Pontosphaera geminipora n. sp. and *Pontosphaera desuetoidea* n. sp., new calcareous nannoplankton species from the Middle Miocene of the Mura Depression (Slovenia, Central Paratethys)

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ABSTRACT: Rich calcareous nannoplankton assemblages were recovered from the Badenian (Middle Miocene) in Slovenske gorice (Eastern Slovenia). Paleogeographically, the investigated area belonged to the Mura Depression, a heterogenous marginal basin of the Central Paratethys. Over one hundred species of calcareous nannoplankton were found in the Badenian marls, among them two new *Pontosphaera* species were determined and are described in this paper. The nannoplankton assemblages, containing specimens of *Pontosphaera geminipora* n. sp. and *Pontosphaera desuetoidea* n. sp., allow their assignment to the standard nannoplankton biozone NN5. Both species are rare and occur in diverse assemblages, indicating warm and stable, relatively deep and oligotrophic depositional environments.

INTRODUCTION

In the beginning of the Middle Miocene, during the Badenian, which corresponds to the Langhian and the Lower Serravallian of the Mediterranean, the Central Paratethys reached its maximum extent (Mandić et al. 2002). It consisted of a series of larger and smaller epicontinental tectonic basins, linking the Mediterranean and, via the Eastern Paratethys, the Indo-Pacific (Rögl 1998, Goncharova et al. 2004). The Badenian is the last fully marine period in the life of the Central Paratethys and corresponds to the final stage of the Miocene Climatic Optimum (MCO), when favourable environmental conditions allowed for the thriving of diverse calcareous nanoplankton assemblages, producing a substantial fossil record.

The Mura Depression was a heterogenous basin near the western margin of the Central Paratethys. The Badenian deposits from this basin stretch across Slovenske gorice (eastern Slovenia) and contain rich calcareous nannoplankton assemblages. Samples from 17 Badenian sections were considered in the micropaleontological survey of calcareous nannoplankton from Slovenske gorice (Bartol and Pavšič 2005, Bartol 2008). Two new species: *Pontosphaera geminipora* n. sp. and *Pontosphaera desuetoidea* n. sp. were found in samples from two sections. The sedimentary sequence in the Lenart section has already been discussed by Pavšič (2002).

The Badenian nannoplankton from the Central Paratethys has already been studied by several authors (eg. Ćorić and Hohenegger 2008 and the references therein), however, most of the work has been done using light microscopes. The detection of two new species in the samples from Slovenske gorice was possible due to the good state of preservation of nanofossils and the use of SEM techniques along with light microscopy. *Pontosphaera geminipora* n. sp. and *Pontosphaera desuetoidea* n. sp. broaden the scope of our knowledge concerning the otherwise well-known and rich assemblages of the Badenian nannoplankton.

GEOLOGICAL SETTING

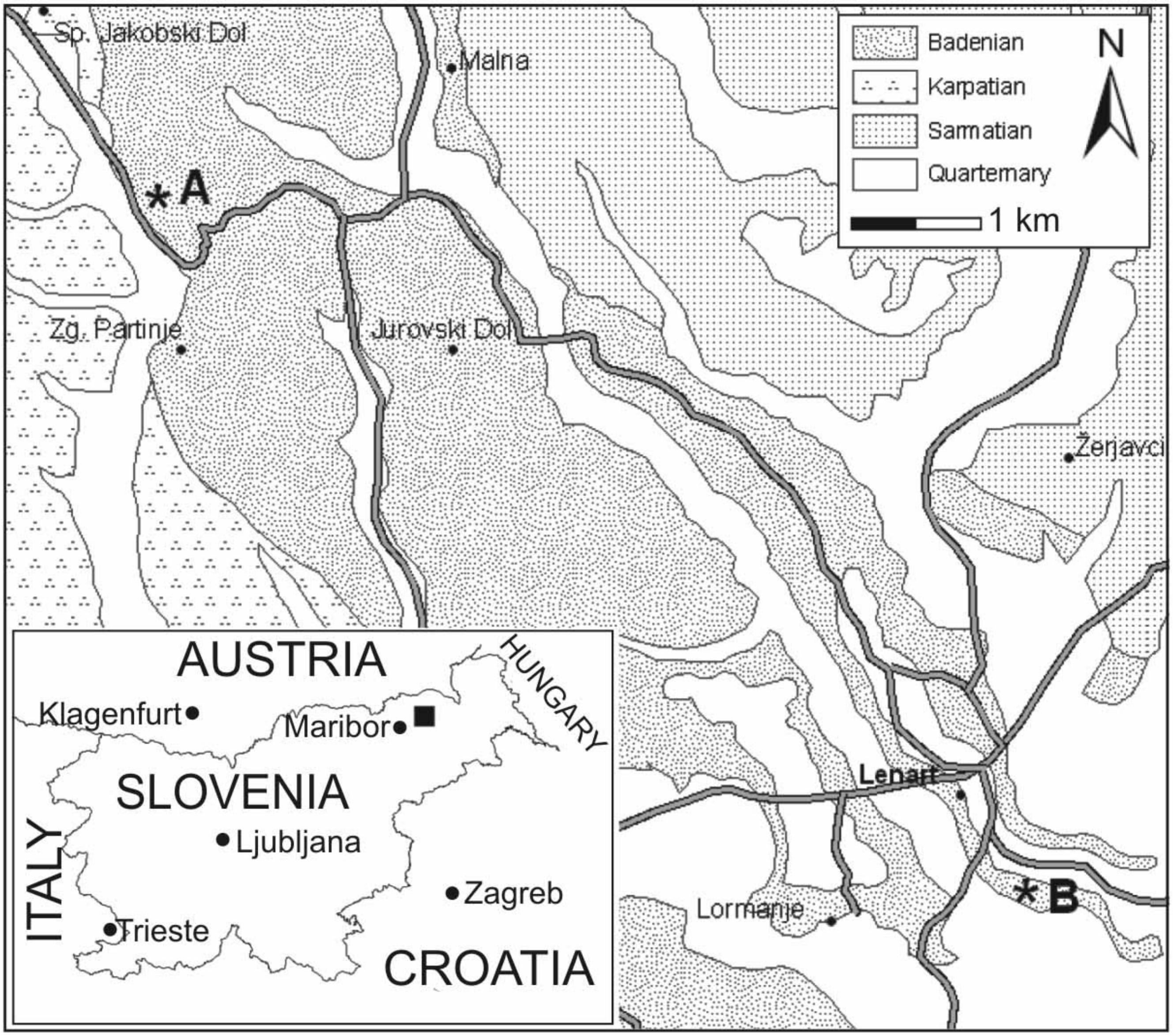
Geologically, the Mura Depression can be divided into three distinct units: the Pre-Neogene basement, the Neogene sediments and the Quarternary cover (Mioč and Žnidarčič 1996). The Pre-Neogene basement of the Mura Basin consists of Triassic carbonates and older metamorphic rocks. The oldest Neogene sediments in Slovenske gorice are Karpatian conglomerates, marls and sands. The thickness of Neogene strata varies from 500m to as much as 4000m. Badenian marine deposits stretch across Slovenske gorice in a belt, a few kilometres wide. Towards the east, they are overlain by the brackish Sarmatian sand and marl and younger sediments. Miocene rocks dominate in exposed elevated grounds, while valleys are covered by the Quarternary sediments (text-fig. 1).

The Badenian deposits from the Mura Depression are characterized by considerable lateral and vertical facies variability, reflecting spatial complexity and considerable environmental changes through time. The Badenian succession in Slovenske gorice consists of basal conglomerates and breccias, covered by marl, sand and lithothamnium limestone (Mioč and Žnidarčič 1996). Badenian marls contain rich and well preserved nannoplankton assemblages.

The Lenart section is located on the southwest of the town Lenart (WGS lat 46.620855° long 15.751156°). *Pontosphaera desuetoidea* was also found in the Jurovski Dol section (WGS lat 46.568106° long 15.837365°), located approximately 9 km northwest of Lenart (text-fig. 1). Stratigraphical columns of both sections are presented in text-figure 2.

METHODS

The sections were measured and sampled in 10cm intervals. Both light microscope (University of Ljubljana, Faculty of Natural Sciences and Engeneering, Department of Geology) and SEM (Ivan Rakovec Institute of Paleontology) were used for



TEXT-FIGURE 1
Location of the two sections discussed in this paper: A - Jurovski Dol, B – Lenart. Stratigraphic information after Žnidarčič and Mioč (1989).

taxonomic analyses. Smear slides for examination under a light microscope were prepared using standard preparation techniques. Some of the samples, containing diverse nannoplankton assemblages in a good state of preservation, were cleaned by repeated centrifugation and resuspension of pellet and then prepared for examination under SEM using standard preparation techniques. Semiquantitative abundance estimations of individual species were done following the methodology, described in Hay (1970).

BIOSTRATIGRAPHY

In total, 17 sections ranging from NN4 to NN6 were studied (Bartol 2008). The newly described species were found in 5 samples from 2 sections. The nannoplankton assemblages found in those samples are shown in table 1. The sediments sampled in the Lenart section can be correlated with NN5 and NN6 standard nannoplankton biozones of Martini (1971). *Pontosphaera geminipora* n. sp. and *Pontosphaera desuetoidea* n. sp were found in samples: LR-34, LR-35, LR-38 and LR-40. All four samples were collected from the interval between the first occurrence of very rare specimens of *Reticulofenestra pseudoumbilica* (Gartner 1967) Gartner 1969, larger than 7µm, and the last occurrence of *Sphenolithus heteromorphus* Deflandre 1953, marking the transition of NN5 and NN6 (text-fig. 2). In the Lenart section the FO of rare specimens of *R. pseudoumbilica* (>7µm) occurs somewhat lower then the LO of *Sphenolithus heteromorphus,* while the FCO of *R. pseudoumbilica* (>7µm) only occurs above this event. The same events in the same order were described in the Mediterranean by Fornaciari et al. (1996). The FCO of *R. pseudoumbilica* (>7µm) in the Mediterranean was dated at 13.10 Ma by Abdul Aziz et al. (2008). Considering the similarity among the nature and timing of biostratigraphic events between the central Paratethys and the Mediterranean (Bartol 2008), this event probably occurs at a similar time in the Central Paratethys.

The biostratigraphic events described above allow the precise bistratigraphic correlation of the interval within the Lenart section, where the two new species were found, with the top of NN5. This correlation is further supported by the presence of *Discoaster braarudii* Bukry, 1971 in all four samples, the presence of *Helicosphaera wallichii* (Lohmann 1902) Okada and McIntyre 1977 in the sample LR-34 and the presence of *Sphenolithus abies* Deflandre 1954 in the sample LR-40 (Tab. 1) as all three species have their first occurrence near the top of NN5 (Chira and Vulc 2003, Kováč et al. 2004).

The Jurovski Dol section was correlated with NN5. The presence of *Sphenolithus heteromorphus* and *Discoaster variabilis* Martini and Bramlette 1963 in sample JU-6, where *Pontosphaera desuetoidea* n. sp. occurs as well, allows the assignment of this sample to biozone NN5. The presence of *Helicosphaera waltrans* Theodoridis 1984 and the absence of *Helicosphaera walbersdorfensis* Müller 1974; table 1) suggests the lower part of NN5.

TAXONOMY

Phylum: HAPTOPHYTA (Hibberd 1972) Cavalier-Smith 1986
Classis: PRYMNESIOPHYCEAE Hibberd 1976
Ordo: ZYGODISCALES Young and Bown 1997
Familia: PONTOSPAHAERACEAE Lemmermann 1908
Genus: *Pontosphaera* Lohmann 1902

Pontosphaera geminipora Bartol **n. sp.**
Plate 1, figures 1-10

Etymology: The pattern of openings (lat. *porus* – transition, passage), arranged in pairs (lat. *gemini* - twins); adjective.

Description: Medium sized to large perforate murolith with pores, arranged in pairs. Pores are slit-shaped (approximately 0.3 long and 0.15µm wide) and radially arranged. The two pores of a single pair are 0.2–0.3µm apart, while neighbouring pairs are 0.3–0.4µm apart. Pores are arranged in three concentric cycles, the outer one is regularly elliptical, the middle one is usually somewhat irregular and the inner one is strongly irregular, often with smaller, round pores.

Muroliths measure 8-10µm by 6.5-8µm, holotype is 8µm long and 6.7µm wide,

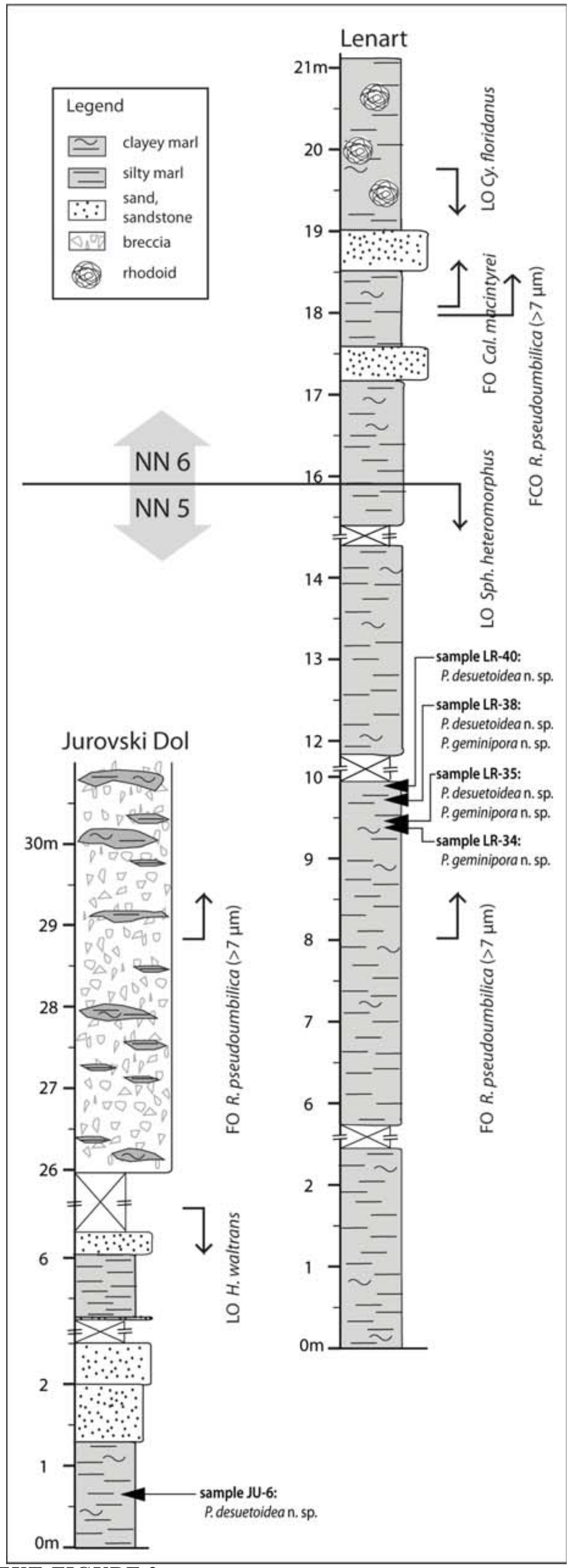
Remarks: The species superficially resembles *Pontosphaera callosa* (Martini 1969) Varol 1982, but differs in the pattern and size of pores. The two species cannot be distinguished under a light microscope.

The common *Pontosphaera multipora* (Kamptner 1948) Roth 1970 emend. Burns 1973 has circular pores and they are much larger than in the case of than *P. geminipora*.

Type designation: Holotype (pl. 1, fig.1. sample LR-35, Lenart section); paratypes (pl. 1, figs. 2-10).

Range: The species occurs as a rare species in the upper part of NN5.

Repository: All specimens are deposited at the Ivan Rakovec Institute of Palaeontology, ZRC SAZU, Ljubljana.



TEXT-FIGURE 2
Basic stratigraphy, lithology and position of samples, containing new species, within the two sections. FO - first occurrence, FCO – first common occurrence, LO - last occurrence.

TABLE 1
Nannoplankton assemblages in samples, containing *Pontosphaera geminipora* n. sp. and *Pontosphaera desuetoidea* n. sp.

SAMPLE	JU-6	LR-34	LR-35	LR-38	LR-40
SPECIES \ PRESERVATION	good	good	good	good	good
Braarudosphaera bigelowii					.
Calcidiscus carlae			.		
Calcidiscus leptoporus		.			
Calcidiscus premacintyrei		•	.	.	.
Calcidiscus tropicus			.		
Calciosolenia brasiliensis	.	.			.
Coccolithus miopelagicus	.	.			.
Coccolithus pelagicus	•	●	●	⬤	⬤
Coccolithus streckeri		.	.	.	.
Cyclicargolithus floridanus	.		.		.
Discoaster adamantheus		•	•	.	.
Discoaster aulacos		.	.	.	.
Discoaster braarudii		.	•	•	•
Discoaster deflandrei		.	.	.	.
Discoaster exilis		•	●	●	•
Discoaster formosus		.	•	•	•
Discoaster kugleri		.	.	.	.
Discoaster moorei		.	.		.
Discoaster musicus			.		.
Discoaster stelullus		•	.	.	•
Discoaster variabilis	.	●	●	.	●
Helicosphaera carteri	●	•	●	●	●
Helicosphaera intermedia		.	•		.
Helicosphaera minuta	.	•	.	•	.
H. walbersdorfensis		.	.		
Helicosphaera wallichii	.	.			
Helicosphaera waltrans	.				
Orthorhabdus serratus			.		
Pontosphaera callosa		.	.	.	.
***Pontosphaera desuetoidea* n. sp.**	.		.	.	.
***Pontosphaera geminipora* n. sp.**		.	.	.	
Pontosphaera multipora	•	•	•	•	•
Reticulofenestra gellida	.	•	•	.	•
Reticulofenestra haquii	•	●	●	•	•
Reticulofenestra minuta	●	●	•	•	⬤
Reticulofenestra minutula	.			.	.
Reticulofenestra perplexa	.				
R. pseudoumbilica (<7μm)	.	●	•	•	●
R. pseudoumbilica (>7μm)					.
Rhabdosphaera procera			.		
Rhabdosphaera sicca	.	•	•	•	•
Sphenolithus abies					.
Sphenolithus heteromorphus	.				.
Sphenolithus moriformis		.	.	.	•
Syracolithus schilleri		.	.	.	
Syracosphaera sp.	.		•		•
Thoracosphaera fossata		.			
Thoracosphaera saxea					.
Thoracosphaera heimii		.			.
Triquetrorhabdulus auritus		.			
Umbilicosphaera jafarii		•		.	
Umbilicosphaera rotula	.	•	•	•	●
NUMBER OF SPECIES	21	36	36	28	38

ABUNDANCE:
. few
• rare
● common
⬤ abundant

Pontosphaera desuetoidea Bartol **n. sp.**
Plate 1, figures 8–10

Etymology: Similar to *P. desueta* (gr. *–oeidës* suffix denoting similarity, from *eidos* – form); adjective.

Description: Large elliptical perforate murolith with distinct marginal wall, measuring 0.6–1μm. Basal plate is pierced by numerous pores arranged in several concentric cycles completely covering basal plate. The openings in the outermost cycle are larger (0.15-0.30μm) than pores in the other cycles (less than 0.10μm). The outer cycle is regularly elliptic and comprises ~30 pores. The inner cycles are irregularly shaped. Only the larger openings in the outermost cycle are visible under a light microscope.

Muroliths measure 9-10μm by 6-8μm, holotype is 7μm wide and approximately 9.5μm long.

Remarks: The species resembles several previously described species of muroliths with larger pores in the outermost cycle and smaller pores in the inner part of the basal plate, but has some specific characteristics.

Pontosphaera desueta (Müller 1970) Perch-Nielsen 1984 is much smaller (7.2 by 5μm), it is more narrowly elliptical and has a smaller number of openings in the outer cycle (~15).

Pontosphaera anisotrema (Kamptner 1956) Backman, 1980 is most similar to *P. desuetoidea* in size and in number of large pores in the outermost cycle. It has narrower pores arranged in 6 regular rows, disposed symmetrically with respect to the main axis of the murolith, which can be seen under the light microscope, whereas *P. desuetoidea* has irregular concentric cycles of narrower pores, which are too small to be seen under a light microscope.

Pontosphaera deflandrei (Kamptner 1956) Aubry 1990 is also similar in size. It has 20 pores in the outermost cycle, which measure 0.5μm, and only three rows of narrow pores, the central one being aligned with the main axis of the murolith. The pores in the outer cycle of *P. desuetoidea* measure no more then 0.15-0.30μm. The narrower pores are arranged in several irregular cycles and are not aligned with the main axis of the murolith.

The common *Pontosphaera multipora* (Kamptner 1948) Roth, 1970 emend. Burns, 1973 can be similar in size to *P. desuetoidea*, however even the smallest pores of this species are much larger than the ones in the outermost cycle of *P. desuetoidea.* The form described as *Discolithus longiforamnis* Baldi-Beke, 1964 has larger pores in the outermost cycle than in the others, but it does not have an elevated marginal wall. Furthermore there are only 15-18 pores in the outer cycle and they are slit-shaped, not round.

All *Pontosphaera* species and forms discussed above can be found in Aubry (1990).

Type designation: Holotype (pl. 1, fig.11, sample LR-38, Lenart section); paratypes (pl. 1, figs. 12-14).

Range: Found in samples from the middle and the upper part of NN5 (the middle Badenian).

Repository: All specimens are deposited at the Ivan Rakovec Institute of Palaeontology, ZRC SAZU, Ljubljana.

Assemblage composition

The assemblages from the Lenart section, containing the two new species, are characterized by very high species diversity (Table 1). The interval in which they occur is enriched in several *Discoaster* species (Bartol and Pavšič 2005). *D. variabilis* and *D. exilis* Martini and Bramlette, 1963 reach relatively high abundances. Discoasters indicate warm water (e.g. Krammer et al. 2006) and their increased abundance suggests deep and oligotrophic (Chapman and Chepstow-Lusty 1997) depositional environment. *Rhabdosphaera sicca* (Stradner 1963) Fuchs and Stradner 1977 is also quite common in the assemblage. The representatives of the genus *Rhabdosphaera* possibly indicate oligotrophy (Negri and Villa 2000) and low turbulence environments (Edwards 1968, Baumann et al. 2005). Rare holococcoliths of *Syracolithis schilleri* (Kamptner, 1927) Loeblich and Tappan, 1963 are present in the asemblages as well. According to Cros et al. (2000) and Cross and Estrada (2008), holococcoliths are characteristic of oligotrophic environments.

The genus *Pontospharea* is represented by species ranging from the latest Paleocene to Recent. It reaches maximum diversity during the Early and Middle Eocene, but only a few species are known from the Oligocene and Miocene. Many species of the genus seem to be more common in hemipelagic than in pelagic sediments (Perch-Nielsen 1985). Melinte (2005) suggests that the genus *Pontosphaera* is an indicator of stable marine environments with only slight salinity fluctuations.

In the Lenart section the genus is represented by four species, *Pontosphaera multipora* (Kamptner 1948) Roth 1970 is the most common, while *P. callosa* (Martini 1969) Varol 1982 and the two new species are rare.

The composition of the nannoplankton assemblages from the Lenart section containing new species indicates stable relatively deep water oligotrophic depositional environment. The high diversity indicates stable open marine conditions as well. This is consistent with the sea-level highstand before the sea-level drop at the end of the 3rd order eustatic cycle TB2.4 according to Rögl et al. (2007) (text-fig. 3). The data from the Lenart section seem to agree with the preference of *Pontosphaera* spp. for stable marine environment, suggested by Melinte (2005).

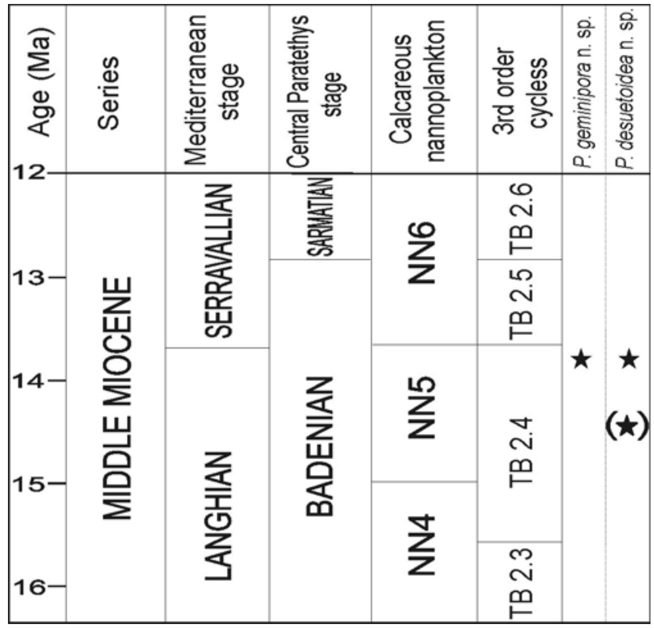
The nannoplankton assemblages of the Jurovski Dol section are similar to those from the Lenart section, but are much poorer in *Discoaster* species. They can be correlated with the 3rd order stratigraphic cycle TB2.4 too. As the precise stratigraphic position of sample JU-6 within NN5 and the 3rd order cycle TB2.4 is not known, the star marking its stratigraphic position in figure 3 is placed in brackets.

Potential significance of *Pontosphaera geminipora* n. sp. and *Pontosphera desuetoidea* n. sp.

In the Badenian the Central Paratethys was well connected with the neighbouring seas, so it does not seem very likely that *P. geminipora* and *P. desuetoidea* are endemic to the Central Paratethys. According to the anti-estuarine two layer circulation model of Báldi (2006), however, Mediterranean waters entered the Central Paratethys through the Slovenian Corridor on the surface and returned below the surface. For the planktonic organisms of the Central Paratethys this could represent a natural barrier for the colonization of the Mediterranean. Indeed, the migration of Mediterranean bryozoans (Moisette et al. 2006) and echinoderms (Kroh 2007) into the Central Paratethys was far more successful than the other way around. The absence of the two new species from the Mediterranean might thus represent an argument in favour of the anti-estuarine type of circulation, suggested by Baldi (2006).

Pontosphaera representatives were only rarely used for biostratigraphic purposes (eg. Čepek 1973). *Pontosphaera desuetoidea* does not seem to be very useful in this respect as it is very rare and is easily overlooked. *Pontosphaera geminipora* is never abundant, but is, nevertheless, more common then *P. desuetoidea.* Due to its large size and prominent features it is easily recognizable in the nannoplankton assemblage even when the specimens are covered (pl. 1, figs. 6, 8), overgrown (pl. 1, figs. 2, 4, 5, 8, 9) or fragmentary (pl. 1, fig. 7).

As such it is at least potentially useful as a stratigraphic marker. For the time being, however, the data on both stratigraphic and geographical distribution of this species remain very limited.



TEXT-FIGURE 3
Stratigraphic correlation of Mediterranean and Central Paratethys regional stages and the stratigraphic position of the samples, containing new species. The stratigraphic position of sample JU-6 cannot be pinpointed with certainty, so the star marking it is placed in brackets. 3rd order sedimentation cycles after Rögl et al. 2007.

CONCLUSIONS

Among over one hundred species of calcareous nannoplankton found in the Badenian marls from the Mura Depression, two new species: *Pontosphaera geminipora* n. sp. and *Pontosphaera desuetoidea* n. sp. were described. They were found in 5 samples from 2 sections. The nannoplankton assemblages from these samples, allow their assignment to the standard nannoplankton biozone NN5 and the 3rd order eustatic cycle TB2.4.

Assemblages are characterized by relatively high species diversity and indicate warm and stable, relatively deep and oligotrophic depositional environments. This is consistent with the sea-level highstand before the sea-level drop at the end of the 3rd order eustatic cycle TB2.4.

During the studied time interval the Central Paratethys was well connected with the neighbouring seas, so it does not seem very likely that *P. geminipora* and *P. desuetoidea* are endemic to the Central Paratethys. Their eventual absence from the Mediterranean might represent an argument in favour of the anti-estuarine type of circulation.

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PLATE 1

1-10 *Pontosphaera geminipora* n. sp.; SEM.

1 Holotype; sample LR-35, Lenart.

2-8 Paratypes; sample LR-35, Lenart.

9 Paratype; sample LR-34, Lenart.

10 Paratype (left) with *Pontosphaera callosa* (right); sample LR-34, Lenart.

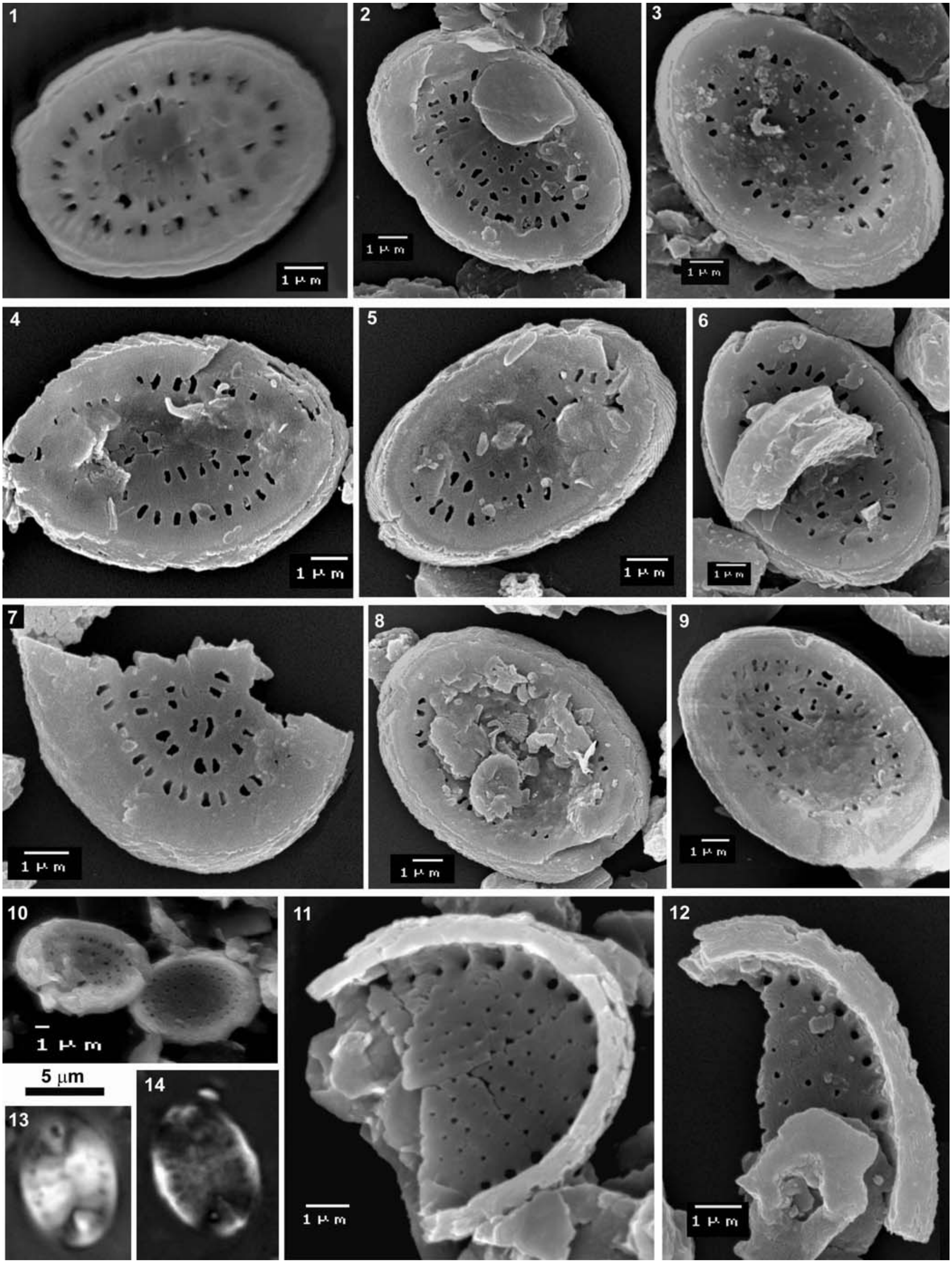
11-14 *Pontosphaera desuetoidea* n. sp.; figs. 11, 12 SEM; figs.13, 14 petrographic microscope, crossed nicols.

11 Holotype, fragment, sample LR-38, Lenart.

12 Paratype, fragment, sample LR-35, Lenart.

13 Paratype, sample JU-6, Jurovski Dol.

14 Paratype, sample LR-40, Lenart, scale bar above fig. 13.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