Badenian discoasters from the section in Lenart (Northeast Slovenia, Central Paratethys)

Badenijski diskoastri v profilu pri Lenartu (severovzhodna Slovenija, Centralna Paratetida)

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Abstract

In Slovenske gorice, south of Lenart, a 20 m profile of Middle Miocene strata has been exposed. During previous research numerous discoasters have been found among other coccoliths. In Slovenia Miocene discoasters have only been found in Badenian sediments in Slovenske gorice and they are particularly useful for paleoecological reconstructions. Additional samples were taken from three selected sections in the middle part of the profile, targeting strata with the greatest abundance of discoasters. In two of the three examined sections 9 species of discoasters were identified, the most abundant being *D. exilis* and *D. variabilis*. Even though warm water species were found in samples from all three sections, discoasters only occurred in two short intervals. This pattern is not a result of temperature changes and is in our opinion connected with the changes in nutrient levels of seawater.

Introduction

The research of Badenian nanoplankton in the territory of Slovenske gorice begun a few years ago, when a large profile of clastic Miocene strata has been exposed on the south side of Lenart during construction works (Figure 1). The profile was sampled and on the basis of nanoplankton assemblage it was established that the sediments are of Badenian age. In the lower part of the sequence poorly preserved shells of eutecosomate pte-
ropods belonging to the species *Vaginella austriaca* were found in great numbers, further confirming Badenian age (Pavšič, 2002). Upper parts of the sequence contain nodules of lithothamniens and sandstone inclusions, which become more frequent in the upward direction. In the uppermost part of the sequence the sandy marlstone contains fossilized plant particles and parts of fish scales and bones. In some parts poorly preserved remains of linear and spiral eutecosomate pteropods were identified (Pavšič, 2002).

Discoasters have been found in the middle part of the sequence. Those were the first discoasters of Miocene age to be found in Slovenia. We were interested why discoasters are only present in this area and furthermore why they are present in some samples and absent in others, this pattern lacking any association with lithologic changes within the sequence.

**Methods and materials**

Additional samples were taken from selected sections of the previously examined profile. We targeted the parts of the sequence in which the presence of discoasters was found to be the most significant. Continuous sampling of long sequences within the Badenian strata was impeded by the presence of dense vegetation. For that reason we were compelled to take samples from three separate sections in close proximity. Those sections were sampled in detail at 2, 5 and 10 cm intervals. In this manner we sampled approximately 7 m of marlstone beds in the central part of the previously examined profile (Figure 2).

The sampled sequences consist mainly of grey marlstone, weathering to brown on the surface. Samples were collected from unweathered marlstone. The interval we examined is a compound of three short sections. In the first section - A - 40 samples were collected at 10 cm intervals (LR 1-40), in the second section - B - 46 samples were collected at 5 cm intervals (LE 1-46) and in the third section - C - 50 samples were taken at 2 cm intervals (LJ 1-50). Sequence C is the part of the profile which contained the greatest quantity of discoasters in previous examination.

Marlstone dust was scraped directly onto a glass slide, distilled water was added. Glass slides were then dried on a hotplate and fixed with Canada balsam. Slides were examined under Zeiss MC 80 DX LM with an oil immersion objective of 100 x with a total magnification of 1000 x. We examined one sample (LR-34), which contained diverse and well preserved fossil coccoliths, with a JE-OL SEM.

Nanoplankton species were identified. Discoasters (*Discoaster* spp.) and coccoliths belonging to the species *Coccolithus pelagicus* and *Helicosphaera carteri* were counted. Complete coccoliths and fragments, sufficiently preserved for identification, were counted until minimum of 500. Double counting was avoided by means of zigzag motion along the 22 x 22 mm cover slip. The abundance of sphenoliths (*Sphenolithus* spp.) was semi quantitatively analysed and rated into 4 different categories according to their abundance.

Calcareous nanoplankton in the samples is relatively well preserved and complete by our appreciation. Considering the level of preservation we believe, that selective dissolution of nanofossils did not take place.

**Results**

153 samples from 3 proximal profiles were thoroughly examined. Apart from identification of all present species, abundance of four taxa was studied in detail: genus *Discoaster*, *Coccolithus pelagicus*, *Helicosphaera carteri* and genus *Sphenolithus*. We were interested in their relative abundance and interdependence.
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Fig. 2. Schematic section of the Badenian strata and distribution of discoasters in Lenart

Sl. 2. Shematski profil badenijskih plasti in razširjenost diskoastrov v Lenartu
Discoasters were absent from the majority of samples, but two culminations in their abundance were noticed. The first was located near the top of the section A (samples LR 32-40) and the other in the upper half of the section B (samples 21-35). Discoasters from section A are in a good state of preservation, while those from B are in a considerably poorer state of preservation, relative to the discoasters from A and to the other species present in the samples from the section B.

In total 31 species and 2 genera were identified (Table 1). 12 species are present in all three sections. The dominating species are *Coccolithus pelagicus* and *Helicosphaera carteri*, the first one being more frequent in nearly all the samples examined. Two small (>5μm) *Reticulofenestra* species were also found to be common in the samples from all

| SPECIES - VRSTE ISECTION - PROFIL | A | B | C |
|-----------------------------------|---|---|---|
| *Coccolithus pelagicus* (Wallich, 1871) Schiller, 1930 | x | x | x |
| *Helicosphaera carteri* (Wallich, 1877) Kampfner, 1954 | x | x | x |
| *Sphenolithus moriformis* (Brönnimann & Stradner, 1960) Bramlette & Wilcoxon, 1967 | x | x | x |
| *Cyclicocystis floridanus* (Roth & Hay, 1967) Bukry, 1971 | x | x | x |
| *Reticulofenestra minuta* Roth, 1970 | x | x | x |
| *Reticulofenestra haugui* Backman, 1978 | x | x | x |
| *Reticulofenestra pseudoumbilica* (media) (Gartner, 1967) Gartner, 1969 | x | x | x |
| *Geminilithella rotula* (Kampfner 1956) Backman 1980 | x | x | x |
| *Rhabdosphaera sicca* Stradner & Backmann et al. 1963 | x | x | x |
| *Pontosphaera multipora* (Kampfner, 1948) Roth, 1970 | x | x | x |
| *Holodiscolithus macroporus* (Deflandre & Fert, 1954) Roth, 1970 | x | x | x |
| *Calciscus premacintyrei* Theodoridis, 1984 | x | x | x |
| *Pontosphaera discopora* Schiller, 1925 | x | x | x |
| *Coronocyclus prionion* (Deflandre & Fert, 1954) Stradner & Edwards, 1968 | x | x | x |
| *Calciscus leptoporus* (Murray & Blackman, 1898) Loeblich & Tappan, 1978 | x | x | x |
| *Thoracosphaera saxa* Stradner, 1961 | x | x | x |
| *Thoracosphaera heimi* (Lohmann, 1919) Kampfner, 1941 | x | x | x |
| *Sphenolithus heteromorphus* Deflandre, 1953 | x | x | x |
| *Helicosphaera walhersdorffensis* Müller, 1974 | x | x | x |
| *Helicosphaera waltrans* Theodoridis, 1964 | x | x | x |
| *Helicosphaera intermedia* Martini, 1965 | x | x | x |
| *Liithstromatium perdorum* Deflandre, 1942 | x | x | x |
| *Discoaster variabilis* Martini & Bramlette, 1963 | x | o | o |
| *Discoaster exilis* Martini & Bramlette, 1963 | x | o | o |
| *Discoaster adamanteus* Bramlette & Wilcoxon, 1967 | x | x | x |
| *Discoaster cf. bromwier* Tan, 1927 emend. Bramlette & Riedel, 1954 | x | x | x |
| *Discoaster formosus* Martini & Worsley, 1971 | x | x | x |
| *Discoaster musicus* Stradner, 1959 | x | x | x |
| *Discoaster moorei* Bukry, 1971 | x | x | x |
| *Discoaster tanii* Bramlette & Riedel, 1954 | o | o | o |
| *Discoaster deflandrei* Bramlette & Riedel, 1954 | o | o | o |
| *Discoaster sp.* | o | o | o |
| *Micrantholithus sp.* | x | x | x |
| *Catinaaster sp.* | x | x | x |

Table 1. Calcareous nanoplankton species and their presence in sections A, B and C. Species with stratigraphic relevance are marked with bold letters. Species considered not autochthonous are marked o.

Tabela 1. Vrste kalitnega nanoplanktona in njihova pogostost v profilih A, B in C. Stratigrafsko pomembne vrste so označene z odebeljenimi znaki. Presedimentirane vrste so označene z o.
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three sections. Diversity of assemblage is highest in the samples from section A, where all 31 identified species are present. Genus *Discoaster* is represented by 9 species, the most common being *D. variabilis*, *D. exilis*, *D. adamantheus* and *D. formosus*. In the samples from section B, where discoasters were found, their presence is less pronounced, and they are in a poorer state of preservation compared to the rest of the assemblage.

The genus *Sphenolithus* is represented by two species: *S. moriformis* and *S. heteromorphus*. A large majority of all sphenoliths we found belong to the first of the two. *S. heteromorphus* sphenoliths are rare in sections A and B and absent in section C. Sphenoliths are common in sections B and C (1-10 sphenoliths / field of view), and abundant in the lower part of section B (>10 sphenoliths / field of view). The samples taken from section A contain fewer sphenoliths. They are present in all examined samples, but are rare (1 sphenolith / 1-10 fields of view) or very rare (<1 sphenolith / 10 fields of view).

The composition of nanoplankton assemblage differs considerably between section A and sections B and C. Samples from section A (LR 1-40) exhibit greater diversity of species and they contain fewer sphenoliths. In the samples taken from the upper portion of the section A a considerable share of discoasters was observed among other coccoliths.

**Discussion**

The presence of *Cyclicargolithus floridanus* and the absence of *Helicosphaera ampliaperta* enables us to place section C into biozone NN 5 or NN 6. The absence of *Sphenolithus heteromorphus* would imply the age correspondent to the upper part of NN 6. As this species is rare in other sections as well its absence could be attributed to extreme rarity. Moreover in the Mediterranean, intervals of temporary absence of this species are known (Fornaciari et al., 1996). For that reason we can not give a more precise stratigraphic position of the section C based only on the absence of *S. heteromorphus*.

Samples from section B contain coccoliths belonging to species *S. heteromorphus*, *D. exilis* and *D. variabilis* as well as *Cy. floridanus*. All listed species are characteristic of biozones NN 5 and the lower part of NN 6.

The most accurate stratigraphic position can be given for section A. Apart from all the species mentioned above, the samples LR contain *D. formosus* and *D. musicus*, stratigraphic markers of biozone NN 5 (Perch-Nielsen, 1985; Bown, 1999) and *D. moorei*, characteristic of the same biozone (Bukry, 1971). The presence of *Helicosphaera* species enables us to narrow the interval further: *H. intermedia*, *H. waltrans* and *H. walbersdorfenis* only coexist in a short interval in the upper part of the biozone NN 5 (Bown, 1999).

The first occurrence of the species *Coccolithus pelagicus* is known from the Lower Paleogene in equatorial latitude. Today it can be found in the polar and sub polar environments of the Northern hemisphere. It is most common in the North Atlantic (Sato et al., 2004). But the species is also known from certain subtropical environments. It has been found in the shelf area along the Portuguese coast (Cachão & Moita, 2000), J Africa (Baumann, 2004), Tasmania and New Zealand (Ziveri et al., 2004). In Western Iberia optimal temperature for its growth has been established at 16 °C (Cachão & Moita, 2000). Ziveri et al. (2004) report, that only the large form (or a sibling species) can be found in subtropical environments while the more common, small form (or species), only lives in cold water. The small form of *Coccolithus pelagicus* can therefore be used as an indicator of cold water.

In the Middle Miocene the paleoecological preferences of *Coccolithus pelagicus* were significantly different. The range of the species was far wider than it is today. The small coccolith variety can only withstand temperatures up to 14 °C, whereas it has been found in Middle Miocene sediments from equatorial latitude (Bukry, 1981). *Coccolithus pelagicus* from the Badenian can therefore not be used as an indicator of cold water.

The presence of discoasters in the sediment is a characteristic of warm low-nutrient sea environment (Chapman & Chepstow-Lusty, 1997). Badenian was a relatively warm period, so we would expect
consistent presence of discoasters in all the sections we have examined. Nevertheless discoasters were only found in short intervals and were absent from the majority of samples. According to the state of preservation we believe that the discoasters found in the samples from section A are autochthonous. We can not be sure of that in the case of discoasters found in section B, as they are in a poorer state of preservation than the accompanying assemblage. The assemblage in section B is much more similar to that in section C than assemblage in section A (apart from containing discoasters of course). This again implies that discoasters in the profile B are not autochthonous.

During the Badenian, the 6 Ma period of the Miocene climatic optimum came to an end (Jiminez- Moreno, 2005). Mean annual precipitation values dropped in the Badenian, and seasonality of precipitation increased at the base and in the middle Badenian. Dry periods lasted up to six months (Böhme, 2003). Temperatures stayed high until the end of Badenian. On the basis of palynological analysis an estimate of mean annual temperature of 16–20 °C has been made (Jiminez-Moreno et al., 2005) while a study of ectotermic vertebrates, plants and bauxite yielded an estimate of 17.4–22 °C (Böhme, 2003). The threshold temperature for discoasters – 14 °C (Chapman & Chepstow-Lusty, 1997) was not exceeded until the end of Badenian. Isotope record of pectinid and brachiopod shells from the Styrian basin indicates significant seawater temperature fluctuation, yet warm climate until 14.2 (+/- 0.1) Ma (Bojar, 2003). According to this the cooling of seawater was somewhat earlier than the cooling of the climate in Central Europe dated between 13.5 and 14 Ma by Böhme (2003).

Species of the genus Helicosphaera are most common in hemipelagic environments, their presence usually marks the areas of upwelling (Perch-Nielsen, 1985). Contrary to this discoasters prefer pelagic low-nutrient environments (Chapman & Chepstow-Lusty, 1997). Those ecological preferences are in accordance with the pattern of fluctuations in abundance of the mentioned genera observed in section A. In the upper portion of this section the abundance of discoasters increases. This occurrence coincides with a significant drop in the abundance of helicoliths belonging to the species H. carteri. This incident is a clear indication of a transition from high-nutrient to low-nutrient environment. No similar event can be observed in section B.

Lithostromation is a genus lacking stratigraphic value, nevertheless its paleoecologic preference for hemipelagic environments is known. It is usually not found in sediments deposited far from the shore. The same is presumed for the entire family Pontosphaeraceae (Perch-Nielsen, 1985). Representatives of the genus Pontosphaera are consistently present throughout the studied material, while Lithostromation perdurum was found in a few samples from sections A and C.

Discoaster and Thoracosphaera are characteristic for pelagic environments. The first of the two is present only in short intervals, the presence of the other is more consistent, but it is very rare.

Nanofossils from all three profiles indicate deposition in a warm epicontinental sea. Sections B and C contain common to abundant sphenoliths. The samples from section A contain fewer sphenoliths, but exhibit high assemblage diversity, characteristic of tropical and subtropical environments. Some contain discoasters, indicative of warm water as well as sphenoliths (Perch-Nielsen, 1985; Bown, 1999). The absence of discoasters can therefore not be attributed to low temperatures. The changes of nanoplankton assemblage composition can neither be explained by seasonal dynamics, as we frequently find species specific for different seasons according to Beaufort (2001) in a single sample.

Apart from surface water temperature the presence of nutrients in seawater is the most significant factor governing the composition of nanoplankton assemblages. Discoasters are typical of low-nutrient waters. Chapman and Chepstow-Lusty (1997) describe a correspondence between an increase in diatom abundance and decrease in discoaster abundance. Diatoms are characteristic of high-nutrient waters. Influx of land-derived detritus has a major effect on the nutrient levels in epicontinental seas and it depends largely on precipitation. Böhme (2003) writes about climatic changes taking place in Badenian in Central Europe. The results of a study concerning fossil vertebra-
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Changes in their abundance is not a consequence of temperature changes, as warm water species were found in all sections. On the grounds of nanoplankton assemblage we are of the opinion that the observed changes are due to fluctuations in nutrient levels of seawater. A clear indication of such events taking place is a coinciding drop in *Helicosphaera carteri* abundance and an increase in the abundance of discoasters in section A. Variation in the amount of precipitation, known to coincide with the studied interval, provides the most plausible reason for fluctuations in nutrient levels.

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**Badenijski diskoastri v profilu Lenart**

(Severovzhodna Slovenija, Centralna Paratetida)

**Uvod**

S proučevanjem badenijskega nanoplanktona na območju Slovenskih goric smo začeli pred leti, ko se je ob priliki gradnje stanovalnega naselja odprl daljši geološki profil na južnem obrobju Lenarta (slika 1). Profil smo podrobno posneli in mu na podlagi nanoplanktonskih vrst določili badenijsko starost. V spodnjem delu profila smo našli tudi večje število slabše ohranjjenih ostankov evtekosomatnih pteropodov vrste *Vaginella austriaca*, ki badenijsko starost še dodatno potrjujejo (Pavšič, 2002). V zgornjih delih obravnanih profilov se pojavljajo leče li-totarnij in posamezne plasti peščenjaka, ki postajajo navzgor vse gostejše. V najvišjem delu profila so v peščenem laporovcu tudi posamezni rastlinski ostanki in ostanki rib-jih skeletov in lusk. Ponekod se pojavljajo tudi slabo ohranjeni ostanki ravnih evtekosomatnih in spiralno zavitih pteropodov (Pavšič, 2002).

**Conclusions**

The studied fossil material was deposited in a warm hemipelagic sea environment. Discoasters, characteristic of low-nutrient pelagic environments have been found in two short intervals, but are, by our appreciation, only autochthonous in one. The pattern of
V vzorcih smo prvič v Sloveniji našli micocenske diskoastre, ki se pojavljajo le v določeni delih sklenjenega profila. Prav prisotnost diskoastrov je bila za nas posebno zanimiva, saj se ne pojavljajo v vseh vzorcih. Zanimalo nas je zakaj se diskoastri pojavljajo le na tem območju in kaj je povzročilo neenakomeren način pojavljanja diskoastrov, saj njihova prisotnost oziroma odstartnost ne sovpadata z litološkimi spremembami v profilu.

Metodika dela

Za dodatno vzorčevanje smo se odločili na mestih, kjer smo v predhodnih raziskavah naleteli na povečano število diskoastrov. Kontinuirano vzorčevanje daljših profilov v badenijskih plastah ovira možnost terena. Zato smo bili prisiljeni sestaviti daljši profil na treh bližnjih, vendar ločenih odsekih. Posamezne odseke profila smo podrobno vzorčevali tako, da smo vzorce pobilali na 2, 5 in 10 cm. Na ta način smo obdelali okoli 7 metrov profila laporovca v osrednjem delu znanega profila (slika 2).

V omenjenih profilih nastopa v glavnem siv laporovec, ki na površini rjavoto prepereva. Vzorčevali smo v svežih nepreperelih delih.

Proučevani interval laporovca je sestavljen iz treh krajših profilov. Prvi interval - A - sestavlja 40 vzorcev, pobranih na 10 cm (LR 1-40), drugi del - B - sestavlja 46 vzorcev, pobranih na 5 cm (LE 1-46), tretji del - C - pa sestavlja 50 vzorcev, pobranih na 2 cm (LJ 1-50). V tem delu smo v prejšnjih raziskavah našli največjo gostoto diskoastrov.

Preparate za proučevanje kalcičnega nanoplanktona smo izdelali po standardni metodi direktnega razmaza laporovčevega praška. Nanoplankton smo opazovali pod optičnim mikroskopom Zeiss MC 80 DX LM z immerzijskim objektivom pri 1000 x povečavi. Iz vzorca z odlično ohranjenim fosilnim materialom (LR 34) je bilo izdelanih in pregledanih več preparatov za vrstični elektronski mikroskop (JEOL SEM).

Plate 1

Tabla 1

|   |   |
|---|---|
| 1 | Discoaster exilis Martini & Bramlette, 1963; sample, vzorec LR-34 JEOL- SEM. |
| 2 | Discoaster variabilis Martini & Bramlette, 1963; sample, vzorec LR-34, JEOL SEM. |
| 3 | Discoaster formosus Martini & Worsley, 1971; sample, vzorec LR-34, JEOL SEM. |
| 4 | Discoaster adamantheus Bramlette & Wilcoxon, 1967; sample, vzorec LR-34, JEOL SEM. |
| 5 | Discoaster adamantheus Bramlette & Wilcoxon, 1967; sample, vzorec LR-34, JEOL SEM. |
| 6 | Discoaster adamantheus Bramlette & Wilcoxon, 1967; sample, vzorec LR-34, JEOL SEM. |
| 7 | Discoaster adamantheus Bramlette & Wilcoxon, 1967; sample, vzorec LR-34, JEOL SEM. |
| 8 | Discoaster sp.; sample, vzorec LR-32, light micrograph, optični mikroskop, 1000x, crossed nicols, navzkrižni nikoli |
| 9 | Pontosphaera dicopora Schiller, 1925, sample, vzorec LR-22, light micrograph, optični mikroskop, 1000x, crossed nicols, navzkrižni nikoli |
| 10 | Sphenolithus moriformis (Brönnimann & Stradner, 1960) Bramlette & Wilcoxon, 1967; sample, vzorec LJ-41, light micrograph, optični mikroskop, 1000x, crossed nicols, navzkrižni nikoli |
| 11 | Discoaster adamantheus Bramlette & Wilcoxon, 1967; sample, vzorec LR-33, light micrograph, optični mikroskop, 1000x, crossed nicols, navzkrižni nikoli |
| 12 | Thoracosphaera heimii (Lohman, 1919) Kamptner, 1941; sample LR-25, light micrograph, optični mikroskop, 1000x, crossed nicols, navzkrižni nikoli |
| 13 | Helicosphaera waltersdorfiensis Müller, 1974; sample LR-17, light micrograph, optični mikroskop, 1000x, crossed nicols, navzkrižni nikoli |
| 14 | Helicosphaera intermedia Martini, 1965; sample, vzorci LR-11, light micrograph, optični mikroskop, 1000x, crossed nicols, navzkrižni nikoli |

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Nanoplankton smo statistično obdelali. Šteli smo rodove, poleg diskoastrov (Discoaster spp.) še primerke Coccolithus pelagicus in Helicosphaera carteri. Upoštevali smo cele primerke, oziroma določljive fragmente do skupnega števila 500 primerkov. Podvr- janju smo se izognili s cik-cakasto obdelavo preparata na polju 22 x 22 milimetrov. Skup- pno smo prešeli omenjene rodove iz 153 vzorcev, poleg vzorcev iz omenjenih treh tren- tervalov še sondažne vzorce, pobrane v ne- enakomernih presledkih vzdol' celotnega profila (L 1-17). Semikvantitativno smo anali- zirali tudi pogostnost sfenolitov (Sphenolithus spp.).

Kalcitni nanoplankton je v preparatih razmeroma dobro ohranjen in po na{i oceni popoln. Glede na stopnjo ohranjenosti me- nimno, da ni pri{lo do selektivnega raztaplja- nja. Rezultati

Detailno smo pregledali 153 vzorcev v se- stavljenem profilu, ki po predhodnih po- drobnih biostratigrafskih raziskavah na osnovi kalcitnega nanoplanktona in evteko- somatnih pteropodov pripada badenijski bioconi NN5 (Pav{i~, 2002). Poleg splo- šnega pregleda nanoplanktonske flore smo posebno pozornost namenili {tirim takso- nom: rod Sphenolithus, rod Discoaster, Helicosphaera carteri in Coccolithus pelagicus. Zanimala nas je njihova pogostnost in med- sebojna odvisnost.

Na{o pozornost so pritegnili nekateri vi- {ki v pojavljanju diskoastrov glede na si- cer{njo bolj ali manj konstantno odsotnost. Vi{ke smo opazili v dveh nivojih: v profilu A, vzorci LR 32-40, in manj{i vi{ek v profilu B, vzorci LE 21-35 (slika 2). V profilu A so diskoastri zelo dobro ohranjeni, tisti iz pro- fila B pa so v bistveno slab{em stanju. V pregledanem materialu smo dolo~ili 31 vrst in 2 rodo- va (tabela 1). 12 vrst se pojav- lja v vseh vzorcih. Prevladujo{i vrsti sta Coccolithus pelagicus in Helicosphaera carteri, o katerih je prva pravi{lo pogost- nej{a. Pogostni sta tudi vrsti rodu Reticulo- fenestra z majhnimi (<5μm) kokoliti in vrsta Sphenolithus moriformis v vzorcih iz profi- lov B in C. Najve{ja je vrstna pestrost v vzorcih iz profila A, kjer se pojavlja vseh 31 identificiranih vrst. Rod Discoaster je v tem profilu zastopan z 9 vrstami, od katerih so najpogostnej{e D. variabilis, D. exilis, D. adamantheus in D. formosus. V profilu B se pojavljajo diskoastrov v precej skromnej{em števitu, pa tudi njihova ohranjenost pravi- loma ne dopu{a identifikacije vrst. Pri- merki, ki jih je mogo{e identificirati pripa- dajo vrstama D. exilis in D. variabilis, v splošnem pa so slab{e ohranjeni tako od diskoastrov v profili A, kot od spremljujoče zdru{be.

Rod Sphenolithus je zastopan z vrstama S. moriformis in S. heteromorphus. Prva od obeh je veliko pogostnej{a, predstavlja ve{ni- no opa{enih sfenolitov in se pojavlja v vseh treh profilih. Vrsta S. heteromorphus je bist- veno redkej{a, pojavljata se v profilih A in B, ne pa tudi v C. V profilih B in C so sfenoliti pogostni (10 sfenolitov na vidno polje), v spodnjem delu profila B pa zelo pogostni (>10 sfenolitov na vidno poje). Vzorci iz pro- fila A vsebujejo bistveno manj sfenolitov. Ti se sicer pojavljata v vseh pregledanih vzor- cih, a so redki (1 sfenolit na 1-10 vidnih polj) ali pa zelo redki (<1 sfenolit na 10 vidnih polj).

Profil A se po nanoflori v veliki meri raz- likuje od ostalih dveh. V vzorcih LR je opa- ziti ve{jo vrstno pestrost, izrazito manj{o prisotnost sfenolitov in v zgornjem delu po- jav opaznega dele{a diskoastrov.

Diskusija

Profil C lahko na podlagi prisotnosti vrste Cyclicargolithus floridanus in odsotnosti vrste Helicosphaera ampliaperta umestimo v biocono NN 5 ali spodnji del NN 6. Isto starost lahko pripisimo profilu B, kjer se pojavljata tudi S. heteromorphus, D. exilis in D. variabilis, vrste, ki potrjujejo omenjeni interval, a ga ne opredeljujejo natan{neje. Najnatan{neje je mogo{e datirati profil C, kjer se pojavljata mnoge stratigrafsko po- membre vrste. Razen vseh zgoraj omenjenih vrst vsebujejo vzorci LR tudi D. formosus in D. musicus, ki ozna{eta biocono NN 5 (Perch-Nielsen, 1985; Bown, 1999) ter za isto biocono zna{ilni D. moorei (Bukry, 1971). Glede na prisotnost vrst rodu Helicosphaera lahko nastanek sedimentov dolo- čimo {e natan{neje: vrste H. intermedia, H. waltrans in H. walbersdorrfensis soobstajajo le v zgornji polovici NN5 (Bown, 1999).
Vrsta *Coccolithus pelagicus* se pojavlja v spodnjem paleogenu v ekvatorialnem območju. Danes jo najdemo v subpolarnih in polarnih vodah S polobre, predvsem v Atlantiku (Sato et al., 2004). *Coccolithus pelagicus* pa se pojavlja tudi v subtropskih vodah. Prisoten je v številnih vodah ob portugalski obali Južne Afrike (Baumann, 2004), Tasmanije in Nove Zelandije (Ziveri et al., 2004). Ob portugalski obali vrsta uspeva pri 16 °C (Cachao & Moita, 2000). V subtropskih vodah se najverjetneje pojavlja samo večja od dveh sestrskih vrst, ki sta morfološko skoraj identični, a imata precej različni ekološki valenci (Ziveri et al., 2004). Recentni *C. pelagicus* upravičeno služi kot indikator hladnih površinskih voda, a le pri podvrsti (ozroma vrsti) s kokoliti, manjšimi od 10 μm.

V srednjem miocenu pa je bila situacija precej drugačna. Areal vrste *Coccolithus pelagicus* je bil veliko večji od današnjega. Vrsta z manjšimi kokoliti kokolitov vrste *Helicosphaera carteri* je značilen za hemipelagična okolja (Chapman & Chepstow-Lusty, 1995). Zb戈 macrofossils (Chapman & Chepstow-Lusty, 1997). Omejena pa je bolj stalna, a omejena na zelo nizko pogostost.

V badeniju se je začel končevati 6 milijonov let trajajoči miocenski klimatski optima (Jiminez-Moreno, 2005). Količina nanofosilov iz *Helicosphaera* je v znatni meri prisoten v vseh obravnavanih profilih, medtem ko se vrsta *Lithostromation perdurum* pojavlja le v nekaterih vzorcih profilov A in C.

Izmed rodov, ki se pojavljajo v pregledanem materialu, sta za odprto morje značilna rodova *Discoaster* in *Thoracosphaera*. Prvi se pojavlja le v kratkih intervalih, prisotnost drugega pa je bolj stalna, a omejena na zelo nizko pogostost.

V badeniju je značilen za hemipelagična okolja, njegovo pojavljanje pravilo označuje območja dvigovanja s hranili bogate globinske vode (Perch-Nielsen, 1985). Za razliko od tega so diskoastrti značilni za pelagična oligotrofna okolja (Chapman & Chepstow-Lusty, 1997). Omejnjenje ekoške pogostosti se ujemajo z vzorcem pojavitve v pregledanih vzorcih. V zgornjih vzorcih profila A se poveča delež diskoastrtov, dogodek sovpadla z upadom deleža kokolitov vrste *Helicosphaera carteri*. Upad pogostnosti *H. carteri* in porast pogostnosti na oligotrofnih območja vezanih diskoastrtov je indikator zmanjšane količine hranil v vodi.

*Lithostromation* je rod brez večje stratiografske vrednosti, znan pa je njegova paleokosloka preferenca do hemipelagičnih morskih okolij (Perch-Nielsen, 1985). V sedimentih, odloženih daleč od obal ali morskih plitvin ga najdemo le redko. Podobno domnevno velja za celotno družino *Pontosphaeraceae* (Perch-Nielsen, 1985). Rod *Pontosphaera* je v znatni meri prisoten v vseh obravnavanih profilih, medtem ko se vrsta *Lithostromation perdurum* pojavlja le v nekaterih vzorcih profilov A in C.

Nanofosili iz vseh treh profilov kažejo na toplje morje. V profilih B in C na to kaže relativna pogostost sfenolitov (Perch-Nielsen, 1985). Vzorci iz profila A vsebujejo
bistveno manj sfenolitov, kljub temu je tudi za te vzorce možno predpostaviti nastanek v toplem morju, saj kažejo visoko vrstno pестrost, značilno za tropska in subtropka okolja. Razen tega so v zgornjem delu profila v opazni meri prisotni diskoastri, ki so prav tako kot sfenoliti indikatorji tople vode (Perch-Nielsen, 1985; Bown, 1999).

Odsotnosti diskoastrov torej ne moremo pripisati nizkim temperaturam. Tudi sezonska dinamika ne pojasna pojavljanje diskoastrov, saj najdemo v istih vzorcih tako vrste, kot so po Beaufortu (2001) značilne za zimo in poletje.

Razlikam v vrstni pестrosti in sestavi profila A od profilov B in C torej ne botrujo razlike v temperaturi vode, ampak drugi dejavniki. Razen temperature je prisotnost hranil v vodi dejavnik, ki najodločajše vpliva na sestavo nanoplanktonskih združb. Diskoastri so značilni za oligotrofnega pelagičnega okolja. Chapman in Chepstow-Lusty (1997) opazita časovno ujemanje med porastom številčnosti populacij diatomej, ki so značilne za okolja z več nutrienti, in obdobji upada pogostosti diskoastrov. Na trofičnost hemipelagičnega okolja vpliva tudi količina nutrientov, ki doteka s kontinenta, ta dotok pa je odvisen od količine padavin. Böhme (2003) poroča o klimatskih spremembah v obdobju badenja v osrednji Evropi. Na podlagi študije razširjenosti vrst vretenčarjev sklepna na sezonsko razporeditev padavin v spodnjem badenju, in na vse bolj suho podnebje na prehodu iz spodnjega v srednji badenij. Datacija profila A s helikosferami postavlja vzorce v prav ta čas (Steininger et al., 1976). Tudi palinološke analize sedimentov centralne Paratetide (Jimenez-Moreno et al., 2005) kažejo na upadano povprečne letne količine padavin v badenju. Upad količine padavin bi lahko povzročil nastanek oligotrofnih razmer v površinskih vodah Paratetide in pomagal ustvariti ugodne razmere za pojav diskoastrov. Nasprotno bi povpraševanje količine padavin zaradi večjega sprememb hranil s poprnega povzročilo spremembo trofičnih razmer v prid sfenolitov in helikosfer. Nenaden pojav in izginotje diskoastrov bi lahko pojasnili z nižanjem količine padavin in v povezavi z dostopnostjo hranil, temperaturo in slanostjo vode.

Dotok nutrientov lahko povzroči kompetitivno ekskluzijo, oziroma lokalno izumrtje, vrst rodu Discoaster. Ponoven pojav diskoastrov bi omogočil rekolonizacijo v ugodnejših razmerah, za to pa je potrebna povezava z drugimi morji. V obravnavanem časovnem intervalu je znana povezava z Mediteranskim morjem med Alpami in Dinardri, ki pa se postopoma zapira. Glede na izsledke študije badenijskih diatomej Horvat (2004) sklepa, da se povezava med Paratetido in Mediteranom stvara do konca badenija. Povezava Vzhodne Paratetide z Indijskim oceanom v badenju je vprašljiva (Bicchi et al., 2003).

Zaključki

Pregledan fosilni material kaže na nastanek sedimentov v toplem hemipelagičnem okolju. Diskoastri, značilni za oligotrofnega pelagičnega okolja se pojavijo v dveh kratkih intervalih, od katerih so le v enem zanesljivo avtohtoni. Vzorce pojavljanja diskoastrov ni posledica temperaturnih sprememb, saj so vrste, značilne za toplo morje prisotne v vseh vzorcih. Na podlagi sestave nanoplanktonskih združb sklepamo, da lahko spremembe najbolje pojasnimo s spremembami količine dostopnih hranil. To potrjuje sočasen upad deleža Helicosphaere carteri in porast deleža diskoastrov med preštetimi kokoliti v vzorcih. Količina padavin, ki v obravnavanem časovnem intervalu niha in postopoma upada, lahko pojasni trofične spremembe v vodnem okolju.

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References - Literatura

Baumann, K.H., Böckel, B. & Frenz, M. 2004: Coccolith contribution to South Atlantic carbonate sedimentation. - Coccolithophores, From molecular processes o global impact. ed. Thierstein, H.R., Young, J. Berlin, Springer Verlag, 367-402.
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doi:10.5474/geologija.2005.018

Beaumont, L. & Heussner, S. 2001: Seasonal dynamics of calcareous nannoplankton on a West European continental margin: The Bay of Biscay. - Marine Micropaleontology, 43, 27-55.

Bicchi, E., Ferrero, E. & Gonera, M. 2003: Palaeoclimatic interpretation based on Middle Miocene planktonic Foraminifera: the Silesia Basin (Paratethys) and Monferrato (Tethys) records. - Palaeogeography, Palaeoclimatology, Palaeoecology, 196, 265-303.

Bojar, A.V., Hiden, H., Fenninger, A. & Neubauer, F. 2004: Middle Miocene seasonal temperature changes in the Styrian basin, Austria, as recorded by the isotopic composition of pectinid and brachiopod shells. - Palaeogeography, Palaeoclimatology, Palaeoecology, 203, 95-105.

Bown, P.R. 1998: Calcareous nannofossil biostratigraphy. Cambridge, Cambridge University Press. str. 1-15.

Böhme, M. 2003: The Miocene Climatic Optimum: evidence from ectothermic vertebrates of Central Europe. - Palaeogeography, Palaeoclimatology, Palaeoecology, 195, 389-401.

Bukry, D. 1971: Discoaster evolutionary trends. V: Micropaleontology, 17/1, 43-52.

Bukry, D. 1981: The Deep Sea Drilling Project: A Decade of Progress, Cenozoic Coccoliths from the DSDP. - Society of Economic Paleontologists and Mineralogists, Special Publication 32, 335-353.

Cachão, M. & Moita, M. T. 2000: Coccolitus pelagicus, a productivity proxy related to moderate fronts off Western Iberia. - Marine micropaleontology 39, 131-155.

Chapman, M. R. & Chepstow-Lusty, A. J. 1997: Late Pliocene climatic change and the global extinction of the discoasters: an independent assessment using oxygen isotope records. - Palaeogeography, Palaeoclimatology, Palaeoecology 134, 109 - 125.

Fornaciari, E., Di Stefano, A.; Rio, D. & Negri, A. 1996: Middle Miocene quantitative calcareous nannofossil biostratigraphy in the Mediterranean region. - Micropaleontology 42/1, 37-63.

Horvat, A. 2004: Srednjemiocenske kremeńine alge Slovenije. Ljubljana Založba ZRC 15, 131-137.

Jiménez-Moreno, G., Rodríguez-Tovar, F.J., Pardo-Iguzquiza, E., Fauquette, S., Sue, J.P. & Müller, P. 2005: High-resolution palynological analysis in late early-middle Miocene core from the Panonian Basin, Hungary: climatic changes, astronomical fluctuations in the Central Paratethys. - Palaeogeography, Palaeoclimatology, Palaeoecology, 216, 73-97.

Pavšič, J. 2002: Badenian nannoplankton and pteropods from surrounding of Lenart in Slovene-gorice (Slovenia). - Razprave 4. razr. SAZU, 48/2, 219-239, Ljubljana.

Perch-Nielsen, K. 1985: Kenozoic calcareous nannofossils. V: Plankton stratigraphy. Hook, A. H. et al. (eds.), Cambridge University Press.

Sato, T., Yuguchi, S., Takayama, T. & Kameo, K. 2004: Drastic change in the geographical distribution of the cold-water nannofossil Coccolitus pelagicus (Wallich) Schiller at 2.74 Ma in the late Pliocene, with special reference to glaciation in the Arctic Ocean. - Marine Micropaleontology 52, 181-193.

Steininger, F., Rögl, F. & Martini, E. 1976: Current Oligocene/Miocene biostratigraphic concept of the Central Paratethys (Middle Europe). - Newsletter Stratigraphy, 174-202, Berlin.

Ziveri, P., Bauman, K.-H., Böckel, B., Bollman, J. & Young, J.R. 2004: Biogeography of selected Holocene coccoliths in the Atlantic Ocean. - Coccolithophores. From molecular processes to global impact: 403-428, Zürich.