THE USE OF BENTHIC FORAMINIFERAL MORPHOCLASSES IN DETERMINING PALEOCEANOGRAPHIC CONDITIONS: A PARADIGM FROM ITHAKI ISL.

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Abstract

The characteristics of the benthic foraminiferal assemblages documented in this study provide insights into paleoenvironmental conditions of the Afales Basin in Ithaki isl. during the Oligocene. The determined benthic foraminiferal taxa were grouped into two classes, "Morphoclasses", which may roughly approach natural grouping in epifaunal and infaunal taxa respectively. The proportion between those two Morphoclasses present in the studied samples, indicate oligotrophic to mesotrophic conditions and moderately oxygenated bottom waters. The oligotrophy was a result of a decrease in organic flux. The documented short-term periods of eutrophic to mesotrophic conditions within the oligotrophic regime might represent a paleoceanographic influence of water-masses from adjacent shoals.

Keywords: paleoceanography, oxygenation, trophic availability.

1. Introduction

Benthic foraminifera are one of the most abundant, diverse, and widely distributed groups of marine organisms in deep-water environments and have a rich fossil record. Deep-sea benthic foraminiferal assemblages have been used extensively to reconstruct palaeoenvironments, including those in the Palaeogene, the early part of the Cenozoic.

The vertical distribution of benthic foraminifera in the sediment column seems to be determined mainly by two factors: food availability and oxygen content (Gooday & Rathburn, 1999; Gooday, 2003). This is supported by a number of field studies and experiments that demonstrate the effects of organic supply and changes in bottom water oxygen concentration on the microhabitat selection (e.g. Rathburn & Corliss, 1994; Ernst & van der Zwaan, 2004). All these observations were summarized in the "TROX – model" of Jorissen *et al.* (1995), which relates the microhabitat selection of a given taxon to a balance between food and oxygen availability. According to this model, oligotrophic systems are food – limited and organisms are concentrated close to the sediment surface, where the majority of the food is located. Although eutrophic systems are oxygen – limited, organisms are also concentrated near the surface in order to avoid anoxic conditions deeper in the sediment. This general scheme has been refined by Jorissen (1999) and Fontanier *et al.* (2002), who suggested that: (1) the organic matter flux is the main parameter controlling foraminiferal microhabitats, (2) oxygen is not the limiting factor for deep infaunal species, and that (3) biological interactions, particularly competition for labile food material, may play a role in microhabitat selection.

Faunal penetration is maximal in "mesotrophic" settings because the oxygen penetration is relatively deep and more or less labile food particles are introduced at depth in the sediment by bioturbating macrofauna creating suitable microhabitats for benthic foraminifera (Jorissen, 1999; Fontanier *et al.*, 2002). In such environments, the subsurface accumulation of organic matter (Rathburn & Corliss, 1994) and/or grazing on populations of anaerobic bacteria associated with redox boundaries (Fontanier *et al.*, 2002) could explain the microhabitat selection of a given foraminifer.

Nevertheless, a number of studies concerning the relationship between morphological groups (morphogroups, morphotypes) of living foraminifera with their microhabitat preference (Corliss, 1985, 1991; Jones & Charnock, 1985; Bernhard, 1986; Corliss & Chen, 1988; Corliss & Emerson, 1990; Corliss & Fois, 1990; Kaiho, 1991, 1994; Buzas *et al.*, 1993; Linke & Lutze, 1993; Kitazato, 1994) showed that this relationship is not always simple (Barmawidjaja *et al.*, 1992), and quite a lot exceptions have been documented (Corliss, 1991 ; Barmawidjaja *et al.*, 1992; Alve & Bernhard, 1995). In particular, Sen Gupta & Machain-Castillo (1993) found no correlation involving specific test morphology and most dysoxic-suboxic benthic foraminifera. Yet, the relationship of trochospiral tests with epifaunal microhabitats, and elongated serial test morphologies with infaunal microhabitats, are usually supported (Bernhard, 1992; De Stigter, 1996; De Stigter *et al.*, 1998).

Foraminiferal microhabitat still remains a promising approach in identifying ancient environmental settings, supposing that fossil morphotypes have the same, or at least similar, ecological requirements as their recent morphological equivalents (Widmark, 1995). Consequently, in this study the use of the benthic foraminiferal morphologies is proposed, in consideration of the trophic and of other palaeoceanographic conditions in the Oligocene Afales basin in Ithaki island. For this reason, benthic foraminifera determined from the studied samples are assigned to two groups named "Morphoclasses" sensu Zivkovic & Babic (2003). The use of the term "Morphoclass" is proposed here for naming groups composed of more than one morphotype, and is preferred compared to the use of terms "epifaunal" and "infaunal", which might be imprecise when used for fossil foraminiferal taxa. Morphotype classification used here is based on classification summarized in Corliss & Chen (1988). The Morphoclass 1 (="epifaunal" after Corliss & Chen, 1988) includes foraminifera with trochospirally coiled tests (rounded trochospiral, plane-convex trochospiral, biconvex trochospiral), and milioline type tests, and the Morphoclass 2 (= "infaunal" after Corliss & Chen, 1988) embraces rounded planispiral, tapered/cylindrical, flattened tapered, spherical, and flattened ovoid type tests. The proportion of the Morphoclass 1 versus Morphoclass 2 in samples studied is used to estimate ancient foraminiferal microhabitats and their palaeoceanographic implications.

2. Geological Setting

Ithaki Island (Fig. 1) is one of the seven Ionian Islands and is situated in the external part of Hellenides. The area belongs to the Ionian Zone.

The Afales Basin is located in the northern part of the island and is surrounded and underlain by thick platform carbonates ranging in age from Late Mesozoic to Late Eocene (de

Mulder, 1975). The basin was formed in the early Oligocene, when the depositional setting gradually changed from a shallow carbonate platform to a deep basin (de Mulder, 1975). Basinal sediments consist of hemipelagic marls that grade upwards or interbedded with calcarenites, sandstones and carbonate breccias (Fig. 2a, b).

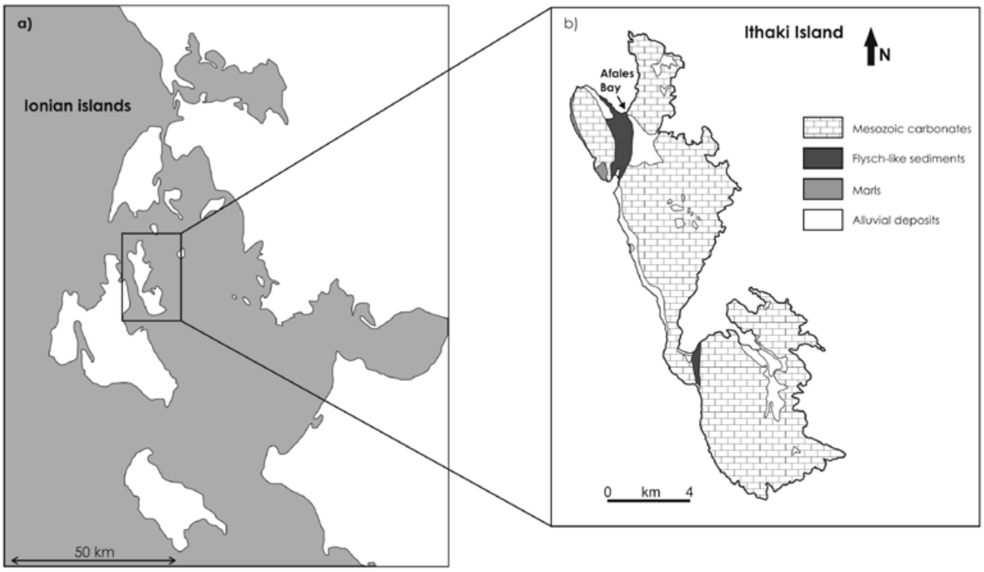

Fig. 1: Geological map of the Ithaki Island, showing the location of the section studied within the Afales Basin.

The studied sequence is located in the eastern margin of the Afales Basin. The section is well exposed and continuous. It covers a total sediment thickness of about 26.5 m and it consists of well-bedded, beige-coloured, detrital limestone beds (Fig. 2b). These beds show positive grading and nearly all of them are merging into more or less indurated, green-grey calcareous marls, steeply dipping to the west. The hemipelagic marls contain abundant planktonic foraminifera, common small benthic foraminifera, some ostracodes and rare fragments of echinoids and molluscs. These deposits have been designated as flysch or flysch-like beds.

2.1 BIOSTRATIGRAPHY

According to Drinia *et al.* (2009), the biostratigraphic analysis of the section revealed that the studied sediments have been deposited during late Rupelian-early Chatian times. In particular, as it is evidenced by the calcareous nannofossils, the presence of *Sphenolithus ciperoensis*, *Sphenolithus distentus*, *Cyclicargolithus floridanus*, *Cyclicargolithus abisectus* and *Reticulofenestra bisecta* indicate the NP24 zone of Martini (1971).

In accordance with these results, the planktonic foraminiferal analysis, which is based on the biozonal definitions of Berggren *et al.* (1995) and revised by Luterbacher *et al.* (2004), indicate that the P21 zone is evidenced by the occurrence of *Globigerina ciperoensis* and the common occurrence of *Paragloborotalia opima opima*. The lack in identification of *Chiloguembelina cubensis* species in the studied samples, which constitutes the worldwide criterion for the recognition of the Rupelian/Chattian boundary or the boundary between Subzones P21a and P21b of Berggren & Miller (1988) and Berggren *et al.* (1995) did not allow assigning this boundary.

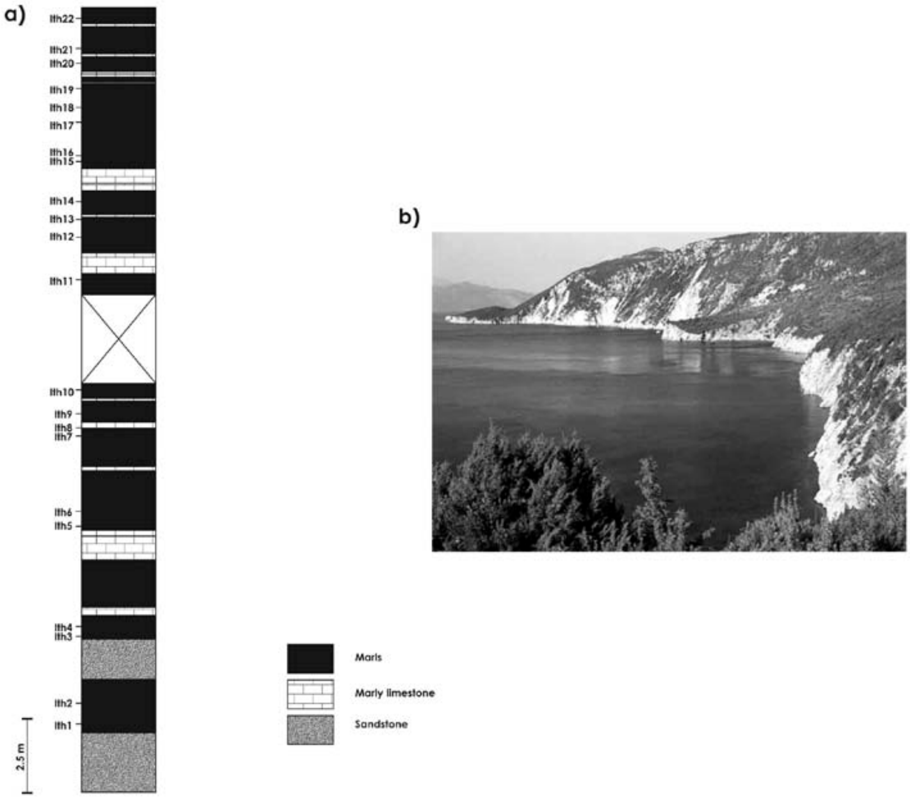

Fig. 2: a).Stratigraphic column of the measured section from the Afales Basin..b) Panoramic view of the studied sediments.

3. Methodology

Samples were taken from uniform and massive, well exposed and fresh, hemipelagic mudstones. The sampling frequency was diverse due to (i) the inaccessibility of rare good outcrops and (ii) locally poor representation of hemipelagic marls.

Samples were prepared using standard micropalaeontolical techniques and the fraction >125 μm was investigated for benthic foraminifera. For assemblage analysis, samples were split to a fraction containing at least 250 calcareous benthic foraminifera. Benthic foraminifera were identified to the generic level following Loeblich & Tappan (1987) and, whenever possible, to the specific level following Cenozoic taxonomic studies (e.g., Tjalsma & Lohmann, 1983; Van Morkhoven *et al.*, 1986).

Moreover, the calcareous benthic foraminifera were classified according to their morphologies into rounded trochospiral, plano-convex trochospiral, biconvex trochospiral, milioline, rounded planispiral, tappered/cylindrical, flattened tapered, spherical and flattened ovoid groups, following the work of Corliss & Chen (1988) and the methodology of Zivkovic & Babic (2003) (Table 1). All trochospiral and milioline foraminifera were included in Morphoclass 1 and others in Morphoclass 2, which correspond to epifaunal and infaunal morphotype groups classified into morphotypes defined by Corliss & Chen (1988). Morphoclass 1 and 2 correspond to epifaunal and infaunal morphotype groups, respectively, by these authors.

Table 1: List of calcareous benthic foraminiferal genera from the Afales Basin.

MORPHOCLASS 1	**MORPHOCLASS 2**	
Rounded trochospiral	**Rounded planispiral**	**Flattened tapered**
Anomalinoides	*Pullenia*	*Astacolus*
Gyroidinoides	*Melonis*	*Bolivina*
Plano-convex trochospiral	**Tapered/cylindrical**	*Marginulina*
Cibicidoides	*Bulimina*	*Marginulinopsis*
Eponides	*Chrysalogonium*	*Saracenaria*
Hanzawaia	*Dentalina*	*Vaginulinopsis*
Nuttallides	*Ellipsonodosaria*	**Spherical**
Planulina	*Nodosaria*	*Glandulina*
Biconvex trochospiral	*Pleurostomella*	*Globocassidulina*
Lenticulina	*Rectuvigerina*	*Globulina*
Oridorsalis	*Stilostomella*	*Lagena*
Osangularia	*Uvigerina*	*Oolina*
Milioline	**Flattened ovoid**	*Polymorphina*
	Ellipsoglandulina	
	Fissurina	

The percentage values of Morphoclass 1 and Morphoclass 2 (Fig. 3) are used as an approximate measure of the degree of oligotrophy/eutrophy and related oxygen level in the Afales Basin, as it has been proposed for relevant data deriving from modern oceans (Corliss & Chen, 1988; Rosoff & Corliss, 1992; Kaiho, 1991, 1994), and similarly used for interpreting trophic and oxygen conditions in ancient seas (Thomas, 1990; Widmark, 1995).

4. Results

Previous micropalaeontological research (Drinia, 2009) in the Afales Basin has revealed a well – developed Oligocene foraminiferal assemblage, abundant and diversified, dominated by planktonic foraminifera. Study of the benthic foraminiferal assemblages (composition, relative abundance, diversity in terms of Shannon (Hs) index and dominance) showed a clear relationship with deep marine environment. The dominant calcareous species groups include *Cibicidoides* spp. (including among others *C. mundulus-praemundulus*, *C. robertsonianus* and *C. grimsdalei*), *Oridorsalis* gr. *umbonatus, Gyroidinoides* spp. (mainly represented by *G. soldanii*), *Stilostomella* spp. (represented by *S. nuttalii* and *S. subspinosa*) and Nodosariidae. Less common calcareous groups include *Anomalinoides* spp., *Nuttallides* spp. (mainly represented by *N. umbonifera*), *Uvigerina* spp., *Globocassidulina subglobosa*, *Bolivina* spp. and unilocular species (*Fissurina*, *Lagena*, *Oolina*).

In this study, in all the samples studied from the Afales Basin both Morphoclasses are recognized, but Morphoclass 1, i.e. "epifaunal" morphotypes, prevail in most samples (Fig. 3). Generally, epifaunal foraminifera are more common than infaunal. The majority of samples contain more than 50% taxa of Morphoclass 1 (Fig. 3), while only two samples approximate 50%, and four samples show less than 50% of Morphoclass 1 and consequent increase of Morphoclass 2.

5. Discussion

Based on our data and using the model proposed by Jorissen *et al.* (1995) to explain the microhabitats in terms of trophic conditions and oxygen concentrations, extreme oligotrophic and extreme eutrophic environments may be excluded. In the former, all metabolizable food would be consumed at the sediment surface and the underlying sediment would contain only small quantities of (refractory) organic material that would cause the absence of infaunal foraminifera. In the latter, epifaunal foraminifera are absent due to decreased oxygen content caused by the decomposition of organic matter. At the same time, opportunistic infaunal foraminifera shift to or near the sediment surface following the shift of the redox front towards the sediment surface.

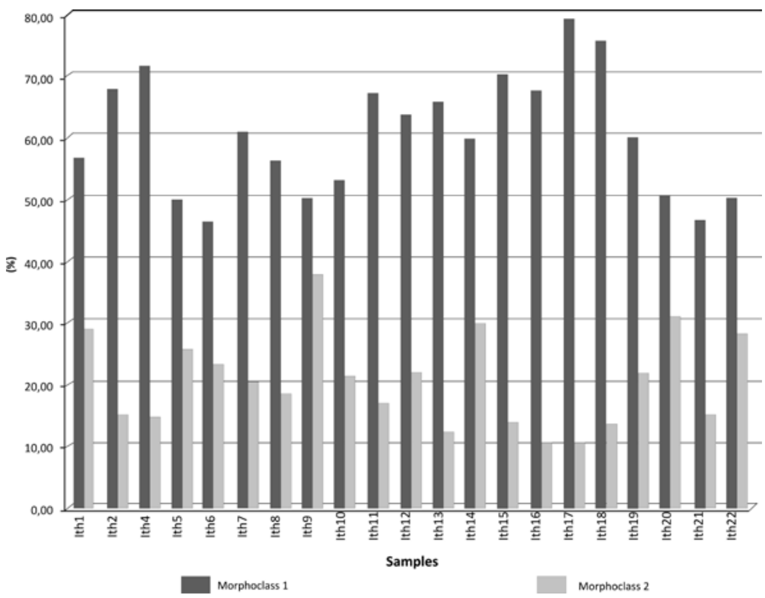

Fig. 3: Percentages of Morphoclass 1 and Morphoclass 2 in the studied samples.

Higher oxygen levels, as indicated by higher Morphoclass 1 abundances and decreased numbers of Morphoclass 2, persisted during most of the time of deposition at the Afales section. These higher oxygenated conditions were probably the result of temporary better ventilation of the basin. The oligotrophic conditions in the Afales section were disrupted in six stratigraphic levels (samples Ith5, Ith6, Ith9, Ith 20, Ith 21 and Ith22) by episodes recorded by a relative increase of Morphoclass 2 and lower percentages of Morphoclass 1. These stratigraphic intervals are indicative of higher organic flux and lowered oxygen levels. These intervals may suggest periods of increased tectonic activity and the resulting higher input of land-derived nutrients. Indeed, the common occurrence of reworked Eocene larger foraminifera such as *Nummulites* and *Discocyclina,* suggests the existence of flourishing larger foraminiferal populations in the vicinity of Afales Basin. According to de Mulder (1975), it seems plausible that a large shoal area existed next to Afales Bay. After emergence, related to tectonic or eustatic activity, this shoal area became subjected to erosion and transport during the Oligocene.

In conclusion, the Afales basin was strongly influenced by the tectonic activity, and the amount and type of organic material, carried from both adjacent and distant sources, had a strong influence on the paleoenvironmental conditions documented in the benthic foraminiferal record. The variability of the benthic foraminiferal morphoclasses indicates strong local environmental control that influenced primary productivity. Higher resolution studies are needed to improve paleoceanographic interpretations.

6. Conclusions

Benthic foraminiferal morphotypes have been grouped into two classes, here called “Morphoclasses”, which may roughly approach natural grouping in epifaunal and infaunal taxa respectively. The distribution of these morphoclasses provides insights into paleoenvironmental conditions and paleogeography of the Afales Basin during the Oligocene. The paleoenvironmental conditions were influenced by local control on the primary productivity and land-derived maretial. The proportion between the two Morphoclasses, indicate oligotrophic to mesotrophic conditions and moderately oxygenated bottom waters. Short term high-flux/low oxygen intervals, within the generally oligotrophic biofacies were also recorded.

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