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Quantitative calcareous nannoplankton biostratigraphy of the Oligocene/Miocene boundary interval in the northern part of the Buda Basin (Central Paratethys)

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Relative abundances of seventeen calcareous nannoplankton species were analysed from around the Oligocene/Miocene boundary interval (NP 25–NN 2 Zones) in the northern part of the Buda Basin (Central Paratethys). A succession of four bioevents can be observed in all sections: FAD of *Helicosphaera carteri*, FAD of *Reticulofenestra* cf. *pseudoumbilica*, and FADs of *Discoaster druggii* and *Helicosphaera scissura*, FAD of *Helicosphaera ampliaperta*. The Oligocene/Miocene boundary lies between the FAD of *Reticulofenestra* cf. *pseudoumbilica* and FADs of *Discoaster druggii* and *Helicosphaera scissura*; events known to approximate it are not recognized.

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INTRODUCTION

Oligocene and Miocene marine basins in the Western Carpathians (Fig. 1) were a part of the Paratethys seas. Paratethys formed a chain of isolated episodically communicating basins. Accurate biostratigraphic correlation within and between such basins, based on biostratigraphic events (LAD, FAD, FCO, LCO) may be problematic because the incoming of new faunas may reflect with opening of local seaways. Good results can be obtained in time intervals characterized by good communication of the basins with the open ocean, when palaeoenvironmental conditions were favourable for index taxa. Good communication of basins depends on both global sea-level changes (Haq *et al*., 1988) and on local tectonic activity as it influences local sea-level changes (Kováč *et al*., 2001). If basins developed in separate tectonic domains (which is the case for the Central Paratethys basins), the correlation of bioevents may be not consistent.

These circumstances probably contributed to the uncertainty regarding the exact position of the Paleogene/Neogene boundary in the Central Paratethys (Báldi, 1986; Rögl, 1998; Cicha *et al*., 1998). This uncertainty is reflected also in the fact that the boundary lies within the local Central Paratethys stage Egerian (Báldi and Seneš, 1975; Steininger *et al*., 1976). Good index taxa upon which to determine the boundary cannot be found, with the exception of large foraminifers (Papp, 1975; Váňová, 1975).

The aim of this research is a detailed quantitative analysis of calcareous nannoplankton bioevents around the broader Oligocene/Miocene boundary interval (Zones NP 25–NN 2) in the northern part of the Buda Basin and an assessment of their utility in determining this boundary.

THE OLIGOCENE/MIOCENE BOUNDARY INTERVAL IN THE CENTRAL PARATETHYS

The Oligocene/Miocene boundary (Fig. 2) has been placed in the upper part of the Egerian (Báldi and Seneš, 1975; Steininger *et al*., 1976; Rögl, 1998), close to the base of the NN 1 Zone of Martini (1971). The Egerian/Eggenburgian boundary was correlated with the NN 1/NN 2 zonal boundary of Martini (1971; Lehotayová and Molčíková, 1975), and is now correlated with the upper part of the NN 2 Zone of Martini (1971; Steininger *et al.*, 1990; Rögl, 1998). The entire interval

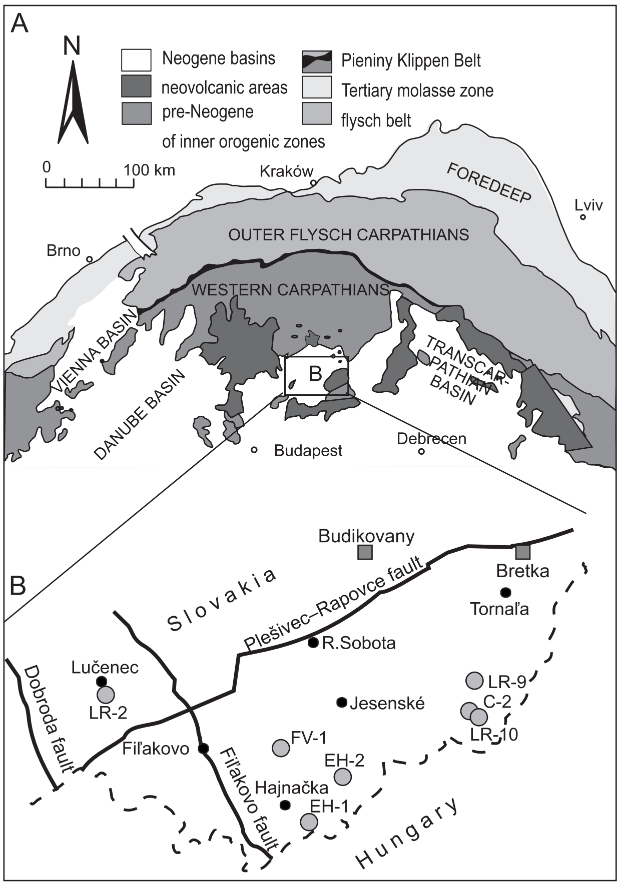

Fig. 1A — regional setting; B — locations of the boreholes (grey circles) and outcrop sections (grey squares) studied against the enlarged area of the northern Buda Basin

studied can be correlated with the upper part of Chattian, the Aquitanian and the lower part of Burdigalian (Rögl, 1998).

The palaeogeography during the late Kiscellian (early Chattian) was characterized by the isolation of the Paratethys. A seaway opened between the Paratethys and the Indian Ocean, enabled penetration of warm-water faunas around the Oligocene/Miocene boundary. The seaway along the Alpine Foredeep was closed for a short time (Rögl and Steininger, 1983; Rögl, 1998, 1999). At the beginning of the Eggenburgian a broad connection between the Indian Ocean and both the Mediterranean and the Paratethys was accompanied by migration of faunas and floras. Seaways along the Alpine Foredeep were reopened (Rögl, 1998, 1999).

Continuous sedimentation across the Oligocene/Miocene boundary interval has been reported from the flysch zone of the Central Paratethys, the Lower Austrian Molasse, the South and East Slovakian basins and the Transcarpathian Basin in Romania (Steininger *et al.*, 1985).

BIOSTRATIGRAPHIC EVENTS IN THE OLIGOCENE/MIOCENE BOUNDARY INTERVAL

Before collecting quantitative biostratigraphic data, the principal calcareous nannoplakton bioevents were summarized for the broader Oligocene/Miocene boundary interval and compared with foraminiferal bioevents. For this synthesis, we use biostratigraphic data from the world oceans (Berggren *et al.*, 1995), generalized data from the Mediterranean (Fornaciari and Rio, 1996) and the data from the Carrosio-Lemme section

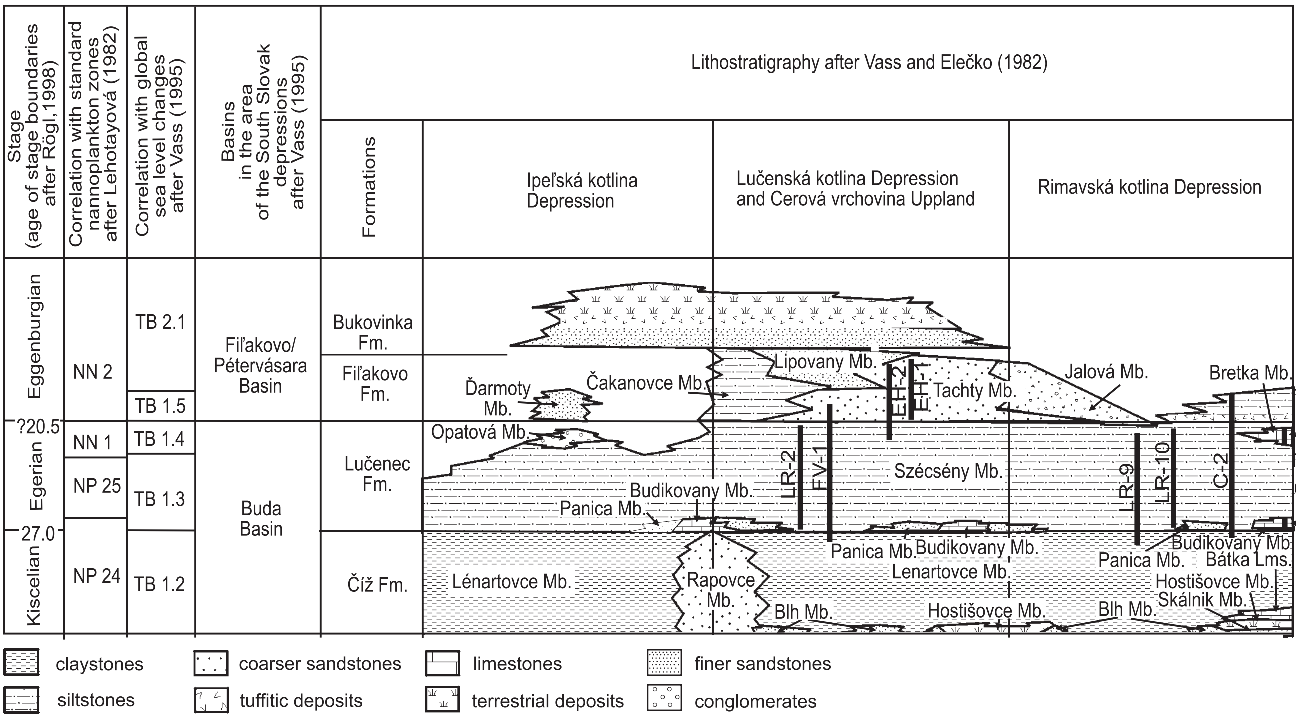

Fig. 2. A synthesis of the hitherto published lithostratigraphic, biostratigraphic and radiometric data from the South Slovak depressions, and a correlation of the studied boreholes and sections with lithostratigraphic units

(Aubry and Villa, 1996; synthesis of Steininger *et al*., 1997). These data were correlated with those from the Central Paratethys basins: data of the present author from the northern part of the Buda Basin (Holcová, 2001) were compared with the data from the southern part of the Buda Basin (Horváth and Nagymarosy, 1979; Horváth, 1983), the Bavarian and Austrian Molasse (Báldi and Seneš, 1975; Rögl in Cicha *et al*., 1998), the Pouzdřany Unit (Krhovský *et al*., 1995), the Ždánice Unit (Molčíková and Straník, 1987), from the flysch zone in Poland (Olszewska in Cicha *et al*., 1998; Oszczypko-Clowes, 2001), and Ukraine (Andreyeva-Grigorovich *et al*., 1997; Trofimovich and Savitska, unpubl. data), and synthetic data for Romania (Popescu in Cicha *et al*., 1998; Marunteanu, 1992). The following calcareous nannoplankton bioevents can be distinguished:

1. LAD of *Helicosphaera recta*

This event defines the NP 25/NN 1 boundary according to Martini (1971). Because the taxon is rare, the event was replaced by the LAD of *Reticulofenestra bisecta* (Berggren *et al*., 1995). In the Mediterranean region (synthesis of data by Fornaciari and Rio, 1996), this event is not isochronous and hence not reliable for biostratigraphic correlation. Marunteanu (1992) described this event from Romania.

2. LAD of *Reticulofenestra bisecta*

This event is used to approximate the NP 25/NN 1 boundary (Berggren *et al*., 1995, 23.9 Ma; Rio *et al*., 1990 for the Indian Ocean). In the Mediterranen, this event has been recorded in the lower part of the NN 1 Zone (Fornaciari and Rio, 1996) and considered to be the best approximation for the Oligocene/Miocene boundary. In the Central Paratethys, it has been reported from younger deposits (NN1/NN2 boundary, Savitska, unpubl. data).

3. LAD of *Reticulofenestra abisecta*

The problematic reliability of this bioevent is connected with the controversial taxonomic status of this species. It is difficult to distinguish smaller specimens from *Cyclicargolithus floridanus* (Rio *et al*., 1990; Bubík, 1992; author's own unpubl. observation). Okada and Bukry (1980) used the LCO of *Reticulofenestra abisecta* for the definition of the CN1a/CN1b boundary in low-latitude zonation. This event was used also in Mediterranean stratigraphy (Theodoridis, 1984) but its reliability was questioned by other authors (Martini and Muller, 1986; Fornaciari and Rio, 1996).

In spite of these problems, this bioevent has frequently been used as a biostratigraphic indicator in the Central Paratethys: it can be correlated with the NP 25/NN 1 boundary according to Báldi-Béke (1984), Bystrická (1979). In Ukraine, the event has been recorded from the NN 1/NN 2 boundary (Savitska, unpubl. data).

4. LAD of *Discolithina latelliptica*

This endemic Paratethys species is considered to be stratigraphically important. According to Báldi-Béke (1984), Bystrická (1979), *etc*. it indicates the Oligocene.

5. LADs of *Sphenolithus conicus* and *S. capricornutus*

These events have been described from the Carrosio-Leme section: the LAD of *Sphenolithus capricornutus* from the Oligocene/Miocene boundary and the LAD of *Sphenolithus conicus* from the NN 1/NN 2 zonal boundary. The events were dated at 23.6 Ma (LAD of *Sphenolithus conicus*) and 23.8 Ma (LAD of *Sphenolithus capricornutus*; Aubry and Villa, 1996). The occurrence of these calcareous nannoplankton species in the Central Paratethys has been reported from Hungary (Horváth and Nagymarosy, 1979) and Poland (Oszczypko-Clowes, 2001).

6. FADs of *Reticulofenestra pseudoumbilica* and *R. excavata*

These are approximately isochronous events in the Central Paratethys. Molčíková and Straník (1987) described the FAD of *R. pseudoumbilica* as somewhat earlier than the FAD of *R. excavata*. Outside this area, the FAD of *R. pseudoumbilica* has been described from different stratigraphic levels. This discrepancy is caused by different taxonomic concepts among different authors: specimens smaller than 11 μm were placed within *R. pseudoumbilica* by some authors but were excluded by others. In the Mediterranean, the FAD of *R. pseudoumbilica* has been described only from the middle Miocene (NN 6 Zone; Fornaciari and Rio, 1996). In the Atlantic Ocean near Madeira, Howe and Sblendorio-Levy (1998) described the FAD of *R. pseudoumbilica* (> 7 μm) from the upper part of the NN 2 Zone. This event is correlated with the NN1/NN 2 boundary in the Central Paratethys in Romania (Marunteanu, 1992).

Reticulofenestra excavata is an endemic species described from the Central Paratethys (Lehotayová, 1975). Its FAD is correlated with the NN 2 Zone (Lehotayová, 1975).

7. FAD of *Discoaster druggii*

The FAD of *D. druggii* was used for the definition of the base of the NN 2 Zone and was dated at 23.2 Ma for the world ocean (Berggren *et al*., 1995). This event is observed in the Mediterranean but it is rare and unsuitable for routine work (Fornaciari and Rio, 1996). In the Central Paratethys, this event has been mentioned from the same level (NN1/NN 2 boundary) from many basins (Horváth and Nagymarosy, 1979; Lehotayová, 1982, 1984; Marunteanu, 1992).

8. FAD of *Helicosphaera mediterranea*

In the Mediterranean region, this event is correlated with the middle part of the NN 2 Zone after the FAD of *H. ampliaperta* (Fornaciari and Rio, 1996). Marunteanu correlated the event with the uppermost part of the NP 25 Zone.

9. FAD of *Helicosphaera carteri*

Perch-Nielsen (1985) described this event from around the NN 1, NN 2 Zones. From the Mediterranean, the FCO of the species has been reported from the NN 2 Zone (Fornaciari and Rio, 1996). The FAD of the species was dated at 22.6 Ma in the NN 2 Zone in the Carrosio/Lemme section (Aubry and Villa,1996).

10. LCO of *Helicosphaera euphratis*

In the Mediterranean region, the LCO has been correlated with the FCO of *Helicosphaera carteri* in the NN 2 Zone (Coccioni *et al*., 1997).

11. FAD of *Helicosphaera ampliaperta*

The FAD of *H. ampliaperta* was dated at approximately 20 Ma in the Mediterranean (Fornaciari and Rio, 1996). From the Central Paratethys, this was described from Romania and placed within the NN 2 Zone (Marunteanu, 1992). This event marks approximately the Egerian/Eggenburgian boundary.

The calcareous nannoplankton bioevents have been correlated with the following foraminiferal events:

1. LAD of *Paraglobigerina opima opima*

Berggren *et al*. (1995) dated this event at 27.1 Ma (= approximately Kiscellian/Egerian boundary *sensu* Rögl, 1998) in the World Ocean. In the Paratethys, Cicha *et al*. (1998) correlated it with the lower Egerian. Approximately at the same level, the large-sized and diverse older planktonic foraminiferal assemblages with *Paraglobigerina opima opima* were replaced by low-diversity assemblages composed mainly of small-sized globigerinas. A decreasing diversity of planktonic foraminifers in this time interval was recorded also in the Pacific Ocean (Kennett and Srinivasan, 1983).

2. LAD of *Uvigerina hantkeni*

The local Central Paratethys event was dated to the Egerian/Eggenburgian boundary (Cicha *et al*., 1986), and subsequently to the middle part of the Egerian (Cicha *et al*., 1998).

3. FAD of *Globigerinoides primordius*

This event has been dated at 26.7 Ma for the World Ocean (Berggren *et al*., 1995) and to the lowermost Egerian in the Central Paratethys (Cicha *et al*., 1998).

4. FAD of *Globigerinoides trilobus*

This event coincides with the LAD of *Paragloborotalia kugleri* in the Carrosio-Lemme section (Iaccarino *et al.*, 1996) which was dated at 21.5 Ma according to Berggren *et al.* (1995). Cicha *et al*. (1998) correlated this event with the uppermost Egerian in the Central Paratethys.

5. FAD of *Uvigerina posthantkeni*

The FAD of this endemic Central Paratethys species was described from the uppermost Egerian (Cicha *et al*., 1986) or to the Egerian/Eggenburgian boundary (Cicha *et al*., 1998).

MATERIAL AND METHODS

The material analysed comes from the South Slovak depressions (Fig. 2). In this area, standard biostratigraphic, lithostratigraphic and sedimentological analyses are well summarized by Vass (1996) and Vass *et al*. (1979, 1983, 1985, 1989, 1992). Lithostratigraphic units were defined by Vass and Elečko (1982). Correlation with standard nannoplankton zones (Martini, 1971) was made by Lehotayová (1982). Palaeogeographical maps were constructed for every stage for the Ipeľ a Rimava Depressions (Vass *et al*., 1979, 1989). Important tectonic events were distinguished (Vass *et al*., 1993; Márton *et al.*, 1995; Vass, 1995). Local sea-level changes (Vass, 1995) were correlated with the global ones of Haq *et al*., (1988).

The geomorphological unit termed the South Slovak depressions formed a part of two marine basins during the Oligocene/Miocene boundary interval (Vass, 1995):

(1) the Buda Basin (Oligocene-Egerian/Eggenburgian boundary); the South Slovak depressions represent the northern part of the Buda Basin;

(2) the Fiľakovo/Pétervásara Basin (Eggenburgian); the South Slovak depressions were situated on the southern margin of this basin.

The area of the South Slovak depressions was flooded during this time interval by the prominent Kiscellian-Egerian transgression and a smaller Eggenburgian transgression. A long-lasting emergence followed, during the Upper Eggenburgian and Ottnangian (Vass, 1995).

Based on important tectonic events distinguished for the Oligocene and Miocene of the South Slovak depressions (Vass *et al*., 1993; Márton *et al*., 1995; Vass, 1995), the left-lateral strike-slip along the Plešivec–Rapovce fault (several tens of km) has been dated at 19–20 Ma. It may have been an influence across the broader Oligocene/Miocene boundary interval.

The time interval studied is represented by three formations (Vass *et al*., 1989; Fig. 2):

(1) The Číž Formation is composed predominantly of dark claystones and siltstones of the Lénartovce Member containing a typical Kiscellian marine fauna (Mollusca: *Nuculana deshayesiana*, *Propeamussium bronni zimanyii*, *Thyasira nysti*, Ondrejíčková, 1978; Foraminifera: *Tritaxia szaboi*, *Lenticulina kubinyi*, Kantorová, 1978). Lehotayová (1978) correlated this lithostratigraphical unit with the NP 24 Zone. This member was analysed only from the bases of boreholes LR-9 and FV-1. Marginal facies of the Číž Formation are represented by the Blh and Hostišovce members.

(2) The Lučenec Formation is represented mainly by calcareous siltstones ("schlier") of the Szécsény Member. This member yielded most of the samples analysed (Fig. 2). *Paraglobigerina opima opima* was recorded in the lower part of the member (Kantorová, 1978) and *Globigerinoides primordius* in the upper part (Holcová, 2001). Lehotayová (1978) correlated this member with the upper part of the NP 24, NP 25 and NN 1 zones. The pollen spectra were determined as typical Oligo-Miocene (Planderová, 1990).

Marginal facies are represented by the Budikovany and Bretka members. These members are lithologically similar, and comprise organodetrital limestones and conglomerates. Both members were dated on the basis of larger foraminifera (Vaňová, 1975). *Miogypsina formosensis* from the Budikovany Member indicates the upper Oligocene age for the Budikovany Member while *Miogypsina gunteri* and *M. tani* indicate a lower Miocene age for the Bretka Member. Nannoplankton from these members was studied from the type sections of Budikovany and Bretka (Báldi and Seneš, 1975).

(3) Fiľakovo Formation: the Tachty Member consisting of sandstones was analysed from this formation. The sandstones contain *Uvigerina primiformis* (Kantorová in Vass *et al*., 1980) the FAD of which is correlated with the base of the Eggenburgian (Cicha *et al*., 1998). Lehotayová (1982) correlated the member with the NN 2 Zone. Other members of the Fiľakovo Formation represent a marginal facies, do not contain calcareous nannoplankton and were not studied.

The calcareous nannoplankton was studied by the standard method using a polarizing light microscope. Quantitative data were obtained counting, when possible, about 500 specimens. 200–300 specimens were used for samples where calcareous nannoplankton was rare (marginal facies of the Egerian in the Budikovany and Bretka sections).

RESULTS AND DISCUSSION

RECOGNIZED BIOEVENTS

The relative abundances of seventeen species were recorded and compared in total (Figs. 3–10). Besides biostratigraphically significant species, relative abundances of the most common species (*Coccolithus pelagicus*, plexus of small *Reticulofenestra*, *Cyclicargolithus floridanus*) were also analysed. Helicoliths (six species) and placoliths (seven species) dominate the assemblage.

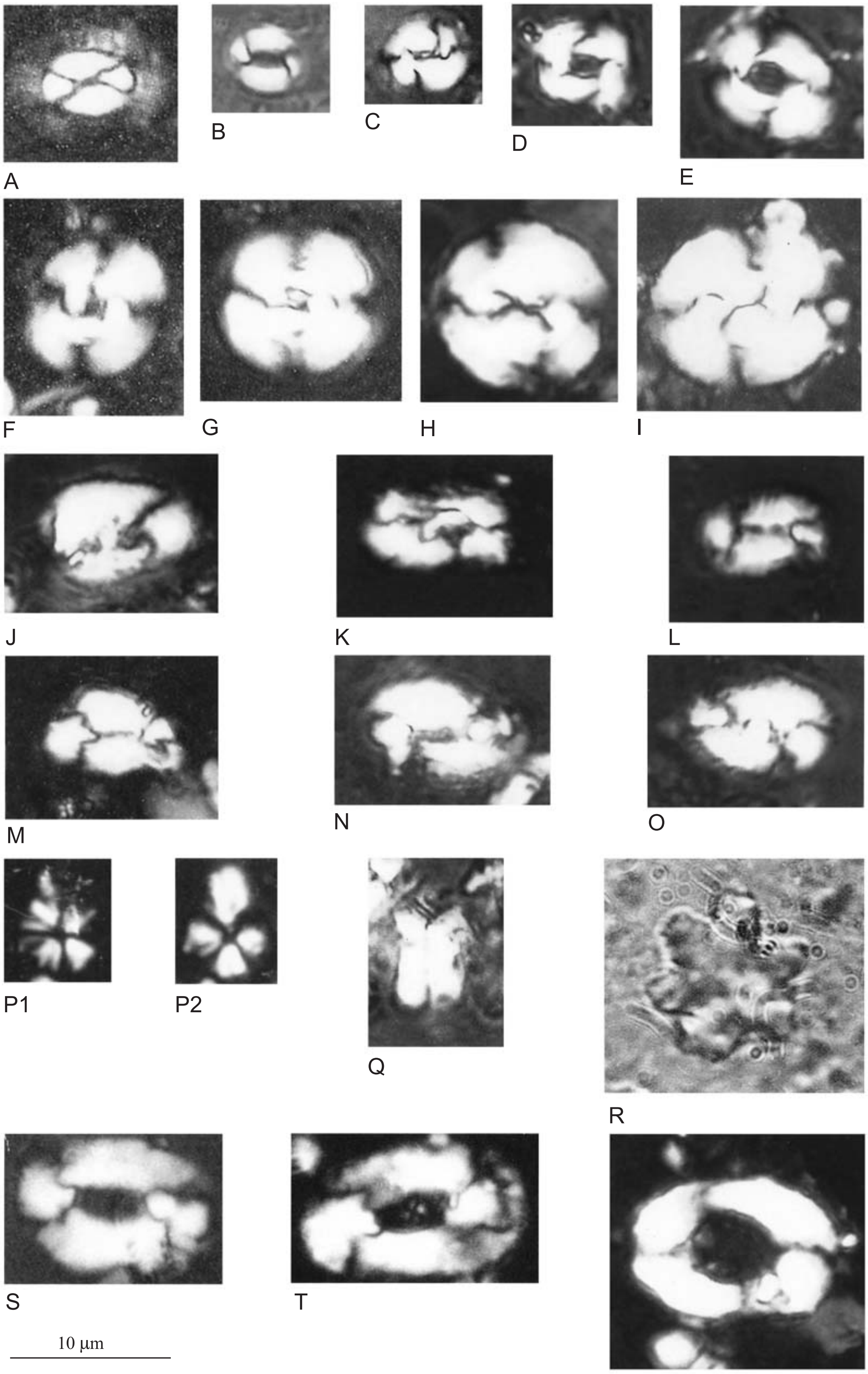

Fig. 3. **A** — *Coccolithus pelagicus* (Wallich) Schiller, borehole C-2, 550 m; **B** — small *Reticulofenestra* sp., borehole FV-1, 60 m; **C** — small *Reticulofenestra* sp., borehole FV-1, 140 m; **D** — *Reticulofenestra* cf. *pseudoumbilica* (Gartner) Gartner (first small specimen), borehole FV-1, 120 m; **E** — *Reticulofenestra cf. pseudoumbilica* (Gartner) Gartner, borehole FV-1, 120 m; **F** — *Cyclicargolithus floridanus* (Roth and Hay) Bukry, borehole C-2, 550 m; **G** — *Cyclicargolithus abisectus* (Müller) Wise, borehole C-2, 350 m ; **H** — *Reticulofenestra bisecta* Hay, Mohler and Wade, borehole FV-1, 140 m; **I** — *Reticulofenestra bisecta* Hay, Mohler and Wade, borehole C-2, 350 m; **J** — *Helicosphaera recta* Haq, borehole C-2, 550 m; **K** — *Helicosphaera euphratis* Haq, borehole C-2, 400 m; **L** — *Helicosphaera carteri* (Wallich) Kamptner (form with larger opening), borehole FV-1, 60 m; **M** — *Helicosphaera carteri* (Wallich) Kamptner (form with narrow opening), borehole C-2, 300 m; **N** — *Helicosphaera scissura* Miller, borehole FV-1, 140 m; **O** — *Helicosphaera mediterranea* Müller, borehole FV-1, 60 m; **P1** — *Sphenolithus conicus* Bukry, crossed nicols 45°, **P2** — *Sphenolithus conicus* Bukry, crossed nicols 0°, borehole LR-9, 400 m; **Q** —*Sphenolithus capricornutus* Bukry and Percival, borehole FV-1, 140 m; **R** — *Discoaster druggii* Bramlette and Wilcoxon, borehole EH-2, 20 m; **S** — *Helicosphaera ampliaperta* Bramlette and Wilcoxon, borehole EH-2, 15 m; **T** — *Helicosphaera ampliaperta* Bramlette and Wilcoxon, borehole EH-1, 38 m; **U** — *Discolithina latelliptica* Báldi-Beke, borehole C-2, 400 m

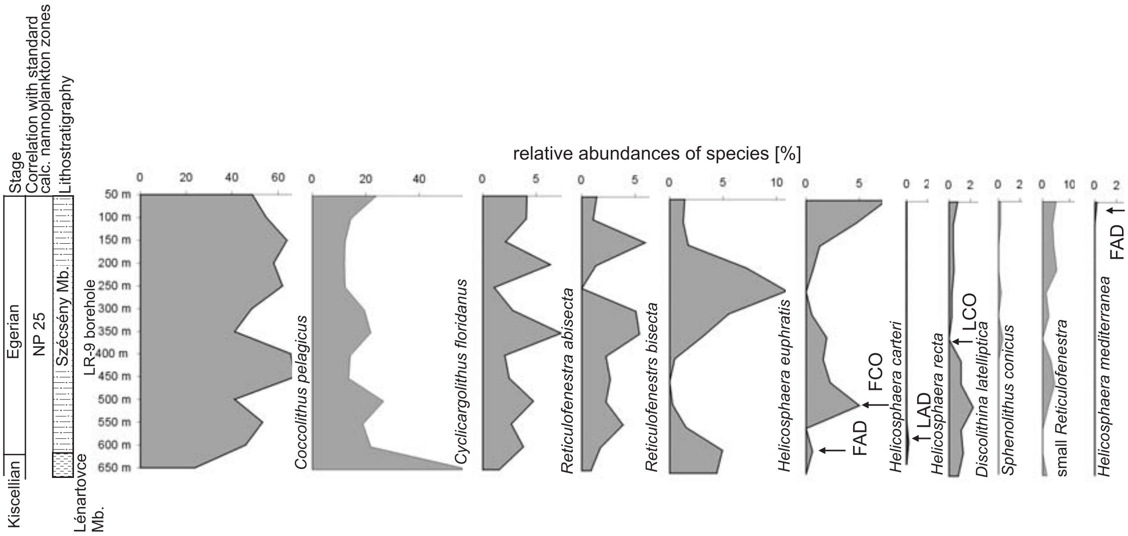

Fig. 4. Relative abundances of the most common and stratigraphically significant taxa of calcareous nannoplankton in borehole LR-9

Other explanations as on Figure 2

Small *Reticulofenestra* (determined as *R. minuta* by, e.g. Haq, 1980; Spezzaferi and Coric, 2001, *etc*.; Fig. 3B, C) represent very probably two or more species which cannot be distinguished under the light microscope (Haq, 1980). Within the Reticulofenestra group, large *Reticulofenestra* (4.5–8 µm in diameter) started to appear. The variety characterized by a large central opening (representing 0.2–0.4 placolith diameter) was here determined as *Reticulofenestra* cf. *pseudoumbilica* (Fig. 3D, E). It can be compared with *Reticulofenestra pseudoumbilica* described from the lower Miocene in other Central Paratethys basins (Molčíková and Straník, 1987; Marunteanu, 1992).

The following bioevents can be recognized in the sections analysed:

— borehole LR-9 (Fig. 4): the FAD of *Helicosphaera carteri* and LAD of *Helicosphaera recta* were recorded at the base of the borehole; their reliability is therefore questionable. These events are overlain by the FCO of *H. carteri* and LCO of *Discolithina latelliptica*. The FAD of *Helicosphaera mediterranea* was described from the uppermost part of the borehole.

— borehole LR-10 (Fig. 5): the FAD of *Helicosphaera carteri* was observed in the lower part of the borehole. In the middle part, two problematic LADs of *Helicosphaera recta* and *Sphenolithus conicus* were recorded based on isolated occurrences of these species. The acme of small *Reticulofenestra* as well as the FAD of *Reticulofenestra* cf. *pseudoumbilica* were observed in the upper part of the borehole.

— Budikovany section (Fig. 6): calcareous nannoplankton is very rare; the FAD of *Reticulofenestra* cf. *pseudoumbilica* was observed only in the uppermost part of the section.

— borehole LR-2 (Fig. 7): an isolated occurrence of *Helicosphaera recta* in one sample was recorded in the lower part of the borehole. The acme of small *Reticulofenestra* as well as the FAD of *Helicosphaera carteri* were observed in the middle part of the borehole. FADs of *Reticulofenestra* cf. *pseudoumbilica*, *Discoaster druggii*, *Reticulofenestra excavata*, *Helicosphaera mediterranea* and *H. scissura* were recorded in the upper part of the borehole near the same level.

— borehole C-2 (Fig. 8): two isolated occurrences of *Helicosphaera recta* were observed in the middle part of the borehole. *Reticulofenestra excavata*, *R.* cf. *pseudoumbilica*, *Discoaster druggii*, *Helicosphaera mediterranea* and *H. ampliaperta* successively appear from the middle to the upper part of the borehole. In this borehole, the LAD of *Reticulofenestra bisecta* can be observed at the level of the FAD of *Discoaster druggii*.

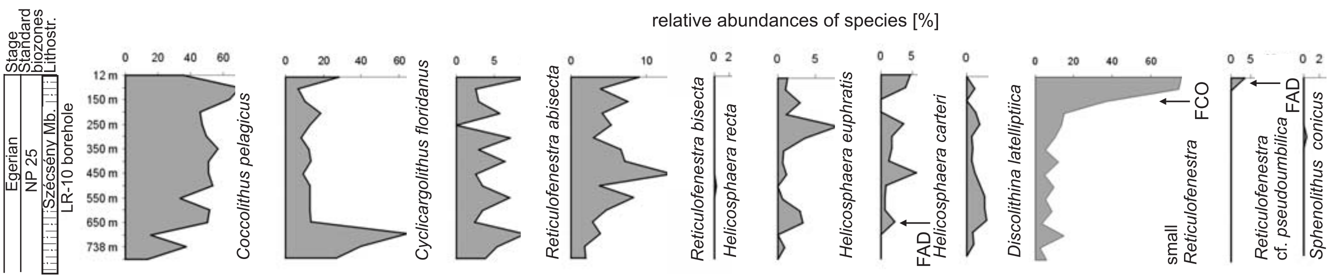

Fig. 5. Relative abundances of the most common and stratigraphically significant taxa of calcareous nannoplankton in borehole LR-10

Other explanations as on Figures 2 and 4

— borehole FV-1 (Fig. 9) yielded a section of prime importance and was sampled in detail. LADs of *Helicosphaera recta*, *Sphenolithus conicus* as well as FADs of *Reticulofenestra* cf. *pseudoumbilica*, *R. excavata*, *Helicosphaera scissura* and *H. mediterranea* are connected with rare and discontinuous occurrences of these taxa. In this borehole, the LAD of *H. euphratis* can be observed. Clear, practically isochronous FCOs of *Reticulofenestra* cf. *pseudoumbilica*

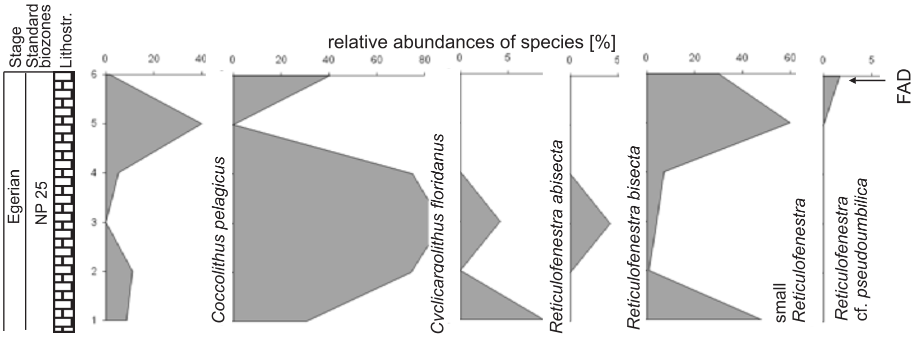

Fig. 6. Relative abundances of the most common and stratigraphically significant taxa of calcareous nannoplankton in the Budikovany section

Other explanations as on Figures 2 and 4

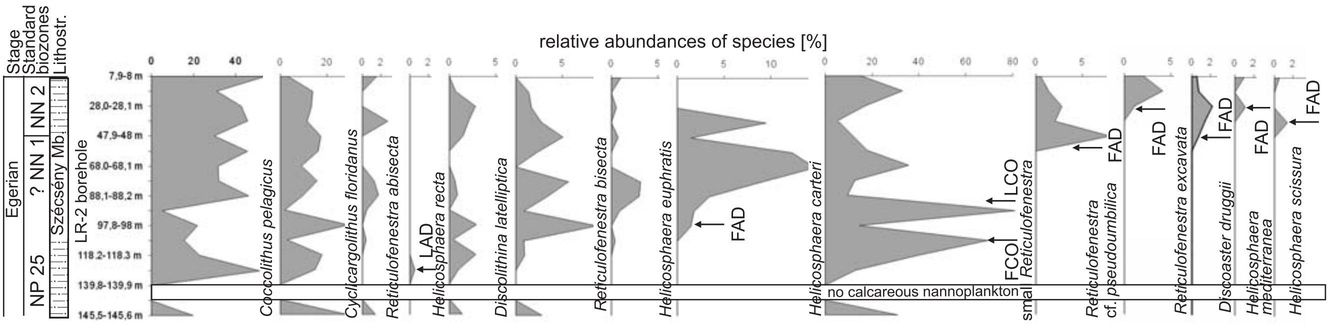

Fig. 7. Relative abundances of the most common and stratigraphically significant taxa of calcareous nannoplankton in borehole LR-2

Other explanations as on Figures 2 and 4

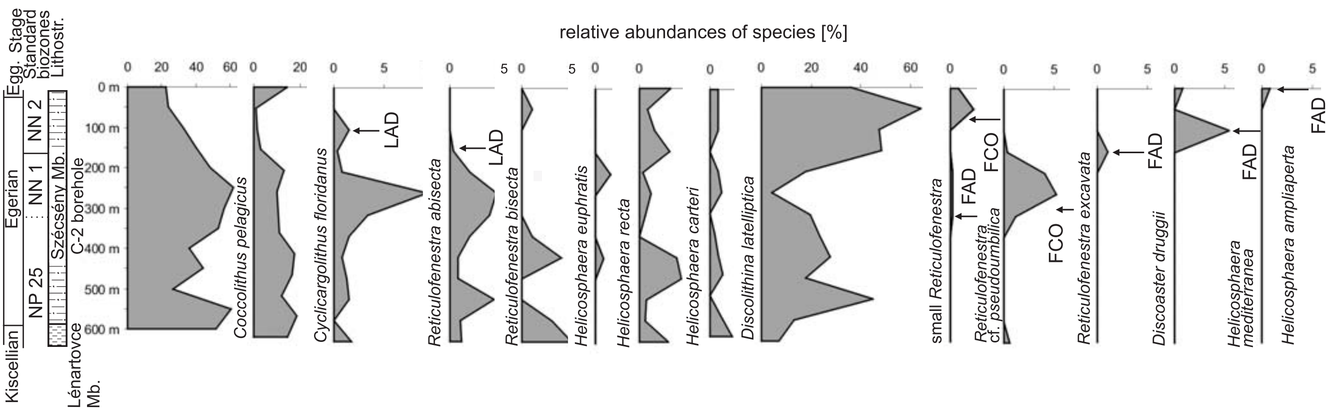

Fig. 8. Relative abundances of the most common and stratigraphically significant taxa of calcareous nannoplankton in borehole C-2

Egg. — Eggenburgian; other explanations as on Figures 2 and 4

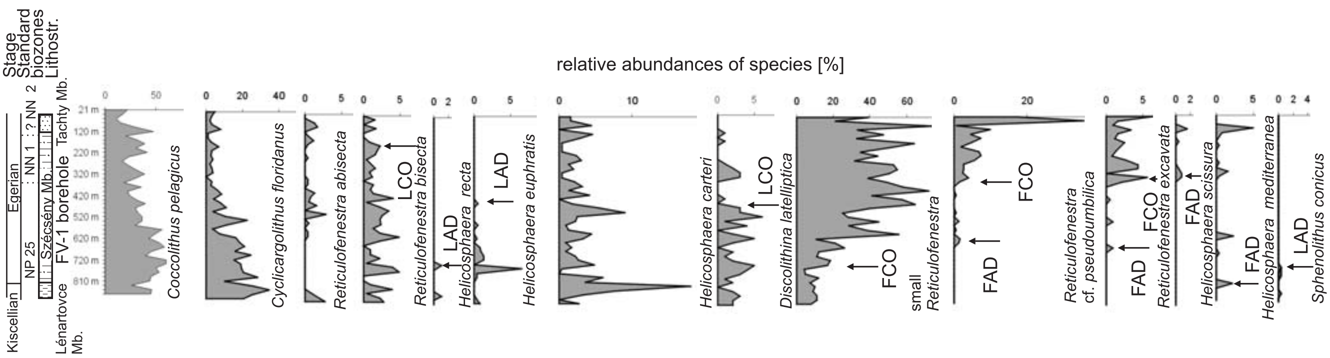

Fig. 9. Relative abundances of the most common and stratigraphically significant taxa of calcareous nannoplankton in borehole FV-1

Other explanations as on Figures 2 and 4

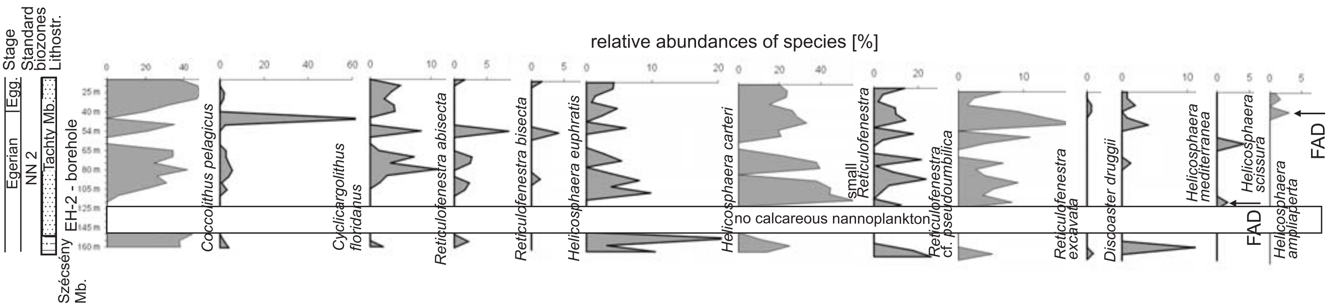

Fig. 10. Relative abundances of the most common and stratigraphically significant taxa of calcareous nannoplankton in borehole EH-2

Other explanations as on Figures 2, 4 and 8

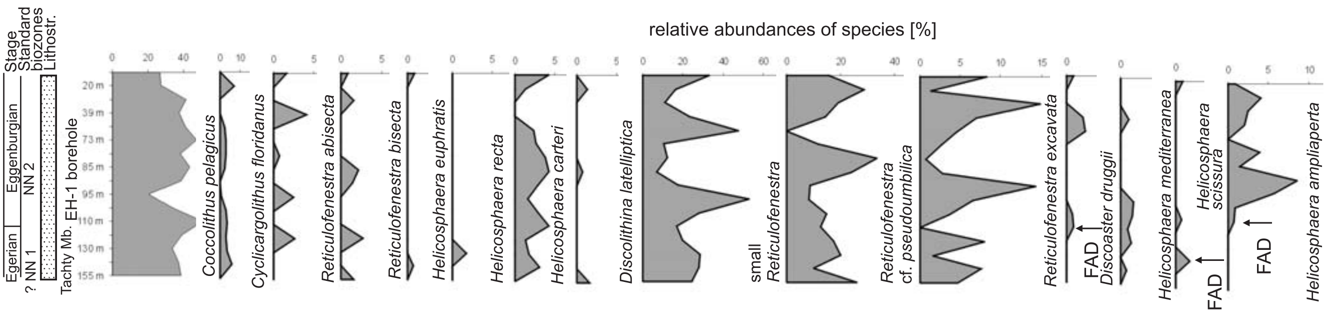

Fig. 11. Relative abundances of the most common and stratigraphically significant taxa of calcareous nannoplankton in borehole EH-1

Other explanations as on Figures 2 and 4

and *R. excavata* were recorded above the FCO of small *Reticulofenestra*.

— borehole EH-2 (Fig. 10): intervals with no calcareous nannoplankton were recorded in this borehole, which may influence the recognition of the calcareous nannoplankton events. Only the FAD of *Helicosphaera ampliaperta* is well defined.

— borehole EH-1 (Fig. 11): a well-defined FAD of *Helicosphaera ampliaperta* lies only slightly above the FAD of *Discoaster druggi*. This species occurred only discontinuously.

The comparison of the succession and character of bioevents described in the individual boreholes enabled classification of the bioevents to the following groups:

1. Well-established biostratigraphic events were recorded in all sections at the corresponding stratigraphical level. Distinct FADs (or LADs) are characterized by continuous occurrences of taxa in all or most of the samples above (or below) the level of the event. The following events can be classified as well-established ones: the FAD of *Reticulofenestra* cf. *pseudoumbilica* (recorded in boreholes LR-10, FV-1, LR-2, C-2, Budikovany section), the FAD of *Reticulofenestra excavata* (recorded in boreholes FV-1, LR-2, C-2), the FAD of *Helicosphaera ampliaperta* (boreholes C-2, EH-1, EH-2), the FAD of *Helicosphaera carteri*: the event was recorded in the lowermost part of sections LR-9, LR-10 where it cannot be well evaluated, but is well documented in borehole LR-2.

2. Less perfectly established events: two types of events were included in this category:

— the species does not occur continuously over its FAD and the events were not recorded in all sections: the FAD of *Helicosphaera scissura* (boreholes FV-1, LR-2, EH-1, EH-2), the FAD of *Discoaster druggii* (boreholes C-2, LR-2, EH-1), the FAD of *Helicosphaera mediterranea* (boreholes C-2, LR-2, LR-9);

— FCOs which cannot be clearly recognized in all sections: the FCO of small *Reticulofenestra* (clearly recognizable in boreholes LR-10, FV-1, unclear in boreholes LR-2 and C-2).

3. Problematic events. Biostratigraphically significant taxa are very rare, occurring in only as a few specimens in the sections. For this reason, the level of the event may be random. The LADs of *Helicosphaera recta, Sphenolithus conicus* and the LAD of *Sphenolithus capricornutus* were assigned to this category.

Based on data from the literature (see chapter Biostratigraphic events in the Oligocene/Miocene boundary interval), the following LADs were expected: LADs of *Reticulofenestra abisecta*, *R. bisecta* and *Discolithina latteliptica*. The LADs of *Reticulofenestra abisecta* and *R. bisecta* were determined only in borehole C-2 around the FAD of *Discoaster druggii*. The LAD of *Discolithina latelliptica* was not recorded. The absence of these events in boreholes may be caused by reworking of the taxa. Therefore, some quantitative criteria were sought to distinguish between reworked and autochthonous occurrences of *Reticulofenestra abisecta*, *R. bisecta* and *Discolithina latteliptica*. Discontinuous occurrences and lower relative abundances of the taxa were expected above their LADs where only reworked specimens can be recorded.

This can be observed only for *Reticulofenestra bisecta* which occurs continuously in boreholes LR-9, LR-10 which can be correlated with Zones NP 25 and NN 1: *Discoaster druggii* was not recorded in these boreholes. Discontinuous occurrences were observed in boreholes EH-2 and EH-1 which can be correlated with the NN 2 Zone based on the occurrence of *Discoaster druggii*. In borehole FV-1, analysed in great detail, the relative abundance of *R. bisecta* decreases in the uppermost part where *Helicosphaera scissura* appears. The LAD of *Reticulofenestra bisecta* cannot be recognized in borehole LR-2 where the clearly recognizable FADs of *Discoaster druggii* and *Reticulofenstra scissura* were recorded.

This change was not observed in *Reticulofenestra abisecta*. The expected discontinuous occurrences were observed in borehole EH-1. At a certain stratigraphical level, in the upper part of borehole EH-2, *R. abisecta* occurs continuously and is relatively abundant. On the contrary, this species occurs sporadically in borehole LR-2 where its autochthonous occurrence was expected.

SUCCESSION OF BIOEVENTS

Successions of calcareous nannoplankton bioevents were compared for the boreholes studied. The following succession can be observed for 17 bioevents analysed (Fig. 12): (1) the FAD of *Helicosphaera carteri*; (2) the LAD of *Sphenolithus conicus* and the FCO of small *Reticulofenestra*; these events were not recorded in all sections; (3) the FAD of *Reticulofenestra* cf. *pseudoumbilica* (with a diameter exceeding 4.5 μm); the FAD of *Reticulofenestra excavata* is coeval or slightly younger; (4) the FADs of *Discoaster druggii* and *Helicosphaera scissura* always lie above the FAD of *Reticulofenestra* cf. *pseudoumbilica* and are usually of the same age. The events were not recorded in all sections analysed; (5) the LAD of *Reticulofenestra bisecta* can be approximately correlated with the FADs of *Discoaster druggii* and *Helicosphaera scissura* and is expressed by discontinuous occurrences of the taxa in the sections; (6) the FAD of *Helicosphaera ampliaperta*.

Two events showed a random position in the sections: the LAD of *Helicosphaera recta* (from the uppermost level studied below the FAD of *Helicosphaera carteri* to the FAD of *Helicosphaera scissura*), the FAD of *Helicosphaera mediterranea* (from the FAD of *Helicosphaera carteri* to the FAD of *Helicosphaera ampliaperta*).

Biostratigraphically significant events observed only once were recorded at the following levels: the LAD of *Sphenolithus capricornutus* between the FADs of *Helicosphaera carteri* and *Reticulofenestra* cf. *pseudoumbilica* near the FAD of *Sphenolithus conicus*; the LADs of *Cyclicargolithus abisectus* and *Cyclicargolithus bisectus* at the level of the FAD of *Discoaster druggii*.

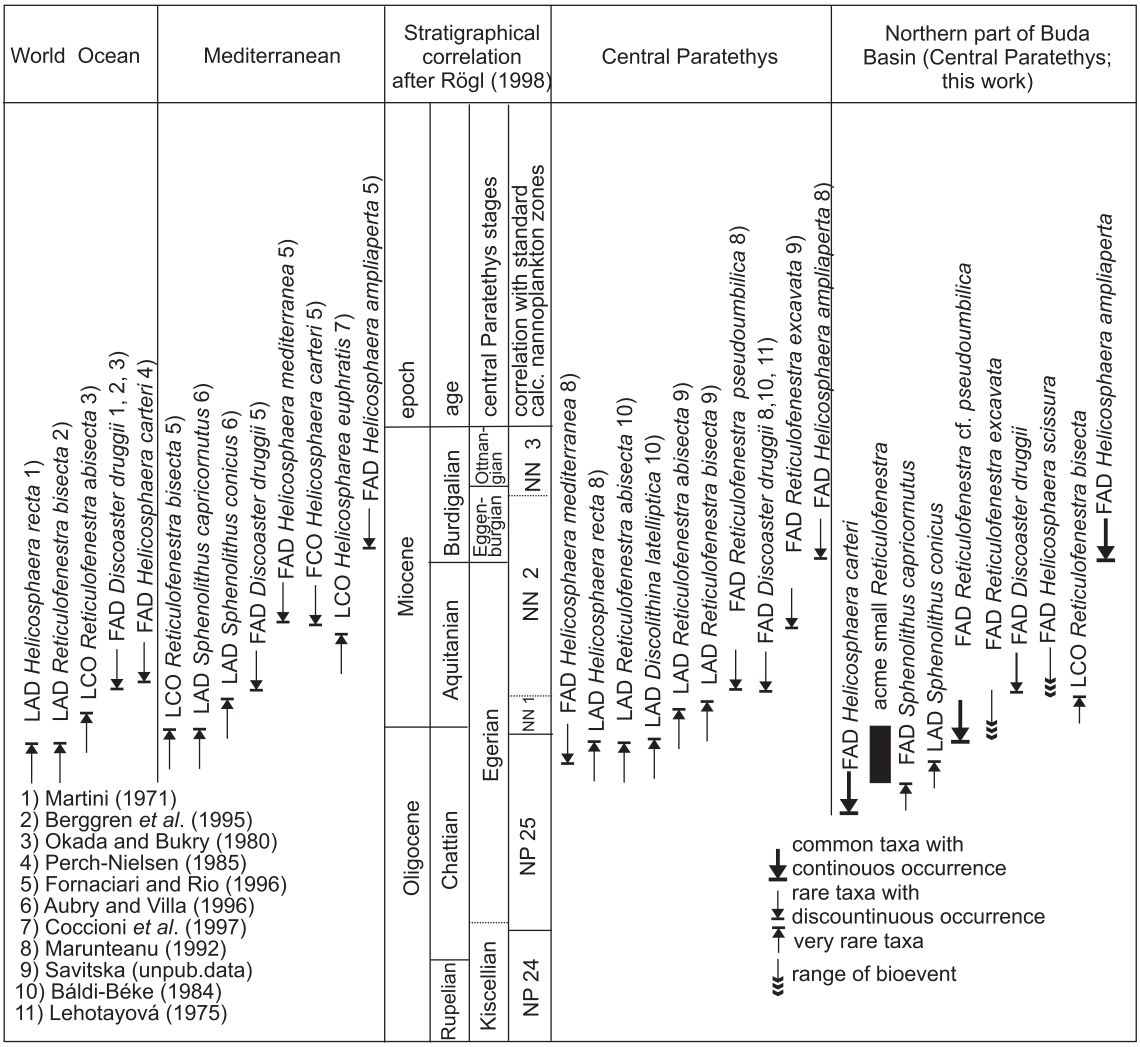

Fig. 12. Correlation of the most significant calcareous nannoplankton bioevents in the studied boreholes and sections studied

CONCLUSIONS

Six of the calcareous nannoplankton events observed can be clearly recognized in the South Slovak depressions. These events were compared with the distribution of planktonic and large foraminifers in the sections analysed, and the following correlation with standard biostratigraphic data can be made:

The FAD of *Helicosphaera carteri* is the oldest event in the studied sections. It was recorded closely above the LAD of *Paraglobigerina opima opima* in borehole LR-9 and can be correlated with the Oligocene. In other areas it was recorded in the younger Miocene NN 1, NN 2 Zones (Perch-Nielsen, 1985; Marunteanu, 1992, *Helicosphaera kamptneri*; Krhovský *et al*., 1995; Aubry and Villa, 1996, *etc*.). Also, its replacement by *H. euphratis* described from the Mediterranean was not observed, and the two taxa occur together.

The interval with abundant occurrence of small *Reticulofenestra* represents an ecostratigraphical event which is also repeated at other stratigraphical levels in the Central Paratethys (Karpatian: Spezzaferri and Coric, 2001; lower Badenian: Švábenická, 2002; Zágoršek and Holcová, in press). Gartner *et al*. (1983) proposed that the changes in relative abundance of *Reticulofenestra minuta* can be correlated with the changes in nutrient dynamics, Kameo (2002) classified very small *Reticulofenestra* ssp. as eutrophic species. This event can be correlated with the LAD of *Sphenolithus conicus* but *S. conicus* is very rare in the boreholes analysed, which reduces the reliability of its LAD.

The approximately isochronous FADs of larger reticulofenestras: *Reticulofenestra* cf. *pseudoumbilica* and *R. excavata* overlie the interval, with abundant occurrences of small reticulofenestras. The FAD of *Reticulofenestra* cf. *pseudoumbilica* can be correlated with the Oligocene on the basis of large foraminifers (Váňová, 1975) observed together with this species in the Budikovany section.

The FAD of *Discoaster druggii*, the standard biostratigraphic marker of the base of NN 2 Zone, was recorded commonly in the Central Paratethys area (Lehotayová, 1982; Marunteanu, 1992). In the section without *Discoaster druggii*, the FAD of *Helicosphaera scissura* can be used to approximately determine this stratigraphical level. The FADs of *Discoaster druggii* and *Helicosphaera scissura* are the first Miocene events recognizable in the South Slovak depressions.

The LAD of *Reticulofenestra bisecta*: this event can be used only for quantitatively analysed sections: above the level of its LAD, the species occurs discontinuously in the section. The event can be approximately correlated with the FADs of *Discoaster druggii* and *Helicosphaera scissura*. This agrees with its stratigraphical position described from the Central Paratethys (NN1/NN2 boundary, Savitska, unpubl. data) and is younger than that in the Mediterranean (lower part of NN 1 Zone around the Oligocene/Miocene boundary; Fornaciari and Rio, 1996).

The FAD of *Helicosphaera ampliaperta* was used as the marker for the base of the MNN 2b Subzone in the Mediterranean region (Fornaciari and Rio, 1996). In the Central Paratethys, this event was placed within the NN 2 Zone also from Romania (Marunteanu, 1992), while Lehotayová (1982) correlated it with the FAD of *Discoaster druggii* and the base of the NN 2 Zone.

This review shows that the interval of the uppermost part of the NP 25 Zone and of the NN 1 Zone lacks calcareous nannoplankton bioevents in the South Slovak depressions. Events occurring near the Oligocene and Miocene boundary in the World Ocean are only last appearance data (LAD) (Berggren *et al*., 1995; Fornaciari and Rio, 1996): LADs of *Reticulofenestra bisecta*, *Helicosphaera recta*, *Sphenolithus ciperoensis*, *Zygrhablithus bijugatus*, *Ericsonia fenestrata*. Among these events, the LADs of *R. bisecta* and *H. recta* can be observed in the area studied but at different stratigraphical positions (Fig. 12). *Helicosphaera recta* is very rare, no continuous occurrence can be observed, and the position of its FAD is not uniquely placed. *Reticulofenestra bisecta* occurred commonly and continuously up to NN 1/NN 2 boundary.

These results showed that the Oligocene/Miocene boundary approximation based on calcareous nannoplankton cannot be recognized in the area studied. The boundary falls between the FAD of *Reticulofenestra* cf. *pseudoumbilica* and the FADs of *Discoaster druggii* and *Helicosphaera scissura*.

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