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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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Ključne besede: Slovenske gorice, vzhodna Slovenija, Centralna Paratetida, miocen, badenij, nanoplankton, diskoastri, paleoekologija

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 occured 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.

Kratka vsebina

Južno od Lenarta v Slovenskih goricah izdanja približno 20 m visok profil srednjemiocenskih plasti. V srednjem delu profila so bili med predhodnimi raziskavami poleg drugih kokolitov najdeni tudi številni diskoastri. Miocenski diskoastri se v Sloveniji pojavljajo le v badenijskih plasteh v Slovenskih goricah, zato so posebej zanimivi za paleoekološko interpretacijo. Trije krajši profili, kjer se je v predhodni raziskavi pojavljalo največ diskoastrov, so bili ponovno podrobno vzorčeni. V dveh od treh vzorčenih profilov je bilo določenih 9 vrst diskoastrov od katerih se množično pojavljata *Discoater exilis* in *D. valiabilis*. Čeprav so vrste, značilne za toplo morje prisotne v vseh treh profilih, je pojavljanje diskoastrov omejeno na dva kratka intervala. Vzorec pojavljanja diskoastrov ni rezultat temperaturnih sprememb, temveč je, po našem mnenju, povezan s spremembami količine hranil v vodi.

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-

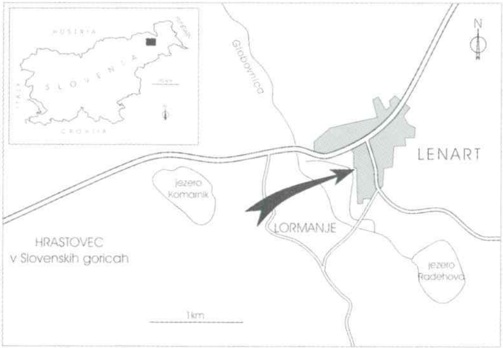

Fig. 1. Location map of the investigated section
Sl. 1. Karta s položajem obravnavanega profila

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 JEOL 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.

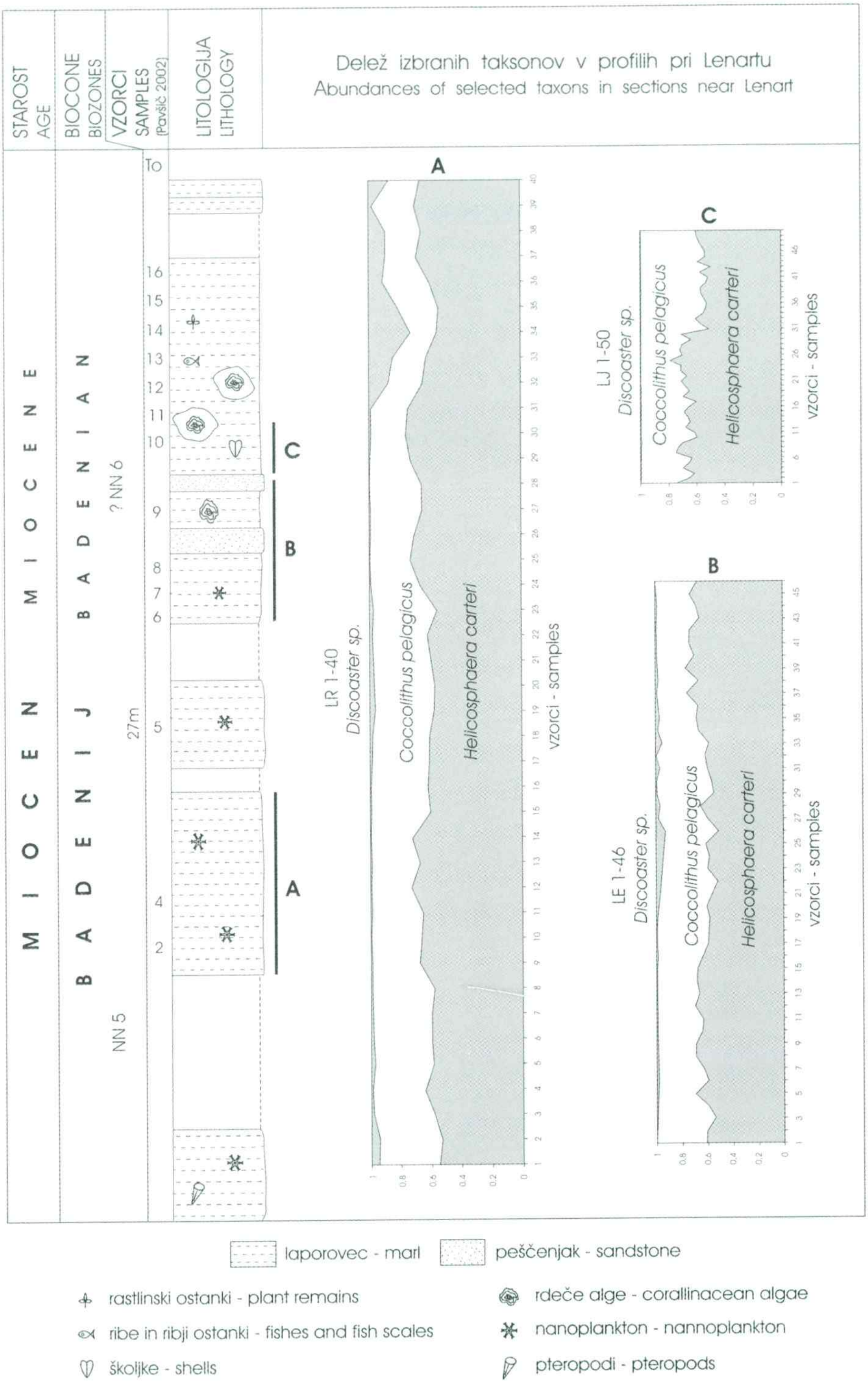

Fig. 2. Schematic section of the Badenian strata and distribution of discoasters in Lenart

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 \SECTION - PROFIL	A	B	C
Coccolithus pelagicus (Wallich, 1871) Schiller, 1930	x	x	x
Helicosphaera carteri (Wallich, 1877) Kamptner, 1954	x	x	x
Sphenolithus moriformis (Brönnimann & Stradner, 1960) Bramlette & Wilcoxon, 1967	x	x	x
Cyclicargolithus floridanus (Roth & Hay, 1967) Bukry, 1971	**x**	**x**	**x**
Reticulofenestra minuta Roth, 1970	x	x	x
Reticulfenestra haquii Backman, 1978	x	x	x
Reticulofenestra pseudoumbilica (media) (Gartner, 1967) Gartner, 1969	x	x	x
Geminilithella rotula (Kamptner1956) Backman 1980	x	x	x
Rhabdosphaera sicca Stradner & Bachmann et al. 1963	x	x	x
Pontosphaera multipora (Kamptner, 1948) Roth, 1970	x	x	x
Holodiscolithus macroporus (Deflandre & Fert, 1954) Roth, 1970	x	x	x
Calcidiscus premacintyrei Theodoridis, 1984	x	x	x
Pontosphaera discopora Schiller, 1925	x		x
Coronocyclus prionion (Deflandre & Fert, 1954) Stradner & Edwards, 1968	x		x
Calcidiscus leptoporus (Murray & Blackman, 1898) Loeblich & Tappan, 1978	x		
Thoracosphaera saxea Stradner, 1961	x	x	
Thoracosphaera heimii (Lohmann, 1919) Kamptner, 1941	x		
Sphenolithus heteromorphus Deflandre, 1953	**x**	**x**	
Helicosphaera walbersdorfensis Müller, 1974	**x**		
Helicosphaera waltrans Theodoridis, 1984	**x**		
Helicosphaera intermedia Martini, 1965	**x**		x
Lithostromation perdurum Deflandre, 1942	x		x
Discoaster variabilis Martini & Bramlette, 1963	**x**	**o**	
Discoaster exilis Martini & Bramlette, 1963	**x**	**o**	
Discoaster adamantheus Bramlette & Wilcoxon, 1967	x		
Discoaster cf. brouweri Tan, 1927 emend. Bramlette & Riedel, 1954	x		
Discoaster formosus Martini & Worsley, 1971	x		
Discoaster musicus Stradner, 1959	**x**		
Discoaster moorei Bukry, 1971	**x**		
Discoaster tanii Bramlette & Riedel, 1954	o		
Discoaster deflandrei Bramlette & Riedel, 1954	o		
Discoaster sp.		o	
Micrantholithus sp.			x
Catinaster sp.			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 kalcitnega nanoplanktona in njihova pogostnost v profilih A, B in C. Stratigrafsko pomembne vrste so označene z odebeljenimi znaki. Presedimentirane vrste so označene z o.

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. walbersdorfensis* 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 dicoasters 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 sphenolits, 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 vertebrate species and the changes of their ranges indicate a seasonal character of precipitation in the lower Badenian and increasingly dry climate on the transition from lower to middle Badenian. The stratigraphic correlation of that transition would coincide with the upper half of NN 5 (Steininger et al., 1976), the time when sediments sampled in section A were deposited. Moreover the palynological study of Paratethys deposits (Jiminez-Moreno et al., 2005) indicates a drop of mean annual precipitation in the Badenian. The reduction in the amount of precipitation could lead to the establishment of low-nutrient environment in the surface waters of Paratethys. This would create conditions that meet the paleoecological requirements of discoasters. On the contrary the increase in the amount of precipitation would cause more nutrients to be washed into the sea and produce a high-nutrient environment, favouring the thriving of genera *Sphenolithus* and *Helicosphaera*. The sudden appearance and disappearance of discoasters could therefore be attributed to the variations in the amount of precipitation leading to changes in nutrient levels of seawater.

An influx of nutrients can cause a competitive exclusion or a local extinction event of *Discoaster* species. Recolonisation in favourable conditions would cause the reappearance of discoasters. This would only be only possible if connections with the surrounding seas existed. In the analysed time interval a connection between the Paratethys and the Mediterranean is known to exist, but is gradually fading. On the basis of a study concerning diatoms Horvat (2004) concludes, that a connection between the Paratethys and the Mediterranean persisted until the end of Badenian. The connection between the Eastern Paratethys and the Indian Ocean in the Badenian is uncertain (Bicchi et al., 2003).

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 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 plansible 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 stanovanjskega 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 ohranjenih ostankov evtekosomatnih pteropodov vrste *Vaginella austiriaca*, ki badenijsko starost še dodatno potrjujejo (Pavšič, 2002). V zgornjih delih obravnavanih profilov se pojavljajo leče litotamnij in posamezne plasti peščenjaka, ki postajajo navzgor vse gostejše. V najvišjem delu profila so v peščenem laporovcu tudi posamezni rastlinski ostanki in ostanki ribjih skeletov in lusk. Ponekod se pojavljajo tudi slabo ohranjeni ostanki ravnih evtekosomatnih in spiralno zavitih pteropodov (Pavšič, 2002).

V vzorcih smo prvič v Sloveniji našli miocenske diskoastre, ki se pojavljajo le v določenih 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 odsotnost 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 plasteh ovira močna poraščenost terena. Zato smo bili prisiljeni sestaviti daljši profil na treh bližnjih, vendar ločenih odsekih. Posamezne odseke profila smo podrobno vzorčevali tako, da smo vzorce pobirali 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 rjavo prepereva. Vzorčevali smo v svežih nepreperelih delih.

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

Preparate za proučevanje kalcitnega nanoplanktona smo izdelali po standardni metodi direktnega razmaza laporovčevega prahu. Nanoplankton smo opazovali pod optičnim mikroskopom Zeiss MC 80 DX LM z imerzijskim 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.

Discoaster exilis Martini & Bramlette, 1963; sample, vzorec LR-34, JEOL SEM.

3 *Discoaster variabilis* Martini & Bramlette, 1963; sample, vzorec LR-34, JEOL SEM.

4 *Discoaster formosus* Martini & Worsley, 1971; sample, vzorec LR-34, JEOL SEM.

5 *Discoaster adamantheus* Bramlette & Wilcoxon, 1967; sample, vzorec LR-34, , JEOL SEM

6 *Discoaster variabilis* Martini & Bramlette, 1963; sample, vzorec LR-34, JEOL SEM

7 *Discoaster adamantheus* Bramlette & Wilcoxon, 1967; sample, vzorec LR-34, JEOL SEM

8 *Discoaster variabilis* Martini & Bramlette, 1963; sample, vzorec LR-34, JEOL SEM

9 *Discoaster* sp.; sample, vzorec LR-32, light micrograph, optični mikroskop, 1000x, crossed nicols, navzkrižni nikoli

10 *Pontosphaera dicopora* Schiller, 1925, sample, vzorec LR-22, light micrograph, optični mikroskop, 1000x, crossed nicols, navzkrižni nikoli

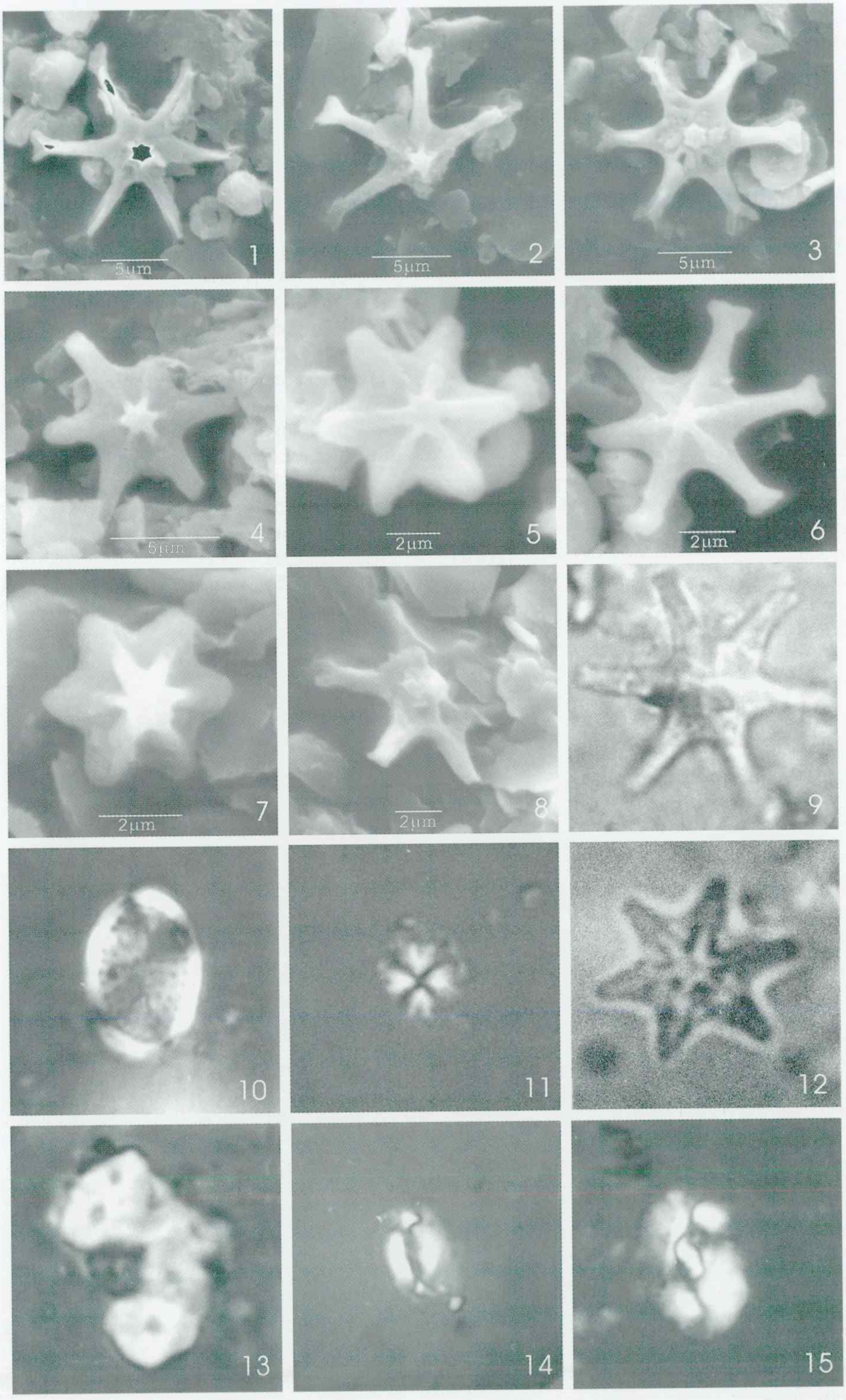
11 *Sphenolithus moriformis* (Brönnimann & Stradner, 1960) Bramlette & Wilcoxon, 1967; sample, vzorec LJ-41, light micrograph, optični mikroskop, 1000x, crossed nicols, navzkrižni nikoli

12 *Discoaster adamantheus* Bramlette & Wilcoxon, 1967; sample, vzorec LR-33, light micrograph, optični mikroskop, 1000x, crossed nicols, navzkrižni nikoli

13 *Thoracosphaera heimii* (Lohman, 1919) Kamptner, 1941; sample LR-25, light micrograph, optični mikroskop, 1000x, crossed nicols, navzkrižni nikoli

14 *Helicosphaera walbersdorfensis* Müller, 1974; sample LR-17, light micrograph, optični mikroskop, 1000x, crossed nicols, navzkrižni nikoli

15 *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. Podvajanju smo se izognili s cik-cakasto obdelavo preparata na polju 22 x 22 milimetrov. Skupno smo prešteli omenjene rodove iz 153 vzorcev, poleg vzorcev iz omenjenih treh intervalov še sondažne vzorce, pobrane v neenakomernih presledkih vzdolž celotnega profila (L 1-17). Semikvantitativno smo analizirali tudi pogostnost sfenolitov (*Sphenolithus* spp.).

Kalcitni nanoplankton je v preparatih razmeroma dobro ohranjen in po naši oceni popoln. Glede na stopnjo ohranjenosti menimo, da ni prišlo do selektivnega raztapljanja fosilne združbe.

Rezultati

Detajlno smo pregledali 153 vzorcev v sestavljenem profilu, ki po predhodnih podrobnih biostratigrafskih raziskavah na osnovi kalcitnega nanoplanktona in evtekosomatnih pteropodov pripada badenijski bioconi NN5 (Pavšič, 2002). Poleg splošnega pregleda nanoplanktonske flore smo posebno pozornost namenili štirim taksonom: rod *Sphenolithus*, rod *Discoaster*, *Helicosphaera carteri* in *Coccolithus pelagicus*. Zanimala nas je njihova pogostnost in medsebojna odvisnost.

Našo pozornost so pritegnili nekateri viški v pojavljanju diskoastrov glede na siceršnjo bolj ali manj konstantno odsotnost. Viške smo opazili v dveh nivojih: v profilu A, vzorci LR 32-40, in manjši višek v profilu B, vzorci LE 21-35 (slika 2). V profilu A so diskoastri zelo dobro ohranjeni, tisti iz profila B pa so v bistveno slabšem stanju.

V pregledanem materialu smo določili 31 vrst in 2 rodova (tabela 1). 12 vrst se pojavlja v vseh vzorcih. Prevladujoči vrsti sta *Coccolithus pelagicus* in *Helicosphaera carteri*, od katerih je prva praviloma pogostnejša. Pogostni sta tudi vrsti rodu *Reticulofenestra* z majhnimi (<5μm) kokoliti in vrsta *Sphenolithus moriformis* v vzorcih iz profilov B in C. Največja 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 najpogostnejše *D. variabilis*, *D. exilis*, *D. adamantheus* in *D. formosus*. V profilu B se pojavljajo diskoastri v precej skromnejšem številu, pa tudi njihova ohranjenost praviloma ne dopušča identifikacije vrst. Primerki, ki jih je mogoče identificirati pripadajo vrstama *D. exilis* in *D. variabilis*, v splošnem pa so slabše ohranjeni tako od diskoastrov v profili A, kot od spremljujoče združbe.

Rod *Sphenolithus* je zastopan z vrstama *S. moriformis* in *S. heteromorphus*. Prva od obeh je veliko pogostnejša, predstavlja večino opaženih sfenolitov in se pojavlja v vseh treh profilih. Vrsta *S. heteromorphus* je bistveno redkejša, pojavlja se v profilih A in B, ne pa tudi v C. V profilih B in C so sfenoliti pogostni (1-10 sfenolitov na vidno polje), v spodnjem delu profila B pa zelo pogostni (>10 sfenolitov na vidno poje). Vzorci iz profila A vsebujejo bistveno manj sfenolitov. Ti se sicer pojavljajo v vseh pregledanih vzorcih, 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 razlikuje od ostalih dveh. V vzorcih LR je opaziti večjo vrstno pestrost, izrazito manjšo prisotnost sfenolitov in v zgornjem delu pojav opaznega deleža 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 pripišemo profilu B, kjer se pojavljajo tudi *S. heteromorphus*, *D. exilis* in *D. variabilis*, vrste, ki potrjujejo omenjeni interval, a ga ne opredeljujejo natančneje. Najnatančneje je mogoče datirati profil C, kjer se pojavljajo mnoge stratigrafsko pomembne vrste. Razen vseh zgoraj omenjenih vrst vsebujejo vzorci LR tudi *D. formosus* in *D. musicus*, ki označujeta biocono NN 5 (Perch-Nielsen, 1985; Bown, 1999) ter za isto biocono značilni *D. moorei* (Bukry, 1971). Glede na prisotnost vrst rodu *Helicosphaera* lahko nastanek sedimentov določimo še natančneje: vrste *H. intermedia*, *H. waltrans* in *H. walbersdorfensis* soobstajajo le v zgornji polovici NN5 (Bown, 1999).

Vrsta *Coccolithus pelagicus* se pojavi v spodnjem paleogenu v ekvatorialnem območju. Danes jo najdemo v subpolarnih in polarnih vodah S poloble, predvsem v Atlantiku (Sato et al., 2004). *Coccolithus pelagicus* pa se pojavlja tudi v subtropskih vodah. Prisoten je v šelfnih vodah ob portugalski obali. O pojavljanju vrste poročajo tudi z obal Južne Afrike (Baumann, 2004), Tasmanije in Nove Zelandije (Ziveri et al., 2004). Ob portugalski obali vrsta uspeva pri temperaturah med 15 in 19 °C, optimalno 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 (oziroma 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 danes tolerira le temperature do 14AC, takrat pa je uspevala tudi na ekvatorialnem območju (Bukry, 1981). Uporaba badenijskih fosilnih ostankov *C. pelagicus* za indikatorje hladnih površinskih voda je torej vprašljiva.

Prisotnost vrst rodu *Discoaster* v sedimentu kaže na toplo oligotrofno morsko okolje (Chapman & Chepstow-Lusty, 1997). Badenij je bil razmeroma toplo obdobje, zato bi pričakovali konsistentno prisotnost diskoastrov v morskih sedimentih. V nasprotju s pričakovanji so bili najdeni le v določenih plasteh, v večini pregledanih vzorcev pa se ne pojavljajo. Glede na stopnjo ohranjenosti nanolitov lahko sklepamo, da so diskoastri v profilu A avtohtoni. Pri profilu B se o avtohtonosti diskoastrov pojavlja dvom zaradi precej slabše ohranjenosti od spremljajoče združbe. Da so presedimentirani lahko zaključimo tudi na podlagi vrstne sestave vzorcev iz profila B, ki je precej podobna tisti, ki jo opazimo pri vzorcih iz profila C, kjer se diskoastri ne pojavljajo.

Rod *Helicosphaera* je značilen za hemipelagična okolja, njegovo pojavljanje praviloma označuje območja dvigovanja s hranili bogate globinske vode (Perch-Nielsen, 1985). Za razliko od tega so diskoastri značilni za pelagična oligotrofna okolja (Chapman & Chepstow-Lusty, 1997). Omenjene ekološke preference se ujemajo z vzorcem pojavljanja v pregledanih vzorcih. V zgornjih vzorcih profila A se poveča delež diskoastrov, dogodek sovpada z upadom deleža kokolitov vrste *Helicosphaera carteri*. Upad pogostnosti *H. carteri* in porast pogostnosti na oligotrofna območja vezanih diskoastrov je indikator zmanjšane količine hranil v vodi.

Lithostromation je rod brez večje stratigrafske vrednosti, znana pa je njegova paleoekološka 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 nekateri 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 pogostnost.

V badeniju se je začel končevati 6 milijonov let trajajoči miocenski klimatski optimum (Jiminez-Moreno, 2005). Količina padavin je v spodnjem badeniju upadla, njihova razporeditev čez leto pa postala izrazito sezonska (Böhme, 2003). Povprečna letna temperatura je do zgornjega badenija ostala precej visoka. Na podlagi pelodnih analiz je povprečna letna temperatura ocenjena na 16–20 °C (Jiminez-Moreno et al. 2005), na podlagi fosilov ektotermnih vretenčarjev, rastlin in boksita pa na 17,4–22 °C (Böhme, 2003). Prag temperaturne tolerance, ki za diskoastre znaša 14 °C (Chapman & Chepstow-Lusty, 1997), v odbobju badenija torej najverjetneje ni bil dosežen. Izotopska analiza pektinidnih in brahiopodnih lupin iz Štajerskega bazena Paratetide nakazuje, da so v morju do pred 14,2 (+/- 0,1) mio let vladali subtropski pogoji (Bojar, 2003). Sodeč po tem je ohladitev morja nekoliko, a ne bistveno, zgodnejša od ohladitve na kopnem v srednji Evropi, ki jo Böhme (2003) postavi med 13,5 in 14 mio let.

Nanofosili iz vseh treh profilov kažejo na toplo morje. V profilih B in C na to kaže relativna pogostnost 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 pestrost, 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 pojasni opaženih sprememb nanoplanktonske združbe, saj najdemo v istih vzorcih tako vrste, ki so po Beaufortu (2001) značilne za zimo in poletje.

Razlikam v vrstni pestrosti in sestavi profila A od profilov B in C torej ne botrujejo razlike v temperaturi vode, ampak drugi dejavniki. Razen temperature je prisotnost hranil v vodi dejavnik, ki najodločilneje vpliva na sestavo nanoplanktonskih združb. Diskoastri so značilni za oligotrofna pelagična 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 pogostnosti diskoastrov. Na trofičnost hemipelagičnih okolij vpliva tudi količina nutrientov, ki doteka s kontinenta, ta dotok pa je odvisen od količine padavin. Böhme (2003) poroča o klimatskih spremembah v obdobju badenija v osrednji Evropi. Na podlagi študije razširjenosti vrst vretenčarjev sklepa na sezonsko razporeditev padavin v spodnjem badeniju, 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 (Jiminez-Moreno et al., 2005) kažejo na upadanje povprečne letne količine padavin v badeniju. Upad količine padavin bi lahko povzročil nastanek oligotrofnih razmer v površinskih vodah Paratetide in pomagal ustvariti ugodne razmere za pojav diskoastrov. Nasprotno bi povečanje količine padavin zaradi večjega spiranja hranil s kopnega povzročilo spremembo trofičnih razmer v prid sfenolitov in helikosfer. Nenaden pojav in izginotje diskoastrov bi lahko pojasnili z nihanjem 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 omogočila rekolonizacija 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 Dinaridi, ki pa se postopoma zapira. Glede na izsledke študije badenijskih diatomej Horvat (2004) sklepa, da se povezava med Paratetido in Mediteranom ohrani do konca badenija. Povezava Vzhodne Paratetide z Indijskim oceanom v badeniju je vprašljiva (Bicchi et al., 2003).

Zaključki

Pregledan fosilni material kaže na nastanek sedimentov v toplem hemipelagičnem okolju. Diskoastri, značilni za oligotrofna pelagična okolja se pojavijo v dveh kratkih intervalih, od katerih so le v enem zanesljivo avtohtoni. Vzorec 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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