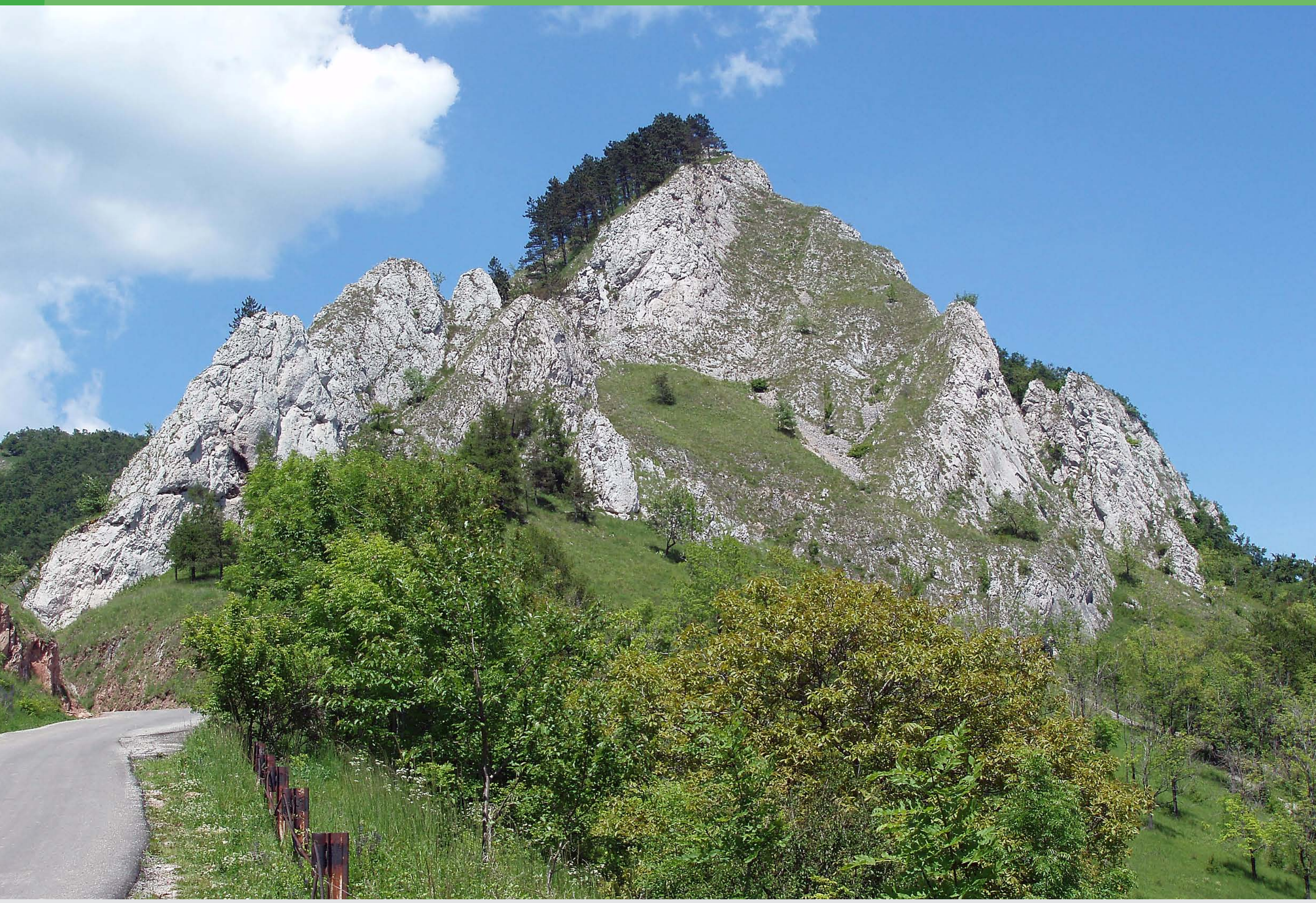
GUIDEBOOK

Palaeokarst, neptunian dykes, collapse breccias, mud-mounds and sedimentary unconformities in Slovakian Western Carpathians

Guide to field trip B4 • 26–28 June 2015

Roman Aubrecht



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Paleokarst, neptunian dykes, collapse breccias, mud-mounds and sedimentary unconformities in Slovakian Western Carpathians

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Route (Fig. 1): The trip starts from Kraków centre to the south by E77 to Dolný Kubín in Slovakia, then by road 709 km southwest to Párnica village, where we take road 583 northwards to Zázrivá and by local roads to its northern part **Zázrivá**-Havrania. To get to the first locality (stop **B4.1**), it is necessary to use a local forest road, for which a permission from the forest owners is necessary. Then the route goes back to Zázrivá and by road 583 to Žilina where by a slip road we enter motorway E75 (E50) to Beluša where we take a local to SE to **Mojtín** village. We walk ca. 15 minutes north to locality **B4.2**. We return to Beluša and take road 61 to SW to Ilava, turn NW, and through Pruské village follow to Vršatské Podhradie, to the parking place at the mountain pass above the village. The **Vršatec** sites (**B4.3**) are distributed around the pass. After returning to Pruské village we take road 507 to the neighbouring Bohunice where we turn to a local road towards the **Krivoklát** village and visit an abandoned quarry (**B4.4**) below the Babin**á hill** on the half-way. The next locality is in the second valley after Bohunice by road 507, near **Slavnické Podhorie**. It is an abandoned quarry (**B4.5**) at the northern margin of the village. Then by road 507 to Dubnica nad Váhom and by road 61 we reach **Trenčín**, for overnight.

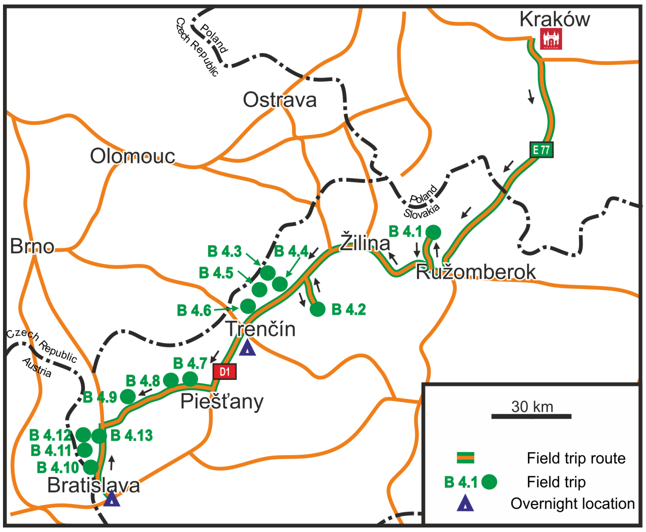

Fig. 1. Route map of field trip B4.

On the second day the trip leads by a local road to **Dolná Súča** village, to an abandoned quarry NW from the village (**B4.6**). Then back to Trenčín and by motorway E75(D1) to Piešťany, where. we turn to 499 through Vrbové to Prašník and by a local road to a dam nead the **Pustá Ves** village. Stop **B4.7** is on the mountain ridge, about 1 km SE from the dam. Then the route again follows road 499 to Brezová pod Bradlom, where it connects to road 501. Stop **B4.8** is by the road, about 2 km

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from the **Brezová pod Bradlom**. Then we continue along road 501 at the NW toe of the Malé Karpaty Mts. to **Sološnica** village. Stop **B4.9** is in an abandoned quarry at the SE end of the village. The trip continues along road 501 to Rohožník and by a local road to Malacky, and by motorway E65(D2) to Bratislava for overnight.

The third day route leads by the local roads to **Devín** and **Devínska Nová Ves** within the limits of Bratislava (stops **B4.10, B4.11, B4.12**). By local roads we follow to road 2 northwards to **Záhorská Bystrica** (now a part of Bratislava). Stop **B4.13** is in an abandoned quarry at the western margin of the village. After the end of the field-trip, the participants have several possibilities, either to go back to Kraków, or to spend some more days in Bratislava, or to leave for Vienna airport using very frequent bus and train connections.

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.

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 breccias with fossil terra rosa and fresh-water cyanophyte limestones resting on the unconformity surfaces.

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) and 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 formation of 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.

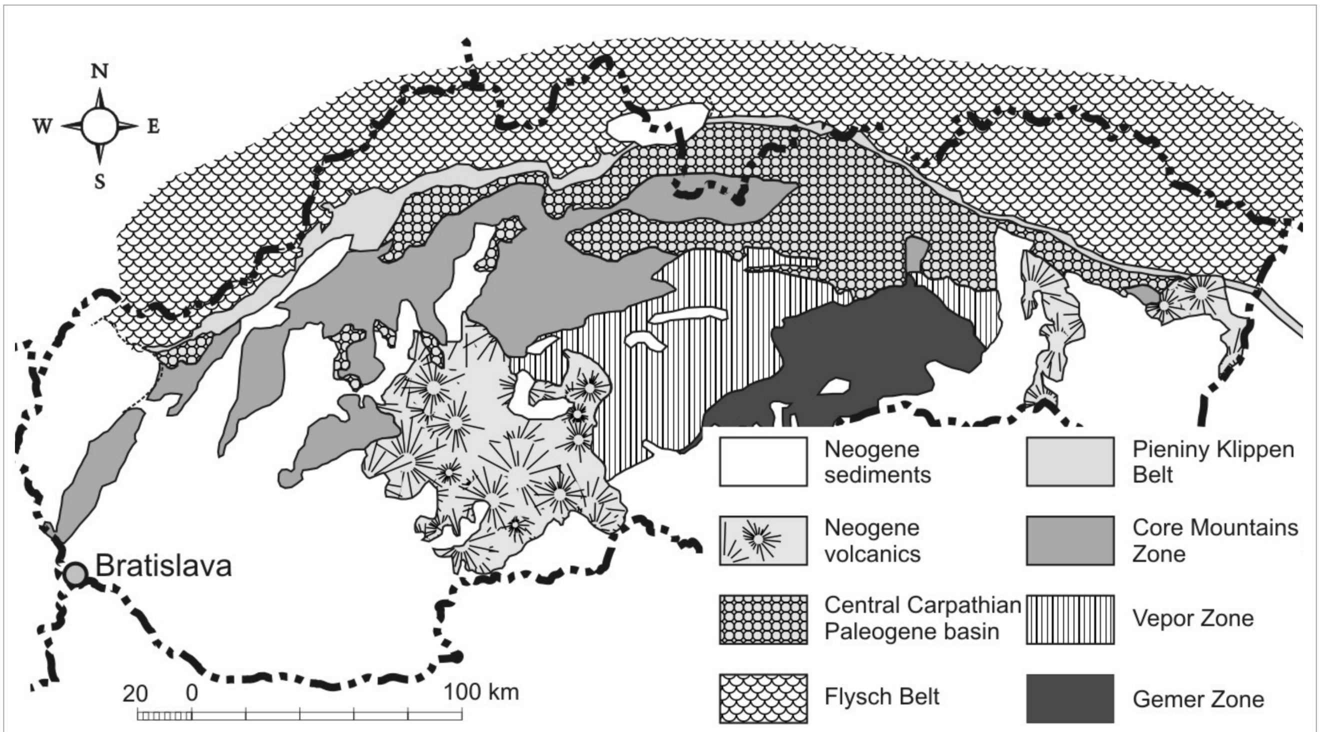

Fig. 2. Simplified geological map of Slovakia, showing the main tectonic zones.

The first two days of the field-trip are dedicated to the manifestations of Jurassic synrift deposition in the Pieniny Klippen Belt, including hardgrounds, cliff- and cave collapse-breccias, neptunian dykes, stromatactis mud mounds, Mid-Cretaceous paleokarst in the Pieniny Klippen Belt, Upper Cretaceous unconformity surfaces, continental deposits and paleokarst which originated after main tectonic phases in the Central Western Carpathians.

Younger erosional and karstification phenomena 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 a chance to observe the pre-transgressional surfaces and manifestation of the latest marine transgression in the West Carpathian-Pannonian realm.

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 Central and Outer Western Carpathians (Fig. 2). The melange consists of several units compressed and strongly deformed between the Central Western 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. 3). 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. 4). Within this basin with relatively low deposition rate, some uncondensed sections 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.

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. There 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. 4). 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 evidence that the non-

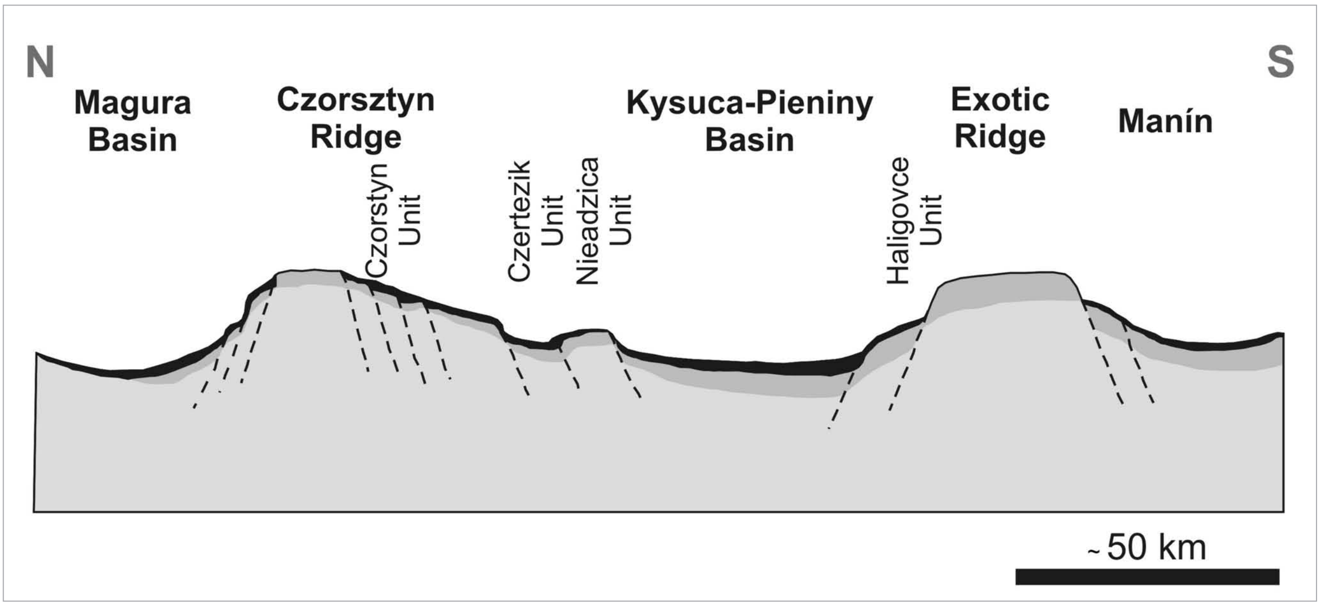

Fig. 3. Paleogeographic reconstruction of the units presently constituting the Pieniny Klippen Belt (slightly modified after Birkenmajer, 1977).

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.

Cretaceous–Paleocene unconformity 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. 5). The nappes are known as so called Subtatric nappes – the 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.

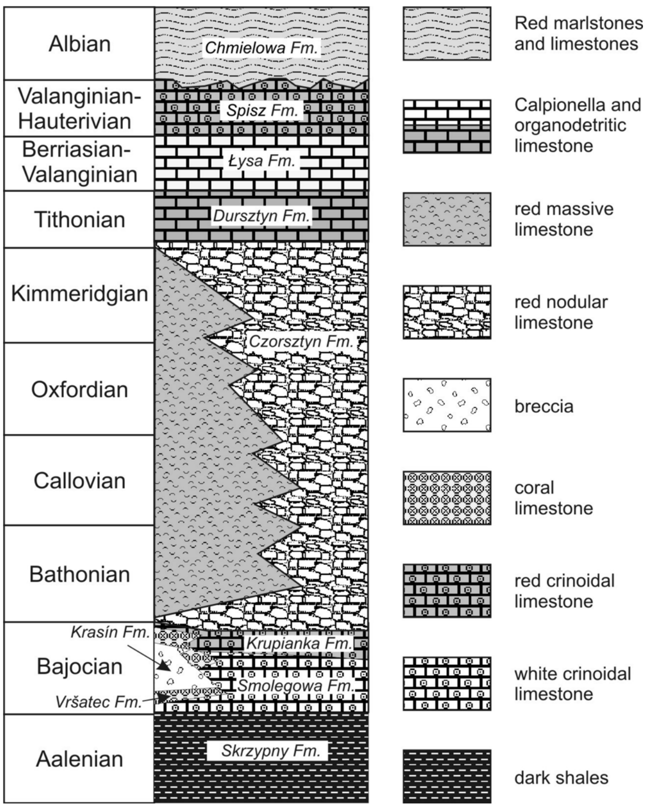

Fig. 4. Lithostratigraphic scheme of the Czorsztyn Succession.

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

The next topic of the field trip is to study Middle/Upper Badenian and earlier, Eggenburgian transgressive surfaces along the eastern shore of the Vienna Basin (Fig. 6). In the early Miocene, the Vienna Basin was only a small piggy-back basin on the Carpathian Flysch Zone. This basin underwent large re-building during Karpatian-Badenian time (uppermost Burdigalian to Serravalian – for correlation between the Central Para-

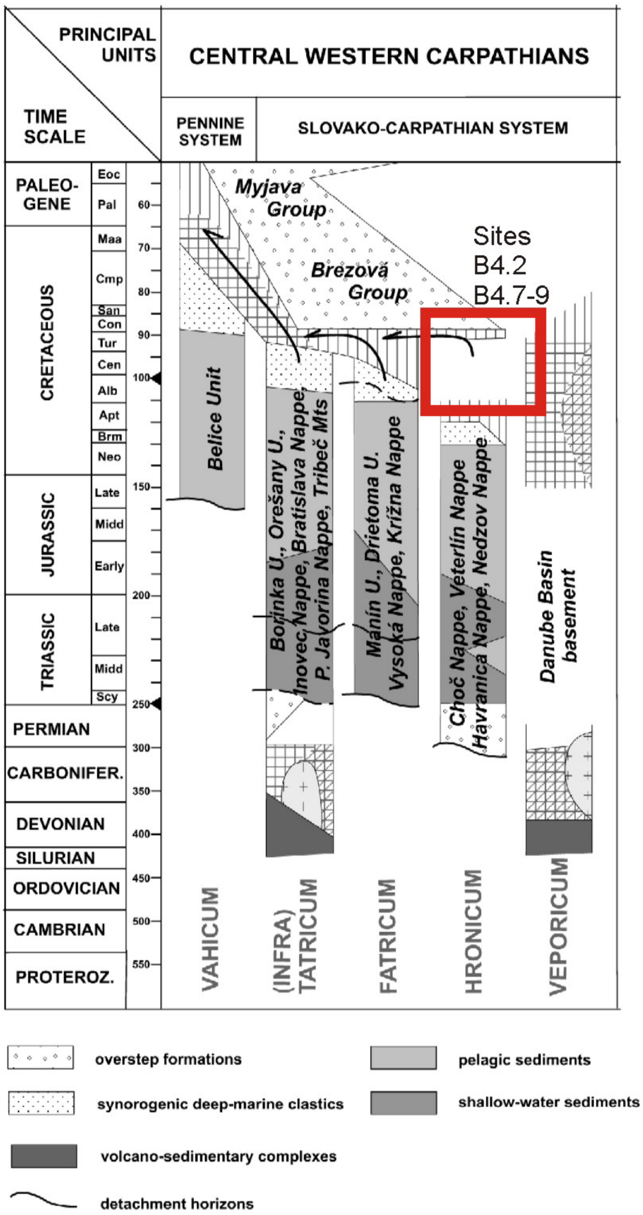

Fig. 5. Correlation table of the pre-Tertiary tectonic units of the Central Western Carpathians, with marked tectonostratigraphic position of the sites Pustá Ves, Brezová pod Bradlom, Sološnica and Mojtín.

tethys and Mediterranean stratigraphic scale, see Fig. 7) when the basin opens to its present form in a pull-apart regime (Kováč *et al.*, 2004). In this time, the horst of the Male Karpaty Mts. (Small Carpathians) originated and limited 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 Devín Castle Hill and to the neighbouring hill Devínska 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 descriptions

B4.1 Zázrivá

(49°17′51″N, 19°13′14″E)

The Early Cretaceous emersion episode of the Czorsztyn Swell, which was accompanied with erosion and karstification, has been documented at several localities. The best locality near Horné Sŕnie was almost destroyed by quarying. Recently, a similar locality with well preserved paleokarst surface was discovered north of the Zázrivá Village in the Orava sector of the Pieniny Klippen Belt (Jamrichová *et al.*, 2012). The klippe of the Czorsztyn Succession is in overturned position (Fig. 8). Its stratigraphy starts with red nodular Czorsztyn Limestone Formation (Ammonitico Rosso facies) of Kimmeridgian to Middle Tithonian age, followed by Dursztyn Limestone Formation (Fig. 9). The latter consists of red bedded micritic limestones of Korowa Limestone Member and white micritic limestones of

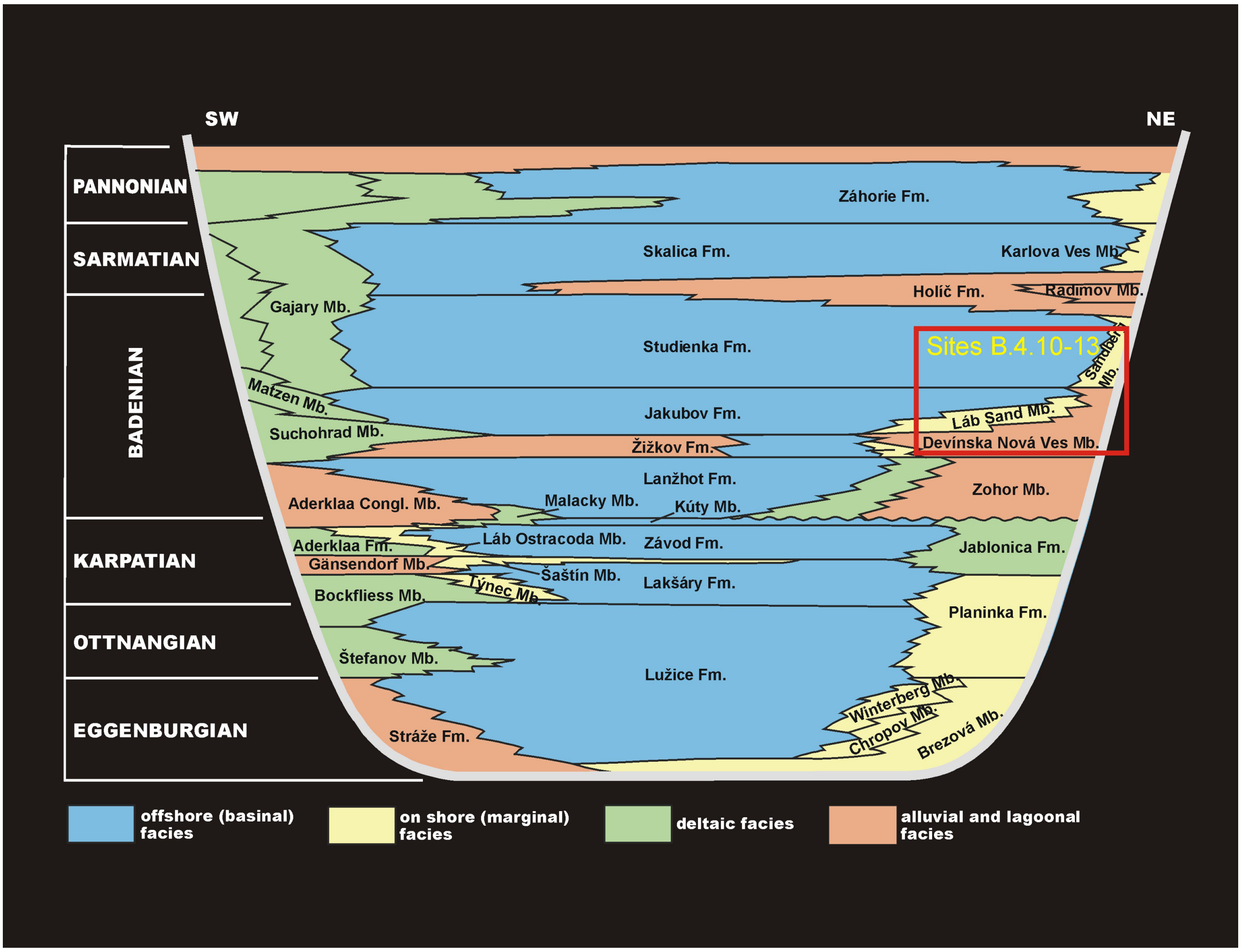

Fig. 6. Lithostratigraphy of the Neogene filling of the Vienna Basin (after Kováč et al., 2004). Rectangle marks the lithostratigraphic position of the visited sites.

the Sobótka Limestone Member. The Korowa Lst. Mb. displays unusual succession of calpionellids, starting with predominance of *Calpionella alpina* which would indicate Early Berriasian, but higher up it is dominated by *Crassicollaria brevis* which indicates Late Tithonian. Then *Calpionella alpina* becomes dominant again in the entire Sobótka Lst. Mb. This repetition of the microfacies dominated by *Calpionella alpina* was reported also from Puerto Escaño section in Southern Spain (province of Córdoba).

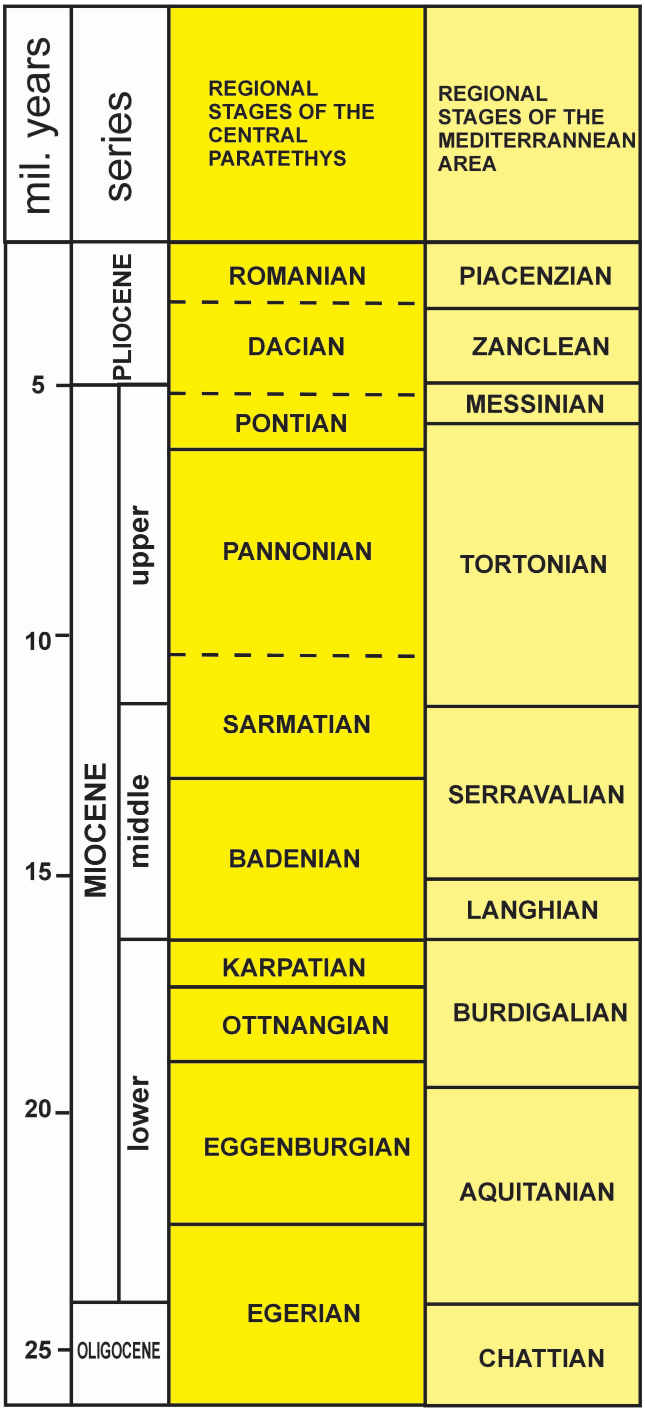

Fig. 7. Correlation between the Central Paratethys and Mediterranean stratigraphic scales.

On the stratigraphic top of the Sobótka Lst. Mb., shallow karren surface (Fig. 8 B-E) was developed (maximum 30-40 cm deep). It is visible not only at the base of the klippe but even better on a large fallen block some tens of meters below the klippe (Fig. 8 C). The surface is similar to that described from the Horné Sŕnie locality (Aubrecht *et al.*, 2006), *i.e.* a relatively flat surface is covered by loafs and hummocks with rounded tops (Fig. 8 D-E). On some hummocks, rainwater grooves perpendicular to the paleokarst surface were observed (Fig. 8E). In the eastern part of the klippe, the paleokarst surface penetrated deeper to the underlying limestone, forming a smooth depression. Shallow bivalve borings (*Gastrochaenolites*) are common on the paleokarst surface (Fig. 10A). Rich fauna of belemnites and some ammonites can be found at the very base of the condensed Albian sequence. The underlying Sobótka Lst. Mb. is dissected by some blocky-calcite veinlets which do not continue to the Albian sediments and are bored by bivalves (Fig. 10B), i.e. they are pre-Albian. Similar cases were also described from Lednica and Horné Sŕnie localities (Aubrecht *et al.*, 2006).

The upper surface of the underlying Sobótka Limestone Member is irregular also in microscale; it is bored (microboring filled with opaque Fe-Mn minerals, Fig. 10 C-D), covered with Fe-Mn-encrustations and phosphatic stromatolites with frequent sessile foraminifers. The karstic surface is covered by condensed succession of red pelagic marly limestones and marlstones (Chmielowa Formation) starting with Late Albian *Rotalipora appennica* Interval Zone. The stratigraphic gap at the studied locality then encompasses the time from Berriasian to Late Albian, with Upper Berriassian to Valanginian rocks presumably removed by erosion. The lowermost part of the Chmielowa Formation locally contains pebble-size detritic admixture, composed mostly of clasts of the underlying limestones with calpionellids (Fig. 10E). Single clast of garnet gneiss was also found (Fig. 10F).

B4.2 Mojtín

(48°59′32″ N, 18° 24′55″ E)

Near Mojtín village in the Strážovské vrchy Mts., one of the few Slovak occurrences of bauxites is situated. In these mountains, other occurrences are near Domaniža and Ďurďová. The occurrences are concentrated in paleokarst depressions and clefts in limestones (Fig. 11) of the

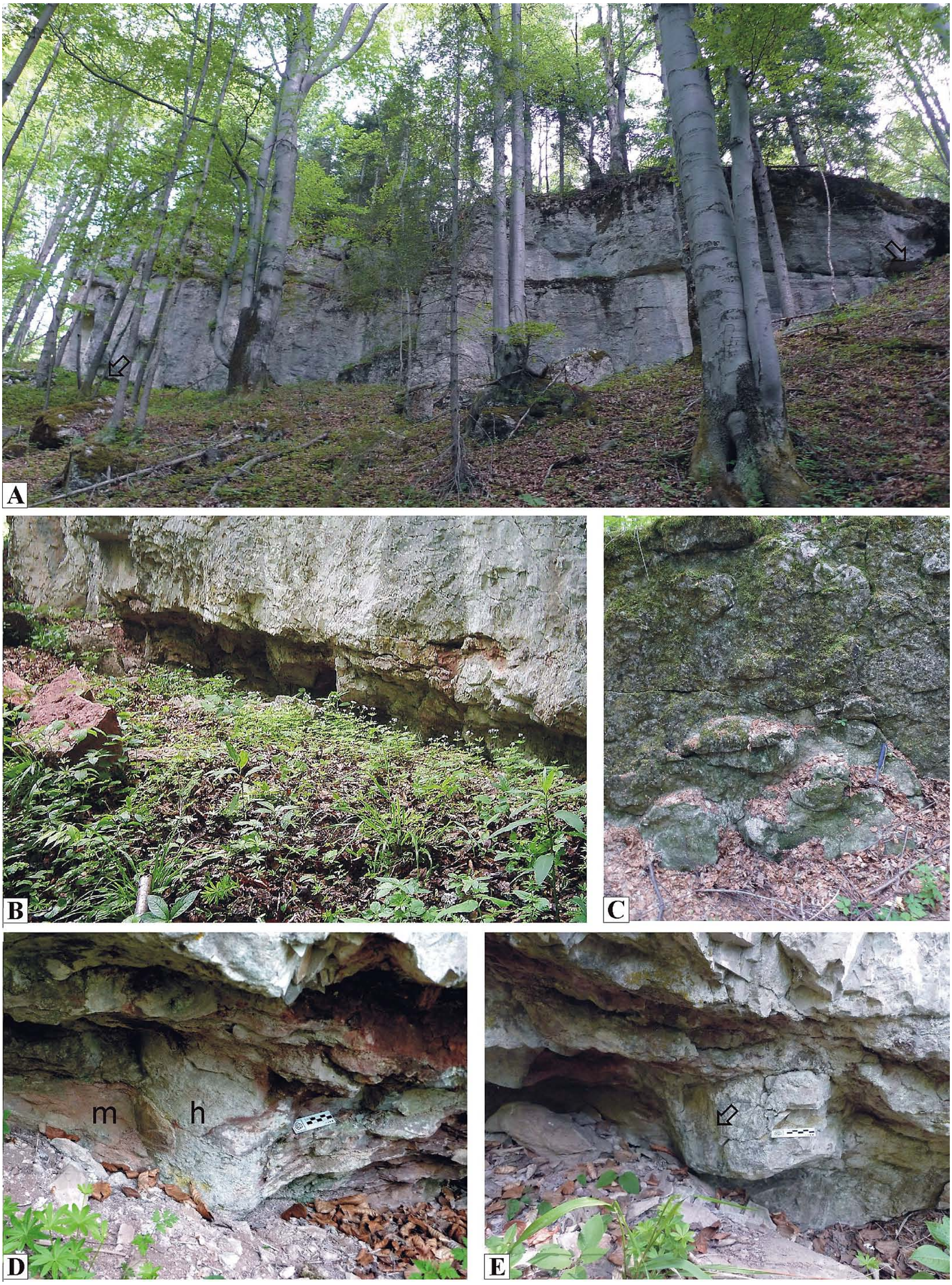

Fig. 8. A – Overall view on the klippe north of the Zázrivá village with preserved pre-Albian paleokarst surface (indicated by arrows). **B** – View on the paleokarst surface preserved at the bottom of the klippe. **C** – View on the paleokarst surface in vertical position on the fallen block below the klippe. **D** – Detailed view on a hummock paleokarst body protruding from the stratigraphically older underlying limestones (h). The paleokarst surface is covered by Late Albian to Cenomanian marls (m). **E** – Another hummock on which rainwater grooves are visible (arrow), being perpendicular to the paleokarst surface.

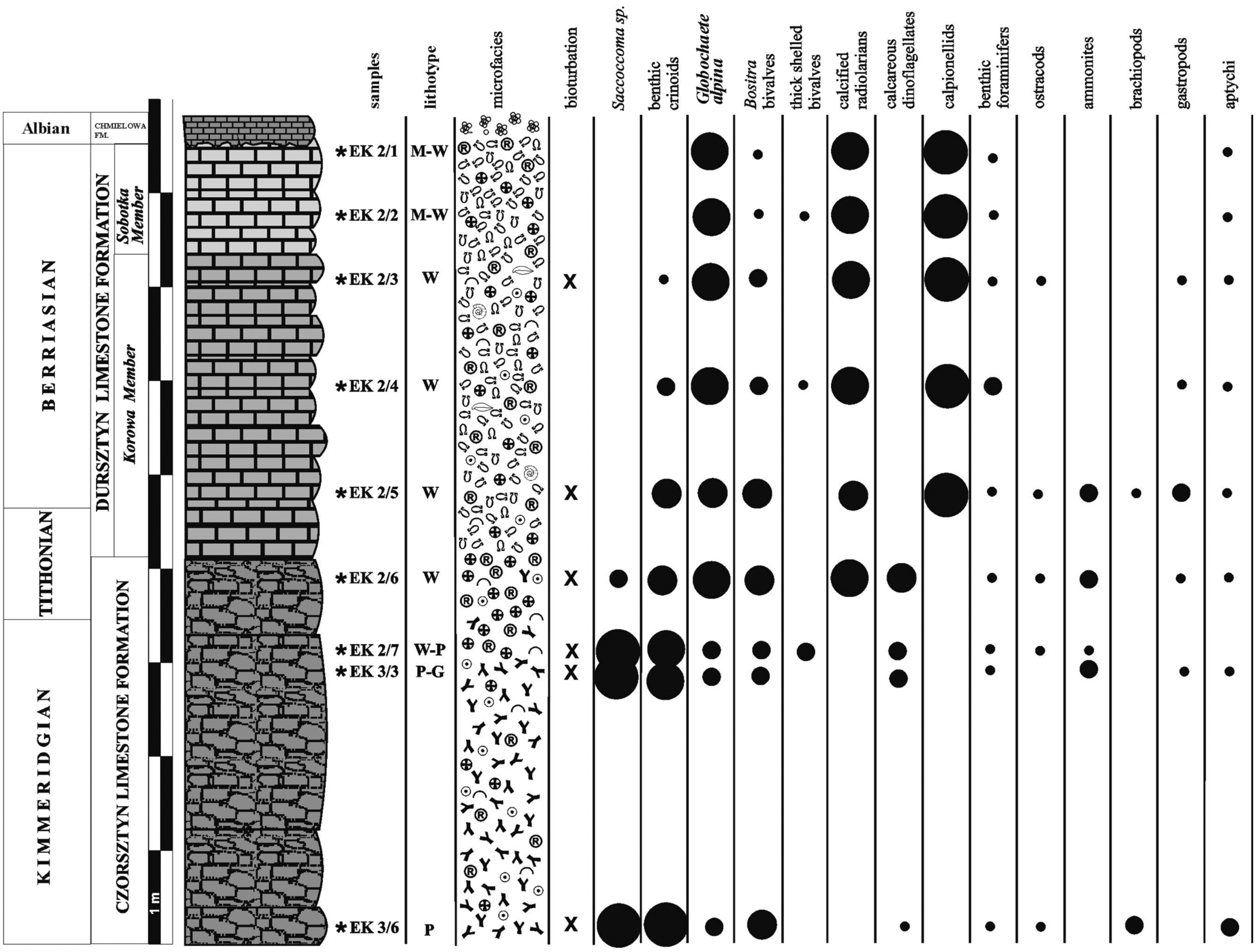

Fig. 9. Lithological section of the examined locality, showing facies and distribution of the allochems.

Strážov Nappe and in dolomites of the Choč Nappe. Outside the Strážovské vrchy Mts., bauxites were found near Markušovce in Spiš (eastern Slovakia). The largest occurrence near Mojtín is situated above Lopušná. The Mojtín bauxites had to originate after thrust of the Subtatric nappes and before Eocene (Lutetian), as the bauxite layers are covered by nummulitic limestones and breccias with bauxitic 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* (Potonić & 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 originated by experimental mining can be seen, 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% haematite (mostly in sphaerical forms – pisoids – Fig. 12). Haematite is missing in pale types. Chemical composition of the bauxites is: Al_2O_3 – 43%, Fe_2O_3 – 19%, SiO_2 – 16%, TiO_2 – 4% (Číčel 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.

B4.3 Vršatec

(top of the Javornik hill: 49°04′17″ N, 18°09′36″ E)

The group of main Vršatec Klippen is the largest in Slovak territory and in the entire Pieniny Klippen Belt. They are situated above the Vršatské Podhradie village,

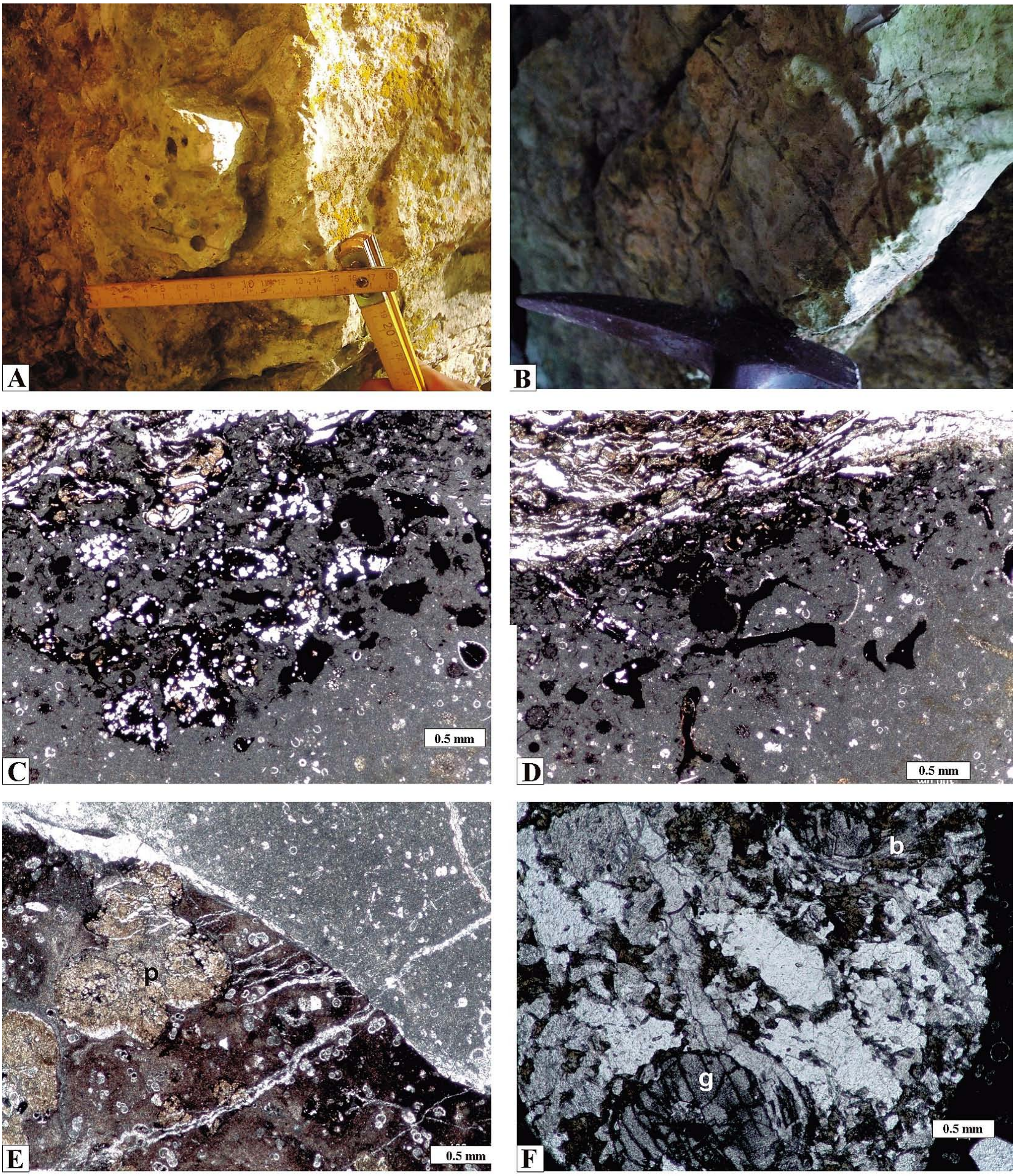

Fig. 10. A – Paleokarst surface at the base of the klippe bored by bivalves (trace fossil *Gastrochenolites*). **B** – Pre-Albian calcite veinlets (appear as straight grooves on the photo) bored by bivalves. **C, D** – Bored limestone of the Sobótka Limestone Member below the base of the Chmielowa Formation. The borings are filled with opaque Fe-Mn minerals. Thin-section, plain polarized light. **E** – Clast of the underlying calpionellid wackestone (the Sobótka Limestone Member, upper right part of the thin-section) in the red marly limestone of the Chmielowa Formation (lower left part). The latter also contains clusters of phosphates (p). Plain polarized light. **F** – Small pebble of garnet gneiss in the Chmielowa Formation. The rock consists of quartz (white to pale-grey), garnet (g) and biotite (b). Thin-section, plain polarized light.

NW of the Ilava town. This locality consists of two tectonic blocks that belong to the Czorsztyn Unit: the Vršatec Castle Klippe (Fig. 13) and the Javornik Klippe. 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 very rare in other Jurassic successions of the Pieniny Klippen Belt. Mišík (1979b) described in detail sedimentological features of the two blocks in an E-W oriented transect 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 (Vršatec Lst.) that are overlying the Middle Jurassic crinoidal limestones (Smolegowa and Krupianka Lst. Fm.). In the second slice, the Middle Jurassic crinoidal limestones are overlain by the Czorsztyn 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) that 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 are *overlying* the biohermal limestones. Secondly, biostratigraphic data indicate that the biohermal limestone is older than thought before, probably of Middle Jurassic age.

Fig. 11. Paleokarst depression revealed by bauxite mining. Mojtín.

Fig. 12. Among other constituents, the bauxite ore contains spherical pisoids.

Stratigraphy of the overturned sequence of the Vršatec Klippen.

The Vršatec Lst. (Fig. 14) 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. The core of the reef is probably preserved near the top of the hill of the Javorník block. Voids and small caverns in the biohermal limestone contain internal sediment, scarce stromatolites of the LLH type (lateral linked hemispheroidal stromatolite) and algae *Verticillodesmis clavaeformis* Dragastan & Mišík. 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 (Kochanová, 1978), the biohermal limestones were assigned to the Oxfordian by Mišík (1979b). However, the bivalves described by Kochanová (1978) are stratigraphically inconclusive (Golej, pers. communication). One neptunian dyke cutting the peribiohermal limestones contains the ammonites *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 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 metres thick.

The Smolegowa and Krupianka limestone formations are formed by grey to reddish crinoidal grainstones that are overlying the biohermal Vršatec 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 the 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 metres.

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 metres. 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 metres. 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 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 passes gradually into the *Crassicolaria* and *Calpionella* microfacies. The Middle Tithonian to Early Berriasian age of the formation is based on calcareous dinoflagellates and calpionellids.

Fig. 13. View on the Vršatec Castle Klippe. Red micritic filling of the neptunian dykes contrasts with white crinoidal limestones.

The Cretaceous deposits are represented by red marls and marlstones. A tectonic 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 Vršatské Podhradie. The sequence of limestones and marls is in reverse position. A normal sedimentological contact between the Dursztyn Lst. Fm. and the red marls is visible at the foot of the Vršatec Castle Klippe, where signs of karstification of the Lower Cretaceous limestones can be observed. The marls are of Late Cenomanian to Campanian age.

Fig. 14. Corals in the Bajocian Vršatec Limestone at the entrance to the Vršatec Castle.

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 and Túnyi (2001) analysed neptunian dyke orientations in four sections in the Pieniny Klippen Belt. They include the Vršatec Castle Klippe, Babiná quarry, Mestečska skala and Bolešovská dolina. In majority, the neptunian dykes are cut into the Bajocian-Bathonian crinoidal limestones (Smolegowa and Krupianka limestone formations) 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 Vršatec locality. However, they represent rejuvenation of older dykes (Mišík, 1979b).

The neptunian dykes (but also crevices in the breccias and even cavities in the stromatactis mud-mounds – see the Babiná and Slavnické Podhorie localities) show presence of cave-dwelling ostracods *Pokornyopsis feifeli* (Triebel) (Fig. 15-16) which are ancestors of the recent genus *Danielopolina* (Fig. 17) which is a common cave dweller in the recent times (mostly in the so-called anchialine caves). This is an evidence that this originally deep-marine fauna started to inhabit submarine cave environment already in Jurassic (Aubrecht and 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.

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. 18). This direction points to the NW-SE oriented Jurassic extension in that area. The paleomagnetic inclination ranging between 21° and 46°, with mean point of about 33°, indicates that the Czorsztyn Ridge was located approximately at 10-30° paleolatitudes in the Middle Jurassic.

Valanginian-Aptian emersion, karstification and Albian drowning of the Czorsztyn Swell – the Vršatec 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

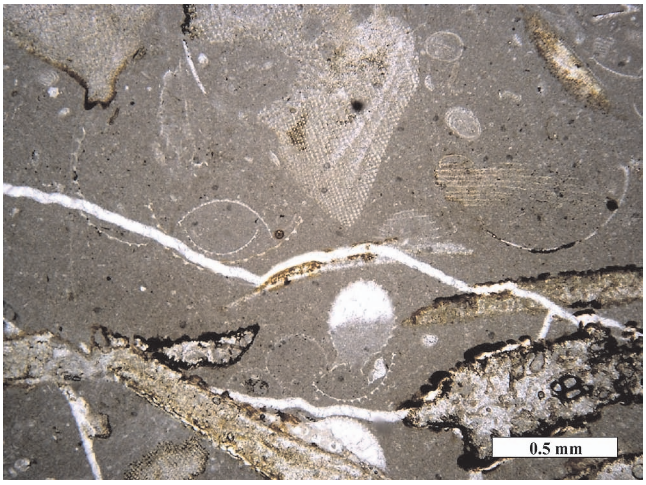

Fig. 15. Cross-sections of cave-dwelling ostracods *Pokornyopsis feifeli* (Triebel) in neptunian dyke filling from Vršatec.

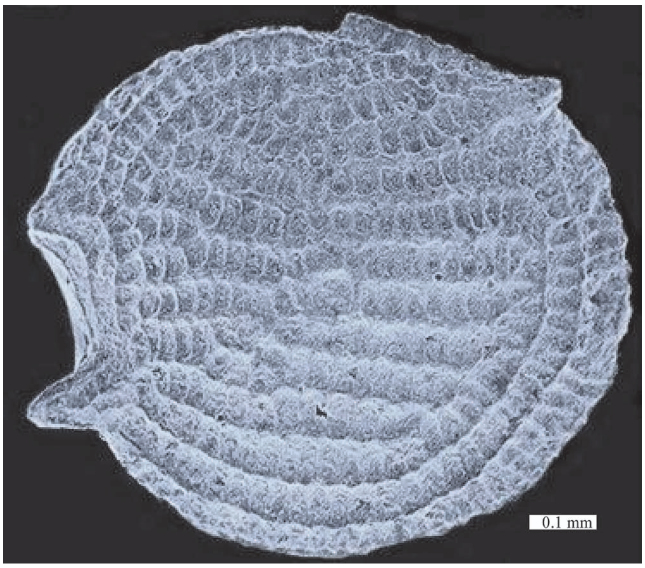

Fig. 16. Holotype of *Pokornyopsis feifeli* (Triebel) from Germany. After Kornicker & Sohn (1976).

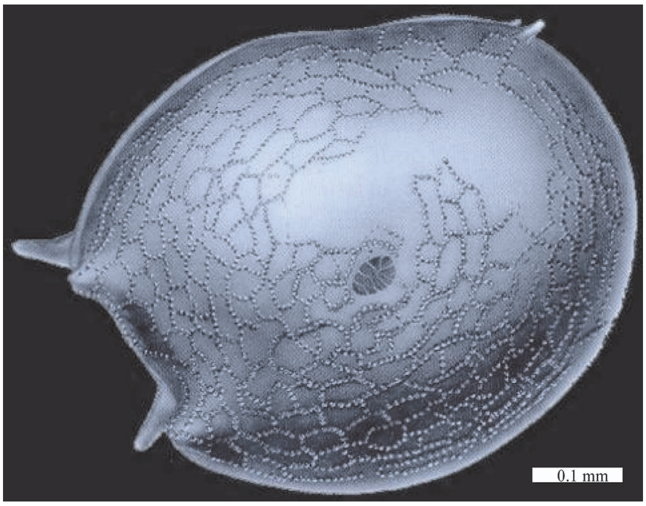

Fig. 17. One of the recent descendants of the Jurassic cave-dwelling ostracod fauna – *Danielopolina orghidani* (Danielopol). After Kornicker & Sohn (1976).

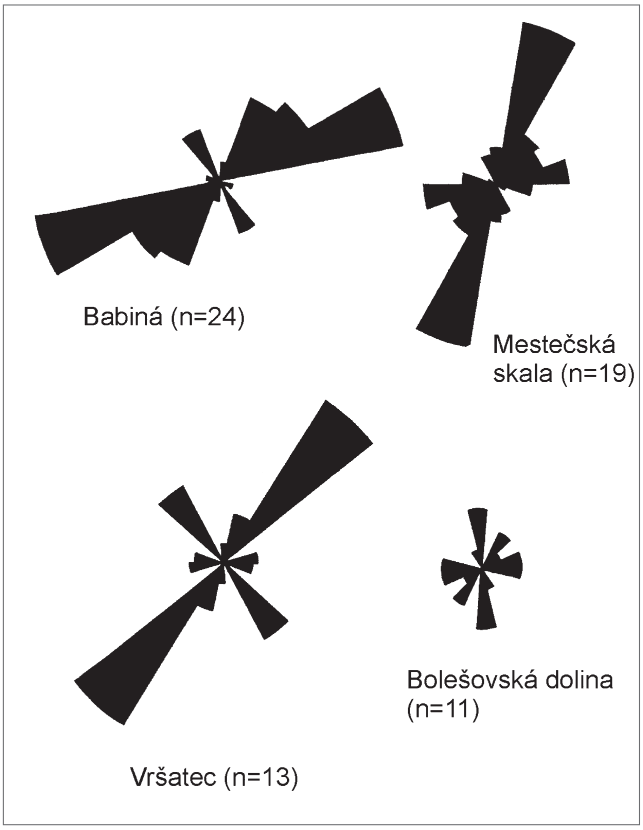

Fig. 18. Evaluation of original orientation (corrected according to paleomagnetic data) of neptunian dykes at four selected localities of the Czorsztyn Succession.

and erosion (Birkenmajer, 1958, 1975), whereas others proposed an emersion of the ridge (Mišík, 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 rocks older than Tithonian or Neocomian. In Jarabiná, 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 Horné Srnie, where the deepest erosion level was found, the Albian deposits overlie 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 later sediment, bizarre fractures and veinlets filled with calcite, were revealed, mainly in the Horné Sŕnie and Lednica sites. This was followed by pelagic deposition, documented by Albian marlstones and limestones with pelagic fauna. At 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 drawning-can not be excluded. Very similar case of Cretaceous paleokarst was reported from 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 Vršatec klippen. Most of them are summarized by Mišík (1979b); two localities were revealed not long ago. The basement below the Albian sediments is commonly irregular (Fig. 19), 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 Vršatec klippe (Sýkora *et al.* 1997) which testifies the rapid sea-level rise after drowning of the swell.

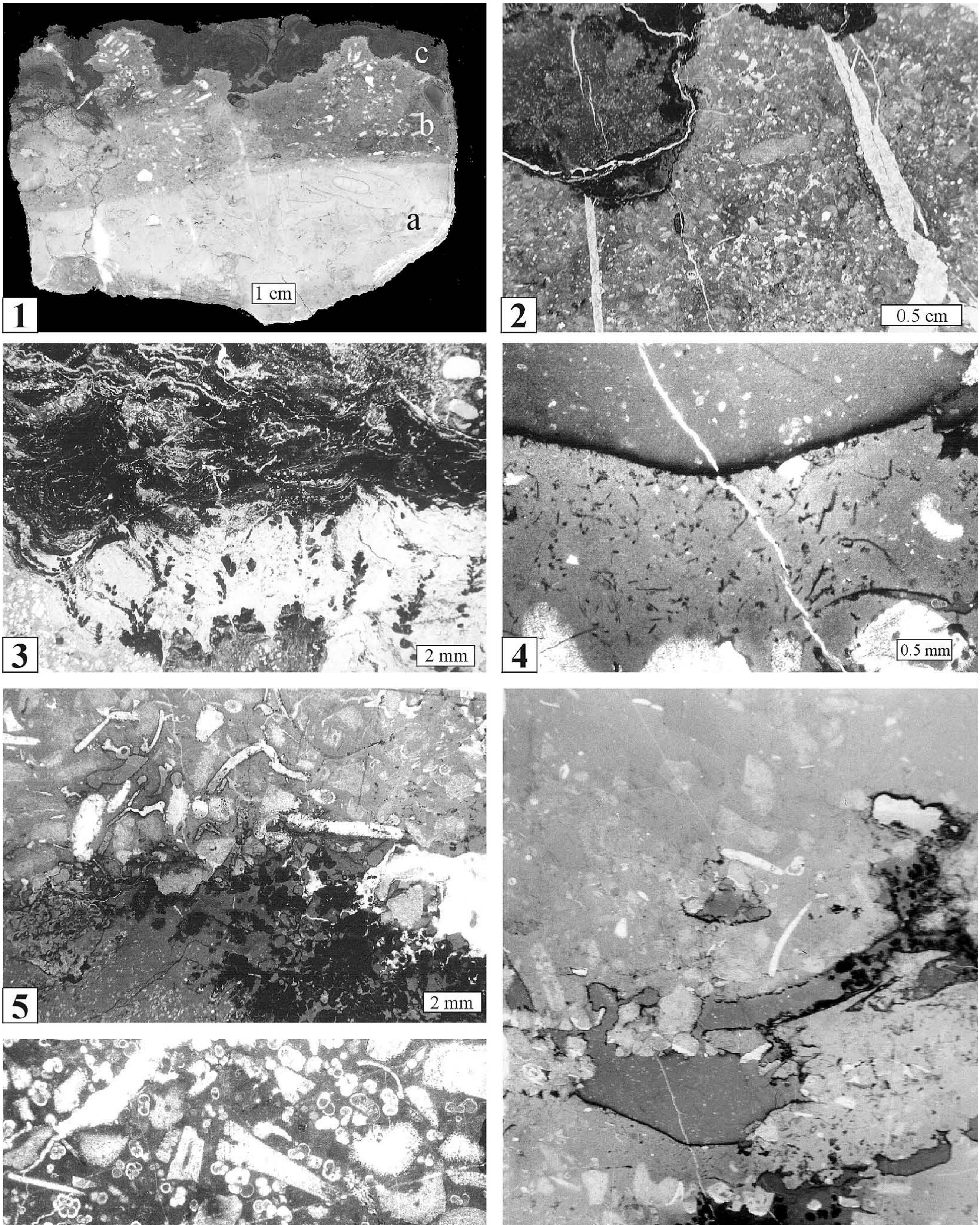

Fig. 19. Slabs and microphotos from the localities at Vršatec. **A** – Slab showing Neocomian limestone (a), covered by Late Albian organo-detrital limestone (b) and by P-Fe stromatolite (c) which is the base of pelagic Albian deposit. Note the uneven surface between the Upper

In the Albian sediments of 6 localities (2 from Vršatec), a detrital admixture containing chrome spinels was found (Jablonský *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 the classical paleogeographic schemes where the Czorsztyn Swell still in Albian formed an isolated ridge, surrounded by deep troughs.

B4.4 Babiná

(49°01′55″ N, 18°10′47″ E)

The locality is an abandoned quarry located at the foot of Babiná Hill, on the road between Bohunice and Krivoklát villages in the Middle Váh Valley in western Slovakia (Fig. 20). It was described in details by Mišík *et al.* (1994a). An overturned Czorsztyn sequence from the Middle Jurassic to the Neocomian crops out in the quarry (Fig. 21). White and pink Bajocian crinoidal limestones (Smolegowa and Krupianka formations) are exposed in the main SE part of the quarry. The crinoidal limestones are cut by numerous neptunian dykes filled with red mudstones of "filamentous" microfacies (Mišík et al., 1994a; Aubrecht and Túnyi, 2001). The rest of the quarry shows red to pink micritic limestones (mudstones) of the Bohunice Limestone Formation (Bathonian-Kimmeridgian) which gradually pass upwards into Tithonian-Lower Cretaceous limestones (Dursztyn Formation).

The detailed description of the individual lithological units is as follows:

1. White and pink crinoidal limestones (Bajocian) form the dominant (left) part of the quarry. The crinoidal limestones are biosparites with sandy admixture of clastic quartz grains and small yellowish dolomite lithoclasts. A thin intercalation of the fine-grained conglomerate with a pebble of maximum size 6 cm (spongolite) was found. The most numerous are pebbles of vein-quartz (white, pink, honey-yellow), silicates (spongolites or without organic remnants), dolomites (some of them with traces of boring bivalvians), dedolomites, single pyroclastic rock of acid volcanites – tuffite and greywacke with kaolinized feldspars. In the highest part, on the edge of the quarry, the following association of brachiopods was found: *Monsardithyris ventricosa* (Ziet.), *Cymatorhynchia* ex gr. *quadriplicata* (Ziet.), „*Terebratula*" aff. *decipiens* Eud.- Desl., *Linguithyris curviconcha* (Oppel), *Antiptychina* aff. *bivalvata* (Eud.- Desl.), *Caucasella trigona* (Quenst.) and *Sphenorhynchia latereplanata* Seifert (Mišík *et al.*, 1994a).

Within the crinoidal limestones, bodies of syndepositional breccias, which originated due the synsedimentary extensional tectonics occur locally (so-called Krasín Breccia). The breccia occurs mostly within the crinoidal limestones in the higher part of the quarry, where it occurs directly within the crinoidal limestone as probable larger cleft filling, as well as at the left part of the quarry, where it is related to networks of neptunian dykes. Both types contain various fillings of interstitial voids but more complex are fillings in the central part of the quarry (Fig. 22A). The breccia has angular to subangular clasts, more or less developed radiaxial fibrous calcite (RFC) crusts (mainly in the breccias from the central part of the quarry), stromatolites (pre- or postdating the RFC, mainly in the left part of the quarry)

Albian 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. **B** – Two veinlets filled with blocky calcite, cutting the Neocomian organodetritic 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. **C** – 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. **D** – 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. **E** – 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). **F** – 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. **G** – Crinoidal-foraminiferal wackestone to packstone of the Late Aptian-Early Albian age, representing sediment of the first phase of flooding after the hiatus.

Fig. 20. Panoramic view on the Babiná quarry.

and the latest, predominantly micritic filling (red in the left part of the quarry and yellowish in the central part) and blocky calcite filling the veinlets and occluding the remaining porosity. Some clasts and cement filling bear signs of leaching, which is indicated by irregular, bizarre surface (Fig. 22C-D). This indicates a likely fresh-water influx into the breccia complex.

Some breccia blocks were found with clasts of crinoidal limestones with simple matrix formed also by crinoidal limestone, free of any additional cement crusts. Moreover, most of such breccias possess the clasts of red crinoidal limestones, whereas the matrix is of white crinoidal limestone (Fig. 22B), i.e. just opposite to the division of Birkenmajer (1977) where the red crinoidal limestone (Krupianka Lst.) should be younger than the white crinoidal limestone (Smolegowa Lst.). This contradiction was mentioned already by Mišík *et al.* (1994a) and Aubrecht *et al.* (1997).

2. Neptunian dykes. Crinoidal limestones are densely penetrated by neptunian dykes with maximum width of 35 cm. Their directions are strongly scattered; the prevailing extension, after dip and paleomagnetic correction was NE-SW (Aubrecht and Túnyi, 2001 – see Fig.16). The filling is red, partly cream-coloured, often with irregular lamination, sometimes oblique or lenticular. Biomicrite (wackestones and packstones) laminae alternate with those of micrite and pelmicrite; frequent intraclasts were derived from the fracture walls. The remaining empty spaces were filled by radiaxial calcite cement. Among organic remnants “filaments” predominate (juvenile bivalves of the Bositra-type, rarely also with thicker shells strongly bored by algae; their tiny canals are impregnated by Fe-hydroxides); the

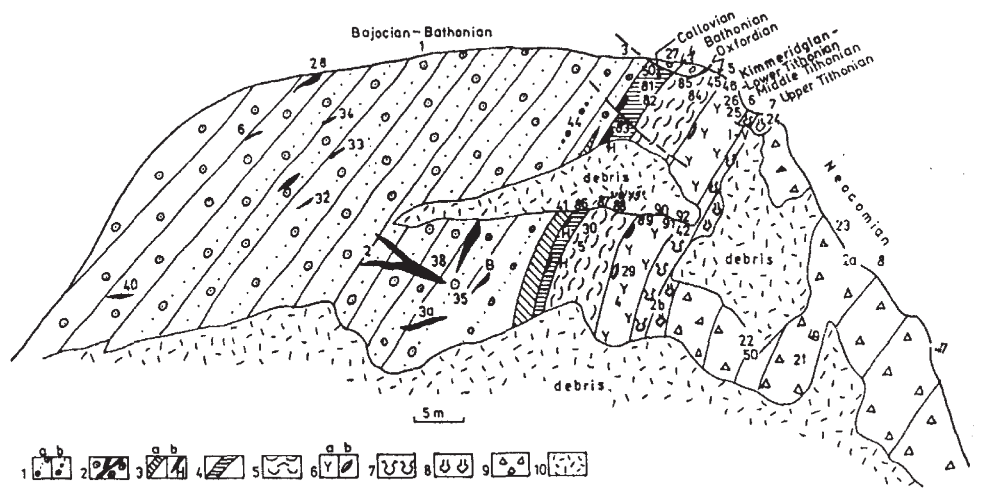

Fig. 21. Lithological sketch of the Babiná quarry. 1a – White and pink crinoidal limestones – Bajocian – Bathonian. 1b – Conglomerate intercalation. 2 – Neptunian dykes – Upper Bathonian – Lower Callovian. 3a – pink biomicrite with “filaments” and stromatactis – Callovian. 3b – Hardground. 4–7 – Bohunice Limestone Formation: 4 – red limestones with “protoglobigerina” – Callovian, 5 – creamy and pink biomicrites with bivalves and *Cadosina parvula* – Oxfordian, 6a – pink biomicrite with Saccocoma and higher with *Parastomiosphaera malmica*, 6b – brachiopods with polarity structures, 7 – pink biomicrite with black coated bivalves – Kimmeridgian – Lower Tithonian. 8–9 – Sobótka Limestone: 8 – white and creamy biomicrite with *Chitinoidella* – Middle Tithonian, 9 – pink biomicrite with black–coated bivalves and Crassicollaria. 10 – Walentowa Breccia – pink and grey limestone breccia with crinoidal matrix – Neocomian. After Mišík et al. (1994a).

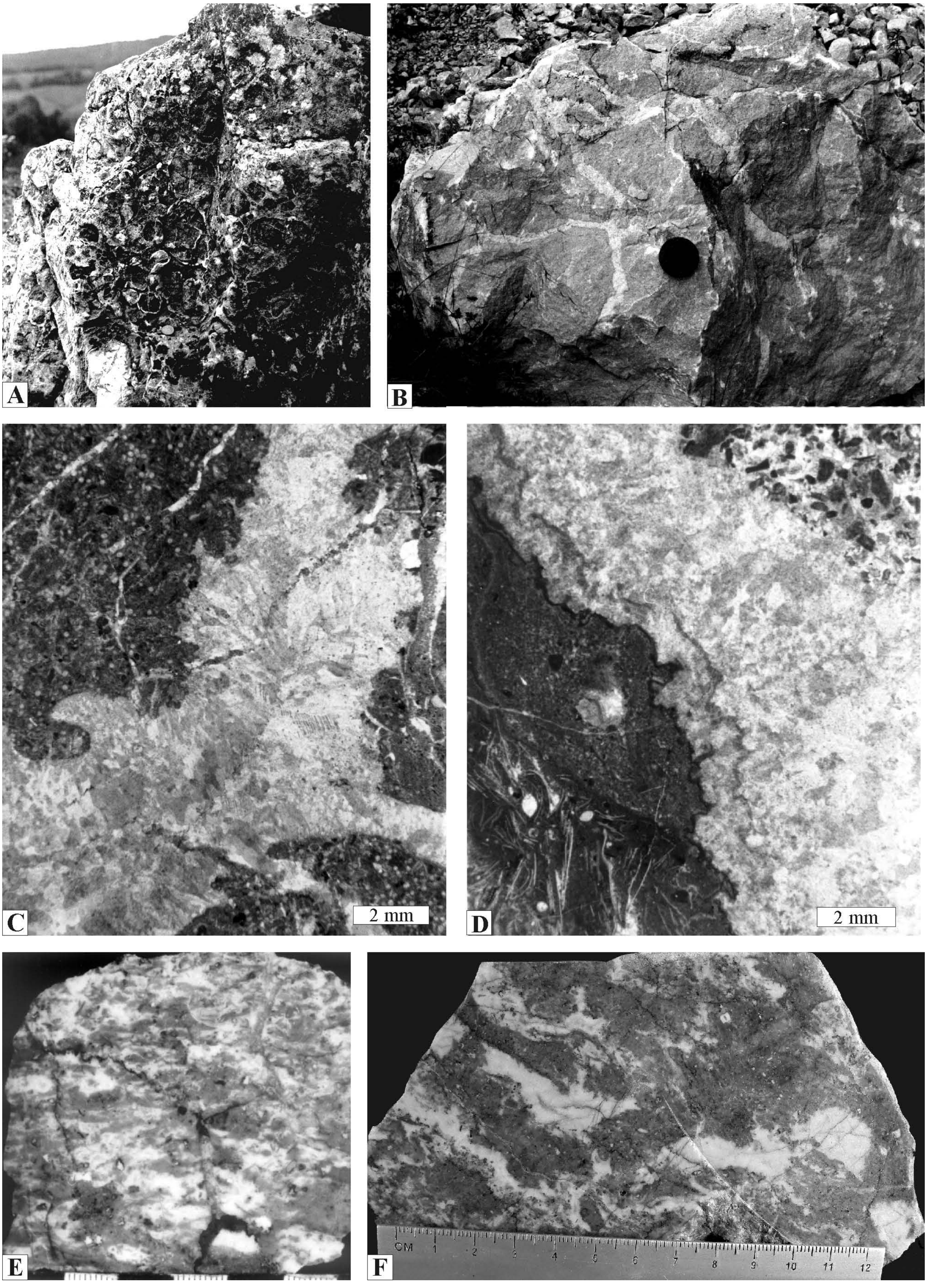

Fig. 22. A – Block of Krasín Breccia with radiaxial fibrous calcite coatings, representing a remnant after Babiná quarry exploitation. Block came most likely from the middle of the quarry. Scale: lens cap is 5.8 cm across. **B** – Block of breccia with clasts of red and matrix of white crinoidal limestone (inverse colouration of the limestones as in the classic scheme of Birkenmajer, 1977). Middle to left part of the quarry. Scale: lens cap is 5.8 cm across. **C** – Irregular surface of the crinoidal limestone clasts, formed probably by etching, healed by RFC. Breccia from the left part of the quarry. **D** – Irregular margin of the RFC crust, related most likely to partial leaching. **E** – Polished slab with anastomosing tiny stromatactis from the layer overlying the crinoidal limestones. **F** – Slab with larger, several cm–size stromatactis.

Fig. 23. View on the abandoned quarry near Slavnické Podhorie.

"umbrella effect" (sparite formed under the concave side protected against the micrite deposition) was frequently observed. Current constituents are echinoderm plates and foraminifers: *Ophthalmidium* cf. *carinatum* Leischner, *Ophthalmidium* sp., *Lenticulina* sp., *Marsonella* sp., *Nodosaria* sp., microforaminifera (Fe-Mn coatings of the juvenile foraminiferal chambers); rare ostracods, globochaete cells, uniserial bryozoans and fucoids are also present. Clastic quartz (to 0.25 mm) and fragments of hardgrounds are very rare. Tiny sterile microdikes penetrate transversally the described neptunian dykes.

There are no direct age indicators concerning the filling of the dykes. It is probably not much younger than the surrounding crinoidal limestones. With regard to the dominant „filament" microfacies and the fact that the dykes do not penetrate into the younger strata, we assume that they are of Upper Bathonian – Lower Callovian age. The „filament" microfacies filling is noteworthy, as such limestones are almost entirely absent in the overlying succession. The fracturation of the white crinoidal limestones and the filling of these fractures took place before the deposition of the next member – creamy and pinkish biomicrites with „protoglobigerina" microfacies.

3. Pink limestone with stromatactis structures (probably Bathonian-Callovian)**.** It is only 80 cm thick and occurs in the middle part of the quarry at the contact of the crinoidal limestones and the hardground. The structure can be characterized as dismicrite with small, atypical stromatactis – irregular anastomosed voids elongated along the plane of stratification (Fig. 22 E-F). The voids are usually limited by thin-shelled bivalves - „filaments" (shelter porosity).

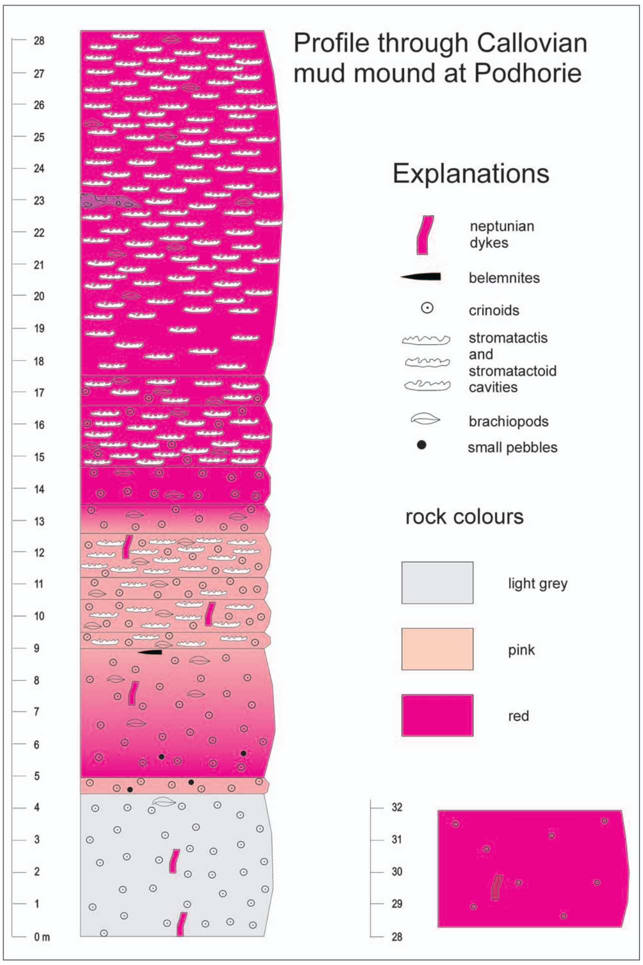

Fig. 24. Section through the core of stromatactis mud-mound at Slavnické Podhorie.

They are filled by radiaxial calcite cement with fluid inclusions and a younger clear blocky cement in their central parts. Sparitic areas are probably enlarged by recrystallization, as can be deduced from the radial aggregates of calcite around the relics of pellets. Besides small bivalves, unusually frequent microforaminifers (basal membranes impregnated by Fe-oxides), echinoderm plates, spicules of siliceous sponges filled by calcite, nubecularids, ophthalmids, single small gastropods and worm tubes occur. Quartz grains are very rare but their size is up to 3 mm. The stromatactis horizon passes in the upper part of the quarry into pink biomicrite with typical „filamentous" microfacies.

This bed is dominated by "filamentous" microfacies which indicates latest Bajocian to Callovian age (cf. Wierzbowski *et al.*, 1999). The same microfacies also represents the infillings of the neptunian dykes cutting the underlying crinoidal limestones. At the top of the mudstone bed a black manganese crust representing a non-deposition surface occurs.

4. Pink and red limestone layers impregnated by Mn-Fe oxides, with black hardground crust (2 cm) on their base – Oxfordian.

The limestone starts as biointramicrite with „protoglobigerina" microfacies. It contains frequent planktonic foraminifers *Globuligerina* sp., less numerous benthic forms, such as *Ophthalmidium* sp., *Marssonella* sp. *Spirillina* sp., *Lenticulina* sp., abundant voids after the radiolarians filled by drusy calcite or dark micrite (these radiolarian „ghosts" resemble round coprolites), originally aragonitic bivalves with red coatings (dissolved and filled by micrite, often with collapsed micritic rims), globochaete cells, ostracods, *Cadosina parvula* Nagy, single juvenile ammonite, rhyncholite, phosphatized fish scale, uniserial bryozoan and echinoid spine. Several intraclasts with the red coatings and traces of dissolution and the fragments of Fe-Mn hardgrounds are further signs of condensed sedimentation. The hardground crust contains 14.3% Mn (= 18.46% MnO), 15.34% Fe_2O_3, 1.92% SiO_2 and 0.54% TiO_2. The presence of *Cadosina parvula* signalized Oxfordian age.

5. Creamy and pink micritic limestones with bivalves – Oxfordian.

Their composition is similar to that of the previous member: abundant radiolarians (frequently only their phantoms reminding coprolites), variable amount of „protoglobigerina" (*Globuligerina* sp.), *Cadosina parvula* Nagy, single *Colomisphaera* sp. etc. Clastic quartz was absent, except one thin-section with a grain 3 mm in size; cubes of epigenetic pyrite occur. A slight nodularity was observed. The thickness is about 5 m.

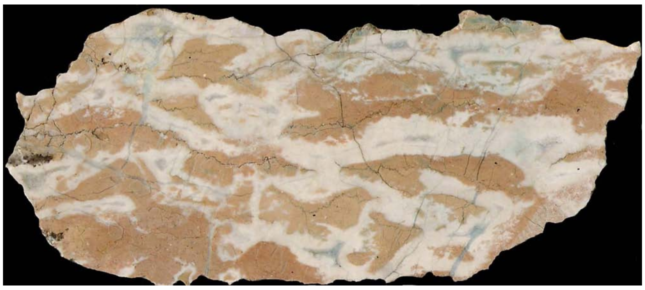

Fig. 25. Slab of the stromatactis-bearing mudstone.

6. Pink micritic limestones – Kimmeridgian – Lower Tithonian.

Generalized characteristic from 5 thin sections: biomicrite, mostly packstone with Saccocoma-Globochaete microfacies, further with numerous juvenile ammonites, foraminifers (genera *Marssonella*, *Involutina*, *Lenticulina*, *Nodophthalmidium* etc.), fragments of brachiopods and bivalves, rare echinoid spines, ostracods and aptychi.

The voids in the microfossils and macrofossils (mainly in brachiopods) contain internal sediment with polarity structures confirming inverted sedimentary succession. Clastic quartz (terrigenous admixture) is absent; rare cubes of epigenetic pyrite up to 0.4 mm occur. Brachiopods *Nucleata bouei* (Zejsz.) and *Lacunosella* aff. *spoliata* (Suess) from point 46 indicate Kimmeridgian. The thickness is about 4.5 m. In this part of the section, stromatactis-like cavities reappear.

7. Pink micritic limestone with small black-coated bivalves – Lower Tithonian.

They can be differentiated only by means of microscope, based on the presence of *Parastomiosphaera malmica* (Borza) and the absence of *Chitinoidella* (Borza, 1984). They are biomicrites with *Saccocoma* microfacies, abundant globochaete cells, bivalves (originally aragonitic ones with the mentioned black coating, red in the thin-sections), rare large crinoidal columnalia (also corroded and with red coatings), *Lenticulina* sp., *Frondicularia* sp., *Bullopora* sp., agglutinated foraminifers, several *Parastomiosphaera malmica* (Borza), *Cadosina parvula* Nagy, *Colomisphaera* sp., tiny filaments genetically connected probably with globochets, single juvenile ammonites, gastropods, calcified radiolarians, aptychi, ostracods, single fish tooth and serpulid worm *Durandella* sp. Rare voids with polarity structures occur. The thickness is 1 m.

The pink and red micritic, massive, not nodular limestones, which locally replace the classical nodular Ammonitico Rosso facies (Czorsztyn Limestone Formation) above the crinoidal limestones was named as the Bohunice Limestone Formation (Mišík et al., 1994a), with stratigraphic span from the latest Bajocian to the Lower Tithonian.

8. White and creamy micritic limestones – Middle Tithonian.

They belong to the *Chitinoidella* zone indicating the Middle Tithonian (Borza, 1984). The generalized description was carried out from nine thin-sections: biomicrites-packstones with *Globochaete-Saccocoma* microfacies containing *Chitinoidella boneti* Doben, voids after dissolved radiolarians filled by calcite, foraminifers (*Involutina* sp., *Marssonella* sp., *Lenticulina* sp.), juvenile ammonites,

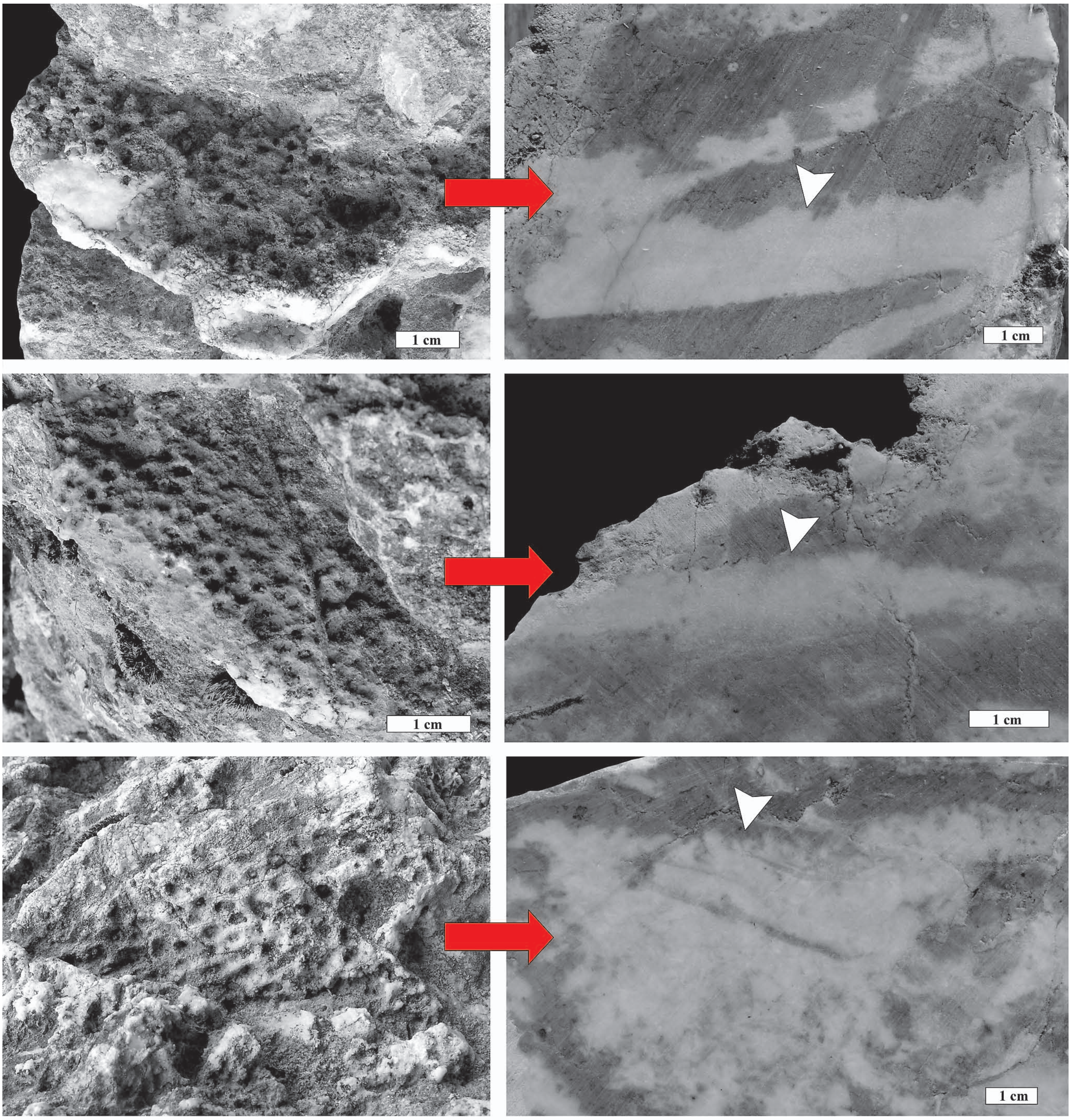

Fig. 26. Relationship between the weathered casts of siliceous sponges (left) and the corresponding cross-sections in slabs (right). The corresponding weathered surfaces are marked with arrows in the slabs. The cross-sections display actual stromatactis shape and composition (relatively flat bottoms and digitate upper parts, initial fillings of radiaxial fibrous calcite and eventual blocky calcite later filling).

tiny filaments with special sculpture, probably connected with globochets, ostracods, *Colomisphaera* sp., aptychi and basket-like sections, probably of a calcareous sponge. The total lack of clastic quartz should be stressed once more. A juvenile specimen of *Pygope* sp. proceeded from these limestones.

9. Pink micritic limestones containing bivalves with black coatings – Upper Tithonian.

They correspond to the Korowa Limestone Member of Birkenmajer (1977). They can be characterized as biomicrites-wackestones, frequently bioturbated with *Crassicollaria* microfacies, mostly with *Crassicollaria intermedia* Durand-Delga, single *Calpionella alpina* Lorenz and *Chitinoidella* sp., abundant globochaete cells and voids after radiolarians filled by calcite, fragments of bivalves, originally aragonitic, with red margins in transmitted light, rarely bordered with black Mn-dendrite; they were dissolved and filled by micritic sediment or by sparitic cement; their micritic rims sometimes collapsed. Single bivalves with prismatic layer in calcitic shell, several juvenile ammonites, ostracods, aptychi, brachiopod fragments, *Spirillina* sp., *Marssonella* sp., *Patellina* sp., *Involutina* sp. and *Cadosina fusca fusca* Wanner have been observed. Corroded and bored intraclasts with thin Fe-crusts occur, as well as voids with polarity structures.

The peculiar very fine-grained pyroclastic admixture (about 20 grains under 0.15 mm in a thin-section) of basic volcanic rocks containing tiny mostly calcified feldspars was identified. The total lack of clastic quartz points to a distant aerial transport from remote volcanic centers probably at the territory of actual Carpathian Ukraine. Another case was identified from the Kyjov-Pusté Pole klippe, Eastern Slovakia, concerning the same stratigraphical horizon and identical unit (Mišík, 1992). Basic volcanites (picrobasalts and basanites) of the same age occur also in the High-Tatric Unit but those submarine effusions hardly could introduce volcanic ash into the atmosphere.

10. Pink and grey fine-grained limestone breccias – Neocomian.

They correspond to the Walentowa Breccia of Birkenmajer (1977) with the exception that *Calpionellites* was not found in the matrix. The predominating size of clasts is 1-2 cm, up to 15 cm. The matrix with echinoderm plates is yellowish or red, the clasts are white, creamy and red. The microscopical description was derived from thin-section study of 13 samples.

Fig. 27. Krasín megabreccia consists of clasts formed by grey crinoidal limestone with matrix of red crinoidal limestone. Krasín Quarry.

The most abundant are lithobiosparrudites. Their matrix is dominated by echinoderm plates including typical brachialia of planctonic crinoids (*Roveacrinidae* ?) with syntaxial rims, frequently limited by the crystal faces. Echinoderm plates are often corroded by Fe-hydroxides along fissility surfaces. Aptychi with cellular structure and bivalves are rare, phosphatic fish teeth exceptional. Some *Hedbergella* sp. found in the matrix allow to suppose the Hauterivian age. The peculiar phosphate intraclasts and intraplasts containing arborescent calcite grains have been already found in the Neocomian limestones in the Krasín klippe (Mišík et al., 1994b). Their syngenetic origin is confirmed by the fact that the phosphate occurs also as the interstitial mass amidst the echinoderm plates in the matrix. The most frequent lithoclasts are biomicrites with the association *Saccocoma* + *Globochaete* + calcified radiolarians (fragments of Kimmeridgian - Lower Tithonian limestones), rarely with *Chitinoidella* (Middle Tithonian); the lithoclasts with *Crassicollaria* (Upper Tithonian) are rarer and smaller. The breccia lacks the quartz. It contains alike cubes and skeletal crystals of epigenetic pyrite as those mentioned in the preceding members, which confirms that the pyrite originated in the whole Callovian - Neocomian successions in the same time, in one of the post-Lower Cretaceous periods.

Sometimes an association of biomicritic lithoclasts with *Saccocoma*, surrounded by the matrix with the structure of ?*Saccocoma* (*Roveacrinidae*) biosparite, has been observed. It can be explained by the existence of the intraformational breccias already in the Kimmeridgian

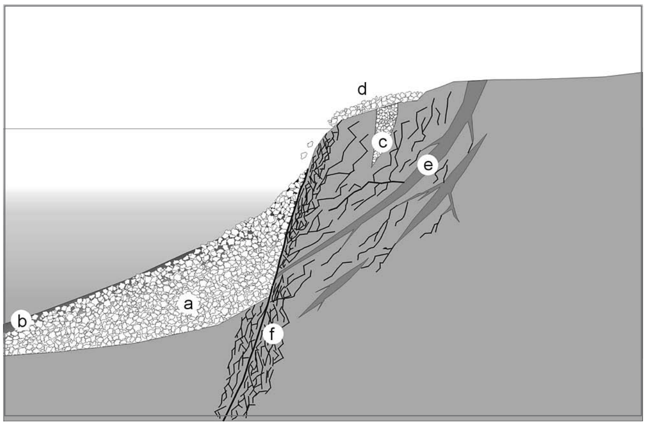

Fig. 28. Model of deposition and cementation of the Krasín Breccia. **a** – inner part of breccia talus in which cements and stromatolite coatings prevail over the internal sediment, **b** - outer part of the talus with predominant sedimentary filling of the interstices, **c** – breccia bodies originated 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).

– Lower Tithonian limestones. The different size of the brachialia in clasts and in the matrix might indicate that they belong to two different genera of planktonic crinoids or it was caused only by hydrodynamic sorting. The existence of big blocks of Kimmeridgian – Lower Tithonian in the Neocomian breccia cannot be excluded (e.g. the lowermost rockwall on the left flank of the quarry).

11. Fine-grained limestone breccia with yellow or red matrix and white micritic limestone lithoclasts – Coniacian.

The matrix of this lithosparrudite is formed by densely packed detritus of double-keeled globotruncanas with some hedbergellas, echinoderm plates with syntaxial rims, fragments of inoceramid bivalves (including isolated prisms) and rare phosphatic fish scales. Among foraminifers the following species were determined: *Falsomarginotruncana angusticarinata* (Gandolfi), *F. pseudolinneiana* (Pessagno), *F. coldreriensis* (Gandolfi), *F. desioi* (Gandolfi), *Marginotruncana schneegansi* (Sigal) and *Clavulinoides* sp. This fauna indicates Coniacian age; no younger forams have been found.

The lithoclasts belong mostly to the biomicrites with *Saccocoma* (Kimmeridgian – Lower Tithonian), rarely with *Crassicollaria* (Upper Tithonian). Neocomian lithoclasts contain small fragments of biomicrites with *Crassicollaria*, without tintinids in the matrix and with phosphatic intraclasts. A lithoclast of red biomicrite with Middle Cretaceous planktonic foraminifers has been found too.

The rock is macroscopically very similar to the Neocomian fine-grained limestone breccia. Such a rock type of Senonian age was unknown from the West Carpathians up till now. We have found it already in 1981 in the outbursted exploitation material in the quarry. The breccia should have filled a pocket within the transgression plane on the emerged Upper Jurassic and Neocomian limestones.

B4.5 Slavnické Podhorie

(49°01′ N, 18°09′31″)

The site lies in the middle part of the Váh River valley, at the village of Slavnické Podhorie, at the foothills of the Biele Karpaty Mts. It represents a tectonically overturned klippe exposed in an abandoned quarry (Fig. 23) revealing a stromatactis mud-mound core. A 32 m-long section was sampled (Fig. 24) 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. The following Bajocian-Bathonian brachiopod fauna have been collected from the crinoidal limestones by Pevný (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* Pevný, *“Sphenorhynchia” rubrisaxensis rectifrons* (Rothpletz), *Acantotharis* 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 the profile.

The mudstones that overlie the crinoidal deposits are dominated by a microfacies with *Bositra* sp. shells which extends 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 Oxfordian age.

Section description

The stratigraphical basis of the examined profile is formed by colour 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 – Fig. 25). 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. Sparite occurs in the parts where micrite was winnowed. It is 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 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 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 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 at the top of the profile (28-32 m), where stromatactis cavities are absent. Unlike in the lower levels, signs of bioturbation are ubiquitous. The same material fills the neptunian dikes found at 10, 12.5, 22.89 (dike with breccious filling) and 29.5 meter levels. In the topmost part of the profile, *Globuligerina* sp. sparcely appears.

The typical stromatactis cavities with flat bottom and undulated top are present in the examined site, but irregular ones are also present. 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.

Stromatactis was first described in the 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 calcareous mud, dynamic metamorphism, slumps and fresh-water karstification. The most recent ideas involve cavities remained after decomposed clathrates in calcareous mud or the cavities are interpreted as a result of sedimentation of stirred poly-disperse sediment. 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 Slavnické Podhorie, the sparry masses that fill stromatactis cavities are weathered out and show casts of sponges (Aubrecht *et al*., 2009b). A parallel study of the weathered casts and their cross-sections in slabs (Fig. 26) 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 the stromatactis cavities.

B4.6 Dolná Súča – Krasín

(48°57′47″ N, 18°01′24″ E)

Locality called Krasín Klippe is situated in an abandoned quarry W of the Dolná Súča 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 (except the Oxfordian bioherm limestone filling a cleft),
3. Lower Cretaceous sediments overlying the Middle Jurassic limestones in the large clefts.

The Krasín Breccia is an example of Jurassic syntectonic sedimentary breccia (Fig. 27), witness of extensional tectonic movements tied to Jurassic rifting (Mišík et al., 1994a; Aubrecht and Szulc, 2006). It is unique and differs from other similar facies, which are exclusively composed of clasts and matrix in its complex post-depositional filling and cementation history that infers a special depositional and post-depositional environment (Fig. 28).

Following members may be discerned there (Mišík et al. 1994b):

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 Krasín klippe. Stratigraphic age is Bajocian.

Krupianka Lst Fm.: Greyish fine-grained crinoidal limestones with brown chert nodules and red crinoidal limestones with loafy 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 vegetation. Supposed age is Bajocian.

Krasín 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. 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 recementation. Moreover the isotope composition of some early generations of stromatolites and early cements indicate possible fresh-water diagenesis.

?Vršatec 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, penetrating the Middle Jurassic limestones. Supposed age is Valanginian-(?)Hauterivian.

In one of the clefts, red marls with intercalations of the fine-grained limestones with *Hedbergella* were found. Their supposed age is Albian.

B4.7 Pustá Ves

(48°37′39″ N, 17°39′05″ E)

The oldest sediments of the Late Cretaceous sedimentary megacycle are represented by fresh-water oncolitic limestones (Pustá Ves Formation). They are known from two areas in the Central Western Carpathians: at the NE termination of the Malé Karpaty Mts. (Brezovské and Čachtické Karpaty Mts.) and in the Spiš-Gemer Ore Mts. (mainly the Stratená Mts.). They occur in the two largest areas with remnants of the Senonian marine sequences in the Central Western Carpathians. The distribution of these rocks is not congruent with the configuration of the succeeding Gosau basins.

Three outcrops are known in the Brezovské- and Čachtické Karpaty Mts. area. The first one, Hrdlákova Skala, W from Čachtice has been erroneously attributed to the Triassic by Hanáček (1954). Brown oncolitic limestones overlie the Anisian Gutenstein Limestone here. The second outcrop is known near the Černík gamekeeper's cottage N from Chtelnica, the third one is situated on the Mladé Háje Hill SE from Pustá Ves, N from Kačín (the two last mentioned localities were described by Mello in Salaj et al., 1987). Pebbles of these limestones were found in the Coniacian Valchov Conglomerate on the stratotype locality (Borza 1962) and in the Karpatian Jablonica Conglomerates (Mišík 1986). The limestones contain characeans, but no representatives of *Munieria*.

The typical rock of the Pustá Ves Formation is represented by brown biomicritic limestones with ostracods, gastropods, algae (*Munieria* and other characeans as well as until now undescribed new taxa of fresh-water algae). Cracks and desiccation pores occur frequently. Almost complete lack of terrigenous admixture indicates sedimentation in shallow lakes on a pediplained surface. Such conditions have arisen after Middle Cretaceous Austrian nappe transport and extensive erosion.

Fresh-water origin of the Pustá Ves Limestone was indicated also by isotopic analyses by Kantor and Mišík (1992) which yielded the following values: $\delta^{13}C$ = -9.49 ‰, $\delta^{18}O$ = -7.87 ‰.

B4.8 Brezová pod Bradlom – Valchovský mlyn

(48° 39′06″ N, 17°30′35″ E)

The escarpment by the road between Jablonica and Brezová pod Bradlom exposes the contact of the Coniacian Valchov Conglomerate with the underlying Upper Triassic Hauptdolomit of the Nedzov Nappe. Dolomite layers are of cyclic character with fine clastic base, indistinct bands of detritus with occasional pseudomorphs after evaporites in the middle part and terminate with loferitic algal-mat lamination.

The Valchov Conglomerate starts with unsorted dolomite breccia alternating with yellow clayey intercalations. The main part of the conglomerate body consists of well rounded clasts of local material with red matrix. The conglomerate represents the basal unit of the Brezová Group which is an equivalent to the Gosau Group of the Eastern Alps and represents the first post-tectonic cover of the Central Western Carpathians, after the nappe thrusting in the Turonian. The conglomerate deposition was preceded by local deposition of fresh-water oncoidal limestones (Pustá Ves Limestone) of presumably Late Turonian age. These limestones, together with the Triassic limestones and dolomites from the basement, form pebbles in the Valchov Conglomerate. Along with these rocks, clasts of the Liassic Adnet Limestone (with Pliensbachian fauna), crinoidal cherty limestones (Early/Middle Jurassic), shallow-water Malm limestones with dasycladal algae *Clypeina* sp., demosponges *Cladocoropsis* sp. and with foraminifers *Protopeneroplis striata*, sandy limestones with hedbergelids (Barremian to Albian) were found, too.

B4.9 Sološnica

(48°27′17″ N, 17°14′19″ E)

The locality Sološnica represents an abandoned quarry located on the left side of the Sološnica Valley, at the foot of the Veľká Vápenná Mt. Anisian dark grey Annaberg Limestone belonging to the Veterlin Nappe. Upper Paleocene/Lower Eocene thick-bedded sandy limestones were quarried here.

The Triassic limestones are covered by a breccia with red matrix, called the Kržľa Breccia (Fig.33). It forms irregular nest-like 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 ripplemarks on the bedding planes were observed on the top of the nearby Veľká Vápenná Mt. (Michalík, 1984). Seventy five percent of the clasts (0.02-0.6 m^3 in size) consist of the Annaberg Limestone; the rest are composed of the Raming Limestone, Reifling Limestone, and dolomites.

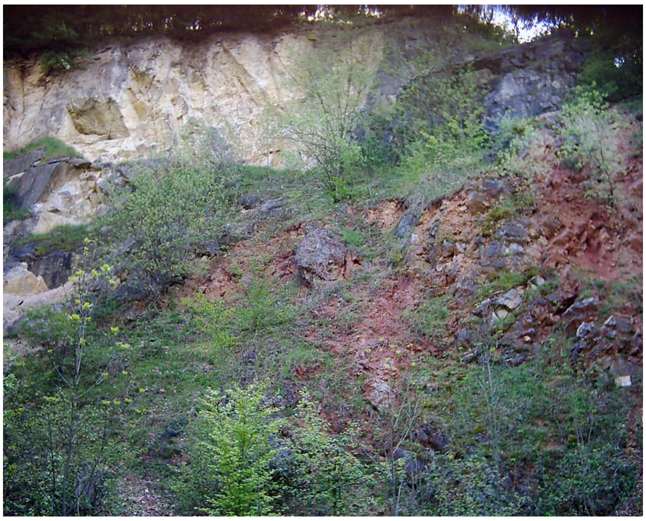

Fig. 29. Senonian-Paleocene Kržľa Breccia – paleokarst breccia with clasts of Annaberg Limestone and terra rossa matrix. Sološnica Quarry.

The matrix forms more important part of the rock (2-5 %) if compared with the Bartalová Breccia. In the Omlaď borehole, located about 800 m to SW, foraminifers and nannoplankton of Paleocene age have been found in the red breccias below the base of the Borové Formation.

The Kržľa Breccia is covered by the base of the Borové Formation (Fig. 29–30) 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. 30. Kržľa Breccia (red) is overlain by Borové Formation (yellowish), representing Upper Paleocene-Eocene *Discocyclina* limestone.

B4.10 Devín Castle

(48°10´27″N, 16°58´38″ E)

Devín Castle was built on a cliff at the confluence of the Danube and Morava rivers. From E to W, the Devín castle hill is built of phyllites of the Tatric crystalline complexes of the Malé Karpaty Mts., covered by Upper Permian terrestrial clastics and Lower Triassic quartzites. Then the succession continues with carbonates, e.g., Middle Triassic dolomites and Jurassic limestones and breccias. The western cliff wall (Fig. 31) is formed of Middle Liassic biodetritic (crinoids, belemnites, brachiopods) breccia limestones with angular clasts of the underlying dolomites and limestones (Fig. 32). The limestones intrude deeply into the Triassic basement in fissure fillings and neptunian dykes, pointing to extensive erosion and faulting before the Lower Jurassic transgression. The breccias originated due to Juras-

Fig. 31. The western cliff wall on which Devín Castle was built

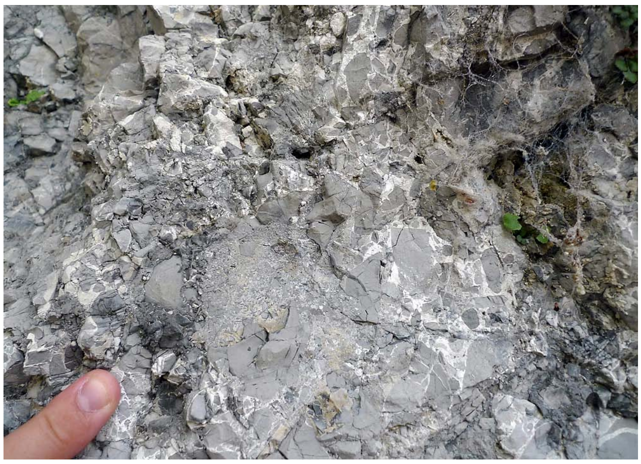

Fig. 32. Middle Jurassic breccia formed by clasts of older, Middle Triassic dolomitic limestones and dolomites. The breccia originated due to Penninic Rifting.

sic rifting related to the opening of the Penninic Ocean (Michalík & Vlčko, 2011).

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. 33), with subsequent filling of marine Upper Badenian sands. Locally, traces after bivalve borings are preserved.

B4.11 Devínska Nova Ves – Sandberg

(48°12′03″ N, 16° 58′26″ E)

The locality is situated on the W slope of the Devínska Kobyla Hill and it represents a facies stratotype of the Upper Badenian (Kosovian, Bulimina-Bolivina Zone) (Švagrovský in Papp et al. 1978). The Upper Badenian Sandberg Formation (Baráth et al. 1994, see Fig. 6) contains more than 300 species of fossil organisms. The sequence is characterized by clastic sediments lying transgressively and discordantly on Jurassic and Lower Cretaceous limestones which formed a cliff in the Late 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* Dub.

Another evidence of the marine transgression are sea caves formed by abrasion. Below Sandberg, there is a small abrasion cave (48°12′07″ N, E 16°58′16″ E) preserved from this time (Fig. 34). It occurs in the wall of a former quarry, about 20 m above the road connecting Devínska Nová Ves and Devín. It was formed in Tithonian marly limestones and shales. Mišík (1979a)

Fig. 34. Abrasion sea cave below the Sandberg Hill originated due to Upper Badenian transgression.

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 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 diamater up to 2–3 cm, after the bivalves *Lithodomus lithophagus* (Fig. 35).

Another abrasion sea cave is preserved in a nearby two-floor high abandoned quarry (Weit's Quarry: 48°11′40″ N, 16°58′50″ E), where it cuts into grey limestones, dolomites and carbonate breccias of Liassic age (Fig. 36). 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. 37) and gravels. Some larger openings (abrasion sea caves) are filled with Upper Badenian partly lithified sands and to a

Fig. 33. Miocene sinter in the Middle Jurassic breccias.

Fig. 35. Upper Jurassic platy limestones drilled by boring bivalves.

lesser extent by gravels. Remnants of fossil seals *Devinophoca claytoni* (originally described as *Pristophoca vetusta*) from the cavern filling 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 Malé Karpaty Mts., sinter-cemented breccias are rare in this quarry.

Fig. 36. Sediment-filled abrasion sea-cave in Weit's Quarry. The cave was formed in grey limestones, dolomites and carbonate breccias of Liassic age.

Fig. 37. Cross-bedding in the sandy filling of the sea cave in Weit's Quarry.

Fig. 38. Coralgal limestones are typical for the upper part of the former quarry.

The succession of open marine sediments on Sandberg Hill is the following: Polymict breccias and conglomerates with sandy calcareous cement, containing gravel lenses lie at the base of the open-marine sequence. Their clastic material is composed mainly of rocks from the near surroundings: granites, pegmatites, amphibolites, limestones, phyllites and quartzites (Mišík, 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 and lenses of massive calcareous sandstones with gravel intercalations. They contain abundant mollusc fauna, mostly bivalves *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*), 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 vertebrates, including fish, and of land vertebrates.

Above these beds lie light-coloured yellowish grey 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. The sandstones include numerous continuous clusters of coralline algae (Figs. 38–39), which form lenses of calcareous lithothamnium sandstones to sandy limestones. These are more widespread on the NE and S slopes of the Devínska 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 claystones 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 determination of the Upper Badenian – Kosovian sediments 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 oxic/anoxic boundary around the sediment/water column interface. Planktonic foraminifers form 20-100% of foraminiferal 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.

The 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 depths greater than 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 needles are frequent in the whole profile.

B4.12 Devínska Nova Ves – former Quarry of Stockerau Lime Factory

(48°12′13″ N, 17°00′11″ E)

The abandoned quarry (Fig. 40) which belonged to Stockerau Lime Factory is situated on the northern slope of Devínska Kobyla Hill, by the railroad from Bratislava to Devínska Nova Ves. The quarry was cut in 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 forms. In the Middle Miocene, between Upper Karpatian and Middle Badenian (17–15 Ma), this area was emerged (Mišík, 1979a). This is the only place in Slovakia with a preserved wall covered with paleokarst sinter older than 15 Ma (Mišík, 1980), forming stalactites and draperies (Fig. 41).

Fig. 39. Detail of the coralgal limestone (Leithakalk) from the upper part of the Sandberg quarry.

Fig. 40. Abandoned quarry of the former Stockerau lime factory.

The clefts acted as natural traps for smaller but also for bigger animals (mostly vertebrates). Accumulations of vertebrate 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. 42). 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

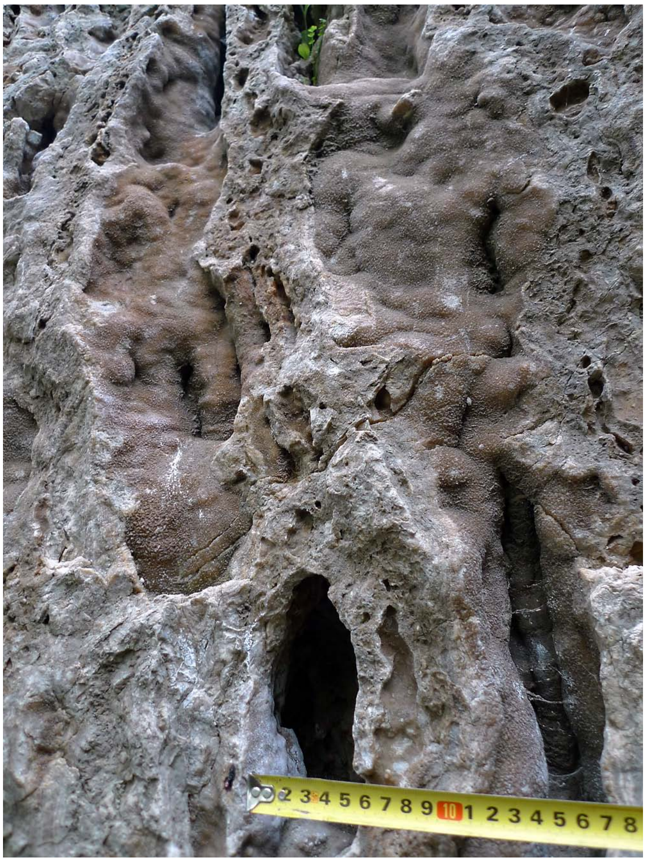

Fig. 41. Miocene (pre-Badenian) sinter preserved on the wall of an ancient cave.

Fig. 42. Sinter bored by bivalves during the Middle/Upper Badenian transgression.

the Austrian professor Helmuth Zapfe from Vienna University who described the mammal fauna trapped in the clefts. The clefts were discovered by mining during the 2nd World War when there was a labour camp in the quarry. The technical manager of the quarry was Ing. Bruno Zapfe, a brother of Helmuth Zapfe. During mining they discovered a ca. 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)

Another important locality named Bonanza was found in 1982 by an amateur paleontologist Štefan Mesároš. This 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. 43). Along with remnants of terrestric fauna, this cleft also contained marine fauna, e.g. shark teeth, fish and seal bones (Sabol, 2005a, b; Sabol and Kováč, 2006). 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).

Besides these localities, several smaller clefts with possible faunal occurrences are known. They are, however, poorly accessible and investigation of their fillings would be risky.

B4.13 Záhorská Bystrica

(48°13′41″ N, 17°03′09″ E)

A Miocene cliff-boulder mass near Bratislava in Southern Slovakia is exposed in a quarry situated on a hill 1.5 km SE of Záhorská Bystrica (Fig. 44). The locality was described in detail by Radwański (1968). The boulder mass is a product of Badenian transgression and represents a thick series of conglomerates which rest on

Fig. 43. Bonanza locality – the latest discovered paleokarst cleft with rich terrestric and marine Neogene fauna.

Fig. 44. Abandoned quarry at Záhorská Bystrica revealing transgressive, coarse-psephitic sediments overlying dark Triassic and Jurassic limestones.

an uneven surface of black limestone breccias, assigned to the Gutenstein Formation (Anisian) and breccias assigned to the Pleš Formation (Jurassic) of the Tatric Mesozoic cover unit of the Malé 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. 45).

The boulder mass can be examined at three successive exploitation levels of the quarry, where it may be clearly seen 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 exceeds 11 meters.

The cliff-boulder mass at Záhorská 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 3.4 x 2.5 x 1.1 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 also 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 10–15°, seems to be mostly of sedimentary origin, as if the deposits had been laid down on the hill slope.

A characteristic feature of the majority of the calcareous blocks are numerous borings of various lithophags (Fig. 54-49); most numerous are gigant 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 lithophagocenosis, 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

Fig. 45. Prior to the transgression, the limestone basement was fractured and the fractures were partially filled with sinters and then by marine sands.

Fig. 46. Various types of borings on boulders.

Fig. 47. Various types of borings on boulders.

sometimes intact. The problem of a specific assignation of these large specimens of *Lithophaga* sp. has not been elucidated so far; all known species, modern 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 with the valve rims. 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. Many borings run directly under the rock surface and are these are often 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 (Fig. 3 D) made by polychaetes *Polydora ciliata* (Johnston); usually their openings are also very much abraded.

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

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 Záhorská 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 Záhorská Bystrica, mostly the biggest blocks and boulders were invaded by lithophags. It is likely that only these larger rock elements rested motionless long enough at the sea bottom to become the habitat of the lithophags. Only

Fig. 48. Various types of borings on boulders.

Fig. 49. Various types of borings on boulders.

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 most part of the space between adjacent pebbles and boulders.

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