Paleokarst, neptunian dykes, collapse breccias, mud-mounds and sedimentary unconformities

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With 55 figures

Field Trip Guide

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Content

Abstract

The field trip is aimed to show special cases in sedimentology, when the marine deposition rate slows down or ceases completely due to emersion. It is interesting to observe the sedimentary record from these periods as there are many special sedimentological phenomena, such as paleokarst features, like collapse breccias, neptunian dykes, paleokarst karren surfaces, preserved paleotopographic features, etc. Also instructive are sedimentological features related to the next onset of marine transgression on these surfaces, like basal conglomerates and breccias with typical intertidal sedimentation, animal borings, etc. In some cases, rapid flooding with onset of deep-water facies over the paleokarstic surface was also recorded.
The Western Carpathians provide an unique area to study all these phenomena. This field trip includes localities of Miocene paleokarst with 15 million year old speleothems, rich terrestric fossil fauna found in caves, Miocene transgression surfaces, Upper Cretaceous paleokarst which originated after main tectonic phases in the Central Western Carpathians, earlier, Mid-Cretaceous paleokarst in the Pieniny Klippen Belt, various manifestations of Jurassic synrift deposition in the Pieniny Klippen Belt, including hardgrounds, cliff- and cave collapse-breccias, neptunian dykes and stromatactis mud mounds.

1. Topics and area of the Field Trip

This 3-day field trip will include visiting of localities of Miocene paleokarst with 15 million year old speleothems, rich terrestric fossil fauna found in caves, Miocene transgression surfaces, Upper Cretaceous paleokarst which originated after main tectonic phases in the Central Western Carpathians, earlier, Mid-Cretaceous paleokarst in the Pieniny Klippen Belt, various manifestations of Jurassic synrift deposition in the Pieniny Klippen Belt, including hardgrounds, cliff- and cave collapse-breccias, neptunian dykes, stromatactis mud mounds (including a locality where sponge origin of enigmatic stromatactis structures has been proved).

Field trip details (Fig. 1)
Day 1: The visited sites include Miocene paleokarst and transgressive surfaces near Bratislava, SW Slovakia (Male Karpaty Mts., Vienna Basin).
Localities:
1 Devin Castle (Jurassic synrift breccias, Miocene neptunian dykes).
2 Sandberg (Miocene transgression surface, marine abrasion caves with fauna).
3 Quarry of former Stockerau Lime Factory (Miocene paleokarst with fauna).
4 Zahorska Bystrica (Miocene transgression surface).

Day 2: The visited sites include Miocene transgressive surfaces, Upper Cretaceous paleokarst, Mid-Cretaceous paleokarst, Jurassic synrift deposition - SW Slovakia (Male Karpaty Mts., Vienna Basin, and Biele Karpaty Mts.).

Localities:

5 Solosnica (Upper Cretaceous paleokarst).

6 Hradiste pod Vratnom (Miocene transgression surface).

7 Dolna Suca - Krasin (Jurassic synrift megabreccias).

8 Horne Srnie (Mid-Cretaceous paleokarst, Jurassic synrift breccias).

9 Slavnicke Podhorie (Middle Jurassic stromatactis mud-mound).

Day 3: The visited sites include Jurassic synrift deposition, mid-Cretaceous paleokarst, Upper Cretaceous/Paleocene paleokarst, bauxites (Biele Karpaty Mts. - Pieniny Klippen Belt, Strazovske vrchy Mts.).

Localities:

10 Vrsatec (Jurassic neptunian dykes, Mid-Cretaceous paleokarst).

11 Mojtin (Upper Cretaceous/Paleocene paleokarst, bauxites).

Fig. 1: Field trip map.

2. Introduction

The aim of the field trip is to see examples of sedimentary unconformities, mainly those related to emersion. Erosional and karstification phenomena can be studied at several sites. These are best manifested along the former, Miocene eastern shoreline of the Vienna Basin. This pull-apart basin was formed and completely flooded in Badenian (Langhian). The field trip participants will have chance to observe the pre-transgressional surfaces and manifestation of the latest marine transgression in the West Carpathian-Pannonian realm. Hradiste pod Vratnom site provides insight to older, Eggenburgian (Aquitanian-Burdigalian) phase of the basin evolution.

An older period of emersion was related to the Mid-Cretaceous crustal shortening and nappe stacking in the central Western Carpathians. The nappe stacking resulted in emersion and karstification of the highest nappe surfaces, forming paleokarst surface depressions filled with bauxites and fossil Terra Rosa.

In the Pieniny Klippen Belt there was an Early Cretaceous emersion of so-called Czorsztyn Swell which resulted in nice paleokarst karren surface. The emersion period ended in Albian with sudden flooding (ingression) with deposition of red pelagic marls. Therefore, until recognition of the paleokarst features, this break in sedimentation was considered to be caused by submarine non-deposition and erosion.

The oldest features which can be observed during the field trip are related to the Middle Jurassic rifting and rising of the Czorsztyn Swell. This was again accompanied by breakage (neptunian dykes), emersion and erosion of new lithified sediments and forming the toe-of-slope megabreccias. There is an interesting cave-dwelling fauna of ostracods *Pokornyopsis feifeli* TRIEBEL, descendants of which still inhabit submarine caves in tropical seas. Further drowning of the Czorsztyn swell led to deposition of the Rosso Ammonitico facies, with local occurrences of stromatactis mud-mounds. Stromatactis structures were enigmatic for over a century but at one of the sites the participants will have a chance to see that stromatactis are just cavities after collapsed siliceous sponges.

3. The Field Trip

3.1. Lower and Middle Miocene transgression on the shores of Vienna Basin and the pre-transgression paleokarst

Topic No. 1 of the field trip is to study Middle/Upper Badenian and earlier, Eggenburgian transgressive surfaces along the eastern shore of the Vienna Basin (Fig. 2). In the early Miocene, the Vienna Basin was only a small "piggy-back" type of basin developed on the Carpathian Flysch Zone. This basin underwent large re-building during Karpatian-Badenian time (uppermost Burdigalian to

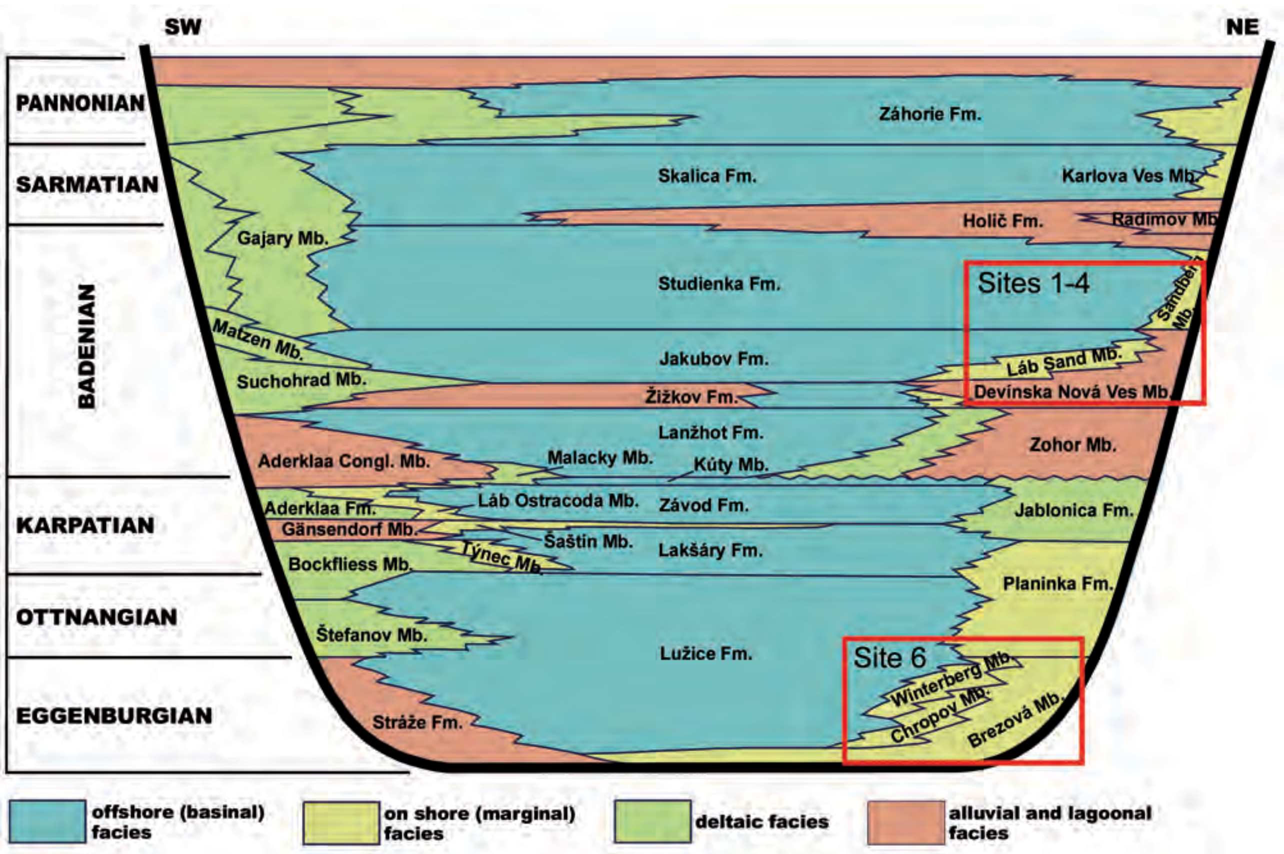


Fig. 2: Lithostratigraphy of the Neogene filling of the Vienna Basin (after KOVAC et al. 2004). Rectangles mark the lithostratigraphic position of the visited sites.

Seravalian - for correlation between the Central Paratethys and Mediterranean stratigraphic scale, see Fig. 3) when the basin opened to its present form in a pull-apart regime (Kovac et al. 2004). In this time, the horst of the Male Karpaty Mts. (Small Carpathians) originated, limiting the basin from the east. The new horst underwent immediate erosion and its limestone series were karstified. Paleokarst phenomena, such as clefts and caves were initially filled with sinters, as well as by terrestrial sediments locally with rich fauna. These phenomena can be traced from the Hainburg Hills in Austria (geologically part of the Male Karpaty Mts.), across the Danube River to the Devin Castle Hill

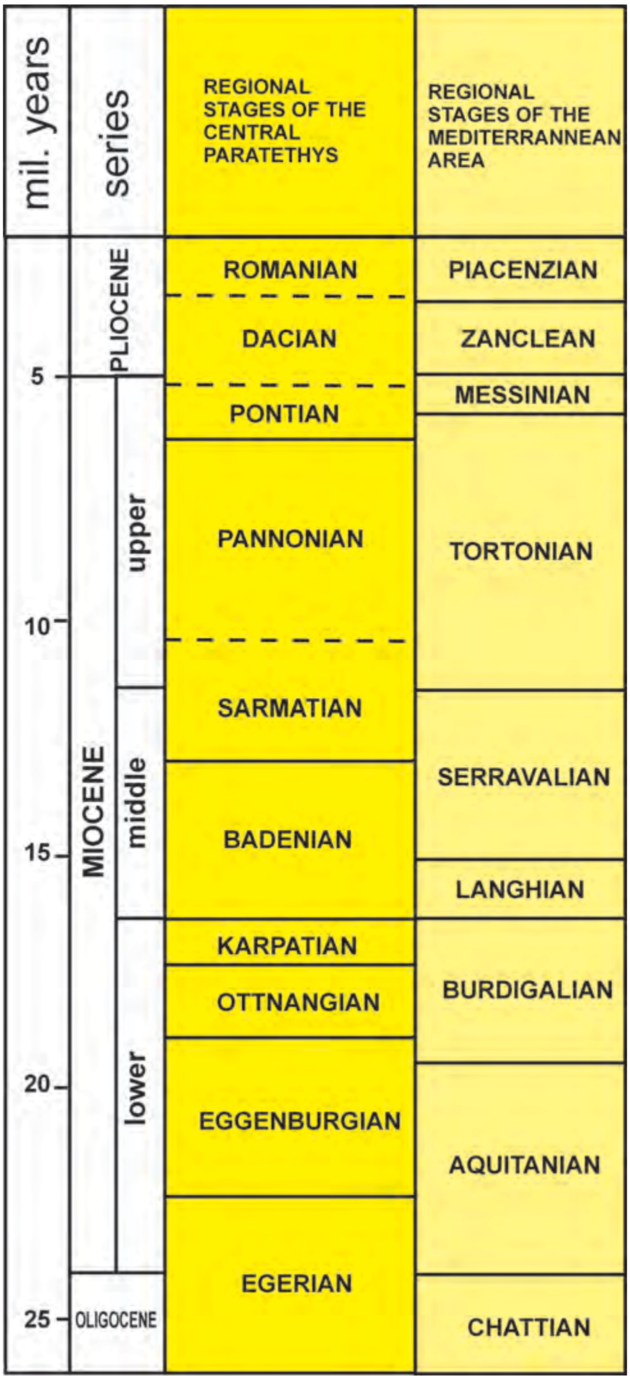


Fig. 3: Correlation between the Central Paratethys and Mediterranean stratigraphic scale.

and to the neighbouring hill Devinska Kobyla. The erosion and karstification phase was followed by the Middle/Late Badenian marine transgression. It was the last true marine incursion to this area, leaving littoral to neritic sediments rich in stenohaline fauna. Various abrasion phenomena, animal borings and other features typical for intertidal zone can be observed on the transgressive surface.

Stop 1: Devin Castle
GPS coordinates: N 48°10’26.96", E 16°58’38.49"

Devin Castle was built on a cliff at the confluence of the Danube and Morava rivers. From E to W, the Devin castle hill is built by phyllites of the Tatric crystalline complexes of the Male Karpaty Mts., covered by Upper Permian terrestrial clastics and Lower Triassic quartzites. Then the succession continues by carbonates, e.g. Middle Triassic dolomites and Jurassic limestones and breccias. The western cliff wall (Fig. 4) is formed by Middle Jurassic biodetritic (crinoids, belemnites, brachiopods) breccia limestones with angular clasts of the underlying dolomites and limestones (Fig. 5). The limestones intrude deeply into the Triassic basement forming fissure fillings and neptunian dykes, pointing to extensive erosion and faulting before the Lower Jurassic transgression. The breccias originated due to Jurassic rifting related to the opening of Penninic Ocean (Michalik & Vlcko 2011).

Fig. 4: The western cliff wall on which Devin Castle was built.

About four small paleokarst caves and several fractures filled with Neogene sediments were recognized in the carbonates and breccia forming the westernmost parts of the castle hill (Kahan et al. 1973). In some of them, old sinters were preserved (Fig. 6), with subsequent filling of marine Upper Badenian sands. Locally, traces after bivalve borings are preserved.

Fig. 5: Middle Jurassic breccia formed by clasts of older, Middle Triassic dolomitic limestones and dolomites. The breccia originated due to Penninic Rifting.

Fig. 7: Abrasion sea cave below the Sandberg Hill originated due to Upper Badenian transgression.

Fig. 6: Miocene sinter in the Middle Jurassic breccias.

Stop 2: Devinska Nova Ves - Sandberg
GPS coordinates: N 48°12' 03.10'' E 16°58' 25.57''

The locality is situated on the W slope of the Devinska Kobyla Hill and it represents a facies stratototype of the Upper Badenian (Kosovian, Bulimina-Bolivina Zone) (Svagrovsky in PAPP et al. 1978). The Upper Badenian Sandberg Formation (BARATH et al. 1994) contains more than 300 species of fossil organisms which have been described here. The sequence is characterized by clastic sediments lying transgressively and unconformaly on Jurassic and Lower Cretaceous limestones which formed a cliff in the Upper Badenian. An evidence of this are frequent occurrences of traces after boring bivalves *Lithophaga*, worms *Polydora* and sponges *Cliona*, similarly as sessile bivalves *Ostrea digitalina* DUBOIS.

Another evidence of marine transgression was abrasion forming sea caves. Below Sandberg there is a small abrasion cave (GPS coordinates: N 48°12' 06.91'' E 16°58' 16.03'') preserved from this time (Fig. 7). It occurs in the wall of former quarry, about 20 m above the road connecting Devinska Nova Ves and Devin. It was formed in Tithonian marly limestones and shales. MISIK (1979a) described it as a sea cave. The cave is about 8 m long, 3 m wide and up to 4 m high. Its bottom slightly rises and the cave space narrows inward. The cave is mostly filled with sands (locally cross-bedded), less by gravels and clasts of limestones, which are partly lithified by secondary calcite. At the cave entrance there are cylindrical borings with diameter up to 2-3 cm, after the bivalves *Lithodomus lithophagus* (Fig. 8).

Another abrasion sea cave is preserved in a nearby two-floor high abandoned quarry (Weit's Quarry - GPS coordinates: N 48°11'40.09'' E 16°58'49.67''), where it is cut into grey limestones, dolomites and carbonate breccias of Liassic age (Fig. 9). In the left and upper walls of the quarry, as well as on the second floor of the quarry the Liassic limestones are unconformably overlain by Upper Badenian breccias cemented by sandy matrix, then subhorizontally layered sandstones, sands (locally cross-bedded - Fig. 10) and gravels. Some larger openings (abrasion sea caves) are filled with Upper Badenian, partly lithified sands and less by gravels. Occurrences of fossil seals *Devinophoca claytoni* (originally described as

Fig. 8: Upper Jurassic platy limestones drilled by boring bivalves.

Fig. 9: Abrasion sea cave filling Weit's Quarry. The cave was formed in gray limestones, dolomites and carbonate breccias of Liassic age.

Fig. 10: Cross-bedding in the sandy filling of the sea cave in the Weit's Quarry.

Pristiphoca vetusta) were described from this sea cave. Clasts and blocks of sinters can be found at this locality, too (including sole blocks with stalagmites). Unlike at other similar localities in the Male Karpaty Mts., sinter-cemented breccias are rare in this quarry.

The evolution of open marine sedimentation observable on Sandberg Hill is following:

On the basement of the open-marine sequence there are polymict breccias and conglomerates with sandy calcareous cement, containing gravel lenses. The clastic material is composed mainly of rocks from the near surroundings; there are granites, pegmatites, amphibolites, limestones, phyllites and quartzites (Misik 1979a). Predominant heavy minerals are zircon, apatite, rutile, anatase, sphene, ilmenite, garnet and biotite, indicating sources predominantly from granites and biotite paragneisses of the Bratislava Nappe. Frequent phenomena are cross-bedding and bioturbation with crab tunnels (Ophiomorpha); teeth of sharks and fish bones can be found as well.

The sequence continues with light yellowish-grey mica-rich coarse-grained sands with cross-bedding and beds as well as lenses of massive calcareous sandstones with gravel intercalations (Figs. 11, 12). They contain abundant mollusc fauna. Represented are above all bivalves such as *Pecten aduncus* (Eichwald), *Flabellipecten solarium* (Lamarck), *Cardita* (*Megacardita*) *jouanetti* Basterot, *Panopea menardi* Deshayes, *Spondylus crassicosta* Lamarck etc.; less frequent are gastropods - *Turitella tricina* Borson, *Conus* sp., frequent are also foraminifers (*Amphistegina*, *Heterostegina*), as well as bryozoans and worm tubes (*Ditrupa cornea* Linné).

Higher up, yellowish grey fine-grained mica-rich sands are exposed, with cross-bedding and lenses of fine-grained gravel. They contain remnants of marine fish and marine as well as land vertebrates.

Above these beds there are light-coloured yellowish gray fine-grained sands with beds of more massive calcareous sandstones containing abundant fauna of foraminifers, bryozoans and molluscs. They contain fillings of crab tunnels, corals, echinoids and brachiopods. In the sandstones there are frequently continuous clusters of coralline algae (Fig. 13, 14), which form lenses of

Fig. 11: Upper Badenian sands to fine gravels of the Sandberg Formation. Sandberg Hill.

Fig. 12: Detailed view on local cross-bedding in the sands.

Fig. 13: Coralgal limestones are typical for the upper part of the former quarry.

calcareous lithothamnium sandstones to sandy limestones. These are more widespread on the NE and S slopes of the Devinska Kobyla Hill.
The uppermost part of the sequence is formed by clayey sandstones to sandy claystones with increasing content of gastropod fauna - *Calliostoma trigonum* (EICHWALD), *Bolma meynardi* (MITSCHI), *Turritella subangulata polonica* FRIEDBERG, etc., indicating gradual decrease of salinity.
Clastic sediments of Sandberg Hill pass towards the Vienna Basin into marine claystone development of the Studienka Fm., cropping out 3 km N of Sandberg in a brickyard pit. The claystones contain abundant Upper Badenian microfauna of foraminifers and calcareous nannoplankton; frequent are remnants of the marine fish *Clupea*.
As far as foraminifers are concerned, rich communities with a prevalence of Bolivinas, Buliminas and Uvigerinas have been found. The classification of Upper Badenian - Kosovian has been done on the basis of *Bolivina dilatata maxima* CICHA & ZAPLETALOVA and *Uvigerina liesingensis* TOULA. The communities contain taxa tolerant to oxygen decrease. Layers of only planktonic foraminifers are an evidence of sporadic oscillation of the boundary between the oxic/anoxic environment from sediment to the water column. Planktonic foraminifers form 20-100% of foraminifera communities. The communities are diversified, predominant is *Globigerina bulloides* D'ORBIGNY. Further there are *Globigerionides trilobus* (REUSS), *Globorotalia siakensis* LE ROY, *Globigerina diplostoma* REUSS, *Globigerina druryi* AKERS.
High content of planktonic foraminifers has been caused most likely by decreased oxygen content and it is not a result of the character of the sedimentation basin, since we do not assume the described sediments to have deposited in greater depths than the neritic.
Nannoplankton communities are rich, dominated by *Cyclococcolithus rotula* (KAMPTNER), frequent are *Micrantholithus* sp., *Ponthosphaera multipora* (KAMPTNER) Roth, *Discoaster variabilis* MARTINI & BRAM, i.e. a community which has been presented as a typical one for the Upper Badenian of the Western Carpathians.
In the wash-out of some beds, some fish remnants can be found (teeth, bones, scales); sponge spicules and echinoid spines are frequent in the whole profile.

Fig. 14: Detail of the coralgal limestone (Leithakalk) from the upper part of the Sandberg quarry.

Stop 3: Devinska Nova Ves - former Quarry of Stockerau Lime Factory
GPS coordinates: N 48°12' 13.43'' E 17°00' 10.54''

The abandoned quarry (Fig. 15) which belonged to Sockerau Lime Factory is situated on the northern slope of Devinska Kobyla Hill, at the railroad from Bratislava to Devinska Nova Ves. The quarry was cut in the Middle Triassic to Liassic limestones. The limestones are tectonically disrupted. The tectonic fractures developed to clefts, which are locally 3.5 m wide and to various karstic phenomena. In the Middle Miocene, between Upper Karpatian and Middle Badenian (17-15 MA), this area was emerged (MISIK 1979a). This is the only place in Slovakia with preserved wall covered with paleokarst sinter older than 15 MA (MISIK 1980) forming stalactites and draperies (Fig. 16).
The clefts acted as natural traps for smaller but also bigger animals (mostly vertebrates). Accumulations of vertebrate

Fig. 15: Abandoned quarry of the former Stockerau lime factory.

Fig. 16: Miocene (pre-Badenian) sinter preserved on the wall of an ancient cave.

Fig. 17: Sinter bored by bivalves during the Middle/Upper Badenian transgression.

bones and teeth were mixed with yellowish soil (Terra Fusca).

The Late Badenian marine transgression disintegrated some of the caves and the rocky shore often covered with sinters was bored by marine bivalves *Lithophaga* (the borings are visible at several places - Fig. 17). The transgressive surface is covered with yellowish sands with marine fauna.

From the paleokarst cavities, two important places are preserved in the quarry. The first one are so-called Zapfe's clefts (German: Spalten) which were named after the Austrian professor Helmuth Zapfe from Vienna University who was responsible for description of the mammal fauna trapped in the clefts. The clefts were discovered by mining during the 2nd World War when there was a labor camp in the quarry. The technical manager of the quarry was Ing. Bruno Zapfe, a brother of Helmuth Zapfe. During mining they discovered about 1.8 m wide cleft containing many vertebrate bones. This material was transported to the Vienna Museum, where most of the material is deposited. The most important findings described by Zapfe were apes *Pliopithecus* (*Epipliopithecus*) *vindobonensis* (Zapfe & Hürzeller) and ungulates *Chalicotherium grande* (Lartet).

Further excavations were performed here in the years 2003-2004. The new material is still under investigation. The investigations confirmed the Middle Badenian age of the terrestric part of the cleft fillings (lower part of the MN 6 biozone; > 13.5 MA).

Fig. 18: Bonanza locality - the latest discovered paleokarst cleft with rich terrestric and marine Neogene fauna.

Another important locality named Bonanza was found in 1982 by an amateur paleontologist Stefan Mesaros. It is a cleft about 3.5 m wide situated directly above the railway track, on the other side of the cliff with the aforementioned sinter wall (Fig. 18). Along with remnants of terrestric fauna, this cleft also contained marine fauna, e.g. shark teeth, fish and seal bones. On the basis of this fauna, the age of the filling was determined as Upper Badenian (upper part of the MN 6 biozone; < 13.5 MA). The most important fossil vertebrates found at this locality were an early toad *Bufo priscus* SPINAR, KLEMBARA & MESAROS, a seal *Devinophoca claytoni* KORETSKY & HOLEC and antelopes *Lagomerix parvulus* (ROGER).

Except of these localities there are several smaller clefts with possible faunal occurrences. They are, however, poorly accessible and a research of their fillings would be risky.

Stop 4: Zahorska Bystrica

GPS coordinates: N 48°13' 41.18'' E 17°03' 09.09''

A Miocene cliff-boulder mass near Bratislava in Southern Slovakia is exposed in a quarry situated on a hill 1.5 km SE of Zahorska Bystrica (Fig. 19). The locality was described in detail by RADWANSKI (1968). The boulder mass is a product of Badenian transgression and represents a thick series of conglomerates which rest on uneven surface of black limestones, assigned to the Gutenstein Formation (Anisian) and breccias assigned to the Ples Formation (Jurassic) of the Tatric Mesozoic cover unit of the Male Karpaty Mts.

Just like at previous localities, the carbonate basement below the Miocene transgressive sediments was fractured and karstified. The fractures were first filled with isopachous sinters and then the remaining spaces were filled with Miocene sands (Fig. 20).

The boulder mass can be examined at three successive exploitation levels of the quarry, where it may be distinctly observed that the uneven bottom surface of the boulder mass rises gradually upwards, more or less parallel with the present surface of the hill. The result is that, although at the individual exploitation levels the boulder mass shows only thicknesses of several meters each, the total thickness over 11 meters.

Fig. 19: Abandoned quarry at Zahorska Bystrica revealing transgressive, coarse-psephitic sediments overlying dark Triassic and Jurassic limestones.

Fig. 20: Prior to the transgression, the limestone basement was fractured. The fractures were partially filled with sinters and then by marine sands.

The cliff-boulder mass at Zahorska Bystrica consists of a set of deposits mostly coarse-psephitic in character, and individual elements reach diameters up to two meters; the largest block observed was 3.4x2.5x1.1 m in size. The coarse-psephitic elements of some half meter to one or two meters in size have the appearance of rounded boulders; those of smaller dimensions rather look like cobbles or pebbles, or they are irregularly shaped. The material was mostly derived from black limestones of the Triassic and Liassic limestones and less from phyllites and other rocks of the crystalline basement. The fine-psephitic and psammitic fraction filling the remaining space consists mostly of quartz material of more allochthonous character.

The bedding of the cliff-boulder mass is very distinct, It is developed as alternating layers with big pebbles, cobbles and boulders on the one hand, and layers of fine-gravelly and psammitic material on the other. Most of the individual layers grow rapidly thinner and laterally peter out streak-like, or they are locally developed in unequal-size depressions and in rough parts of the substratum. The slight westward dip of the layers, of some ten to fifteen degrees, seems to be mostly of sedimentary origin, as if the deposits had been laid down along the slope of the hill.

A characteristic feature of the majority of the calcareous blocks are numerous borings of various lithophags (Fig.

21-25); most numerous are gigantic borings made by the pelecypods *Lithophaga* sp. and, owing to their size, they are well visible from a distance. Single blocks show borings either on one side only, or all over. By the frequency at which the individual lithophags occur, the assemblage of lithophag borings, i.e. the lithophogcoenosis, may be characterized as follows:

1. Pelecypods *Lithophaga* sp. For the most part their cigar-shape borings attain considerable dimensions, up to 12-14 cm in length. The openings of the gigantic forms are almost always abraded while minor forms, distributed over the uneven surfaces of larger blocks, remained sometimes intact. The problem of a specific assignation of these large specimens of *Lithophaga* sp. has not been elucidated so far; all known species, recent and fossil are much smaller.

2. Pelecypods *Barnea* sp. Their borings are pear-shaped, mostly slightly wider in one direction where arc-like grooves are visible, made by the pelecypods while they mechanically increased their borings by the rims of the valves. These borings are also relatively large, up to 8 cm. long and 3-3.5 cm in their widest part, and here, also, the outlets are mostly abraded.

3. Various species of sponges of the genus *Cliona* Grant; most common among them are the species *Cliona vastifica* Hancock and likewise *Cliona celata* Grant. Much less frequent is *Cliona viridis* (Schmidt). These species can only be identified when the system of their borings is well preserved. Where abrasion has been more intensive, any identification becomes difficult and is open to doubt. It seems certain that some fragments of borings may originate from other species of these sponges.

4. Polychaetes *Potamilla reniformis* (Müller). These borings are round in cross-section and up to 15 cm long; they are mostly twisted or almost meandering. Frequently the borings run directly under the rock surface, and therefore they are often much damaged by abrasion,

5. Minor borings made by pelecypods, belonging to the genus *Gastrochaena* Spengler, usually with abraded openings.

6. Locally occurring U-shaped borings made by the polychaetes *Polydora ciliata* (Johnston); usually their openings are also very much abraded,

7. Additionally there are small borings made by indeterminable polychaetes.

Fig. 21-25: Various types of borings on boulders.

The above list shows that within the discussed assemblage of boring animals, pelecypods and sponges predominated. The structural and textural features of the deposits at Zahorska Bystrica as well as the state of preservation of the borings indicate an eulittoral cliff environment in which the blocks and pebbles have developed, and a similar environment for their deposition: all this rock material has probably been laid down in local depressions of a rocky seashore.
It should be noted, that in the boulder material at Zahorska Bystrica mostly the biggest blocks and boulders were invaded by lithophags. It is likely that, as only these larger rock elements rested motionless for a certain, relatively long time at the sea bottom, they became the habitat of the lithophags. Only such large objects were not subject to surface abrasion, and this favored the development of boring animals up to the time when violent storms moved and transported all rock material resting on the sea bottom. On the other hand, finer material like cobbles and pebbles were probably in constant motion and continuously broken up or abraded between the larger boulders and blocks which for long periods had been motionless and firmly anchored to the sea bottom. This would explain why only sporadically the smaller rock elements became the habitat of lithophags. As the result of diagenetic processes within the boulder-mass material, indistinct pit spots appear at points of contact between individual rock elements, pebbles or boulders. They originated from weakly advanced pitting processes; the full effect of these processes which finally would have produced distinct pits in the surfaces, has been inhibited by the presence of great quantities of matrix occupying for the most part the space between adjacent pebbles and boulders.

Stop 6: Hradiste pod Vratnom
GPS coordinates: N 48°38´19.19”, E 17°29´49.37”

In a large active quarry 1 km NE from the village, a transgressive contact of Eggenburgian (Aquitanian) clastic sediments with the basement represented by Upper Triassic dolomites of the Jablonica Nappe can be observed (Fig. 26). The Eggenburgian sediments belong to filling of earlier stages of the Vienna Basin development and are composed of boulder breccias at the base, in which dolomite blocks attain 2-5 m in diameter. The blocks as well as the basement representing a shore cliff bear abundant traces after boring activities of bivalves, worms and sponges (similar to the Zahorska Bystrica locality). The sedimentary sequence continues with several gradational cycles of variably cemented coarse-grained to fine-grained breccias and conglomerates. More fine-grained beds are frequently cross-bedded. Several massive unsorted breccia beds represent mass-flows of clastic material from the margins to deeper parts of the basin which could have been caused by synsedimentary fault activity. The sediments display a decrease of grain-size in upward direction and in the upper part of the sequence the quantity of sandy beds in conglomerates increases. The detritic material of breccias and conglomerates is formed almost exclusively by Upper Triassic dolomites of the immediate basement; pebbles of red Senonian limestones and Liassic crinoidal limestones have been found sporadically.

Fig. 26: Active quarry near Hradiste pod Vratnom showing contact of the Upper Triassic dolomites of the Jablonica Nappe and Eggenburgian transgressive clastic sediments.

3.2. Senonian-Paleocene paleokarst after the main nappe stacking in the Central Western Carpathians

The main tectonic phase that affected the Central Western Carpathians was the Mediterranean phase in the Middle Turonian. It resulted in nappe stacking over the Tatric crystalline basement and its Mesozoic cover units (Fig. 27). The nappes are known as so called Subtatric nappes - Fatric and Hronic nappes. After this period, most of the Central Western Carpathians area was emerged and affected by erosion. On the most exposed carbonate complexes of the Subtatric (mainly Hronic) nappes, karstification started at that time. Paleokarst depressions formed on the surface were filled either by red karstic soils (Terra Rossa) or by bauxites. The latter originated by severe lateritic weathering of nearby crystalline complexes, products of which were transported through the paleokarst area and trapped in sinkholes.

Stop 5: Solosnica
GPS coordinates: N 48°27.291' E 17°14.317'

The locality Solosnica represents an abandoned quarry located on the left side of the Solosnica Valley, at the foot of the Velka Vapenna Mt. Anisian dark grey Annaberg Limestone belonging to the Veterlin Nappe and Upper Paleocene/Lower Eocene thick bedded sandy limestones have been quarried here.
The Triassic limestones are covered by a breccia with red matrix, called the Krzla Breccia (Fig. 28). It forms irregular nest bodies filling small cavities and fissures in the Triassic limestone. Red colour of its matrix is interpreted as a result of karstic weathering of the underlying limestone basement. Larger cavities filled with laminated, graded, red silty marls with ripple marks on the bedding planes were observed on the top of the nearby Velka Vapenna Mt. (MICHALIK 1984). 75% of the clasts (0.02-0.6 m^3 in size) consist of the

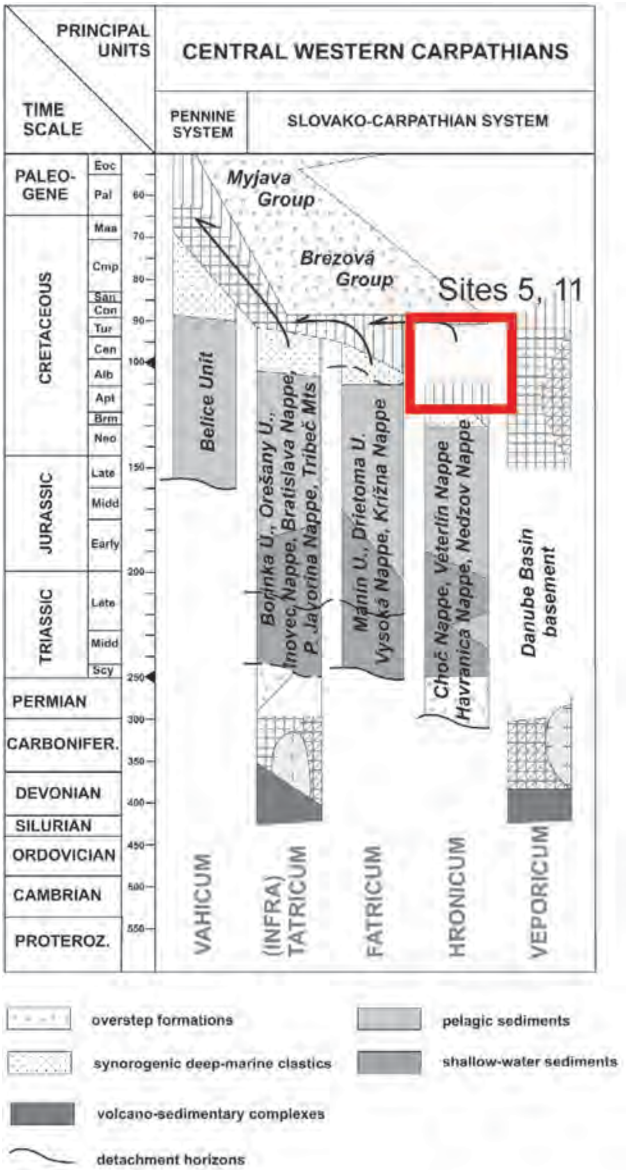


Fig. 27: Correlation table of the pre-Tertiary tectonic units of the Central Western Carpathians (after Froitzheim et al. 2008), with marked tectonostratigraphic position of the sites Solosnica and Mojtin.

Annaberg Limestone; the rest is composed of Raming Limestone, Reifling Limestone, and dolomites. The matrix forms more important part of the rock (2-5%) if compared with the Bartalova Breccia. In the Omlad 1 borehole, located about 800 m SW, foraminifers and nannoplankton of Paleocene age have been found in the red breccias below the base of the Borove Formation (Upper Paleocene to Eocene).

The Krzla Breccia is covered by the base of the Borove Formation (Fig. 29) consisting of thick-bedded sandy limestones and calcareous sandstones, rich in organic detritus, including nummulite tests. The fauna comprises Lower Eocene forms, such as *Nummulites* cf. *inkermanensis* Schaub, *N. burdigaliensis* De la Harpe, *Assilina placentula* (Deshayes), *Alveolina* sp. and *Discocyclina* sp. (Buday et al. 1967). Several beds bear marks of submarine slumping.

Fig. 28: Senonian-Paleocene Krzla Breccia - paleokarst breccia with clasts of Annaberg Limestone and Terra Rossa matrix. Solosnica Quarry.

Stop 11: Mojtin
GPS coordinates: N 48°59.532', E18°24.915'

Near Mojtin village in the Strazovske vrchy Mts., one of the few Slovak occurrences of bauxites is situated. In these mountains, other occurrences are near Domaniza a Durdova. The occurrences are concentrated in paleokarst depressions and clefts in limestones (Fig. 30) of the Strazov Nappe and in dolomites of the Choc Nappe. Outside the Strazovske vrchy Mts., bauxites were found near Markusovce in Spis area (eastern Slovakia). The largest occurrence near Mojtin is situated above Lopusna. The Mojtin bauxites had to originate after thrust of the Subtatric nappes and before Eocene (Lutetian), as the bauxite layers

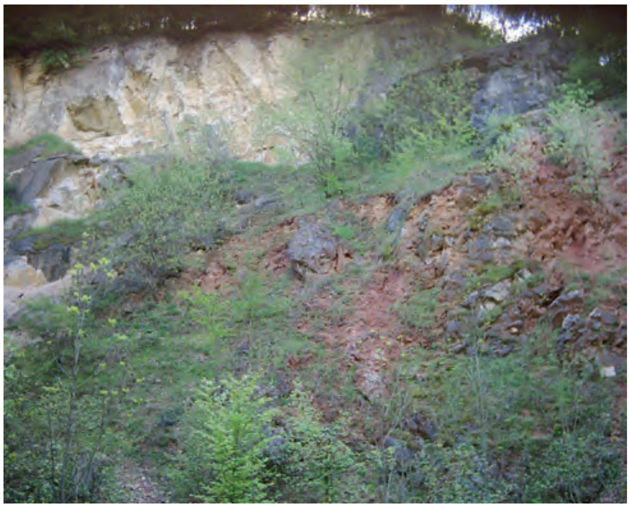


Fig. 29: Krzla Breccia (red) is overlain by Borove Formation (yellowish), representing Upper Paleocene-Eocene *Discocyclina* limestone.

Fig. 30: Paleokarst depression revealed by bauxite mining. Mojtin.

Fig. 32: Among other constituents, the bauxite ore contains spherical pisoids.

are covered by nummulitic limestones and breccias with bauxite cement. Presumed age of the bauxites is Upper Cretaceous (Senonian). Part of the bauxites was likely eroded still before Eocene. Presence of the spores of lycopodian plants (*Reticulatiporites* sp.), spores and pollen grains of *Stereisporites stereoides* (POTONIC & VENKATACHALA) PFLUG, *Taxodium* sp., pollen grains of the genera *Ginkgo*, *Tilia* (lime-tree), *Nymphea*, etc. indicate that the bauxite originated in very humid and warm environment of lakes or swamps.

The bauxite occurrences are small and without industrial importance. At the locality, a bauxite waste-dump formed by experimental mining can be seen (Fig. 31), together with uncovered Senonian paleokarst sinkholes. Technically the bauxites represent hydrargilite-boehmite type of red, yellowish, brown to greyish-white colour. Their mineralogical composition is as follows: 35% hydrargilite, 20-30% kaolinite, 15-20% boehmite, 18% hydrogoethite, 2-3% hematite (mostly in spherical forms - pisoids - Fig. 32). Hematite is missing in the pale types. Chemical composition of the bauxites is: Al_2O_3 - 43%, Fe_2O_3 - 19%, SiO_2 - 16%, TiO_2 - 4% (CICEL 1958).

The bauxites originated most likely by pervasive lateritic weathering of acidic (indicated by: B, Zr, Sn, Li) or basic (indicated by: V, Ni, Cr, Co) eruptive rocks, which were situated outside the karstic area. The weathering products were transported in form of fine mud and colloidal solutions and trapped in paleokarst depressions and clefts.

Fig. 31: Bauxite waste-dump originated by experimental mining.

3.3. Middle Jurassic synrift sedimentation on the Czorsztyn Swell of the Pieniny Klippen Belt - breccias, neptunian dykes and stromatactis-mud-mounds

The Pieniny Klippen Belt is a melange zone situated between the Inner and Outer Western Carpathians (Fig. 33). The melange consists of several units compressed and strongly deformed between the Inner Carpathians and the Carpathian foreland (e.g., Bohemian Massif, Polish Platform). The individual successions now form tectonic blocks in this melange. The Czorsztyn Succession is the most shallow-marine unit of this belt and it was deposited on the Czorsztyn pelagic carbonate platform (Fig. 34). This swell was strongly influenced by the Middle Jurassic rifting, as evidenced by numerous neptunian dykes and syntectonic breccias (AUBRECHT et al. 1997). The initial Bajocian deposition of shallow-water crinoidal limestones was later replaced by more condensed neritic deposition of Ammonitico Rosso facies (Fig. 35). Within this basin with relatively low deposition rate, some uncondensed sections

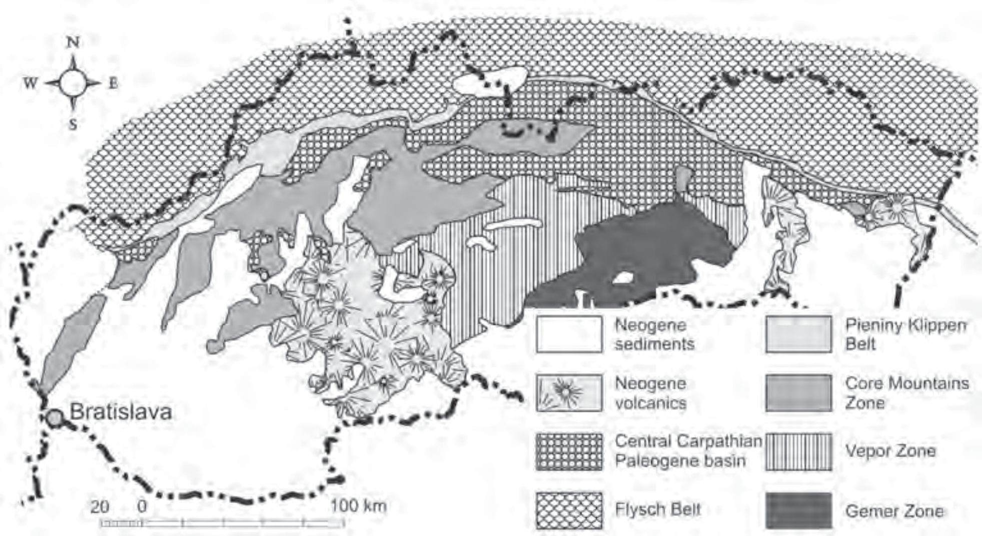


Fig. 33: Simplified geological map of Slovakia, showing the main tectonic zones.

can be found. As they bear traces of microbial cementation and presence of the so-called stromatactis structures, they were interpreted as stromatactis mud-mounds.

Stop 7: Dolna Suca - Krasin
GPS coordinates: N 48°57´47.2", E 18°1´24.1"

Locality called Krasin Klippe is situated in an abandoned quarry W of the Dolna Suca village and belongs to the shallow-water Czorsztyn Unit. However it differs from the classical Czorsztyn Succession by some peculiarities:
1. Presence of the submarine breccias of the Middle Jurassic age,
2. Upper Jurassic limestones removed by erosion,
3. Lower Cretaceous sediments overlying the Middle Jurassic limestones in the large clefts.

The Krasin Breccia is an example of Jurassic syntectonic sedimentary breccia (Fig. 36), witness of extensional tectonic movements tied to Jurassic rifting (Misik et al. 1994; Aubrecht & Szulc 2006). It is unique in its complex post-depositional filling and cementation history that infers a special environment (Fig. 37).

Following members may be discerned there (Misik et al. 1994):
Smolegowa Lst. Fm.: White bedded to massive crinoidal limestones with ammonite *Teloceras blagdeni* Sowerby, with small fragments of dolomites, rare red neptunian dykes and void fillings. Clastic admixture is more or less abundant, mainly represented by quartz grains and dolomites. The limestones form also the whole crest of the Krasin klippe. Stratigraphic age is Bajocian.
Krupianka Lst. Fm.: Greyish fine-grained crinoidal limestones with brown chert nodules and red crinoidal limestones with loaf weathering forms. They are limited only to the northern confines of the klippe; the best outcrops could be found in the old quarry, now entirely covered by

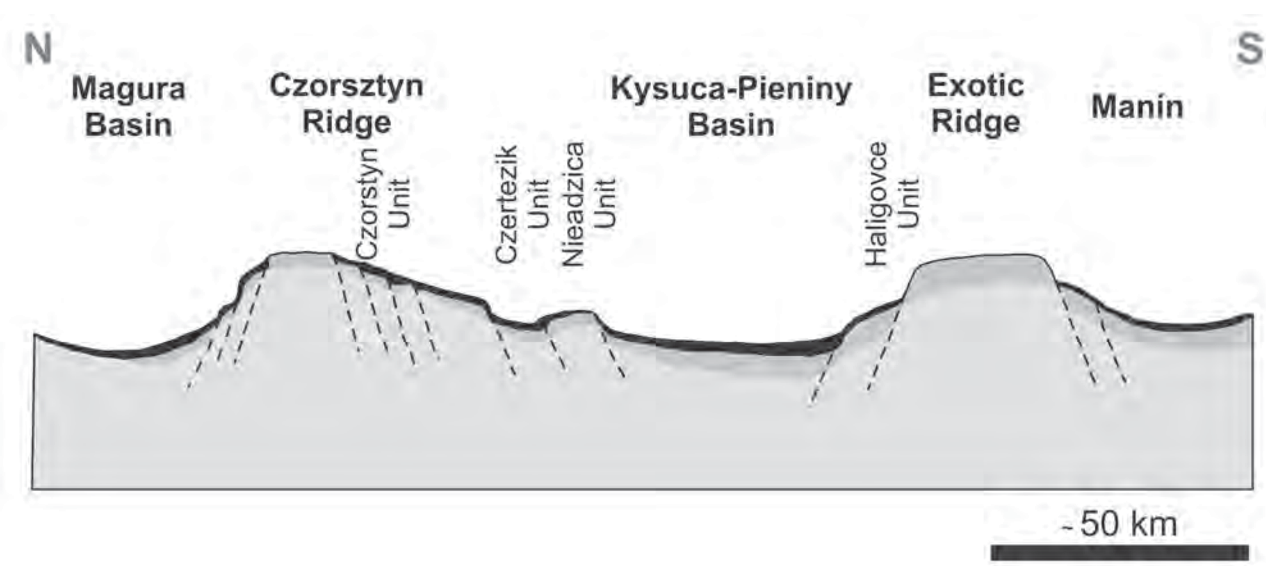


Fig. 34: Paleogeographic reconstruction of the units presently constituting the Pieniny Klippen Belt (slightly modified after Birkenmajer 1977).

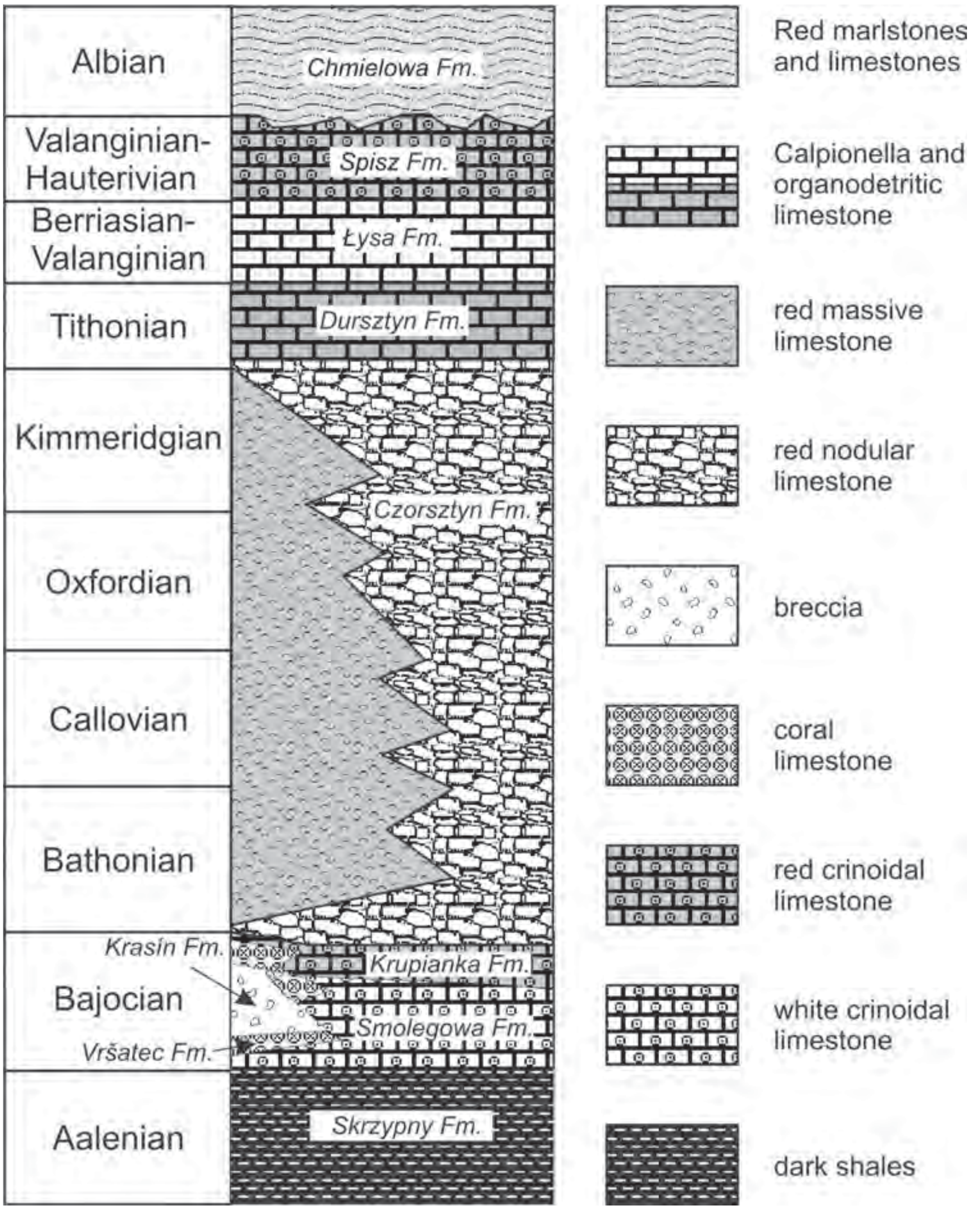


Fig. 35: Lithostratigraphic scheme of the Czorsztyn succession.

Fig. 36: Krasin megabreccia consists of clasts formed by gray crinoidal limestone with matrix of red crinoidal limestone. Krasin Quarry.

vegetation. The supposed age is Bajocian.

Krasin Breccia: Grey, pinkish and red brecciated crinoidal limestones (submarine scarp-breccia), massive with small dolomite fragments and frequent void fillings, penetrated by neptunian dykes of red micritic limestone, roughly of the same age. Supposed stratigraphic age is Bajocian-Bathonian. This rubble breccia usually has very complex filling. The clasts are coated by at least one generation of stromatolite (mostly cryptic stromatolites) and subsequently cemented by radiaxial fibrous calcite. The remaining void filling starts with the crinoidal detritus, which indicates that the breccia was formed due to synsedimentary tectonics occurring during the deposition of crinoidal limestones. The next infilling step is represented by micritic limestone with filamentous microfacies (Bathonian-Callovian) and by almost sterile micrite with cavity-dwelling ostracods. The breccia bears evidence of numerous instances of disturbance, resedimentation and re-cementation. Moreover the isotope composition of some early generations of stromatolites and early cements indicate

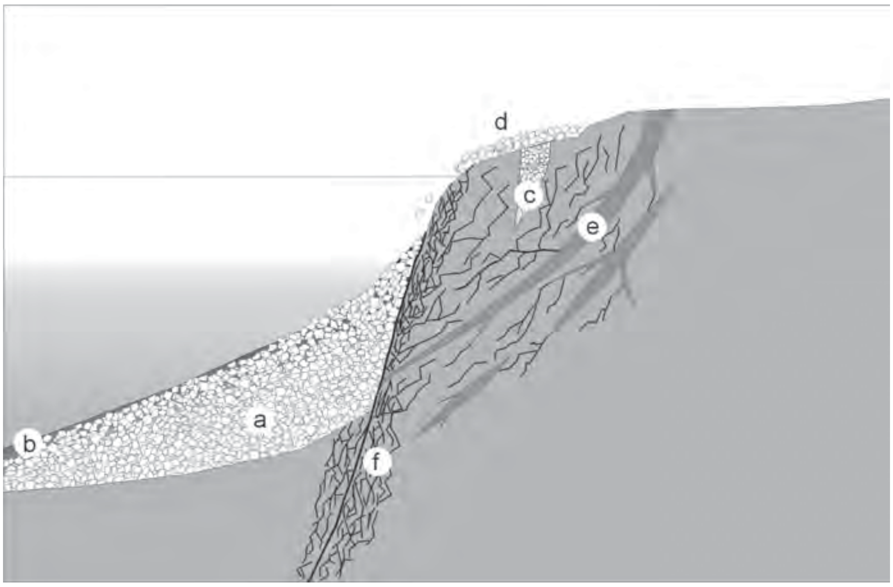


Fig. 37: Model of deposition and cementation of the Krasin Breccia. **a**. Inner part of breccia talus in which cements and stromatolite coatings prevail over the internal sediment. **b**. Outer part of the talus with predominant sedimentary filling of the interstices. **c**. Breccia bodies originated in clefts and caverns. **d**. Rubble originated on the emerged land and initially coated with fresh-water stromatolites. **e**. Clefts (neptunian dykes) that served as conduits of the fresh water. **f**. In-situ brecciated wall rock (crackle breccia) near the main fault (after Aubrecht & Szulc 2006).

possible fresh-water diagenesis.
?Vrsatec Lst.: Light grey and pinkish bioherm breccia with dolomite lithoclasts. It fills only a pocket in the left upper part of the quarry. The stratigraphic position of the limestone is unclear, although the Bajocian age of the lithoclasts of biohermal facies can be supposed.
Walentowa Breccia. The breccia is formed by clasts of the red crinoidal limestones and small fragments of white *Crassicollaria*-bearing limestones. They filled some clefts with variable thickness (maximum 25-30 m) penetrating the Middle Jurassic limestones. Supposed age is Valanginian-(?)Hauterivian.
In one of the clefts, red marls with the intercalations of the fine-grained limestones with *Hedbergella* were found. Their supposed age is Albian.

Stop 9: Slavnicke Podhorie
GPS coordinates: N 49°1’0.1’’, E 18°9’31.4’’

The site occurs in the middle part of Vah River valley, at the village Slavnicke Podhorie, on the foothills of the Biele Karpaty Mts. It represents a tectonically overturned klippe exposed in an abandoned quarry (Fig. 38) revealing a stromatactis mud-mound core. A 32 meter long profile was sampled (Fig. 39) in the southern part of the quarry (Aubrecht et al. 2002).
Major part of the quarry cuts the Middle Jurassic crinoidal limestones (Smolegowa Formation) that is stratigraphically older than the mud-mound. In the crinoidal limestone at the base of the profile, a fragment of the ammonite *Parkinsonia* sp. was found indicating the Bajocian/Bathonian boundary. Following Bajocian-Bathonian brachiopod fauna have been collected from the crinoidal limestones by Pevny (1969) and Aubrecht et al. (2002): *Morrisithyris* aff. *phillipsi* (Morris), *Monsardithyris buckmani* (Davidson), *Monsardithyris ventricosa* (Zieten), *Linguithyris bifida* (Rothpletz), *Zeilleria waltoni* (Davidson), *Zeilleria emarginata* (Sowerby), *Zeilleria* aff. *subbucculenta* Chapuis-Dewalque, *Lobothyris ventricosa* (Hartmann), *Loboidothyris perovalis* (Sowerby), *“Terebratula” retrocarinata* Rothpletz, *“Terebratula” varicans* Rothpletz, *Antiptychina puchoviensis* Pevny, *“Sphenorhynchia” rubrisaxensis rectifrons* (Rothpletz), *Acantothyris* sp., *Gnathorhynchia trigona* (Quenstedt), *Sphenorhynchia* aff. *plicatella* (Sowerby), *Sphenorhynchia rubrisaxensis rectifrons* (Rothpletz), *Rhactorhynchia subtetrahedra* (Davidson), *“Rhynchonella”* aff. *obsoleta* (Sowerby), *Cymatorhynchia quadriplicata* (Sowerby), ?*Weberithyris* sp., ?*Caucasella trigonella* (Rothpletz), *Parvirhynchia* sp. The basis of the mudstones is therefore of ?Bajocian-Bathonian age. Some forms as *Caucasella* and *Weberithyris* indicate rather younger, Bathonian-Callovian age. This is also supported by a *Pygope* aff. *janitor* Pictet in the debris near the entrance of the quarry, but this species has not been found in situ.
The mudstones that overlie the crinoidal deposits are dominated by a microfacies with *Bositra* sp. shells which extend to the end of the Callovian. As only very rare foraminifers *Globuligerina* sp. have been found in the mudstones, mass occurrence of which is indicative for the Oxfordian in this basin, the section does not reach the

Fig. 38: View on the abandoned quarry near Slavnicke Podhorie.

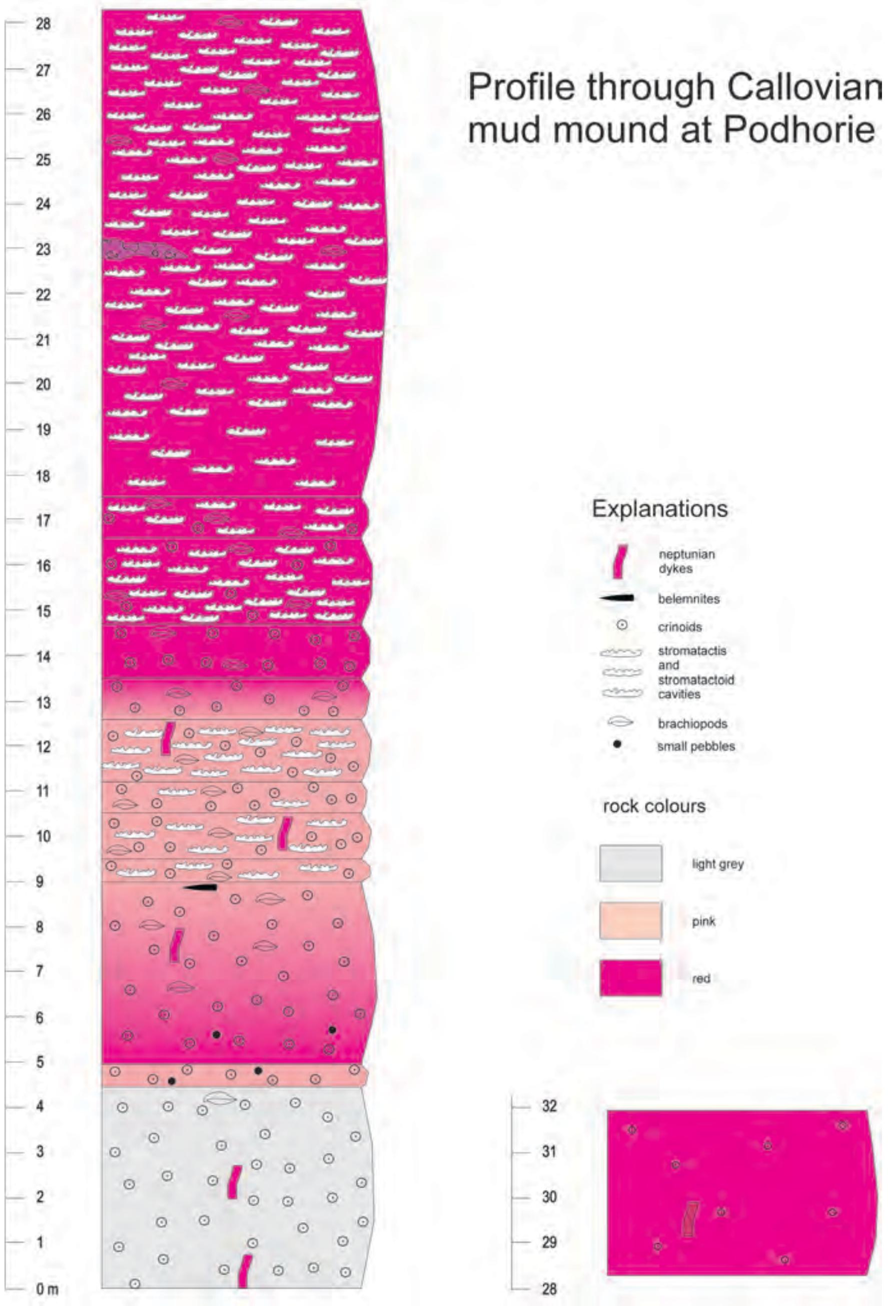


Fig. 39: Section through the core of stromatactis mud-mound at Slavnicke Podhorie.

Oxfordian age.

Section description

The stratigraphical basis of the examined section is formed by gray crinoidal limestones (0-13 m), passing gradually into pink and red micritic limestone (13-32 m). Stromatactis cavities appear as low as the crinoidal limestone (9-13 m) but they reach their maximum in the micritic limestones (15-28 m - Figs. 40-41). At the 28 m level, the stromatactis cavities disappear. Since the stromatactis cavities are approximately parallel to stratification, the examined section may probably represent the core part of the mound. As the klippe is just a large tectonic block, no transition to the offmound facies has been observed.

Crinoidal limestones represent skeletal packstones to grainstones with micritic to sparitic matrix. The sparite occurs in the parts where the micrite was winnowed. It is a clear blocky calcite, locally with margins rich in inclusions. Where the stromatactis cavities occur, the matrix is locally pelmicritic to sparitic. However, in contrast to the clear blocky calcite mentioned above, the spar is mostly represented by a short-bladed fibrous calcite. It is obviously related to the radiaxial fibrous calcite filling of the stromatactis cavities. The sediment was relatively poorly sorted. Besides crinoidal ossicles, sand-sized detrital quartz grains are abundant. Bryozoan fragments, echinoid spines, ostracod shells, foraminifers (*Lenticulina* sp.), agglutinated foraminifers (*Ophthalmidium* sp.) and fragments of pelecypods and brachiopods are ubiquitous. Upsection, bivalves and brachiopods gradually prevail and thin-shelled bivalves appear, passing to the overlying

Fig. 40: Weathered-out cements of stromatactis cavities at Slavnicke Podhorie.

mudstones. Many allochems are affected by heavy micritization and microborings.
The pink, red to yellowish mudstones form the main host rock of the stromatactis cavities and are predominantly a wackestone to packstone (biomicrite, biopelmicrite) and even to grainstone (biopelsparite). In the limestone, thin-shelled bivalves (mainly *Bositra* sp.), thin-shelled ostracods and foraminifers (*Ophthalmidium* sp., *Lenticulina* sp., *Patellina* sp., *Spirillina* sp., *Dorothia* sp., sessile nubeculariid foraminifers, nodosariid foraminifers and "microforaminifers") occur. Detritus from thicker-walled bivalves (commonly dissolved and replaced by micrite) and brachiopods, rare gastropods, juvenile ammonites, echinoid spines and serpulid worm tubes are quite common. Calcareous sponges, silicisponge spicules, fragments of corals and bryozoans are rarely preserved. Crinoidal ossicles, which are common in the lower, transitional parts, are less frequent in the mudstone. Rare quartz grains occur, too. The relatively monotonous "filamentous" microfacies (packstone) with its micritic matrix, free of peloids, also represents the main part of the micritic limestones on top of the profile (28-32 m), where the stromatactis cavities are missing. Unlike in the lower levels, signs of bioturbation are ubiquitous. The same material fills the neptunian dykes found at 10, 12.5, 22.89 (dyke with breccia filling) and 29.5 meter levels. In the topmost part of the profile, *Globuligerina* sp. scarcely appears.

The typical stromatactis cavities with flat bottom and undulated top are present in the examined site, but the irregular ones are also common. The first and the main filling of the stromatactis cavities is represented by radiaxial fibrous calcite. The radiaxial fibrous calcite is followed by internal micritic filling and by blocky calcite cement.

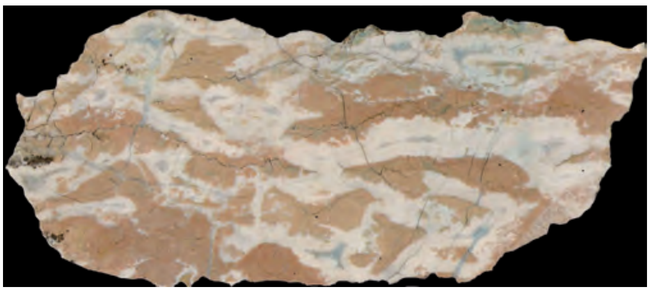


Fig. 41: Slab of the stromatactis-bearing mudstone.

Stromatactis was first described in 19th century and it is still an enigmatic phenomenon. There is still no agreement in opinions concerning its origin. The suggested origins for stromatactis included internal erosion and reworking of small cavities, dewatering or escape of fluids, neomorphism or recrystallization of the calcareous mud, dynamic metamorphism, slumps and fresh-water karstification. Most recent ideas involve frozen clathrate hydrates in the calcareous mud, after which the stromatactis cavities remained or the cavities are interpreted as a result of sedimentation of stirred poly-disperse sediment. Second, biogenic origins for stromatactis have also been suggested. The most widely invoked origin for stromatactis is that they are cavities which remained after decomposition of an unknown soft-bodied organism or by neomorphism of carbonate-secreting organism. The suggested organisms include stromatoporoids, bryozoans, algae, stromatolites, microbial colonies, and burrowing activity of crustaceans. The organisms which are most frequently mentioned in the stromatactis literature are sponges. At Slavnicke Podhorie, the sparry masses that fill stromatactis cavities are weathered out and show casts of sponges (Aubrecht et al. 2009b). Parallel study of the weathered casts and their cross-sections in slabs (Fig. 42) showed that they bear all the signs of stromatactis (relatively flat bottoms and digitate upper parts, radiaxial fibrous calcite initial fillings and eventual blocky calcite later filling). Almost no original sponge structures were preserved. This strongly supports the possible sponge-related origin for stromatactis cavities.

Stop 10: Vrsatec

GPS coordinates (top of the Javornik hill): N 49°4'16.7'' E18°9'35.6''.

The group of main Vrsatec Klippen is the largest in Slovak territory and in the entire Pieniny Klippen Belt. They are situated above the Vrsatske Podhradie village, NW of the Ilava town. This locality consists of two tectonic blocks that belong to the Czorsztyn Unit: the Vrsatec Castle Klippe (Fig. 43) and the Javornik Klippe (Fig. 44). They are formed by a succession of the Middle Jurassic-Lower Cretaceous carbonates that are capped by the Upper Cretaceous marls. Importantly, this locality exposes relatively thick, coral-dominated biohermal deposits, which are missing or are very rare in other Jurassic successions of the Pieniny Klippen Belt. Misik (1979b) described in detail sedimentologic features of the two blocks in an E-W oriented transects based on seven stratigraphic sections. He suggested that the blocks consist of two tectonic slices with different stratigraphic successions.
According to this hypothesis, the first slice contains the Upper Jurassic biohermal limestones (Vrsatec Lst.) resting on the Middle Jurassic crinoidal limestones (Smolegowa and Krupianka Lst. Fm.). In the second slice, the Middle Jurassic crinoidal limestones are overlain by the Czorsztyn

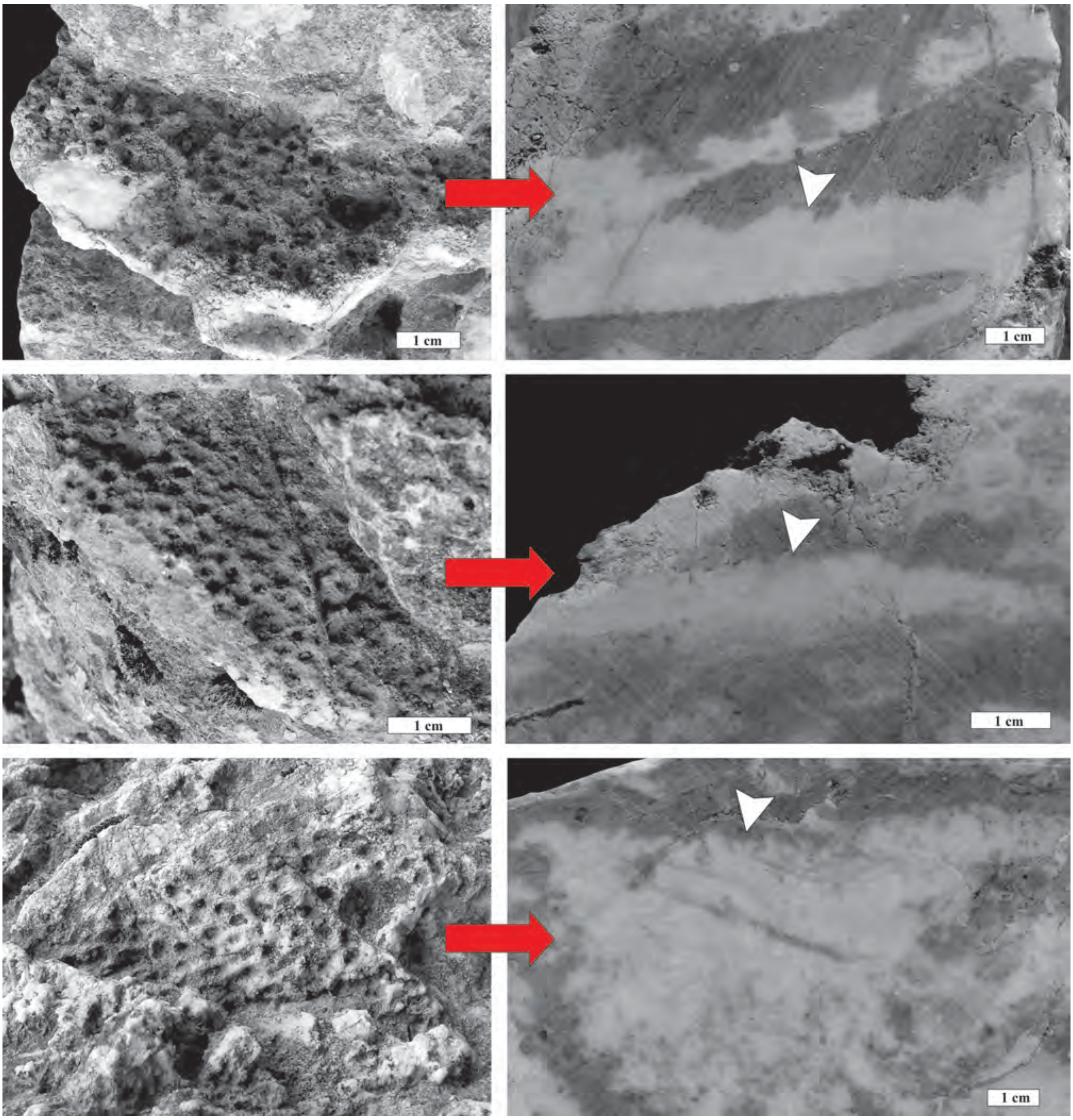


Fig. 42: Relationship between the weathered casts of siliceous sponges (left) and the corresponding cross-sections in slabs (right). The corresponding weathered surfaces are marked with arrows in the slabs. The cross-sections display actual stromatactis shape and composition (relatively flat bottoms and digitate upper parts, initial fillings of radiaxial fibrous calcite and eventual blocky calcite later filling).

Lst. Fm. The contact between the two slices should lie within the crinoidal limestones of Middle Jurassic age. However, this hypothesis is contradicted by new litho- and biostratigraphic data (SCHLÖGL et al. 2006) which indicate that only one succession is present in the blocks, probably with high horizontal and lateral variations in facies composition. Firstly, based on geopetal infillings within brachiopod shells, the crinoidal limestones rest on the biohermal limestones. Secondly, biostratigraphic data indicate that the biohermal limestone is older than thought before, probably of Middle Jurassic age.

The stratigraphy of the overturned sequence of the Vrsatec Klippen

The Vrsatec Lst. (Fig. 45) is formed by white to pinkish biohermal limestones with corals and calcareous sponges, and locally with bivalves and brachiopods. The biohermal limestones are laterally replaced or overlain by pink and grey peribiohermal limestones and reef breccia (Fig. 46). The core of the reef is probably preserved near the top of the hill of the Javornik block. Voids and small caverns in the biohermal limestone contain internal sediment, scarce stromatolites of the LLH type (lateral linked

Fig. 43: View on the Vrsatec Castle Klippe. Red micritic filling of the neptunian dykes contrasts with white crinoidal limestones.

Fig. 45: Corals in the Bajocian Vrsatec Limestone at the entrance to the Vrsatec Castle.

hemispheroidal stromatolite) and algae *Verticillodesmis clavaeformis* Dragastan & Misik. The peribiohermal limestones contain scarce corals, brachiopods, bivalves, sessile foraminifers, crinoidal ossicles, bryozoans, juvenile gastropods, calcified silicisponges and ostracods. The voids range up to dm in size and are filled with laminated muddy limestone with cross-bedding that results from replacement of inflow openings. Bioclasts in the voids and small caverns are mostly represented by ostracods. These crustaceans together with unknown pellet-producers might represent original inhabitants of the caverns.

Based on bivalves (Kochanova 1978), the biohermal limestones were assigned to the Oxfordian by Misik (1979b). However, the bivalves described by Kochanova (1978) are stratigraphically inconclusive. One neptunian dyke cutting the peribiohermal limestones contains the ammonite *Nannolytoceras tripartitum* Raspail of the Latest Bajocian or Early Bathonian age. Moreover most of the dykes show filamentous microfacies (*Bositra* Limestone), which in the Czorsztyn Unit is restricted mainly to the Bathonian-Callovian. The Oxfordian deposits are already

Fig. 44: View on slightly overturned klippen of the Javornik Hill.

characterized by *Protoglobigerina* microfacies. Thus, based on the infillings of the neptunian dykes, cutting the limestones, the age of the biohermal and peribiohermal limestones is probably Lower Bajocian. The exposed part of the limestones is at least 15 meters thick.

The Smolegowa and Krupianka Lst. Fms. are formed by grey to reddish crinoidal grainstones that are overlying the biohermal Vrsatec Lst. The top of the biohermal facies is marked by thin Fe/Mn-crusts and impregnations. In contrast, the boundary between the peribiohermal facies and crinoidal limestones seems to be gradual in most sections. Only some brachiopods were collected from the base of the formation, including long-ranged taxa such as *Acanthothiris spinosa* (Linnaeus), *Striirhynchia subechinata* (Oppel), *Apringia* aff. *polymorpha* (Oppel) with possible stratigraphic range Bajocian-Callovian. Because of lack of a stratigraphically more valuable fauna, the age of crinoidal limestones is based on the dating of the equal crinoidal deposits in the area as Bajocian. The thickness is around 35 meters.

The Czorsztyn Lst. Fm. consists of red micritic, locally nodular limestones. Based on ten detailed stratigraphic sections along both blocks, the thickness of this formation can vary between 20 cm and more than 15 meters. There is invariably a 0.5-2 cm-thick Mn-crust at the base of the formation, marking the hiatus between the crinoidal and red micritic limestones. Based on ammonites and on data from other sections, the age of the whole formation is Bathonian to Early Tithonian. The thickness of the Bathonian-?Callovian deposits, which are separated from the overlying red micritic limestones by another Mn/Fe-hardground, attains few cm up to 3.5 meters. The deposits contain mainly filaments (filamentous packstones), juvenile gastropods, benthic foraminifers and crinoidal ossicles. The overlying massive limestones show the *Protoglobigerina* microfacies, suggesting their Oxfordian age. The massive limestones pass gradually into massive red micritic limestones with the *Saccocoma* microfacies. Ammonite fauna including *Orthaspidoceras uhlandi* (Oppel) and *Hybonoticeras hybonotum* (Oppel) indicates

Fig. 46: Fore-reef breccia within the Vrsatec Limestone. The clasts in the breccia were derived from the coral bioherms, the matrix is red micritic limestone with "filamentous" microfacies.

a Kimmeridgian and Early Tithonian age.

The Dursztyn Lst. Fm. consists of massive, red, pinkish or yellowish micritic limestones. Locally, they can be rich in crinoidal ossicles (forming lenses of crinoidal packstones) and fine shelly debris. The *Saccocoma* microfacies pass gradually into the *Crassicolaria* and *Calpionella* microfacies. The Middle Tithonian to Early Berriasian age of the formation is based on calcareous dinoflagellates and calpionellids.

The Cretaceous deposits are represented by red marls and marlstones. A tectonized contact of the Upper Tithonian to Berriasian white to pinkish *Calpionella* limestones with the red marls and marlstones is exposed in the road cuts in the saddle above the village Vrsatske Podhradie. The sequence of limestones and marls is in reverse position. A normal sedimentological contact between Dursztyn Lst. Fm. and the red marls is visible on the foot of the Vrsatec Castle Klippe, where the signs of karstification of the Lower Cretaceous limestones can be observed. The marls are of Late Cenomanian to Campanian age.

Importance of the locality in the light of paleomagnetic reconstruction of the original klippen orientation

As the sections in the Pieniny Klippen Belt represent isolated blocks and tectonic lenses which were rotated along several axes, paleomagnetic analyses are necessary for the reconstruction of their original palaeogeographic position. AUBRECHT & TUNYI (2001) analysed neptunian dyke orientations in four sections in the Pieniny Klippen Belt. They include the Vrsatec Castle Klippe, Babina quarry, Mestecska skala and Bolesovska dolina. In majority, the neptunian dykes are cut into the Bajocian-Bathonian crinoidal limestones (Smolegowa and Krupianka Lst. Fms.) and consist of red micrites or biomicrites. They contain mainly juvenile bivalves or rarely the *Globuligerina* microfacies. These microfacies indicate that the dykes range from the Bathonian to Oxfordian. Exceptionally, neptunian dykes of Tithonian and Albian age were found at the Vrsatec locality. However, they represent rejuvenation of the older dykes (MISIK 1979b).

The measurements of the neptunian dykes and their evaluation, with utilizing of paleomagnetic correction, enable estimating the paleogeographic orientation of the Czorsztyn Ridge. The mean orientation of the neptunian dykes is NE-SW (with N-S to ENE-WSW variations), thus indicating the most probable orientation of the Czorsztyn Ridge during the Middle Jurassic (Fig. 47). This direction points to the NW-SE oriented Jurassic extension in that area. The paleomagnetic inclination ranging between 21º and 46º, with mean point of about 33º, indicates that the Czorsztyn Ridge was located approximately at 10-30º paleolatitudes in the Middle Jurassic.

3.4. Lower Cretaceous emersion and paleokarst on the Czorsztyn Swell

The Czorsztyn Swell (see introduction to the previous topic) all through its history was a submarine pelagic swell with only one exception. It was a break in sedimentation during Early Cretaceous (Valanginian to Aptian). Earlier theories considered this break as caused by submarine non-deposition and erosion. The main reason for this opinion was that this break was followed by deep-marine pelagic deposition of Albian red marls (Chmielowa Formation - see Fig. 35). Some other authors proposed an emersion and subsequent flooding of the Czorsztyn Swell. Only latest data showed that the pre-Albian surfaces bear many features characteristic for paleokarst surfaces. It was an

Fig. 47: Evaluation of original orientation (corrected according to paleomagnetic data) of neptunian dykes at four selected localities of the Czorsztyn Succession.

evidence that the non-deposition was caused by emersion of the Czorsztyn Swell, accompanied by karstification and erosion. The period of emergence ended by sudden flooding (ingression) in the latest Aptian-Early Albian.

Stop 10: Vrsatec (continuation)

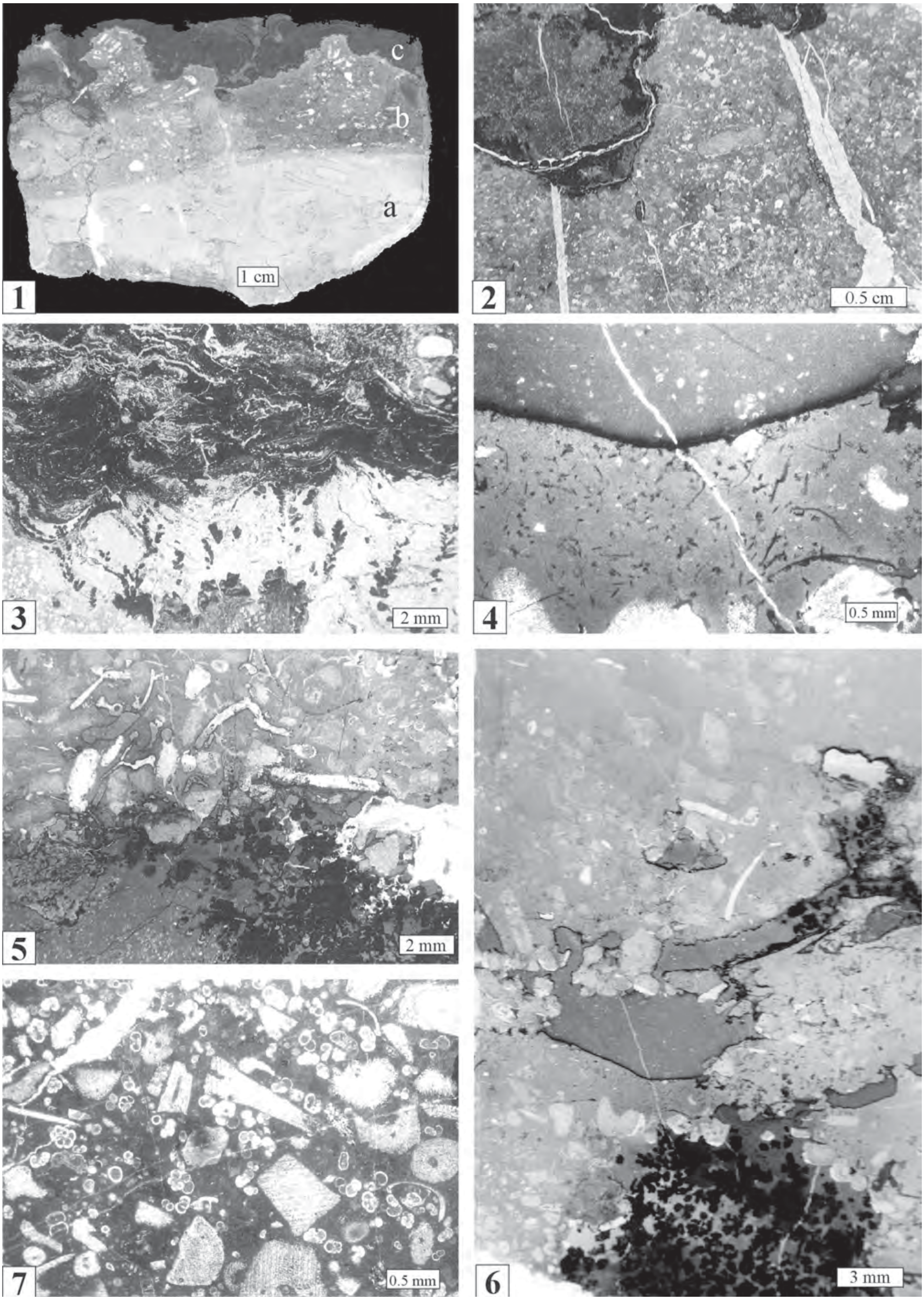
Valanginian-Aptian emersion, karstification and Albian drowning of the Czorsztyn Swell - the Vrsatec examples

The Czorsztyn Unit is the shallowest Pienidic unit of the West Carpathian Pieniny Klippen Belt. After the Hauterivian, a hiatus encompassing almost the whole Barremian and Aptian occurred in this unit. Tithonian-Lower Cretaceous limestones are overlain by pelagic Albian marlstones and marly limestones. A nature of this hiatus was many times discussed in the literature. Most authors favoured a submarine non-deposition and erosion (Birkenmajer 1958, 1975), whereas others proposed an emersion of the ridge (Misik 1994).

In the last years, most of the formerly known sites were reexamined and some new sites were found with the preserved contact between the Albian and the underlying formations of the Czorsztyn Unit. At two sites, the Albian marlstones and limestones are in contact with the rocks older than Tithonian or Neocomian. In Jarabina, the Barremian-Aptian erosion reached the level of Kimmeridgian red micritic limestones but clasts of limestones with "filamentous" microfacies indicate that Bathonian-Callovian limestones had to be uncovered too. At Horne Srnie, where the deepest erosion level was found, the Albian deposits overlay Bajocian-Bathonian crinoidal limestones. Except of deep erosion, unequivocal signs of subaerial exposure and karstification (karren landform with vertical drainage grooves, small cavities in the bottom rock filled with younger sediment, bizarre fractures and veinlets filled with calcite, were revealed, mainly in Horne Srnie and Lednica sites. This was followed by pelagic deposition, documented by Albian marlstones and limestones with pelagic fauna. In this time, the paleokarst was bored by boring bivalves and overgrown by deep-water Fe-Mn to phosphatic stromatolites. This suggests a very rapid relative sea-level rise, most likely due to a marine ingression. A tectonic platform collapse and drowning cannot be excluded. Very similar case of Cretaceous paleokarst was reported from the Betic Cordillera, Spain (Martin-Algarra & Vera 1996).

Several relics of the Albian marlstones overlying the Neocomian limestones, together with some Albian neptunian dykes cutting the underlying rocks, were found in the Vrsatec klippen. Most of them are summarized by Misik (1979b); two localities were revealed not long ago. The basement below the Albian sediments is commonly irregular (Fig. 48), which was most probably caused by karstification and boring animals. Small caverns in the Lower Cretaceous limestones filled by Albian sediments are common too. The Albian deposits are pelagic marlstones to limestones, with fauna of belemnites (for example *Neohibolites minimus* Lister), bivalves *Aucellina* sp. and numerous planktonic foraminifers *Ticinella roberti* (Gandolfi), *Thalmanninella ticinensis* (Gandolfi), *Hedbergella infracretacea* (Glaessner), *Thalmanninella apenninica* (Renz), *Planomalina buxtorfi* (Gandolfi) and many agglutinated foraminifers. The foraminifer assemblage indicates an Albian to Cenomanian age of the overlying beds. Deep-water bacterial Fe-Mn-P stromatolites, oncoids and frutexites are common in the basal parts, sometimes directly overgrowing the underlying limestones. Higher up, some radiolarian cherts were found in the Cenomanian-Turonian marlstones at the southernmost Vrsatec klippe (Sykora et al. 1997) which testifies the rapid sea-level rise after drowning of the swell. In the Albian sediments of 6 localities (2 from Vrsatec), a detrital admixture containing chrome spinels was found (Jablonsky et al. 2001, Aubrecht et al. 2009a). Such minerals, derived from an unknown ophiolitic source area are common in the Albian deposits of the Klape Unit, the Tatric and Fatric units, but they were not found so far in the Czorsztyn Unit. The presence of ophiolitic detritus in the Albian of the Czorsztyn Unit is very surprising and contradicts to the classical paleogeographic schemes where the Czorsztyn Swell still in Albian formed an isolated ridge, surrounded by deep troughs. The Albian deposits in the nearby troughs (Kysuca-Pieniny and Grajcarek units) are

Fig. 48 (next page): Slabs and microphotos from the localities at Vrsatec. **1**. Slab showing Neocomian limestone (a), covered by Late Aptian organic-detrital limestone (b) and by P-Fe stromatolite (c) which is the base of pelagic Albian deposit. Note the uneven surface between the Upper Aptian limestone and the covering stromatolite. The surface was most likely shaped by karstic dissolution. It provides an evidence of repeated emersion of the sedimentary area still after the first phase of flooding in the Late Aptian. **2**. Two veinlets filled with blocky calcite, cutting the Neocomian organic-detritic limestone but not continuing to the Albian stromatolitic hardground above. Their age is then pre-Albian and their filling may be of fresh-water origin. **3**. Albian stromatolite (with ptygmatitically folded calcite veinlets - upper part of the photo) and bush-like *Frutexites*-type stromatolites growing in the Albian sediment towards the stromatolite. The latter means that the sediment represents filling of a larger cavity and the stromatolite above grew on the roof of the cavity. This context could not be recognized in the field. **4**. Network of Mn-oxides filled traces in the Neocomian limestone created by boring organisms, most likely fungi (the traces are locally branching) below the base of the Albian sediments. **5**. Geopetal filling of the leached bivalves in the Neocomian limestone (above) contradicts to the location of the Albian sediment (below). It indicates that the Albian sediment deposited in a cavity (most likely karstic). **6**. Bizarre cavities in the Neocomian limestone filled with Albian micrite. Their geopetal filling enables to orient the photo properly, in spite of the position of the Albian stromatolite and sediment (below). They most probably represent filling of a larger karstic cavity. **7**. Crinoid-foraminifera wackestone to packstone of the Late Aptian-Early Albian age, representing sediment of the first phase of flooding after the hiatus.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mostly free of detritic admixture, except of local distal turbidites of Trawne Member (Birkenmajer 1987).

Stop 8: Horne Srnie
GPS coordinates: N 49°0'4.2'', E 18°7'0''

The locality is situated in the highest level of the active quarries of a cement factory at the northern margin of Horne Srnie village in middle Vah Valley. Contact of the Albian sediments of the Czorsztyn Succession (Pieniny Klippen Belt) with their basement was observed at SW margin of the highest step of the quarry and its continuation was found below, in the lower part of the quarry. The locality is unique by depth of pre-Albian erosion and by preserved paleokarst phenomena (Aubrecht et al. 2006). In an overturned position, the contact of the Upper Bajocian crinoidal limestone (Smolegowa Lst. Fm.) and Albian sediments is visible (Fig. 49). Along with crinoids and brachiopods, the limestones also contain numerous bivalves. Except the crinoidal limestones, some relics of younger organodetritic limestones with "filamentous" microfacies (Bathonian-Callovian) were found in the basement rocks, mainly as filling of fissures in the crinoidal limestones. The rest of Jurassic sediments is missing. The Albian rocks, as a rule, represent both, the organodetritic limestones with crinoids, belemnites, bivalves and siliciclastic admixture (up to size of small pebbles) and somewhat younger, more pelagic red marlstones to marly limestones containing only planktonic fauna. At the base of the Albian deposits, greenish-yellow, brown to black P-Fe-Mn stromatolites and oncoids occur. Locally, white marly limestones fill the karstic depressions, containing a Middle Turonian microfauna. This is a further evidence of continuous episodes of non-deposition and/or erosion still after flooding.

The complete lack of the Bathonian to Lower Cretaceous sediments points to a deep-reaching erosion that so far was not found in the Czorsztyn Unit. Field observation showed that inclination of geopetal fillings of brachiopod shells in both, the Albian limestones and in the underlying crinoidal limestones displays no difference. That implies that no large tilting took place between Bathonian and Albian. Deep erosion thus cannot be explained by a large-scale tilting-induced emergence. The erosional surface is irregular due to karstification (Fig. 50). Rainwater grooves perpendicular to the basement and karren surface as deep as 1 m can be seen at the contact. Pre-Albian calcite veinlets penetrate several meters down to the underlying rocks (Fig. 50F-G). However, they are irregular and filled with polyphase fibrous calcite that can be suspected to represent a fresh-water sinter. The bizarre course of the veinlets

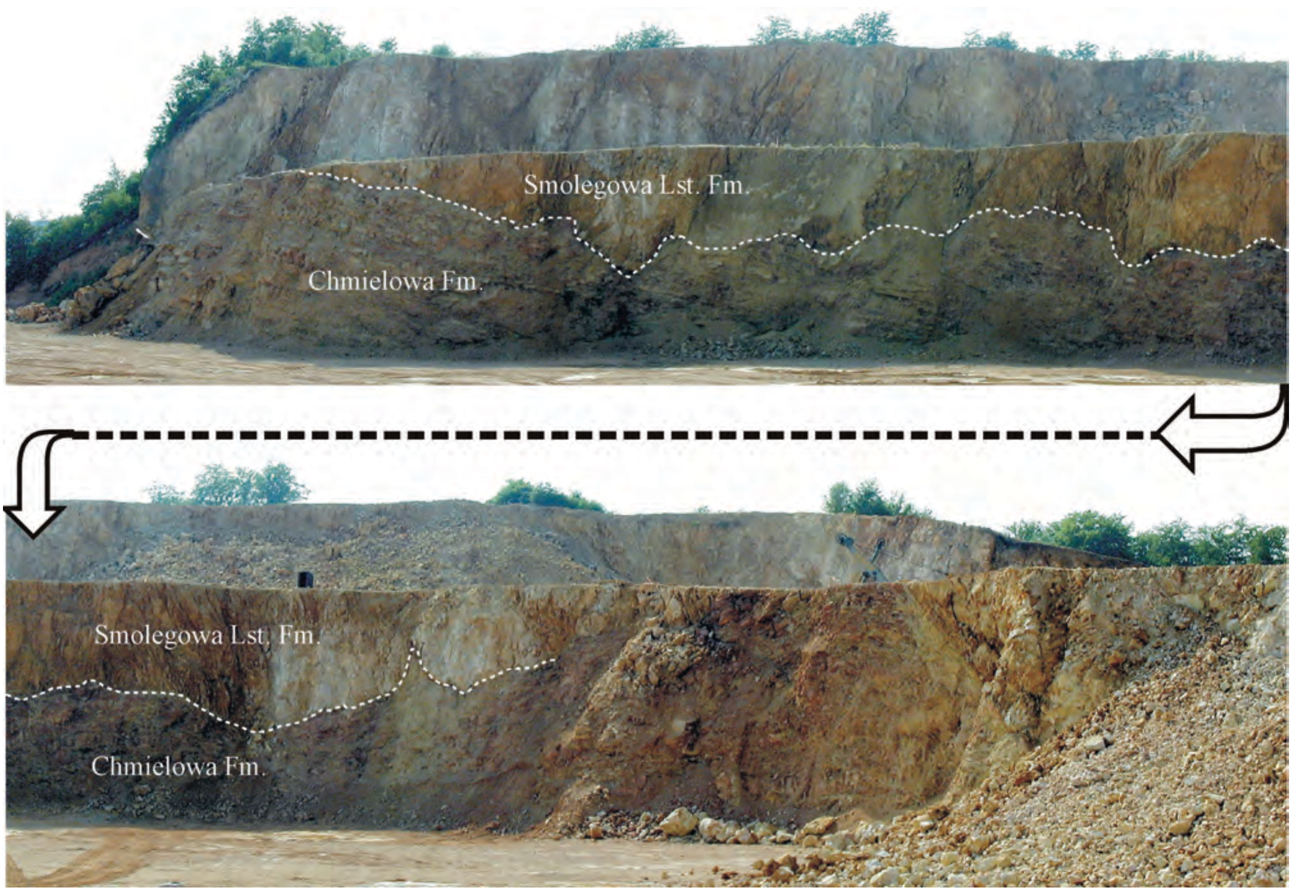


Fig. 49: Field view showing the uppermost steps of the quarries at Horne Srnie. Sharp irregular boundary (dotted line) between the Bajocian crinoidal limestone (Smolegowa Limestone Formation) and the Upper Aptian/Albian marly limestones and marls (Chmielowa Formation) originated by deep erosion and karstification that removed all the Bathonian to Hauterivian sediments. The succession is tectonically overturned. State from the year 2003.

suggests their origin by karstic leaching. Some wider veinlets, however contain remnants of neptunian dyke fillings of beige micritic limestone.

Smolegowa Lst. Fm.: Crinoidal packstone to grainstone consisting of crinoidal ossicles, numerous clasts of micritic carbonates (mostly dolomites and de-dolomites, some of them were bored) and less numerous fragments of bivalves (in places only ghosts i.e. leached and filled with micrite) and brachiopods, echinoid spines, agglutinated and lenticulinid foraminifers. Besides the micritic carbonates, some clasts of calcarenites were found, too. The crinoidal limestone also contains dispersed sandy quartz admixture. The crinoidal ossicles are overgrown by clear syntaxial calcite rims, but at the contact with the overlying Albian sediments they use to be strongly corroded. Voids in the crinoidal limestone commonly contain calcite crystal silt. The latter features can be also attributed to fresh-water leaching.

Relics of micritic limestone (Fig. 51C) represent packstones with "filamentous" microfacies (cross-sections of thin-shelled epi-planktonic bivalves *Bositra buchi* RÖMER) and dispersed bigger crinoidal ossicles.

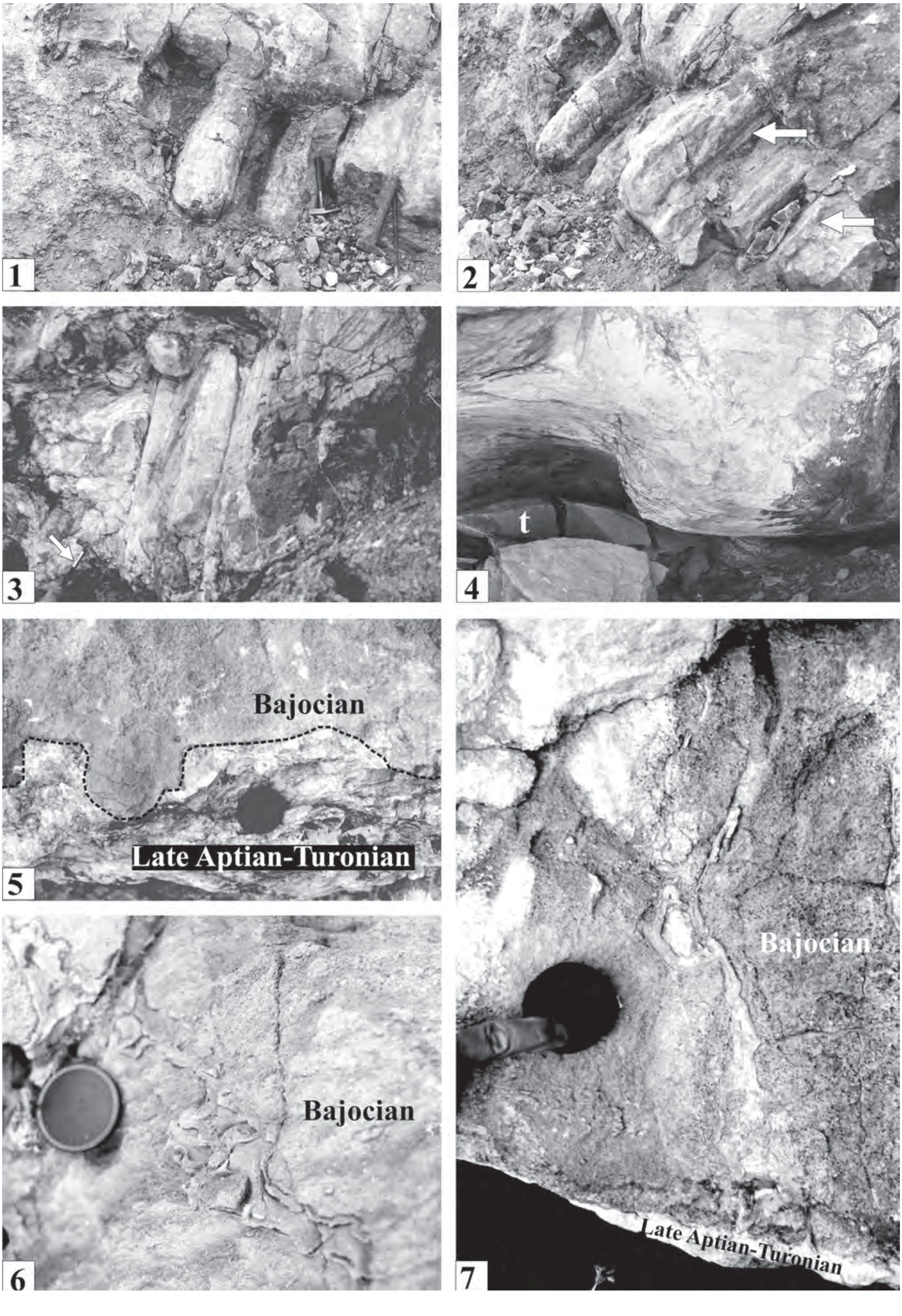
Remnants of the neptunian dykes were found in two cases only. In the first case, the infilling represents a sterile laminated pelmicrite, with laminae parallel to the course of the dyke. The pelmicrite may be of microbial stromatolitic origin. In the second case it represents a wackestone with "filamentous" microfacies, also with thin-shelled ostracods (including cave-dwelling *Pokornyopsis* sp.). This filling represents an older, Bathonian-Callovian neptunian dyke, preserved in the crinoidal limestone. This filling was not related to the Barremian-Aptian emersion and karstification. However, some Albian neptunian microdykes were found, too.

"Organodetritic Albian" represents wackestone with planktonic and agglutinated benthic foraminifers, crinoidal ossicles, echinoid spines, bivalve fragments (mostly *Aucellina* sp.), fish teeth, some tiny gastropods, bryozoan fragments, ostracods and silicisponge spicules. Radiolarian tests were preserved only if impregnated by Fe-Mn oxides. The benthic biodetritus is strongly bored. The foraminiferal assemblages are dominated by planktonic genera, but also nodosariid and sessile nubecularid foraminifers occur. The foraminifera assemblages indicate a Late Aptian-Early Albian age. At the base of the "organodetritic Albian", a clastic admixture is commonly concentrated, mostly represented by sandy quartz grains up to small pebble size. The quartz grains are angular and strongly corroded. Along with them, lithoclasts of Triassic dolomites and de-dolomites, as well as tiny lithoclasts of Upper Tithonian micritic limestones with *Crassicollaria* occur. From accessory minerals, some grains of chrome spinels, rutile, garnet and epidote were found. Authigenic glauconite is sparse but ubiquitous.

Stromatolites that locally occur at the base are greenish-yellow (predominantly phosphatic), rarely brown (goethite). They are finely laminated, with lamination being planar or slightly undulated. Some contain sessile foraminifers that give the stromatolite structure a bubble-like appearance in cross-section. Some stromatolites occur only as ghosts due to strong replacement by phosphatic minerals. *Frutexites*-type stromatolites are common. Unlike planar stromatolites, these bush-like forms are commonly brownish, i.e. formed predominantly by hematite and goethite. Along with planar and *Frutexites*-type stromatolites, some oncoids were found. The oncoids are pale-brown and reach up to 1 cm in size. Their shapes are ovoidal, with laminae slightly undulated. Two types of oncoids can be distinguished under microscope: the first, consisting of pinkish, fine-grained calcite with several more intensively colored concentric layers, and the second, more rare type, consists of brownish, low birefringence (seemingly almost isotropic) phosphate. In the first type of oncoids, sessile nubecularid foraminifers are common, mostly occurring in depressions of the lamination. In the second type, phosphatic oncoids are brownish-yellow (Fig. 51A), passing even to clear, colorless matter towards periphery. Their cores are sometimes broken oncoids, or they may be broken themselves. In this type of oncoids, the sessile foraminifers are almost missing. Pelagic Albian is similar to the "organodetritic" Albian but is free of echinoderm ossicles and contains more abundant inoceramid prisms. Based on planktonic foraminifers the age is Early to Middle Albian.

White, to creamy marly limestone occurring locally at the base of palaeokarst contains a rich assemblage of planktonic and less abundant benthic foraminifers indicating late Middle Turonian age (Fig. 51E). Besides the foraminifers, the limestone also contains inoceramid prisms, oyster-like bivalves and fish scales. The allochems are irregularly distributed which points to severe bioturbation of the sediment. Rare phosphatic grains that can be found in the sediment are irregularly penetrated

Fig. 50: Field documentation of the paleokarstic surfaces at the Horne Srnie locality: **1**. Deep karren landform (all photos are in the recent position, i.e. tectonically overturned) artificially exhumed in the year 2000 (recently destroyed by quarrying). Bizarre phalloidal promontories are formed by the Bajocian crinoidal limestone; the depressions contain multiphase filling, involving Upper Aptian up to Turonian sediments. **2**. Another view on the same. Note the grooves (arrows) perpendicular to the former basement, originated by rain water. **3**. Other instance of the vertical grooves, testifying the subaerial origin of the karstic surface. Hammer as a scale (arrow). **4**. Paleokarstic surface filled by white marly limestones of Middle Turonian age (t). This indicates multiple events of erosion and removal of sediment, lasting as late as Turonian. The erosion later than Albian might originate in submarine environment. **5**. Paleokarstic surface on the Bajocian crinoidal limestone (above), covered by Albian and younger marlstones (below). **6**. Bizarre veinlet filled with fibrous calcite. The veinlet starts at the paleokarst surface and penetrates the Bajocian crinoidal limestone. Its irregular shape indicates its origin by dissolution and its filling is probably of fresh-water origin. **7**. Another dissolution veinlet of similar character, penetrating from the paleokarst surface.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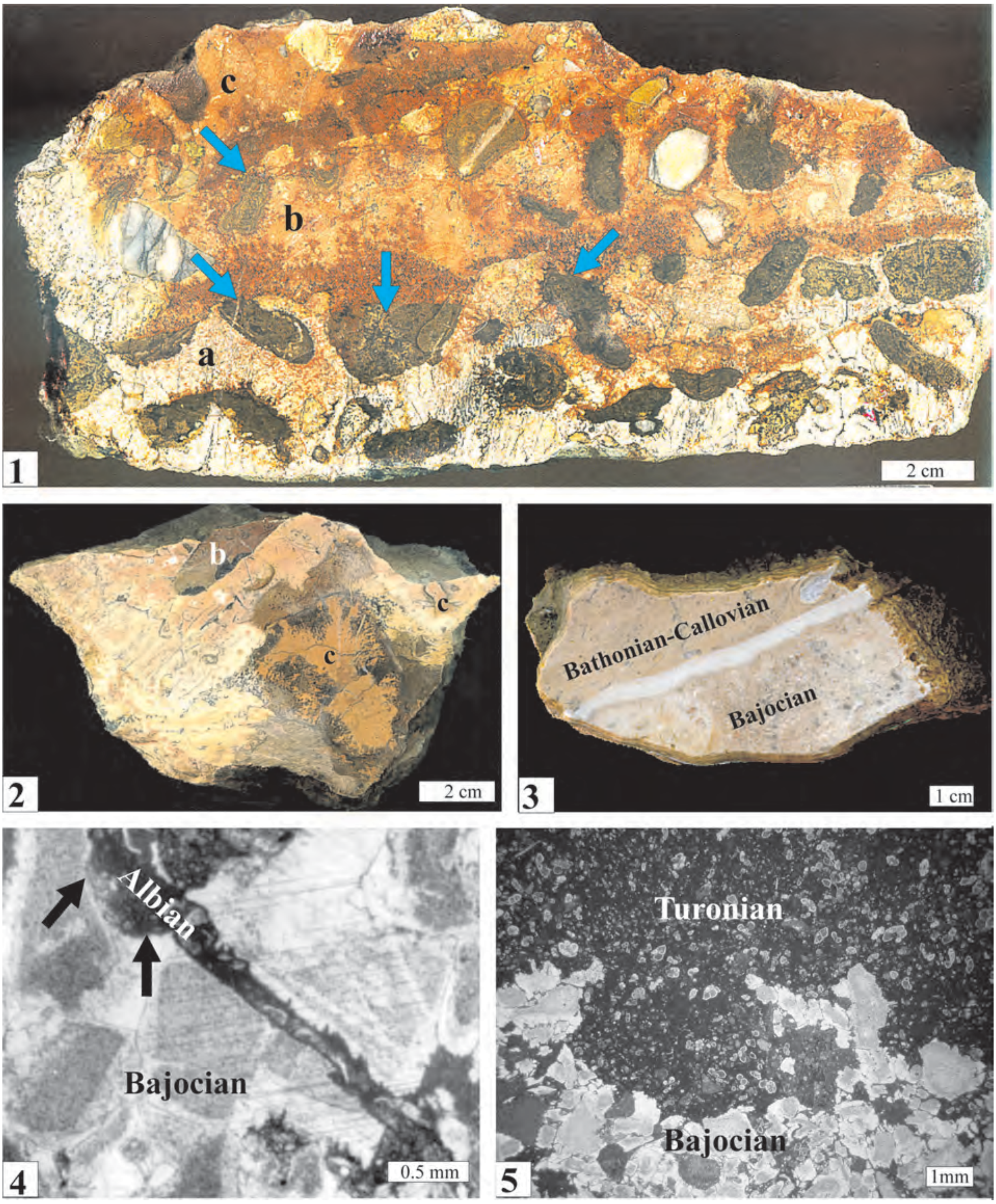

Fig. 51: Slabs and micro-photos from the Horne Srnie locality: **1**. Slab showing the Upper Aptian limestone overlying the karstified surface. The limestone contains rich clastic admixture in form of quartz pebbles (white) and greenish P-Fe oncoids. The slab shows three small units (a, b c), that were separated by phases of non-deposition connected with dissolution, affecting also the oncoids (blue arrows). **2**. Slab showing the Upper Aptian limestone bored and karstified, with borings (b) and karstic dissolution cavities (c) filled with dark-red Albian sediment. **3**. Slab showing Bajocian crinoidal limestone (below) with remnant of neptunian dyke filled with “filamentous“ microfacies (Bathonian-Callovian, above). Both lithologies are separated by thin seam of fibrous calcite (white, middle). Limestones with “filamentous“ microfacies (composed by shells of bivalves *Bositra buchi* (ROEMER)) are preserved almost only in neptunian dykes; their open-marine equivalents were mostly removed by erosion at this locality. **4**. Onset of the Albian-Cenomanian marly limestone on the Bajocian crinoidal limestone. Note the corrosion affecting both, crinoidal ossicles and syntaxial calcite cement (arrows). The Albian-Cenomanian sediment also fills a thin neptunian microdyke. **5**. Onset of the Turonian marly limestone with *Helvetoglobotruncana helvetica* BOLLI on the irregular, corroded surface of the Bajocian crinoidal limestone.

and replaced by calcite. Siliciclastic admixture is missing.

4. Discussion and conclusions

The field trip was related to paleokarst sedimentological features, neptunian dykes, collapse breccias, mud-mounds and sedimentary unconformities. They represent special cases in sedimentology, when the marine deposition rate slows down or ceases completely due to emersion. It is interesting to observe the sedimentary record from these periods as there are many special sedimentological phenomena, such as paleokarst features, like collapse breccias, neptunian dykes, paleokarst karren surfaces, cements, preserved paleotopographic features, etc. Also instructive are sedimentological features related to next onset of marine transgression on these surfaces, like basal conglomerates and breccias with typical intertidal sedimentation, animal borings, etc. In some cases, rapid flooding with onset of deep-water facies over the paleokarstic surface was also recorded. The Western Carpathians provide unique area to study all these phenomena.

The field trip topic is subdivided to four partial topics:

1. Lower and Middle Miocene transgression on the shores of Vienna Basin and the pre-transgression paleokarst

The sites display two marine transgressions in the evolution of the Vienna Basin - the Lower Miocene (Eggenburgian) and Middle Miocene (Badenian). They correspond to two main stages of the basin evolution - a small piggy-back basin, followed by the main pull-apart opening of the basin. The field trip participants can compare manifestations of these two phases as well as pre-transgression paleokarstic relief, including tectonism which led to opening of paleokarst fissures. All these phenomena can be shown along the western margin of the Male Karpaty Mts. which is a horst originated during the pull-apart opening of the Vienna Basin. Less information is available from the continuation of these mountains to Austria (Hundsheimer Berge), where also paleokarst features occur. Very little is known about possible paleokarst occurrences on the opposite shores of the Vienna Basin. Except of trapped terrestrial fauna, the paleokarst cavities are perspective to contain coelobitic organisms, similar to those described from Jurassic neptunian dykes (see the topic No. 3).

2. Senonian-Paleocene paleokarst after the main nappe stack in the Central Western Carpathians

The sites show paleokarst features developed in the Central Western Carpathians after the Turonian nappe stack. The presence of paleokarst is important from the tectonic point of view. The paleokarst was developed on the highest nappes at that time and enables to reveal a secondary position of some nappes which were considered to be even higher, such as Havranica, Jablonica and Nedzov nappes in the Male Karpaty Mts. It is obvious that these seeming higher nappes were in fact attached to these mountains much later, by lateral strike-slips (if there was a Senonian-Paleocene paleokarst developed on the Veterlin Nappe there should not be any higher nappes). This supports a theory that these "higher" nappes in fact do not belong to the Central Western Carpathians but they represent an Eastern Alpine element emerging on the other side of the Vienna Basin. This also leads to further assumptions that the marine Senonian sediments of the Brezova Group, which cover the Nedzov Nappe, are then true Gosau Group from the Eastern Alps and do not represent a Carpathian element. Except of some small occurrences of marine Senonian in the SE Slovakia, rest of the West Carpathian area was fully emerged. During Cretaceous, this area was situated most likely in the tropic zone, as evidenced by presence of bauxites. However, rarity of these occurrences indicates that most of the area was covered with sedimentary complexes and the crystalline basement was uncovered only in some places.

3. Lower Cretaceous emersion and paleokarst on the Czorsztyn Swell

The phenomena related to the topic No. 4 originated in the period when large paleogeographic and paleotectonic changes took place in the Western Carpathians. As such, they are very important from the point of view of paleogeography and paleotectonics. The Barremian-Aptian shallowing, accompanied by onsets of Urgonian carbonate platforms are typical for the Central Western Carpathians. However, the complete emersion of the Czorsztyn Swell is unique. The research showed that the emersion was very extensive because the sediments from this period are missing also in transitional units which were originally situated downslope on the Czorsztyn Swell. In the basinal Kysuca-Pieniny Unit, mostly deep-water marlstones are present. There was only a relatively narrow zone with shallow-water Urgonian-like facies at the margin of the Kysuca-Pieniny Basin - the Nizna Unit. Except of the Urgonian facies, erosional breccias typically occur at the base, evidencing that the emerged land was quite close. Quite surprising is then the rapid flooding. The Late Aptian phase was only a temporary submergence, with subsequent short emersion which caused common karstification of the older, Jurassic deposits and the deposits from the temporary submersion. Then followed a very rapid flooding with red *Globotruncana* marls. The basal parts of the this formation are considerably condensed, indicating strong bottom currents being active long time after drowning (at Horne Srnie locally even Turonian sediments rest on the karren surface). Mechanism of the flooding is yet unknown. Because of character of the Czorsztyn Swell, it is more substantiated to presume sudden crustal collapse and sinking of the whole ridge than breakage of some barrier which would preserved the dry land on the swell.

Very surprising is the presence of ophiolitic detritus in the Late Aptian sediments which connects this sedimentary area with unknown exotic source which supplied several sedimentary areas with ophiolitic material and was called as Pieniny Cordillera, Exotic Ridge or Andrusov Ridge. The nature of this exotic ridge has not been solved yet but it is supposed that it was an accretionary wedge developed

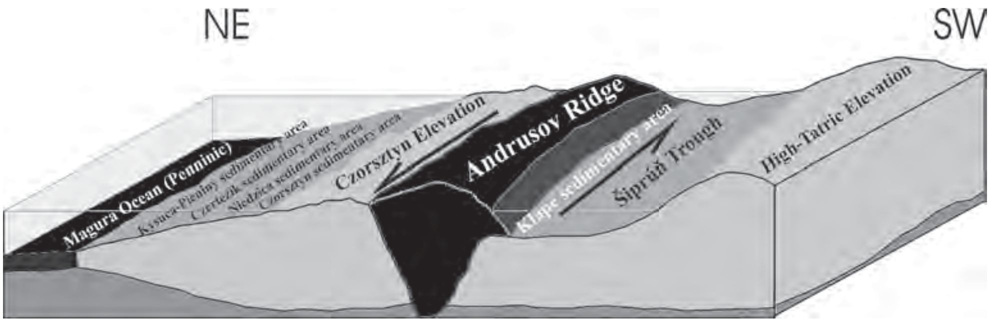

Fig. 52: New proposed paleogeographic reconstruction of the Pieniny Klippen Belt units in Albian (compare with Fig. 34). After AUBRECHT et al. (2009a).

in the Middle Cretaceous in front of the overriding Central Western Carpathians and was slowly approaching the Oravic units which form recently the main part of the Pieniny Klippen Belt. The problem was with the previous reconstructions of BIRKENMAJER (1977) who inferred that between the Central Western Carpathians (+ the Exotic Ridge) there was one of the Penninic branches - the Kysuca Pieniny Trough which would prevent any transport of ophiolite detritus to the Czorsztyn Swell. To explain it, the complete succession of the Oravic units as drawn by BIRKENMAJER (l.c.) has to be turned in 180º (AUBRECHT et al. 2009a) and one of the Penninic branches has to be removed (the Kysuca-Pieniny Basin most likely continued to the Magura Ocean in the north - Fig. 52).

4. Middle Jurassic synrift sedimentation on the Czorsztyn Swell of the Pieniny Klippen Belt - breccias, neptunian dykes and stromatactis-mud-mounds

The sites show the whole scale of sedimentary phenomena related to the Middle Jurassic rifting in the Pieniny Klippen Belt, such as cliff and karst collapse breccias, neptunian dykes and condensed sedimentation with local stromatactis mud-mounds. All these features are preserved in the sediments deposited on the Czorsztyn Swell during the opening of the Penninic Ocean. Paleomagnetic measurements combined with structural analysis show that the predominant original orientation of the dykes was NE-SW, which indicates NW-SE oriented extension. At the same time, the paleomagnetic results show a very large Middle Jurassic south-vergent shift of the whole crustal block from about 45º of the northern latitude to about 20º, which infers that the Penninic Ocean was much wider and opened much faster than previously expected.

The neptunian dykes, crevices in the breccias and even cavities in the stromatactis mud-mounds show presence of cave-dwelling ostracods *Pokornyopsis feifeli* (TRIEBEL) (Fig. 53-54) which are ancestors of the recent genus *Danielopolina* (Fig. 55) which is a common cave dweller in the recent times (mostly in the so-called anchialine caves). This is evidence that this originally deep-marine fauna started to inhabit submarine cave environment already in Jurassic (AUBRECHT & KOZUR 1995). Except of pressure and temperature, the cave environment possess all the properties identical to the deep-marine habitats, such as tranquil, steady environment, with lack of light, less competitive organisms and less predators. Except of some fresh-water early cements on some clasts in the breccias and bizzare shapes of some neptunian dykes there were no signs of fresh-water influence. Therefore, the environment of cavities that evolved at that times (neptunian dykes+breccia interstices) was not very similar to the recent anchialine caves which are typical by fresh-water upper layer and a halocline developed in the water column. It is mostly due to the sea-level rise in Bathonian which completely flooded the Czorsztyn swell, including

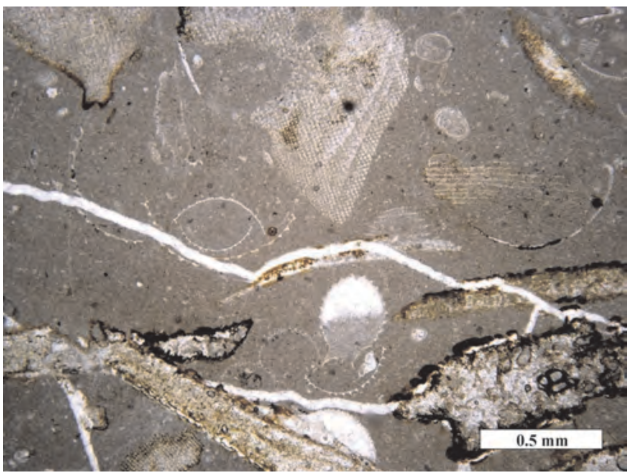

Fig. 53: Cross-sections of cave-dwelling ostracods *Pokornyopsis feifeli* (TRIEBEL) in neptunian dyke filling from Vrsatec.

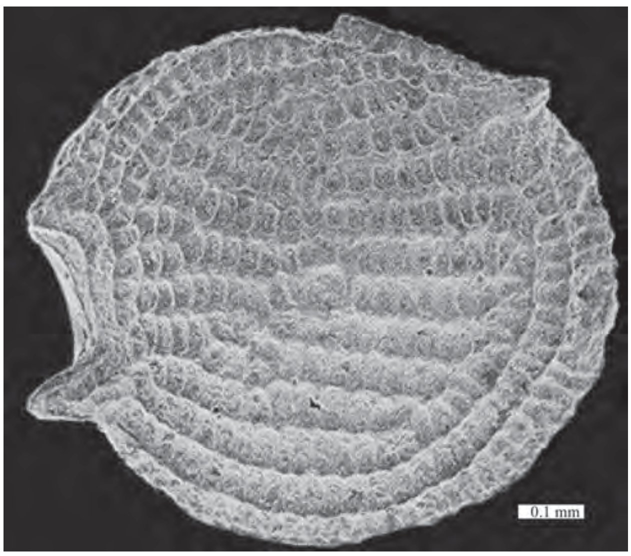

Fig. 54: Holotype of *Pokornyopsis feifeli* (TRIEBEL) from Germany. After KORNICKER & SOHN (1976).

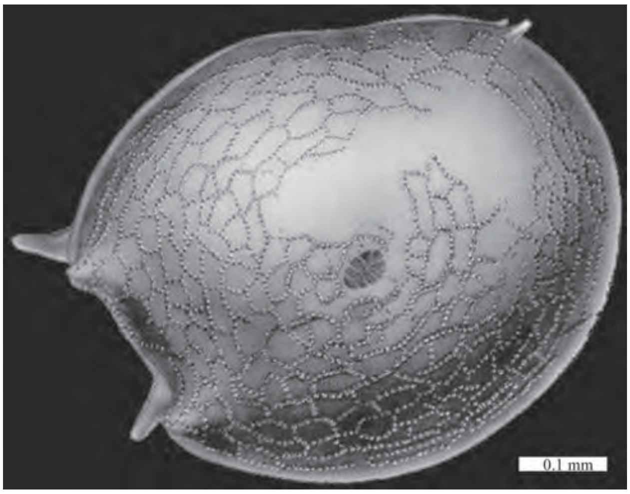

Fig. 55: One of the recent ancestors of the Jurassic cave-dwelling ostracod fauna - *Danielopolina orghidani* (Danielopol). After Kornicker & Sohn (1976).

the previously emerged land. The period of possible freshwater influx was then relatively short, reduced solely to Bajocian, when deposition of coral and crinoidal limestone took place, including the main phase of the Krasin Breccia deposition.

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