BENTHIC FORAMINIFERAL BIOFACIES ASSOCIATED WITH MIDDLE TO EARLY LATE MIOCENE OXYGEN DEFICIENT CONDITIONS IN THE EASTERN MEDITERRANEAN

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EXTENDED ABSTRACT

The Potamos Section from the Upper Serravallian of Gavdos Island, Greece, has been investigated with respect to foraminiferal assemblages. The main objective was to analyze qualitatively and quantitatively and to interpret paleoecologically the benthic foraminiferal fauna of the Potamos Section. The concept, which has been adopted, is that species fitness is primarily affected by changes in nutrient abundance. The occupation of different microhabitats is governed by a more local interplay of nutrient availability, oxygen supply and seasonality. Benthic foraminifera represent one of the most sensitive indicators of dissolved oxygen levels and can therefore be used to interpret ancient sediments. Criteria to estimate oxygenation are based on foraminiferal morphology, test size, wall thickness or indicative taxa. Therefore, according to these criteria the determined benthic foraminifera have been grouped into three catergories: oxic indicators, suboxic indicators and dysoxic indicators. The Benthic Foraminiferal Oxygen Index (BFOI) based on foraminiferal characteristics reflects aspects of these processes.

The analysis showed that oxygenation was the most important factor for the distribution of the faunas in the investigated area.

The entire section is characterized by high percentage values of the representatives of the Dysoxic and Suboxic group. Oxic indicators are of minor importance. Microfaunas adapted to these low-oxygen conditions indicate temporal sluggish bottom-water circulation, which can be associated with high fresh water fluxes. The lower part of the section (Interval I) is characterized by a decline in the abundance of the oxic indicators and an increase of the suboxic morphogroup related to intermediate oxygenated conditions. Interval II is characterized by the presence of potentially infaunal taxa, representing the establishment of a restricted environment with abundant nutrients. In this dysoxic part, foraminifera were more abundant and assemblages exhibited higher dominance, lower species richness and lower diversity. Finally, the upper part of the section (Interval III) is dominated by the "oxic" morphogroup.

Our data indicate that biologically important factors such as oxygen and nutrient content of the waters played a great role in the palaeoecosystem evolution.

Key words: Benthic Foraminifera, Late Serravallian, oxygenation, BFOI.

1. INTRODUCTION

The small size and vast abundance of foraminifera (shelled marine protists), in seafloor sediments of the present day and geologic past, has resulted in their becoming the most used fossil group for determining the age and the depositional environment of Cenozoic sedimentary rocks.
Foraminiferal abundance and biomass are closely related to food availability [1], [2], [3]. Foraminifera flourish where food is plentiful, but in order to gain access to food they must endure the oxygen depletion that often accompanies an abundance of organic matter. Oxygen concentrations in the sediment pore water become a limiting ecological factor in these environments and foraminiferal assemblages are composed largely of low-oxygen tolerant species [4]. Since the ability of foraminifera to withstand oxygen deficiency varies among major taxa and species (e.g. [5]), reduced oxygen concentrations will influence both the taxonomic composition and species diversity of foraminiferal assemblages by eliminating the less tolerant species, generally those which exhibit epifaunal adaptations [6].
This paper discusses benthic foraminifera in the Middle to Early Late Miocene record from the Eastern Mediterranean Basin. The aim of the present study is to increase our knowledge of how benthic foraminiferal assemblages develop under fluctuating bottom water oxygen.

2. STUDY AREA-STRATIGRAPHY

The selected study area is located in Gavdos Island, South Crete and constitutes part of the Potamos Formation encountered along an elongate northwest-southeast trending trough occupying the middle part of island and delineated to the north by the Potamos bay coastal cliffs and to the south by an NE-SW trending fault line (Fig. 1). The Potamos Section (112 m) is mainly composed of alternations of whitish to grayish-bluish marls and sands (Fig. 1). Upwards these beds change into shale and sand alternations with significant presence of *Chlamys latissima* and *Gryphaea (Crassostrea) gryphoides crassissima* exposed in a distinct bed. In the uppermost levels of the Potamos Section *Heterostegina* sands with *Clypeaster* and coral flagments, followed by red soils, top the deposits.
Calcareous nannoplankton and planktonic foraminifera obtained from the upper basal part of the Potamos Section suggest a middle Serravallian age, while faunal assemblages in the uppermost part of the section suggest a late Serravallian to early Tortonian age [7]. A detailed age determination has been carried out by [8] through an integrated biostratigraphy, which has pointed to an Upper Serravallian age for the overall section.

3. DATA ACQUISITION AND APPROACH

56 samples were selected throughout the section. Samples were washed, dried and sieved, under running water through >250, 250-125 and >63 μm mesh sieves. Washed residues were then split, using an OTTO microsplitter to obtain approximately 300 specimens per fraction for each split. Specimens of benthic and planktonic foraminifera were picked from one split per fraction for each sample, identified with a binocular microscope and counted. Raw data of microfossils were then transformed into percentages over the total abundance and percentage abundance curves were plotted. Species with phylogenetic affinities and similar environmental significance were also grouped to better interpret distribution patterns.
Measures obtained from the database included faunal diversity, relative abundance of species and ratios between groups including planktonic to benthic ratios (P/B).

In addition, benthic foraminiferal data were analyzed to calculate the Benthic Foraminifera Oxygen Index (BFOI) of [9], [10]. BFOI is an empirical ratio of dysoxic and oxic forms which was defined as:

[a/(a+n)x100], where a is the number of oxic species and n the number of dysoxic species. When a=0 and n+s>0 (s is the number of suboxic indicators) then the BFOI value is given by [s/(s+n)-1]x50.

4. BENTHIC ASSEMBLAGES: DATA AND DISCUSSION

Microfossil assemblages are generally abundant, well preserved and small-sized (125 μm) throughout the Potamos Section. Large-sized (>250 μm) benthic foraminiferal assemblages are scarce and consist of discontinuously distributed *Praeglobobulimina ovata, P. pupoides, Lenticulina* spp., together with abundant smaller-sized (125 μm) *Bulimina, Bolivina, Nonion, Cibicides, Pullenia bulloides, Oridorsalis umbonatus, Valvulineria complanata, Siphonodosaria* spp.

4.1. Faunal pattern

The abundance of major foraminiferal species and groups is graphed in Fig. 1. A comparison of these metrics suggests a change in benthic foraminiferal composition through time.

The lower part of the section consists of high abundances of *Cibicides* sp., while *Gyroidina soldanii* and *Globobulimina* sp. are found in lower frequency values. According to [11] these abundant occurrences in combination with the frequency patterns of *Oridorsalis umbonatus* would be indicative of a well-oxygenated benthic environment. The relatively high abundance of *Pullenia bulloides* in this part of the section may be associated with areas of low productivity in the surface waters and therefore low flux of organic matter to the sea floor [12]. On the other hand, *Gyroidinoides neosoldanii* has a propensity for the transition between normal marine and oxygen-depleted conditions.

Indeed, the peak occurrence of *O. umbonatus* in combination with *Valvulineria complanata,* in the topmost part of the lower part of the section is correlated with high percentages of organic matter and low oxygen concentration in the sediment [13], [12], [14].

In particular, *V. complanata* shows three significant peak abundances in our record (at 29.25, 39.8 and 83.78 m) indicating high benthic productivity, which is often related to moderate environmental stress [15], [4].

In addition, representatives of the infaunal Bolivinids-Buliminids and *Globobulimina* sp. are well presented in the middle part of the section, indicating adaptation to high-organic carbon and low oxygen conditions of deep infaunal microhabitats [16].

Going upwards in the section the high occurrence of *Nonion* sp. indicates the transition to an environment with relatively good connections with open marine waters and fairly normal marine salinities, although it can stand some salinity decrease.

Finally, in the upper part of the section, *Ammonia beccarii* in co-existence with *Elphidium* sp. is characteristic of the nearshore zone, with coarse substrate, rich in calcium carbonate and poor in organic matter [17], [18]. The presence of brackish *Ammonia*-dominated faunas in this part of the section is interpreted as evidence of freshwater outflow. According to [19], foraminiferal faunas with >70% *Ammonia* characterize very shallow deltaic or lagoonal environments with salinities 5‰.

The approximate water depth for the sediments from the Potamos Section is assessed through the plankton/benthos ratio, 100P/(P+B), where P is the plantkonic foraminifera and B is the Benthic Foraminifera. In the Potamos Section, we identify an inner shelf environment (values not exceeding 20%) and a slope to outer shelf environment (values >20-60%).

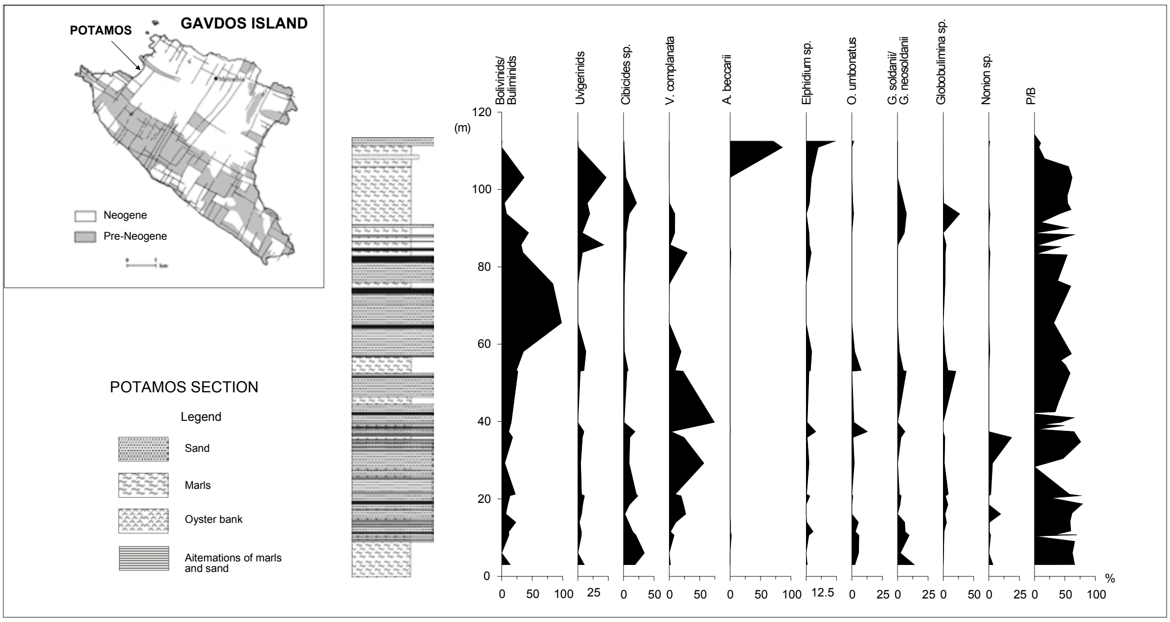

Figure 1: Location map and lithostratigraphical column depicting the faunal pattern of the Potamos Section.

4.2. Species diversity and Dominance trends

Species diversity can be viewed as a gross measure of the effect of environmental stresses on benthic foraminiferal communities.

Calculated from the data are Shannon index (entropy, H(S)), which takes into account the number of individuals as well as number of taxa [20], [21], the Fischer α-index [22] which shows the relationship between the number of species and the number of individuals in an assemblage, the species Dominance, which indicates the species that is dominant, or numerically most abundant, at a particular sample and the Equitability which measures the evenness with which individuals are divided among the taxa present.

Values of Fischer-$\alpha<5$ generally indicate brackish or hypersaline marginal environments but may also indicate normal marine environments with a high dominance of a single species. From the data of H(S) values>2.1 indicate normal marine environments.

Some important factors controlling species diversity include changes of thophic (resource) level and stability of the environment [23], [24], [25]. Therefore, the lower part of the section is characterized by high diversity and low dominance (Fig. 2), which corresponds to low levels of ecological stress, as, commonly met in relatively stable and well ventilated deep-sea environments.

In the uppermost lower and middle part of the section, low diversity, low equitability and high dominance characterize the three levels in which *V. complanata* predominates. On the contrary, higher Fischer-α values and heterostegeneity associated with lower abundance of *V. complanata* may suggest that the structure of the communities may be considered normal for areas characterized by high benthic productivity.

One of the most prominent characteristics in the middle and upper part of the section is that infaunal forms (Bolivinidae and Uvigerinidae) are abundant. The associated faunas in these parts of the section are less diverse but abundant in individuals.

In the uppermost part of the section low diversity values and high dominance trend represent a shallow shelf area which is subject to less stable environmental conditions, and therefore display less diversified benthic foraminiferal assemblages characterized by higher dominance.

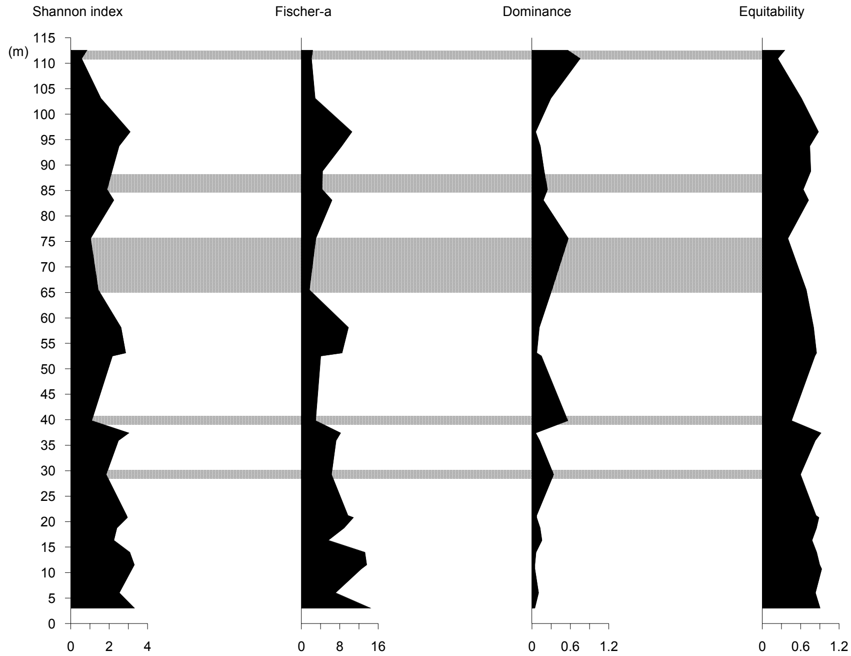

Figure 2: Faunal parameters (diversity pattern) of the Potamos Section.

4.3. Benthic Foraminiferal morphogroups

Benthic foraminiferal assemblage data from the Potamos Section were used to calculate the benthic foraminiferal oxygen index (BFOI) of [9], [10]. The benthic foraminiferal assemblages did not include any significant amount of organically cemented agglutinated taxa, therefore the BFOI was calculated using the calcareous forms.

The relative proportions of three benthic foraminiferal morphogroups are used to provide an estimate of the dissolved oxygen content of the bottom waters. [9] adapted the morphogroup concepts of [26] and [27] to define these three groups (only taxa found in the Potamos Section are mentioned here):

Dysoxic indicators characterizing oxygen contents of 0,1 to 0,3 ml/l. This group includes the genera *Bolivina, Bulimina, Cassidulina, Chilostomella, Dentalina, Stilostomella, Globobulimina (Praeglobobulimina).* These are usually thin-walled, elongate, flattened, mostly small species which also live as infauna under highly oxygenated conditions. Numerous studies have documented the occurrence of these genera in dysoxic environments worldwide [27], [9].

Oxic indicators pointing to oxygen contents of >1,5 ml/l. This group includes species that have large, ornamented tests and thick walls. These species are mostly epiphytes or vegetation bound or show positive correlation with epiphytes. The genera *Valvulineria, Ammonia, Asterigerinata, Cibicides, Globocassidulina* as well as all the lagenids and miliolids are included in this group. Such species are absent in low oxygen environments.

Suboxic indicators characteristic for oxygen contents of 0,3 to 1,5 ml/l. This group includes *Bulimina, Cassidulina, Gyroidinoides, Lenticulina, Melonis, Nonion, Oridorsalis, Pullenia, Sphaeroidina bulloides, Uvigerina, Elphidium.* These taxa prefer shallow to intermediate infaunal microhabitats [29], [30]. They show intolerance to oxygen deficiency as well as increased salinity and never proliferate during times of nutrient abundance.

The benthic foraminiferal assemblages recovered from the section reveal BFOI values that are variable but generally high, which never reach zero. Index values between 0 and 50 correspond to oxygen concentrations between 1,8 and 3 ml/l, values >50 correspond to >3ml/l.

From the plot of Fig. 3, it may be inferred that the entire section is characterized by high percentage values of the representatives of the Dysoxic and Suboxic group. Oxic indicators are of minor importance.

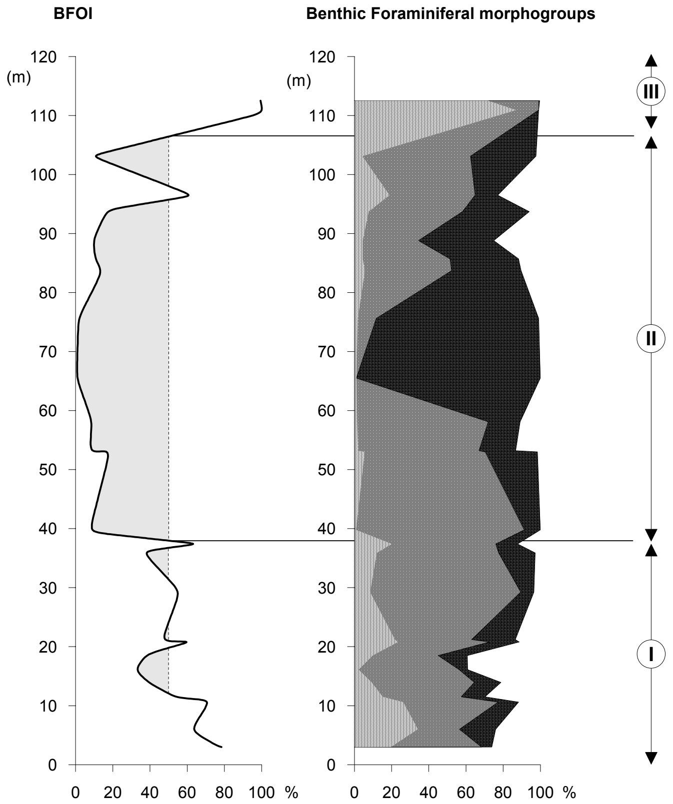

Figure 3: Bottom water oxygenation and benthic foraminiferal morphogroups from the Potamos Section. BFOI values between 0 and 50 correspond to oxygen concentrations between 1.8 and 3ml/l, values >50 correspond to concentrations >3ml/l.

The lower part of the section (Interval I) is characterized by a decline in the abundance of the oxic indicators and an increase of the suboxic morphogroup. Dysoxic indicators occur occasionally with low percentages. This interval shows the lowest percentages of the potentially infaunal taxa and three peak occurrences of *V. complanata.* The high percentage values of *V. complanata* in combination with peak occurrences of *Nonion* sp. is correlated with high percentages of organic matter and low oxygen concentration in the sediment. These taxa seem to be excellent marker of high benthic productivity, which is often related to moderate environmental stress [28]. According to [15], *V. complanata* peaks and the potentially infaunal taxa weak increase suggest an increase in the influence of fluvial input. The same authors stress the high impact of increased terrestrially derived nutrient, organic matter and sediment input for the types of benthic communities.
Moreover, in 39 to 53 m, the abundant foraminiferal assemblages have BFOI values near 10, which correspond to a dissolved oxygen content of ~1,5%.
Interval II is characterized by the presence of potentially infaunal taxa, suggesting that a dysoxic period occur. *B. spathulata* increases in frequency while species such as *Uvigerina* spp., previously quite common, display an abrupt decrease. In particular, in between 65 to 75,5 m, the lack of any species belonging to “aerobic” or “intermediate” morphogroups indicates that the waters were severely dysoxic, with dissolved oxygen concentrations probably below 0,5%. [31] consider *B. spathulata* the least sensitive to hypoxia and typical of the low oxygen environment and suggest that it may have the ability to track oxygen gradients. Consequently, the sum of the species belonging to this

group may be regarded as an indicator of the frequency of dysoxic episodes. The assemblage characterized Interval II registers BFOI values between 1,1 to 2. These low values point to a dissolved oxygen content below 1,5%. From this minimum, the BFOI values increase upsection.

The benthic foraminiferal assemblages recovered from the top of the section (Interval III) reveal high BFOI values. The upper part of the section is dominated by the "oxic" morphogroup. The dysoxic forms are entirely absent at 110 to 113 m. Well oxygenated conditions corresponding to the high oxic levels of [10] are indicated for this Interval. Moreover, a reduced oxygen supply can be assumed for the lower part of Interval III. However, since oxygen indicators are frequent, this association may represent the low oxic level.

5. CONCLUSIONS

The most important factor for the foraminiferal distribution in the investigated area is oxygenation (possibly in connection with fluctuations of nutrient supply) and therefore it is necessary to briefly analyze causes for different oxygen levels.

At the lower part of the sediment column (Interval I), the oxygen content, although low, was sufficient to sustain communities of predominantly "suboxic" and "dysoxic" foraminifera.

The middle part of the marine sediment column (Interval II) consists mostly of infaunal forms that are known from oxygen-deficient environments rich in organic matter.

The outflow from small rivers that empty into the Potamos shelf has been adequate to create a low-salinity lid in the upper part of the sediment column (Interval III). A low-diversity *Ammonia* assemblage indicates these brackish conditions.

Therefore, in our section, the temporal increase in the proportion of infaunal benthic foraminifera (particularly *B. spathulata*) reveals one time interval of reduced bottom-water oxygenation.

The dysoxic indicators of the Potamos Section contain benthic foraminifera taxa that are commonly found on continental margins which correspond to high productivity areas (e.g. *Globobulimina, Bulimina, Bolivina, Fursenkoina*).

The origin of this low-oxygen event might be associated with changes in the humidity of the borderlands and corresponding fresh-water inputs. Enhanced river run-off into the Potamos basin probably triggered high productivity and enhanced fluxes of organic carbon to the sea floor. Simultaneously, the stratification of the water column caused a severe decrease in the ventilation of the subsurface waters (review in [32]).

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