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CLIMATIC VARIATIONS DURING SAPROPEL DEPOSITION IN GAVDOS ISLAND, EASTERN MEDITERRANEAN SEA: A KEY FOR UNDERSTANDING FORMATION PROCESSES.

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EXTENDED ABSTRACT

The Neogene eastern Mediterranean record is characterized by the cyclic occurrence of dark, distinct sediment layers with organic carbon contents ranging from a few to almost 30 weight percent. These organic-rich layers, called sapropels, are centimeters to decimeters thick, and they are embedded in light brown to grey hemipelagic sediments. The origin of sapropels is thought to be related to paleoclimatic changes in the Mediterranean area.

One of the very few complete hemipelagic successions in Mediterranean is found in Gavdos Island – Metochia section (SW Crete). Metochia section is a Late Miocene hemipelagic marl succession, characterized by the rhythmic alternations of poorly non-bioturbated brown-grey, organic rich laminated beds (sapropels) and bioturbated, light grey-blue, homogeneous, hemipelagic marl beds. The thickness of successive sapropel and marl beds varies such that distinct small and large-scale clusters can be distinguished.

The purpose of this study is to determine sea-surface condition changes influence on the sapropel formation process in Metochia section. High resolution sea surface productivity and sea surface temperature records are based on the quantitative analysis of planktonic foaraminiferal species recognized in the section, using their present-day habitat characteristics. Planktonic foraminifera are excellent tools to describe past variations in global and regional climate.

The quantitative data from the Metochia section have been processed by spectral analysis using bandpass filter of 21 and 41 kyr components. Spectral analysis was used to verify the periodicity of the relative abundance fluctuations of the planktonic foraminifera. The analysis revealed that variations in sea surface productivity and sea surface temperature are controlled by periodic variations in the Earth's orbital cycles. Sapropels in Metochia section are characterized by increased sea surface productivity and sea surface temperature.

The precession-related variations in sea surface productivity are correlated with the sedimentary cycles suggesting that increased river discharged and shoaling of the pycnocline and the associated intensification of the Deep Chlorophyll Maximum layer.
The precession-related variations in sea surface temperature are correlated to periods of maximum insolation during the Northern Hemisphere summer.

Key words: Late Miocene, planktonic foraminifera, sapropels, Eastern Meditteranean.

1. INTRODUCTION

The Miocene is a period in which Mediterranean underwent substantial changes. During the Middle-Late Miocene the convergence of the African and Eurasian plates resulted first in narrowing and finally closure of the seaways that existed between the Mediterranean Sea and the Atlantic and Indian Oceans [1]. These tectonic events caused important changes in the water circulation and deep-water ventilation. The complete cut-off of the connections to the surrounding oceans in the late Messinian led to the accumulation of a huge series of evaporites during the late Miocene (the Messinian Salinity Crisis) [2,3]. As a result of changes in the circulation pattern was the alternating of oxic-anoxic bottom water conditions and led to the regional deposition of rhythmically bedded sedimentary sequences including organic-rich laminated beds, the so-called sapropels which are characterized with more than 2% total organic carbon [4].

The origin of sapropels has been debated from the time of their discovery until the present-day. The key problem for interpreting these deposits rich is either an increased preservation rate of organic matter under bottom water anoxia due to stagnation, or an increased productivity of organic matter in the photic zone. More recently has been estimated that sapropel formation requires both marked density stratification of the water column and an increase in primary productivity [5,6,7,8].

All models are related to global climatic variations that have occurred, such as those referred to as “astronomical forcing models”.

In this study we use the quantitative analysis of the planktonic foraminiferal assemblages of one of the very few complete hemipelagic successions of the Upper Miocene in Mediterranean, Metochia section in Gavdos Island (SW Crete), in order to reconstruct surface conditions during sapropel formation in the Eastern Mediterranean.

2. MATERIALS AND METHODS

2.1. Geological Setting-Stratigraphy

Metochia section, a Late Miocene hemipelagic marl succession, is located at the northeast part of the Gavdos Island and contains 96 rhythmic alternations of poorly to non bioturbated brown-grey, organic-rich laminated beds (the so called “sapropels”) and bioturbated, light grey-blue, homogeneous, hemipelagic marl beds (Fig. 1).

The section covers the time span from 9.7 to 6.6 Ma, a period of substantial changes in the Mediterranean-Atlantic connections [9]. Individual sapropel-marl couplets are correlated to the Earth’s orbital cycles and particularly to precession cycles (with periodicities 23 and 19 Kyr) with the sapropels corresponding to the precession minima [9,10].

2.2. Micropaleontological Analysis

560 samples of 1 cm thickness have been taken at intervals of approximately 20 cm. Assemblages of planktonic foraminifera, after the appropriate procedure, were sorted out, identified and counted. The quantitative distribution pattern of the identified planktonic foraminiferal categories is presented in Fig. 2. A standardized Principal Component Analysis (PCA program of [11]) has been carried out to extract the most important factor in determining the overall faunal change. Spectral analysis has been applied in order to investigate the frequencies of variations recognized in the principal component analysis. Finally, an independent t-test was applied to test if the faunal composition and, hence, the outcome of PCA are related to changes in lithology.

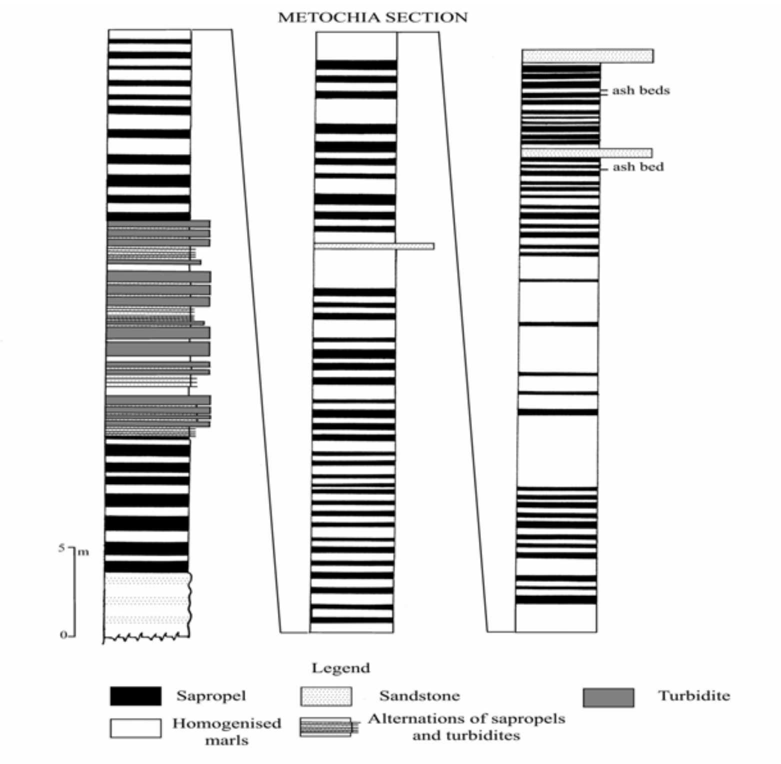

Figure 1: Lithology of the Metochia Section

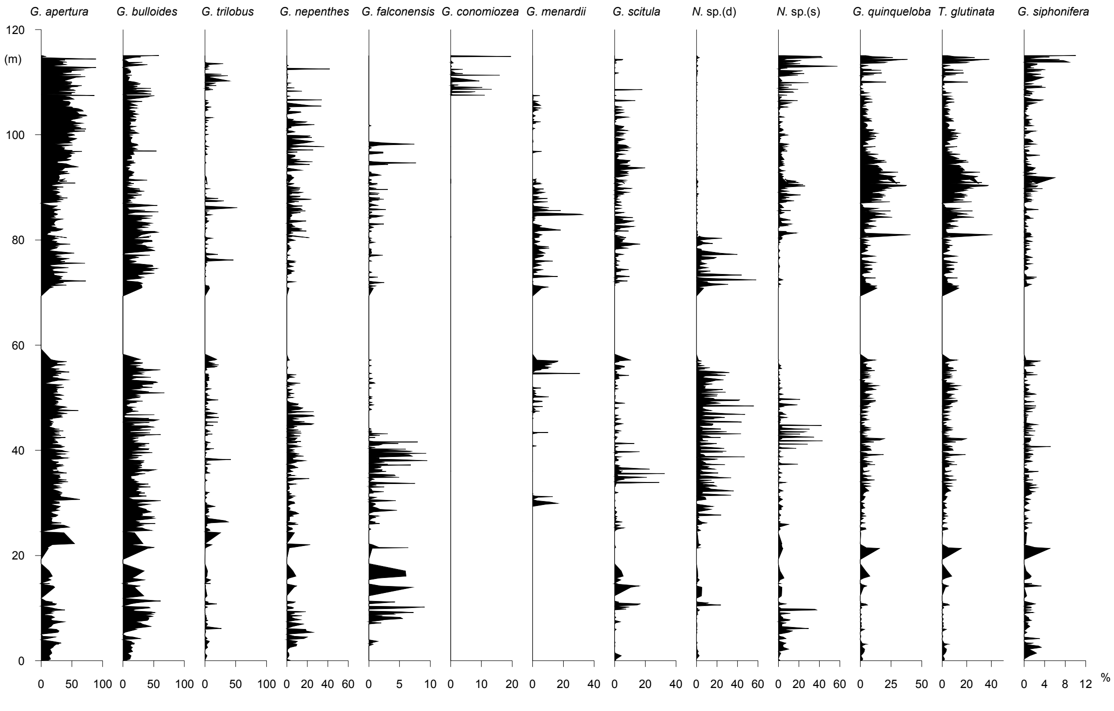

Figure 2: Faunal abundances pattern of planktonic foraminifera.

3. RESULTS

3.1. Multivariate and Spectral Analyses

The Principal Component Analysis yielded two statistical significant components.

The first principal component (PCA-1) describes 15% of the total variance (Table 1). Based on the ecological habitat characteristics of the species, PCA-1 seems to discriminate between an association made up of predominately cool-water species (having positive loadings) [12,13,14] and a mixed association of oligotrophic, warm water species and eutrophic species (species showing negative loadings) [15,16,17,18]. Therefore, PCA-1 (Fig. 3) shows primarily variations in the sea surface temperature (SST).

The second principal component PCA-2 (Table 1) discriminates between an association made up of oligotrophic, warm-water species (positive loadings) [15,16,17,18] and an association of predominately eutrophic species (negative loadings) [19,20,21,22,23]. The score plot of PCA-2 (Fig. 3) seems to reflect mainly variations in sea surface productivity (SSP).

Therefore, the proxy curves that came out from the Principal component analysis simplify the original and highly complex faunal patterns of individual taxa, recognized in Metochia section, characterized by short-term (SSP) and long-term variations (SST) (Fig. 3).

The results of the t-test analysis (Table 1) show that the foraminiferal assemblages on the sapropels are characterized by higher abundances of *Neogloboquadrina acostaensis* (s), the *G. apertura - G. obliquus, G. bulloides, G. trilobus* and lower abundances of *G. conomiozea* and *G. scitula.* All these taxa show significant higher means in the sapropel layers dominate the negative loadings on PCA-2, except the species warm water species *G. apertura- G. obliquus* and *G. trilobus* whose distribution pattern display short-term variations through the whole section and are the most abundant species in the faunal composition. In contrast, those species having positive loadings on PCA-2 are more abundant in the blue-marl beds (Table 1). The t-test further indicates that sapropels are characterized by increased sea surface productivity and increased sea surface temperature conditions, which is remarkable since high productivity regions are generally characterized by relatively cool sea surface waters.

PARAMETER-species	PCA-1	PCA-2	SAPROPEL	MARL	t- values
Globoturborotalita apertura-obliquus	0	0	34,02	32,84	-0,83
Globigerina bulloides	0,05	-0,52	9,4	5,2	-5,92
Globigerina falconensis	0,65	-0,24	2,43	7,84	7,81
Globoturborotalita nepenthes	0,3	-0,01	3,57	6,6	4,57
Globigerinella siphonifera	-0,08	0,22	0,72	1,01	2,77
Globigerinita glutinata	0,45	0,02	3,03	8,59	11,08
Globigerinoides trilobus	-0,03	-0,33	7,12	2,28	-7,98
Globorotalia scitula	0,08	0,02	2,77	2,52	-0,61
Globorotalia menardii	0,15	-0,03	1,47	1,64	0,47
Globorotalia conomiozea	-0,06	0,01	0,53	0,17	-1,81
Turborotalia quinqueloba	0,11	0,29	4,28	7,52	5,24
Orbulina universa	-0,08	0,42	1,64	1,92	1,53
Neogloboquadrina sp (d)	-0,04	-0,45	4,58	1,15	7,12
Neogloboquadrina sp (s)	-0,11	-0,44	14,78	5,69	-10,63
Globorotaloides falconarae	0,27	-0,16	0,48	0,84	2,29
Sphaeroinellopsis seminulina	-0,02	0,23	0,09	0,33	1,41

Table 1: Loadings of the planktonic foraminiferal species on the first and second principal component and t-values resulting from the t-test.

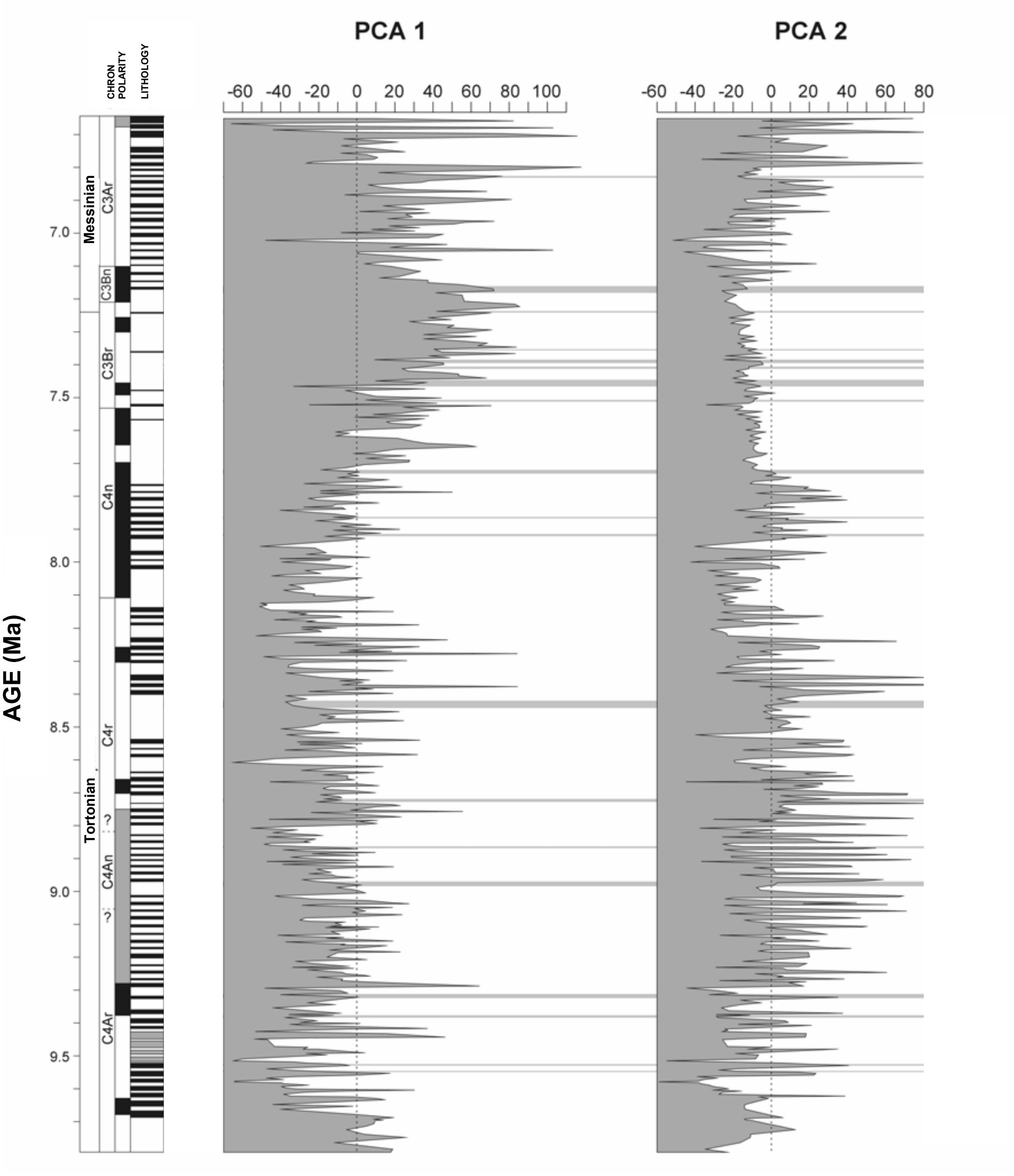

Figure 3: Score plots of PCA-1 and PCA-2 correlated to SSP and SSP respectively.

In order to investigate the possible influence of astronomical forcing to the variations observed, a spectral analysis has been carried out (Fig. 4). Power spectra were applied to extract the orbital frequency component from our proxy records 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 precession frequency band (23 and 19 Kyr), indicating that variations in sea surface temperature and sea surface productivity are astronomically controlled.

In particular, the results from the spectral analysis show that sapropel cycles are astronomically forced by precession cycles while sea surface temperature variations are controlled by precession and obliquity (41Kyr) variations. This orbital configuration during sapropel formation indicates strongly seasonal contrast [24].

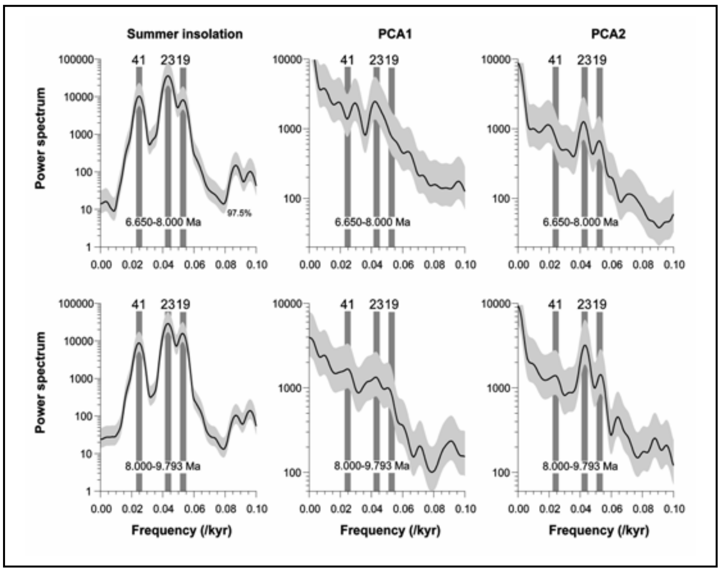

Figure 4: Spectra analysis of PCA-1 and PCA-2 and summer insolation curve.

4. DISCUSSION

Changes in regional climate seem to be responsible for the cyclic occurrence of sapropel and associated marl layers in the Metochia section. Sapropels occur at times during which excess evaporation is severely reduced due to increased river discharge [25]. Sapropels were deposited at times when the precession index reached minimum values, indicating that perihelion occurred in Northern Hemisphere summer [26,27,28,24]. Through increased summer insolation, such an orbital configuration leads to intensification of the Indian Ocean's summer monsoon and therefore to a precipitation maximum resulting in increased freshwater discharge via the river Nile into the Mediterranean. Precipitation in the northern borderlands of the eastern Mediterranean seems to have increased as well at times of sapropel formation.

The relationship between increased freshwater and increased sea surface productivity at times of sapropel formation can be explained by increased input rate of river-borne nutrients into the basin [29], and by shoaling of the pycnocline into or within the euphotic layer leading to the development or intensification of the Deep Chlorophyll Maximum (DCM) layer [5].

Evidence for shoaling the pycnocline in Metochia section is the elevated percentages of *Neogloboquadrina acostaensis* (s) [16,17,21] at the sapropels levels. This shoaling, however must have occurred within the euphotic layer since *N. acostaensis* (s) is not restricted to sapropels but occurs also at non-sapropel levels (Table 1).

The increase in abundance of the neogloboquadrinids in Gavdos sapropels, is accompanied by an increase in the abundance of the *G. apertura*-*G. obliquus* group. In contrast, modern representatives of *G. obliquus* and *G. apertura* (*G. rube*r and *G. rubenscens*) inhabit warm and oligotrophic surface waters [15].

Erosion of the pycnocline during winter by deep mixing (resulting from minimum boreal winter isolation), may have favored spring bloom conditions and, hence higher export productivity and oxygen consumption rates. On the other hand, increased thermal stratification and decreased nutrient replenishment during summer (resulting from maximum boreal summer insolation) resulted in maximum surface water temperatures and oligotrophy at times of sapropel formation as indicated by peak abundances of *G. obliquus*-*G. apertura* group. The combination of the abundances of this last group and neogloboquadriniids indicates that seasonal contrast reached maximum at times of precession minima.

The elevated percentages of the shallow-dwelling species *G. bulloides* in (table 1) sapropels suggest that also the mixed layer was eutrophicated during these periods, which would result from increased input rates of river-borne nutrients, transfer of nutrients from the shallow pycnocline up into the mixed layer by turbulent mixing and/or deep stirring in winter cooling during periods of sapropel formation is in line with precession maximum which implies a decrease a winter insolation (for the Northern Hemisphere).

In addition to orbital influence of SSP, precession related SST values have been observed. High conditions of SST correlate well with sapropels. This high SST conditions occurred when the precession index reached minimum values and eccentricity maximum, and thus, when Northern Hemisphere summer insolation reached maximum and winter insolation minimum values [24].

The inferred orbital configuration, in Gavdos sapropels, with precession minima and eccentricity maxima at times of sapropel formation implies an increased seasonal contrast in insolation-maximum in summer and minimum in winter. Higher summer insolation may have generated higher SST values during summer and higher fluxes of shallow-dwelling, warm-water species as *G. nepenthes*, *G. trilobus,* *G. siphonifera* and *G. apertura-obliquus.* We suggest therefore that the higher SST values during periods of sapropel formation actually represent a summer signal. The contrasting winter signal is represented by the elevated percentages of *G. bulloides* and *G. scitula.*

5. CONCLUSIONS

The sapropels of Gavdos were deposited during periods of increased productivity and increased sea surface temperature.

Statistical analyses on late Miocene sea surface productivity and sea surface temperature proxy records yielded strong influence by the Earth's orbital cycles.

Precession-forced maxima in sea surface productivity conditions at times of sapropel formation can be explained by increased input rates of river-borne nutrients and by shoaling of the pycnocline.

Precession-forced maxima in sea surface temperature at times of sapropel formation indicate seasonal contrasts and reflect a summer (temperature) signal due to increased summer insolation at the Northern Hemisphere.

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