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SEDIMENTARY, BIOLOGICAL AND ISOTOPIC RECORD OF EARLY APTIAN PALEOCLIMATIC EVENT IN THE PIENINY KLIPPEN BELT, SLOVAK WESTERN CARPATHIANS

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Abstract: Orbital perturbations of Barremian/Aptian climate traceable by sedimentological, biological and chemical proxies have been studied in Mt. Rochovica (Western Carpathians, Pieniny Klippen Belt) sedimentary sequence. This pelagic carbonate sequence represents a record of sedimentation on a distal edge of the Paleoeuropean shelf. Pelagic carbonate deposition was influenced by clastic input from the elevated Czorsztyn Ridge (microbreccia of Tithonian/Berriasian limestones) and by fluxoturbidites derived from unknown carbonate buildups. Interruption of carbonate deposition by the terrigeneous Koňhora Formation has been interpreted as a consequence of a humid event in the initial stage of the mid-Cretaceous Greenhouse climate. Three anoxia models (depositional, productivity and stagnant one) have been distinguished in the depositionary regime.

Key words: Lower Cretaceous, Western Carpathians, Slovakia, lithology, stratigraphy, bioevents, anoxic sediments, C-isotopes.

Introduction

A narrows formed by the Kysuca River (called the Kysuca Gate) penetrating through a tectonic body of the Jurassic/Cretaceous pelagic limestone (Fig. 1) exposes the sequence of the Kysuca Unit — one of the typical units of the Pieniny Klippen Belt. The Lower Cretaceous part of this sequence is exposed along the right riverside on the Mt. Rochovica foothill. This paper analyses the passage from the basinal Maiolica limestone with Barremian calciturbidite intercalations to dark shales of the successive Lower Aptian Koňhora Formation.

Our investigation is based on a multidisciplinary approach. The data are used for an interpretation of the sedimentary development of the Kysuca Basin from the paleoceanographical and paleoclimatological points of view.

Methods

The Hauterivian to Lower Albian sequence (more than one hundred meters) was sampled in two parallel sections: the first one is exposed along the road escarpment from Vranie to Rudinka villages (designated as the R-section in the text), the second one was eroded by 1997 summer floods along the right margin of the rocky bed of the Kysuca River (the K-section in the text). The rock samples for microfacies analysis were taken at one-meter intervals, more dense (up to decimeter scale) sampling being provided in critical parts of the sequence. Thin sections were made from each sample, then twenty one microcomponents from each section were evaluated in the optical microscope. A total of 448 thin sections have been examined. The results have been computed and illustrated (by the use of the personal computer) graphically (Fig. 2).

Quantitative analysis of the allochem spectra including plankton remnants can provide a base for the reconstruction of oceanographic environmental changes during sedimentation. Moreover, changes of fossil associations if compared with the carbon-isotope data can serve as a tracer of past environments. We focused on quantification of the full allochem spectrum in order to understand its response to both regional and global environmental changes and to analyze the relationship between evolution, climate, ocean behaviour and geological processes. The quantitative share of individual microplankton constituents was analysed in thin sections of limestone sample sets (see above). Biozonations introduced by Vašíček et al. (1994), Reháková (1995b), or Rehá-

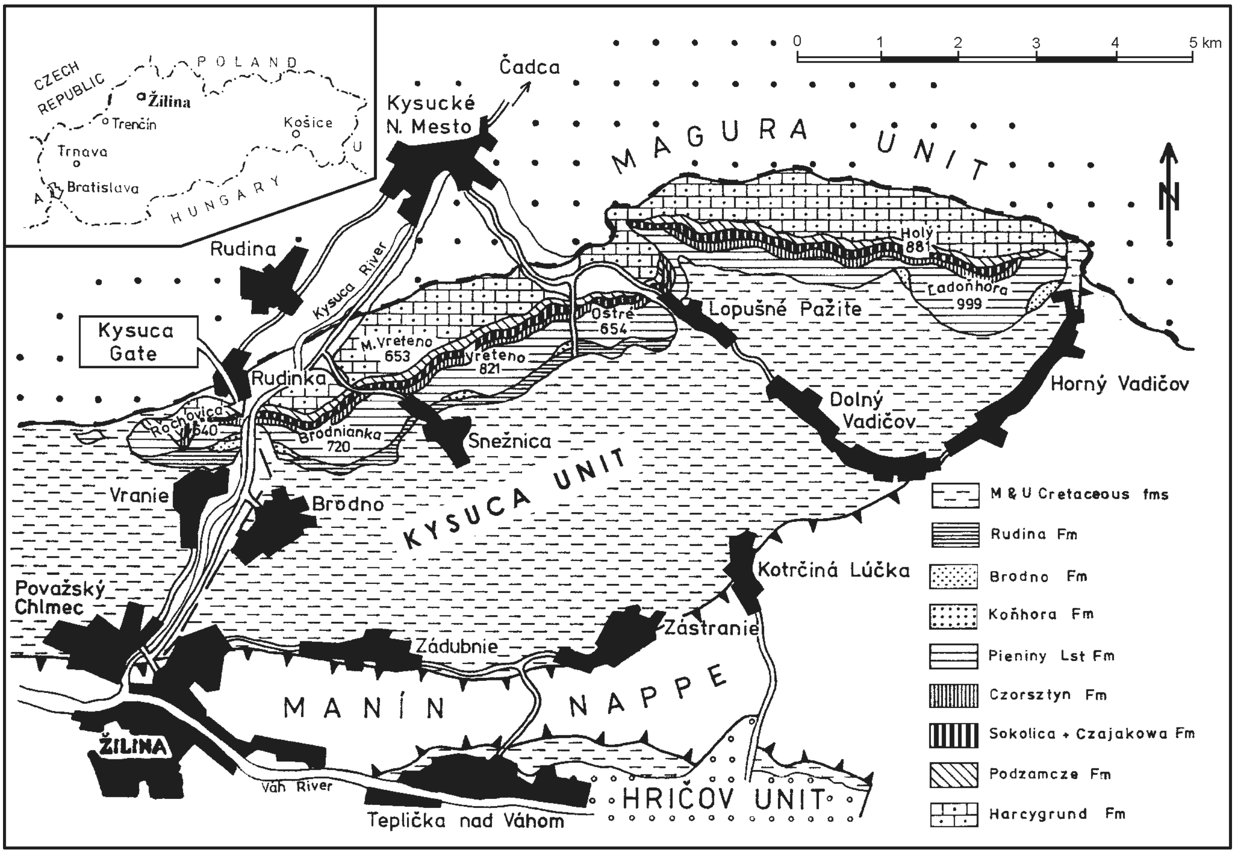


Fig. 1. Geological sketch of the Kysuca Gate area, NNE of Žilina, NW Slovakia (its position in Slovakia is indicated in the upper left corner) composition of the Kysuca Unit.

ková & Michalík (1997a) have been used. The foraminifers from the Rochovica profile were studied mostly in thin sections (with the exception of samples No. K-385, K-422.8, K-425.7, K-418). This fact, along with corrosion and recrystallization of many tests sometimes hampered more precise specific determination.

Thirty seven samples have been analysed for O a C isotope content. Stable isotopes were measured by a Finigan MAT-2 mass spectrometer. The analyses were done by the Czech Geological Survey in Prague. This laboratory method has been described in Michalík et al. (1995). The isotopic data are reported in the usual ‰ notation relative to the International Isotopic Standard PDB.

The TC, TIC and TOC was determined using an IR device, model C-mat 5500 (Stroehlein). The TC was determined directly in the combustion tube in the furnace. As the second step, 0.001 gram of rock sample was diluted in 1:10 HCl acid to remove TIC by vaporization. The TOC in the residue sample was determined by the same way at the TC. The TIC was calculated as the subtraction TC–TOC. The device was calibrated using synthetic spectral-pure $CaCO_3$.

Geological setting

In Mesozoic times, the Outer Western Carpathians formed a part of the northern Tethyan margin SE of the Bohemian Massif (Vašíček et al. 1994). The Pieniny Klippen Belt is interpreted as a deformed ridge on the edge of this shelf (Fig. 3). In spite of tectonic fragmentation of this complex structure, this area yields an almost complete record of the Jurassic and Cretaceous sedimentation. A Lower Cretaceous pelagic carbonate sequence belonging to the Kysuca Basin (adjacent to the main Czorsztyn Ridge) is well preserved in several tectonic slices (Andrusov 1938; Andrusov & Scheibner 1960; Scheibner 1968; Andrusov & Samuel 1973; Haško 1973; Birkenmajer 1977; Samuel et al. 1988; Vašíček et al. 1992).

Upper Tithonian to lowermost Albian Maiolica type limestones were deposited over wide parts of the Western Carpathians (Wieczorek 1988; Reháková 1995a; Michalík 1995). Two formations were distinguished in the Rochovica maiolica-type sequence. The lower one, called the *Pieniny Limestone Formation* by Birkenmajer (1977) is separated by the shaly *Koňhora Formation* from the upper limestone complex named the *Brodno Formation* (Fig. 2).

The Upper Tithonian–Barremian *Pieniny Limestone Formation* consists of white to grey nannofossil limestones with chert nodules and bands. Rhythmical bedding, best visible in the Lower Valanginian part of the sequence, is expressed either by alternation of limestone and marly layers or by repetitive mutual substitution of calcareous and siliceous plankton remnants, as well (Reháková & Michalík 1994). The Upper Valanginian facies variation, decrease of plankton and

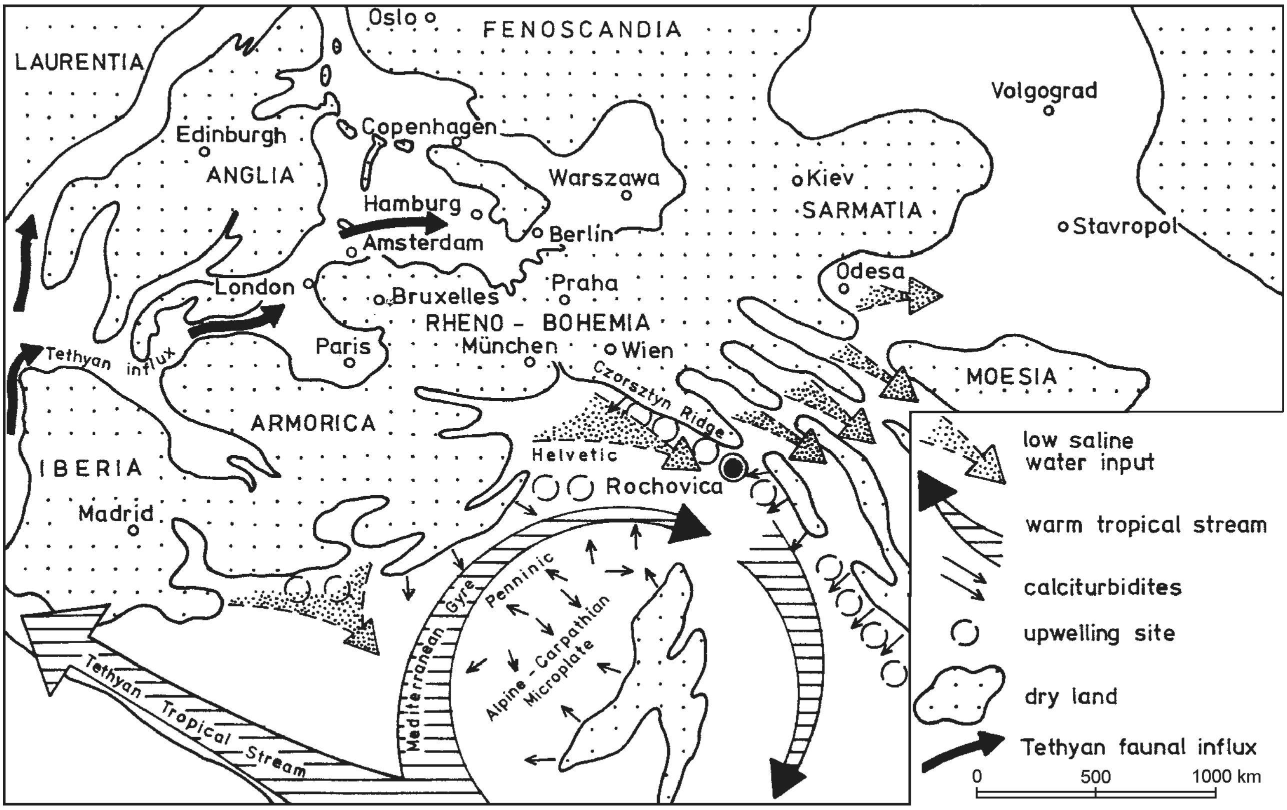


Fig. 2. Aptian paleogeography of Europe (with use of data from Baraboshkin 1997, Mutterlose 1992, Vašíček et al. 1994) with respect to the Rochovica section (indicated by full circle).

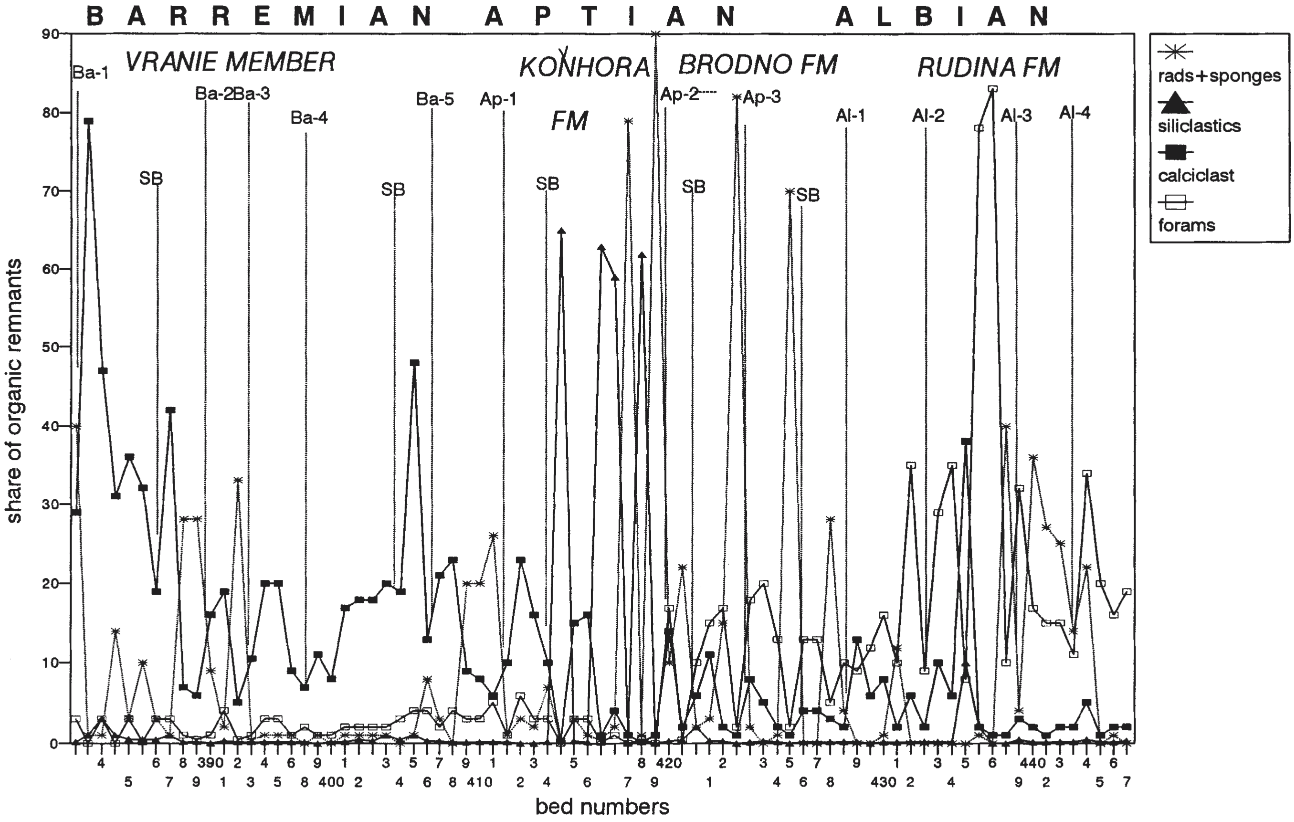


Fig. 3. Quantitative evaluation of share of organic remnants (radiolarians, sponge spicules, planktonic foraminifers and fragments of neritic benthic organism skeletons) and siliciclastics (quartz silt and clay) correlated with sequence stratigraphic division of the Vranie Mb., Koňhora-, Brodno- and Rudina Formations in the Rochovica (R) section.

their relations to the fluctuations in the C-isotope record were discussed by Michalík et al. (1995). Another five events with minimum plankton abundance are recognizable in the overlying Hauterivian to Aptian sequence. However, the carbon isotope geochemistry has not been studied here, yet.

The Barremian *Vranie Member* (new name, Figs. 2, 4) represents a calciturbidite-rich section in the uppermost Pieniny Limestone Formation. It consists of well bedded grey and dark grey, marly spotted nannoconid and foraminiferal wackestones to packstones interrupted by calcarenite layers with abundant fragments of benthic organisms. Sporadically observed gradation of biodetrital particles is considered a proof of the distal turbidite origin of several beds.

The Vranie Mb. limestone sequence is covered by the *Koňhora Formation* (Andrusov in Andrusov & Samuel 1973, or Andrusov & Fusán 1973; Fig. 4). Abrupt substitution of pelagic carbonates by dark marlstone with coalified plant fragments and pyrite indicates an important environmental change.

The Koňhora Fm. is followed by the Upper Aptian–Lower Albian *Brodno Formation* (Scheibner in Buday et al. 1967; Fig. 4) consisting of spotted limestones with intercalations of dark and red marls. This formation is covered by Upper Albian pelagic red marls of the *Rudina Formation* and by the Cenomanian *Lalinok Member* (Scheibner 1958) of the *Jaworki Formation* (Birkenmajer 1977).

Results

Sedimentological record and its sequence stratigraphic interpretation

The thickness variablity of pelagic limestone layers, thickness variation or absence of marly interbeds, presence of allodapic beds and intensity of bioturbation are the most expressive textural marks in the apparently monotonous Rochovica sequence. These data, along with quantitative changes in allochem representation in individual beds of the sequence were correlated with respect to the sea level changes in the Hauterivian–Aptian time (Vail et al. 1977; Haq et al. 1987). Individual allochem shares are of different interpretational value from the sequence stratigraphical point of view. First of all, the radiolarians, silicisponge spicules, planktonic foraminifers, neritic biodetrital- and terrigeneous clastic grains represent the constituents of the highest importance (Fig. 2).

The Vranie Member of the Pieniny Limestone Formation

The uppermost part of the Pieniny Limestone Formation consists mostly of planktogenic limestones with occasional intercalations of (calciturbiditic) calcarenites, slightly siliceous (contourite) calcisiltites marlstones and marls. The bedding is well developed, the thickness of beds attains 2 to 38 cm. Closer observation allowed us to distinguish intervals attributable to the 3rd-order sequence tracts.

The intervals interpreted as the *lowstand tracts* start with apparent thick (25–38 cm) layers of wackestones or packstones with abundant fine organic debris and with only thin (if any) intercalations of marl. The share of shallow benthic organism (echinoids, crinoids, benthic foraminifers, ostracods) debris is high (18–30 %), sometimes accompanied by a rise of the terrigenous clastic component (1 to 8 % in the higher part of the sequence). Tiny globular planktonic hedbergellid foraminifers occurring in limestone matrix represent (in accordance with Robaszynski & Caron 1995) opportunistic organisms of an unstable marine environment. Clasts of Berriasian calpionellid limestone (0.5 to 2 mm) containing conoglobuligerinid foraminifers also occur. Sometimes, indications of oriented debris lamination or erosion marks can be observed. The bioturbation is very strong, infaunal burrows being sometimes arranged in more-or-less regular galleries. In a complete development, tiering patterns of trace fossil generations similar to those illustrated by Uchman (1997) or Kedzerski & Uchman (1997) from the Valanginian–Barremian Koscieliska Formation in the High Tatra Mts. (*Thalassinoides–Planolites–Chondrites*) are preserved.

The intervals interpreted as probable *shelf margin tracts* are typically evolved in the upper part of the sequence studied. The thickness of wackestone layers is much smaller, if compared with the typical lowstands (attaining 15–22 cm only), slumping textures, or similar deformations occur. The amount of biogenic neritic organisms debris is low (5 to 18 %). Bioturbation is common, sometimes being arranged in more and less bioturbated bands (Pl. II: Figs.1, 6, 7).

The intervals interpreted as the *transgressive tracts* can be distinguished by regularly bedded (8–19 cm) wackestones with a medium bioturbation (*Planolites–Chondrites*, Pl. I: Figs. 3, 8) and common chert nodules. Marly layers occur irregularly. The content of calcareous dinoflagellates and globochaetes is raised moderately (1 to 3 %) compared to the lowstand- or highstand conditions. Silicification is infrequently observable. Calcarenite (packstone) layers with erosive bases were interpreted as calciturbidite beds occurring in the higher part of the sequence. They often replace interbeds of laminated siliceous calcisiltites (with thin lamina of radiolarian sand with erosive base compared with contourites), commonly occurring in the Pieniny Limestone Formation, but also in equivalent parts of both the Brodno and Rudina Formations (Pl. I: Fig. 9).

The sediments interpreted as the *highstand tract* systems are characterized by less bioturbated (mostly *Chondrites*), sometimes laminated mudstones (Pl. I: Fig. 5). Thin light-coloured beds (2–10 cm) with regular marly intercalations are often arranged in a rhythmic pattern. Silicification is extensive, with cherts sometimes forming stratiform bands. The maximum concentrations of radiolarians and/or sponge spicules are usually associated with the maximum flooding surfaces. On the sketch of Andrusov (in Andrusov & Fusán 1973), the uppermost beds of the Pieniny Fm. sequence below the Koňhora Fm. are deformed, resembling subaquatic slumping. Slumping phenomena have been also reported by Arthur & Premoli Silva (1982), Bersezio (1994) in an equivalent level (the uppermost part of the Maiolica Lst. Fm.), indicating a loading of poorly consolidated sediment by a huge input of terrigenous clastics.

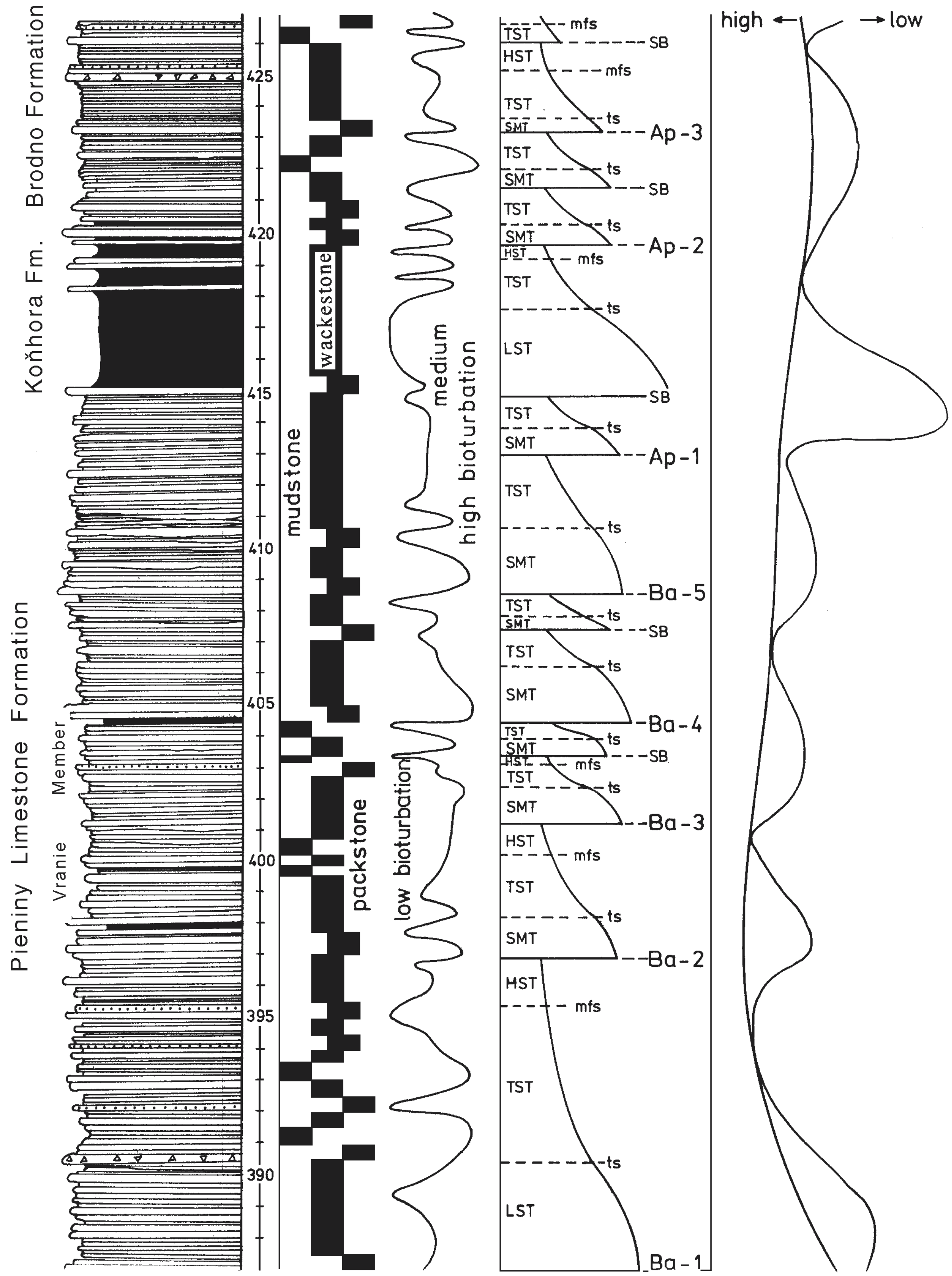
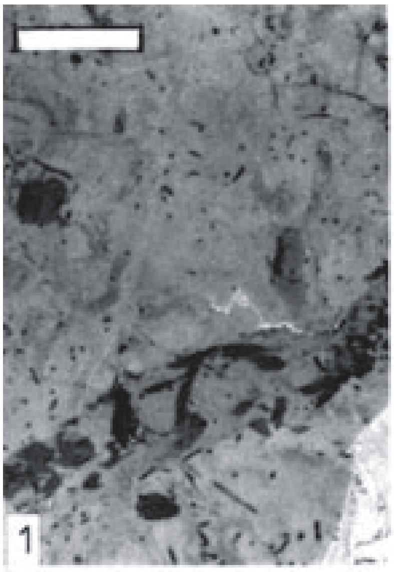


Fig. 4. Lithology, microfacies and bioturbation of the Vranie Mb., Koňhora and Brodno Fms. of the Rochovica sequence, K (Kysuca) section and its sequence stratigraphic interpretation correlated with the global sea level fluctuation curve (Vail et al. 1977).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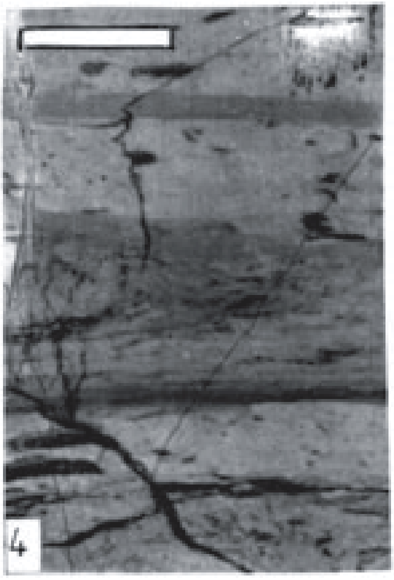
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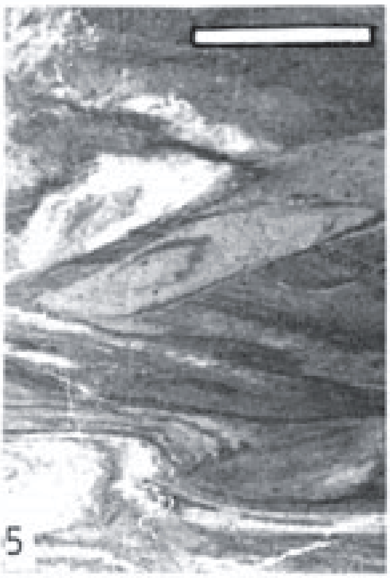
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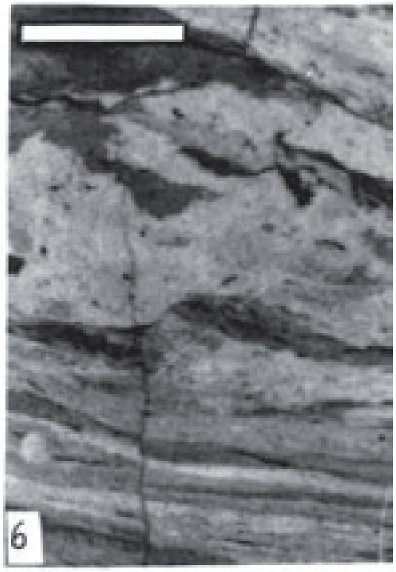
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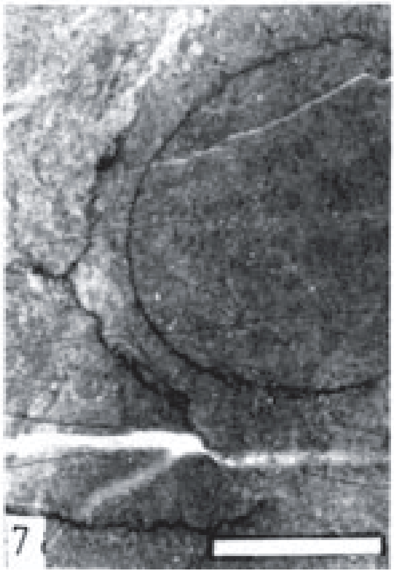
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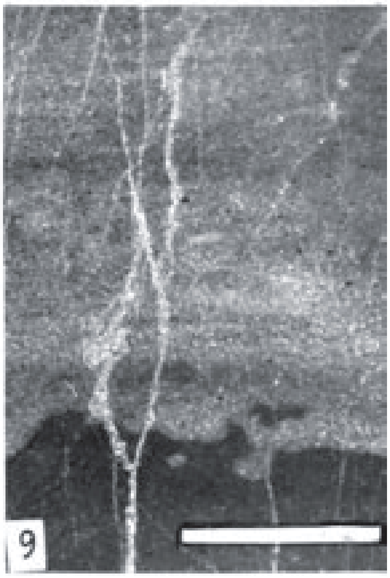
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The Koňhora Formation

According to Andrusov & Fusán 1973, it consists of a six to twenty meters of black to dark brown clays rich in plant fragments, common silt-sized quartz- and glauconite grains (Pl. II: Figs. 4, 5). Pyrite concretions are commonly altered into limonitic bodies. Benthic faunal remnants are missing, but pyritized remnants of ammonites and carbonized fish scales, bones and teeths occur sporadically. The major part of this sequence can be attributed to the lowstand facies expressively influenced by terrigenous influx.

Clayey beds represent decreasing terrestrial input upward, limestone intercalations appearing in the upper part of the formation represent time slices with raised calcareous plankton productivity (Pl. II: Fig. 9) and with sporadic marly limestone intercalations in the higher part. Bioturbation is common here, with infaunal burrows sometimes arranged in more-or-less regular galeries (Pl. I: Fig. 4). Parallel laminated radiolarian-rich laminae (Pl. II: Figs. 6–8) appear periodically in shaly sequence. In warmer intervals, indicated by an anoxic bottom regime, more stable marine conditions favoured the development of diversified planktonic foraminifer associations. This part of the Koňhora Formation was deposited during ongoing transgression.

The Brodno Formation

This, 13–16 m thick complex is represented by well bedded marly limestones with intercalation of grey (in the upper part reddish) marls. The Albian part of this formation is characterized by a renewal of the turbidite deposition. The sequence stratigraphic division is similar to that of the Vranie Member. Three sequences in which shelf margin and transgressive tracts have been distinguished, almost lack their highstand parts (Fig. 4). The uppermost, 35 cm thick layer of calciturbidite origin with large clasts of calpionellid limestone already belongs to the base of the overlying, 25 m thick Rudina Formation.

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Plate I: Limestone facies of the Rochovica section. **Fig. 1.** Ap-1 shelf margin tract facies (Vranie Mb., sample K-413.7) with *Chondrites* sp., and *Planolites* sp.; **Fig. 2.** Intensively bioturbated lowstand facies Ap-2 (Koňhora Fm., sample K-419.2) with *Planolites* sp.; **Fig. 3.** Transgressive stand facies (Pieniny Lst. Fm., sample K-345), ?*Planolites* sp. with gallery-like infilling; **Fig. 4.** Transgressive stand facies Ap-2 with lamination and *Planolites* sp. burrows (Koňhora Fm., sample K-420.5); **Fig. 5.** High stand facies Ba-3 of fine laminated limestones affected by slumping (Vranie Mb., sample K-404.4); **Fig. 6.** Shelf margin tract facies Ba-5, lamination destroyed by bioturbation (Vranie Mb., sample K-409); **Fig. 7.** Shelf margin tract facies Ha-3, fine detrital limestone with irregular sea urchins (Pieniny Lst. Fm., sample K-356); **Fig. 8.** Transgressive stand facies Ha-7, cherty limestone with silicified burrows of *Chondrites* sp. containing sponge spiculae accumulations (Vranie Mb., sample K-383); **Fig. 9.** Highstand contourite facies Al-1, calcisilte with radiolarian concentrations in laminae and with erosive base (Rudina Fm., sample K-428.6). Scale = 10 mm.

Microfacies

Four different microfacies were recognized in the studied section, all indicating open marine environments. Microfacies F1 to F3 indicate pelagic to hemipelagic environments which prevailed during sedimentation of the whole sequence studied. On the other hand, the microfacies F4 reflects the influence of outer platform (circalittoral) conditions: it occurs in calciturbidite beds of the Vranie Mb. The microfacies F1 consists of a biomicrite with rare ostracods, sponge spicules, planktonic foraminifers and small echinoderms debris. It is characteristic of a pelagic environment of the uppermost part of the Koňhora Formation, as well as of the Brodno Formation (Pl. II: Fig. 9). The microfacies F2 is a biomicrite with abundant recrystallized sponge spicules and radiolarians. It indicates hemipelagic to pelagic environments of the Koňhora Formation (Pl. II: Fig. 6). The microfacies F3 is characterized by a biomicrite with very abundant well preserved sponge spicules and radiolarians (F3A, Pl. II: Figs. 7, 8), or with abundant recrystallized planktonic foraminifers (Pl. II: Fig.10) with silty matrix rich in organic matter and pyrite accumulations (F3B). This microfacies indicates a pelagic to hemipelagic anoxic environment of the Koňhora Fm.

The microfacies F4 is represented by a biomicrite with an increasing amount of crinoids accompanied by bivalves, echinoids, benthic foraminifers, ostracods, sponges, radiolarians, dinoflagellates and planktonic foraminifers. Several beds contain bioclasts with calpionellids and conoglobigerinids (or almost free tests of them) evidently derived from older (mostly Lower Berriasian) horizons (Pl. II: Figs.1–3; Pl. VII: Figs.1–2). This microfacies has been observed in fluxoturbidite beds of the Vranie Member.

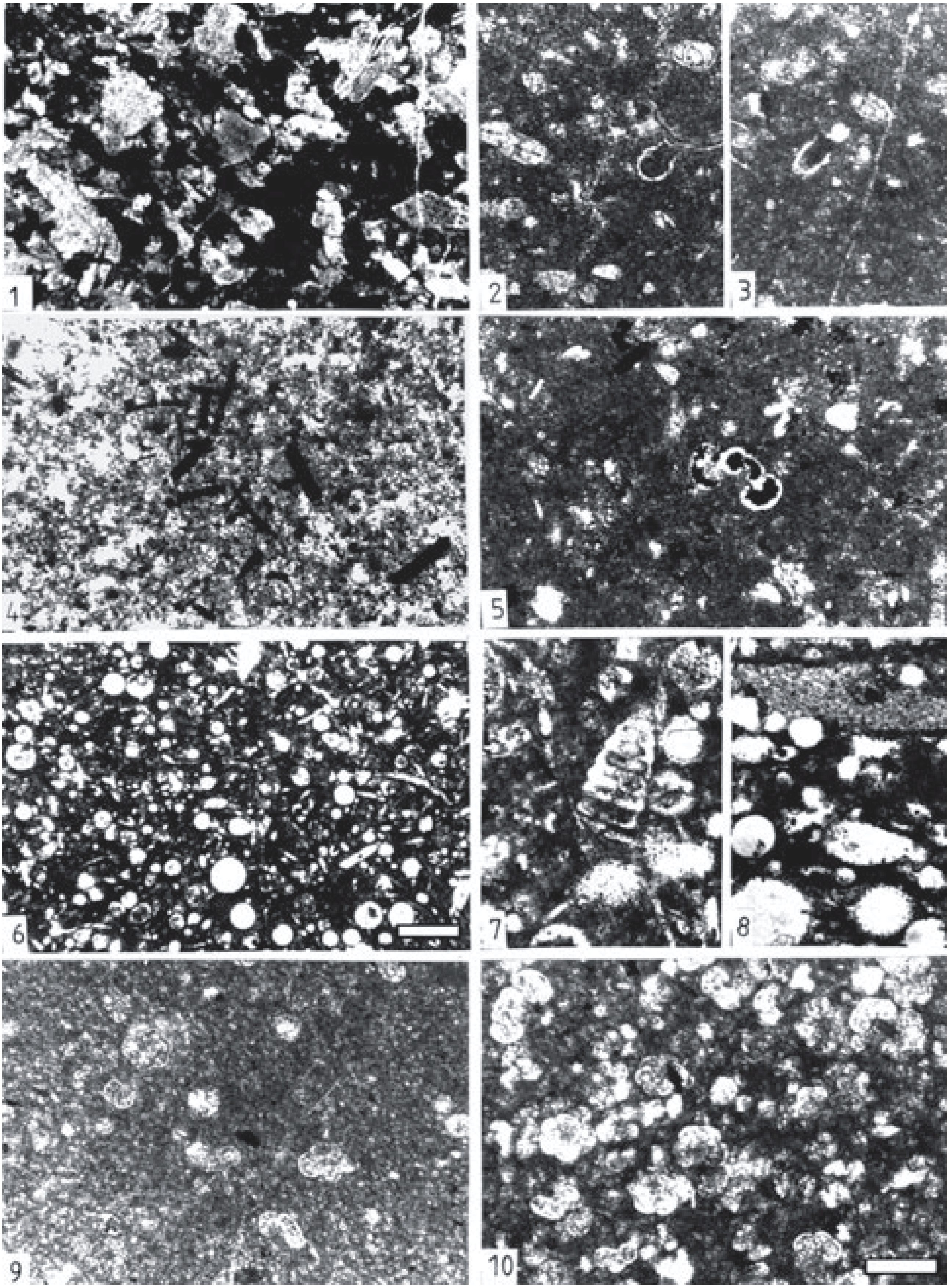
Biostratigraphical record

The Rochovica section study allows us to correlate several results of detailed bio-, sequence- and isotope stratigraphy. The biostratigraphic framework is based on integrated calpionellid, calcareous nannofossil, planktonic and benthic foraminifer and radiolarian events.

Calpionellids

The Hauterivian part of the Tintinnopsella Zone of Borza (1984) was defined as an interval by the occurrence of the last calpionellids represented by *Tintinnopsella carpathica* (Murgeanu & Filipescu). It is present in the middle part of the Pieniny Limestone Formation. Nannoconid mudstones (rarely wackestones) contain tiny debris of organic remnants dominated by ostracode tests and crinoid columnalia over benthic foraminifers (*Patellina subcretacea* Cushman & Alexander, *Spirillina italica* Dieni & Massari, *Textularia* sp., *Lenticulina* cf. *ouachensis* (Sigal)) and calcareous dinoflagellate cysts (*Cadosina semiradiata fusca* (Wanner)*, Cadosinopsis nowaki* Borza). A few cross-sections of *Tintinnopsella carpathica* were observed in association with the first representatives of planktonic foraminifers *Favusella hoterivica* (Subbotina).

PLATE II



Calciturbidite interlayers in both the Vranie Mb. and Brodno Formation contain rare, but surprisingly well preserved cross-sections of Berriasian calpionellids (*Calpionella alpina* Lorenz, *Crassicollaria parvula* Remane; Pl. II: Figs. 2, 3) and planktonic foraminifers *Favusella hoterivica* (Pl. VII: Figs. 1, 2).

Reháková & Michalík (1997b) stated, that the evolution of this group of calcareous microplankton reflects changes of the global climate. In turn, these changes directly influence the salinity and the sea water temperature. It seems that the calpionellid stagnation and radiation phases also coincided with sea level oscillations.

Planktonic foraminifers

Planktonic foraminifers, forming only a subordinate part of the foraminiferal microfauna in the Pieniny Limestone Formation, attain a dominant position in the Koňhora Formation. They are represented by *Hedbergella* sp., *H.* aff. *delrioensis* (Carsey), *H.* aff. *infracretacea* (Glaessner), *H. planispira* (Tappan) (Pl. IV: Fig. 6), *H. seminolensis* (Harlton), *H. similis* Longoria (Pl. IV: Fig. 3), *H. trocoidea* (Gandolfi), *H. tuschepsensis* (Antonova). Hedbergellids co-occur with *Planomalina (Globigerinelloides)* sp. (Pl. IV: Figs. 4–5), *Pl. (Gl.) algerianus* Cushman (Pl. V: Fig. 4), *Pl. (Gl.) blowi* (Bolli), *Pl. (Gl.) ferreolensis* (Moullade), *Pl. (Gl.)* cf. *maridalensis* (Bolli), *Clavihedbergella eocretacea* Neagu (Pl. IV: Figs.1–2), *Cl. subcretacea* (Tappan), *Leupoldina* cf. *pustulans* (Bolli) (Table 5, Figs.1, 2), *L. reicheli* (Bolli), *Biglobigerinella barri* Bolli, Loeblich & Tappan (Table 5, Fig. 3). Ancestral forms of the evolutionary lineage *Hedbergella trocoidea* (Gandolfi) – *Ticinella roberti*, appear in the higher parts of the Koňhora Formation sequence.

Foraminifers represent a rock forming constituent in several thin layers (sometimes rather laminae or "nests") in the Koňhora Formation. Current orientation was observed. Recrystallization of tests is obvious, pyrite fillings have been recorded in almost all thin sections (Pl. IV: Fig. 7). Foraminiferal fauna is sometimes substituted by the spumellarian type of radiolarians and sponge spicules. Common planktonic foraminifer tests filled by quartz, pyrite or rough calcite crystalls are represented by *Hedbergella* sp., *H.* aff. *delrioensis* (Carsey), *H.* aff. *infracretacea* (Glaessner), *H. planispira* (Tappan), *H. similis* Longoria, *H. tuschepsensis* (Antonova), *Clavihedbergella* sp., *Cl. eocretacea* Neagu, *Planomalina (Globigerinelloides)* sp., *Leupoldina reicheli* (Bolli) along with radiolarians and sponge spicules occur in the sample R-420-A (Pl. IV: Figs.1–6). Both the complete remnants of any benthic animals and the signs of bioturbation are missing here. Therefore, it seems that the bottom level was not inhabited by benthos and that skeletal fragments came from another environment (surface waters and/or more neritic parts of the bottom). Pyrite (now limonite) infillings of the tests (sample K-418, etc.) represent early diagenetic processes in anoxic black shale facies. Surprisingly, well preserved specimens of benthic *Lenticulina muensteri* (Roemer) and *Lenticulina* sp. preserved in original calcite test composition probably represent redeposits from the neritic zone.

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Plate II: Microfacies of Vranie Mb., Koňhora- and Brodno Fms. Figs. 1–3. Microfacies F4: biomicrite with abundant crinoids (Fig. 1) accompanied by rare benthic foraminifers, ostracods, and bioclasts with calpionellids. *Calpionella alpina* Lorenz, *Crassicollaria parvula* Remane are shown on Figs. 2–3. Vranie Mb., samples K-383.3; K-385; K-414. **Figs. 4–5.** Dark grey to black clayey Koňhora Fm. marlstone. Silty matrix is rich in organic matter and pyrite accumulation. Organic remnants are sporadicaly presented (*Hedbergella* sp. on the Fig. 5), Samples R-416; R-420. **Figs. 6–8.** Microfacies F3A: radiolarian-sponge packstones with common claystone fragments, glauconite and quartz grains occur occasionally. Koňhora Fm., samples R-419, R-422.8. **Fig. 9.** Microfacies F1: nannoconid mudstone with rare sections of planktonic foraminifers. This microfacies is typical of the uppermost part of the Koňhora Formation as well as of the Brodno Fm. Sample R-424 (thin nannoconid rich laminae were observed throughout all the Koňhora Fm. too, samples R-417). **Fig. 10.** Microfacies F3B: packstone with abundant diverse planktonic foraminiferal association. Brodno Formation, sample R-423.5. The bar in the Fig. 6 is equal to 200 µm, other figures are related to the bar in Fig.10 = 100 µm.

The Aptian part of the Brodno Formation yields an association of *Ticinella* sp., *T. bejaouaensis* Sigal, *Hedbergella* sp., *H. seminolensis* (Harlton) (Pl. VI: Figs. 2–5), *Clavihedbergella subcretacea* (Tappan) (Pl. VI: Fig. 1) Albian planktonic foraminifers are represented by *Ticinella roberti* (Gandolfi) (Pl. V: Fig. 5), *Biticinella breggiensis* (Gandolfi) (Pl. V: Fig. 6), *Thalmaninella ticinensis subticinensis* (Gandolfi) and *Th. ticinensis ticinensis* (Gandolfi) (Pl. V: Figs. 7, 8). These are accompanied by radiolarians, smooth ostracods and sponge spicules in the Brodno Formation. Rare glauconite proves the presence of bottom currents.

Calcareous nannofossils

Calcareous nannofossils in the Rochovica section were mostly examined from marly shales intercalated in pelagic limestones. Low diverse nannofossils were generally poorly preserved, and dominated by the most common solution-resistant long-ranging taxa like *Nannoconus, Watznaueria, Micrantholithus,* or *Rucinolithus*. Nannofossil biostratigraphical markers are very rare.

According to Deres & Acheritequy (1980), the first appearence datum (FAD) (sample No. 325) of *Nannoconus bucheri* aproximates to the Valanginian/Hauterivian boundary near the sample 325. Nannoconids start to be abundant in the upper part of the Lower Hauterivian interval of the Pieniny Limestone Formation (sample 343). Other frequent taxa are rather long ranging *Micrantholithus hoschulzii, Zeugrhabdotus embergeri, Conusphaera mexicana.* Rare occurrences of the Early Hauterivian-Early Barremian index species (sensu Mutterlose et al. 1996) *Litraphidites bollii* (with FAD in 331 and the last appearence datum—LAD 343), *Cruciellipsis cuvillieri* (LAD 331) denoting by its last occurrence the Early/Late Hauterivian boundary, or *Calcicalathina oblongata* occuring sporadically (FAD 331, LAD 337) in Lower Valanginian to Lower Barremian deposits (Mutterlose et al. 1996) are useful. The maximum dominance of *Nannoconaceae* (namely *N. steinmanni*) was recorded in limestone sample No 368. The first representatives of *Rucinolithus* started in the Upper Hauterivian part of the section (sample 368).

The change in the nannoplankton assemblages near the Hauterivian/Barremian boundary (sample 390) showed decreasing nannoconid size, but increasing diversity of the assemblage (*N. globulus, N. colomi, N. kamptneri, N. bucheri, N. boneti*, abundant micrantholiths).

The Vranie Member yields very abundant *Watznaueria barnesae* and the Barremian-Early Aptian (Erba et al. 1996) index species *Nannoconus circularis* (sample 409).

The Koňhora Formation contains a diverse nannofossil association heavily damaged during diagenesis. Sudden increase of the nannolith group Polycyclolithaceae (*Assipetra infracretaceea*, *Rucinolithus irregularis, R. terebrodentarius*) and decrease of Nannoconacea was observed. A similar decrease event ("nannoconid crisis") was described by Erba 1994. The FADs of *Chiastozygus litterarius* (416) and *Rucinolithus irregularis* (418) were recorded.

The Brodno Formation is characterized by abundant *Rucinolithus* (423, 425), higher dominated *Watznaueria barnesae* and *Nannoconus*, while *Rucinolithus* occurs in low numbers only. According to Perch-Nielsen (1985) the LAD of *Conusphaera mexicana* indicates the Early/Late Aptian boundary. This event was recorded in the sample No. 423. The FAD of *Ephrolithus floralis* and this of *Rhagodiscus angustus* (436) could evidence the Late Aptian Rhagodiscus angustus Zone.

The Rudina Formation include a relatively rich association of poorly preserved calcareous nannoflora dominated by *Watznaueria barnesae*. The presence of poorly preserved *Eiffelithus turriseiffelii* (samples 437, 439) points to the presence of Upper Albian-Lower Cenomanian (CC9 Zone) nannofaunal complexes. On the other hand, the Early Albian *Prediscosphaera columnata* (CC8) zonal index was not found.

In summary, nine nannofloral bioevents have been observed in the section studied:

437 — FAD *Eiffelithus turriseiffelii*

436 — FAD *Rhagodiscus angustus* + *Ephrolithus floralis* (see discussion in Bischoff 1998 and Bischoff & Mutterlose 1998)

423 — LAD *Conusphaera mexicana* (redeposited specimens have also been found in the beds up to 436)

418 — FAD *Rucinolithus irregularis* + *Chiastoyzgus litterarius*

390 — FAD *Rucinolithus terebrodentarius*

356 — LAD *Calcicalathina oblongata* (redeposited specimens have also been found in the beds up to 420)

343 — LAD *Litraphidites bollii*

331 — FAD *Litraphidites bollii* + LAD *Cruciellipsis cuvillieri*

337 — *FAD Calcicalathina oblongata*

325 — FAD *Nannoconus bucheri*

Several changes in assemblage composition, namely abrupt increase of *Rucinolithus terebrodentarius* and decrease of *Nannoconaceae* were recorded in sample sequence 416–423. Redeposition was observed several times (420, 433, 436).

Dinoflagellates and palynomorphs

The Vranie Member contains an association of long-ranging Barremian-Aptian dinocysts (Table 1, sample 408.5) of rather low diversity (8 species).

The dinocyst diversity of the Koňhora Fm. association is much higher, being dominated by (30 %) *Odontochitina operculata*. This association, in which the bisaccate pollen grains form 1/3 of the assemblage, characterizes a restricted shallow marine environment. *Achomosphaera verdieri*, *A. triangulata*, *Bathiacasphaera saidensis*, *Coronifera tubulosa* found in layer 415, indicate Aptian age (Below 1981, 1982, 1984; Below & Hirsch 1996). An increasing share (27 %) of *Achomosphaera* and *Spiniferites* in the higher part of the formation indicates more open marine conditions.

The presence of *Callaiosphaeridium trycherium, Florentinia laciniata* and *F. mantelii* in the higher part of the Koňhora Fm. (samples 419, 421) could indicate mid-Aptian age (Below l.c.; Verdier 1974).

Frequent middle/upper Aptian dinocyst occurrence (40 % of *Cerbia tabulata*, accompanied by 28–37 % of *Oligosphaeridium*) in the Brodno Formation (beds Nos. 421–425) confirms open marine conditions. Marly bed No. 429.2 contains a redeposited Upper Aptian association with *Cerbia tabulata* (Leereveld 1995; Below l.c.).

Radiolarians

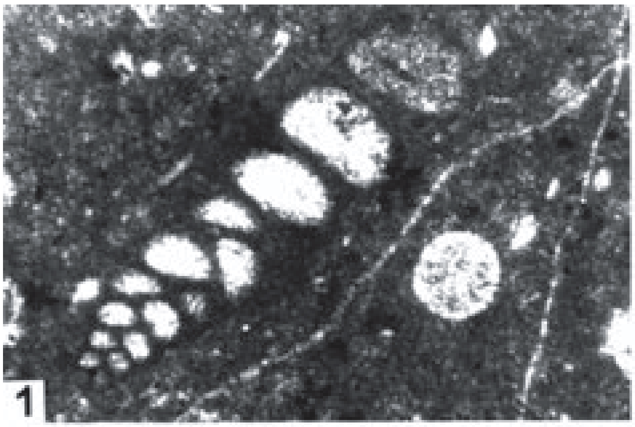
Three radiolarian assemblages have been obtained from chert nodules and siliceous bands of both the Koňhora and Brodno Formations (samples Nos. 419, 422.9 and 422.7; Table 2). Radiolarian tests are usually corroded, the nassellariids/spumellariids ratio 4:2 could have been affected by a preservation bias caused by preferable dissolution of the larger and less resistent spumellariid tests.

The association from the Koňhora Formation (sample No. 419) is dominated by *Archaedictyomitra apiarium* and *Xitus spicularius* over species of *Angulobracchia, Dictyomitra, Parvicilgula, Stylospongia* and *Thanarla*.

The second association (sample No. 422.9) coming from the Brodno Formation contains common *Archaedictyomitra apiarium*, *Dictyomitra pseudoscalaris*, *Pseudodictyomitra lilyae, Pantanellium squinaboli* accompanied by *Cryptamphorella clivosa*, *Sethocapsa trachyostraca*, *Tritrabs* cf. *ewingi*, *Orbiculiforma* sp. and *Sethocapsa* sp. The third association (sample No. 425.7 of the same formation) is composed

Plate III: Barremian/Aptian benthic foraminifers of the Rochovica section. **Fig. 1.** *Aaptotoichus clavellatus* (Loeblich & Tappan), sample K-390; **Fig. 2.** *Textularia haeusleri* Kaptarenko, sample K-410; **Fig. 3.** *Proromarssonella praeoxycona* (Moullade) sample K-424; **Fig. 4.** *Kadriayina granata* (Berthelin), sample K-416; **Fig. 5.** *Dorothia praehauteriviana* Dieni & Massari, sample K-397; **Fig. 6.** *Spirillina italica* Dieni & Massari, sample K-361.5; **Fig. 7.** *Meandrospira favrei* (Charollais, Bronnimann & Zaninetti), sample K-377; **Fig. 8.** *Haplophragmoides* cf. *vocontianus* Moullade, sample K-343. The magnification of all figures is uniform, indicated by the bar on Fig. 8 = 100 µm.

PLATE III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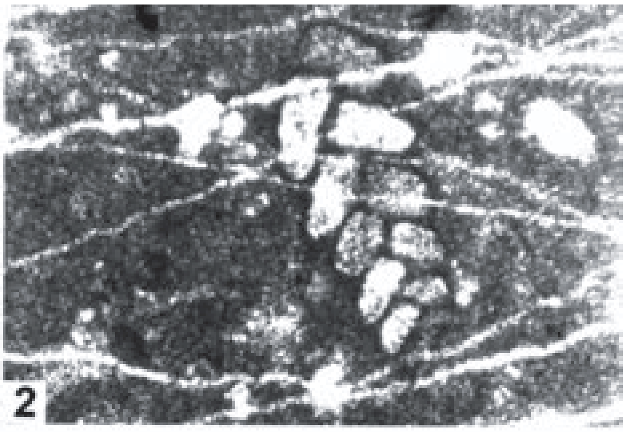
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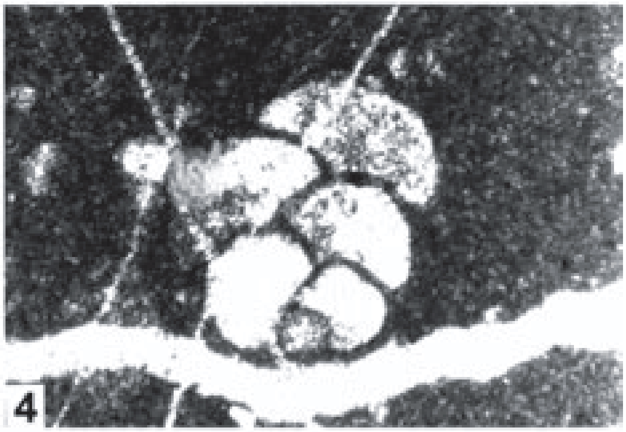
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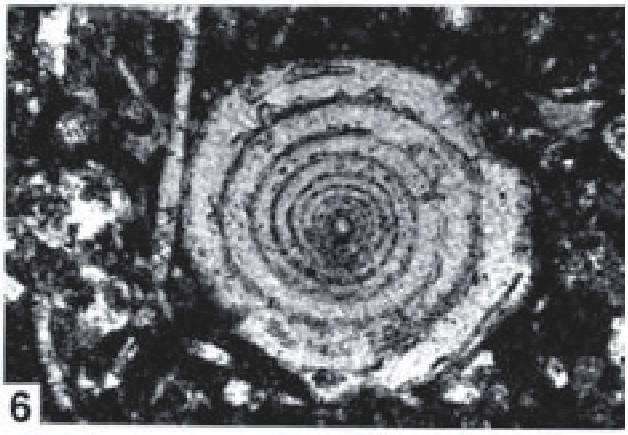
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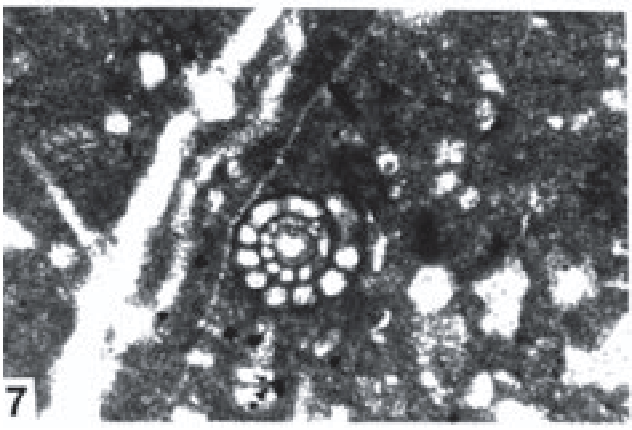
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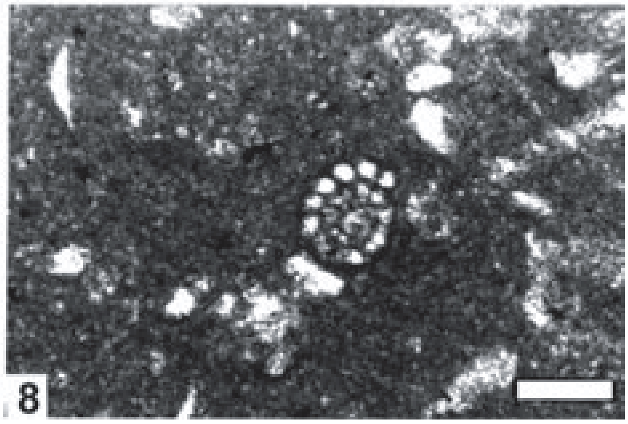
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Table 1: Relative abundance of dinoflagellate cysts and other palynomorphs in the Koňhora Formation (sample 408.5 comes from close underlying beds, sample 429.2 from overlying beds). x — rare (less than 4 %), xx — occasional (4–8 %), xxx — common (8–15 %), xxxx — abundant (15–30 %), xxxxx — very abundant (more than 30 % of all palynomorphs).

Vranie Mb	Koňhora Fm.		Brodno Formation			
408.5	415	419	421	425	429.2	Samples/data
						Dinoflagellate cysts
x						*Pterodinium aliferum*
xx						*Cribropteridinium edwardsii*
x	x		xx			*Oligosphaeridium asterigerum*
xx	x	xxx	x			*Exochosphaeridium muelleri*
x				x		*Endoscrinium campanula*
x			x	x		*Achomosphaera ramulifera*
x	xxx	xx	xx	x	x	*Spiniferites ramosus*
xxxxx	xxx	xxx	xxxxx	xxxx	xxx	*Oligosphaeridium complex*
	x					*Callaiosphaeridium asymmetricum*
	x					*Cassiculosphaeridia reticulata*
	x					*Cometodinium whitei*
	x					*Cyclonephelium brevispinatum*
	x					*Kiokansium polypes*
	xx					*Batiacasphaera saidensis*
	xx					*Cribroperidinium cooksoniae*
	xx					*Florentinia cooksoniae*
	x	x				*Kleithriasphaeridium corrugatum*
	x	x				*Kleithriasphaeridium eoinodes*
	x		x			*Coronifera tubulosa*
	x	x	x			*Coronifera oceanica*
	x		x	xx		*Achomosphaera triangulata*
	x	xxxx			x	*Achomosphaera neptunii*
	xx	x	x		x	*Achomosphaera verdieri*
	xxxx	xxxxx			xx	*Odontochitina operculata*
		x				*Cribroperidinium orthoceras*
		x				*Florentinia mantelli*
		xx	xxxxx	xxxxx	xxxx	*Cerbia tabulata*
		xx			x	*Florentinia laciniata*
			x			*Dissiliodinium globolus*
			x			*Florentinia radiculata*
			x			*Spiniferites ramosus reticulatus*
			x			*Trabeculidinium quinquetrum*
			x	x		*Callaiosphaeridium trycherium*
				x		*Cribroperidinium auctificium*
				x		*Prolixosphaeridium parvispinum*
				x		*Systematophora cretacea*
				xx		*Apteodinium granulatum*
				xx		*Lithodinia stoveri*
				xx		*Oligosphaeridium verrucosum*
					x	*Dapsilidinium multispinosum*
					x	*Palaeoperidinium cretaceum*
					x	*Spiniferites ancoriferus*
					x	*Systematophora silybum*
					xxxx	*Circulodinium distinctum*
					xxxx	*Cyclonephelium* sp.
						Other palynomorphs
xxxxx	x	x	x			microforaminiferal test linings
x	x	x	x		x	spores
xxx	xxx	xxxx	xxxx	xx	xxxxx	bisaccate pollen grains
8	20	13	15	13	13	Total abundance

of *Acanthocicus trizonalis* s.l., *Acanthocicus* sp., *Angulobracchia* (?) *portmani portmani*, *Archaeodictyomitra apiarium, Archaeodictyomitra* sp., *A. chalilovi, Dictyomitra communis, D. pseudoscalaris, Godia tecta, Holocryptocanium* sp., *Mirifusus chenodes, Orbiculiforma* sp., *Pseudodictyomitra* sp., *Pantanellium squinaboli, Sethocapsa trachyostraca, Thanarla pulchra, Wrangellium puga* (Table 2).

According to Baumgartner (1995), the presence of *Stylospongia* (?) *titirez* and *Godia tecta* limits lower Aptian UA Nos. 20 to 22. According to O´Dogherty (1994), *Dictyomitra communis* represents a Late Aptian age.

Benthic foraminiferal fauna

The benthic foraminifers prevail in the lower members of the sequence studied. According to Maamouri et al. (1994) *Conorotalites* ex gr. *bartensteini* Bettenstaedt, found in the Vranie Member (sample R-391; Pl. VII: Fig. 3) represents a

Table 2: Relative abundance of radiolarians in the Koňhora and Brodno Formations. o — occasional, oo — common, ooo — abundant occurrence.

419	422.5	425.7	samples/data
o			*Stylospongia (?) titirez*
oo			*Xitus spicularius*
oo			*Xitus* sp.
oo			*Parvicingula* sp.
o		o	*Angulobrachia(?) p.portmani*
oo	oo	ooo	*Archaeodictyomitra apiarium*
oo	oo	oo	*Dictyomitra communis*
o		oo	*Thanarla pulchra*
	o		*Tritrabs* cf.*ewingi* s.l.
	o		*Sethocapsa* sp.
	oo		*Pseudodictyomitra lilyae*
	oo		*Cryptamphorella clivosa*
	o	o	*Sethocapsa trachyostraca*
	o	o	*Orbiculiforma* sp.
	o	ooo	*Pseudodictyomitra* sp.
	oo	oo	*Dictyomitra pseudoscalaris*
	ooo	ooo	*Pantanellium squinaboli*
	ooo	ooo	*Archaeodictyomitra* sp.
		o	*Godia tecta*
		o	*Holocryptocanium* sp.
		oo	*Acanthocircus trizonalis* s.l.
		oo	*Acanthocircus* sp.
		oo	*Archaeodictyomitra chalilovi*
		oo	*Mirifusus chenodes*
		oo	*Wrangellium puga*

Table 3: Content of $\delta^{18}O$, $\delta^{13}C$, TOC and $CaCO_3$ in selected samples from Vranie Mb., Koňhora, Brodno and Rudina Formations in the Rochovica R section.

Beds	δ ^{13}C	δ ^{18}O	TOC	CaCO3
m	‰(PBD)		%	
320	1.7	-2.8	0.05	93.90
324	1.7	-1.8	0.05	67.60
352	1.5	-2.1	0.06	87.80
375	1.7	-2.4	0.05	81.30
384	2.1	-1.6	0.05	91.40
389	2.3	-1.7	0.05	91.20
392	2.8	-1.5	0.05	89.60
394	2.6	-2.4	0.05	44.70
395.1	2.6	-2.1	0.12	90.40
396	2.5	-1.6	0.05	88.50
412	2.4	-2.6	0.05	90.80
413	2.4	-2.6	0.05	89.60
416	1.6	-5.0	1.50	28.70
417	1.8	-4.7	0.44	48.10
418	1.7	-4.2	1.16	27.00
420	3.2	-3.7	1.27	57.80
422.5	4.4	-2.2	0.05	87.30
422.8	3.7	-2.0	0.07	77.90
423.5	4.6	-2.5	0.18	84.10
425	4.4	-2.3	0.05	82.40
427	4.9	-2.3	0.06	82.20
428	4.8	-2.7	0.05	87.30
430.1	4.6	-2.3	0.05	84.23

Barremian index. The occurrence of *Patellina* cf. *turriculata* Dieni & Massari (Pl. VII: Fig. 4) is remarkable, as the species was currently reported from Albian beds only.

Calcarenite layers forming characteristic element of the Vranie Member contain rich associations of fragments derived from neritic benthic skeletons, dominated by crinoid columnalia and other echinoderm remnants. Benthic foraminifers are represented by *Aaptotoichus clavellatus* (Loeblich & Tappan) (Pl. III: Fig. 1), *Ammodiscus tenuissimus* (Guembel), *Dorothia* cf. *glabrata* Cushman, *Dorothia kummi* (Zedler), *Dorothia praehauteriviana* Dieni & Massari (Pl. III: Fig. 5), *Gaudryina tuchaensis* Antonova, *Gavelinella* cf. *barremiana* Bettenstaedt, *Gyroidinoides gracillima* (Dam), *Haplophragmoides* cf. *vocontianus* Moullade (Pl. III: Fig. 8), *Spirillina minima* Schacko, *Spirillina italica* Dieni & Massari (Pl. III: Fig. 6), *Meandrospira favrei* (Charollais, Bronnimann & Zaninetti) (Pl. III: Fig. 7), *Ophthalmina* cf. *scariosa* Loeblich & Tappan, *Pseudoreophax* sp., *Sabaudia minuta* Hofker, *Textularia hausleri* Kaptarenko (Pl. III: Fig. 2), *Spiroloculina duestensis* Bartenstein & Brand, *Trocholina* sp. (Pl. VI: Fig. 6). They are accompanied by very abundant (58 % of palynospectrum in sample 408.5) microforaminifers, indicating transport from a shallow neritic environment. Smooth valved ostracods (Pl. VI: Fig. 9) are also present.

Only *Kadriayina gradata* (Berthelin) (Pl. III: Fig. 4) was identified in the lower part of the Koňhora Formation. *Anomalina flexuosa* Antonova was identified in its higher part.

Calciturbiditic intercalations in the Brodno Formation yield rare specimens of *Dorothia* aff. *oxycona* (Reuss) (Pl. VI: Fig. 7), *Proromarssonella praeoxycona* (Moullade) (Pl. III: Fig. 3), *Lenticulina* cf. *subangulata* Reuss, *Lenticullina* (L.) *ouachensis* (Sigal) (Pl. VI: Fig. 8), *Discorbis wassoewizi* Djaffarov & Agalarova, *Lenticulina muensteri* (Roemer), *Anomalina* sp. (Pl. VII: Fig. 5) and *Ammovertella cellensis* Bartenstein & Brand.

Distribution of redeposited benthic foraminiferal fauna can be effectively used in correlation of pelagic developments with contemporaneous shallow marine carbonate platform sequences, little investigated at present.

Geochemistry

Paleoceanographic and paleoclimatic changes during the mid-Cretaceous are detectable with use of C and O isotope geochemistry and the accumulation record of organic matter. That is the reason why geochemical studies oriented towards these problems became popular in the Earth sciences. Episodes with large-scale storage of organic matter coincide with sea-level rises, which were produced by an increased rate of sea floor spreading (Schlanger et al. 1981; Schlanger & Cita 1982; de Boer 1983). A dramatic increase in ocean crust production and abnormal mid-Cretaceous interplate volcanism was postulated by Larson (1991). At the Barremian/Aptian transition, the volcanic Ontong Java Plateau was formed, near the Aptian/Albian boundary Kerguelen Plateau volcanism was active (Schlanger et al. 1981; Tarnudo et al. 1991; Bralower et al. 1997). Excessive CO_2 added to the atmosphere during this “superplume” may have triggered glo-

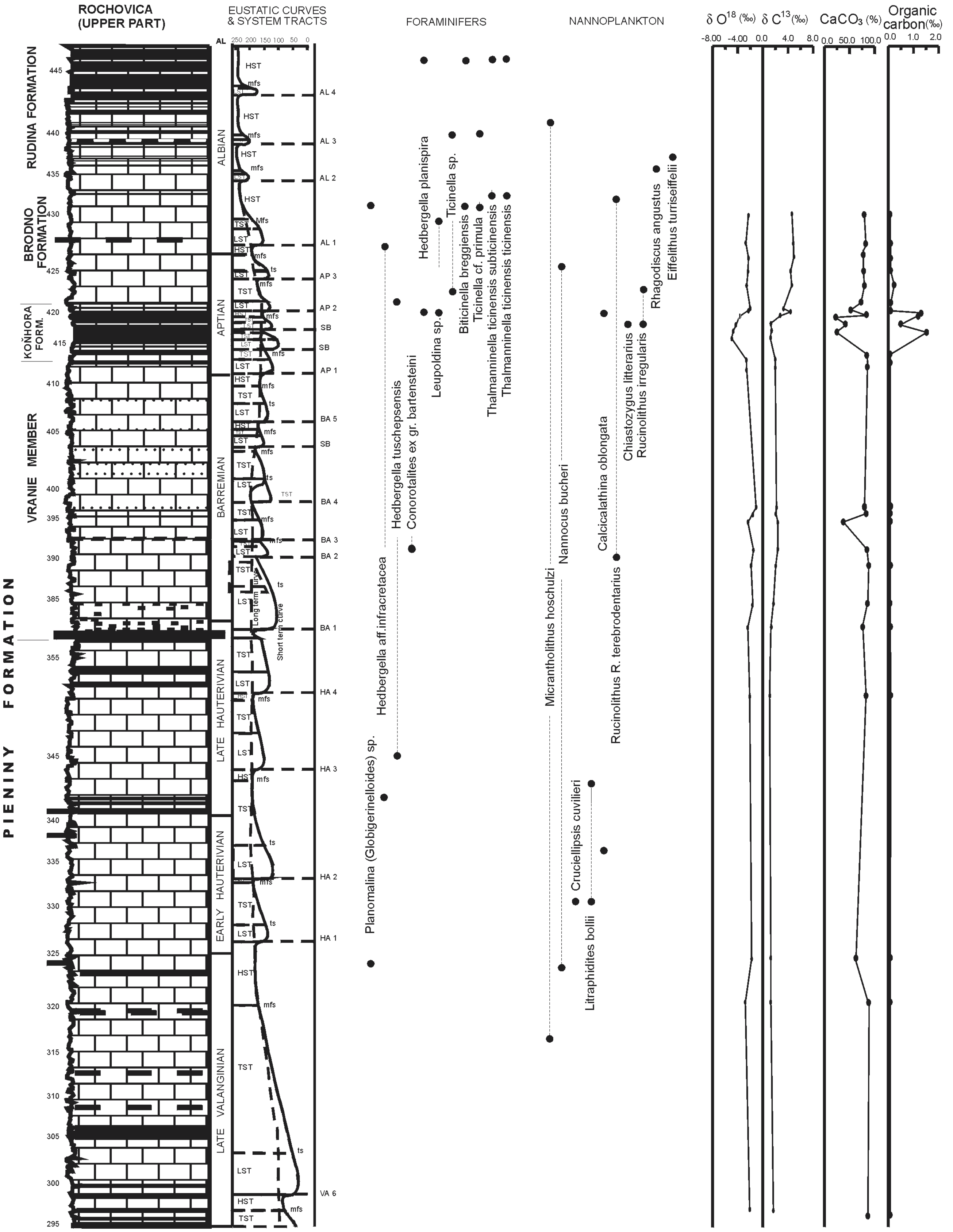

Fig. 5. C and O isotope record in pelagic carbonate sequence of the Rochovica section in the Kysuca Gate near Žilina. Numbers denote metric scale of the exposure.

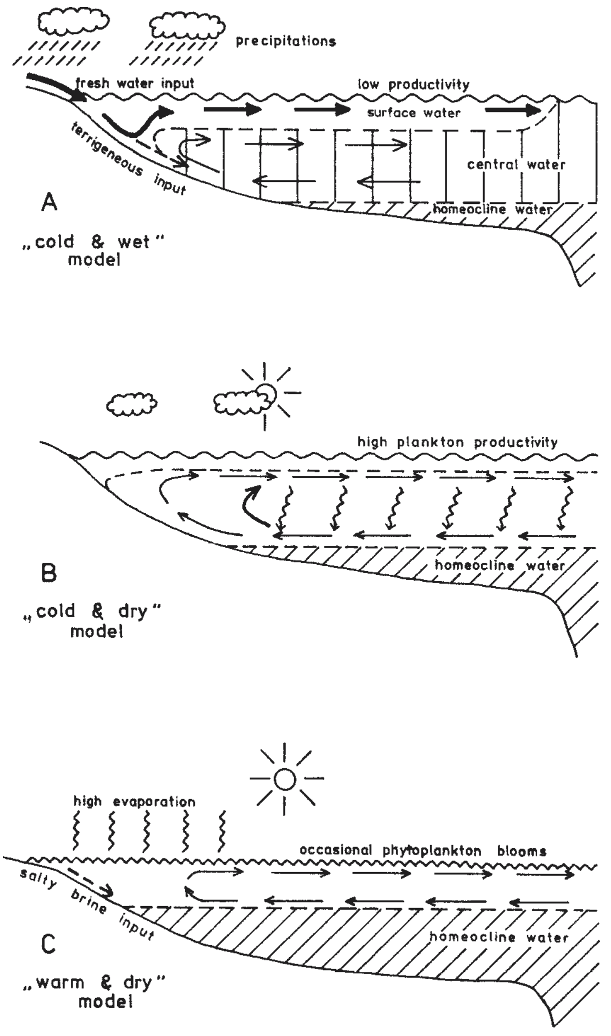

Fig. 6. Models of oceanic circulation interpreting the development of the Koňhora Formation sedimentary environment. **A**) Model of "Detritic Anoxic Event". High freshwater input during relative sea -level fall brought terrigeneous material, leading to a decrease of salinity, water mixing and increased mobility of the water column. The origin of anoxic sediments was provoked by increasing input of terrestrial organic matter and its rapid burial. **B**) Model of "Productivity Anoxic Event". Intensified water circulation after ceasing of fresh water input enabled upwelling of nutrient-rich central waters to the surface level and decrease of the oxygen minimum zone. Mass production of radiolarian plankton in the open sea was accompanied by sponge growth along the shelf margin (Senkovskyi 1978, 1979). In stages of low level of homeocline water, contour currents followed the shelf slope and mixed radiolarian and sponge spiculae accumulations. During climate warming, the role of radiolarians was subsequently replaced by foraminiferal plankton having no benthic counterparts. **C**) Model of "Stagnant Anoxic Event". Raised temperature caused salinity increase in shallow zones, enlargement of the oxygen minimum zone and decrease of mobility in the surface water layer. Occasional phytoplankton blooms could originate.

bal climatic change (Weissert 1989; Weissert & Lini 1991) resulting in the warm and humid climate of the mid-Cretaceous greenhouse.

Oxygen and Carbon isotopes

The C and O isotopic composition of the Valanginian and Hauterivian part of the Pieniny Limestone Formation has been studied in 16 bulk samples (Michalík et al. 1995). The results indicated a perturbation of the carbon cycle during the late Valanginian. The values of $\delta^{13}C$ increased significantly from an Early Cretaceous average level of +1.0 or +1.7 ‰ to +2.2 or even +2.8 ‰ and characteristically document global change in the C-cycle (Weissert & Channell 1989; Lini et al. 1992; Weissert & Mohr 1996).

New results of C and O isotope analyses of the Hauterivian to lowermost Albian bulk samples of the Rochovica section are presented in Table 3 and Fig. 5. The C-isotopic profile of the Barremian Vranie Member shows increased $\delta^{13}C$ values ranging from +2.1 to +2.8 ‰ (Lintnerová et al. 1997; Fig. 5) indicating to some extent the above mentioned variations in Barremian sedimentation reflecting sea-water/climate changes in the C-cycle.

The $\delta^{13}C$ values of the lower part of the Koňhora Formation slightly decrease (+1.6 to +1.8 ‰) in the shale sample (beds 416 to 418) in comparison with the Vranie Beds calcites (+1.5 to +2.8 ‰) but the values are still close to the Lower Cretaceous average. The decrease in $\delta^{13}C$ and $\delta^{18}O$ values is visible in beds with strong terrigeneous input and could indicate a change in sea water composition (e.g. mixing with monsoonal meteoric water). Calcite content forms 27 to 48 % (carbonatic claystone) of these $\delta^{18}O$ depleted samples (Table 3) and bears no signs of diagenetic recrystallization. The $\delta^{18}O$ ratio of shale complex changes from 1 to 2.5 ‰ and it can indicate 4 to 10 °C increase (according to Craig´s paleotemperature equation). As the decrease in $\delta^{18}O$ correlates with the terrigeneous organic matter input and with the TOC increase, one can suppose that this change was related rather to the composition of the sea water. The $\delta^{13}C$ content is less sensitive to temperature variations, but meteoritic water input can cause considerably change it (Patterson & Walter 1994). This is not the case in our sample set.

The C and O isotopic ratio in the upper part of the Koňhora Formation changes more dramatically. A new increase of the $\delta^{13}C$ content was recorded here. Huge production and resulting accumulation of the organic matter led to an anoxic sedimentary regime (Lee 1992; Pedersen & Calvet 1990). Later, reduction of this matter in sediment caused the origin of diagenetic pyrite. The Lower Albian part of the Brodno Formation yielded samples (horizons Nos. 427 to 430) with even the highest positive peak of $\delta^{13}C$, reaching values above +4 ‰ (Fig. 5).

Organic Carbon

The total organic carbon (TOC) content in the limestone is very low (close to the critical limit of the method sensitivity: 0.05 %, see Table 3, Fig. 5) indicating that it was not buried during limestone deposition at all. TOC was stored in marlstone intercalations with the average value of 0.55 %, rising from 0.06 % in bed No. 325 to the highest value of TOC measured in marlstone layer No. 409 in the middle of the Vranie Member (1.6 %) and decreasing again to 0.28 % in bed No. 437.

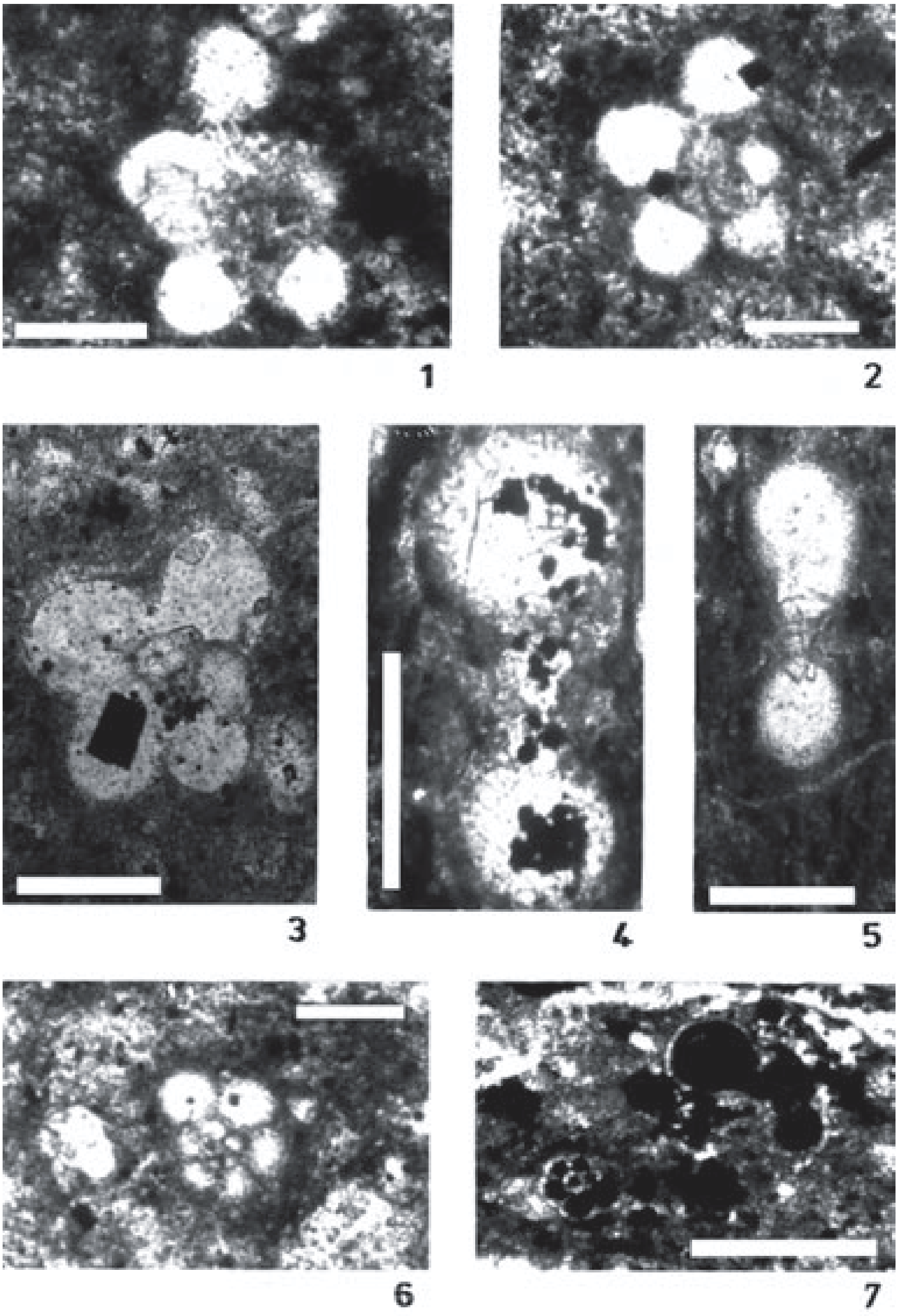

Plate IV: Planktonic foraminifers of the Koňhora Formation. **Figs. 1–2.** *Clavihedbergella eocretacea* Neagu, sample R-420 A; **Fig. 3.** *Hedbergella similis* Longoria, sample R-420 A; **Figs. 4–5.** *Planomalina* (*Globigerinelloides*) sp., sample R-420; **Fig. 6.** *Hedbergella planispira* (Tappan) sample R-420; All above mentioned species are silicified. **Fig. 7.** Pyrite accumulation in tests of planktonic foraminifers, Koňhora Fm., sample K-417.5. Bars indicate distance of 100 µm.

The dark calcareous claystones of the Koňhora Member contain a higher fraction of terrestrial organic matter. It consists mostly of fusinite and semifusinite, less of vitrinite. Both macerate types represent different stage of carbonization, indicating mixing of different land sources, possibly also with marine ones.

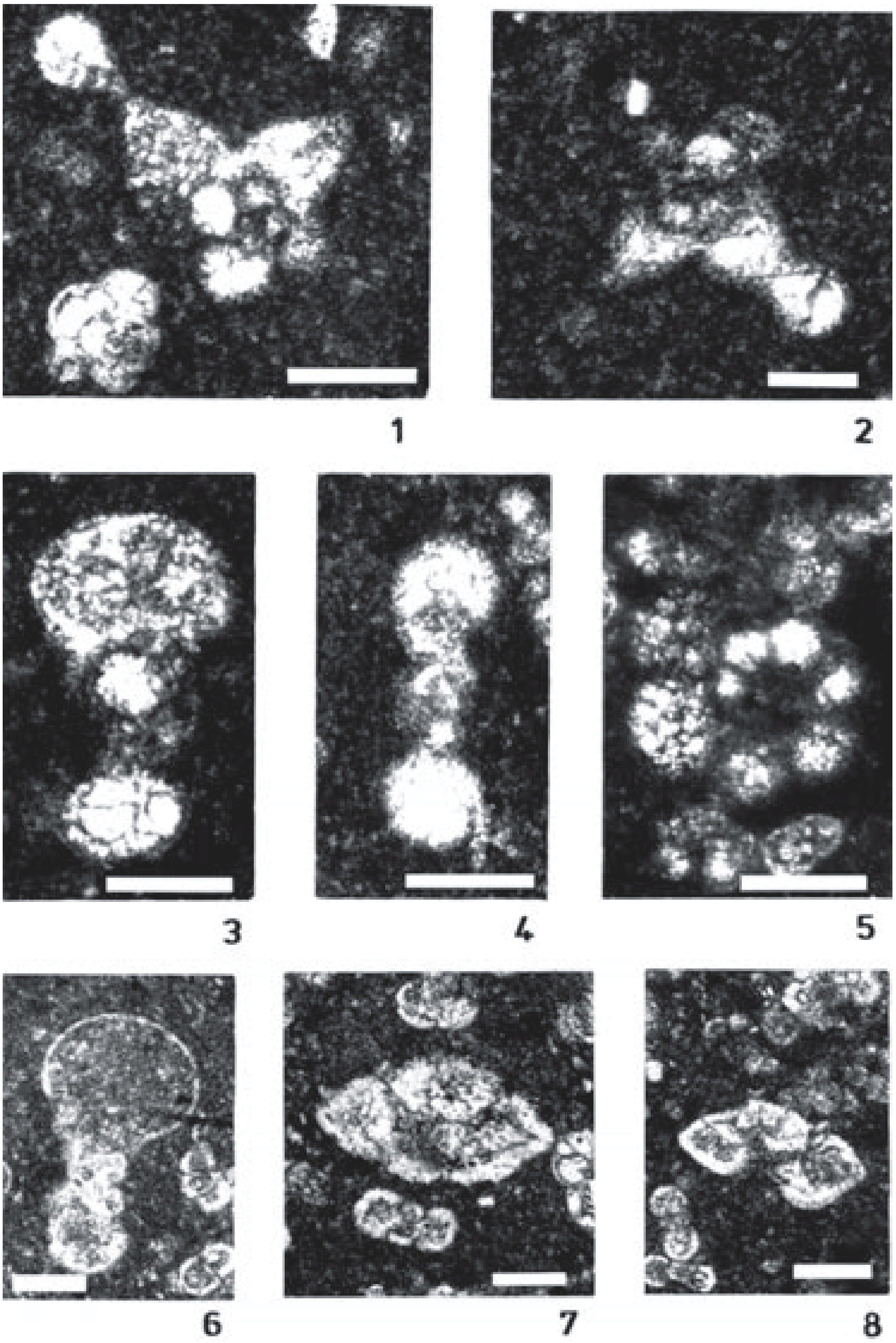

Plate V: Figs. 1–2. *Leupoldina* cf. *pustulans* (Bolli), sample K-424.5; **Fig. 3.** *Biglobigerinella barri* Bolli, Loeblich & Tappan, sample K-422.5; **Fig. 4.** *Planomalina* (*Globigerinelloides*) *algerianus* Cushman & Ten Dam sample K-421; **Fig. 5.** *Ticinella roberti* (Gandolfi), sample K-427.5; **Fig. 6.** *Biticinella breggiensis* (Gandolfi), sample R-432; **Figs. 7–8.** *Thalmanninella ticinensis ticinensis* (Gandolfi), sample R-432. Bars indicate distance of 100 μm.

Discussion

A hot and dry climate at the beginning of Mesozoic Era supported a stagnant salinity gradient of deep oceanic water stratification (Haq 1984; Railsback 1990): this pattern persisted until the early Late Jurassic. It was interrupted by colder, more humid episodes in the early Carnian, Rhaetian and Hettangian. A slight temperature decrease of the Earth's atmosphere in the late Jurassic resulting in an extremely humid climate (Weissert & Mohr 1996) re-established climatic belts and temperature-driven stratification of oceanic waters (Moore et al. 1992). Dense warm "brines" on the oceanic bottom were gradually substituted by colder, low saline and more mobile polar waters, emerging in upwelling sites (Parrish & Curtis 1982; Hay 1997).

Early Cretaceous paleoclimate models (Barron et al. 1985, 1989; Hay 1995) stress the sensitivity of the northern Tethyan margin to orbital variations. This area was periodically affected by strengthened monsoonal circulation. A distinct rhythmical pattern of alternating limestone/marlstone couplets was observed in the Valanginian part of the Pieniny Lst. Fm. sequence (Michalík et al. 1995). Limestone beds here contain an increased share of tiny neritic limestone clasts (in lowstand tract intervals), or concentrations of radiolarian tests (in transgressive- or highstand tracts). On the other hand, the marine plankton content in marly interbeds is remarkably low. Thus, the conclusion of Barron et al. (1985), that these marly intercalations recorded monsoonal precipitation periods (the cooler parts of Milankovich cycles?) connected with fresh-water and terrigeneous input, seems to fit these facts.

The Hauterivian part of the Pieniny Lst. Fm. sequence indicates a rised global sea level (Vail et al. 1991). Marly intercalations are sporadic (mainly in HST intervals) and rather thin. On the other hand, intervals of thin-bedded laminated radiolarian limestones interpreted as contourites occur here. Their typical appearance in the Ha3 and Ha4 sequences is well comparable with the Bandol Fm. contourites described by Machhour et al. (1994). Radiolarian tests accompanied by silicisponge spicules are concentrated in thin (0.1–2 mm) laminae indicating the presence of bottom currents, but also dysaerobic conditions at the foot of the slope. These laminated beds alternate with layers rich in neritic organic skeleton fragments indicating transport by gravity currents. The occurrence of limestone clasts with calpionellids of the Early Berriasian Alpina Subzone indicates an erosion lasting since (at least) Late Hauterivian until Early Albian (sedimentary gap of comparable duration was recorded in the neighbouring elevational Czorsztyn Ridge). Calciturbidites became dominant in the SMT and TST intervals of the Barremian to lowermost Aptian Vranie Member of the uppermost Pieniny Lst. sequence. They record prograding development of carbonate platforms on neighbouring shallows connected with the general sea-level fall indicated by Vail et al. (1977) or Sahagian et al. (1996). "Urgonian-type" buildups are not known from the Czorsztyn Ridge. However, Mišík (1990) supposed their existence on an unknown ultrabasic-rich elevation (similar to the hypothetical "Andrusov Ridge" of Birkenmajer 1988) close to this area.

The top of the member is sharply overlain by the shales of the Koňhora Formation. They consist of multiplicate alternation of precipitation–runoff rhythms formed by laminae of silty claystones, calcisiltite marls and radiolarian marlstones. The composition of the material indicates a large source area formed by deeply weathered crystalline rocks: this area is incomparable with the surface of the Czorsztyn Ridge supplying Berriasian carbonates, or with adjacent (?) elevations covered by topmost Hauterivian/Barremian neritic carbonate buildups. Sudden substitution of pelagic limestone deposition by shaly sequence indicate substantional environmental changes possibly caused by orbitally controlled climate change. From this point of view, there are many similarities between the Koňhora Fm. and the Strati di Selli of the Apennines and Southern Alps (Bersezio 1993, 1994; Coccioni et al. 1989; Erba 1994), the Arcillas de Morella Fm. of NE Iberia (Salas & Martín-Closas 1991), the Goguel Beds of the Vocontian Trough (Bréhéret & Delamette 1989) or the Fischschiefer of the German Basin (Mutterlose 1998; Mutterlose & Böckel 1998). According to Barron et al. (1989) and Moore et al. (1992), orbital rhythms could have influenced the storm tracks of monsoons and their intensity could be one-order stronger in comparison with their modern counterparts. The area affected by such monsoons lasting all year must have been oversupplied by the continental clastics brought by a river influx.

Cretaceous ocean hydrodynamic pattern was interrupted several times by warmer periods of climate equalization (greenhouse episodes, Berner et al. 1983) accompanied by renewal of the salinary (Hay 1997; "over-fed" cf. Hoffman et al. 1991) regime. Greenhouse events should be signalized by: 1) radiolarian extinction events (Erbacher & Thurow 1995) with low diversity, high dominance and density of aglutinant foraminifers (Thies & Kuhnt 1995); 2) origin of black shale facies (model 3 in Oschmann 1995); 3) anomaly in $\delta^{18}O$ and $\delta^{13}C$ isotopes distribution (Hoffman et al. 1991, etc.).

Large runoff brought a large amount of terrigenous organic matter which was quickly buried in marine environments. The resulting anoxic processes fit well with the Detritic Oceanic Anoxy Event of Erbacher & Thurow (1995). It corresponds with i a slight inexpressive decrease of the δ C curve. On the other hand, nutrification of the surface water layer after ceasing of the fresh water input (Hay 1995), and renewed upwelling led to increased plankton productivity, decrease of mean water temperature (De Boer 1982) and to an expansion of the oxygen minimum zone. In fact, the Koňhora event was a composed event, which can be illustrated by a succession of all three, Detrital-, Productivity-, and Stagnant Oceanic Anoxy models (Fig. 6).

Disruptions of circulation, which caused acceleration of accumulation or deceleration of decay of organic C in the oceanic system (detectable by sudden change of carbon isotope ratio), happened at the Permian/Triassic boundary, during the early and late Oxfordian (Hoffman et al. 1991), middle and late Tithonian (Olóriz et al. 1995; Weissert & Mohr 1996), Late Valanginian (Weissert & Chanell 1989; Lini et al. 1992; Channell et al. 1993), late Early Aptian (Weissert & Lini 1991; Erba 1994), Cenomanian/Turonian- (de Boer 1983), and Campanian/Maastrichtian boundary (Barrera et al. 1997). Hoffman et al. (l.c.) were able to distinguish (1) local circulation changes, when the $\delta^{13}C$ content changes more significantly than the $\delta^{18}O$ share (the Productivity Anoxic Event of Erbacher & Thurow 1995, accompanying rising sea level), for (2) extrabasinal reasons, when the ^{18}O amount is accumulated more rapidly than the ^{13}C one (according to the above mentioned authors, the origin of the Detrital Anoxic Event can be evoked by a sudden influx of fresh, or at least less saline waters with a higher amount of isotopically light oxygen during sea level lowstands).

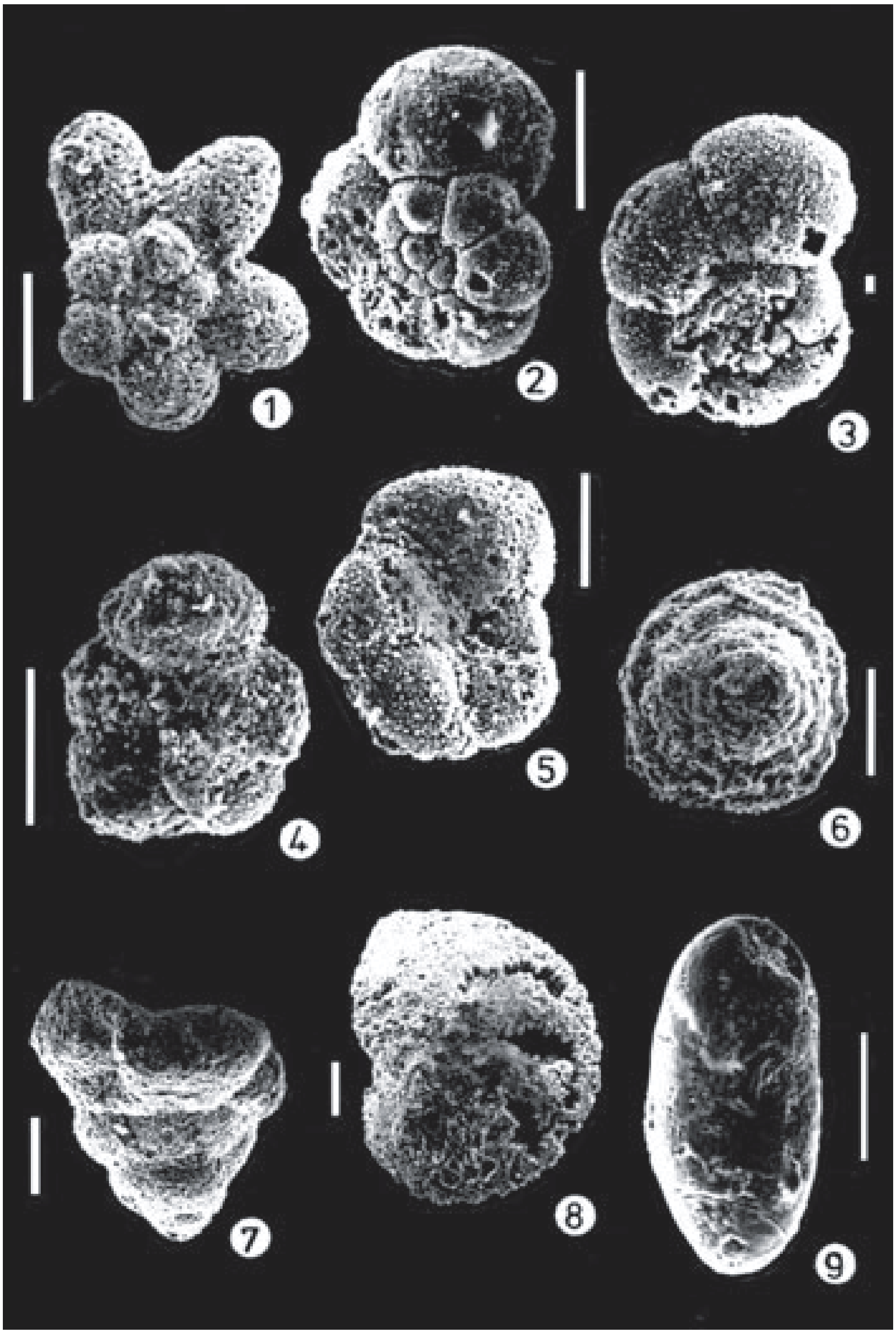

Plate VI: Fig. 1. *Clavihedbergella subcretacea* (Tappan), sample R-422.8; **Figs. 2–3**, **5.** *Hedbergella seminolensis* (Harlton), sample R-422.8; **Fig. 4.** *Hedbergella seminolensis* (Harlton), sample R-425.7; **Fig. 6.** *Trocholina* sp., sample R-385; **Fig. 7.** *Dorothia* aff. *oxycona* (Reuss), sample R-422.8; **Fig. 8.** *Lenticulina* (L.) *ouachensis* (Sigal), sample R-422.8; **Fig. 9.** *Ostracoda* div. sp., sample R-385. Bars indicate distance of 100 µm.

The Rochovica isotope profile shows a negative change of $\delta^{18}O$ in the place of C_{org} accumulation. We suppose that the oxygen isotope ratio in the post-sedimentary little modified Rochovica sequence is not substantially influenced by diagenesis but rather by relative salinity- and temperature changes during sedimentation. Fresh water input could have modified the oxygen- (but also carbon) isotopic composition of the sea water. However, it is not easy to decide, if this change reflects the evolution of the deep waters where the sediment was deposited, or if it could be rather ascribed to the surface waters where the nannoplankton (as the producer of the main rock-forming elements) lived.

Significant morphological differentiation of planktonic foraminiferal faunas resulted from their evolutionary strategy (Hart & Bailey 1979), Caron & Homewood (1983), Salaj (1985), Robaszynski & Caron (1995). Bé (1977) and Salaj

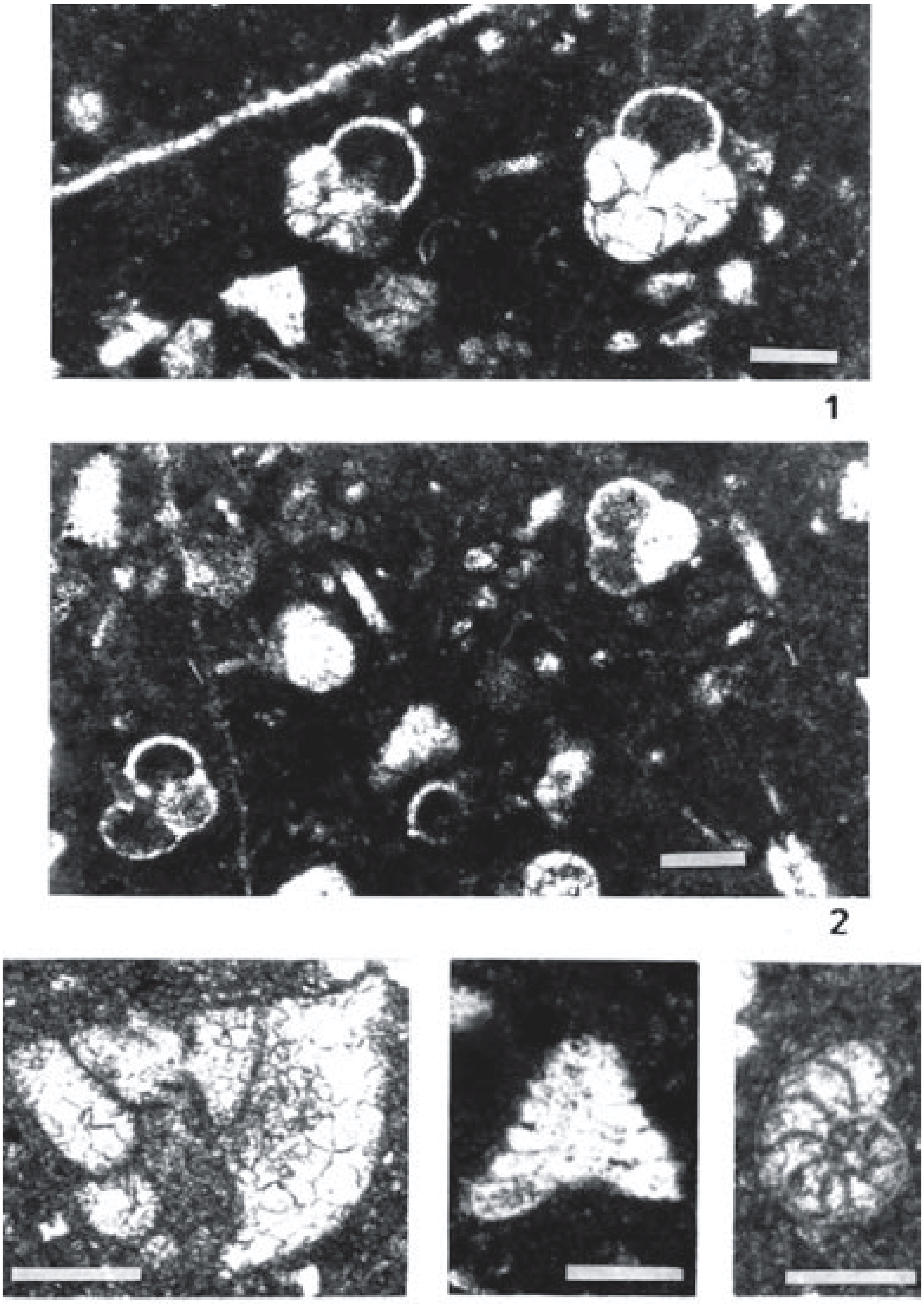

Plate VII: Planktonic and benthic foraminiferal species of the Rochovica section. Figs. 1–2. *Favusella hoterivica* (Subbotina), sample K-374; **Fig. 3.** *Conorotalites* ex.gr. *bartensteini* Bettenstaedt, sample R-391; **Fig. 4.** *Patellina* cf. *turriculata* Dieni & Massari, sample K-410; **Fig. 5.** *Anomalina* sp., sample R-426.7. Bars indicate distance of 100 µm.

(l.c.) attributed foraminiferal biota to several biological, or bathymetric zones. Associations of planktonic foraminifers of the Vranie Member and lower part of the Koňhora Formation consist of rare primitive morphotypes with small, thin and smooth tests controlled by r-selection strategy. According to the above-mentioned bathymetric zonation, these foraminifers inhabited the 1st zone, equivalent to the upper water layer (up to 50–100 m depth). The environment was characterized by fluctuating temperature, salinity, oxygen and nutrients. As the lithology of particular strata representing general Barremian/lowermost Aptian shallowing (Fig. 4) indicates common neritic debris support, the redeposition of sediment into a deeper setting cannot be excluded. On the other hand, vertical life-column range restriction could also result from thinning of the surface water layer above the raised oxygen minimum level in rising sea level conditions.

The upper part of the Koňhora Formation (and the Brodno Formation as well) contains layers with more diverse foraminiferal fauna consisting of larger forms with greater weight, living in much broader water column along with scarce benthic forms. These associations indicate K-selection strategy supported by a deeper, more stable and better aerated environment.

Conclusions

Pelagic marine sediments exposed in the Rochovica section show a rhythmic pattern comparable with precipitation/runoff cycles. Rhythmic pattern is punctuated 1) by limestone/marl alternation in the Valanginian- and also in highstand tracts of upper part of the Pieniny Lst. Formation, 2) by contourite intercalations of Hauterivian transgressive tracts of the Pieniny Fm., as well as 3) by fine alternating terrigenous and biogene laminae in the Koňhora Fm. 4) This pattern was disturbed by the calciturbidite regime of the Vranie Member, which registered carbonate platform growth in the Barremian decreasing sea level stand conditions. Similar tendencies appeared in the Upper Aptian/Lower Albian Brodno Formation.

— During the late Early Aptian humid climatic event, a huge amount of terrigeneous material was repeatedly transported into the Kysuca Basin. Deposition of the material brought by rivers was interrupted by occasional drier seasons with high primary production of radiolarian- and (later) nannoconid-foraminiferal skeletal material. Three (detrital, productive and stagnant) models of anoxia have been recognized in the sedimentary regime of the Koňhora Formation (Fig. 6).

— Two major partial δ^{13}C excursions have been recognized in the Upper Barremian–lowermost Albian record of this isotope ratio. The lower one coincides with the increased C_{org} content in the uppermost part of the Vranie Member. The upper one starts in the uppermost parts of the Koňhora Fm. and continues in the Brodno Formation. These two peaks are separated by the less positive part of the δ^{13} C curve belonging to the Koňhora Fm., representing runoff/temperature perturbation of the marine productivity regime.

— Noticeably, decreased values of δ^{18}O in the above mentioned part of the rock column could be connected with a temperature decrease and/or with an intensified freshwater input into the ocean.

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