MORPHOTYPE VARIATION OF ORTHOPHRAGMINIDS AS A PALAEOECOLOGICAL INDICATOR: A CASE STUDY OF BARTONIAN LIMESTONES, POD CAPKAMI QUARRY, TATRA MTS, POLAND

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Abstract: Nummulites-Discocyclina bioclastic packstone and Discocyclina rudstone occur in the transgressive sequence of the Middle-Upper Eocene deposits in the Tatra Mts. The succession of the studied facies is a direct response to a rapid environmental change, related to progressive deepening. Facies transition from Nummulites-Discocyclina bioclastic packstone of proximal mid-ramp to Discocy­clina rudstone of distal mid- and outer-ramp is an exemplary record of a deposition during deepening conditions. Increasing of diversity of the genus Discocy­clina, decreasing of diversity of other foraminifera up the section and vertical variation of orthophragminid morphotypes from the ovate- through saddle- to the disc-shaped tests are related to deepening and shadowing of the depositional environment.

Key words: Larger benthic foraminifera, orthophragminids, morphotype, transgression, palaeoenvironment, Eocene, Tatra Mts, Western Carpathians.

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INTRODUCTION

The symbiont-bearing larger benthic foraminifera (LBF) are a good indicator of oligotrophic, tropical shallow marine carbonate depositional conditions, especially in terms of their environmentally sensitive depth distribution and morphology. An analysis of the morphology of larger foraminiferal tests provides a good tool for palaeoenviron­mental reconstructions (e.g., Reiss & Hottinger, 1984; Hallock & Glenn, 1986; Hottinger, 1997; Hallock, 1999; Geel, 2000; Hohenegger, 2004, 2005, 2009). The distribution patterns of recent LBF were investigated as the envi­ronmental indicators in respect to depth, light limitations, type of substrate and energy regime (Hohenegger & Yordanova, 2001; Beavington-Penney & Racey, 2004; Jorry et al., 2006). Distribution of the recent LBF is strongly influenced by light level and by water energy (e.g., Larsen, 1976; Larsen & Drooger, 1977; Hallock et al., 1986; Hallock, 1979,1985; Hohenegger, 2009; Hallock & Pomar, 2008). The former factor strongly affects symbiont bearing LBF and determines the shapes of LBF tests.

Orthophragminids (including genera Discocy­clina, Nemkovella, Orbitocy­peus and Asterocy­clina – sensu Less, 1987) extinct at the Eocene/Oligocene boundary and they have no present-day representatives. However, Discocy­clina can be regarded as homeomorphs to recent Cyclo­cy­peus (Hohenegger & Yordanova, 2001), whose habitat and environmental requirements are well known.

Knowledge on the palaeoecology of orthophragminids refers mainly to their morphology, palaeobathymetric distri­bution and faunal associations (Fermont, 1982; Ferrandez-Cañadell & Serra-Kiel, 1992; Ferrandez-Cañadell, 1998). According to Fermont (1982), the tests of Asterocy­clina and Discocy­clina become more flattened with increasing depth. Discocy­clina test morphology is strongly environment­ally influenced, mainly due to adaptation of the foraminifera to endosymbiotic algae (Ferrandez-Cañadell, 1998).

LBF are characteristic features of Eocene carbonate de­posits in the Tatra Mts (Bieda, 1963; Olempska, 1973; Kulka, 1985). Nummulites, that are widely known as a palaeoenvironmental indicator (Beavington-Penney & Racey, 2004; Beavington-Penney et al., 2006), constitute the most characteristic components of these deposits. Nonetheless, Discocy­clina are dominant component in some facies of these deposits. They may be also a very important and useful tool for palaeoenvironmental reconstructions of Eocene deposits (e.g., Čosović et al., 2004; Bassi, 2005; Nebelsick et al., 2005).
A few examples of application of *Discocyclina* test morphology as a palaeoenvironment indicator are known (Cosović & Drobné, 1995; Geel, 2000; Jach et al., in press). The purpose of the study is the application of changes of orthophragminid morphology, diversity and abundance in the assemblage of LBF as palaeoenvironmental indicators.

**GEOLOGICAL SETTING**

The shallow water Eocene deposits are part of the so-called Central Carpathian Paleogene complex (Passendorfer, 1959). The Middle–Upper Eocene deposits crop out along the northern margin of the Tatra Mts (southern Poland; Fig. 1). Generally, these deposits illustrate progressive deepening of depositional environment (Roniewicz, 1969; Kulka, 1985; Olszewska & Wieczorek, 1998; Bartholdy et al., 1999). The Eocene sequence commences with conglomerates composed of bedrock clasts (Fig. 2), covered by litoral extraclastic packstone with *Nummulites brognarii* D’Archiac et Haimé, which is locally capped by nummulitic bank facies with *Nummulites perforatus* (Montfort) of the Early Bartonian SBZ 17 (shallow benthic zone according to Serra-Kiel et al., 1998). These deposits are, in turn, covered by *Discocyclina*-bearing facies comprising *Nummulites-Discocyclina* bioclastic packstone with *Nummulites perforatus* (Montfort), *Nummulites puschi* D’Archiac, of the Early Bartonian SBZ 17 zone, and *Discocyclina* rudstone containing in the uppermost part *Discocyclina augustae* Van der Weijden and *Operculina aff. alpina* Douville of the Late Bartonian SBZ 18. The rudstone is overlain by glauconitic marls with globigerinids (Alexandrowicz & Geroch, 1963; Olszewska & Wieczorek, 1998; Olszewska, 2009). The uppermost part of the section is formed by organo-detritic limestones and conglomerates. These deposits represent Priabonian SBZ 19 zone on the basis of *Operculina alpina* Douville, *Heterostegina reticulata* Rittmeyer and *Nummulites fabianii* (Prever). The carbonates are succeeded by an about 2.5 km thick complex of Oligocene turbiditic deposits (Radomski, 1959).

*Discocyclina*-bearing facies, especially the transition from the *Nummulites-Discocyclina* bioclastic packstone to *Discocyclina* rudstone, is a record of an abrupt transgression (Fig. 2). *Discocyclina*-bearing facies (*Nummulites-Discocyclina* bioclastic packstone and *Discocyclina* rudstone) occurs at several localities, such as the Strążyska Valley, Spadowiec Valley, Pod Capkami Quarry, Olczyska Valley, Jaszczyrówka, and the Chłabówka Stream in the Tatra Mts (Fig. 1). The most representative, complete and relatively well documented section crops out in an abandoned Pod Capkami Quarry (Fig. 1; Bieda, 1963; Alexandrowicz & Geroch, 1963; see also Bartholdy et al., 1995, 1999). This section was selected for detailed analysis (GPS coordinates: N49°16.746', E19°58.361').

**MATERIAL AND METHODS**

The studied Pod Capkami Quarry section contains *Discocyclina*-bearing facies, which crops out on the northern slope of Mała Krokiew (Fig. 1). The section was analysed bed-by-bed with detailed sampling. Polished slabs and thin sections were prepared for microfacies and palaeoecotological analysis.

Since most of the *Nummulites-Discocyclina* bioclastic packstone samples have been collected from hard limestones, the microfacies and microfauna were studied mainly in thin sections. Samples of relatively poorly cemented *Discocyclina* rudstone were disaggregated and washed in order to extract the LBF tests, especially for identification of *Discocyclina* species (sensu Neumann, 1958). Specimens of foraminifera were picked from the residue and polished or split to obtain equatorial sections of the tests.

Biometric analysis of LBF is based on the thickness to diameter (T/D) ratio. The LBF were determined from axial or nearly axial sections, and orthophragminid from *Discocyclina* rudstone additionally were determined from isolated forms. A ratio of small megalospherical A-forms to large microspherical B-forms was identified only when equatorial sections were possible to be observed, that is on the basis of tests isolated from the *Discocyclina* rudstone.

Samples and thin sections are housed at the Institute of Geological Sciences of the Jagiellonian University.
RESULTS

Discocyclina-bearing facies comprises Nummulites-Discocyclina bioclastic packstone covered by Discocyclina rudstone. The Nummulites-Discocyclina bioclastic packstone, up to 1.5 m thick, is distinctly bedded (Figs 2, 3A). It is composed of numerous small Nummulites sp., spherical in axial section, accompanied by ovate or fusiform-shaped orthophragminids – representatives of Orbitoclypeus sp. and Asterocyclina sp., saddle-shaped Discocyclina sp., robust and spherical tests of Nummulites perforatus (Montfort), as well as flat disc-shaped Nummulites cf. maximus (Archiac), with maximum diameter up to 11 cm (Fig. 3B), and diversified rotalids, such as: Asterigerina sp. and Amphistegina sp. Beside foraminifers, very rare coralline algae and tubes of Ditirupa sp. occur. Matrix rich in abundant bioclastic debris, mainly nummulitic, is commonly observed (Fig. 3C). The bioclasts are often fragmented and abraded. The orthophragminid tests in this facies display the average T/D (thickness/diameter) ratio of 0.4–0.5. The contact with the overlying Discocyclina rudstone is sharp (Fig. 3A).

The Discocyclina rudstone, up 2 m thick, is built almost exclusively of the macrospherical forms of Discocyclina (A/B ratio 21/1). The lower part of the rudstone is dominated by saddle-shaped Discocyclina pratti (Michelin); moreover, disc-shaped Discocyclina sella (D’Archiac) and Discocyclina sp. (Fig. 3D, E), as well as numerous ovate-shaped Asterocyclina sp. and Orbitoclypeus sp. occur. The lower part of the rudstone contains Discocyclina tests with the average T/D ratio of up to 0.2. The tests are horizontally orientated, densely packed, commonly with stylolitic contacts, with rare signs of fragmentation or abrasion. In the upper part of the Discocyclina rudstone, the lack of abraded detritus is observed (Fig. 3F). The uppermost part of the Discocyclina rudstone contains glauconite grains, in some cases with relics of planktonic foraminifera.

DISCUSSION

Depositional environment

The Nummulites-Discocyclina bioclastic packstone comprises high-diversity LBF community with numerous spherical, ovate and massive tests of Nummulites and Discocyclina. Such a test morphology strongly reflects ecological and physical condition of relatively shallow photic-zone and high-energy regime. The observed moderate abrasion (outer wall partly missing and damaged), reworking and fragmentation of the tests suggest allochthonous biofabric of Nummulites and Discocyclina (Racey, 2001; Beavington-Penney, 2004; Beavington-Penney & Racey, 2004; Beavington-Penney et al., 2006). In turn, micrite-rich fabric and diverse fauna assemblage of varied palaeoecological modes suggest redeposition from shallower parts of the ramp to the deeper setting (cf. Aßal et al., 2011). All this evidence that the discussed Nummulites-Discocyclina bioclastic packstone displays features typical of deposition in the proximal mid-ramp setting dominated by intense reposition processes.

The overlying Discocyclina rudstone is almost exclusively composed of Discocyclina tests with domination of megalospherical A-forms (the ratio A/B forms is 21/1). According to Aigner (1985), strong dominations of the
Discocyclina-bearing facies, Bartonian, Pod Capkami Quarry section. A. Pod Capkami Quarry section – general view. The lower massive part of the section formed by Nummulites-Discocyclina bioclastic packstone; while the upper part is built up of distinctly bedded Discocyclina rudstone. B. Nummulites-Discocyclina bioclastic packstone composed of various small and spherical Nummulites sp. and saddle-shaped Discocyclina sp. as well as Orbitoclypeus sp., Asterocyclina sp., and Discocyclina sp., Nummulites cf. maximus (Orbigny); scan of the thin section. C. Nummulites-Discocyclina bioclastic packstone; scan of the thin section. D. Discocyclina rudstone general view; polished slab. E. Discocyclina rudstone – lower part of the facies. The rudstone, besides saddle-shaped Discocyclina sp. tests, is composed of numerous ovate-shaped Orbitoclypeus sp. and small, spherical Nummulites sp.; scan of the thin section. F. Disc-shaped Discocyclina sella (D’Archiac) tests horizontally orientated and densely packed, with stylolitic contacts; thin section. G. Disc-shaped Discocyclina sella (D’Archiac) tests horizontally orientated and densely packed, with stylolitic contacts; thin section.
A-forms is typical of parautochthonous deposits. Hottinger (1997) regarded such an assemblage with dominance of megalospheric forms as an indicator of marginal depth range of the population. Low-diverse foraminifera community of Discocyclina rudstone facies is caused by strongly oligotrophic condition (Čosović & Drobin, 1995; Racey, 2001; Čosović et al., 2004; Bassi, 2005; Afzal et al., 2011).

The Discocyclina rudstone assemblage is parautochthonous, which is proved by test-supported fabric, scarcity of micrite and well preserved Discocyclina tests (cf. Aigner, 1985; Racey, 2001; Yordanova & Hohenegger, 2002). Analogous facies was described as deposited in distal mid-ramp and outer-ramp settings (Pappazoni, 1994; Racey, 2001; Afzal et al., 2011). Probably, low degree of tests abrasion and scarce occurrence of micrite are an effect of intense winnowing, below the storm wave base (Aigner, 1982), which leads to concentrations of Discocyclina tests (Fig. 3F, G). Thus, the test-supported fabric seems to be an effect of winnowing and slower sedimentation rate (Aigner, 1982; Bassi, 2005).

Generally, transition from the highly-diverse LBF community dominated by Nummulites and Discocyclina to the low-diverse community dominated by Discocyclina reflects successive deepening of the depositional environment and lowering of energy regime. Thus, the Discocyclina-bearing facies marks progressive deepening from proximal mid-ramp setting to distal mid- and outer-ramp. It is additionally supported by occurrence of rare planktonic foraminifera in the uppermost part of Discocyclina rudstone.

Variation of orthophragmniid test morphology

Along with the above discussed changes in the LBF composition, the changes of orthophragmniid morphotypes is visible in the studied section. The vertical transition of orthophragmniid morphotypes is clearly recorded up the studied section, whose lowermost part is dominated by ovate- and fusiform-shaped orthophragmniids (Discocyclina sp., Orbitocyopsidea sp., Asterocyopsidea sp. Ovate and fusiform shape tests with thick wall reflect shallower environment with characteristic high energy and high light conditions (e.g., Hohenegger, 2009).

The saddle-shaped tests of Discocyclina dominate in the upper part of Nummulites-Discocyclina packstone and in the lower part of Discocyclina rudstone. The saddle-shaped tests of Discocyclina have already been interpreted by Bieda (1963) who suggested that this morphology of tests is an adaptation to increase in the adherence capability of the test to plants. According to Olempska (1973), saddle-shaped tests are a physical adaptation to the irregularities of the substrate. However, based on the recent observations of undulate Cylocyopsidea, it seems more probable that the saddle-shape of the tests is an adaptation to deeper euphotic zone. The saddle-shaped tests allow better absorption of sunlight, which strikes on the surface of the test at the different angle (Ferrandez-Cañadell & Serra-Kiel, 1992; Ferrandez-Cañadell, 1998; Beavington-Penney & Racey, 2004; Beavington-Penney et al., 2006). Thus, this morphotype seems to be better adapted to a dim environment than to shallow photic-zones where oval-shaped tests dominate (Hottinger, 1983; Hallock & Glenn, 1986; Hallock, 1999).

In the upper part of Discocyclina rudstone, flat, disc-shaped tests dominate. Such tests suggest low energy and very low light environment. Extremely flat disc-shaped tests, in the discussed case T/D ratio (up to 0.2), are characteristic for individuals living close to the extremes of their characteristic depth range. The tendency to flattening of disc-shaped tests and thinning of their walls is connected with requirements of algal endosymbionts of the LBF. Extremely flat disc-shaped tests of Discocyclina and their thin transparent hyaline walls allow light penetration into the interior of the tests (Hottinger, 1997; Renema, 2005; Hohenegger, 2009). Morphological resemblance between Eocene Discocyclina and recent Cyclocyopsidea suggests similar ecological conditions. Cyclocyopsidea species are observed in the deepest part of the photic zone, according to Pomar (2001) in ologrophic zone.

The above interpretation based on variation of orthophragmniid morphotypes is consistent with the above discussed general trend of vertical facies variation being a record of deepening, lowering energy and gradual shadowing of the depositional milieu. Thus, orthophragmniids seem to be a good and sensitive indicator of palaeoenvironmental conditions.

CONCLUSIONS

1. The Nummulites-Discocyclina bioclastic packstone represents proximal mid-ramp setting, whereas the Discocyclina rudstone typifies the distal mid-ramp and outer ramp.

2. The Discocyclina facies in the Pod Capkami Quarry section is a model example of LBF community response to transgression record. It is expressed in vertical change of orthophragmniids morphotype from ovate through saddle- to disc-shaped tests.

3. Discocyclina test morphology is environmentally strongly controlled. Shallower settings are characterized by ovate-robust tests. Such test morphology is related to good illumination condition and higher energy regime. Flattened saddle-shaped or flattened disc-shaped tests are associated with deposition in dim setting and relatively lower energy regime.

4. Orthophragmniids seem to be a good and sensitive indicator of palaeoenvironmental conditions.

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REFERENCES


Ferrandez-Cañadell, C., 1998. Morphostructure and paleobiology of Mesogean orthophragminids (Discocyclinidae and Orbitho­


Hohenegger, J., 2005. Estimation of environmental paleogradient values based on presence/absence data: a case study using benthic foraminifera for paleodepth estimation. Palaeo­
geography, Palaeoclimatology, Palaeoecology, 217: 115–130.


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51: 197–216.