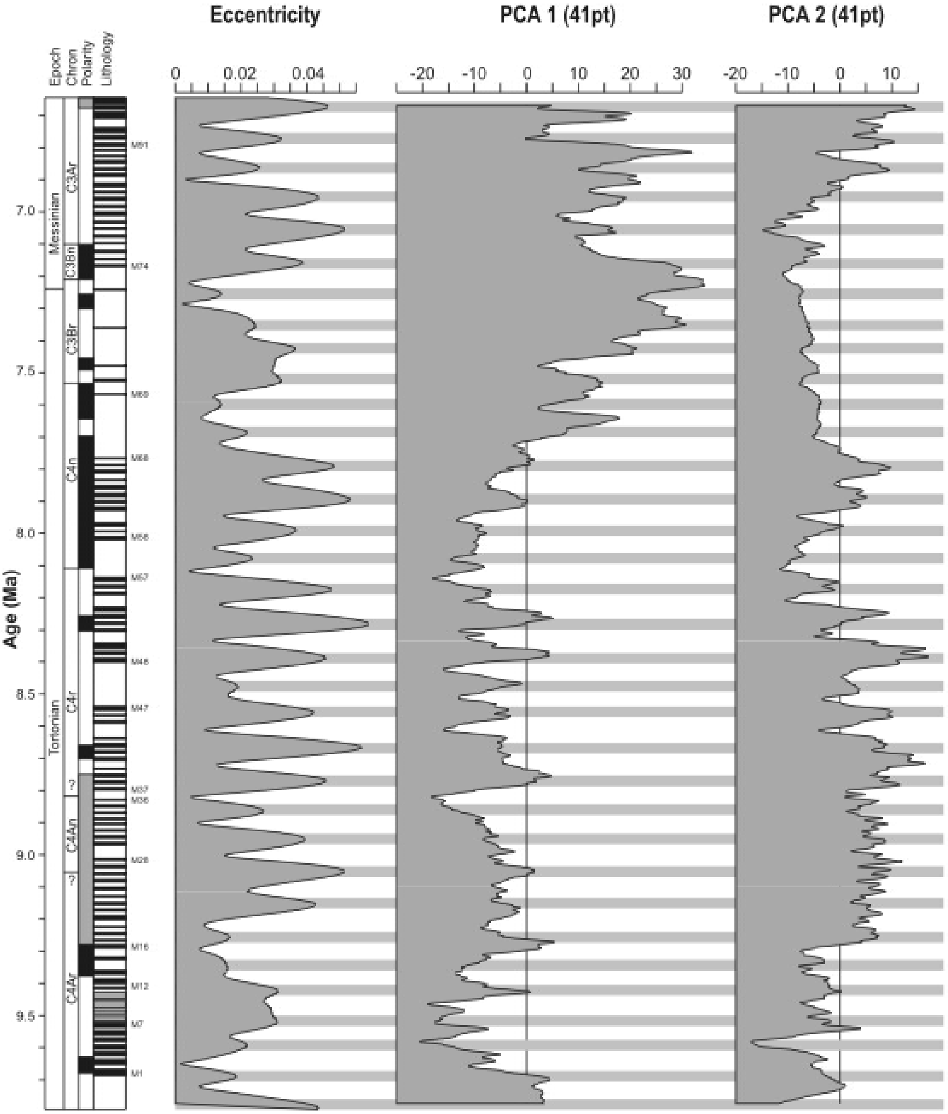

Figure 5. Sample-scores of PCA-1 and PCA-2, based on a standardized Principal Component Analysis of the 17 planktonic foraminiferal species. Comparison with the Eccentricity cycles of 100 kyr.

The proxy curves that came out from the Principal component analysis simplify the original and highly complex faunal patterns of individual taxa, recognized in the Metochia section, characterized by short-term and long-term variations.

In order to investigate the possible influence of astronomical forcing to the variations observed, we carried out a spectral analysis (Figures 5 and 6). Power spectra were applied to extract the orbital frequency component from our proxy records (Figure 7) for all the species identified in the section based on their quantitative data and also for two different time intervals from 9.7-8 Ma and 8-6.6 Ma.

All spectra revealed a significant peak in the eccentricity frequency band (100Ka), indicating that variation in sea surface temperature and sea surface productivity are astronomically controlled.

The results from the spectral analysis show that sedimentary cycles (sapropel cycles) are astronomically forced by precession and eccentricity cycles while sea surface temperature variations are controlled by precession and obliquity variations. This orbital configuration during sapropel formation indicates a strong seasonal contrast.

Moreover, power spectra analysis applied for the species identified in our record, revealed that the relative abundance fluctuations of *G. menardii* together with *N. acostaensis* dext., *G. falconarae* and *G. glutinata* are related to obliquity (41 kyr) cycles and precession (23 kyr) cycles. This is a mixed association of eutrophic and tropical species. These species are more abundant in the lower part of the section for the time interval 9.7 to 8 Ma.

DISCUSSION

Late Miocene climate in Eastern Mediterranean, as this is reflected in Metochia section, was quite stable. Long-term climatic changes are determined by a cooling trend from 9.7 Ma to 7.6 Ma, a warmer period from 7.6 to 7.2 Ma and then a cooling trend again which ends at the Messinian.

Hodell and others (1994), who worked on Moroccon (extra-Mediterranean) material, found benthic isotopic evidence for a warming trend that started a bit later and crossed the Tortonian/Messinian boundary. Together with a warming, the vertical circulation slowed down. A similar scenario had been postulated earlier by Vergnaud-Grazzini (1983). Constriction of the Atlantic-Mediterranean connections could further contribute to increasing residence time of deeper waters.

On approaching the Tortonian/Messinian boundary interval (at 7.24 Ma), the more or less stable conditions present before were subject to more profound changes. The subsequent influx of *G. miotumida* group suggests biogeographical changes related to cooling (Zachariasse, 1979; Chamley and others, 1986).

The extra-Mediterranean isotope record of Hodell and others (1994) suggests a more prolonged cool period than our record, but the start of the "siphon event" (influx of deep cold Atlantic waters through the Riffian Corridor), proposed by Benson and others (1991), could be biostratigraphically correlated to this cooling.

In the Metochia section, this cooling is characterized by the replacement of *G. menardii* group by *G. miotumida* group. This fact has been also observed in other regions e.g. the northeast Atlantic and the Mediterranean sea (Sierro, 1985; Benson and Rakic-El Bied, 1991a,b; Sierro and others, 1993).

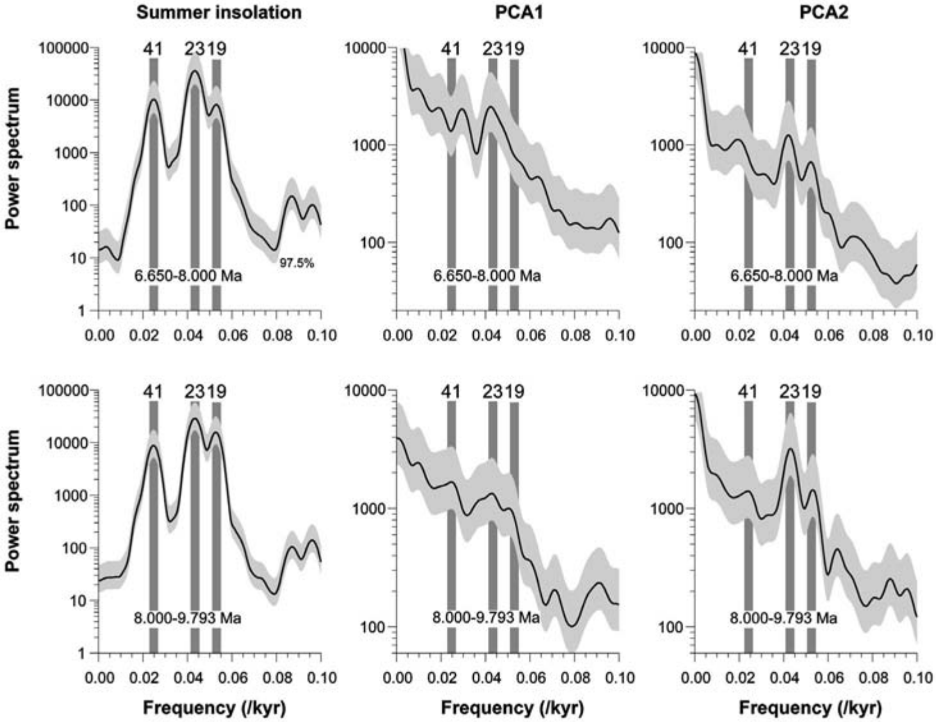

Figure 6. Spectral Analysis of the PCA-1 and PCA-2. The 41, 23 and 19 Ky periods were selected to extract information from proxy records connected with precession and obliquity

In the modern oceans, *G. menardii* occurs in subtropical and tropical water masses with a clear maximum in relative abundances in equatorial and tropical environments (Sierro, 1985). Preferences are pronounced for warm sea surface temperatures and normal marine salinities. During the Miocene, the *G. menardii* group was restricted to the tropical and subtropical region whereas the *G. miotumida* group was present in temperate areas. Significant provincialisms in the Miocene planktonic foraminifera have been recognized by many authors (Jenkins, 1971, 1978; Scott, 1979, 1983; Srinivasan and Kennett, 1981; Poore, 1981; Berggren, 1984; Kennett and others, 1985; Hodell and Kennett, 1985; and others) in both hemispheres of the Pacific, Indian and Atlantic Oceans.

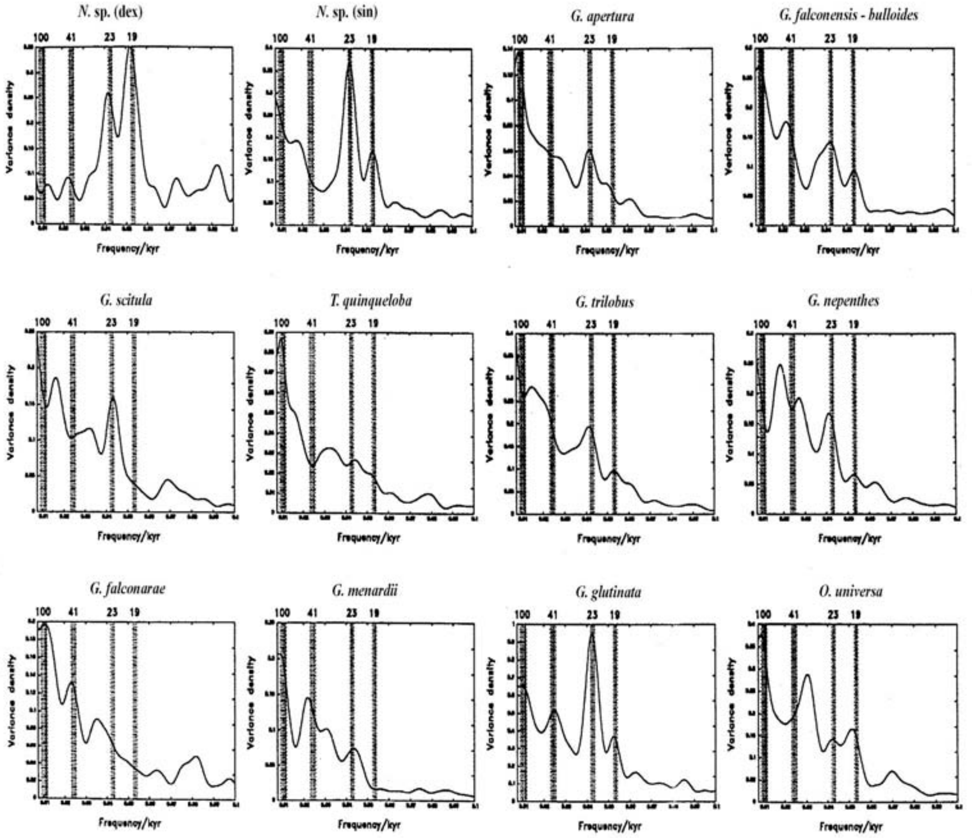

Figure 7. Spectral Analysis for selected species.

Berggren (1984) suggested the existence of sharper thermal gradients in the North Atlantic Ocean during the Late Miocene. However, planktonic foraminifera provincialism does not seem to be well defined in the North Atlantic, at least until the Messinian, since the *G. miotumida* group was rarely been recorded in the area studied prior to that period (Sierro and others, 1993). In the North Atlantic Ocean, *G. menardii* extends throughout the temperate zone up to the Latest Tortonian. Then a first southward retreat of the group probably took place from a part of the North Atlantic (Guadalquivir basin, South Rifian basin and the Mediterranean Sea). It is also believed that during the short interval in which the group is absent or sporadic, a change in coiling from sinistral to dextral took place in the *G. menardii* group. This change may be probably correlated with the one found in the N17 Zone at DSDP sites 214 and 289, in the tropical Indian and Pacific Oceans (Heath and McGrowan, 1984) and in the Eastern Atlantic (Berggren, 1984).

Benson and others (1991) suggested increasing circulation intensity in the North Atlantic subtropical gyre near the Tortonian/Messinian boundary for the replacement of the two globorotaliid groups. This would have led to a better definition of the faunal boundaries and water masses during the Late Miocene. At the Atlantic margin of Morocco, both Hodell and others (1994) and Benson and others (1991) documented a current reversal in the Rifian Corridor whereby cold Atlantic waters flow eastward and replace the warm Mediterranean outflow waters.

It is evident that the characteristic pattern of short incursions of keeled globorotaliids is useful for biostratigraphic correlations. In the Metochia section the LCO of *G. menardii* form 4 at 7.5 Ma and the FO of *G. menardii* form 5 at 7.369 Ma (Krijgsman and others, 1997) is reported by Hodell and others (1994) and Zhang and Scoott (1996) as an important coiling change of *G. menardii* from sinistral to dextral. This event is equivalent to PF-Event 1 of Sierro and others (1993), suggesting a southward retreat of the form in the North Atlantic.

Furthermore, as it is evident in our record, the abundances of *Globorotalia* species reveal a distinct cyclic pattern (Fig. 4). This cyclical pattern is compared with the amplitude changes in summer insolation (Fig. 4) and the eccentricity (100Kyr), as it is the most significant taxa in order to define the Tortonian/Messinian climatic change.

Moreover, variations in the relative abundance of these keeled globorotaliids, essentially reflect variations in sea surface temperatures, with *G. menardii* correlated with warmer intervals and *G. miotumida* group with cooler intervals. These variations are used to identify regional short-term climatic fluctuations, whereas the replacement is used to identify long-term climatic fluctuations in the Upper Miocene.

Spectral analyses are applied to depict the evolution of sea surface temperature and *Globorotalia* record and hence, to determine shifts in the relative abundance of this taxa and climatic proxy curve in the orbital frequency bands (Figure 7).

Eccentricity

The eccentricity–forced variations in the climatic proxies and in the faunal variability are obvious. Our data reflect a somewhat strong influence of the 100Kyr cycles during the warmer period (7.6-7.2 Ma) of our record (Fig. 5 and 4). In this interval two 400-kyr eccentricity minima correlated with low amplitude variations in summer insolation around 7.6 and 7.2 Ma are observed. This low amplitude variability in summer insolation is also recorded by low amplitude variability in *Globorotalia* species, at around 7.5-7Ma.

The strong influence of the 100 kyr eccentricity cycle may point to enhanced precession induced regional climate variations and low amplitude variations in solar insolation.

Beaufort (1994) showed that amplitude variation of 100-kyr cyclicity, in two detailed and continuous 16 myr long Miocene climatic proxy records reflecting migrations of the Antarctic polar front and associated variations in paleoproductivity near Kerguelen Island), fluctuate quasi-periodically, with periods related to the long-term periods of eccentricity and obliquity. In addition, the amplitude variations of the 100 kyr cycles are enhanced during the Mi-events (Miller and others, 1991; Oslick and others, 1994), indicating that the 100 kyr cycle was straightened at times of glacial expansion just as they were during the late Pleistocene and are controlled by either obliquity or eccentricity or by a combination of both.

According to Lourens and Hilgen, 1997 the Tortonian/Messinian boundary according to Lourens and Hilgen, 1997 coincides to the base of a significant sea level fall and corresponds with the beginning of an interval with amplitude variations in obliquity of the 1.2 kyr cycle. Furthermore the same authors suggest that the influence of 2.3 kyr eccentricity cycle has largely contributed to the long–term variations in the left-coiling neogloboquadrinids and third-order cycles in the studied time interval. According to them, this is because of the influence of obliquity or eccentricity or a combination of both.

In the Metochia section, the Tortonian/Messinian boundary is marked by the replacement of *G. menardii* by *G. miotumida* and a strong increase of left-coiling neogloboquadrinids. In our record the influence of obliquity cycles is not well expressed around the Tortonian/Messinian boundary but the lack of the 100-kyr eccentricity cycle around 7.2 Ma (Figure 5) may point to the obliquity influence.

The lack of the 100 kyr eccentricity cycle is noted also around 9.5, 9.3, 8.95, 8.85, 8.1 and 7.4 Ma. However, deviating sapropel clusters occur around 9.5 and 7.4 Ma (Hilgen, 1991; Hilgen and others, 1995) that lack the usually pronounced expression of the 100 kyr cycle due to the occurrence of the ~2.3 myr cycle. This interval is controlled by the obliquity 41kyr cycle.

Precession

The influence of precession cycles (23 and 19 Kyr) is well expressed in our data in the climatic proxy curves (Fig. 6) and the faunal variability (Fig. 7) related to the sedimentary cycles (sapropels). In the open ocean, the precession component reflects, above all, global variations in ice volume and occurs superimposed on the prominent 100 kyr cycles (Imbrie and others, 1984; Lourens and Hilgen, 1997). In the Mediterranean, the precession component in $\delta^{18}O$ is closely related to lithology (Lourens and others, 1992; 1996; Antonarakou, 2001). The $\delta^{18}O$ minima most probably reflect an increase in wetness of circum Mediterranean climate and continental runoff (Rossignol-Strick, 1983; Gudjonsson and van der Zwaan, 1985; Lourens and others, 1992).

In our data, this orbital configuration reflects, above all, regional short-term variations in climate and productivity. High values of sea surface temperature occur at times of sapropel formation. These conditions occurred when the precession index reached minimum values and eccentricity maximum (Fig. 5), and thus, Northern Hemisphere summer insolation reached maximum and winter insolation minimum values. Higher summer insolation may have generated higher sea surface temperature values during summer and higher fluxes warm-water species as *G. menardii, G. nepenthes*, *G. trilobus,* and *G. apertura-G. obliquus***.** During the Pleistocene, this orbital configuration corresponds to an interglacial period with the ice volume relatively at a minimum (Lourens and others, 1996), while for Upper Miocene may reflect summer signal.

Obliquity

The influence of the obliquity variations is recorded in the interval 9.7-8 Ma in the climatic proxy curves, indicating that the long- and the short-term variations are obliquity controlled. Obliquity-related variations, in the benthic δ^{18}O records from the open ocean, have been interpreted to reflect primarily changes in global ice volume (e.g. Shackleton and others, 1990; 1995; Raymo and others, 1989; Tiedemann and others, 1994). Obliquity-related variations in sea surface temperature are in phase with δ^{18}O indicating that the glacial cycles affected sea surface temperature conditions in the Mediterranean as well (Lourens and others, 1992).

However, low peaks in abundances of *Globorotalia* species are recorded around 9.3 to 8.8 Ma. This interval corresponds with a maximum in the ~2.3 myr of eccentricity cycle and is obliquity controlled related to global climatic cooling (Mi7 cooling event (Miller and others, 1991; Oslick and others, 1994), which is dated in 9.3 Ma).

In this case the obliquity signal in abundance of *Globorotalia* species is amplified due to regional changes in sea surface salinity and/or temperature that affected Mediterranean before the salinity crisis.

CONCLUSIONS

The relative abundance data of *Globorotalia* species and the cyclostratigraphic interpretation of the Upper Miocene interval in the Metochia section of Gavdos island, was the main reference to estimate the periodicity in the abundance fluctuations of the *Globorotalia* species, in the stratigraphic interval between the first occurrence of *Globorotalia menardii* form 4 and the first regular occurrence of *Globorotalia miotumida,* which marks the Tortonian/Messinian boundary.

The periodicity and the astronomical forced variations identified in the section are verified by spectral analysis. This statistical analysis has been also used to correlate *Globorotalia* relative abundance fluctuations with the insolation curve evaluated from Laskar and others (1993) as it is the most significant taxa in order to define the Tortonian/Messinian climatic change. Therefore, the comparison of the record of abundance of *Globorotalia* species with the astronomical record yielded some similarities. Spectral analysis revealed the influence of eccentricity, precession cycles and obliquity 41 kyr cycle.

Climatic warming, during 7.6 to 7.2 Ma, is reflected by significant faunal changes in the Mediterranean such as the increase in abundances of *G. apertura/G. obliquus*, *G. nepenthes* and *O. universa* and the decrease of *N. acostaensis* sin., *T. quinueloba* and *G. bulloides-G. falconenis*.

Other faunal events, such as the vanishing of *G. menardii* group and the successive entry of *G. miotumida* group are related to long-term climatic fluctuations superimposed on longer-term astronomically driven climate changes. The short-term variations in climate and faunal composition are related to precession-controlled sedimentary cycles and the long-term trend in climate is related to eccentricity and obliquity glacio-eustatic cycles. Regional changes in sea surface salinity and/or temperature in combination with variations of solar insolation may have caused the cyclical astronomical controlled pattern of *Globorotalia* species.

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