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Barremian-Aptian erosion of the Kysuca-Pieniny trough margin (Pieniny Klippen Belt, Western Carpathians)

ŠTEFAN JÓZSA and ROMAN AUBRECHT

Department of Geology and Paleontology, Faculty of Natural Sciences, Comenius University, Mlynská dolina, 842 15 Bratislava, Slovak Republic; roman.aubrecht@fns.uniba.sk

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Abstract: The Pieniny Klippen Belt is a tectonic melange representing the boundary between the Outer and Central Western Carpathians. Within this melange, Jurassic and Cretaceous sedimentary rocks from deep-water (Kysuca Basin) to shallow-water environments (Czorsztyn Unit) occur. The Nižná Unit of the Pieniny Klippen Belt was distinguished as a particular development of the Kysuca Unit. As a result of a sea-level fall in the Barremian, the Barremian-Aptian Nižná Limestone Formation (organodetritic Urgonian-like facies) rests unconformably on older formations. At the base of this transgressional contact the newly discovered Tvrdošín Breccia Member occurs. This breccia consists of clasts of radiolarites, red limestones, white Calpionella limestones, and black chert nodules extracted from these limestones. The presence of breccia shows that the pre-Barremian strata in the Nižná Unit were eroded to relatively deep levels. This event was coeval with, and probably related to, the hiatus in other units situated on the Czorsztyn Swell. The Nižná Limestone Formation is overlain by the uppermost Aptian to Cenomanian pelagic marlstones, limestones and radiolarites at least 10 m thick. These are followed by flysch with exotic pebble material. Its age is younger than Cenomanian, which contradicts previous opinions. An earlier (Albian) onset of exotic flysches would be indicative of more southern units, close to the exotic Andrusov Ridge. This implies that the Nižná Unit was situated at the northern margin of the sedimentary area of the Kysuca Unit, closer to the Czorsztyn Swell, where the exotic flysch sedimentation came later.

Key words: Cretaceous, Western Carpathians, Pieniny Klippen Belt, Nižná Unit, paleogeography, lithostratigraphy, erosion.

Introduction

The Pieniny Klippen Belt is the most complex zone in the Western Carpathians. It represents the boundary between the internides and externides of the Western Carpathians. Its complex character results from at least two deformational phases which occurred at the Cretaceous/Tertiary boundary and in the Neogene. Its recent structure is a melange of predominantly sedimentary rocks of Jurassic and Cretaceous age. As such, its paleogeographical reconstruction is still a difficult task. The melange consists mainly of blocks (klippen) of various units belonging to the independent terrane called the Oravicum (Maheľ 1986), and also of units that originally belonged to the Central Western Carpathians. The Nižná Unit was originally distinguished by Scheibner (1967) as being a particular subunit of the Kysuca Unit of the Pieniny Klippen Belt. The Kysuca Unit (i.e. the Branisko Unit of Birkenmajer 1977), together with the very similar Pieniny Unit and the Grajcarek Unit (Birkenmajer 1977) sedimented in the deepest part of the Oravicum. According to the reconstruction of Birkenmajer (1977), the Kysuca Unit was situated south of the most elevated Oravic part called the Czorsztyn Swell (Birkenmajer 1977); the Grajcarek Unit was presumably situated north of the swell and, therefore, it belonged to the Magura Unit of the Flysch Zone. The reason for distinguishing the Nižná Unit from the Kysuca Unit is that it differs in its relatively shallow-water organodetritic sedimentation during the Barremian-Aptian time. The Jurassic/Lower Cretaceous development of both units is approximately the same, consisting of Callovian-Oxfordian radiolarites (Czajakowa Radiolarite Formation), Kimmeridgian red nodular to pseudonodular limestones (Czorsztyn Limestone Formation) and Tithonian-Lower Cretaceous white Calpionella and Nannoconus limestones with cherts (Pieniny Limestone Formation). Organodetritic limestone named the Nižná Limestone by Scheibner (1967) is present higher up in the Nižná Unit. It replaces the dark grey to black foraminiferal marls of the Koňhora Formation which are typical of the Kysuca Unit. This Urgonian-like limestone was originally mapped as Middle Jurassic crinoidal limestone (Andrusov 1931). The limestone is mostly of talus to distal allodapic origin, with detritus from a shallow-water platform. Detailed microfacies analysis of the limestone was carried out by Mišík (1990). The age of the limestones was estimated as Barremian to Albian (Scheibner 1967; Mišík 1990; Gross et al. 1993). The first lithostratigraphic concept presented by Scheibner (1967) proposed that the Nižná Limestone is directly overlain by exotic flysch which he believed to be of Al-

bian–Cenomanian age, and this was later followed by higher Cenomanian-Senonian marly sediments. The proposed Albian age of the exotic flysch resulted in the assumption that the Nižná Unit was paleogeographically closer to the more southern Manín and Klape Units, with Albian-Cenomanian exotics, than to the other Oravic units where the exotic flysch sedimentation commenced as late as in the Coniacian. Re-examination of the Nižná Unit revealed new data that contradict this asssumption and radically change the view on the paleogeographical position and the evolution of the Nižná Unit within the context of the whole Oravicum.

Methods

Eight outctops were studied during field research. This involved evaluation of the individual sections, local enhancement of the natural outcrops by trenching, lithological and sedimentological study of the sequences, local bed-by-bed sampling, investigation and description of fossil contents and study of microfacies. Material for micropaleontological study was treated by the standard laboratory methods, including thin sections and study of washed material from slightly lithified marls. The recovered fauna was also observed under SEM.

The klippen of the Nižná Unit are located in the Orava district (northern Slovakia), in a section between Tvrdošín (local part of the town called Medvedzie) and Dlhá nad Oravou (Fig. 1). All the relevant sections of the Nižná Unit were re-examined (Fig. 2). They include the sections mentioned by Scheibner (1967) — Medvedzie (GPS coordinates: N 49°19′50.6″, E 19°32′24.0″), Krásna Hôrka (N 49°19′40.8″, E 19°32′11.9″), Zemianska Dedina (2 sections: N 49°19′31.0″, E 19°31′56.7″ and N 49°19′31.6″, E 19°31′59.8″), Ostražica (N 49°18′57.4″, E 19°31′20.4″), then a section found by Mišík (1990) — Ostrý Vrch (N 49°16.521′, E 19°26.455′) and Vysoký Grúň (N 49°17′17.9″, E 19°27′41.4″), known previously from unpublished reports. One new section of key importance, was found near Dlhá nad Oravou (N 49°16′10.6″, E 19°26′12.3″). So far it is the southernmost section of the Nižná Unit in the Orava district.

Formations composing the Nižná Unit

The "Gresten Beds"

The oldest lithostratigraphic units, considered to belong to the Nižná Unit (Scheibner 1967) are exposed in an old abandoned quarry near the Zemianska Dedina locality (Fig. 3.1, GPS coordinates of the quarry: N 49°19′24.9″, E 19°32′09.0″). In earlier Slovak geological literature the formations attributed to the Gresten Beds were not precisely defined. The only common elements were the rich sandy admixture and the Hettangian–Sinemurian age. Therefore, this previous appelation comprised the whole spectrum of lithologies, from sandy limestones to quartzites. However, in the case of

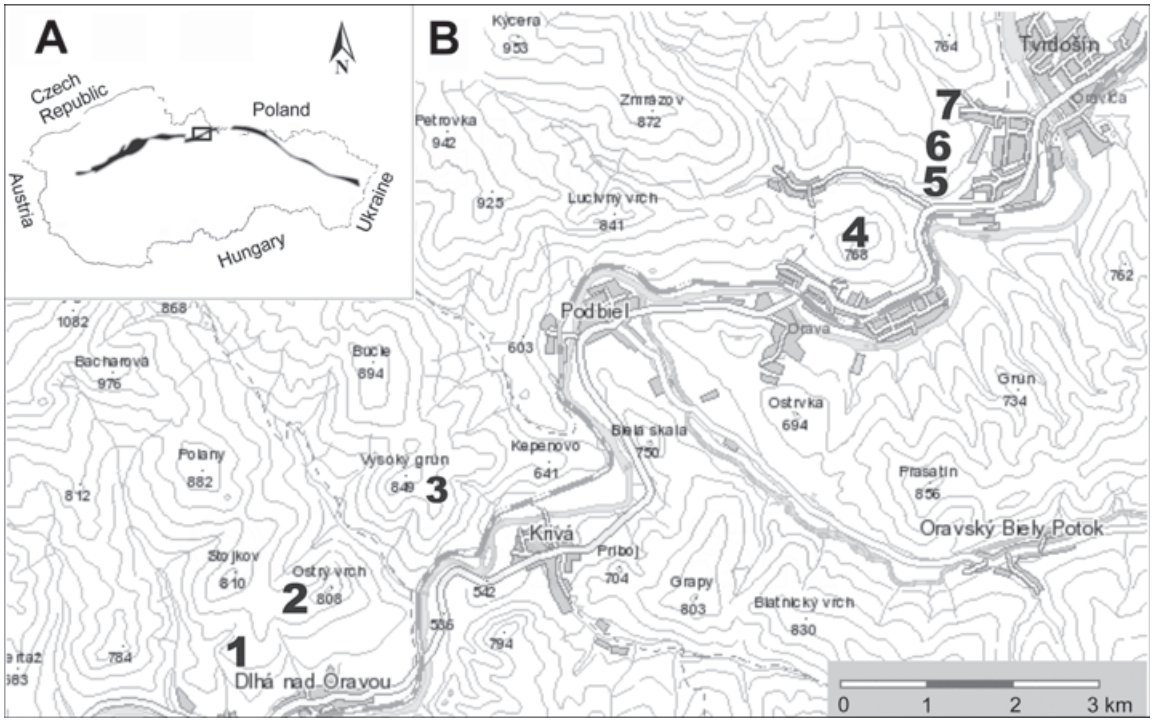

Fig. 1. Location map of the studied sections. **A** — Sketch map of the Pieniny Klippen Belt showing the location of the detailed map of occurrences of the Nižná Unit. **B** — Location of the studied sections (1 — Skalka, 2 — Ostrý Vrch, 3 — Vysoký Grúň, 4 — Ostražica, 5 — Zemianska Dedina, 6 — Krásna Hôrka, 7 — Medvedzie).

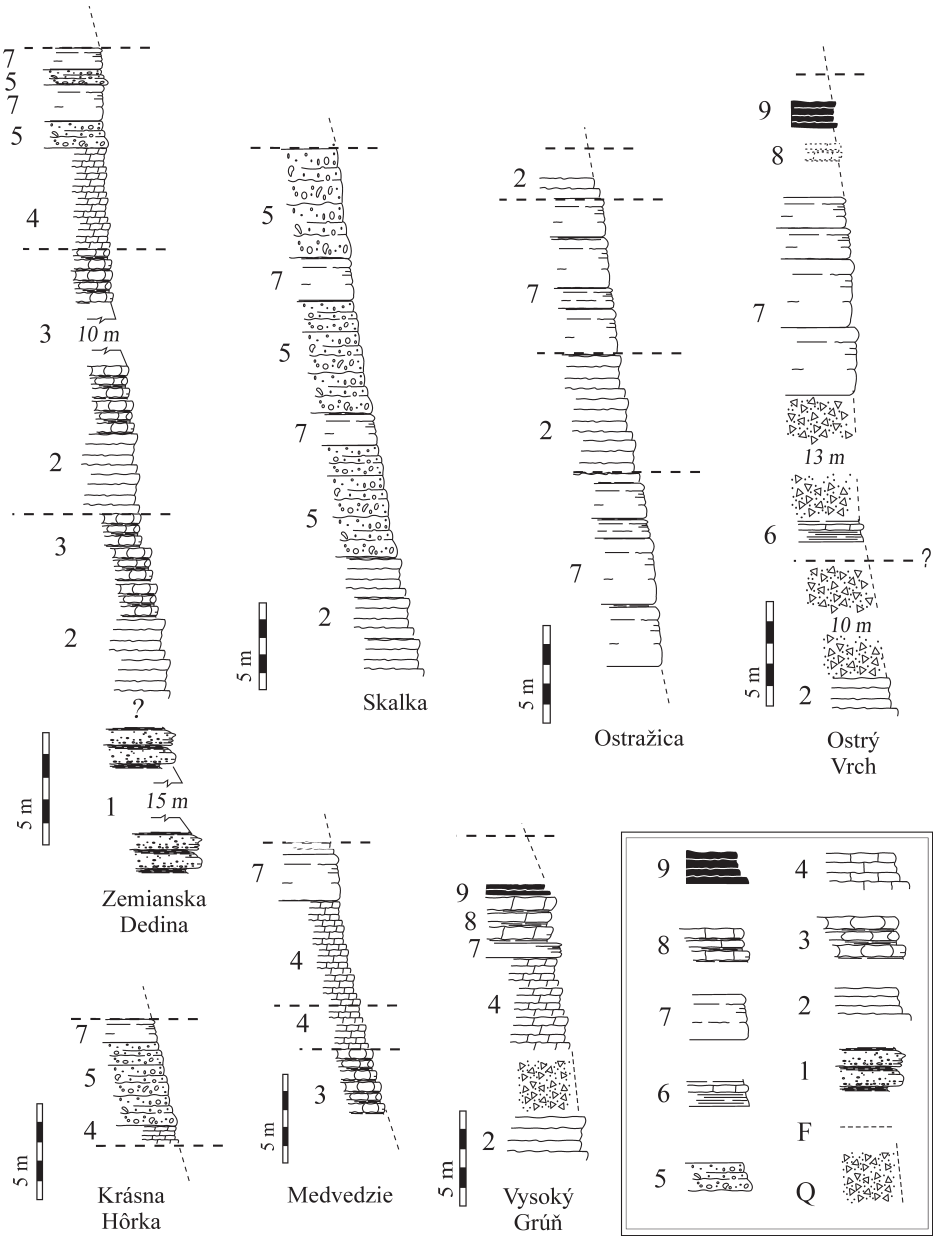

Fig. 2. Lithological profiles of the studied sections. Explanations: **1** — Gresten Formation (arkosic sandstones to microconglomerates, sandy crinoidal limestones and marlstones). **2** — Czajakowa Radiolarite Formation (red, locally greenish to grey bedded radiolarites). **3** — Czorsztyn Limestone Formation (red nodular to pseudonodular limestones, alternating with red calcareous shales). **4** — Pieniny Limestone Formation (white Calpionella limestone with grey cherts). **5** — Tvrdošín Breccia Member (massive polymictic breccia with organodetritic matrix). **6** — interlayers of black shales (lithological equivalent of the Koňhora Formation). **7** — Nižná Limestone Formation (massive to thick-bedded, grey, white to reddish, fine- to coarse-grained organodetritic limestone, often with silicified detritus). **8** — Tissalo Formation (grey- to red silicites, marlstones and shales). **9** — Groń Radiolarites (black bedded radiolarites). **F** — fault, **Q** — Quaternary cover (soil, debris).

the Nižná Unit, the utilization of this name is more or less correct. The Gresten Beds of Scheibner (1967) are represented by arkosic sandstones to microconglomerates, with interlayers of claystones and crinoidal limestones exposed in the lower part of the quarry. In the upper part of the quarry, sandy crinoidal and organodetritic (mainly sponge) limestones with laminae of sandy claystones containing redeposited fauna of bivalves and brachiopods are exposed. Sandy organodetritic to crinoidal limestones are detritic packstones to grainstones with common crinoid ossicles, calcified sponge spicules, ostracods, brachiopod and bivalve shells (mainly gryphaeids), echinoid spines and bryozoans. The organic detritus is commonly silicified. The clastic admixture is dominated by quartz, feldspars (mostly microcline, pertite), micritic limestone clasts, organodetritic limestone clasts and dolomites. The heavy mineral assemblage is dominated by garnet, with lesser amounts of zircon, rutile and tourmaline (Aubrecht 2001), and this is very similar to the Gresten Beds from the Eastern Alps (Faupl 1975). Garnets are predominantly pyrope-almandines, which indicate their granulitic or eclogitic origin (Aubrecht & Méres 2000). The age of the rocks was determined on the basis of ammonite ?*Coroniceras (Methophioceras)* sp. as Early Sinemurian, Conbeari Zone (Rakús 1995). The Middle and Upper Jurassic sediments of the Nižná Unit occur in the quarry on the opposite side of the hill (Fig. 3.2, our locality Zemianska Dedina — section 1) and Scheibner (1967) supposed there a continuous succession. However, the transition is covered by vegetation and, moreover, the sedimentary succession in this quarry is completely reversed with respect to the position of the Sinemurian clastics. Therefore the proximity of the localities was the only

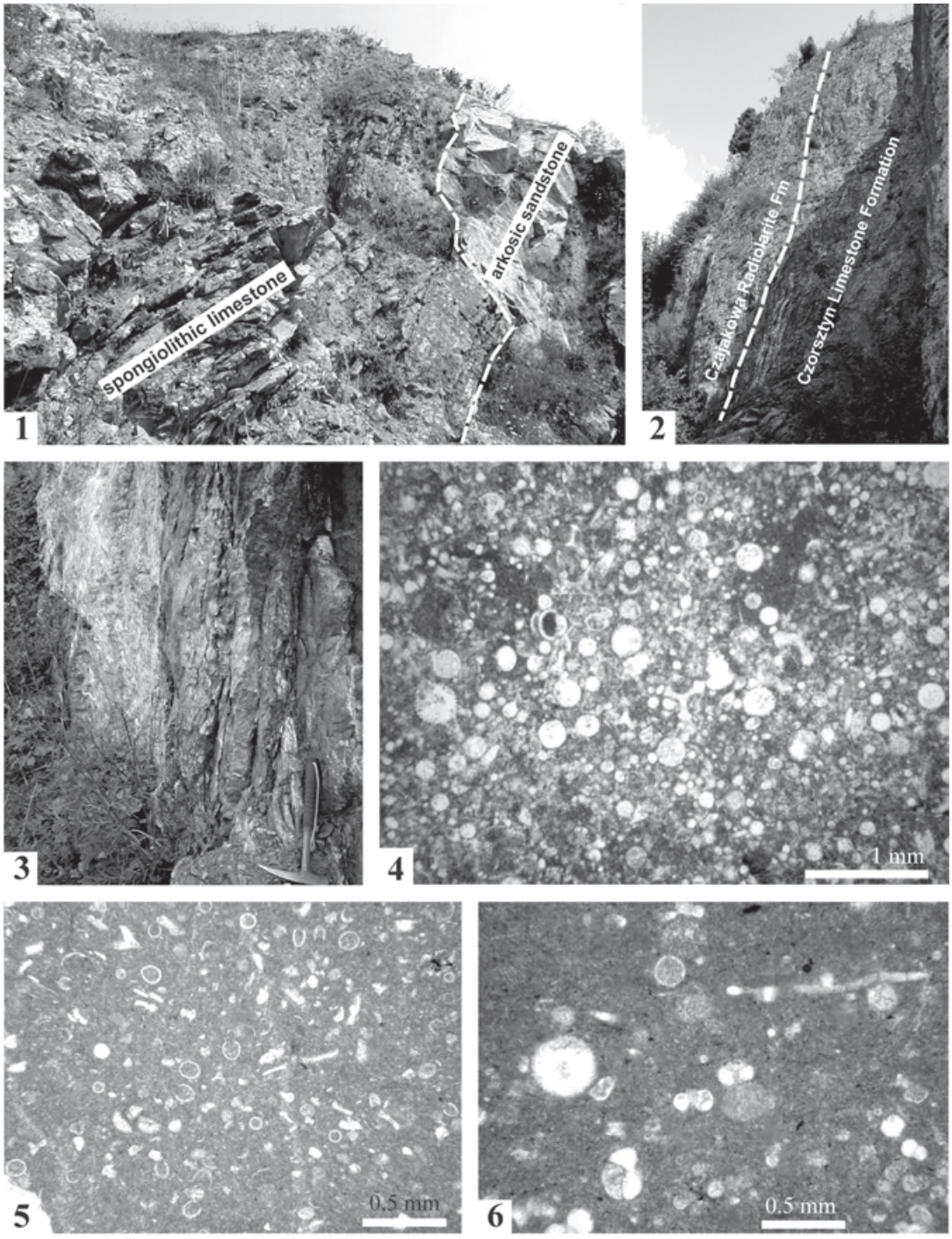

Fig. 3. **1** — Quarry between Krásna Hôrka and Zemianska Dedina exposing the Liassic sediments which are considered to belong to the Nižná Unit. **2** — Quarry near Zemianska Dedina exposing the Middle and Upper Jurassic sediments of the Nižná Unit. **3** — Detail from the previous, showing the Czorsztyn Limestone Formation. **4** — Radiolarian packstone (Callovian-Oxfordian), Ostrý Vrch Section. **5** — Calpionella wackestone, Zemianska Dedina Section 1. **6** — Radiolarian-foraminiferal wackestone (Barremian), Vysoký Grúň Section.

argument of Scheibner (1967) for attribution of these clastics to the Nižná Unit.

The Czajakowa Radiolarite Formation

The first formation actually belonging to the Nižná Unit consists of the Callovian to Oxfordian radiolarites. The older Podzamcze Limestone (formerly known as the "Supraposidonia" Beds) can be found only in debris below the Vysoký Grúň section. The radiolarites are mostly wackestones, and in some places packstones (Fig. 3.4). The greenish Podmajerz Radiolarite Member is richer in spumellarians, whereas the younger red Buwald Radiolarite Member contains more nasellarians.

The Czorsztyn Limestone Formation

The Czorsztyn Limestone Formation consists of nodular to pseudonodular limestone (Fig. 3.3) with aptychi and rhyncholites. Microscopically it represents *Saccoccoma* packstones to wackestones, which shows that it is Kimmeridgian to Early Tithonian in age. Its presence was found at the Zemianska Dedina, Medvedzie and Vysoký Grúň localities.

The Pieniny Limestone Formation

This limestone is white to pale grey, with numerous dark grey to black cherts. It is relatively thin, varying in thickness from 0 to 5 m. The limestone represents Calpionella wackestone (Fig. 3.5), in its uppermost part containing Nannoconus to foraminiferal-radiolarian microfacies (Fig. 3.6). Where present, the upper age limit of the Pieniny Limestone Formation below the overlying Nižná Limestone Formation is usually Late Berriasian (Calpionellopsis Zone, Oblonga Subzone sensu Reháková 1995). This is indicated by calpionellid fauna of *Calpionella elliptica* Cadisch, *Calpionellopsis simplex* (Colom), *Calpionellopsis oblonga* (Cadisch), *Calpionella minuta* Houša, *Tintinnopsella carpathica* (Murgeanu et Filipescu), *Calpionella alpina* Lorenz, *Remaniella cadischiana* (Colom), *Remaniella duranddelgai* Pop, *Remaniella filipescui* Pop, *Tintinnopsella longa* (Colom), as well as by calcareous dinocysts of *Cadosina fusca* Wanner, *Stomiosphaera wanneri* Borza and *Schizosphaerella minutissima* (Colom).

In the most complete sections (Vysoký Grúň), the sedimentation of the Pieniny Limestone Formation continued into the Valanginian (Calpionellites Zone, Darderi Subzone sensu Reháková, 1995), with *Calpionellites darderi* (Colom), *Calpionella elliptica* Cadisch, *Calpionella alpina* Lorenz, *Tintinnopsella carphatica* (Murgeanu et Filipescu) and *Calpionella minuta* (Houša), then by Hauterivian Nannoconus mudstone with rare pyritized radiolarians, crinoid ossicles, thin-shelled bivalves, rare calcareous dinocysts *Stomiosphaera echinata* Nowak and rare *Globochaete alpina* Lombard, as high as the Barremian radiolarian-foraminiferal wackestone, with planktonic foraminifers *Blefusciana* sp. (similar to *Blefusciana* cf. *aptiana* (Bartenstein)).

The Nižná Limestone Formation

This limestone is thick-bedded to massive, often forming cliffs (Fig. 4.1). It represents a spectrum of facies from the shallow-water coarse-grained and reef facies, with erosional features on the base, as far as the distal detrital fan (Fig. 5). Its microfacies is represented by biodetritic, relatively coarse-grained, poorly sorted packstone, grainstone to rudstone. Boundstones with selectively silicified corals were also found (Fig. 4.2). The bioclasts are commonly rounded, micritized or silicified and, hence often impossible to differentiate. In some places, black shale intercalations occur in the Nižná Formation at the base of the section (e.g. at Ostrý Vrch locality), and these are identical to the coeval shales of the Koňhora Formation of the Kysuca Unit. Moreover, this study distinguished the basal breccia member of the Nižná Limestone Formation which had not been previously recognized, and which plays a key role in the paleogeographical reconstruction of the Nižná Unit. Descriptions of the various microfacies varieties of the Nižná Limestone are provided here (for detailed microfacies contents of the Nižná Limestone — see also Mišík 1990). The basal breccia and foraminiferal fauna of the black shale intercalations is also described. Micropaleontological evidence from the Nižná Limestone Formation shows that its deposition took place during the ?Barremian–Aptian.

Basal breccia member (the Tvrdošín Breccia Member — new name)

The breccia is best developed at the Skalka locality (Fig. 4.1). This locality represents a klippe in a stratigraphically reversed position. It shows about a 15 m section of breccia resting directly on Jurassic radiolarites (Fig. 4.2–3). The breccia consists of chaotically arranged, poorly sorted clasts and larger blocks (up to 40 cm in diameter) of radiolarites, red limestones, white Calpionella limestones and their black chert nodules. The chert nodules are always free (see Fig. 8.2); no limestone clasts with inserted cherts were found. The clasts are mostly angular to subangular and rounded pebbles are rare. The breccia matrix is organodetritic (Fig. 4.4), similar to the Nižná Limestone (organic detritus of bivalves, coralline algae, benthic and occasionally planktonic foraminifers and rudists).

After thorough examination, such breccia was also found at Krásna Hôrka (Fig. 4.5–6) and in both sections near Zemianska Dedina (Fig. 8.1–2). Apart from Dlhá nad Oravou, where the breccia is thickest (about 10 m), it does not reach more than 5 m in other sections. For the newly discovered breccia, the name Tvrdošín Breccia Member is proposed. It represents the basal member of the Nižná Limestone Formation.

Coarse-grained grainstone, packstone to rudstone variety of the Nižná Limestone

This rock-type consists of redeposited biodetritus derived from shallow-water environments (Fig. 6.3–4). The size of the detritus particles often exceeds 2 mm in diameter (rudstone). Intergranular spaces in this microfacies are filled with alternating micrite and sparite, with sparite being more plentiful here. The limestone occasionally contains lithoclasts of Calpionella limestone (Pieniny Limestone Formation — Fig. 6.5). The bioclasts consist of echinoderm particles (crinoid ossicles, echinoid plates and spines — Fig. 6.3–4), fragments of bryozoans (Fig. 6.6), serpulid worm tubes (Fig. 6.7), bivalve (mostly oysters and rudists), gastropod and brachiopod shells,

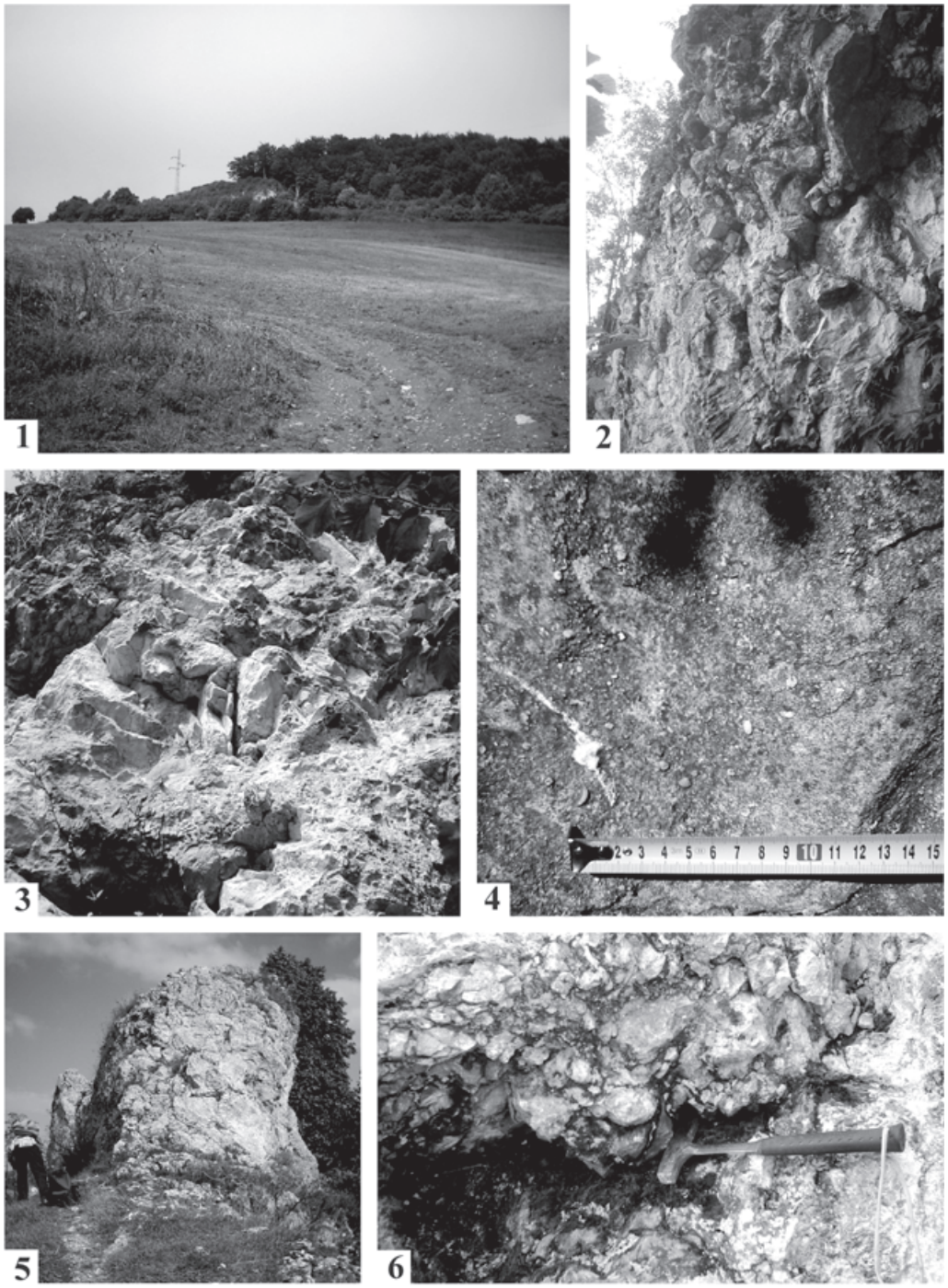

Fig. 4. **1** — View on Skalka locality from Dlhá nad Oravou. **2** — Coarse-grained chaotic breccia (Tvrdošín Breccia Member) with clasts of Middle Jurassic to Lower Cretaceous limestones and silicites. Skalka. **3** — Another view of the breccia. **4** — Organodetritic matrix of the Tvrdošín Breccia, identical to the Nižná Limestone. Skalka. **5** — Krásna Hôrka locality. The klippe consists of Pieniny Limestone Formation (covered with grass on the left) and Nižná Limestone Formation (cliff), with Tvrdošín Breccia Member at its base. **6** — Tvrdošín Breccia Member at the base of the Nižná Limestone Formation, Krásna Hôrka.

fragments of dasyclad and coralline algae (these include also *Ethelia alba* (Pfender) and *Solenphoridae* gen. et spec. indet.), together with problematics *Gemeridella minuta* (Borza) and zoospores *Globochaete alpina* Lombard. Foraminifers are also present, mainly as fragments of orbitolinid foraminifers without preserved embryonic chambers; to a lesser extent there are miliolid, lagenid and agglutinated biserial forms, and rarely also planktonic forms. The coarser varieties also contain fragments of calcareous sponges and oncoids (Fig. 6.8). The bioclasts are often partly silicified. Chalcedony and microquartz also occasionally fill intergranular pores. Redeposition

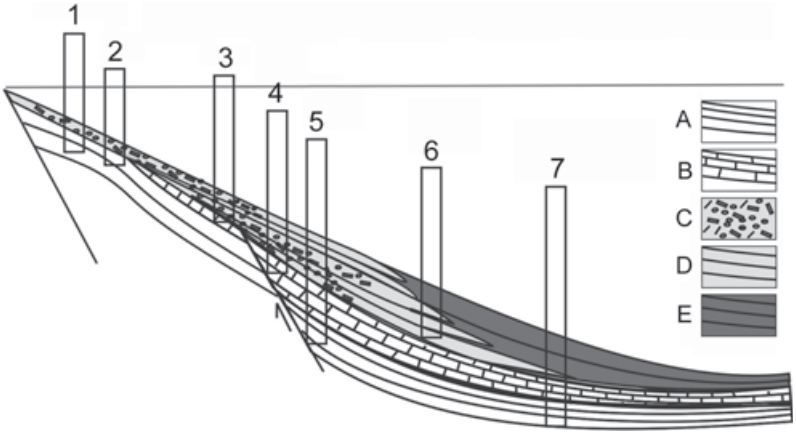

Fig. 5. Position of the Nižná Limestone Formation in the studied sections, in the context of other lithostratigraphic units. **A–E** — Lithostratigraphic units: A — Czajakova Radiolarite Fm; B — Pieniny Limestone Fm; C — Tvrdošín Breccia Member in the Nižná Limestone Fm; D — Nižná Limestone Fm; E — Tissalo Fm. **1–7** — Sections and their situation in the depositional area: 1 — Skalka, 2 — Ostražica, 3 — Krásna Hôrka, 4 — Medvedzie, 5 — Zemianska Dedina, 6 — Ostrý Vrch, 7 — Vysoký Grúň.

caused considerable fragmentation of the bioclasts and resultant poor preservation. Some bioclasts, mostly echinoderm particles, are frequently bored by sessile organisms. The rock also contains a detritic admixture consisting of angular quartz grains, with occasional well-rounded garnet, as well as authigenic glauconite, phosphatic grains, and authigenic pyrite.

Fine-grained packstone to grainstone varieties

This microfacies differs from the previous one in having relatively good detritus sorting and a finer grain size not exceeding 2 mm. In some places, the limestone is laminated and silicification of bioclasts is rare. The sediment is composed of rounded bioclasts and pellets which are usually partly or completely micritized. The bioclasts consist of echinoderm fragments, rare spherical radiolarians, fragments of orbitolinid foraminifers, biserial agglutinated forms, and planktonic foraminiferal tests. Well-rounded quartz grains are also present, plus some rare glauconite. There are very rare lithoclasts of Calpionella limestone. The following planktonic foraminiferal taxa were observed in thin sections of both microfacies varieties: *Globigerinelloides ferreolensis* (Moullade), *Globigerinelloides algerianus* (Cushman et Ten Dam), *Biglobigerinella barri* (Bolli, Loeblich et Tappan) (Fig. 7.1), *Blefusciana* cf. *aptiana* (Bartenstein) and *Blefusciana* cf. *infracretacea* (Glaessner) (Fig. 7.2). Scheibner (1967) estimated the stratigraphic range of the Nižná Limestone Formation as Barremian-Early Albian, according to the presence of *Palorbitolina* cf. *lenticularis* (Blumenbach). The new data show presence of the genus *Globigerinelloides* which is characteristic of the Late Aptian (*G. ferreolensis* (Moullade), *G. algerianus* (Cushman et Ten Dam)). Although the formation also contains Barremian bioclasts, these were most likely redeposited.

Black shale intercalations (= Koňhora Formation)

Black shale intercalations were found only at the Ostrý Vrch locality, near the base of the Nižná Limestone Formation. They are dark grey to black claystones with leaf-like disintegration. They provided fauna of benthic foraminifers, such as *Caudammina crassa* (Geroch), *Laevidentalina oligostegia* (Reuss), *Laevidentalina cylindroides* Reuss, *Laevidentalina communis* d'Orbigny, *Lenticulina muensteri* (Roemer), *Vaginulinopsis* cf. *harpa* Reuss, *Marginulinopsis* sp., *Saracenaria* cf. *frankei* Ten Dam, *Ramulina tappanae* Bartenstein et Brand, *Gavelinella* ex. gr. *intermedia* (Berthelin), *Gyroidina* ex. gr. *nitida* (Reuss), planktonic foraminifers: *Blowiella duboisi* (Chevalier), *Blowiella maridalensis* (Bolli), *Blowiella moulladei* Bou Dagher-Fadel, *Claviblowiella saundersi* (Bolli), *Leupoldina protuberans* Bolli, *Schackoina cepedai* (Obregón de la Parra), *Schackoina pentagonalis* (Reichel), *Blefusciana kuznetsovae* Banner et Deshai, *Blefusciana aptiana* (Bartenstein), *Blefusciana infracretacea* (Glaessner), *Lilliputianella bizonae* (Chevalier), *Lilliputianella kuhryi* (Longoria), and radiolarians: *Godia concava* (Li et Wu), *Dactyliodiscus lenticulatus* (Jud), *Syringocapsa* cf. *coronata* (Squinabol), *Praeconocaryomma* cf. *prisca* Pessagno, *Dictyomitra* sp., *Staurosphaeretta* sp. and *Williriedellidae* gen. et spec. indet. The planktonic foraminiferal assemblage is characteristic of the upper part of the Lower Aptian, and this correlates well with the age of the Koňhora Formation.

Variegated marly limestones and marls (Tissalo and Lalinok Formations)

These lithologies were found only at the Vysoký Grúň and Ostrý Vrch localities (Fig. 9.5). The marly limestones consist of foraminiferal packstone, formed almost exclusively by planktonic foraminiferal tests. These include *Blefusciana* cf. *aptiana* (Bartenstein), *Blefusciana infracretacea* (Glaessner), *Hedbergella* cf. *trocoidea* Gandolfi, *Hedbergella* cf. *delrioensis* (Carsey), *Ticinella bejaouensis* Sigal (Fig. 9.1–2), *Ticinella roberti* Gandolfi (Fig. 9.3), *Globigerinelloides algerianus* (Cushman et Ten Dam) (Fig. 9.4–5), *Globigerinelloides ferreolensis* (Moullade). The foraminifers indicate a Late Aptian to Late Albian age of the marly deposits. Tests of benthic rotaliids and agglutinated foraminifers are relatively rare. The following taxa of benthic foraminifers were identified: *Hippocrepina* sp., *Ammodiscus cretaceus* (Reuss), *Gaudryina* ex. gr. *dividens* Grabert, *Gaudryina pyramidata* Cushman, *Tritaxia gaultina* (Morozova), *Dorothia gradata* (Berthelin), *Dorothia* sp., *Laevidentalina oligostegia* (Reuss), *Lenticulina muensteri* (Roemer), *Globulina prisca* Reuss, *Gyroidina* ex. gr. *nitida* (Reuss), *Gavelinella* ex. gr. *intermedia* Berthelin, *Gavelinella* sp.

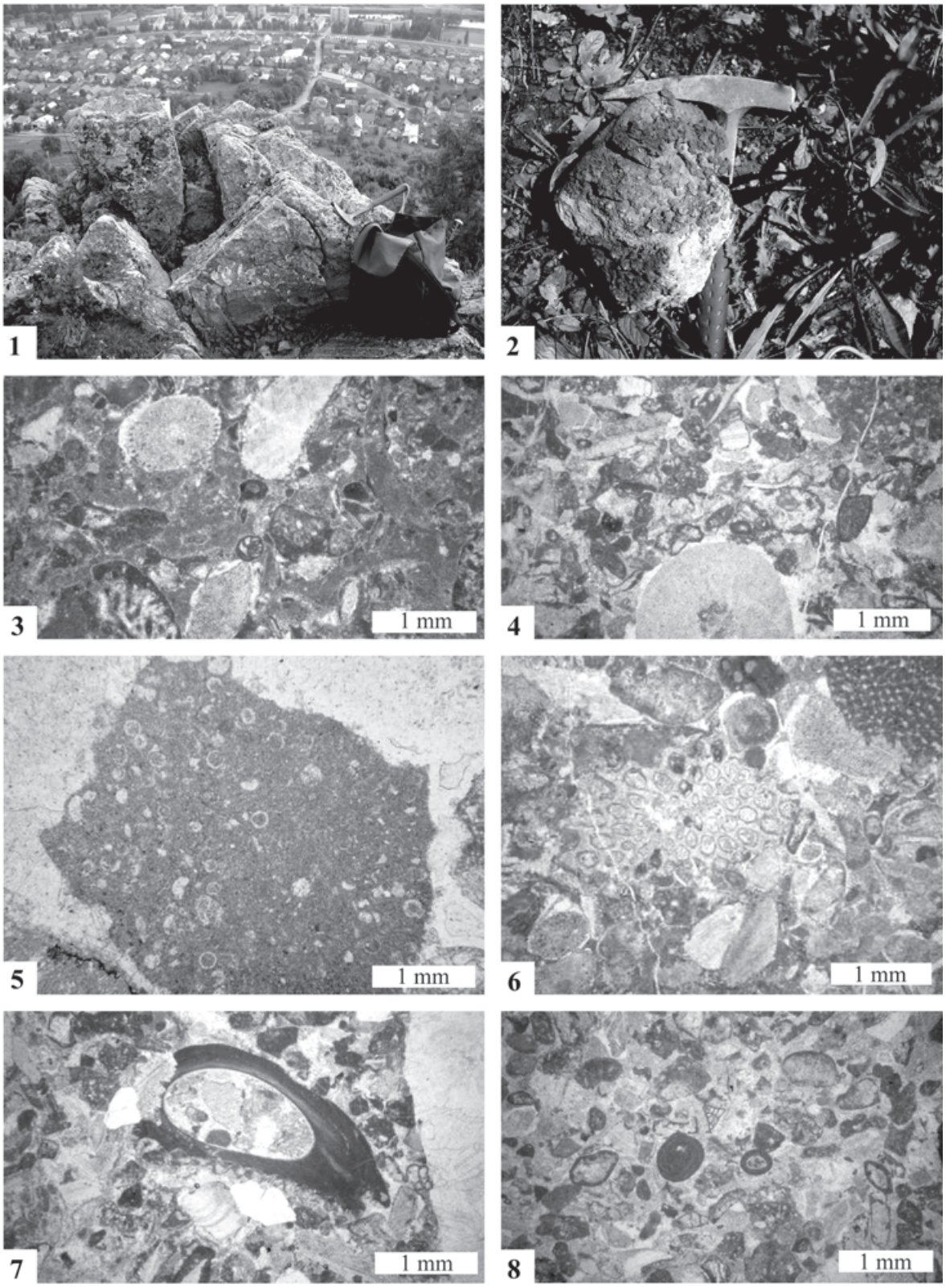

Fig. 6. Nižná Limestone — field and microscopic photos. **1** — Massive Nižná Limestone (Nižná village in the rear). **2** — Coral boundstone with positively weathered silicified corals. Skalka Section. **3** — Coarse-grained organodetritic packstone, with benthic foraminifer *Lituola strogguloides* Arnaud-Vanneau in the centre. Skalka section. **4** — Coarse-grained organodetritic packstone. Ostražica locality. **5** — Clast of Calpionella limestone in the Nižná Limestone. Ostražica locality. **6** — Bryozoan fragment in the Nižná Limestone. Vysoký Grúň Section. **7** — Coarse-grained Nižná Limestone with cross-section of serpulid tube and detritic quartz. **8** — Nižná Limestone with microoncoids.

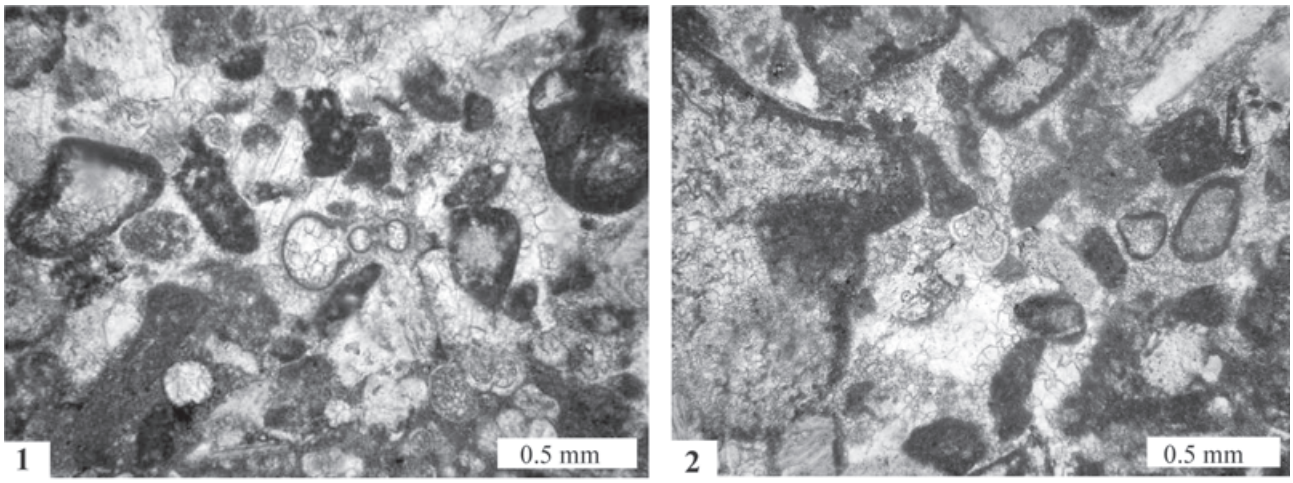

Fig. 7. Autochthonous planktonic foraminifers from the Nižná Limestone Formation. **1** — *Biglobigerinella barri* (Bolli, Loeblich et Tappan), in fine-grained calciturbidite, peripheral cross-section. Ostrý Vrch Section. **2** — *Blefusciana* cf. *infracretacea* (Glaessner). Same sample as previous.

(Fig. 9.6), *Conorotalites bartensteini aptiensis* (Bettenstaedt) and *Pleurostomella* sp. Several radiolarian taxa were also determined: *Thanarla spoletoensis* O'Dogherty, *Rhopalosyringium mosqyense* (Smirnova et Aliev), *Pseudoeucyrtis apochrypha* O'Dogherty, *Pseudodictyomitra carpathica* (Lozyniak), *Holocryptocanium geysersensis* Pessagno, *Syringocapsa* cf. *spinosa* (Squinabol), *Praeconocaryomma* sp., *Dicroa rara* sp., *Sethocapsa* sp. and *Syringocapsa* sp. The ratio of benthic organisms increases upwards, together with clay admixture. Other rare bioclasts are represented by silicisponge spicules, thin-shelled bivalves, pellets and rarely by echinoderm particles. Sandy detritic admixture is present in some places, represented by angular quartz grains and occasionally by glauconite.

Black radiolarites (Groń or Pomiedznik Formation)

Black radiolarites were found only at the Vysoký Grúň locality. They consist of poorly outcropped black to dark grey bedded silicites. Microscopically they contain radiolarian- to radiolarian-spiculitic wackestones (Fig. 9.7–8). Radiolarian tests are mostly represented by spumellarians; and nasellarians are rarely encountered. Planktonic foraminiferal tests are also occasionally present and these are similar to genera *Blefusciana* or *Hedbergella*. Judging from the superposition and lithostratigraphy of the Kysuca/Grajcarek Units, the radiolarites are probably of Cenomanian age.

"Exotic" flysch

"Exotic" flysch consisting of pale yellowish sandstones with some pebbles and rich coalified tiny plant detritus (Fig. 8.6) occurs at many localities, but due to the scarcity of outcrops a contact with the older strata is not directly visible. Only at Vysoký Grúň do they appear as subsequent deposits to the black radiolarites. The age of the flysch is estimated as Cenomanian or younger.

Interpretation of the sections

Contact between the Nižná Limestone Formation and underlying beds

This study revealed that all the examined sections show a strong reduction in the Upper Jurassic-Lower Cretaceous strata underlying the Nižná Limestone Formation (Fig. 10). The white Calpionella limestone (Pieniny Limestone Formation) is preserved only at the Medvedzie, Krásna Hôrka, Zemianska Dedina and Vysoký Grúň localities. It is relatively thin, measuring 5 m and less. Calpionellid zones in the uppermost beds of this limestone never exhibited an age younger than the Late Berriasian. An exception exists at the Vysoký Grúň locality, where the Pieniny Limestone Formation is most complete and comprises Barremian strata. At this location, the completeness of this formation is caused by its distal, basinward position in the sedimentary area, since the Nižná Limestone Formation here represents only thin layers (up to 0.5 m) of distal calciturbidites (Fig. 8.3). The Vysoký Grúň section shows that even the original thickness of the Pieniny Limestone Formation in the Nižná Unit was not great. At some sites (Skalka, Ostrý Vrch and Ostražica), the Nižná Limestone Formation is in direct contact with Callovian–Oxfordian radiolarites of the Czajakowa Radiolarite Formation and their strata formations lay relatively conformably on each other (Fig. 8.4). Additional light was shed on the secondary reduction or absence of the pre-Barremian strata by the discovery of the Tvrdošín Breccia Member. This indicates that the contact between the Nižná Limestone Formation and the Jurassic strata is erosional and that emersion and erosion played an important role in the Cretaceous evolution of the Nižná Unit.

Beds overlying the Nižná Limestone Formation

Scheibner (1967) proposed that the exotic flysch directly overlies the Nižná Limestone Formation. The Os-

Fig. 8. **1** — Zemianska Dedina Section 2. **2** — Spherical clasts of black cherts at the base of the Nižná Limestone Formation (Tvrdošín Breccia Member). The cherts came from the Pieniny Limestone Formation. **3** — Nižná Limestone Formation as thin distal calciturbidite. Vysoký Grúň Section. **4** — Nižná Limestone (pale, left) conformably overlying greenish Jurassic Czajakowa Radiolarite Formation (dark, right). Rest of the Jurassic and Lower Cretaceous sediments is missing. Ostražica. **5** — Red to grey marlstones and limestones (Tissalo and Lalinok Formations), overlying the Nižná Limestone Formation. Artificially trenched section at Vysoký Grúň. **6** — Exotic flysch sandstone with coalified plant detritus. Debris above the Vysoký Grúň Section.

trý Vrch and Vysoký Grúň localities show that the Nižná Limestone Formation was in fact overlain by uppermost Aptian to Cenomanian pelagites at least 10 m thick. The combined natural and trenched section at Vysoký Grúň revealed a more or less continuous succession, where the relatively thin Pieniny Limestone Formation (5 m) is overlain by thin allodapic layers of the Nižná Limestone Formation (about 1 m) which is succeeded by alternating red pelagic limestones, marls and shales (about 3 m) of Late Aptian to earliest Albian age. These lithostratigraphic units are identical to the Tissalo and Lalinok Formations of the Kysuca Unit. Higher up, black radiolarites of presumably Cenomanian age occur and these are identical to the Pomiedznik or Groń radiolarites defined by Birkenmajer (1977). Although

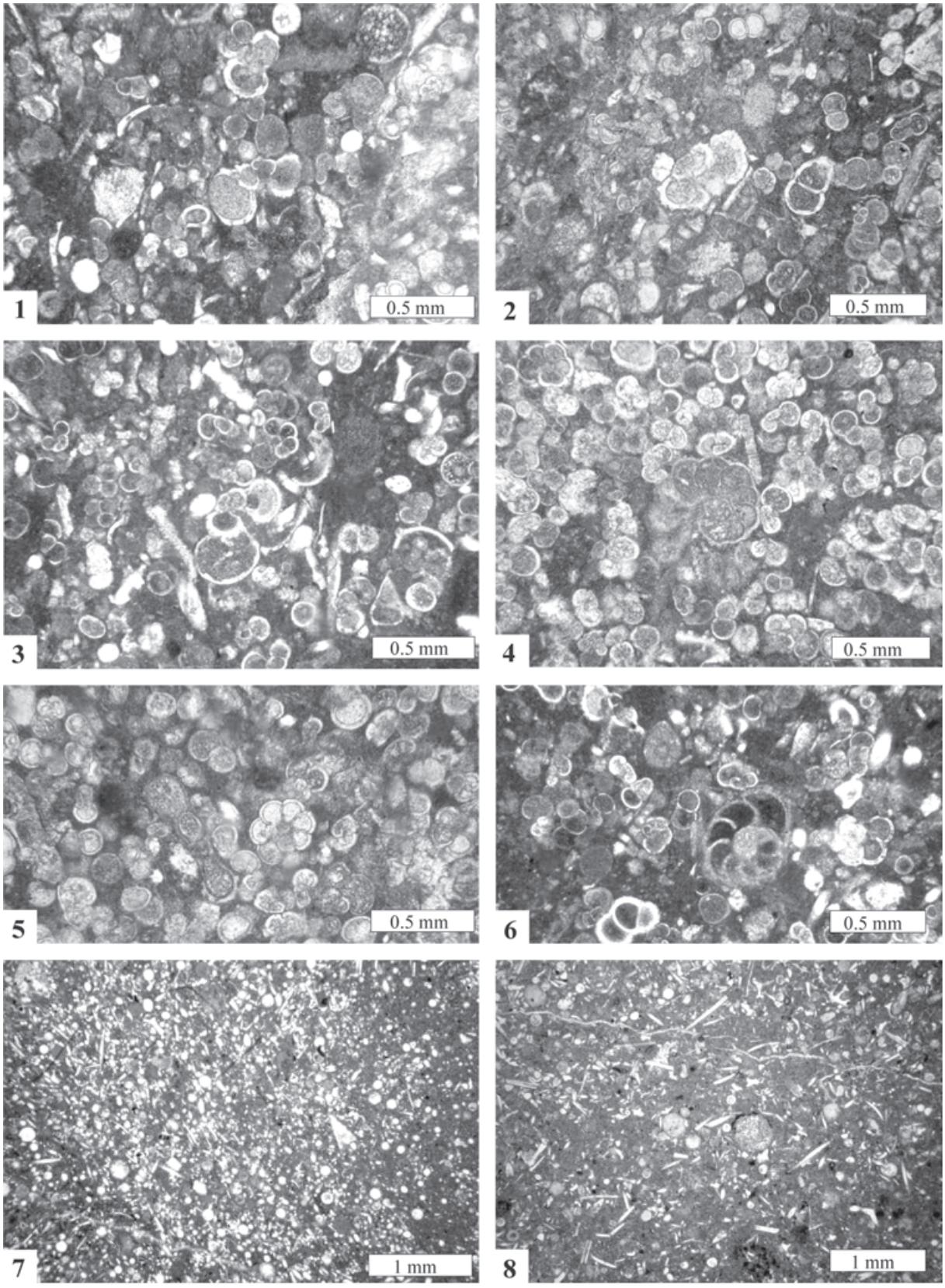

Fig. 9. Foraminifers and microfacies from the Aptian-Cenomanian pelagites from Vysoký Grúň Section. **1,2** — *Ticinella bejaouensis* Sigal. **3** — *Ticinella roberti* (Gandolfi). **4,5** — *Globigerinelloides algerianus* (Cushman et Ten Dam). **6** — Benthic foraminifer *Gavelinella* sp. **7** — Radiolarian packstone (probably Albian-Cenomanian) from black radiolarite. **8** — Radiolarian-spiculitic packstone from the same formation.

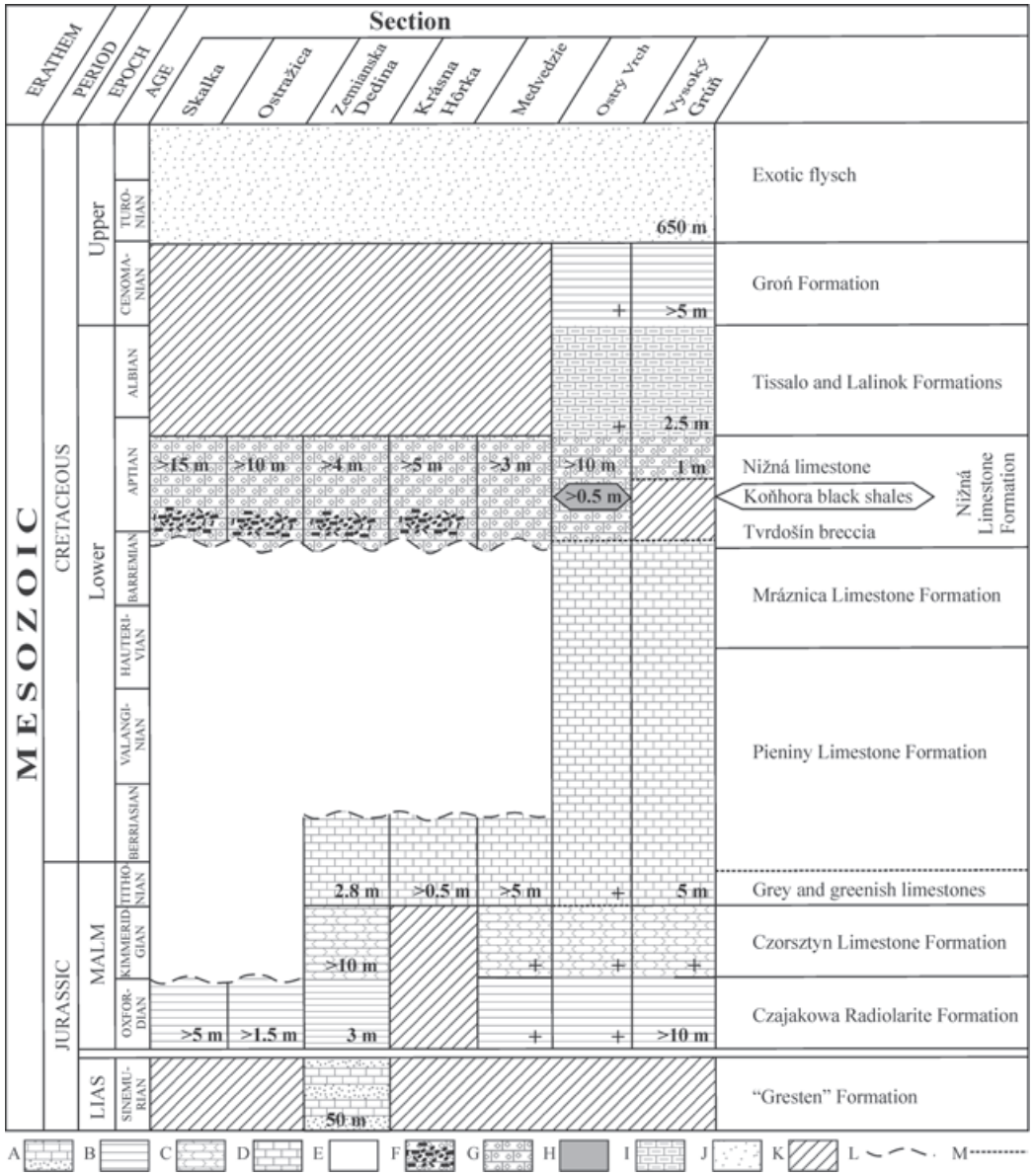

Fig. 10. Lithostratigraphic units of the Nižná Unit and their thickness in the studied sections. Lithology: **A** — sandstones and sandy limestones, **B** — radiolarites and radiolarian limestones, **C** — nodular limestones, **D** — maiolica limestone, **E** — gap, **F** — breccia in limestone matrix, **G** — biodetritic limestones, **H** — black shales, **I** — platy limestones and marlstones, with silicites locally, **J** — sandstones and microconglomerates, **K** — lithotype not present, **L** — erosional surface, **M** — unconformity.

their estimated thickness is about 3 m, this could not be verified by trenching. Just above them, pale yellowish sandstones occur, and these may be considered to be the above mentioned exotic flysch. Although no direct stratigraphic evidence was found in the flysch, the age of its onset was surely younger than that proposed by Scheibner (1967), meaning at least Cenomanian–Turonian.

Discussion — the Cretaceous evolution and paleogeographical position of the Nižná Unit

The secondary reduction of the pre-Barremian strata in the Nižná Unit can be interpreted only as a result of emersion and erosion. The presence of the polymictic basal breccia in the Nižná Limestone Formation shows that the pre-Barremian strata in the Nižná Unit were locally eroded to deep levels. As to the character of this erosion, a submarine erosion can be excluded. Only emergence could produce such deep erosion and could extract free cherts from the Pieniny Limestone Formation. Purely submarine slumps occur mostly in unlithified, plastic or semi-plastic sediments but here the clasts in the breccia were lithified rocks. Although the clasts in the breccia are never bored by bivalves or other organisms, their low degree of roundness shows that these clasts spent a rather short time in an agitated environment (the shoreline here was most probably narrow and steep). Scheibner (1967) mentioned the

basal breccia only from the second of the sections near the Zemianska Dedina. His estimation of the breccia's thickness was restricted to only 1 m at the base, where resedimented cherts are clearly visible. In fact, the breccia is about 4 m thick, but the clasts in the higher strata are formed by less pronounced Calpionella limestone and, therefore, remained unrecognized. The existence of such basal breccia was also reported by Mišík (1990), who identified lithoclasts of Upper Jurassic-Lower Cretaceous limestones and radiolarites but without estimating the breccia's thickness. The only sections in which the Upper Jurassic-Lower Cretaceous sediments were really intact from erosion are those that were originally situated in the distal offshore position (Vysoký Grúň).

Another example of the Tvrdošín Breccia Member can be found in Mišík (1990, p. 40–42) who described a block of very similar breccia, with numerous clasts of cherts and limestones. However, this occurrence was found outside the Orava territory, near Krivoklát in the middle part of the Váh Valley. It is highly probable that this breccia also belongs to the Nižná Unit. Although distant from Orava, some phenomena typical for the Orava sector of the Pieniny Klippen Belt can also be encountered in the Váh Valley (Schlögl 1998; Schlögl et al. 2000).

The shallowing and emergence in the sedimentary area of the Kysuca already started in the Hauterivian, as seen in other sections in the Pieniny Klippen Belt. At Horná Lysá near Vršatec, shallow-water detritus and small clasts of older rocks occur in an otherwise purely pelagic Pieniny Limestone Formation (Mišík et al. 1994). Similar evolution was observed at the still undescribed locality in Durcovie Valley near Stará Turá. At Istebné, slump bodies and coarse turbidites with limestone and radiolarite clasts (i.e. local material from the Kysuca Unit) were also found in the Hauterivian marlstones (Aubrecht 1994). Although older, the composition of these Hauterivian clastics is almost identical to the Tvrdošín Breccia Member. According to Aubrecht (1994), although this Hauterivian resedimentation event slightly preceded the Barremian-Aptian events in the Nižná Unit, it was probably related to them.

Scheibner (1967) presented his opinion that the Nižná Limestone Formation is directly overlain by Albian-Cenomanian exotic flysch. In such case, the Nižná Unit would be the only Oravic Unit in which the deposition of exotics started as early as in the Albian. This development would therefore be close to the Klape Unit, which was supposedly situated at the southern margin of the subducting Oravic branch of the Penninic Ocean. The opinion about the southern provenance of the Nižná Unit was also proposed by Polish authors (Birkenmajer 1986). Some authors affiliated it to the Haligovce Unit which is considered to be derived from the northern margin of the Central Western Carpathians (Matějka & Andrusov 1931; Andrusov 1938; Birkenmajer 1959; Kotański 1963). According to Mišík (1990), the sedimentary area of the Nižná Unit was close to that of the Manín Unit. These presumptions were also based on the presence of the Urgonian-like facies in all the above mentioned units. Except for the rare occurrence of the Trawne Member in the Kysuca Unit (=Branisko Unit, Birkenmajer 1987), the flysch sedimentation in the more northern part of the Kysuca-Pieniny trough started as late as the Turonian. The Ostrý Vrch and Vysoký Grúň localities contradict the theory about the early start of the exotic flysch in the Nižná Unit. The presence of the Aptian to Cenomanian pelagites provides evidence that the onset of the flysch was in the Cenomanian–Turonian, exactly as in the typical Kysuca Unit. Scheibner (1967) also reported that rare exotic pebbles were found in the uppermost parts of the Nižná Limestone Formation. However, such pebbles were not observed during this study.

Investigations in the Czorsztyn Unit (the shallowest Oravic Unit) showed that a large portion of the Oravic domain (as far as the Niedzica/Pruské sedimentary area) might have emerged during Barremian–Aptian time (Aubrecht et al. 2002, 2006). This emergence may even have started as early as in the Hauterivian. Although no detritic material derived from the Czorsztyn, Niedzica, or Czertezik Units was found in the Tvrdošín Breccia Member, this event may be related to the same emergence event. In the Nižná Unit, this emergence surely covered a time span from Barremian to Middle Aptian. According to the pelagic foraminiferal assemblages, the age of the Nižná Limestone Formation is mainly Late Aptian. During this time there was a repeated submersion of the Nižná Unit, and this fits perfectly with the age of the repeated submersion of the Czorsztyn Unit (Aubrecht et al. 2006).

All the above mentioned data imply that the Nižná Unit was situated on the margin of the sedimentary area of the Kysuca Unit. With the exception of the Nižná Limestone Formation, the lithostratigraphy of the Nižná Unit corresponds very well with that of the Kysuca Unit. On the other hand, there are big differences when the lithostratigraphy is compared to that of the Haligovce Unit (Birkenmajer 1959). Heavy mineral assemblages in the Lower Ju-

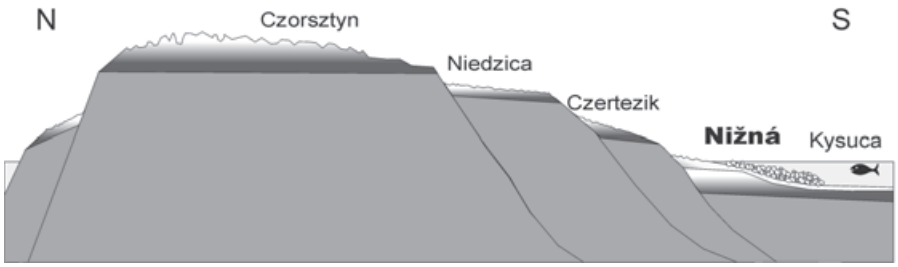

Fig. 11. Reconstruction of paleogeographical position and sedimentary environment of the Nižná Unit during the Hauterivian-Barremian relative sea-level drop in the Oravic area.

rassic sediments of the Nižná and Haligovce Units are completely different which indicates their different provenance (Aubrecht 2001). Similarly, the lithostratigraphy of the Manín Unit is different from the Nižná Unit. Therefore, in contradiction to previous opinions, we propose that the Nižná Unit was situated on the opposite (northern ?) side of the Kysuca Trough, closer to the Czorsztyn Swell.

Conclusions

Deep erosion caused by emergence, together with the onset of exotic flysch later than originally supposed, shed more light on the problem of paleogeographical position of the Nižná Unit. In the case of the Czorsztyn Unit, Aubrecht et al. (2006) showed that a large area of the Oravic domain (as far as the Niedzica/Pruské zone) may have emerged during Barremian–Aptian time. This emergence may even have commenced as early as the Hauterivian. Although no detritic material derived from more shallow-water units was found in the Tvrdošín Breccia Member, we propose that it may be related to the same emergence. In the Nižná Unit, this emergence surely occurred during the time from Barremian to Middle Aptian. According to the planktonic foraminiferal assemblages, the age of the Nižná Limestone Formation is mostly Aptian. Repeated submersion of the unit occurred in this time, as in the Czorsztyn Unit. The processes that led to the emergence of the Nižná Unit had most likely already commenced in the Hauterivian, as shown by some occurrences of coarse-grained turbidites and mass-flow deposits in Hauterivian marls of the Kysuca Unit.

These data imply that the Nižná Unit can be placed in the Kysuca sedimentary area on the northern side of the Kysuca Trough, closer to the Czorsztyn Swell (Fig. 11).

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