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JURASSIC TO LOWER CRETACEOUS DEPOSITS OF THE PIENINY KLIPPEN BELT AND MANÍN UNIT IN THE MIDDLE VÁH VALLEY (BIELE KARPATY AND STRÁŽOVSKÉ VRCHY MTS, WESTERN SLOVAKIA)

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STRUCTURE OF THE PÚCHOV SECTOR OF THE PIENINY KLIPPEN BELT

Dušan Plašienka

In the Western Slovakia, the Pieniny Klippen Belt (PKB) is morphostructurally divided into four sectors: Podbranč-Trenčín, Púchov, Varín and Orava, which differ in their inner structure and in presence of the individual units. The geological and tectonic division of the PKB is however more complex. Numerous units, developments, lithostratigraphic and tectonic units have been distinguished during long-term investigations (e.g. Birkenmajer 1977, Mišík *et al.* 1996).

The Púchov part of the PKB, between the Vlára river valley and town of Bytča in NW Slovakia, is a SW-NE trending, some 45 km long and up to 20 km wide zone of extremely intricate structure. It involves all types of units known in the PKB – the Oravic superunit, as well as the "non-Oravic" units of the Central Carpathian affiliation (Fig. 1).

The Oravic (or "Pienidic" in older literature) Superunit includes typical Klippen of the ridge-derived Czorsztyn Succession (including the largest klippe of this succession in the entire PKB – the Vršatec Klippen), basinal Kysuca and Pieniny Successions (the first one corresponding to the Branisko Succession in Poland) several types of "transitional" successions as the Pruské Succession (similar to the Niedzica Succession from the Polish part of the PKB – *cf.* Aubrecht & Ožvoldová 1994), the Czertezik Succession (Wierzbowski *et al.* 2004), the Orava Succession (Schlögl *et al.* 2000), the Nižná Succession (Józsa & Aubrecht

2008), the Mariková Succession, or the Streženice Succession (Began & Borza 1963). A special Fodorka Succession (Salaj 1987) was described from the Horné Sŕnie area – it is a succession deposited presumably north of the Czorsztyn Ridge, i.e. it would correspond to the Grajcarek Succession of the Magura Superunit in the Polish PKB part. Klippen of the Oravic Superunit occur along the northwestern margin of the PKB, forming a narrow (a few km) "Klippen Belt *sensu stricto*". The much broader southeastern part is mostly built by the "non-Oravic" units, with occasional tectonic windows of Oravic units and the Senonian-Palaeogene overstepping cover (Gosau Supergroup). This zone was designated as the "Periklippen Zone" by Maheľ (1980).

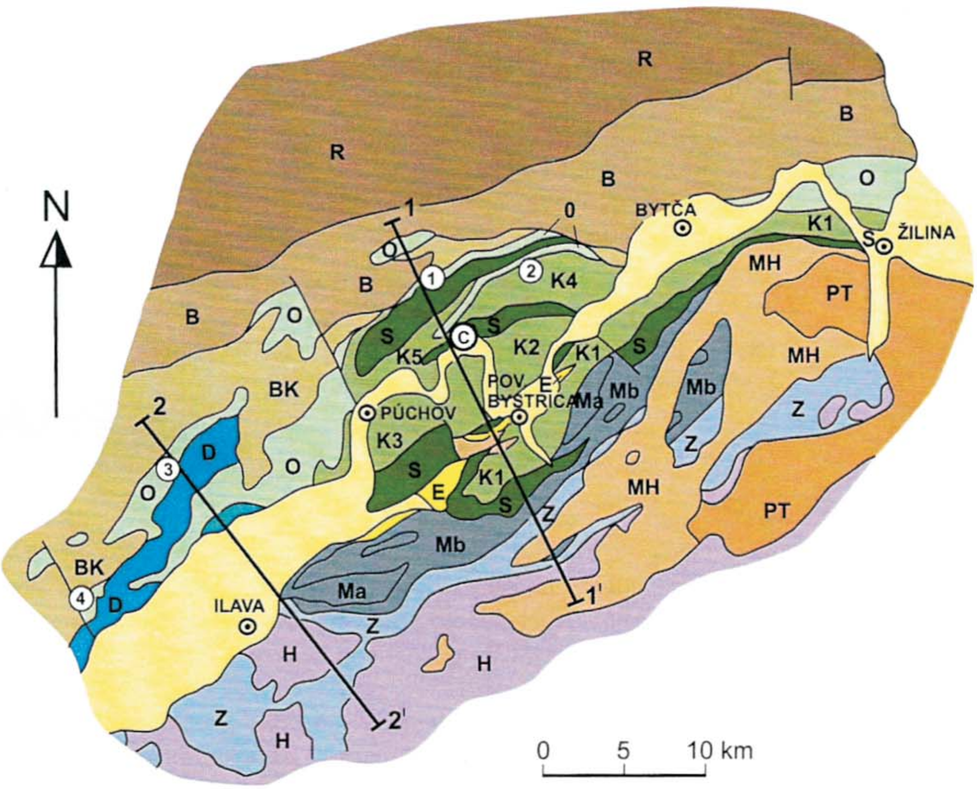


Fig. 1. Distribution of principal units in the Púchov sector of the Pieniny Klippen Belt and adjacent areas. Based on the map of Mello ed. (2005). For the key see figure 2. Numbers correspond to excursion localities (except Hatné locality, which is outside the map)

Three large units compose the "non-Oravic" Peri-klippen zone. The Drietoma Unit, embracing Upper Triassic-Cenomanian, dominantly basinal succession of likely Fatric (Krížna-Zliechov Succession) provenance, overrides the Oravic units. It forms synclinal tectonic outliers in the Vršatec area, but dominates towards the SW in the Trenčín sector of the PKB. The youngest member of the Drietoma Unit is the mid-Cretaceous (Albian-Cenomanian) synorogenic flysch with "exotic" conglomerates. This provides a link to the huge Klape Unit, which prevails in the Púchov Peri-klippen Zone. The Klape Unit is composed of some thousand metres thick mid-Cretaceous wildflysch complex (the Klape Flysch) with big olistolites of Triassic and Jurassic carbonates (e.g. the spectacular Klape Klippe). In the Považská Bystrica area (around the Nosice dam), the belt of the Klape Unit is up to 15 km wide, composed of four to five juxtaposed subunits divided by antiformal strips of the Kysuca Unit and/or synforms of overstepping Gosau sediments (Fig. 1). These Klape subunits are considered to represent strike-slip duplexes, accumulation of which caused exceptional broadening of the PKB in the Púchov sector.

The SE-most component of the Peri-klippen Belt is the Manín Unit, which is occurring on the left side of the Váh river, in the NW part of the Strážovské vrchy Mts (Fig. 1). Its Lower Jurassic-Cenomanian sequence (including the characteristic Urgon-type platform limestones) closely relates to the Vysoká-type ridge successions of the Fatric Superunit (e.g. the Belá Unit in the Strážovské vrchy Mts). However, many authors prefer the Tatric affiliation of the Manín Unit. The Manín Unit is dominated by mid-Cretaceous hemipelagic and flysch formations, older stiff limestones build several large "Klippen", which are in fact brachyanticlines (Butkov, Podhorie, Manín Narrows, Drieňovka). Senonian sediments within both the Klape and Manín Units were either considered to represent their integral continuous sequences (Salaj 1990), separated by a stratigraphic hiatus in places (Marschalko & Kysela 1980), or tectonic windows of the underlying Kysuca Unit (Podháj Succession, Rakús & Hók 2005). However, we favour the variant in which the Senonian sediments in the Klape and Manín Zone represent a post-nappe, Gosau-type cover (Fig. 2). The mid-Cretaceous flysch of the Manín Unit is from the SE overridden by the frontal Fatric elements with basinal Zliechov Succession (typical Krížna Nappe). Nevertheless, there occurs also a strip of another puzzling element – the Kostolec Unit. Presently, the blocky Kostolec Klippen of shallow-water Jurassic limestones, embedded in the mid-Cretaceous flysch, are regarded as olistolites of an unknown provenance (Rakús & Hók 2005).

In places along the NW margin of the Púchov sector of the PKB (Vršatec, Maríková), it can be documented that the Oravic units overthrust various Upper Cretaceous-Eocene flysch formations of the Magura and/or Biele Karpaty Superunits. However, this early thrust-related structure was strongly overprinted by the Tertiary transpression; consequently all units are forming a broad positive flower structure. Oravic units along the NW margin are mostly steeply SE dipping, while the Peri-klippen Belt is affected by large-scale upright folding (Fig. 2). Local axial plane cleavage is developed in the fold hinges. Macrofold axes strike parallel, or slightly oblique to the belt boundaries. They are seldom horizontal, but rather plunging in both directions, thus forming brachyclines (Fig. 1). Numerous post-folding faults – slickensides are generally steep to vertical, with gently plunging striae pointing to an oblique- or strike-slip, dominantly dextral movement. In the NE tip of the Púchov sector, near the town of Bytča, the PKB is rapidly narrowing, almost disappearing, due to dextral offset along the W-E trending dextral fault named the Bytča fault zone. The next Varín sector of the PKB is W-E trending and located within the southern limb of the structural flower, therefore it is strongly affected by backthrusting (Marko *et al.* 2005).

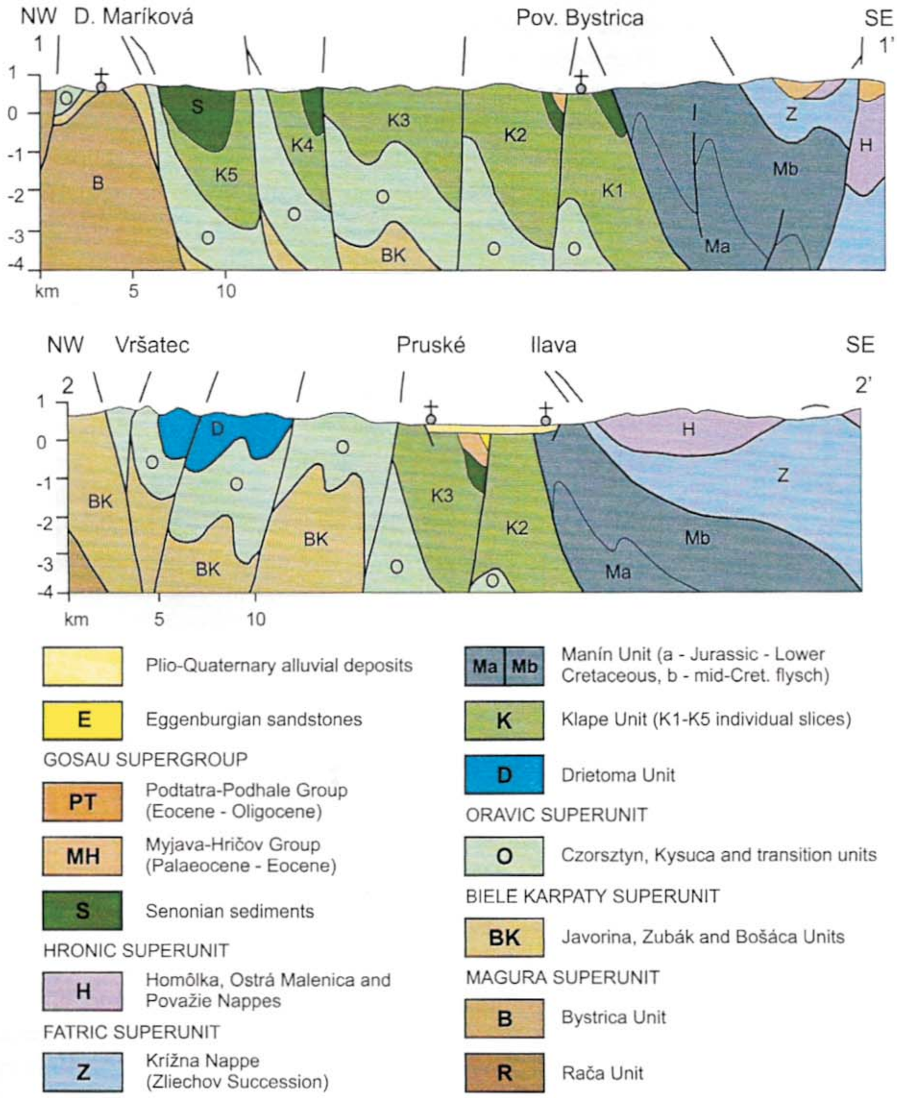


Fig. 2. Cross-sections through the Púchov sector of the Pieniny Klippen Belt. For the location see figure 1

Summing up, the Púchov sector of the PKB is the widest one (if considered together with the Peri-klippen Zone), embracing numerous units, both Oravic and "non-Oravic". The latter most probably represent the frontal elements of the Central Carpathian Fatric cover nappe system incorporated into the PKB structure. Exceptional breadth of the Púchov sector is caused by accumulation of several strike-slip duplexes of the Klape Unit. The structural relationships indicate first downward (NW-ward) propagated, piggy-back mode of thrusting during the Late Cretaceous-Early Tertiary, followed by large-scale upright folding passing into dextral wrenching during the Oligocene-Lower Miocene, which incorporates also the Eggenburgian (Burdigalian) sediments. The Middle-Late Miocene period is characterized by sinistral transtension along the Mur – Mürz – Leitha – Dobrá Voda – Považie – Žilina wrench corridor, and opening of the small Ilava Basin filled with Pliocene-Quaternary fluviatile sediments.

OUTLINE OF TECTONIC EVOLUTION OF THE PIENINY KLIPPEN BELT

Dušan Plašienka

Based on the existing data mostly from western Slovakia, the following principal evolutionary tectonic stages can be reconstructed in the units participating on the structure of the Pieniny Klippen Belt and adjacent zones (Plašienka 2003, 2008) (Fig. 3):

Triassic – carbonate platform in the Oravic domain.

Liassic to Aalenian – wide symmetric rifting, tectonic subsidence with mostly anoxic sedimentation in halfgrabens.

Bajocian – origin of the Czorsztyn Ridge due to thermal uplift above a lithospheric-scale north-dipping detachment fault accompanying the strongly asymmetric rifting phase.

Bathonian – continental breakup on the inner side of the Czorsztyn Ridge, opening of the South Penninic-Vahic oceanic tract with the Kysuca-Pieniny Basin being located on its northern (in present coordinates) flanks.

Callovian to **Tithonian** – overall thermal subsidence in entire Oravic domain.

Berriasian to **Valanginian** – renewed asymmetric rifting, repeated thermal uplift of the Czorsztyn Ridge, south-dipping detachment fault on the northern side of the Czorsztyn Ridge.

Hauterivian to **Barremian** – breakup of the North Penninic-Magura Ocean north of the Czorsztyn Ridge.

Late Early Cretaceous to **Late Cretaceous** – thermal subsidence, the Czorsztyn Ridge became a pelagic swell.

Late Turonian – nappe emplacement of frontal diverticulates of the Fatric (Krížna) nappe system of the Central Western Carpathians (CWC) (Drietoma, Klape, Manín units) onto the southern flanks of the Vahic oceanic crust.

Coniacian to **Santonian** – commencement of subduction of the Vahic oceanic lithosphere below the Central Western Carpathians, the Krížna elements deformed in a position of a "false" accretionary complex, resedimentation of a part of Albian exotic conglome-rate material from the Klape Unit into flysch deposits of the Oravic Kysuca-Pieniny Unit.

Campanian to **Maastrichtian** – gradual closing of the Vahic Ocean, partial positive inversion of the Magura Basin.

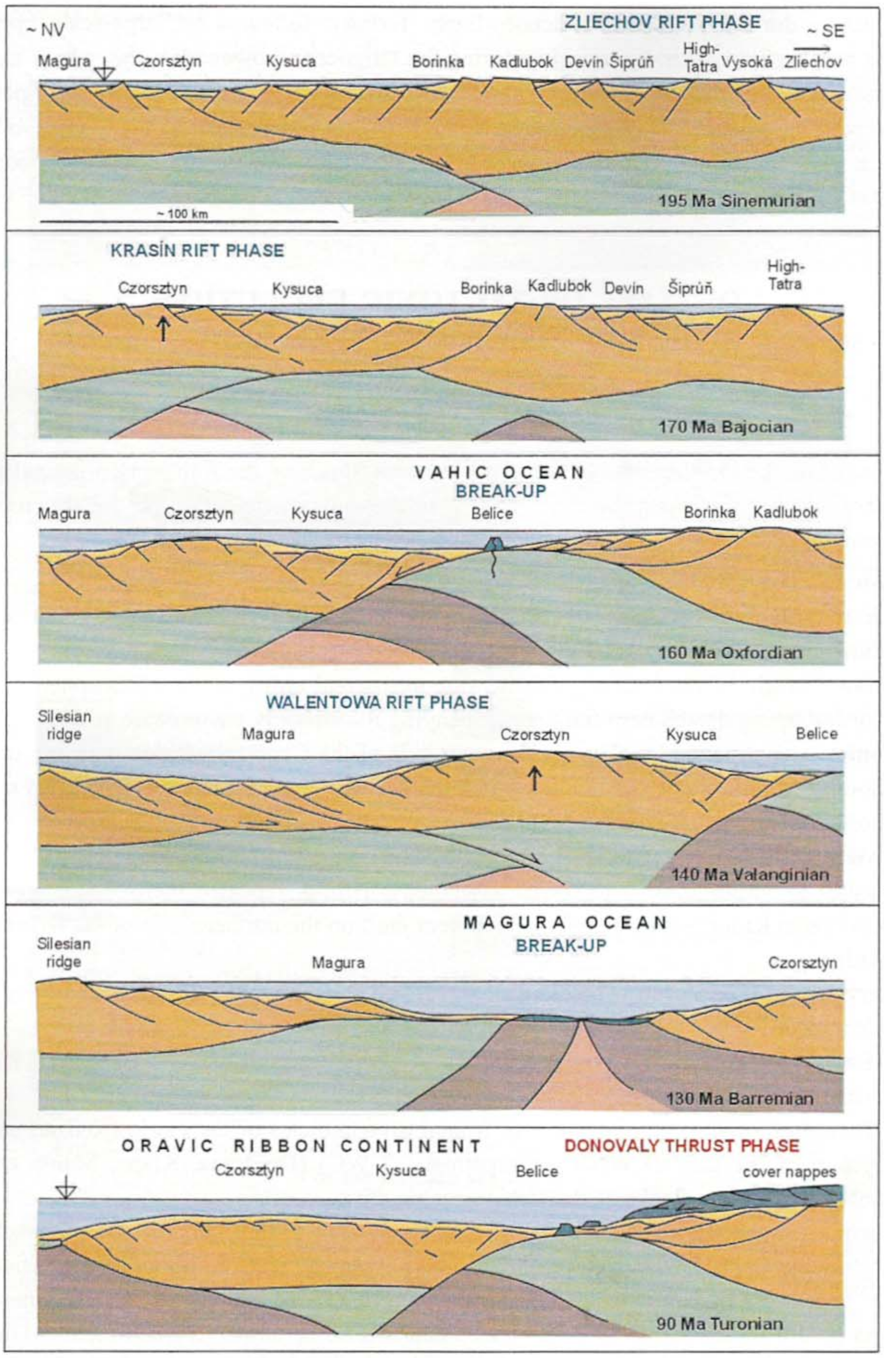


Fig. 3. Reconstruction of the Jurassic-Cretaceous rift phases that formed the Oravic Czorsztyn Ridge (Plašienka 2003)

Maastrichtian to **Palaeocene** – final closure (still incomplete) of the Vahic Basin with numerous narrow remnant and piggy-back flysch basins, collision of the accretionary complex with the Czorsztyn Ridge, detachment and thrusting of inner Oravic units along horizons of Liassic black shales and formation of an incipient foreland fold-and-thrust belt of detached and piggy-back units and synorogenic Gosau sediments.

Eocene – beginning of subduction of the Magura Ocean, detachment of the Czorsztyn unit from its basement that was underthrust beneath the CWC, its duplexing, recumbent folding and thrusting on the southern Magura elements.

Middle Eocene to **Oligocene** – extension and subsidence on the inner side of the PKB, formation of the Central Carpathian (Podhale) Palaeogene Basin in the fore-arc position.

Early Miocene – closure of the Magura Ocean, dextral transpression and oroclinal bending in the Pieniny Klippen Belt due to counterclockwise rotation of the Central Western Carpathian block, development of a positive flower structure – the flower is usually centred by a narrow, generally vertical zone of the PKB s.s., in which strike-slipping prevailed that has lead to the formation of the typical "klippen" (block-in-matrix) tectonic style caused by pervasive brittle faulting.

Middle to **Late Miocene** – sinistral transtension along the western, SW-NE trending sector of the Pieniny Klippen Belt; the NW-SE trending eastern Slovakian sector underwent only dextral wrenching – first transpression during the Early-Middle Miocene, then transtension pursued by general extension during the Late Miocene and Pliocene (opening of the Transcarpathian Basin); the eastern PKB is followed by the so-called Pieniny andesite line (PAL) that extents from the Polish Pieniny Mts (Mt Wżar) to the eastern Slovakian – Ukrainian chain of Sarmatian-Pannonian subduction-related stratovolcanoes.

LITHOSTRATIGRAPHY OF PIENINY KLIPPEN BELT UNITS AND PERI-KLIPPEN UNITS

Ján Schlögl & Roman Aubrecht

Lithostratigraphy of the Oravic Units (Figs 4, 5)

The sedimentary history of Pieniny Klippen Basin (Fig. 4) can be divided in three stages, with (1)?Hettangian-Aalenian mostly oxygen-depleted dark terrigenous deposits within an undifferentiated epicontinental sedimentary basin, (2) Bajocian to Lower Cretaceous crinoidal, reefal, *Ammonitico Rosso*, siliceous (cherty limestones and radiolarites) and *Biancone* or *Maiolica*-like deposits sedimented in the platform-through system, and (3) synorogenic Late Cretaceous marly and flysch deposits.

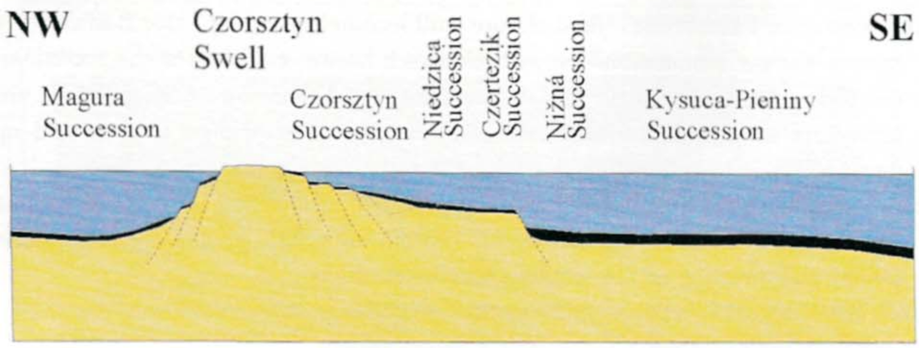


Fig. 4. Simplified NW-SE oriented bathymethric transect through the Pieniny Klippen Belt (from Tomašových 2006)

Czorsztyn Unit (Fig. 5)

The Czorsztyn Unit represents sedimentary succession, with Lower Jurassic – Aalenian part sedimented in the relatively shallow epicontinental conditions, and Bajocian-Lower Cretaceous deposited in the shallow parts of the former pelagic carbonate platform (PCP) called Czorsztyn Swell. Late Cretaceous is represented by marly and flysch deposits. The Middle-Upper Jurassic sedimentary history was accompanied by numerous synsedimentary tectonic features; such as neptunian dykes and scarp-breccias.

The only possible Triassic deposits of the Czorsztyn Unit are dolomites preserved in the small klippe Michalova Hora near Dolná Maríková, but their attribution to this unit is disputable, mainly due to different Upper Jurassic development of the here-preserved succession. Similarly, the stratigraphical and palaeogeographical position of the quartzites occurring near the Mariková klippen remains unclear, although their assignement to the Upper Triassic Keuper facies seem to be most probable.

Lower Jurassic deposits are preserved at a few localities only, mainly in the Slovak and Ukrainian parts of the Pieniny Klippen Belt. Upper Sinemurian *Fleckenmergel-Fleckenkalk* deposits with *Echioceras raricostatum* were documented behind the Vršatec Klippen. Lower Sinemurian dark organodetritic limestones and Upper Sinemurian/Pliensbachian *Fleckenmergel-Fleckenkalk* facies were described from Dolný Mlyn near Stará Turá (W Slovakia), Beňatina (E Slovakia) and Priborzhavskoje and Velyky Kamenets (Ukraine) (Hlôška 1992, Schlögl *et al.* 2004).

Middle and Upper Jurassic deposits display some important sedimentary turnovers (Fig. 5). Uppermost Liassic to Lower Bajocian grey spotted marly limestones, marlstones and black shales (Krempachy Marl Formation. and Skrzypny Shale Formation) were "suddenly" replaced by white and red crinoidal limestones during the late Lower and Upper Bajocian (Smolegowa and Krupianka Limestone formations), which probably mirrors both the sea level drop and the local extensional tectonics, associated with the tilting of the crustal blocks. The crinoidal limestones contain more or less rich clastic admixture, derived from the still emerged parts of the Czorsztyn Swell.

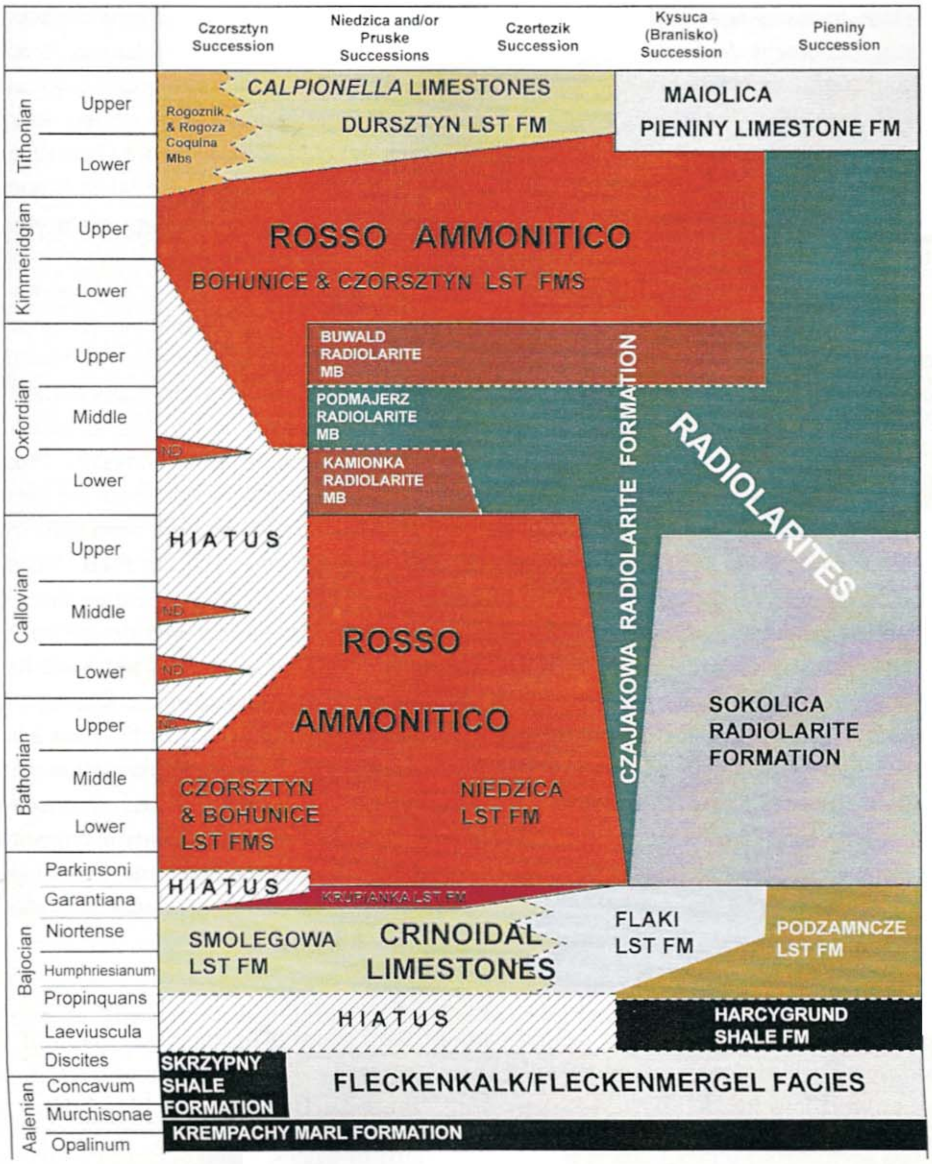


Fig. 5. Stratigraphic correlation scheme between Middle-Upper Jurassic lithostratigraphic units of Oravic Successions (from Wierzbowski *et al.* 2004, modified)

In addition to quartz grains, mainly dolomite clasts prevail, indicating that the Triassic rocks were present in the source area. The extension and the platform breakdown were accompanied by the deposition of the syntectonic scarp-breccias on the toes of the rising blocks.

This facies is restricted to the West Slovak part of the PKB only, called the Krasin Breccia (Aubrecht & Szulc 2006), and pro-bably also Vršatec peribiohermal breccia (Schlögl *et al.* – under study). The latter represents a facies derived from the coral-calcareous sponges biohermal limestones (Vršatec Limestones). Stratigraphical age of this unique facies was recently estimated as Lower Bajocian (Schlögl *et al.* 2006) and not Oxfordian as it was thought before (Mišík 1979). Later sedimentary turnover during the latest Bajocian and Bathonian was probably related to a global sea-level rise and/or breakup unconformity at the beginning of thermal subsidence period (Plašienka 2003 – *cf.* Fig. 3). Biodetritic platform deposition was replaced by pelagic deposition of *Ammonitico Rosso* or red non-nodular micritic limestones (Czorsztyn Limestone Formation, Bohunice Formation). Their sedimentation, althought interrupted by the Late Bathonian to the Early Oxfordian sedimentary break, continued until the Early Tithonian. This long-lasting hiatus was probably controlled by both, eustasy and rapid palaeogeographic rearrangement of the host basins, as indicated by recently acquired palaeomagnetic data from various sections from Slovakia, Poland and Ukraine (Lewandowski *et al.* 2005, 2006). The contemporaneous deposits are almost completely missing, and can be traced only by detailed observations of neptunian dyke infillings, extensively developed especially in the Púchov segment of the PKB (Vršatec, Štepnická skala, Vieska-Bezdedov). Evolution to the overlying Dursztyn Limestone Formation is gradual; the formation shows a large facies variability from micritic and sparitic coquinas (Rogoża Coquina and Rogoźnik Coquina) to micritic, more or less bioclastic limestones (Korowa Limestone Member and Sobótka Limestone Member of the Dursztyn Limestone Formation) of the Tithonian age. They were followed by bioclastic Łysa Limestone Formation of the Berriasian age and by crinoidal Spisz Limestone Formation of the Valanginian age. The carbonate sedimentation was interrupted by the period of emersion, with sedimentary break covering the Barremian-Aptian. At least local subaerial exposition was documented by paleo-karst surfaces (Aubrecht *et al.* 2006). Albian and Cenomanian red marly limestones and marlstones and cherts (Chmielowa and Pomiedznik formations) overlie directly the paleokarst surface.

Kysuca-Pieniny Unit (Fig. 5)

The deposits of the deepest central parts of the Pieniny Klippen Basin south of the Czorsztyn Swell are represented by the Lower Jurassic to Upper Cretaceous pelagic and flysch formations of the Kysuca-Pieniny Unit (Branisko Unit was distinguished as an equivalent of the Kysuca Unit in Poland – Birkenmajer, 1977).

Althought the Lower Jurassic part of the succession was documented at numerous sections, their assignement to this unit is not always clear, due to prevalent disconnection of the Lower Jurassic strata from the Middle Jurassic strata. Continuous sections are very rare. Another reason is that some klippen belonging to different klippen units, such as Orava or Drietoma units were formerly erroneously included into the Kysuca-Pieniny Unit.

Lower Jurassic age of the Zázriva Beds was recently rejected, due to the new biostratigraphic data suggesting their Aalenian age (Aubrecht *et al.* 2004). Therefore, the oldest known Lower Jurassic deposits are sandstones, arkoses and quartzites of the Sinemurian age (*Gresten* facies – Orava, Ukraine), overlain by *Fleckenmergel-Fleckenkalk* deposits of the Pliensbachian to Early Bajocian age (Krempachy Marl Formation, Skrzypny and Harcygrund Shale formations). The time of deposition of dark shales with abundant thin-shelled bivalves *Bositra* (Harcygrund Shale Formation, former *Posidonia* Beds) in the Kysuca-Pieniny Basin is represented in the Czorsztyn Unit by hiatus, separating the oxygen-depleted dark deposits and biodetritic platform deposits. While the Sinemurian-Lower Bajocian sedimentation indicates the still undifferentiated depositional basin, the next sedimentary history already points to the dissection of the Pieniny Klippen Basin into elevations (Czorsztyn Swell) and troughs (Kysuca-Pieniny Basin). Deposition of the late Early and late Late Bajocian deep-water cherty limestones and spongiolites (Podzamcze Limestone Formation) are laterally replaced by cherty crinoidal limestones. In the Kysuca-Pieniny Basin these crinoidal limestones are represented by distal turbidites only (Flaki Limestone Formation). Siliceous deposition related to rise of the CCD level in the whole Tethys is represented by black, red and green radiolarites stratigraphically ranging from the Callovian to the Kimmeridgian or Lower Tithonian (Sokolica Radiolarite Formation and Czajakowa Radiolarite Formation). Similar deep-water deposits are widespread in the basinal successions of the whole Western Carpathians. During the Kimmeridgian, the sedimentation of radiolarites still continued in the Pieniny Unit, but it was replaced by red nodular limestone in the Kysuca Unit (Czorsztyn Limestone Formation). Next depositional stage is uniformly represented by grey micritic limestones of *Biancone* or *Maiolica* type, locally with cherts, with the stratigraphic range from the Tithonian to the Barremian (Pieniny Limestone Formation). This *Calpionella* or calcareous nannoplankton-bearing facies is overlain by Barremian to Aptian dark shales (Koňhora Beds). Albian to Lower Cenomanian of the Kysuca Unit is represented by bluish to greenish marls with limestone beds (Tisalo Formation), followed by red marls and marlstones of the Middle and Upper Cenomanian age (Lalinok Formation); the end of marly sedimentation is represented by red marls with thin sandstone intercalations of the Lower and Middle Turonian age (Kysuca Formation). Start of the turbiditic deposition in the Turonian (Snežnica Beds) marks the change of the sedimentation. These sandstone turbidites are followed by psamitic to psefitic deposits of the Coniacian and Santonian age (Sromowce Beds), which are analogous to the Upohlav conglomerates of the Klape Unit, suggesting the tectonic approximation of these units. The upper limit of the overlying red marls (Campanian) represents a sedimentation break, caused by orogenic phase related to collision of the Inner and Central Carpathians and the Oravic Block. The southernmost Kysuca-Pieniny Unit was the first one affected by this orogeny. Sandstones, breccias (Jarmuta Beds) and limestones with *Orbitolina* are deposited on the folded pre-Maastrichtian strata.

Transitional Units (Figs 4, 5)

The Czorsztyn and Kysuca-Pieniny units are the successions deposited in the bathymetrically contrasting environments of the Pieniny Klippen Basin with numerous transitional units developed between them. These can be arranged basinwards as following: Niedzica Unit and/or Pruské Unit, Czertezik Unit, Streženice Unit, Orava Unit and Nižná Unit. Niedzica and Czertezik units have a very similar development with thick complex of crinoidal limestones (Smolegowa and Krupianka Limestone formations), red nodular limestones (Niedzica and Czorsztyn Limestone formations), radiolarites (Czajakowa Radiolarite Formation) and *Calpionella* and calcareous nannoplankton-bearing limestones (Dursztyn Limestone Formation), but in the second one should lack the lower red nodular limestone (Niedzica Limestone Formation). However, actual study revealed the permanent presence of thin calcareous deposits between the crinoidal limestones and radiolarites in all the localities of Czertezik Unit (Fig. 5, Wierzbowski *et al.* 2004), which indicates closer affinity between Czertezik and Niedzica successions than between Czertezik and Czorsztyn successions as proposed by Birkenmajer (1959). Its position between the Niedzica and Kysuca-Pieniny zones seems to be more probable. Moreover, the new data question the necessity of distinguishing the Czertezik Unit as a separate paleogeographic unit (?=Niedzica Unit). Pruské Unit is known essentially from the type area in the Púchov segment of the PKB, near Pruské. It can be distinguished from the similar Niedzica Unit only by presence of the Bajocian-Bathonian carbonate (crinoidal) flysch deposits (Samášky Formation). The common feature of both units is the presence of radiolarites sandwiched between lower and upper red nodular limestones. Orava Unit united formerly distinguished Podbiel and Orava Castle developments, as well as the successions of the Kozinec and Havranský Hill near Zázrivá. Formerly it was considered to be restricted to the Orava segment of PKB; recent findings showed that it is also present in the Middle Váh Valley in Púchov segment of PKB (Schlögl *et al.* 2000). The Lower Jurassic deposits comprise *Fleckenmergel* and *Fleckenkalk* facies of the Late Sinemurian age, greenish to reddish marly limestones of Pliensbachian age and Toarcian red nodular limestones (Adnet Formation). Overlying formations are represented by cherty limestones and spongiolites, radiolarites and red nodular limestones of Aalenian to Kimmeridgian age and by *Biancone* or *Maiolica*, sometimes cherty limestones of Tithonian to Hauterivian age. General opinion on the palaeogeographic position of Orava Unit is not uniform, some authors propose its origin in the Fatric sedimentation area (Mahel' 1986).

Streženice Unit was defined by Began & Borza (1963) and it belongs to deeper-water units with spotted limestones, cherty limestones, lower and upper red nodular limestones, radiolarites, grey micritic limestones and greenish shales. The entire stratigraphic span is from the Upper Sinemurian to Albian, but it is worth to note, that the majority of stratigraphic data was extrapolated from other similar sections with valuble biostratigraphic indicators. This unit is known only from the type locality Streženice near Púchov.

Nižná Unit, known only from the Orava area has the same Jurassic development as the Kysuca Unit; the general difference is in the development of the shallow-water Urgonian deposits of the Aptian age in the Nižná Unit (Józsa & Aubrecht 2008). Sometimes it is considered as a subunit of the Kysuca Unit.

Owing to its assumed palaeogeographic position, the Fodorka Unit, introduced by Salaj & Began (in Salaj 1987) is similar to the Grajcarek Unit, distinguished in Polish part of the PKB (Birkenmayer 1977). Grajcarek Unit is very similar to the Kysuca – Pieniny Unit; the reason to separate these two units was based on assumption of that the sedimentation area of the Grajcarek Unit was situated externally of the Czorstyn Swell, within the Magura Basin. However the Upper Jurassic lithostratigraphy of the Fodorka Unit, mainly the absence of the Oxfordian radiolarites, is closer to the Czorsztyn Unit. In the Púchov sector it is known from the Horné Sŕnie – Ostrá Hora area. The Lower Cretaceous black marlstone deposits bear some breccia intercalations with clasts of Tithonian limestones. They are overlain by flysch deposits of the Albian – Turonian age, with some organodetritic deposits with layers of organogenic *Orbitolina* limestones on its base. These strata are conformably reposing on the Upper Jurassic sequence, consisting of Oxfordian *Globuligerina* limestones, Kimmeridgian *Saccocoma* limestones and Tithonian limestones.

Peri-klippen units

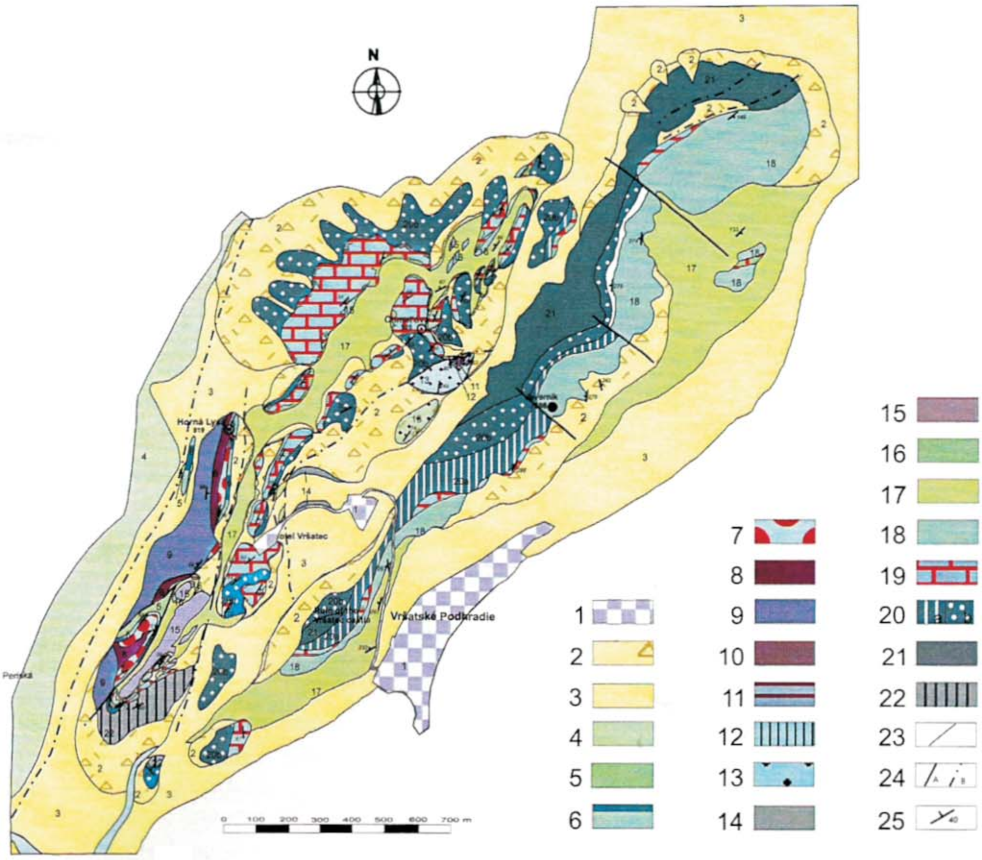
Klape Unit is considered either as a part of the Vahic accretionary complex (Maheľ 1981), marginal wildflysch complex of a laterally moving plate margin (Marschalko 1986), or as a diverticulation Fatric nappe (Krížna Unit) of the Central West Carpathians (Plašienka 1995). The Vahicum is a zone with Jurassic oceanic crust, analogous to the South Penninic zones of the Eastern Alps. Klape Unit consists of thick Middle and Upper Cretaceous, mostly flysch complexes with exotic conglomerates (Upohlav conglomerates) and klippen (olistoliths in this case) of Triassic and Jurassic carbonates. The flysch complexes are separated by a sequence of shallow-water oyster-bearing sandstones of Cenomanian age (Orlové Formation). Conglomerates contain an extraordinary variety of sedimentary and magmatic pebbles derived from the Inner Carpathians (e.g. Mišík & Sýkora 1981), their sources were often placed in the completely disappeared "Ultrapieninic Cordillera", later renamed as the exotic "Andrusov Ridge" (Birkenmajer 1988). The Klape Klippe is built of shallow-water Jurassic limestones. The unit is exposed in the Púchov and Varín sectors of the PKB (Rakús & Marschalko 1997). The pre-Turonian members of the Drietoma Unit represent probably original parts of Fatricum. Drietoma Unit outrops occur in the Podbranč-Trenčín sector of the PKB. It contains also the Upper Triassic rocks, the Carpathian Keuper and Kössen Formation, which are not typical of the Pieniny Klippen Belt. Overlying strata, such as thick Lower Jurassic Kopienec and Allgäu formations, Upper Jurassic radiolarites and nodular limestones, as well as Lower Cretaceous cherty and biodetritic limestones are akin to the Fatric Zliechov Unit. Terrigenous turbiditic sequence, resembling the Klape or Poruba flysch complexes, is the youngest, Albian-Cenomanian member of the Drietoma Unit (Began 1969).

STOP 1 – VRŠATEC AREA – GROUP OF KLIPPEN OF VARIOUS PALAEOGEOGRAPHIC ORIGIN

Ján Schlögl, Adam Tomašových, Roman Aubrecht, Jana Bučová & Vojtech Mikuš

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

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, NW of the Ilava town. This locality consists of two tectonic blocks that belong to the Czorsztyn Unit: the Vršatec Castle Klippe and the Javorník Klippe (Figs 6, 7). 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 otherwise absent in the whole PKB.



Mišík (1979) described in detail sedimentologic 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 Limestones) that are overlying the Middle Jurassic crinoidal limestones (Smolegowa and Krupianka Limestone formations). In the second slice, the Middle Jurassic crinoidal limestones are overlain by the Czorsztyn Limestone Formation. 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 that indicate that only one succession is present in the Vršatec Klippen, with marked 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 (Figs 7, 8).

Fig. 6. Geological map of the Vršatec – Chmelova area: 1 – Holocene antropogenic deposits; 2–3 – Pleistocene-Holocene; 2 – Deluvial loamy-stony and sandy-stony deposits and debris; 3 – Undivided deluvial slope sediments; 4 – Biele Karpaty Unit, Lopeník Formation, Javorina Member: thin bedded flysch with sandstone domination (Kampanian-Maastrichtian); 5–9 – Kysuca Unit, Pieniny Klippen Belt: 5 – Lalinok Formation: variegated marls (Cenomanian-Middle Turonian); 6 – Horná Lysá Limestone: micritic limestones with crinoidal debris and small lithoclasts (Tithonian-Barremian); 7 – Czorsztyn Limestone Formation: red nodular limestones (Kimmeridgian); 8 – Czajakowa Radiolarite Formation: radiolarites and radiolarian limestones (Callovian-Oxfordian); 9 – Harcygrund Shale Formation and Podzamcze Limestone Formation: dark marly shales, dark spotty marly limestones (Aalenian-Callovian); 10–14 – Niedzica and/or Pruské Units: 10 – Czajakowa Radiolarite Formation: red radiolarites and radiolarian limestones (Oxfordian); 11 – Niedzica Limestone Formation: red nodular limestones (Upper Bajocian-Callovian); 12 – Krupianka Limestone Formation: red crinoidal limestones (Upper Bajocian); 13 – Smolegowa Limestone Formation: light crinoidal limestones, silicified spotty limestones (Lower-Upper Bajocian); 14 – Skrzypny Shale Formation and Krempachy Marl Formation: dark shales, grey spotty marly limestones and marlstones (Aalenian-Middle Bajocian); 15–22 – Czorsztyn Unit: 15 – Hyaloclastites of leucitic tefrit composition (Cenomanian-Maastrichtian); 16 – Breccia with xenolites of carbonates (Cenomanian-Maastrichtian); 17 – Púchov Formation: variegated marls (Lower Albian-Lower Campanian); 18 – Dursztyn Limestone Formation: yellow to reddish massive limestones (Tithonian-Hauterivian); 19 – Czorsztyn Limestone Formation: nodular limestone (Callovian-Kimmeridgian); 20a – Krupianka Limestone Formation: red crinoidal limestones (Bajocian); 20b Smolegowa Limestone Formation: white limestones (Bajocian); 21 – Vršatec Limestones: light biohermal limestones (Lower Bajocian); 22 – Skrzypny Shale Formation and Krempachy Marl Formation: dark shales, grey spotty marly limestones and marlstones (Aalenian-Lower Bajocian); 23 – Boundaries of lithostatigraphic units; 24 – Faults: A – observed, B – inferred; 25 – Strike and dip of beds

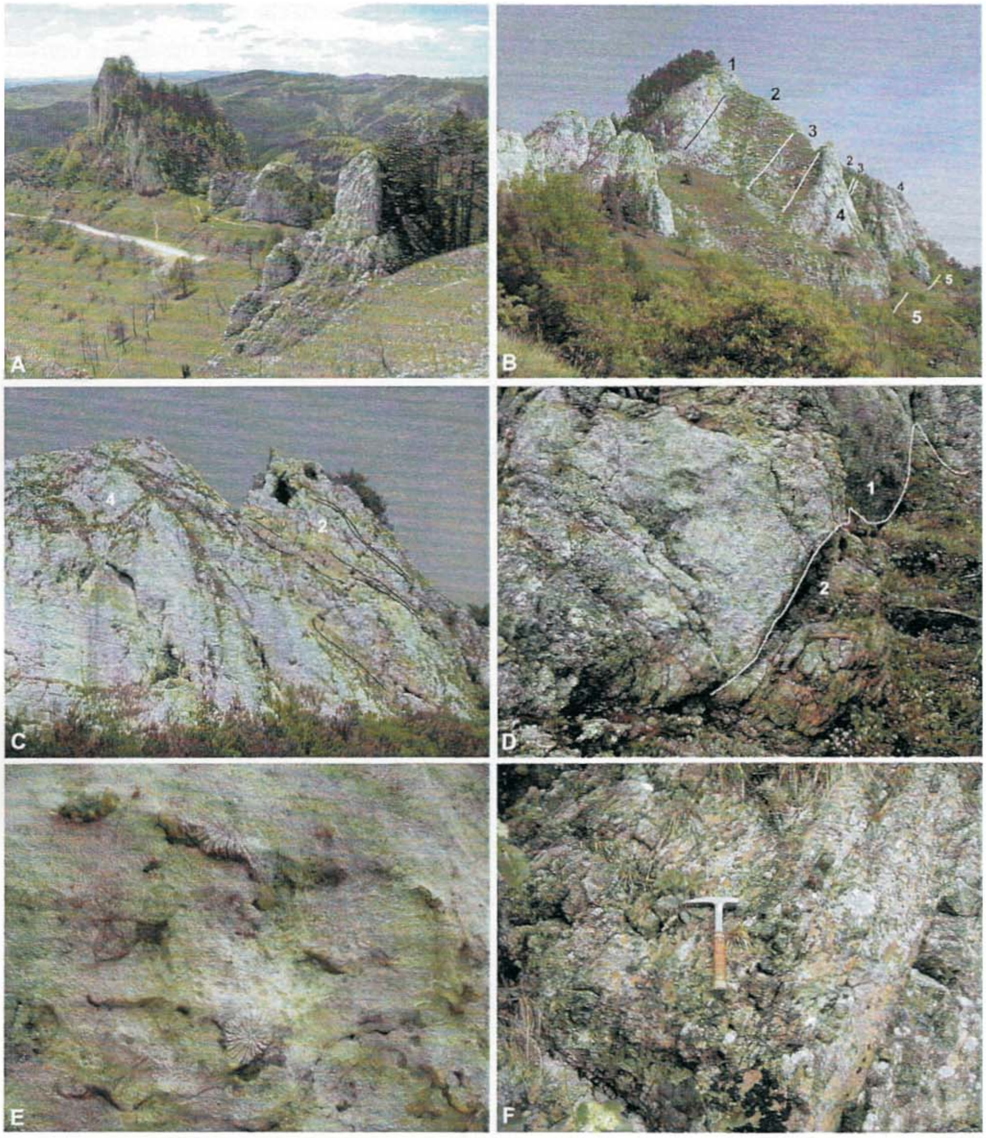


Fig. 7. A) General view on the Vršatec Castle Klippe (photographed from the peak Javorník). B) Javorník Klippe, view from the castle: 1 – Vršatec Limestones; 2 – Smolegowa Limestone Formation; 3 – Bohunice Formation; 4 – Dursztyn Limestone Formation; 5 – Púchov marls. C) Detailed view on the SE wall of the Vršatec Castle Klippe. Note numerous neptunian dykes in the left part of the wall (within Bajocian crinoidal limestones). D) Detail of the contact between the biohermal Vršatec Limestone and the crinoidal limestones. E) Upper surface detail of Vršatec coral biohermal limestone with traces of Mn/Fe encrustations. F) Lower part of the crinoidal limestone complex overlying the Vršatec limestone. Reddish crinoidal packstones to grainstones contains numerous brownish chert

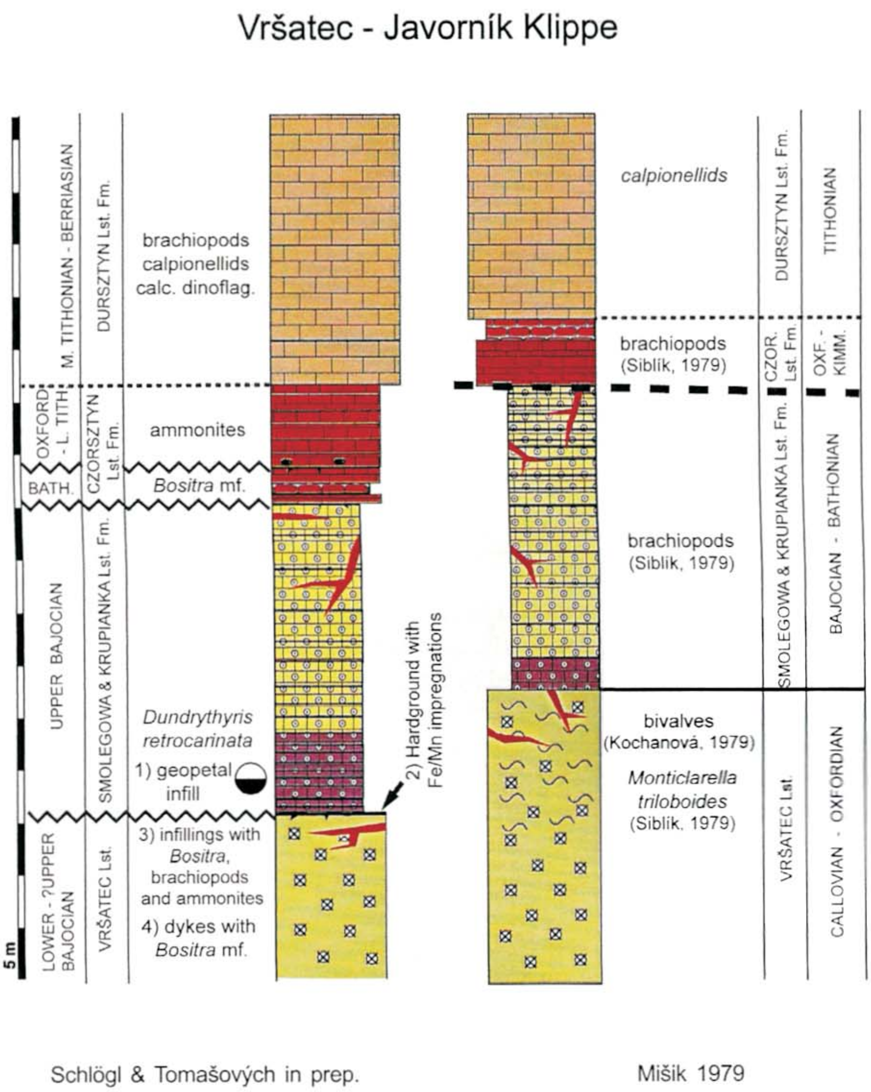


Fig. 8. Comparison of the old theory on the geological structure of Vršatec Klipen and the new one with last field and laboratory data included

The stratigraphy of the Vršatec Klippen

The whole succession is in overturned stratigraphic position. The **Vršatec Limestones** 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 hilltop of the Javorník block. Voids and small caverns in the biohermal limestone contain internal sediment, scarce stromatolites of the LLH type and algae *Verticillodesmis clavaeformis* Dragastan and 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 1979) the biohermal limestones were assigned to the Oxfordian by Mišík (1979). However, the bivalves described by Kochanová (1979) are stratigraphically inconclusive (Golej, pers. communication). One neptunian dyke cutting the peribiohermal limestones contains ammonites *Nannolytoceras tripartitum* of the latest Bajocian or Early Bathonian age. Moreover most of the dykes show filamentous microfacies (Fig. 10C), which in Carpathian area is restricted mainly to 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 Early 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 Limestones (Fig. 7F). The top of the biohermal facies is marked by thin Fe/Mn crusts and impregnations (Fig. 7E). In contrast, the boundary between the peribiohermal facies and crinoidal limestones seems to be gradual in most sections. Only some brachiopods were collected from the base of the formation, including long-ranged taxa such as *Acanthothiris spinosa* (Linnaeus), *Striirhynchia subechinata* (Oppel), *Apringia* aff. *polymorpha* (Oppel) with possible stratigraphic range Bajocian-Callovian. Because of lack of the stratigraphicaly more valuable fauna, the age of crinoidal limestones is based on the datation of the equal crinoidal deposits in the area as Bajocian. The thickness is extremely variable, from almost completely missing in the Vršatec Castle Klippe to 56 metres in the Javorník Klippe (Fig. 9).

The **Czorsztyn Limestone Formation** (and **Bohunice Formation**) consists of red micritic, locally nodular limestones. Based on fifteen detailed stratigraphic sections along both blocks, the thickness of this formation can vary between 20 cm and more than 15 metres (Fig. 9). There is invariably a 0.5–2 cm-thick Mn-crusts 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 wackestones to packstones), juvenile gastropods, benthic foraminifers and crinoidal ossicles. The overlying massive limestones show the *Globuligerina* microfacies, suggesting their Oxfordian age. These massive limestones pass gradually to massive red micritic limestones with the *Saccocoma* microfacies. Ammonite fauna including *Orthaspidoceras uhlandi* (Oppel) and *Hybonoticeras hybonotum* (Oppel) indicates Kimmeridgian and Early Tithonian age.

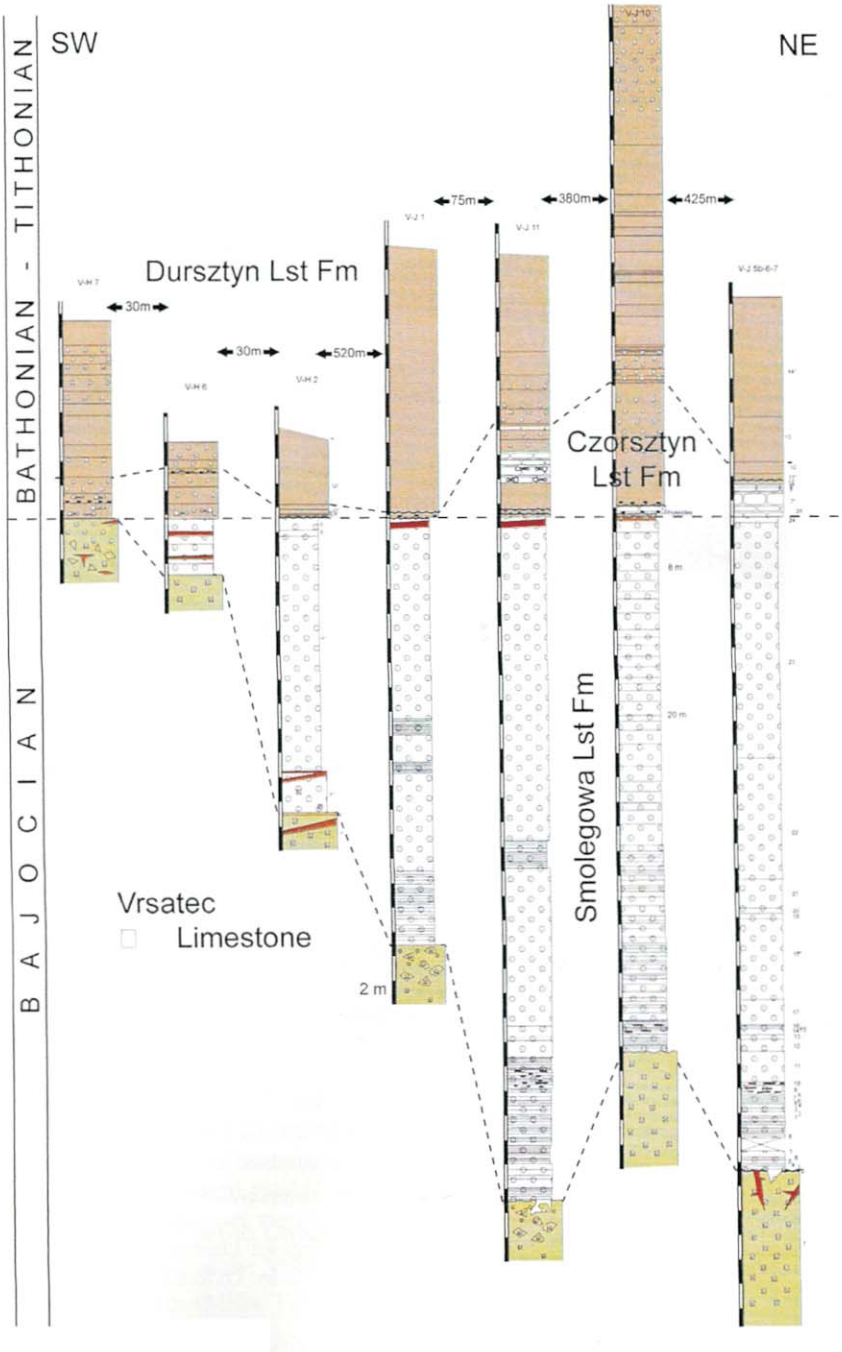


Fig. 9. Correlation of seven selected paralel sections through the Vršatec Castle Klippe and the Javorník Klippe. Note the sudden lateral changes in facies and thickness of the formations

Neptunian dykes (Fig. 10). Crinoidal limestones as well as biohermal limestones are extensively cutted by fissures, subparalell to stratification or diagonally cutting the older deposits. They are more common in the Vršatec Castle Klippe, which is typical of more condensed sedimentation. Mišík (1979) discerned several opening and infilling phases. Most common are the Middle Jurassic dykes (Bathonian-Callovian), less abundant are Oxfordian and younger dykes. Generally they are filled with massive to delicately laminated red micrites (Fig. 10A), locally with abundant ammonites, brachiopods, gastropods and bivalves (Fig. 10D), enabling their datation. Massive red micrites are often extensively bioturbated (Fig. 10B). One Oxfordian dyke yielded boreal ammonites of the genus *Cardioceras* (Fig. 10D).

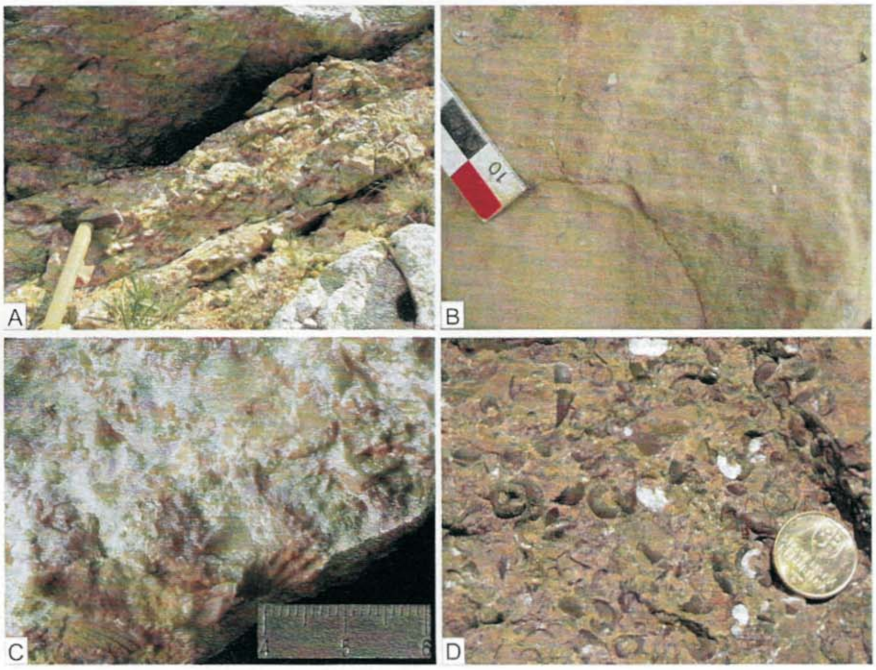


Fig. 10. Neptunian dykes. A) Thick neptunian dyke in Vršatec Limestones showing polyphase infilling with red micritic limestone. Bathonian or Callovian. B) Detail of the same dyke, showing dense framework of bioturbation. The feature is common in massive, non-laminated dykes. C) Sparitic coquina from the fissure infilling within Vršatec limestone. Note the numerous shells of *Bositra* sp. The same dyke yielded ammonites of Upper Bajocian or Lower Bathonian age. D) Micritic ammonite coquina filling a dyke in Smolegowa Limestone Formation. Note small *Cardioceras* in the left part of the photo. Oxfordian

The **Dursztyn Limestone Formation** 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.

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. Normal sedimentological contact between Dursztyn Limestone Formation and the red marls is visible on the foot of the Vršatec Castle Klippe, where the signs of karstification of the Lower Cretaceous limestones can be observed (Fig. 11). The marls are of Late Cenomanian to Campanian age.

Fig. 11. Detail of the Lower Cretaceous paleokarstic surface within the Tithonian-Berriasian limestones of the Dursztyn Limestone Formation with the transgressive Albian lag deposits with abundant belemnite rostra, coral fragments and oncoids. Scale bar 3 cm

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

As the sections in the PKB 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 & Túnyi (2001) analyzed neptunian dyke orientations in four sections in the PKB, including the Vršatec Castle Klippe, Babiná quarry, Mestečská 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, generally they represent rejuvenation of the older dykes (Mišík 1979).

The measurements of the neptunian dykes and their evaluation, with utilizing of paleomagnetic correction, enable to estimate 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. 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°, which indicates that the Czorsztyn Ridge was located approximately at 10–30° paleolatitudes in the Middle Jurassic.

Surrounding klippen (Fig. 6)

The closest coulisse of small klippen between village and the saddle below Chotúč klippe is built of deposits of deep-water Orava Unit (Schlögl *et al.* 2000). Succession is well outcropping on the steep slopes of Strapková and Dúbravka Klippen and can be summarized as follows: bedded *Fleckenmergels/Fleckenkalks* of Late Sinemurian age, thin-bedded greenish-grey and red marly limestones, yellowish-greenish marly limestones of late Upper Sinemurian-Pliensbachian age, red nodular limestones of probably Toarcian age, spongolites and cherty limestones of Aalenian-Early Oxfordian age, lower red nodular limestone and green and red radiolarites of Middle Oxfordian to Early Kimmeridgian age, upper red nodular limestone with red cherts in its lower part, of Middle Kimmeridgian to Middle Tithonian age, passing gradually to grey micritic limestones with dark cherts of Late Tithonian to Late Berriasian age. It is to note, that these klippen represents the only klippen belonging to Orava Unit outside the Orava region.

The Chotúč Klippe is built of deep-water sequence starting by huge complex of spongiolites, cherty limestones, spotted limestones, dark-brown marls and marlstones of Podzamcze Limestone Formation, which is probably of Bajocian-Bathonian age, overlain by Oxfordian-Lower Kimmeridgian radiolarites, Upper Kimmeridgian thin red nodular limestones and grey micritic limestones with dark cherts of Tithonian to Early Cretaceous (Early Hauterivian) age (Schlögl 1998). It is to note, that older lithostratigraphic units are outcropping in the close vicinnity of the Chotúč Klippe and were formely considered as a part of the same succession. This fact could not be proved in the field, because these two sequences are in tectonic contact exclusively. Nevertheless, following succession can be traced E of Chotúč Klippe: white to pink quartzites and Q conglomerates, carbonate microconglomerates probably belonging to Karpathian Keuper; dark shales, calcareous sandstones and bioclastic limestones (Rhaetian); sandstones with marly intercalations (Lower Jurassic, probably Hettangian to Upper Sinemurian) and dark-grey marls with spotted marly limestones and cherty limestones (Pliensbachian-Aalenian).

Moreover the geological situation is complicated by a recent discovery of Aalenian dark shales in the saddle between Chotúč and Vršatec, which are only in tectonic contacts with all surrounding units.

Next coulisse behind the Chotúč Klippe consists of small klippen of Czorsztyn Unit (Malé and Veľké Hradište Klippen and Pod mokrou skalou Klippe), with both developments, with or without Bajocian biohermal facies. Moreover, the Podhradská dolina Valley running down from the Vršatec Klippen is the type locality of the transitional Pruské Unit (Andrusov 1945). The klippen west of the Vršatec Klippen (Chmelová coulisse) belong to the classical Czorsztyn Unit without biohermal limestones and to some type of Niedzica-like transitional units (Bučová 2006). The sections in the red nodular limestones are outcropping below the Hotel Vršatec yielded rich and biostratigraphically valuable ammonite fauna. The section just below the hotel represents time interval Upper Kimmeridgian Eudoxus/Beckeri Zone and Lower Tithonian Hybonotum Zone. The section on the slope to Klivoklát Valley, some 60 m SW from the hotel, shows the crinoidal limestones of Smolegowa Limestone Formation and *Ammonitico Rosso* of the Czorsztyn Limestone Formation. The boundary between these two units is errosive with stratigraphic hiatus of uncertain time span; the oldest ammonite fauna collected from the base of Czorsztyn Limestone Formation indicates Parkinsoni Zone of the Upper Bajocian. Hardground with Fe/Mn mineralization occuring some 6.5 m above the base of the Czorsztyn Limestone Formation represents hiatus, covering (?)Middle and Upper Bathonian and Callovian at least, based on ammonite fauna typical of late Lower Bathonian collected from a condensed bed approx. 1 m below the hardground (Schlögl *et al.* 2005).

The newly discovered bodies of volcanic rocks (alkaline basalts) occur in two localities within the variegated marls of Late Cretaceous age. The first, smaller occurrence (a few metres in diameter) is situated on the northern slopes of the Chmeľová hill. The second, much larger occurrence is situated SSW-ward of the Chmeľová hill on SE slopes of the unnamed crest about 1 km SW of the Vršatec hotel (GPS coordinates of the approximate centre of the body: N 49°03'52.9", E 18°08'34.6"). This occurrence is represented by three volcanic bodies, the largest body being up to 100 m wide and over 500 m long.

The whole area is dominated by macroscopic fold structures with SW-NE trending axes and younger, mainly strike-slip faults. Bulk of volcanic rocks is situated in the core of a tight brachysyncline. The sedimentary succession containing the analysed volcanic body cannot be assigned without reservations to any typical Oravic successions described in the literature. As the oldest member, it contains dark grey spotty limestones with intercalations of sandy crinoidal limestones and spongiolites, which are partly analogous to the Samášky Formation described from the transitional Pruské Succession (Aubrecht & Ožvoldová 1994), or to the Flaki Limestone Formation known from the Branisko (Kysuca) succession in Poland. This formation is overlain by greenish and red platy radiolarites (Sokolica and Czajakowa Radiolarite formations), followed by red nodular limestones (Czorsztyn Limestone Formation). Lower Cretaceous sediments are of a special type with pinkish allodapic bioclastic limestones (Horná Lysá Formation – Mišík *et al.* 1994). Brick-red marlstones, which can be possibly correlated with the Cenomanian Lalinok Formation, and the volcanic rocks are the youngest members of this succession. The described succession bears features of either a non-typical Kysuca Succession, or the transitional Pruské Succession. Volcanic rocks lie in superposition over variegated marlstones of the Lalinok Formation. The volcanic bodies consist of hyaloclastic breccias, in a larger scale they represent basaltic submarine lava flows. Determination of an approximate age of volcanic rocks is based on the foraminiferal tests found in micritic, partly thermally recrystallized carbonate forming an interstitial substance and fissure fillings in hyaloclastites. The found tests belong to the family Globotruncanidae. These are characteristic for the time interval Cenomanian-Maastrichtian. Accordingly, the basaltic lavas were emplaced during the Late Cretaceous.

STOP 2 – SLÁVNICKÉ PODHORIE KLIPPE – KEY SECTION FOR THE "STROMATACTIS" ORIGIN

Roman Aubrecht & Ján Schlögl

GPS coordinates N 49°01'00,1", E 18°09'31,4"

This site is situated in the middle of Váh River valley, near the village Slavnické Podhorie, at the foot of the Biele Karpaty Mountains. It represents a tectonically overturned klippe cut by an abandoned quarry. A 32 m long section was measured in the southern part of the quarry (Figs 12 and 13) where the core of a stromatactis mud-mound is exposed (Aubrecht *et al.* 2002, Aubrecht 2006). Major part of the quarry exposes crinoidal limestones dated by ammonites *Nannolytoceras tripartitum* (Raspail) and especially *Parkinsonia* sp. to the uppermost Bajocian or lowermost Bathonian. 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), *M. ventricosa* (Zieten), *Linguithyris bifida* (Rothpletz), *Zeilleria waltoni* (Davidson), *Z. emarginata* (Sowerby), *Z.* aff. *subbucculenta* Chapuis-Dewalque, *Lobothyris ventricosa* (Hartmann), *Loboidothyris perovalis* (Sowerby), *"Terebratula" retrocarinata* Rothpletz, *"T." varicans* Rothpletz, *Antiptychina puchoviensis* Pevny, *"Sphenorhynchia" rubrisaxensis rectifrons* (Rothpletz), *Acantotharis* sp., *Gnathorhynchia trigona* (Quenstedt), *Sphenorhynchia* aff. *plicatella* (Sowerby), *S. rubrisaxensis rectifrons* (Rothpletz), *Rhactorhynchia subtetrahedra* (Davidson), *"Rhynchonella"* aff. *obsoleta* (Sowerby), *Cymatorhynchia quadriplicata* (Sowerby), ? *Weberithyris* sp., ?*Caucasella trigonella* (Rothpletz), *Parvirhynchia* sp. The overlying pink to red micritic limestones (mudstones) are of Bathonian to ?Callovian in age. Stromatactis are present in the crinoidal limestone, but they reach their maximum development in the micritic limestones, where they are weathered out in positive relief. At 28 m from the base of the section, the stromatactis cavities disappear. The mudstones that overlie the crinoidal deposits are dominated by a microfacies with *Bositra* sp. filaments, which extends to the end of Callovian. As only very rare foraminifers *Globuligerina* sp. have been found in the mudsones, mass occurrence of which is indicative for the Oxfordian in this basin, the section does not reach the Oxfordian age.

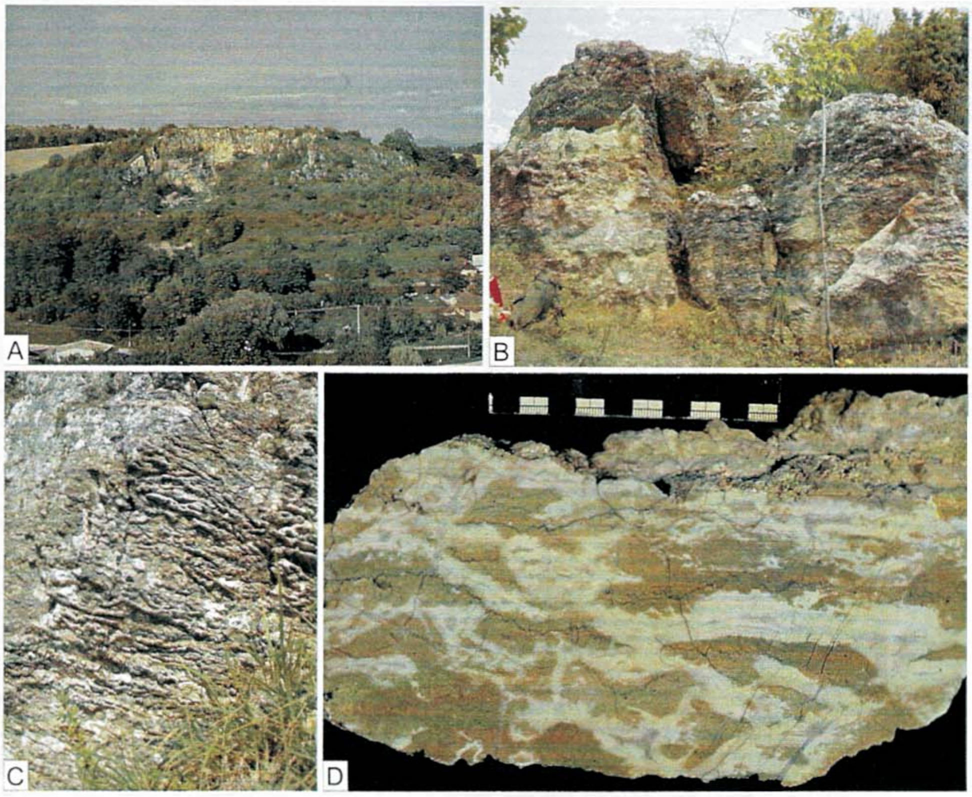


Fig. 12. A) Slávnické Podhorie and the research field site above the village. B), C) Weathered-out spar fillings of the stromatactis cavities. D) Polished slab of the pink micritic limestone with stromatactis cavities

Section description (Fig. 13)

The stratigraphical basis of the examined profile is formed by 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). 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.

Smolegowa/Krupianka Limestone formations. Crinoidal limestones represent skeletal packstones to grainstones with micritic to sparitic matrix. The sparite occurs in the parts where the micrite was winnowed. Where the stromatactis cavities occur, the matrix is locally pelmicritic to sparitic. However, in contrast to the clear blocky calcite mentioned above, the spar is mostly represented by a short-bladed fibrous calcite.

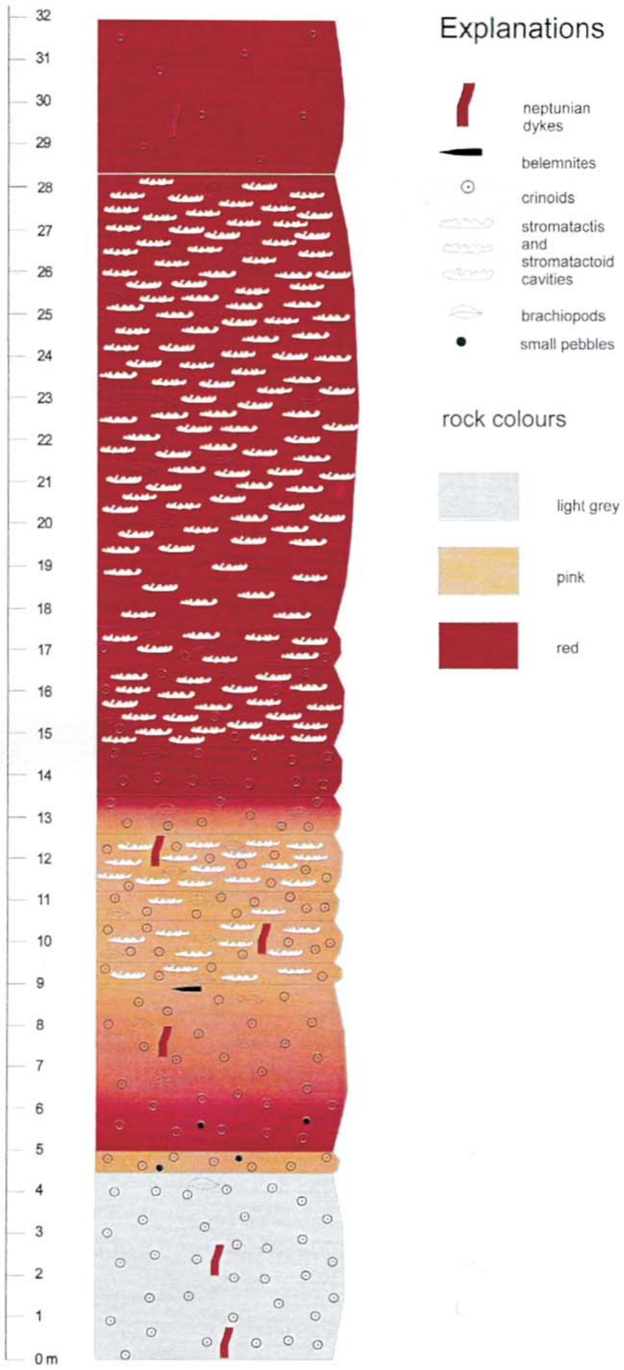


Fig. 13. Lithological profile through Slávnické Podhorie quarry (after Aubrecht *et al.* 2002)

It is obviously related to the RFC filling of the stromatactis cavities as there is a very indistinct transition to its first, short-bladed generation. The sediment was relatively poorly sorted. Besides crinoidal ossicles, sand-sized detrital quartz grains are abundant. Bryozoan fragments, echinoid spines, ostracod tests, foraminifers (*Lenticulina* sp.), agglutinated foraminifers (*Ophthalmidium* sp.) and fragments of pelecypods and brachiopods are ubiquitous. Upsection, bivalves and brachiopods gradually prevail and filament shells appear, passing to the overlying mudstones. Many allochems are affected by heavy micritization and microborings.

Bohunice Formation. The pink, red to yellowish mudstones form the main host rock of the stromatactis cavities and are predominantly a wackestone to packstone (biomicrite, biopelmicrite) and even to grainstone (biopelsparite). Thin-shelled bivalves (mainly *Bositra* sp.), thin-shelled ostracods and foraminifers (*Ophthalmidium*, *Lenticulina*, *Patellina*, *Spirillina*, *Dorothia*, 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 very rare. Crinoidal ossicles, which are common in the lower, transitional parts, are less frequent in the mudstone. Rare quartz grains occur, too. Some brachiopod shells were observed, initially filled by short-bladed RFC and later by pendant fine-grained calcite grains (crystal "silt"). The rest of the shells were filled by clear blocky calcite. The relatively monotonous "filamentous" microfacies (packstone) with its micritic matrix, free of peloids, also represents the main part of the micritic limestones on top of the profile (28–32 m), where the stromatactis cavities are missing. Unlike in the lower levels, signs of bioturbation are ubiquitous. The same material fills the neptunian dykes found at 10, 12.5, 22.89 (dyke with 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 the irregular ones are also present. Some cavities in the crinoidal limestone appear to have roof and floor lined by micrite, which may represent a microbial crust (a kind of initial endostromatolitic lining). The first and the main filling of the stromatactis cavities is represented by radiaxial fibrous calcite (RFC). The first phase of RFC is short-bladed and almost identical with that penetrating into the surrounding host rock. This phase is gradually followed by long crystals without sharp boundary. Apart from these two phases, the RFC filling represents just one distinct generation. Multi-generation fillings have been observed only if some interruptions by micritic or thin intercalations of cryptic stromatolites occur. In some thin sections, tests of cave-dwelling ostracods *Pokornyopsis* sp. were found surrounded by the latest stages of the RFC. These ostracods indicate that part of the stromatactis cavities formed an open network through which the ostracods and their larvae could migrate (Aubrecht & Kozur 1995). Around the 28 m level, the stromatactis cavities give way to shelter porosity filled by clear drusy blocky calcite, predated by a dog-tooth calcite rim around the cavity. The shelter porosity gradually disappears topwards and the sediment becomes free of the voids.

Internal sediment precedes or postdates the RFC filling of the stromatactis cavities. In the crinoidal limestones, the internal sediment of stromatactis cavities displays similar composition as to the host rock. In the mudstones, the internal sedimet is either sterile micrite or pelmicrite, sometimes containing small fragments of "filaments" and thin-shelled non-sculptured ostracods. The micrite is usually laminated and sometimes disturbed by bioturbation.

Blocky calcite represents the latest filling of the stromatactis cavities and of some fenestral-like voids in the micrite. It is either pure or contains inclusions. The crystals commonly possess twinning lamellae. The transition from the RFC to blocky calcite is gradual but sometimes the two phases are separated by microstylolites.

Stromatactis origin

Our research has revealed evidence that siliceous sponges have contributed to the origin of the stromatactis structures described here (Fig. 14). Most of the upper surfaces of the weathered out RFC stromatactis are fillings display casts after siliceous sponges. The sponge-related theory for stromatactis origin was first introduced by Bourque & Gignac (1983), who presented stromatactis structures as cavities that remained after decayed sponges and the peletoidal fabrics of the host rocks as originated due to microbial cementation. The evidence for sponges was based on ubiquitous sponge spicules found in the host rocks of the stromatactis mud-mounds (Bourque & Gignac 1983); and some were even found in the spar infillings of stromatactis cavities (Boulvain 1993) but the body fossils were scarce. There seemed to be a contradiction between the sponge mounds with numerous preserved body fossils and stromatactis mud-mounds with few sponge body fossils. Even the researchers working in sponge mounds attributed the stromatactis-like cavities in these mounds to other processes, like internal erosion, cavitation or they considered them as shelter porosity (*cf.* Matyszkiewicz 1993, Delecat & Reitner 2005). The supporters of the sponge theory looked for indirect proofs, like microbial cementation responsible for the micropeloidal (clotted) fabrics of the so-called automicrite that dominates the mud-mounds. Sponges contain symbiontic microbes, which contribute to their metabolic processes (Reitner *et al.* 2001). These microbes are believed to play an important role also in post-mortem decay and early calcification of sponge tissues. Therefore, micropeloidal fabrics of the host rocks in stromatactis mud-mounds are attributed to this mass "inoculation" by symbiontic microbes. However, still uncertain is their role in formation of the sparry masses. There were some notes in the literature, which interpreted the origin of RFC as happening at the expense of decaying tissues or an organic matter (Monty 1995). In the cases presented here, no evidence of such processes has been observed, despite earlier opinions of Aubrecht *et al.* (2002). In the context of the new findings it seems plausible that the RFC filled empty collapsed cavities after sponges. Cavities were empty prior to being filled with radiaxial fibrous calcite, as evidenced by the presence of cave-dwelling ostracods trapped in the RFC and seawater isotope signatures of many RFC calcites. Rarely preserved pores or borings within the RFC filling may be interpreted as the evidence that the observed stromatactis did not represent just shelter cavities below at sponges but the structures actually represent molds after their decayed bodies. To remain preserved, sediment fillings of the pores and/or borings should be at least slightly lithified prior to the decay. Such filling may be also responsible for the presence of "floating" allochems and sediment islets surrounded by RFC. Early lithification of the covering sediment is also the only way how to explain preservation of the casts by the radiaxial fibrous calcite.

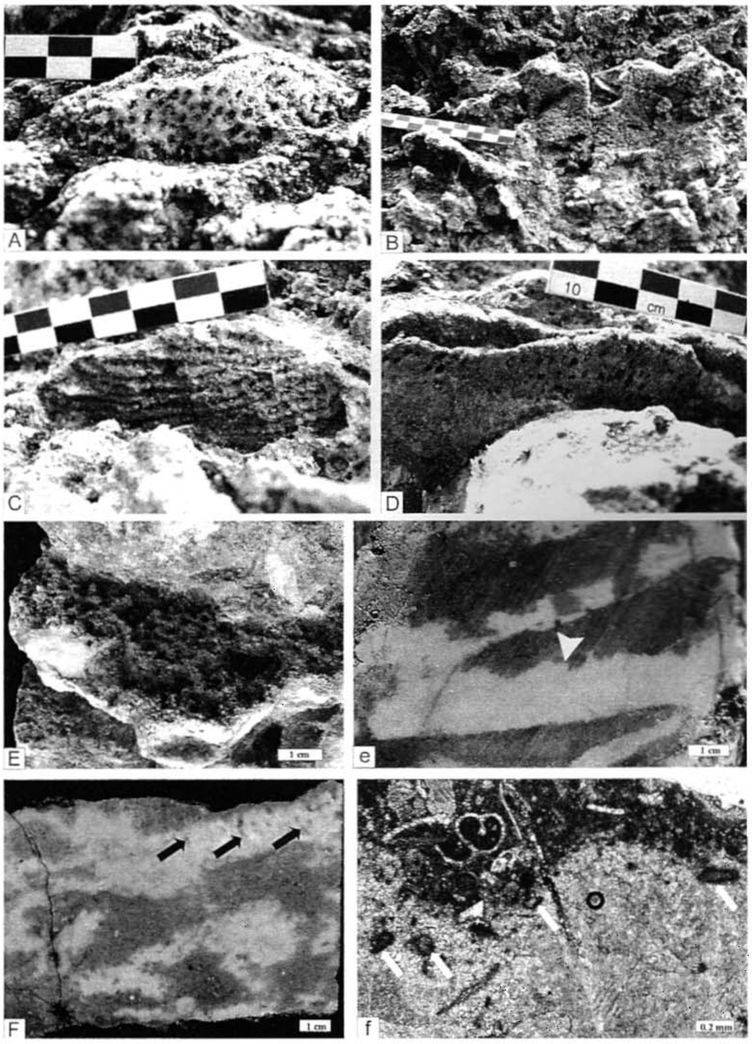


Fig. 14. A)–D) Casts after siliceous sponges on the upper surfaces of the weathered-out RFC fillings of the stromatactis cavities at Slavnické Podhorie. E) Relationship between the weathered casts of siliceous sponges (E) and the corresponding cross-section in slab (e). The cross-section displays actual stromatactis shape and composition. F) Stromatactis with some original sponge structures preserved (pores, or borings – marked by arrows). Thin section photo of the sample with relic pores (arrows) surrounded by radiaxial calcite

Big effort has been also spent on looking for the evidence by study of siliceous sponges fossilization (e.g. Delecat & Reitner 2005, Neuweiler *et al.* 2007). Our results suggest that stromatactis is one of the results of the sponge taphonomy. They represent a special case of post-mortem structures as correctly suggested by Neuweiler *et al.* (2001). Excluding the sponge casts preserved on the surface of the RFC filling, the earlier presence of sponges is almost completely obliterated. This is emphasized by the fact that the cavities after sponges collapsed and thus any original shape of the dead organism was deformed. The $\delta^{13}C$ and $\delta^{18}O$ values of the host's rocks and the initial spar inlling (Fig. 15), do not show any biofractionation that would suggest their biogenic origin; these components predominantly show a normal seawater isotope ratio. The casts on the stromatactis surfaces are therefore the only feature which betrays their origin. Carbon and oxygen stable isotopes were analysed in order to reconstruct the process of mud-mound cementation.

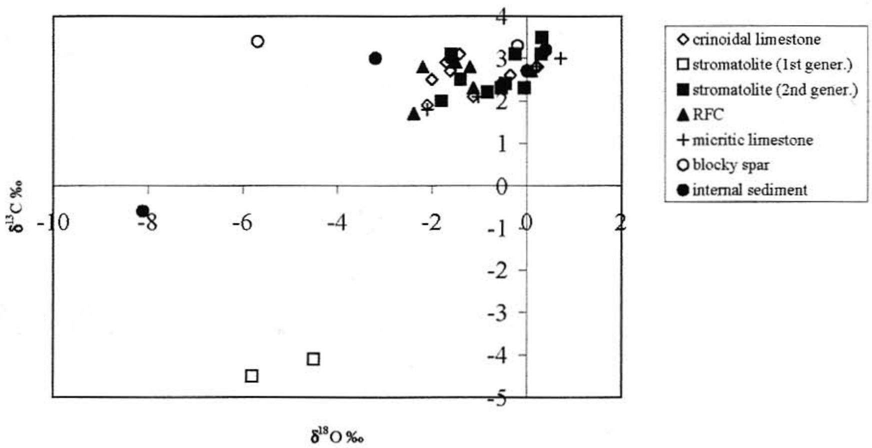


Fig. 15. Crossplot of the carbon and oxygen isotope values ($\delta^{18}O$ *vs.* $\delta^{13}C$) of individual rock components. SP – results from Slavnické Podhorie (after Aubrecht *et al.* 2009)

STOP 3 – KRASÍN KLIPPE – MIDDLE JURASSIC SYNTECTONIC CLIFF BRECCIA (Fig. 16)

Roman Aubrecht

GPS coordinates N 48°57'47,2", E 18°1'24,1"

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 (Fig. 16): 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 are overlying the Middle Jurassic limestones in the large clefts. The Krasín Breccia is an example of Jurassic syntectonic sedimentary breccia, witness of extensional tectonic movements tied to Jurassic Neotethys rifting. 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. 17). Apart from Krasín locality, this peculiar facies was studied in the localities Horné Sŕnie quarry, Babiná quarry, Babíná Hill, Bolešov and Drieňová, exclusively located in the Púchov segment of the PKB.

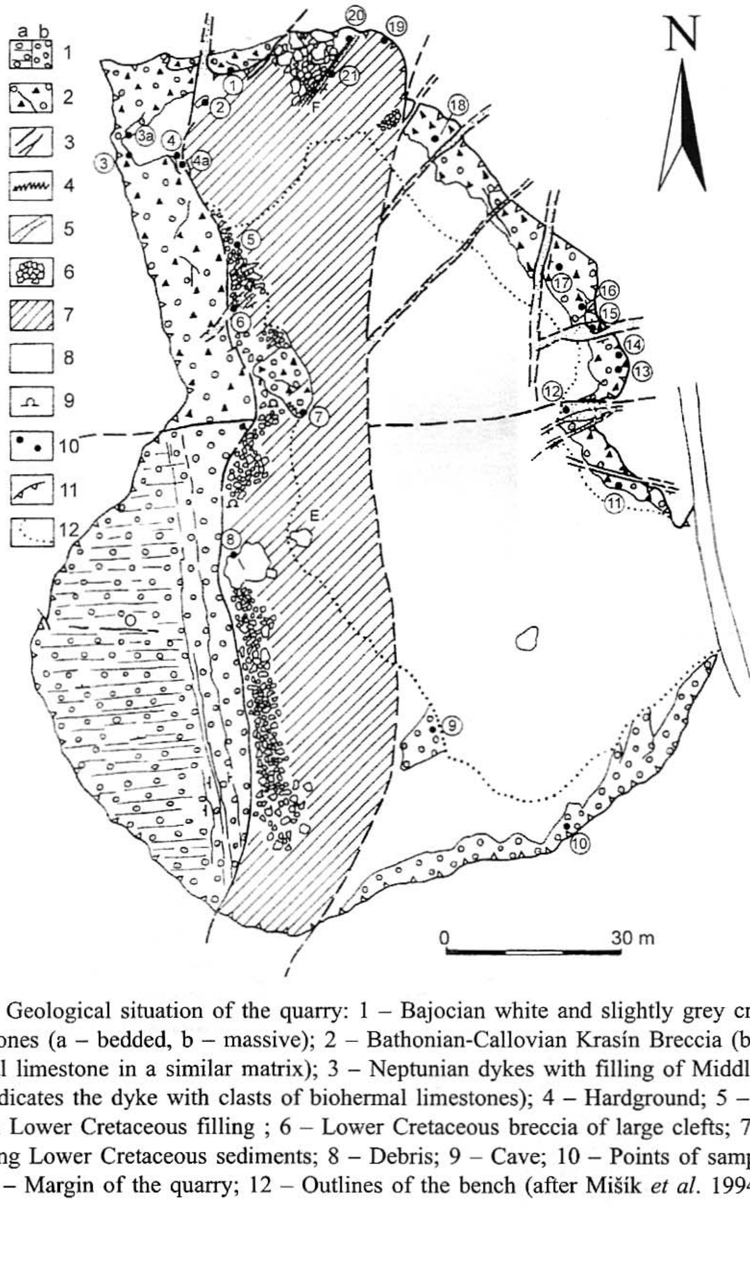


Fig. 16. Geological situation of the quarry: 1 – Bajocian white and slightly grey crinoidal limestones (a – bedded, b – massive); 2 – Bathonian-Callovian Krasín Breccia (blocks of crinoidal limestone in a similar matrix); 3 – Neptunian dykes with filling of Middle Jurassic age ("O" indicates the dyke with clasts of biohermal limestones); 4 – Hardground; 5 – Neptunian dykes with Lower Cretaceous filling ; 6 – Lower Cretaceous breccia of large clefts; 7 – Debris covering Lower Cretaceous sediments; 8 – Debris; 9 – Cave; 10 – Points of sampling; 11 – Margin of the quarry; 12 – Outlines of the bench (after Mišík *et al.* 1994)

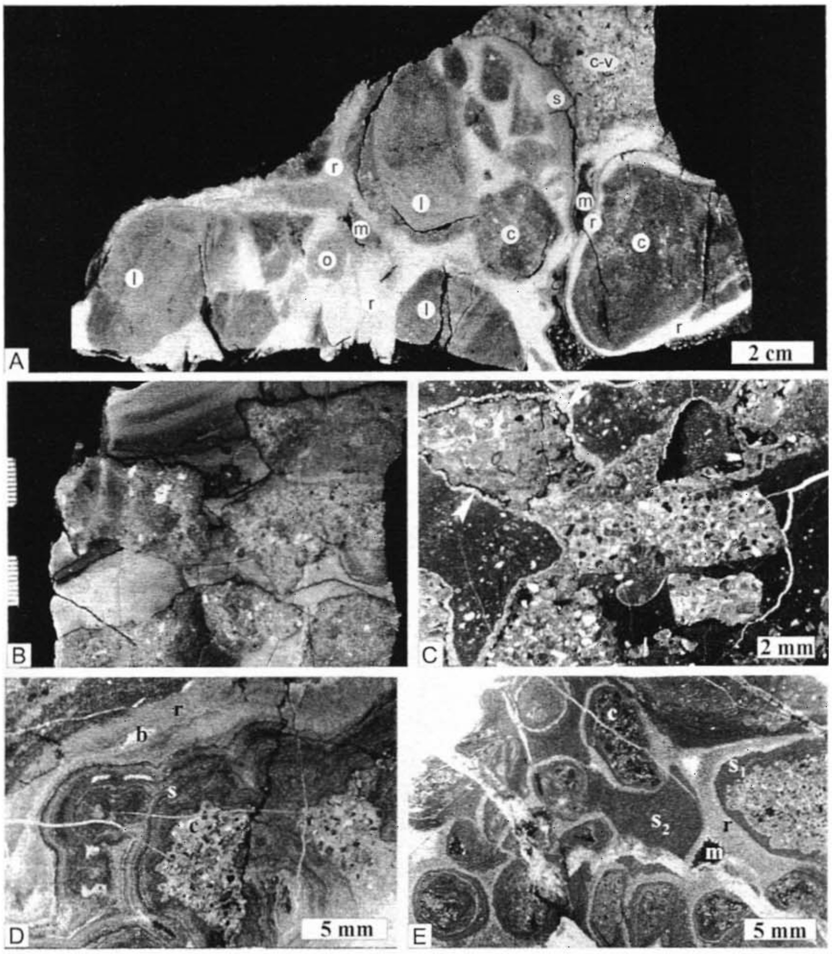


Fig. 17. A) Complex cementation of the breccia from Horne Srnie: c – clasts of crinoidal limestone; l – clasts and coatings of laminated organodetritic limestone (sediment probably mediated by microbial mats), r – radiaxial fibrous calcite filling of interstitial voids, c–v crinoidal limestone as a void filling; m – micritic void filling; o – micritic void filling with cave-dwelling ostracods *Pokornyopsis* sp.; B) Slab of crinoidal limestone with bizarre voids filled with sterile red laminated micrite. The irregular surface of the voids was caused by karstification, Babina Hill. C) Thin-section photomicrograph showing clasts of crinoidal limestone leached (arrows) prior to micrite filling of the interstices. Babina Hill. D) Stromatolite crusts (s) joining angular clasts of crinoidal limestones (c), prior to being cemented by the radiaxial fibrous calcite (r) and blocky calcite (b). Note that the stromatolite crusts may attain spherical shape (centre left), Drienova. E) Clasts of crinoidal limestones (c) cemented by stromatolites (s1, s2) and radiaxial fibrous calcite (r). The latest filling is represented by micrite (m). Note that the stromatolite coatings may predate (s1) or post-date (s2) the radiaxial fibrous calcite. As evidenced by the isotope analysis, part of the s1 generation may be of fresh-water origin. Horne Srnie (after Aubrecht & Szulc 2006)

Following members may be discerned in the Krasín quarry (Mišík *et al.* 1994):

Smolegowa Limestone Formation. White bedded to massive crinoidal limestones with ammonite *Teloceras blagdeni*, with small fragments of dolomites, rare red neptunian dykes and void fillings. Clastic admixture is more or less abundant, maily represented by quartz grains and dolomites. They form also the whole crest of the Krasín klippe. Stratigraphic 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 possesses the most complex filling. The clast are coated by at least one generation of stromatolite (mostly cryptic stromatolites) and subsequently cemented by radiaxial fibrous calcite. The remining void filling starts with the crinoidal detritus, which indicates that the breccia was formed due to synsedimentary tectonics occuring during the deposition of crinoidal limestones. Next infilling step is represented by micritic limestone with fillamentous microfacies (Bathonian-Callovian) and by almost sterile micrite with cavity-dwelling ostracods (?Oxfordian). 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.

Krupianka Limestone Formation. Grey 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.

?Vršatec Limestones. Light grey and pinkish bioherm breccia with dolomite lithoclasts. It fills only a pocket (cleft) in the left upper part of the quarry. The stratigraphic position of the infillings is unclear, although the Bajocian age of the lithoclasts of biohermal facies can be supposed.

Walentowa Breccia. Breccias formed by clasts of the red crinoidal limestones and small fragments of white *Crassicollaria*-bearing limestones. They filled some clefts with variable thickness (maximum 25–30 m) penetrated the Middle Jurassic limestones. Supposed age is Valanginian-?Hauterivian.

Red marls with the intercalations of the fine-grained limestones with *Hedbergella* were found only in a cleft between the points 14 and 15. Supposed age is Hauterivian.

During a short inspection of the quarry in exploitation twelve years ago, we found a thin intercalation of red nodular Czorsztyn Limestone. The intercalation was mentioned also by Began (1969, p. 59). Similar intercalation only 1.5 m thick is present also within the Middle Jurassic crinoidal limestone of the Mestečská Skala klippe (Aubrecht 1992).

The following model may be proposed for the breccia origin (Fig. 18). Deposition of white crinoidal limestone (Smolegowa Limestone Formation) took place during the Early Bajocian due to rising of the Czorsztyn Swell. After the first tectonic impulse, which caused elevation of the sedimentary area, accompanied with shallow-water sedimentation, a second one followed, approximately in the Middle Bajocian. This impulse resulted in partial emersion of the previous deposits and created a scarp and tectonic clefts. This scarp was from several metres to tens of metres high but it did not exceed the thickness of the previous crinoidal limestones as no other rocks were eroded. The main breccia body was deposited at the toe of the scarp, accompanied by smaller bodies in clefts. Most of the clasts were derived from the scarp walls. A certain number of clasts was probably derived from the emerged land, where some of them were rounded, partially leached and coated by fresh-water calcareous stromatolites. After the primary deposition, interstitial pores at the surface of the breccia talus were filled with Upper Bajocian crinoidal limestone (mostly red Krupianka Limestone Formation). In the inner parts, the clasts were coated by marine calcareous stromatolites and cemented with the RFC. Some fresh-water incursions through the clefts and fractures are proposed, too. Some further downslope movements of the breccia caused some of the previous coatings and cements to be involved as secondary clast in the breccia. Subsequently, most of the remaining pores were occluded by Bathonian-Oxfordian micrite, first with filament (*Bositra*) microfacies, then with sterile micrite with dominant cave dwelling *Pokornyopsis* ostracods. Finally, the clear blocky calcite occluded most of the tiny remaining pores and filled newly formed fractures.

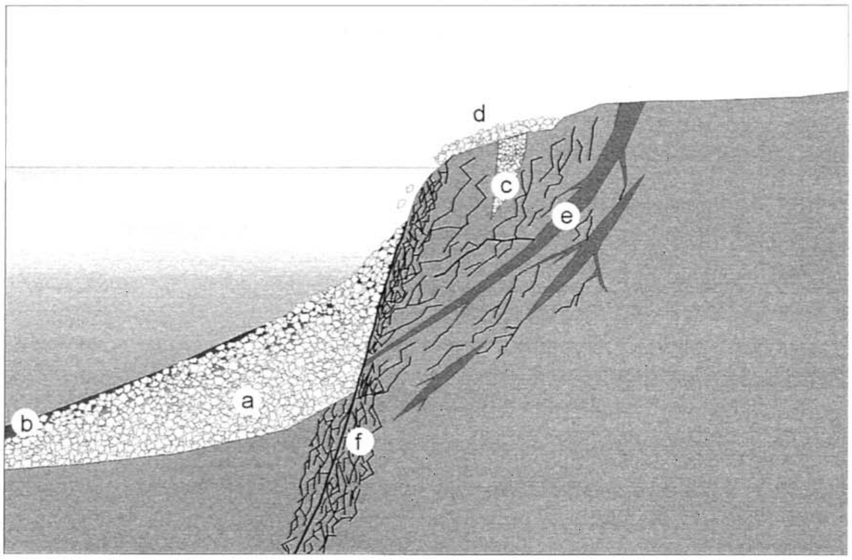


Fig. 18. Model of deposition and cementation of the Krasin Breccia: a – inner part of breccia talus in which cements and stromatolite coatings prevail over the internal sediment, b – outer part of the talus with predominant sedimentary filling of the interstices, c – breccia bodies originated in clefts and caverns, d – rubble originated on the emerged land and initially coated with fresh-water stromatolites, e – clefts (neptunian dykes) that served as conduits of the fresh water, f – in situ brecciated wall rock (crackle breccia) near the main fault (after Aubrecht & Szulc 2006)

STOP 4 – HATNÉ KLIPPE – CROSS-BEDDED CRINOIDAL LIMESTONES (CZORSZTYN SUCCESSION)

Roman Aubrecht & Milan Sýkora

GPS coordinates: N 49°11'35.7", E 18°22'31.2"

The locality Hrádok at Hatné village belongs to the Czorsztyn Unit. It represents the klippe of red crinoidal limestones of Bajocian age (Krupianka Limestone Formation) passing upwards, in the uppermost preserved part, to red nodular limestone (Czorsztyn Limestone Formation). It is cut by Marikovský creek into two parts. The examined part of the klippe is a quarry occurring directly at the road connecting Udiča and Dolná Mariková villages, near the cemetery of the Hatné village. The locality has been mentioned by Pevný (1969), who described its brachiopod fauna. He reported the following brachiopods from this locality: *Loboidothyris perovalis* (Sow.), *Gnathorhynchia trigona* (Quenst.), *"Rhynchonella" balinensis* (Suess) and *Aulacothyris concava* (Parona). Latter, this locality was mentioned by Salaj (1994) as a site with the thickest preserved red crinoidal limestone in examined by him area. The latest paper published about the locality was that of Aubrecht & Sýkora (1998).

Crinoidal limestones forming the main portion of the klippe display sedimentary features, which are not typical for these sediments known from the Czorsztyn Unit. Their sedimentary area appears to be shallower and more dynamic than of the other localities of the Krupianka Limestone Formation. The red crinoidal limestones are thick bedded, with frequent cross-beddings (Figs 19, 20), a feature which is very rarely encountered in this formation. Cross-bedding in the lower part of the profile tends from left to right side of the quarry, while in the upper parts an opposite direction appears, with some beds showing both directions. The individual beds are not always continuous; some of them wedge out as observed in the quarry face.

The highest part of the Krupianka Limestone Formation is represented by bedded (with beds about 10–20 cm thick) red crinoidal limestone with undulating bedding planes. Colour of the limestones depends on their character, i.e. the cross-bedded strata are of light grey, white to yellowish in colour, whereas the structureless or parallel-bedded ones are red. The crinoidal limestones contain rich siliciclastic and dolomitic admixture of sand to small pebble size (up to 1 cm); some beds have intraclasts derived from the underlying layers, concentrated at the bottom. In the upper left part of the quarry, a steep onlap of the white crinoidal limestone onto the red one is observable. The contact is stair-shaped which can be related to synsedimentary tectonics. The white crinoidal limestone contains also up to 5 cm clasts derived from the red crinoidal limestone, close to this contact. These features reflect clearly a dynamic water environment; the sediments were most likely deposited above the wave base. The higher part of the formation displays gradual deepening of the sedimentary area and cessation of the wave influence.

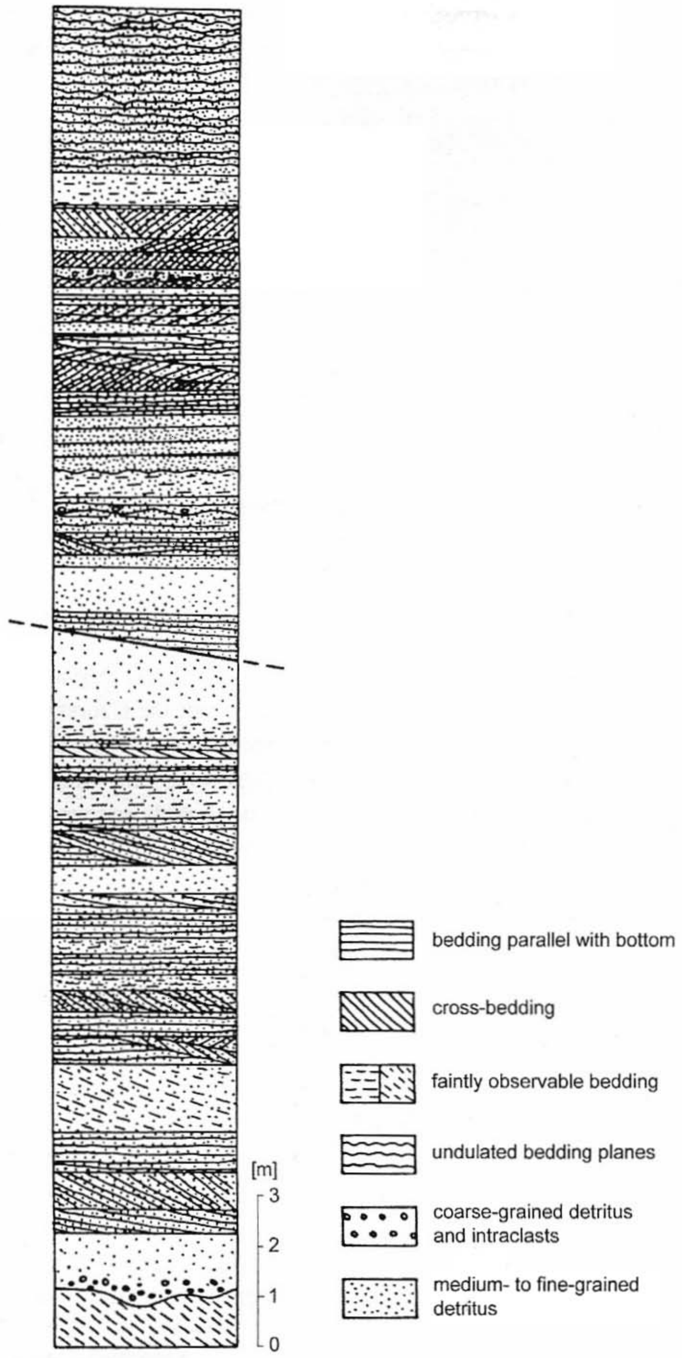


Fig. 19. Hatné. Lithological and sedimentological profile through middle part of the quarry wall (after Aubrecht & Sýkora 1998)

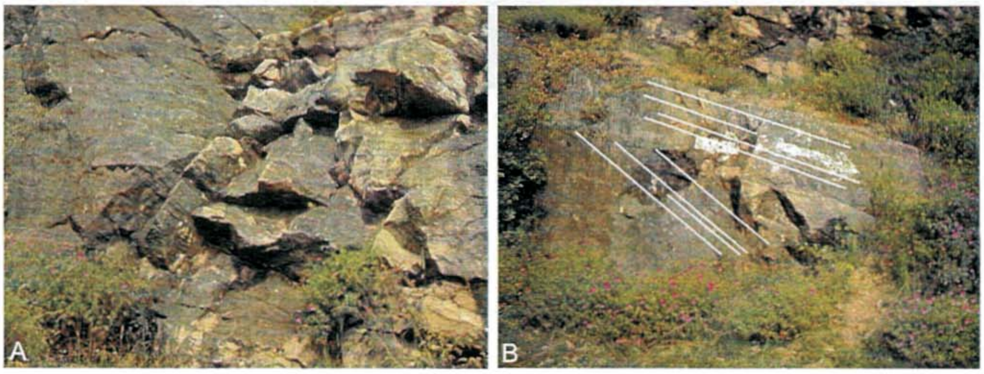


Fig. 20. Hatné. Northward dipping cross-bedding in the lower part of the quarry (A, B)

Microfacies analysis displays also a large difference between the white (cross-bedded), and red (parallel-bedded) crinoidal limestones. The first one represents crinoidal biosparite (grainstone) whereas the latter is biomicrite (packstone), with more diversified skeletal composition. The grainstones evidence more dynamic sedimentation where the red mud was winnowed from the interstices.

However, biota and clastic contents in both kinds of limestones is identical, though in somewhat different ratios (the red limestones have more diversified skeletal composition). The main portion of sediment consists of crinoid ossicles. Preservation of the crinoid skeletons is very poor; their stems were disintegrated completely (exceptionally some pluricolumnals even with attached cirri have been found), with individual ossicles frequently broken. This indicates Z4 zone of deposition of Głuchowski (1987) i.e. the near-shore shallow water environment, which is consistent with other sedimentological observations. Crinoidal detritus is usually full of small inclusions (even of cloudy appearance), but the syntaxial rims are clear.

Except crinoidal ossicles, also bryozoan fragments, echinoid spines, bivalvian and brachiopod shells are ubiquitous; gastropod shells and serpulid tubes are rare. In one instance, a poorly preserved fragment of coral or calcareous sponge was found. An absence of foraminifers in the sediment is striking. The sediment was strongly affected by compaction, as indicated by frequent pressure-solution features among the skeletal detritus up to the formation of frequent stylolites. They represent the latest diagenetic stage as they cut fully developed syntaxial rims on echinoderm particles.

Yellowish dolomitic and/or dedolomitized clasts are frequent in the sediment. They are either micritic of crystalline. In case of dedolomitization the crystals are often oriented inward the clast, indicating dedolomitization after redeposition. They sometimes possess Liesegang's stripes indicating their weathering on land. Around the dolomitic clasts, thin limonitic films developed frequently, related to iron expulsion during dedolomitization. The only rare faunal relics in dolomitic clasts were thin ostracod shells.

Most of quartz grains in the sediment display signs of corrosion, which is typical for alkaline environment inside limestone. However, at the very top of a bed 4 m above the bottom of the profile (parallel bedded red crinoidal limestone), the quartz grains possess syntaxial authigenic quartz overgrowths (Fig. 21). They cut neither the surrounding crinoidal ossicles nor their syntaxial rims. Instead, they use to copy the original shape of surrounding grains and fill the pores, hence they represent relatively early diagenetic phase. These overgrowths exhibit often undulatory extinction in continuation to the detrital core. The undulosity was either caused by effect of pressure in the sediment after formation of the authigenic overgrowths or it originated by strict copying of the detrital crystal structure during growth. In some instances of close opposite growing of the rims, straight compromise boundaries were formed between them. The first variant seems more probable. In some cases, the remnants of microquartz (chalcedony) were found, connected with authigenic rim. It is clear that the overgrowths were not formed in late diagenetic phases under burial conditions, as indicated by their occurrence only in one bed, filling of pores and predating of all the diagenetic phases including syntaxial rim formation on crinoidal detritus. Our interpretation of this phenomenon is that the overgrowths represent part of the silcrete sequence, developed during emergence of the crinoidal sand shoal.

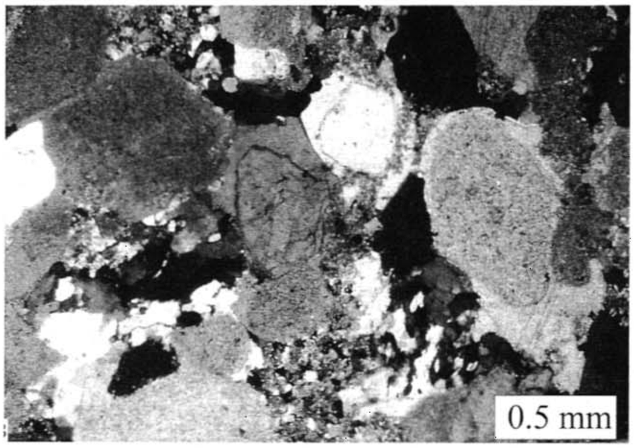


Fig. 21. Two close detrital quartz grains with syntaxial rims forming a compromise boundary between them (after Aubrecht & Sýkora 1998)

Red, partly nodular limestone (base of the Czorsztyn Limestone Formation) is preserved only at top of the right part of the quarry, which is relatively thrown down along a small normal fault. It is represented by wackestone to packstone (locally grainstone), with calcified sponge spicules and crinoidal ossicles being dominant skeletal components. Bivalve and brachiopod shells, together with gastropods, juvenile ammonoids, echinoid spines and bryozoan fragments form smaller portion of the skeletal detritus. However, the diversity of skeletal components is remarkably higher than in the underlying crinoidal shoal complex. The dominance of micrite, together with absence of the siliciclastic admixture are indicative of deepening of the sedimentary area and flooding of land areas of the Czorsztyn Swell. The sediment itself is penetrated by veinlets filled by clear blocky calcite. These veinlets are, however, cut by numerous stylolites, which then appear to be the latest diagenetic phenomenon in the limestone.

STOP 5 – BRODNO QUARRY – REGIONAL STRATOTYPE FOR THE J/C BOUNDARY

Jozef Michalík & Daniela Reháková

Continuous Jurassic-Cretaceous pelagic limestone sequence of the Kysuca Unit (Pieniny Klippen Belt) of the Brodno section is exposed in an abandoned quarry near the Brodno railway station (Fig. 22). It offers the best possibility to document the J/K passage in a wide area of the Western Carpathians. Good calpionellid, and nannofossil stratigraphic record completizes the older paleomagnetic data. High-resolution quantitative analysis of calpionellids, dinoflagellates and calcareous nannofossil assemblages indicates major variations in their abundance and composition. Correlation of the calcareous microplankton distribution and stable isotope analyses was used in the characterization of the J/K boundary interval as well as in the reconstruction of the paleoceanographical proxies during this time (Figs 23, 24).

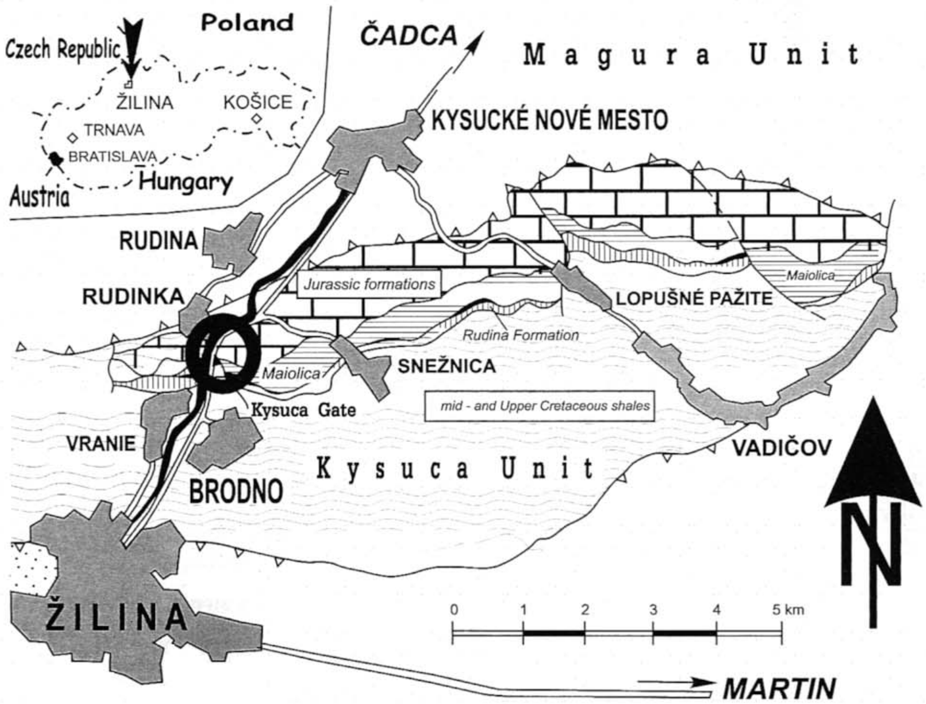


Fig 22. Location of the Brodno section in the Kysuca Gate (circle), north of Žilina

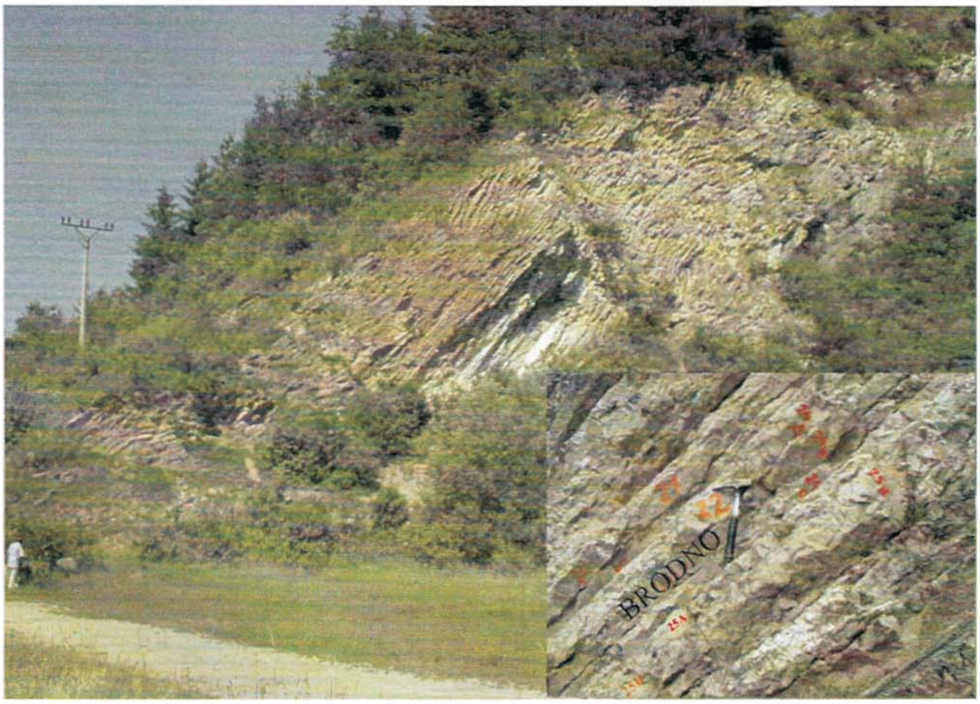


Fig. 23. General view of the Brodno quarry. The sequence is overturned, the left upper side consists of the Czorsztyn Limestone Formation, and the right side is formed by the Pieniny Limestone Formation. Lower right: a detailed view of the interval of Jurassic/Cretaceous boundary with the Brodno Sub-magnetochron

The succession starts with red nodular marly limestones of the *Ammonitico Rosso* lithofacies, known as the Czorsztyn Limestone Formation (Fig. 24). According to an analysis of the microfacies distribution, several long eccentricity (400 ka) cycles 0.5 to 1.6 m thick were recognized in part of the sequence appearing on the left side of the quarry wall roughly equal to. The architecture of these cycles seems to be controlled by eustatic sea level changes. The sequence is arranged into inexpressive low frequency (40 ka, i.e., obliquity) cycles expressed by an alternation of limestone layers and more marly insertions, controlled by climatic (humidity driven) oscillations. The biostratigraphic boundaries are usually not identical with the sequence ones, the former running usually within the highstand part of the underlying cycle.

1. The lowermost cycle (beds L51 to L58; Fig. 24) consists of pale greenish to rosa-coloured limestones (*Saccocoma* to *Globochaete* wackestones) with microfossils (*Cadosina parvula*, *Stomiosphaera moluccana*, *Cadosina semiradiata semiradiata*, *Colomisphaera pulla*, and *Carpistomiosphaera tithonica* documenting Early Tithonian Pulla and Tithonica zones. The last, thickest and most micritic layer (L58) represents the highstand conditions close to the end of the M22 normal paleomagnetic chrone.

2. The second cycle of thin-bedded nodular to brecciated pale greenish limestones (wackestone to packstone) with red cherts and marly interlaminae (L59 to L67 beds) is terminated by thicker L68 layer forming the highstand part. *Saccocoma* Agassiz and *Globochaete alpina* Lombard predominate over crinoid ossicles, bivalve and aptychi fragments, ostracod shells, foraminifer tests, calcified radiolarians, and dinoflagellates (*Cadosina semiradiata semiradiata*, *Cadosina semiradiata fusca* and *Parastomiosphaera malmica*) of the Early Tithonian Malmica Zone association.
   The calcareous nannofossil assemblage from the interval L52 to L68 is dominated by *Conusphaera mexicana mexicana*, *C. mexicana minor*, *Cyclagelosphaera margerelii*, *C. deflandrei*, *Watznaueria barnesae*, and *W. manivitae*. The absence of the nannolith *Polycostella beckmannii* in the association permits parallelization with the Early Tithonian Hexapodorhabdus cuvillieri (NJ 20-A) Subzone of the Conusphaera mexicana mexicana Zone.
3. The lower part (beds L69–L74) of the higher, third cycle (the upper part of the normal M21 magnetozone), consists of a radiolarian-globochaetid wackestone and packstone. Acme accumulation of thick-walled *Cadosina semiradiata semiradiata* (L69) and *C. semiradiata fusca* (the Semiradiata Acme Zone) accompanied by abundant *Conusphaera* could be a proxy of increasing sea surface temperature conditions.
   The middle part (beds L75–L79) of the cycle is formed by rose-grey biomicrite of the radiolarian – *Saccocoma* – *Globochaete* microfacies (packstone, wackestone). Calcareous dinoflagellate cysts (*Parastomiosphaera malmica*, *Schizosphaerella minutissima*, *Colomisphaera carpathica*, *Cadosina semiradiata semiradiata*, *C. semiradiata-fusca*) and early calpionellid forms with microgranular lorica (*Longicollaria dobeni*, *Borziella slovenica* and *Daciella danubica*) indicate the Dobeni Subzone of the Middle Tithonian Chitinoidella Zone (the lowermost part of the reversed M20 magnetozone).
   The upper part (L80–L89) of the cycle consists of marly nodular to brecciated limestones with marly interlaminae. Calcareous dinoflagellates are represented by *Schizosphaerella minutissima*, *Colomisphaera carpathica*, *C. nagyi*, *C. tenuis*, and *Cadosina semiradiata semiradiata*. The occurrence of *Chitinoidella boneti*, *Borziella slovenica*, *Dobeniella tithonica*, *D. cubensis*, and *D. bermudezi* characterizes the Boneti Subzone of the Chitinoidella Zone.
   Calcareous nannofossils obtained from L69 up to L96 were assigned to the Polycostella beckmannii Subzone (NJ 20-B) within the range of the Middle Tithonian; magnetochrone M 21n to M 20n. The assemblages of the lower part of this interval are dominated by *Conusphaera mexicana mexicana*, accompanied by *C. mexicana minor*, *Watznaueria barnesae,* and *W. manivitae*. The nannolitic form of *Polycostella beckmannii* are abundant in the interval L77 to L83. *Discorhabdus ignotus* and *Zeugrabdothus erectus* occur less frequently.
4. The fourth cycle (L90–L98) is represented by a complex of pale bedded indistinctly nodular biomicrite limestones. Wackestones of radiolarian – *Saccocoma* – *Globocha-*

ete, and locally silicified *Saccocoma* – radiolarian biomicrites contain *Colomisphaera tenuis*, *Schizosphaerella minutissima*, and *Colomisphaera carpathica*. *Chitinoidella boneti*, *Dobeniella tithonica*, *D. bermudezi* and transitional early hyaline *Praetintinnopsella andrusovi* characterize the uppermost Boneti Subzone (Chitinnoidella Zone) and the passage into the Praetintinnopsella Zone.

5. The fifth cycle starts with the L99 layer (paleomagnetic Kysuca Subzone) below well-bedded pale rose-grey *Maiolica* limestones of the Pieniny Limestone Formation. Each limestone layer (4 to 20 cm thick) is separated by thin (2 to 40 mm) marly interlaminae. If the sedimentary rate is assumed to attain 2.9 mm/ka, each bed represents a time interval of 40 ka climatically driven obliquity cycle. Then, the eccentricity cycle comprises 60 to 232 cm in thickness. Biomicrite wackestone with *Crassicollaria* – *Globochaete* – radiolarian microfacies contains *Crassicollaria intermedia*, which predominate over *Crassicollaria massutiniana*, *C. parvula*, *Calpionela alpina*, *C. grandalpina, Tintinnopsella remanei,* and *T. carpathica*. The association of calcareous dinoflagellates is composed of *Schizosphaerella minutissima*, *Colomisphaera carpathica*, *Cadosina semiradiata semiradiata*, *C. semiradiata fusca*, and *Stomiosphaerina proxima*. The calpionellid index association indicates the Remanei Subzone of the Crassicollaria Zone.

   Samples L98 to C26 were attributed to the Microstaurus chiastius Zone NJK. The FO of *Helenea chiastia* and *Hexalithus noeliae* indicates the Late Tithonian Hexalithus noeliae Subzone (NJK-A) of the Watznaueriaceae coccoliths (*Watznaueria barnesae, W. manivitae*) fluctuate in a range of 25 to 80%, *Cyclagelosphaera margerelii* in 3–20%. *Discorhabdus ignotus* and *Zeugrabdothus erectus* is abundant (up to 10%) in the C1B bed. The LO of *Polycostella beckmannii* observed in the C4A sample indicates Late Tithonian age.

6. The sixth cycle (C14–C16) is built up of well bedded pale *Maiolica* limestones (biomicrite *Crassicollaria* – *Globochaete* and radiolarian – *Crassicollaria* wackstone) with thin (up to 2 cm) marly interbeds. Small *Crassicollaria brevis* dominates over *Calpionella grandalpina*, *C. alpina*, *Crassicollaria parvula* and *Tintinnopsella carpathica.* Their association with calcareous dinoflagellates of *Schizosphaerella minutissima*, *Colomisphaera carpathica,* and *Stomiosphaerina proxima* characterize the Brevis Subzone of the Late Tithonian Crassicollaria Zone. Here, the FO of *Nannoconus infans* (C13) and with the FO *Nannoconus wintereri* (C17) has been recorded. Both forms, which flourished under warmer and possibly more nutrient-depleted surface waters, indicate the Late Tithonian NJK-b to NJK-c subzones.

7. Bedded pale gray biomicrite wackestone to packstone (C17–C22) with thin (up to 2 cm) marly interbeds consists of crassicollarian-globochaete and radiolarian-globochaete-crassicollarian microfacies. Common *Globochaete* with *Crassicollaria parvula* and *Calpionella grandalpina* predominate over *Crassicollaria colomi*. *Calpionella*

alpina, *Tintinnopsella carpathica*, and *T. doliphormis* are frequent. Dinoflagellates contains *Schizosphaerella minutissima*, *Colomisphaera carpathica*, *C. fortis*, and *Stomiosphaerina proxima*. The presence of *Crassicollaria colomi* indicates the Colomi Subzone of the Crassicollaria Zone. Sole *Cruciellipsis cuvillieri* was found in C20, close to the FO of *Nannoconus wintereri.*

8. The calpionellid-globochaete microfacies in a well bedded pale gray biomicritic wackestone with thin (up to 1 cm) marly insertions (C23A–C25A) is dominated by small sphaerical *Calpionella alpina*. *Crassicollaria parvula*, *C. colomi* along with *Calpionella grandalpina* and *Tintinnopsella carpathica* are less frequent. The base of the Alpina Subzone of the Calpionella Standard Zone was identified in the C24A Bed. The Brodno Magneto-Subchron was located in the layer C24B.
9. Well bedded pale biomicritic wackestones with Calpionella-Globochaete and Calpionella-radiolarians microfacies (C25B–C27E). *Globochaete alpina* dominates over *Crassicollaria parvula*, *Tintinnopsella carpathica*, *Cadosina semiradiata fusca*, *C. semiradiata semiradiata*. The microbreccia layers contain small limestone clasts with Tithonian microfossils.
10. A complex with anomalously thick (20–48 cm) layers of biomicritic Calpionella wackestone (C28A–C29A) is terminated by submarine slump. Small sphaerical *Calpionella alpina* still dominates. The FO of *Nannoconus steinmanni minor*, the increase in abundance and diversity of nannoconids in C28 enabled drawing the base of NJK-D Nannoconus steinmanni subsp. minor Subzone, which is correlated with the earliest Berriasian. The start of nannoconid bloom is indicated by the FO of *Nannoconus steinmanni minor*, *N. globulus minor*, and *N. kamptneri minor* accompanied by *Conusphaera mexicana mexicana*, *Cyclagelosphaera deflandrei*, *C. margerelii*, *Diazomatholithus lehmannii*, *Discorhabdus ignotus*, *Watznaueria barnesae*, *W. britannica*, *W. manivitae*, and *Zeugrhabdotus embergeri.*
11. The radiolarians in thick-bedded cherty limestones with radiolarian – Calpionella microfacies (C29B–C38) are dispersed in the wackestone, but also concentrated in six 4–6 cm thick radiolarite layers. The first occurrence of *Remaniella ferasini* (Catalano) in the overlying thick bedded cherty *Maiolica* limestones indicates the base of the Ferasini Subzone of the standard Calpionella Zone.

Stable isotope ($\delta^{18}O$, $\delta^{13}C$) analyses indicate a relatively cold period occasionally disturbed by warm episodes during the latest Tithonian. This is also documented by low contents of organic carbon. Near the J/K boundary the oxygen isotope values indicated temperature and salinity changes probably influenced by an invasion of warm water (or stagnancy of cold water input) into the basin resulting in nannoconid bloom episodes. Late Tithonian cooling was followed by temperature increase during the very end of the Tithonian and at the beginning of the Berriasian.

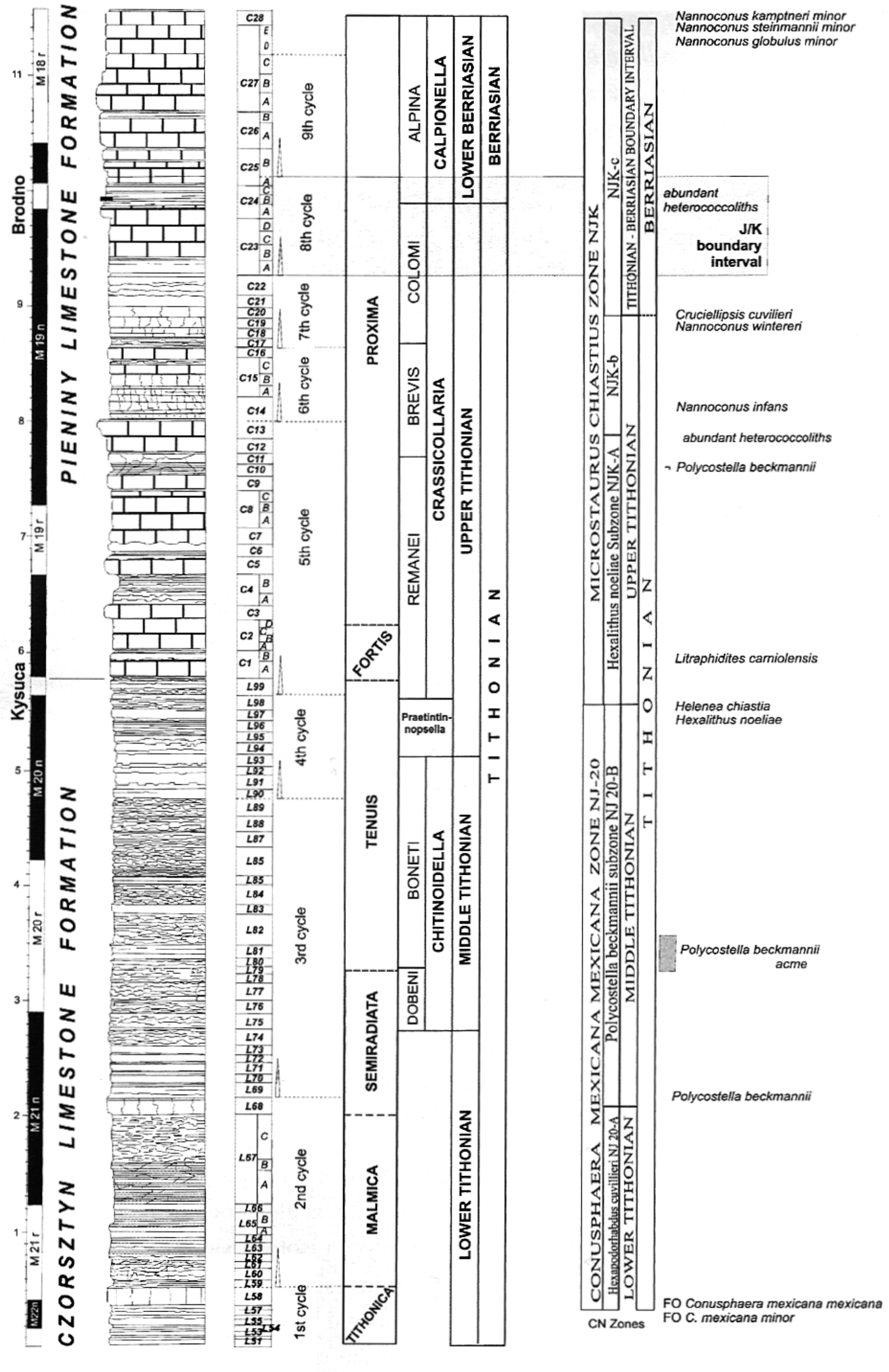


Fig. 24. Comparative scheme of magnetostratigraphy, litostratigraphy, lithology, cyclostratigraphy, and dinocyst, calpionellid and nannofossil biostratigraphy in the Brodno section

THE MANÍN UNIT IN THE GEOLOGICAL STRUCTURE OF THE STRÁŽOVSKÉ VRCHY MTS (Fig. 25)

Jozef Michalík

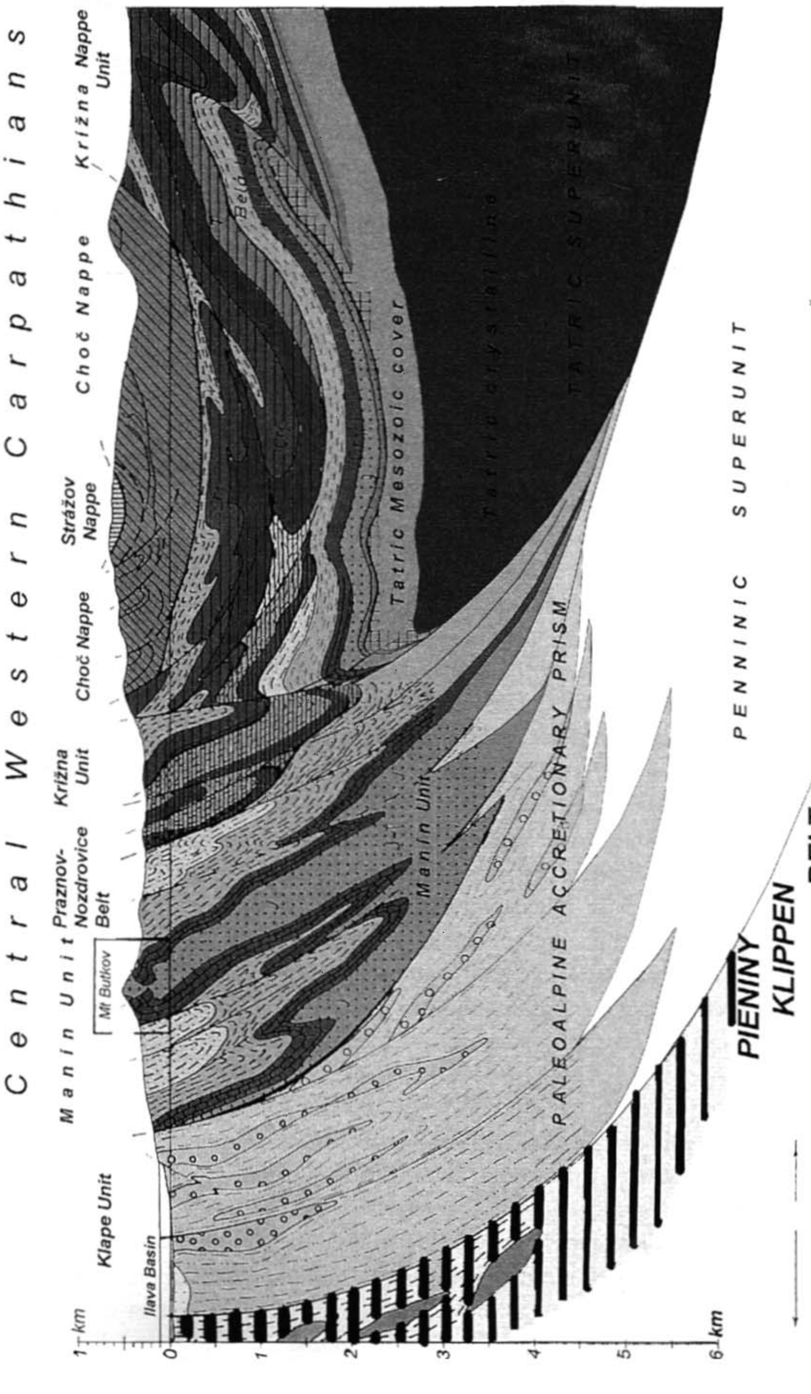
The Central Carpathian block is rimmed by an extensive, dissected Strážovské Vrchy Mts. This mountain range crops out along the left bank of the Váh River between the towns of Žilina and Trenčín, being separated by the Jastrabie Saddle from the Považský Inovec Mts on the S, by the Fačkov Saddle from the Lúčanská Malá Fatra on the E and by five basins: Rajec-, Žilina-, Púchov-, Ilava- and Trenčín basins on NE, N and W.

The geological structure of the Strážovské Vrchy Mts traceable on 300 square kilometers large area is assymetric with a crystalline "core" situated far on the SE periphery. Complex Paleoalpine superficial nappe structure consists of almost all Centro-Carpathian units starting with the Tatric through the Manín Unit, Fatric Belá and the Krížna nappes, the Choč Unit of Hronic with the Čierny-, Biely Váh and the Bebrava partial nappes, or with the Middle and Upper Cretaceous sequences of the accretionary Peri-klippen Belt including olistostromatic Kostelec and Klape complexes. The Paleogene and Neogene cover is preserved in rests of intra-mountain basins (Fig. 25).

Neoalpine tectonic structure is characterized by partial imbrications and nappe slices, affected by the Savian back thrusting. Finally, the area was dissected by NW-SE and NNW-SSE transversal fault systems concealing the original zonal architecture.

The Tatric crystalline core is typical of migmatite, amphibolite and paracrystalline mantle rocks dominating over granitoids. Neosome layers (or intrusions ?) pass through migmatites of several types in paraschists complexes preserving its original pre-Alpine structure. Its Mesozoic cover sequence commences with Scythian quartzose sandstones of the Lúžna Formation overlain by Middle Triassic carbonates (Gutenstein Limestone, Ramsau Dolomite). The Carpathian Keuper is transgressively overlain by Jurassic/Lower Cretaceous complex of black shales with intercalations of silicites and cherty limestones. The Albian claystones contain large paraconglomerate bodies.

The Manín Unit is regarded as a marginal element of either Tatric or Fatric tectonic system. The sequence starts with Triassic members in the SW part of the mountains, whereas Lower Jurassic limestones lie on the base of the sequence in northernmore areas. There are at least four different structures recognizable in the area: the Manín zone, the Jelenia skala – Podmanín – Skalica zone, the Butkov body and the complicated zone between Trenčianske Teplice Spa and Skalka Hill near Trenčín. Triassic complexes attributed by several authors to the Manín Unit occur in the last area only. The Manín type of the Jurassic-Lower Cretaceous sequence is characterized by shallower facies (e.g. red nodular limestones), the Butkov type comprises also middle Jurassic silicites. Lower Cretaceous sequence consists of pelagic limestone facies, followed by carbonate platform products (it started during Late Hauterivian in Manin, but as late as in Aptian in the Butkov area). The sequence is covered by Late Albian-Cenomanian marls and by Upper Cretaceous flysch facies.



from Žitt & Michalík, 1988 (adapted)

Fig. 25. Geological section of the margin of Central west Carpathians built by the Manín and Kostelec Units (after Žitt & Michalík 1988, modified)

The character of Triassic sequences in both the Belá- (marginal nappe slice) and Zliechov units of the Krížna Nappe is comparable. However, Jurassic sediments are represented by crinoidal limestones in the Belá Unit, while the Jurassic sequence of the Zliechov Unit consists of Hettangian Kopieniec Formation, Lower Jurassic "Fleckenkalk", Adnet limestone, Middle Jurassic silicites of the Ždiar Formation, and by Upper Jurassic dark marlstones of the Jasenina Formation. Similarly, Lower Cretaceous carbonates with frequent gaps are covered by "Urgonian" limestones and by black Albian limestones (resembling the Manín sequence) in the Belá Unit, while Berriasian hemipelagic *Biancone* (Osnica Formation) and spotted Valanginian to Aptian limestones (Mráznica Formation) with small volcanoclastic bodies represent Lower Cretaceous sequence of the Zliechov Unit. Albian and Cenomanian strata are represented by shaly Poruba Formation, passing upwards into distal flysch.

The Choč Unit is represented by Permian shales with paleobasalt bodies and by thick complex of Triassic carbonates. In frontal part of the nappe, Jurassic and Lower Cretaceous limestone sequence is preserved. It terminates with Hauterivian/Barremian marls with sandy admixture containing abundant grains of chromium spinels.

The Bebrava Unit is characterised by the Anisian Steinalm Limestone with small bioherm bodies and by frequently brecciated Wetterstein and Upper Triassic dolomites.

The Strážov Nappe is the highest tectonic unit in the nappe structure. The sequence commences with Anisian grey foraminiferal, crinoidal and bioherm limestones of the Wetterstein type. They are overlain by Upper Triassic dolomites.

Paleogene sequences fill rest of basins both in the Palaeoalpine suture (the Hričov Zone) and in the intra-Carpathian Rajec Basin. The Mesozoic substrate was karstified prior to the transgression, the karstic holes were filled by bauxite and laterite wastes. The base of the Paleogene sequence is diachronic, becoming younger from outer zones into orogene. The sequence consists of thick carbonate breccias and conglomerates with occasional algal reef bodies (in the marginal zone).

Neogene sediments fill several pull-apart basins sealing the Peri-Pieninian Fault zone, which separates the mountain range from the Pieniny Klippen Belt. On the other hand, they form only small erosive relics on levelled surfaces and denudation terraces in the mountains.

STOP 6 – TUNEŽICE QUARRY – LOWER LIASSIC TO AALENIAN SEQUENCE OF THE MANÍN UNIT

Jozef Michalík, Ján Schlögl & Marián Golej

Still exploited Tunežice quarry is situated on the E slope of the Kalište Hill (679.5 m), approx. 1800 m S of the Ladce village. Lower Liassic sequences belonging to the Manín Unit are outcropping here (Fig. 26). Importance of the locality is that they represent the continuation of the sequences uncovered in the Butkov quarry. It is to note, that the formal names of the lithostratigraphic units exploited in the quarry are not in agreement with the classical facies from type localities. To avoid useless enlargement of the facies variability of ancient lithostratigraphic units, some of them should be probably defined as new. Except the Early Liassic Holiak Formation, all other Liassic formation can be observed in the quarry.

Fig. 26. Tunežice quarry

Holiak Formation (Rakús & Hók 2005, not outcropping in the quarry) consists of dark-grey to black organodetrital slightly-sandy limestones with black silicites intercalated by grey claystones and siltstones. The thickness of the formation in the Holiak type locality is 5 m, but 30–150 m in the Manín Narrows. Pressumed age is Hettangian.

Trlenská Formation (Bujnovský *et al.* 1979) (Figs 27, 28). It is a facialy variable unit, and can be subdivided in three parts:

Beds 120–360: bedded fine-grained grey-brownish, grey to dark-grey spiculitic limestones with common dark-grey, black to brown cherts and marly intercalations (Fig. 27A). Cherts generally represent silicified galeries of *Thallassinoides* burrows (Fig. 28). Beds usually have undulated surfaces. Thick-shelled *Gryphaea* sp. occurs from the bed 268, and can be find until the bed 315, some beds bears *Gryphaea* accumulations, shells are often in live position (Fig. 27B). Apart these, common brachiopods, belemnites, and some other bivalves are present too. Ammonites are scarce, some Arietitids were found on the base of studied section, probably of Lower Sinemurian in age. *Gryphaea* interval yielded severeal badly preserved echioceratid ammonites, most probably of the Upper Sinemurian age. Uncovered thickness is 130 m.

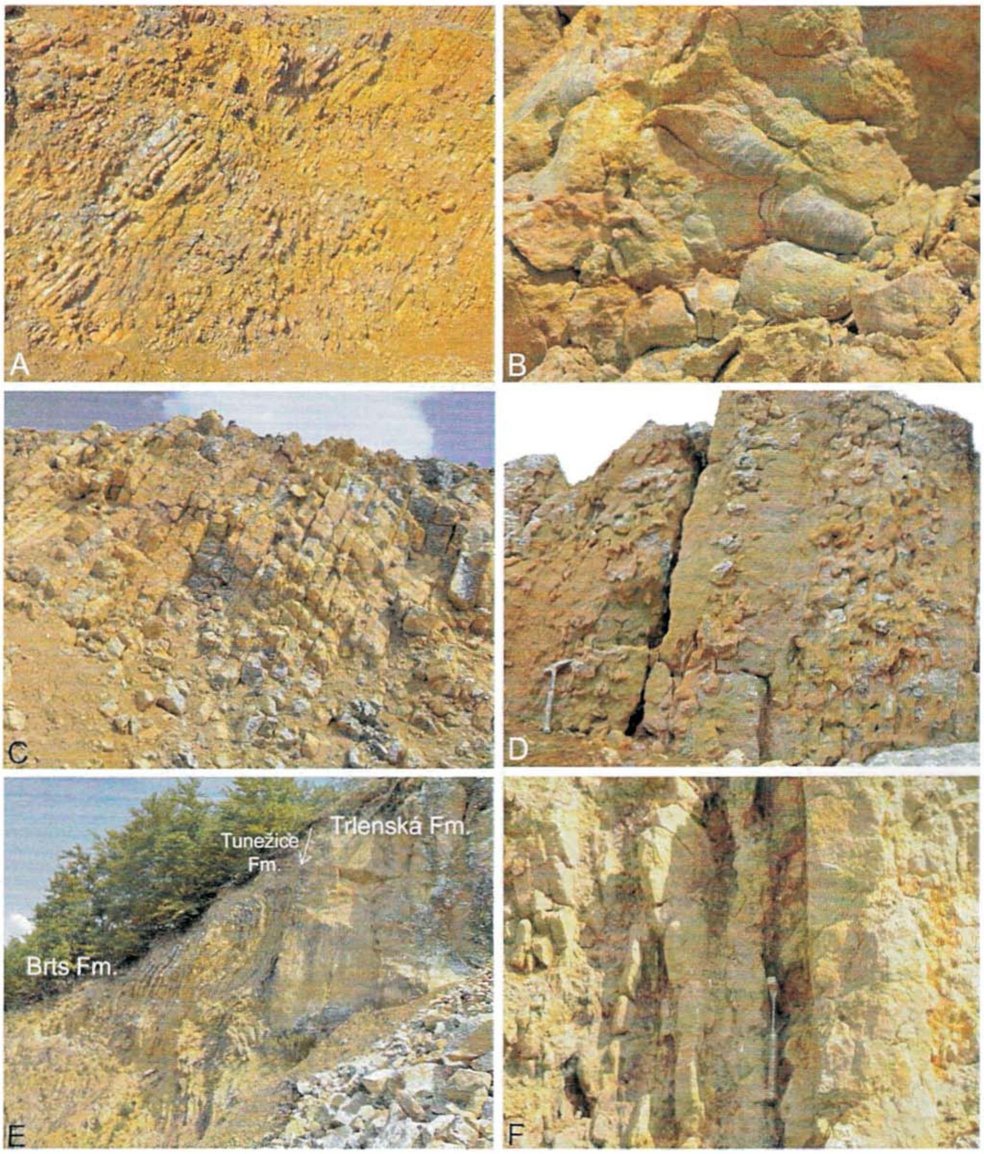


Fig. 27. A) Trlenská Formation, bedded grey spiculitic limestones with cherts and *Gryphaea* sp. B) Detail of *Gryphaea* shells in live position. C) Thick-bedded grey crinoidal cherty limestones with *Thallasinoides* galeries. D) Thick beds with silicified *Thallassinoides* galeries. E) Contact of the uppermost part of the Trlenská Formation, massive sandy-limestones, and the condensed limestones with marls of the Tunežice Formation. F) Detail of the condensed horizon with abundant ammonites of the Bifrons Zone of Middle Toarcian

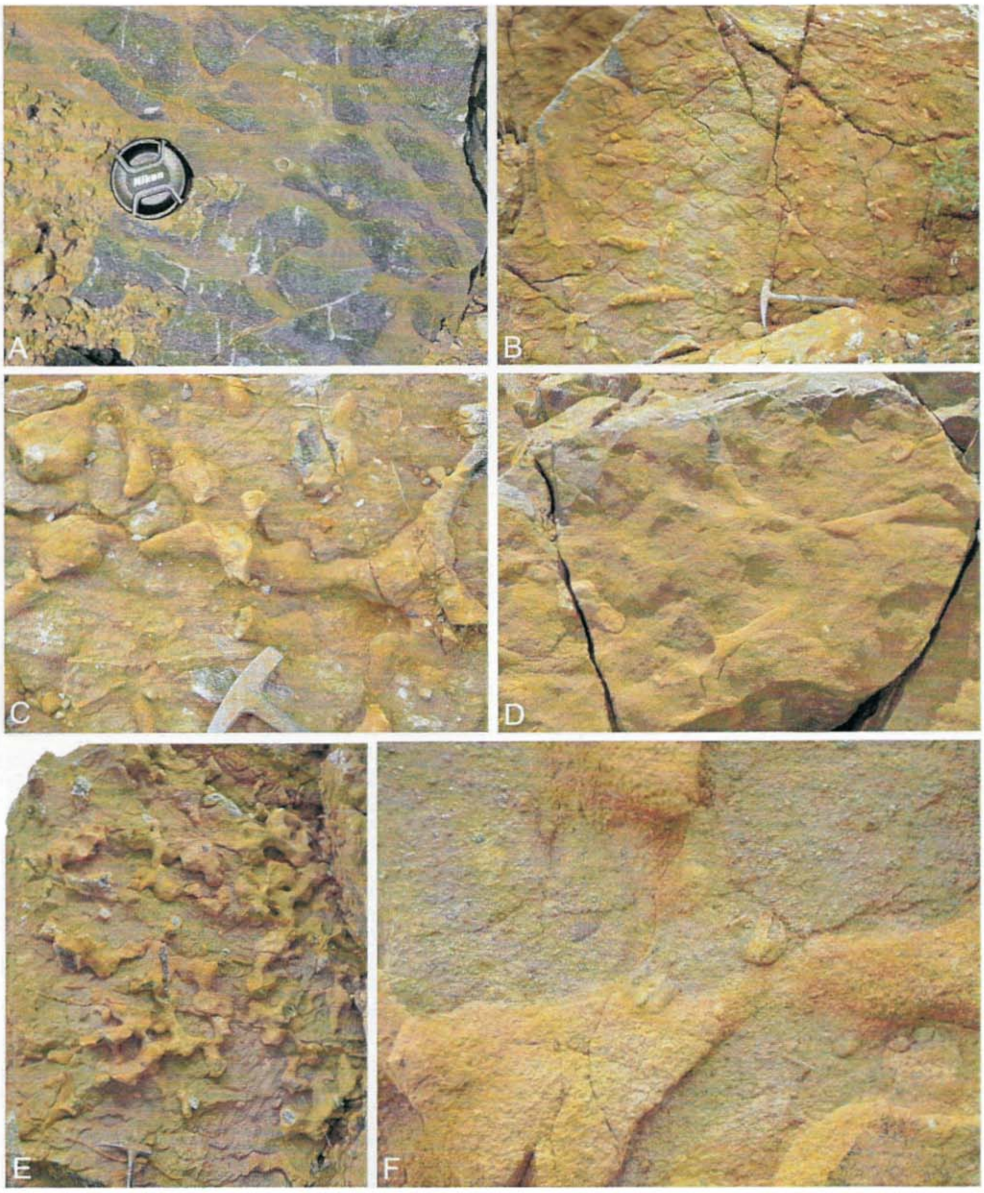


Fig. 28. A) Extensively bioturbated dark-grey crinoidal limestones of the Trlenská Formation, galeries are filled with marly deposits, deformed by compaction of the sediment. B)–E) Silicified *Thallassinoides* bioturbations. F) Abundant silicified brachiopods in the sediment surrounding the silicified *Thallassinoides* burrows

Beds 361–502: thickly bedded fine to medium-grained grey to dark-grey crinoidal to spiculitic limestones with clastic Q admixture and common darkgrey to brown cherts.

Cherts are often situated in the lower parts of beds, and represents silicification of the *Thallassinoides* galeries (Figs 27C, D, 28). Belemnites and brachiopods are abundant, usually also silicified (Fig. 28F). Overall thickness is around 24 m.

Interval ***below bed 502***: Thick-bedded dark-grey crinoidal limestones rich in clastic Q admixture pass gradually to massive pale well sorted sandy limestones to almost sandstones (Figs 27E). These gradually pass to sandy light-grey massive limestones. Thickness is around 13 m.

Tunežice Formation (Rakús & Hók 2005). Between the massive sandy limestones and bedded limestones of the Tunežice Formation, there is a interval of bedded pink sandy crinoidal limestones with thin marly intercalations. The interval is 100 cm thick. No macrofauna.

Following 14 cm thick bed is a marker horizon (Fig. 27F), which can be traced until the Butkov quarry. It is condensed reddish to greenish limestone bed rich in ammonites and belemnites. Overlying violet and green marl interval also yielded numerous ammonite casts.

Preliminary list of fauna:

Limestone bed: *Catacoeloceras* sp. cf. *jordani* Guex
Dactylioceras sp.
Hildoceras sublevisoni Fucini
Hildoceras bifrons (Bruguičre)
Hildoceras cf. *bifrons* (Bruguičre)
Hildoceras crassum Mitzopoulos
Hildoceras cf. *lusitanicum* Meister
Hildoceras sp. (m)
Harpoceras sp.
Harpoceras gr. *falciferum* (Sowerby)

This fauna is indicative of the Bifrons Zone of Middle Toarcian.

Marl intercalation: *Hildoceras* cf. *bifrons* (Bruguičre)
Hildoceras cf. *lusitanicum* Meister or *H. apertum* Gabilly
Hildoceras cf. *tethysi* Géczy

This fauna is also indicative of the Bifrons Zone of Middle Toarcian.

The section continues with beds of brownish to pinky crinoidal limestones, wackestones to packstones (Fig. 27E). Lowermost beds contain also abundant small lithoclasts. Beds are separated by thick intercalations of violet to greenish marls, some "beds" represents aligned limestone lenses within the marly interval. Overall thickness of the Tunežice Formation is around 3 m.

Brts Formation (Rakús & Hók 2005). Pinky crinoidal limestones of the Tunežice Formation pass to bedded grey cherty limestones with dark-grey marly intercalations. Middle part of the formation yielded *Tmetoceras* sp., indicating Aalenian age (Rakús & Hók 2005). The formation has the same characteristics as in the Butkov quarry and will not be dealt in detail here.

STOP 7 – BUTKOV QUARRY – UPPER LIASSIC TO CRETACEOUS SEQUENCE OF THE MANÍN UNIT

Jozef Michalík, Daniela Reháková & Ján Schlögl

More than one half of century, the Manín Unit remains the source of controversies in the Carpathian geology. The Butkov anticlinal body consists of Jurassic and Lower Cretaceous formations in facies similar to peripheral Fatric (or Tatric) zones but occurring along close proximity of the Pieniny Klippen Belt. Some authors consider resemblance of both the Manín and Klape units and stress the continuity of Cretaceous sequence and the absence of Cenomanian-Turonian gap, obvious in Central Carpathian units.

Triassic part of the Manín sequence is exposed in its southermost part, between Trenčín and Trenčianske Teplice. It is represented by Upper Triassic dolomites and Rhaetian bituminous shales, and shelly limestones. In northernmore area, the sequence starts with Jurassic members. Extensive outcrops of this sequence are exposed by the Butkov quarry (Fig. 29) of the Ladce Cement Works in the middle Váh Valley.

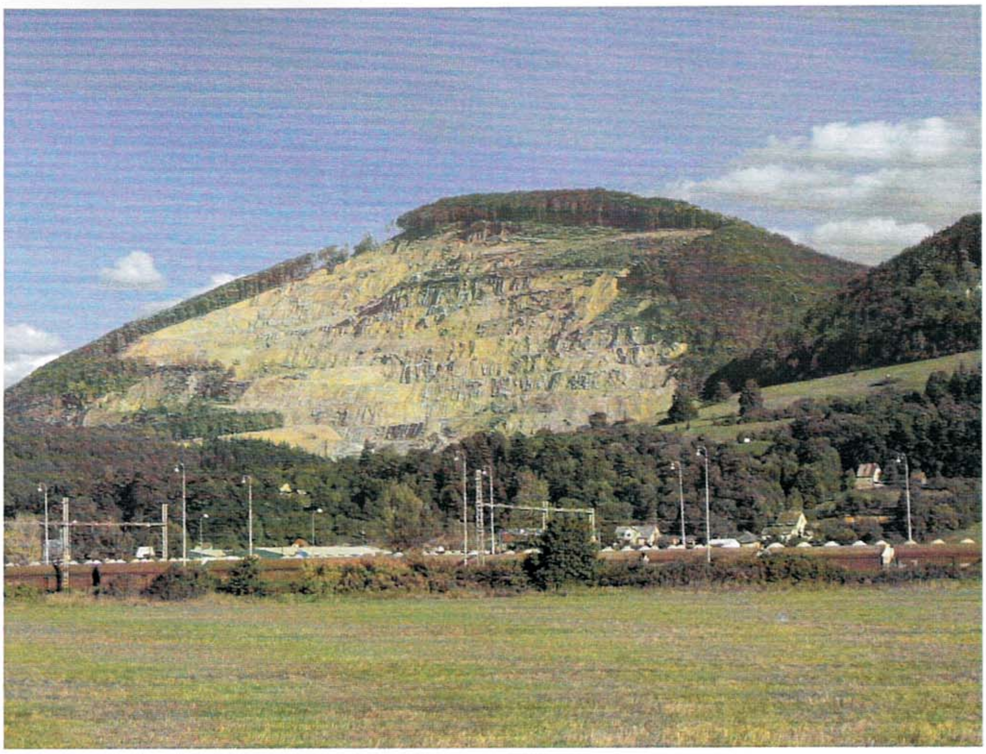


Fig. 29. Panoramic view on north-western slope of Mt Butkov with the Ladce Cement Works quarry. Jurassic deposits are uncovered on the uppermost three levels

Trlenská Formation (Bujnovský *et al.* 1979). Only uppermost part of the formation up to 10 m thick outcrops here. It is composed of massive to thickly layered (20–80 cm) grey sandy crinoidal calcarenites with common belemnite rostra (Fig. 30A). Pliensbachian age is supposed for the uncovered here part of the formation (Rakús & Hók 2005).

Tunežice Formation (Rakús & Hók 2005) is build by thin bedded greenish gray spiculitic limestones with crinoid ossicles intercalated with green claystone with glauconite. The uppermost part consists of grey biomicrite limestone. Its age is estimated as Late Pliensbachian-Middle Toarcian. In all studied oucrops there is invariably a condensed limestone-marl horizon situated in the basal part of the formation (Fig. 30B, C).

Preliminary list of ammonite fauna (after Čunderlíková 2007, and new collections of JS):
Calliphylloceras sp.
Lytoceras aff. *siemensi* Denckmann
Lytoceras aff. *verpillierense* Rulleau
Dactylioceras cf. *commune* Sowerby
Dactylioceras (Orthodactylites) cf. *semiannulatum* Howarth
Catacoeloceras sp.
Porpoceras cf. *vortex* (Simpson)
Hildoceras bifrons (Bruguičre)
Hildoceras sublevisoni (Fucini)
Hildoceras lusitanicum Meister
Hildoceras sublevisoni (Fucini)
Hildoceras apertum Gabilly
Hildoceras crassum Mitzopoulos
Hildoceras semipolitum Buckman
Hildoceras aff. *lusitanicum* Meister
Frechiella subcarinata Young et Bird
Frechiella cf. *kammerkarensis* Stolley
Harpoceras sp.
Harpoceras cf. *subplanatum* (Oppel)
Phymatoceras gr. *robustum* (Simpson)
Denckmania sp. (various species)
Haugia sp.

Majority of the fauna is indicative of the Bifrons Zone of the Middle Toarcian. Taxa, such as *Denckmania* and *Haugia* are stratigraphically younger, restricted to the Variabilis Zone of the late Middle Toarcian.

Brts Formation (Rakús & Hók 2005). Gray well bedded organodetrital limestones (Fig. 30D) with low quartz sand content, gray-brown chert nodules and thin interbeds of grayish green marl in lower part of the formation are terminated by 30 cm layer with fluid casts. The middle part is formed by bedded (10–20 cm) cherty sandy limestone with interbeds (5–8 cm) of silty marlstone. The upper part consisting of gray limestone and marl is terminated by expressive condensation Mn-Fe rich level full of belemnite rostra, ammonites, nautiloids. The age of this 30 m thick formation is Late Toarcian-Aalenian.

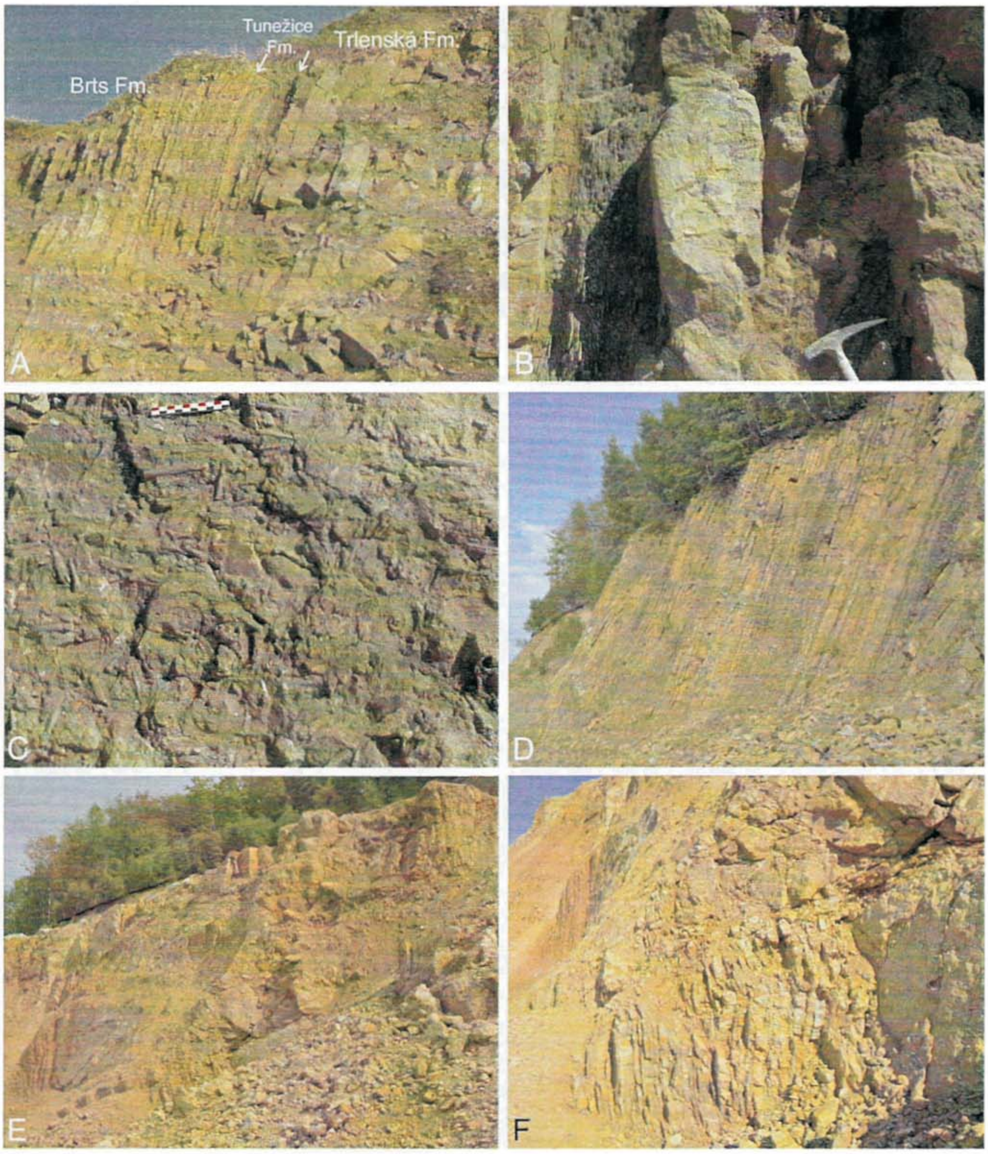


Fig. 30. A) Contact of the thick-bedded sandy-limestones of the Trlenská Formation with condensed limestone-marly deposits of the Tunežice Formation. Left side is built of cherty limestones and marls of Brts Formation. Arrow points to the condensed bed with abundant ammonites and belemnites of the Middle Toarcian age. B) Detail of the condensed ammonite level (with hammer). C) View on the lower surface of the condensed ammonite bed, to note several *Hildoceras* species. D) Cherty dark limestones of the Brts Formation. Aalenian. E) Heavily deformed Middle and Upper Jurassic part of the sequence on the 14^{th} level. F) Radiolarite limestones overlying lower *Ammonitico Rosso*

Six metres thick complex of greenish gray to brown-gray siliceous detritic limestones with brown red (diffuse) cherts with crinoids and belemnites probably represents Aalenian strata. The uppermost layer formed by yellowish red brown, grained siliceous limestone with ferruginous crust is overlain by reddish gray fine detrital limestones with red cherts.

The lowermost *Ammonitico Rosso* consists of brown grey nodular limestone (Fig. 30E). Ammonite fauna includes *Nannolytoceras* cf. *tripartitum* (Raspail), ?*Morphoceras* sp., *Oxycerites* sp. and *Choffatia (Subgrossouvria)* sp., which indicate its Early to Middle Bathonian age (Rakús & Ožvoldová 1999). It is followed by 3–4 m thick brown-gray fine-grained radiolarian limestone with stratiform layers of red brown radiolarite (Fig. 30E, F). Based on radiolarian associations its age is Late Bathonian (Rakús & Ožvoldová 1999). The silicite complex is separated by few layers of red and grey micritic nodular limestone from overlying beds of greenish yellow radiolarian limestone and silicite ("banana-silicite" Michalík *et al.* 1990) of Oxfordian age.

Czorsztyn Limestone Formation (Mojsisovics 1867). The complex of red nodular micritic limestones contains microfossils of Kimmeridgian and Tithonian age (saccocomids, calcareous dinoflagellates and calpionellids, radiolarians, globochaete), belemnites, brachiopods (*Pygope*), bivalves, echinoids and crinoid calyces. Berriasian strata were affected by strong erosion being mostly removed. Lower Cretaceous sequence starts with synsedimentary breccia composed of clast of Tithonian limestones. The "Basal Breccia" attains thickness of 1 to 5 meters.

Ladce Formation (Borza *et al.* 1987) consists of "sublitographic" massive slightly marly limestones exposed predominantly in the higher levels of the quarry. The formation is divided into the lower clastic and the upper pelagic member. Their thickness is a about 30–35 m. The ammonite fauna of the Campylotoxus Zone confirms the start of thin bedded pale marly limestone deposition of the Ladce Formation during Early Valanginian. *Vergoliceras salinarium* (Uhlig), *Kilianella retrocostata* Sayn, *Karakaschiceras inostranzewi* (Karakasch) occur together with the index *Busnardoites campylotoxus* (Uhlig). *Neocomites teschenensis* (Uhlig), *N. platycostatus* (Sayn), *N. beaumugnensis* (Sayn), *Olcostephanus guebhardi* Kilian occur somewhat higher up in the sequence. The sedimentation of the Ladce Formation was finished during Late Valanginian, documented by *Olcostephanus nicklesi* Wiedmann et Dieni, *O. tenuituberculatus* Bulot, *Himantoceras trinodosum* Thieuloy, *Rodighieroites belimelensis* Mandov (Peregrinus to Furcillata zones). The cephalopod distribution was correlated with the aptychi fauna collected in coeval strata. Twelve taxa of ribbed aptychi come from the Ladce Formation – for example *Lamellaptychus mortilleti mortilleti*, *L. aplanatus aplanatus*, *L. a. retroflexus*, *L. bermudensis*, *L. beyrichodidayi*, *L. symphysocostatus*.

Marly limestones contain calpionellids and calcareous dinoflagellates of the Valanginian Calpionellites Standard Zone (Darderi and Major Subzones). *Nannoconus* spp. and *Watznaueria barnesae* constitute 40–90% of rather low diverse assemblages of the Calcicalathina oblongata NK-3 Zone.

Mráznica Formation (Borza *et al.* 1987). The boundary between the Ladce Formation and overlying it Mráznica Formation is not sharp. Abundant ammonite remnants (several hundreds of specimens) of the Furcillata Zone date Late Valanginian age of the Mráznica Formation: *Criosarasinella furcillata*, *C. mandovi*, *C. coniferus*, *Teschenites subflucticulus*. Higher part of the sequence yielded *Crioceratites heterocostatus*, *Teschenites subpachydicranus*, *Olcostephanus densicostatus*, *Oosterella cultratoides*. Marly limestone sequence contain very rare microfossils of the Tintinnopsella Zone, rare remaniellids indicate erosion of older deposits. Calcareous nannofossils belong to the Late Valanginian Tubodiscus verenae Subzone (NK-3). The composition of dinoflagellate assemblages reflects original marine environment of several hundred meter depths (littoral to brackish types predominate, e.g. *Circulodinium, Muderongia*).

Kališčo Formation (Borza *et al.* 1987). The formation starts with calciturbidite layer. Thick-bedded limestones of the lowstand tracts (thickness of 1–3 m) contain brachiopod shells and crinoid calyces. Rich ammonite and nannofossils associations characterise transgressive system tracts. The radiolarians reached the maximum of abundance during maximum flooding intervals. Calcareous lamellaptychi are represented by thick-valved types dominated by *L. didayi* and *L. seranonis*. Highstand system tracts are build of thin bedded limestones with marly intercalations.

Ammonites *Teschenites flucticulus*, *Eleniceras tchechitevi*, *Jeanthieuloyites nodosus*, *Olcostephanus hispanicus* prove for earliest Hauterivian age (the Radiatus Zone) of the Kališčo Formation base. The Sayni Zone was proved by findings of *Subsaynella sayni* co-occuring with *Ptychoceras meyrati* in pelagic chert limestone sequence of the Kališčo Formation *Plesiospitidiscus ligatus* accompanied by *P. meyrati* and *Abrytusites thieuloyi* Vašíček & Michalík dates Late Hauterivian Ligatus Zone. *Tintinnopsella carpathica* occurs sporadically in the Kališčo Formation. Calcareous nannofossils denote the NC-4A and NC-4B Subzones correlated with the onset of the Nodosoplicatum Amonite Zone. Low content of nannoconids and the abundance of *Micrantolithus hoschulzii* is a characteristic feature of Early Hauterivian nannofossil associations. Association of non-calcareous dinoflagellates belongs to the *Muderongia staurota* Zone, the span of which is correlated with the ammonite Radiatus and lowermost Nodosoplicatum zones. This assumption is estimated also by the first appearence of *Achomosphaera verdieri*, *Histiocysta outananensis*, *Florentinia* sp., *Coronifera oceanica* and by the presence of coeval nannofossils. *Lithodinia stoveri* dinozone was identified in the uppermost Lower Hauterivian ammonite Nodosoplicatum Zone.

Lúčkovská Formation (Borza *et al.* 1987). the ammonites found in the basal part of well bedded grey micritic limestones of the Lúčkovská Formation use to be associated with it frequent *Barremites*, *Crioceratites* ex gr. *majoricensis*, ?*Discoidella vermeuleni*. The presence of the Compressissima Zone is supported by abundant barremitids, but also *Nicklesia pulchella*, *Moutoniticeras nodosum*, *Dissimilites dissimilis*, *Patruliusiceras lateumbilicatum*, *Parasaynoceras tzankiovi*, *Metahoplites* cf. *nicklesi*, *Holcodiscus* cf. *gastaldii*, *Paraspiticeras* sp. *Toxancyloceras vandenheckii* in the highest part of the Lúčkovská Formation sequence supports the presence of the basal Late Barremian Vandenheckii Zone.

The Upper Hauterivian aptychi represent stratigraphically youngest specimens within lamellaptychi associations studied. Sporadic *Tintinnopsella carpathica* occurs in the lowermost part of the formation. The calcareous nannofossil assemblage belongs to the Litraphidites bollii Zone, NC-5B Subzone. If compared with Kališčo Formation, nannoconid abundance increased. Rich palynomorphs were observed in the Lúčkovská Formation, although none specific dinozone could have been determinable in the lower part of sequence. Early Barremian *Subtilisphaera scabrata* dinozone (with the first occurence of *Cerbia tabulata*) and Late Barremian *Odontochitina operculata* dinozone (with the first occurence of *Prolixosphaeridium parvispinum*) were identified in the upermost part of the formation. Dinoflagelate cysts of littoral environment (*Cerbia*, *Tenua*) dominate over neritic types.

Podhorie Limestone Formation (Borza *et al.* 1987). Dark bituminous organodetrital cherty limestones contain bad preserved, corroded dinoflagellates, such as *Cerbia tabulata*, *Cleistosphaeridium clavulum*, *Oligosphaeridium dividuum*, which allow to suppose Late Barremian or younger age of the formation. Upwards, they pass into carbonate platform limestones of the Manín Formation (Michalík & Soták 1990). These shallow water carbonate deposits have not been studied in detail, yet.

Butkov Formation (Kysela *et al.* 1982). Dark brown gray shales rest with gap on the corroded condensed surface of the Manín Formation. They contain glauconite grains, plant debris and planktonic foraminifers (Boorová & Salaj 1992). Dinoflagelate cysts of open neritic (*Achomosphaera*, *Litosphaeridium*) and pelagial associations (*Pterodinium*) dominate over acritarchs (*Wallodinium*, *Veryhachium*), bisaccate pollen grains and microforaminifers. The first occurrence of *Litosphaeridium siphoniphorum* coincides with Late Albian ammonite Inflatum Zone, the appearence of *Protoellipsodinium conulum* together with *Endoceratium dettmaniae* and *Ovoidinum verrucosum* coincides with the youngest Albian ammonite Dispar Zone. *Atopodinium perforatum*, *Dinopterigium cladoides*, *Pervosphaeridium pseudhystrichodinium*, *P. truncatum*, *Xiphophoridium alatum*, and other Albian forms are abundant in dinoflagellate associations. Very rare findings of *Eiffelithus turriseiffelii* allow supposing late Early Albian age of the formation or assigning the base of the Eiffelithus turriseiffelii Zone (CC9) sensu Perch-Nielsen (1985).

The Butkov section could serve as a key Valanginian-Barremian West Carpathian section correlable with these described from classical French and Spanish Mediterranean regions. At present, this place represents the richest locality of Lower Cretaceous ammonites in the whole Western Carpathians with purely Mediterranean species from Early Valanginian Campylotoxus Zone to Late Barremian Vandenheckii Zone. The ammonite associations resemble these from the Vocontian Trough in France. Since 1979 to 2004 more than twelve hundred ammonite specimens were collected.

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