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

Elżbieta MACHANIEC, Renata JACH & Michał GRADZIŃSKI

Institute of Geological Sciences, Jagiellonian University, Oleandry 2a, 30-063 Kraków, Poland, e-mails: elzbieta.machaniec@uj.edu.pl; renata.jach@uj.edu.pl; michal.gradzinski@uj.edu.pl


**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 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.

*Manuscript received 5 October 2011, accepted 21 November 2011*

**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, Orbitoclypeus 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 *Cycloclypeus* (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.*, Cosović *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.

GEOPHYSICAL SETTING

The shallow water Eocene deposits are part of the so-called Central Carpathian Palaeogene 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., 1998). The Eocene sequence commences with conglomerates composed of bedrock clasts (Fig. 2), covered by littoral extraclastic packstone with Nummulites brogniarti D’Archia et Haime, 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’Archia, 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 organodetrinitic limestones and conglomerates. These deposits present Priabonian SBZ 19 zone on the basis of Operculina alpina Douville, Heterostegina reticulata Rütimeyer 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 Strażyska Valley, Spadowie Valley, Pod Capkami Quarry, Olszynska Valley, Jaszczurówka, and the Chlabówka 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 Mala Krokiew (Fig. 1). The section was analysed bed-by-bed with detailed sampling. Polished slabs and thin sections were prepared for microfacies and palaeoecological 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 foraminifers 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 orthophragmins – 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 rotaliids, such as: Asterigerina sp. and Amphistegina sp. Beside foraminifers, very rare coralline algae and tubes of Ditrupa 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 not 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 0.2–0.25. In its upper part, the orthophragmind tests become thinner and flattened, dominated by disc-shaped Discocyclina sella (D’Archiac), with single Discocyclina augustae Wejden and Discocyclina radians (D’Archiac), and less numerous saddle-shaped Discocyclina sp. (Fig. 3F, G). The upper 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. Aftal 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 redeposition 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
Fig. 3. *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 (Cosovic & Droben, 1995; Racey, 2001; Cosovic 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 orthophragminid test morphology**

Along with the above discussed changes in the LBF composition, the changes of orthophragminid morphotypes is visible in the studied section. The vertical transition of orthophragminid morphotypes is clearly recorded up the studied section, whose lowermost part is dominated by ovate- and fusiform-shaped orthophragminids (Discocyclina sp., Orbitocyclus sp., Asterocyclus 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 Cyclocyclus, 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 Cyclocyclus suggests similar ecological conditions. Cyclocyclus species are observed in the deepest part of the photic zone, according to Pomer (2001) in oligophotic zone.

The above interpretation based on variation of orthophragminid 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, orthophragminids 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 Discocylina 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 orthophragminid 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. Orthophragminids seem to be a good and sensitive indicator of palaeoenvironmental conditions.

**Acknowledgements**

This research has been financially supported by the Polish Ministry of Science and Higher Education 0529/B/P01/2007/33. Additional support was provided by the Jagiellonian University (DS funds). The authorities of the Tatra National Park are gratefully acknowledged for providing permission for the field work. Prof. M. A. Gasiński is thanked for reading the manuscript and for his constructive comments. The authors also thank ASGP reviewers Professor Vlasta Čosović and Professor Ewa Olempska-Roniewicz for critical suggestions on the earlier version of the manuscript.
REFERENCES


