Composition, structure and evolution of the Pieniny Klippen Belt and adjacent zones in western Slovakia

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Structure of the Púchov sector of the Pieniny Klippen Belt

Dušan Plašienka

In 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 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 intricated 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), and several types of "transitional" successions as the Pruské Succession (similar to the Niedzica Succession from the Polish part of the PKB – cf. Aubrecht and Ožvoldová, 1994), the Czertezic Succession (Wierzbowski et al., 2004), the Orava Succession (Schlögl et al., 2000), the Nižná Succession (Józsa and Aubrecht, 2008), the Marikova Succession (see Plašienka et al., this volume), or the Streženice Succession (Began and 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–Paleogene overstepping cover (Gosau Supergroup). This zone was designated as the "Peri-klippen Zone" by Maheľ (1980).

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 (Chotúč Klippe), but dominates towards the SW in the Trenčín sector of the PKB. The youngest member of the Drietoma Unit is the Middle 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 Middle Cretaceous wildflysch complex (the Klape Flysch) with big olistoliths 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 separated by antiformal strips of the Kysuca Unit and/or synforms of overstepping Gosau sediments (**Figs. 1** and **2**). These Klape subunits are considered to represent strike-slip duplexes, accumulation of which caused exceptional broadening of the PKB in the Púchov sector (**Fig. 3**).

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 (e.g. Rakús and Hók, 2005). The Manín Unit is dominated by Middle 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 (e.g. Salaj, 1990), separated by a stratigraphic hiatus in places (Marschalko and

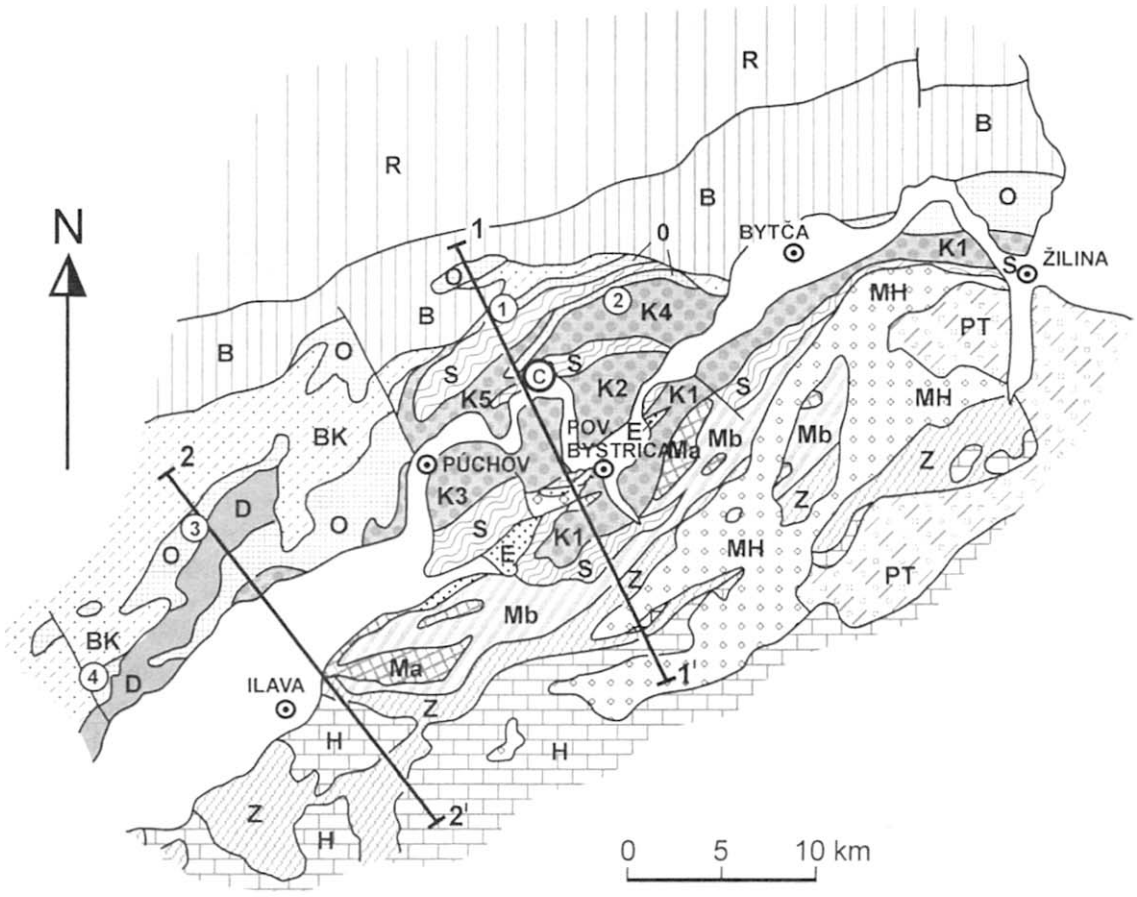


Fig. 1. Distribution of principal units in the Púchov sector of the Pieniny Klippen Belt and adjacent areas. Based on the map by Mello ed. (2005). For the key see Fig. 2. Numbers in circles – excursion stops, C – conference site.

Kysela, 1980), or tectonic windows of the underlying Kysuca Unit (Podháj Succession; Rakús and Hók, 2005). However, we favour the variant in which the Senonian sediments in the Klape and Manín Zones represent a post-nappe, Gosau-type cover (Fig. 2). The Middle Cretaceous flysch of the Manín Unit is from the SE side 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 Middle Cretaceous flysch are regarded as olistoliths of an unknown provenance (Rakús and 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 (cf. Figs. 1 and 3). Numerous post-folding faults – slickensides are generally steep to vertical, with gently plunging striae pointing to an oblique- or strike-slip with dominant 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 fault (Fig. 3) 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 back-thrusting (e.g. Marko et al., 2005).

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 Upper Cretaceous – Lower 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 – Upper 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.

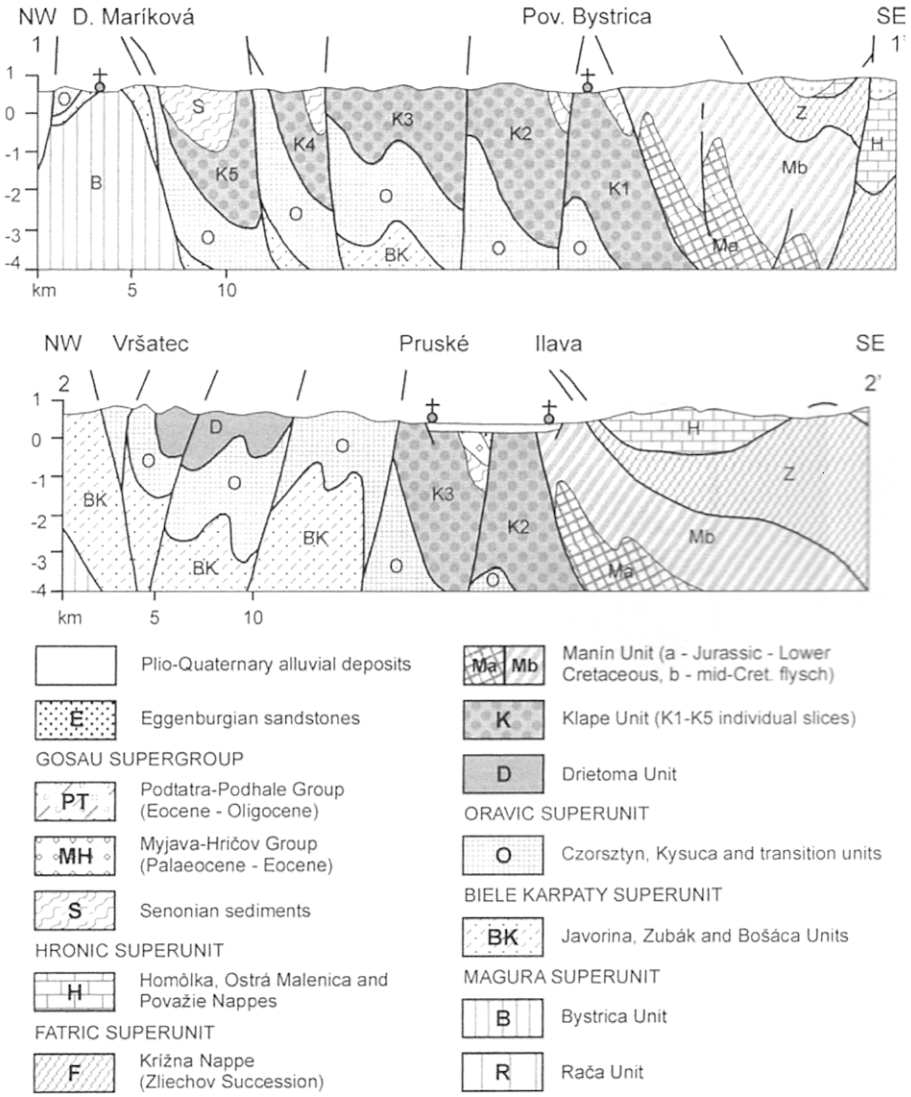


Fig. 2. Cross-sections through the Púchov sector of the Pieniny Klippen Belt. For the location see Fig. 1.

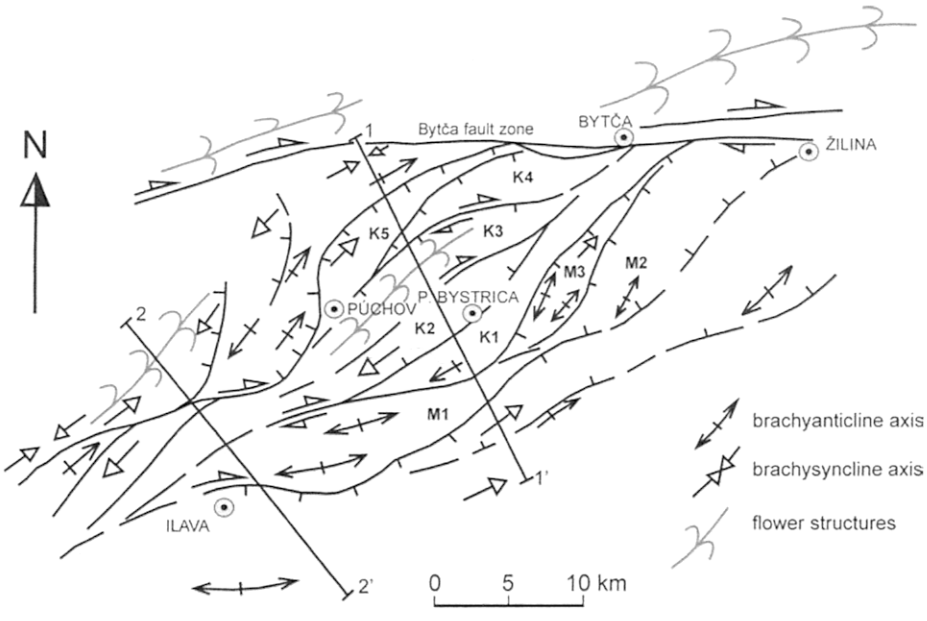


Fig. 3. Kinematic framework of the Púchov sector of the Pieniny Klippen Belt.

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; in press); Figs 4 and 5:

- Triassic – carbonate platform in the Oravic domain;
- Lias to Aalenian – wide symmetric rifting, tectonic subsidence with mostly anoxic sedimentation in half-grabens;
- 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-

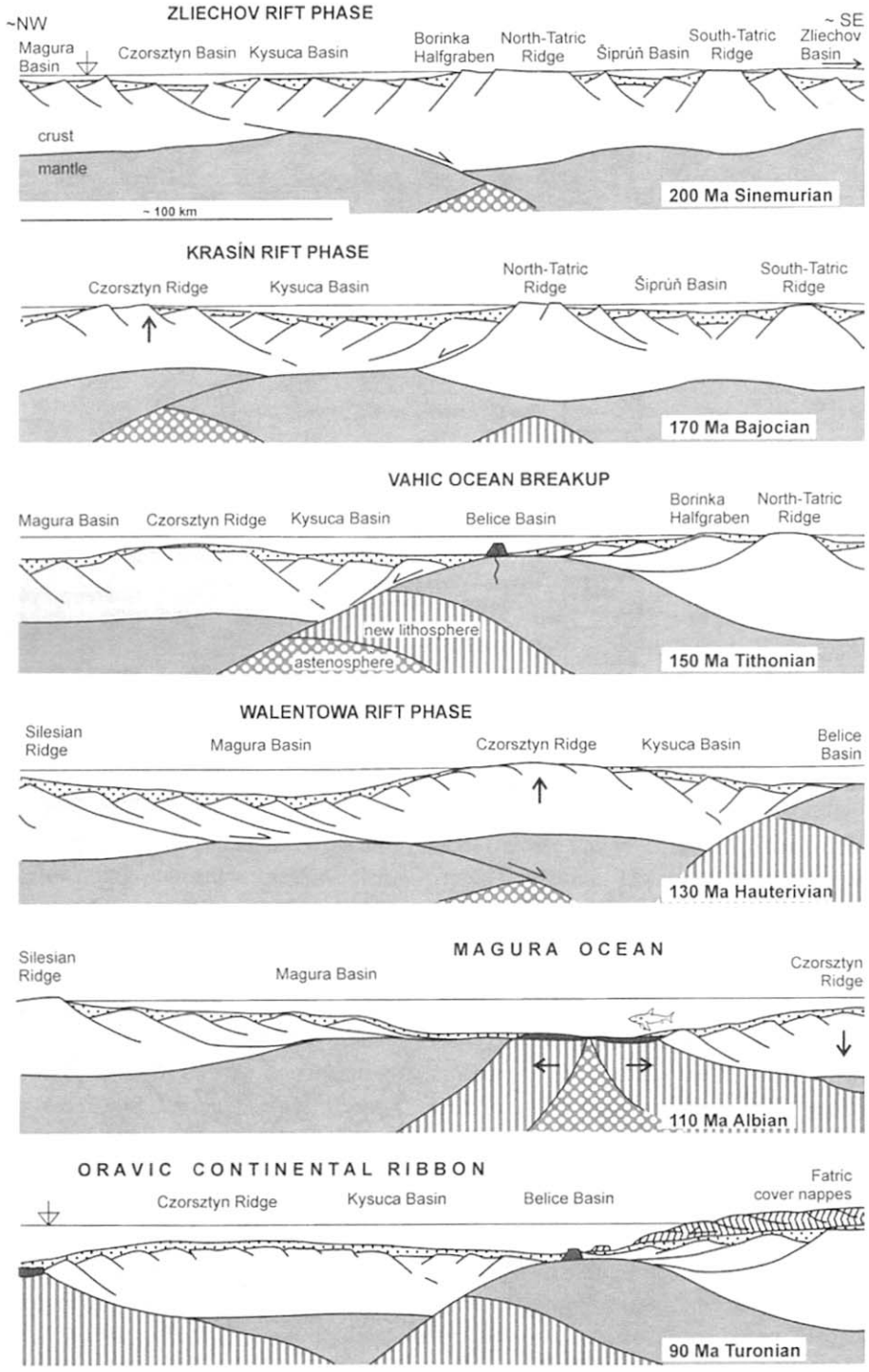


Fig. 4. Reconstruction of the Jurassic–Cretaceous rift phases that formed the Oravic Czorsztyn Ridge (Plašienka, 2003).

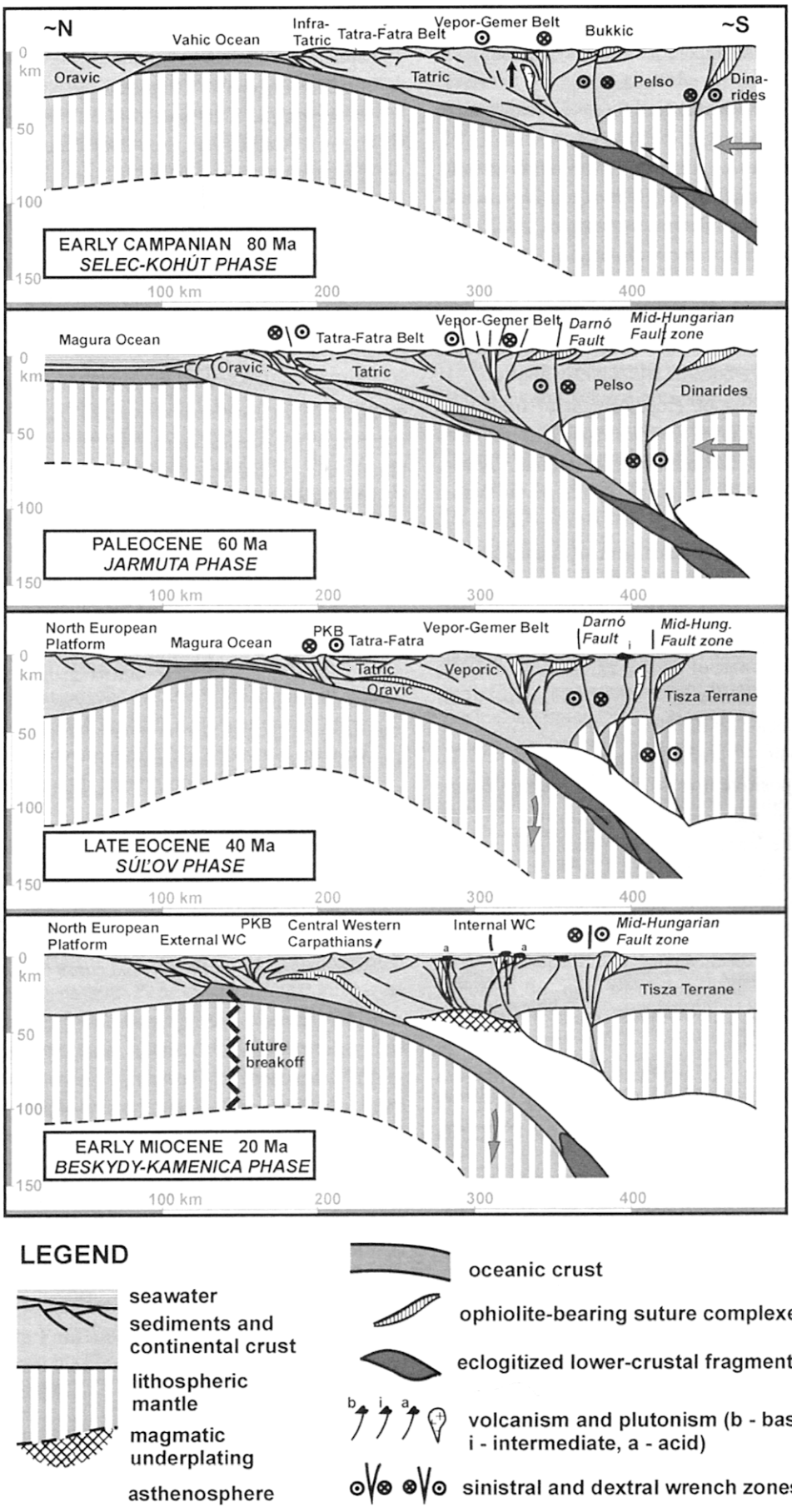


Fig. 5. Tentative paleogeodynamic sections of the Western Carpathian orogen during the Upper Cretaceous to Lower Miocene (Plašienka, in press).

Vahic oceanic tract with the Kysuca-Pieniny Basin being located on its northern (in the present-day coordinates) flanks;

- Callovian to Tithonian – overall thermal subsidence in entire Oravic domain;
- Lower Neocomian – renewed asymmetric rifting, repeated thermal uplift of the Czorsztyn Ridge, south-dipping detachment fault on the northern side of the Czorsztyn Ridge;
- Upper Neocomian – breakup of the North Penninic-Magura Ocean north of the Czorsztyn Ridge;
- Middle Cretaceous to Senonian – thermal subsidence, the Czorsztyn Ridge became a pelagic swell;
- Upper Turonian – nappe emplacement of frontal diverticulates of the Fatric (Krížna) nappe system of the Central Western Carpathians (Drietoma, Klape, Manín Units) onto the southern flanks of the Vahic oceanic crust;
- Lower Senonian – 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, re-sedimentation of a part of Albian exotic conglomerate material from the Klape Unit into flysch deposits of the Oravic Kysuca-Pieniny Unit;
- Upper Senonian – gradual closing of the Vahic Ocean, partial positive inversion of the Magura Basin;
- Maastrichtian to Paleocene – 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 Oravic, piggy-back "non-Oravic" 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 Biele Karpaty and/or Magura elements;
- Middle Eocene to Oligocene – extension and subsidence on the inner side of the PKB, formation of the Central Carpathian (Podhale) Paleogene Basin in a fore-arc position;
- Lower 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 steep zone of the PKB s.s., in which strike-slipping prevailed that has led to the formation of the typical "klippen" (block-in-matrix) tectonic style caused by pervasive brittle faulting;
- Middle to Upper 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 Lower–Middle Miocene, then transtension pursued by general extension during the Upper 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. 6 and 7)

The Oravic Superunit embraces several sedimentary successions derived from an independent paleogeographical zone around the intra-oceanic Czorsztyn Ridge (Fig. 6). The sedimentary history of Oravic basins can be divided into three stages, with (1) Hettangian? – Aale-

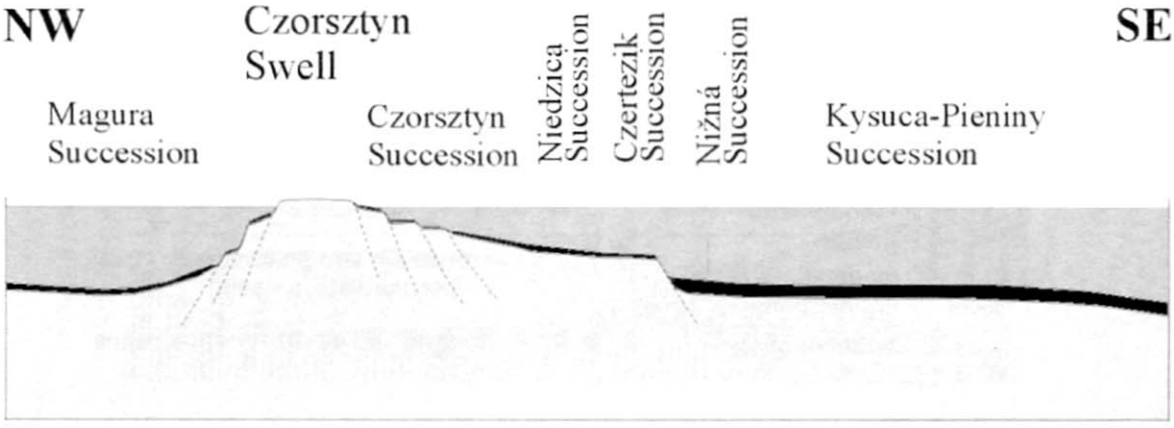


Fig. 6. Simplified N-S oriented bathymethric transect through the Pieniny Klippen Belt (from Tomašových, 2006).

nian, 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 Upper Cretaceous marly and flysch deposits.

Czorsztyn Unit (Figs. 7 and 8)

The **Czorsztyn Unit** represents sedimentary succession, with Lower Jurassic - Aalenian part sedimented in the hemipelagic, oxygen-depleted conditions, and Bajocian-Upper Jurassic sediments deposited in the shallow parts of the carbonate platform called the Czorsztyn Swell. Upper 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 (see abstract by Plašienka et al., this volume). Similarly, the stratigraphical and paleogeographical position of quartzites occurring near the Mariková Klippen remains unclear, although their assignment to the Upper Triassic Keuper facies is most probable.

Lower Jurassic deposits are preserved in 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 at the NW foot of the Vršatec Klippen. Lower Sinemurian dark organodetritic limestones and Upper Sinemurian/Pliensbachian Fleckenmergel-Fleckenkalk facies were described from Dolný Mlyn near Stará Turá (western Slovakia), Beňatina (eastern Slovakia) and Priborzhavskoje and Velyky Kamenets (Ukraine) (Hlôška, 1992; Schlögl et al., 2004).

Middle and Upper Jurassic deposits display some important sedimentary turnovers (Fig. 8). Uppermost Liassic to Lower Bajocian grey spotted marly limestones, marlstones and black shales (Krempachy Marl Fm. and Skrzypny Shale Fm.) were "suddenly" replaced by white and red crinoidal limestones during the late Lower and Upper Bajocian (Smolegowa and Krupianka Lst. Fms., Stop No. 1), which probably mirror 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. In addition to quartz grains, dolomite clasts are frequent, 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 (Stop No. 5). This facies is restricted to the West Slovak part of the PKB only, called the Krasin Breccia (Aubrecht and Szulc, 2006), and probably also the Vršatec peribiohermal breccia (Schlögl et al., under study, Stop No. 3). The latter represents a facies derived from the coral-calcareous sponges biohermal limestones (Vršatec Lst.). Stratigraphical age of this unique facies was recently estimated as Lower Bajocian (Schlögl et al., 2006), contrary to Oxfordian as it was thought before (Mišík, 1979). Later sedimentary turnover during the uppermost 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. 4). Biodetritic platform deposition was replaced by pelagic deposition of Ammonitico Rosso or red nonnodular micritic limestones (Czorsztyn Lst. Fm., Bohunice Fm.). Their sedimentation, although interrupted by the Upper Bathonian to the Lower Oxfordian sedimentary break, continued until the Lower Tithonian. This long-lasting hiatus was probably controlled by both, eustasy and rapid paleogeographic rearrangement of the host basins, as indicated by recently acquired paleomagnetic 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). Transition to the overlying Dursztyn Lst. Fm. is gradual; the formation shows great facies variability from micritic and sparitic coquinas (Rogoza Coquina and Rogoznik Coquina) to micritic, more or less bioclastic limestones (Korowa Lst. and Sobotka Lst.) of the Tithonian age (Fig. 7). They were followed by bioclastic Lysa Lst. Fm. of the Berriasian and Valanginian age and by crinoidal Spisz Lst. Fm. of the Hauterivian age. The carbonate sedimentation terminated by the period of emersion, with sedimentary break covering the Barremian – Aptian. At least local subaerial exposition is documented by paleo-karst surfaces (Aubrecht et al., 2006). Albian and Cenomanian red marly limestones and marlstones and cherts (Chmielowa and Pomiedznik Fms) overlie directly the paleo-karst surface (Stop No. 4).

Kysuca-Pieniny Unit

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).

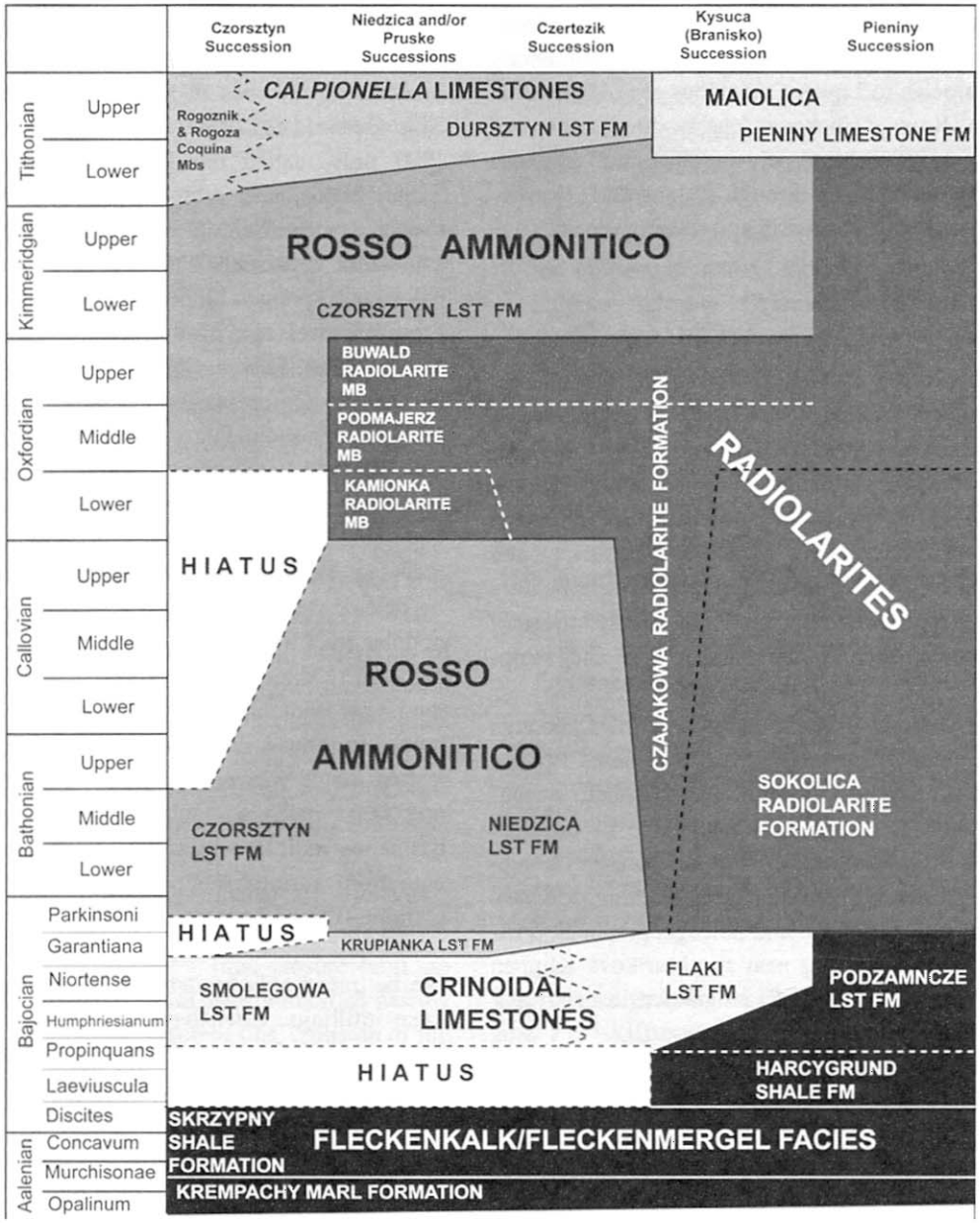


Fig. 7. Stratigraphic correlation scheme between Middle–Upper Jurassic lithostratigraphic units of Oravic Successions (from Wierzbowski et al., 2004, modified).

Although the **Lower Jurassic** part of the succession was documented at numerous sections, their assignment to this unit is not always clear, due to prevalent disconnection of the Lower Jurassic strata from the Middle Jurassic strata. Complete 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 assigned to 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 Fm.**, Orava, Ukraine), overlain by Fleckenmergel-Fleckenkalk deposits of the Pliensbachian to Lower Bajocian age (**Krempachy Marl Fm., Skrzypny** and **Harcygrund Shale Fms.**). The time of deposition of the dark shales with abundant thin-shelled bivalves *Bositra*

(**Harcygrund Shale Fm.**, 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 Lower and late Upper Bajocian deep-water cherty limestones and spongiolites (**Podzamcze Lst. Fm.**) are laterally replaced by cherty crinoidal limestones. In the Kysuca-Pieniny Basin these crinoidal limestones are

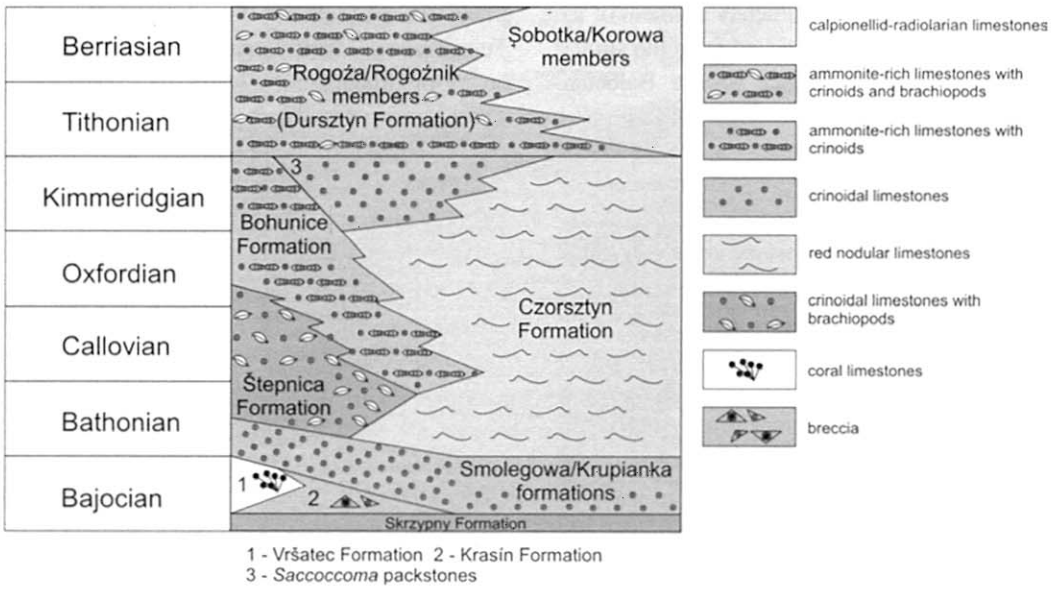


Fig. 8. Lithostratigraphic subdivision and spatial relationship of the Middle and lowermost Cretaceous deposits of the Czorsztyn Unit (Pieniny Klippen Belt; after Aubrecht et al., 2002, and Tomašových, 2006).

represented by distal turbidites only (**Flaki Lst. Fm.**). 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 Fm.** and **Czajakowa Radiolarite Fm.**). 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 Lst. Fm.**). Next depositional stage is uniformly represented by the grey micritic limestones of "biancone" or "maiolica" type, locally with cherts, having the stratigraphic range from the Tithonian to the Barremian (**Pieniny Lst. Fm.**).

This *Calpionella* or calcareous nannoplankton-bearing facies is overlain by Barremian to Aptian dark shales (**Koňhora Fm.**). Albian to Lower Cenomanian of the Kysuca Unit is represented by bluish to greenish marls with limestone beds (**Tisalo Fm.**), followed by red marls and marlstones of the Middle and Upper Cenomanian age (**Lalinok Fm.**); the end of marly sedimentation is represented by red marls with thin sandstone intercalations of the Lower and Middle Turonian age (**Kysuca Fm.**). Start of the turbiditic deposition in the Turonian (**Snežnica Fm.**) marks the change of the sedimentation. These sandstone turbidites are followed by psammitic to psephitic deposits of the Coniacian and Santonian age (**Sromowce Fm.**), which are analogous in composition 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 Fm.**) and limestones with *Orbitolina* are deposited on the folded pre-Maastrichtian strata.

Transitional Units

The Czorsztyn and Kysuca-Pieniny Units are the successions deposited in the bathymetrically contrasting environments of the Oravic Basin with numerous transitional units developed between them. These can be arranged basinwards as follows: **Niedzica Unit and/or Pruské Unit, Czertezik Unit, Streženice Unit, Orava Unit and Nižná Unit.** The **Niedzica** and **Czertezik Units** have a very similar development with thick complex of crinoidal limestones (**Smolegowa** and **Krupianka Lst. Fms.**), red nodular limestones (**Niedzica** and **Czorsztyn Lst. Fms.**), radiolarites (**Czajakowa Radiolarite Fm.**) and *Calpionella* and calcareous nannoplankton-bearing limestones (**Dursztyn Lst. Fm.**), but in the second one should lack the lower red nodular limestone (**Niedzica Lst. Fm.**). However, the actual study revealed the permanent presence of thin calcareous deposits between the crinoidal limestones and radiolarites in all the localities of Czertezik Unit (Fig. 7; Wierzbowski et al., 2004), which indicates a 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 the presence of the Bajocian-Bathonian carbonate (crinoidal) flysch deposits (**Samášky Fm.,** Stop No. 4). The common feature of both units is the presence of radiolarites sandwiched between lower and upper red nodular limestones. **Orava Unit** united the previously 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 the Púchov segment of PKB (Schlögl et al., 2000). The Lower Jurassic deposits comprise eckenmergel and Fleckenkalk facies of the Upper Sinemurian age, greenish to reddish marly limestones of Pliensbachian age and Toarcian red nodular limestones (**Adnet Fm.**). 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 paleogeographic position of Orava Unit is not uniform; some authors propose its origin in the Fatric sedimentation area (Maheľ, 1986).

Streženice Unit was defined by Began and 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 and Aubrecht, 2008). Sometimes it is considered as a subunit of the Kysuca Unit.

Owing to its assumed paleogeographic position, the **Fodorka Unit,** introduced by Salaj and Began (in Salaj, 1987) is comparable 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 wild-flysch 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,** Stop No. 2) 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 Fm.**). Conglomerates contain an extraordinary variety of sedimentary and magmatic pebbles derived from the Inner Carpathians (e.g. Mišík and 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 and Marschalko, 1997).

The pre-Turonian members of the **Drietoma Unit** represent probably original parts of Fatricum. Drietoma Unit outcrops in the Podbranč-Trenčín sector of the PKB. It contains also the Upper Triassic rocks, the Carpathian Keuper and Kössen Fms., which are not typical of the Pieniny Klippen Belt. Overlying strata, such as thick Lower Jurassic Kopienec and Allgäu Fms., 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).

The Manín Unit in the geological structure of the Strážovské Vrchy Mts.

Jozef Michalík

The Central Carpathian block is rimmed by 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 Jas-

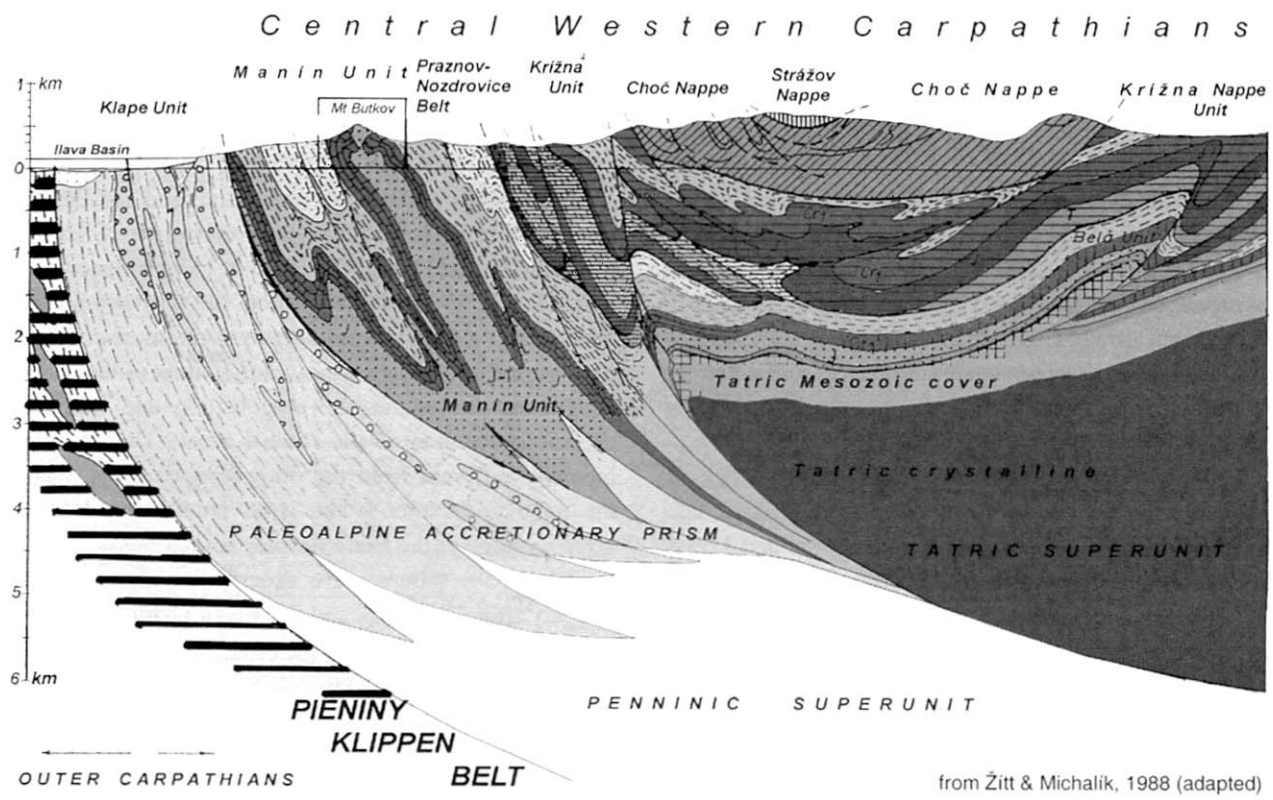


Fig. 9. Geological section of the margin of Central Western Carpathians built by the Manín and Kostelec Units (after Žítt and Michalík, 1988, modified).

trabie saddle from the Považský Inovec Mts. in the south, by the Fačkov saddle from the Lúčanská Malá Fatra in the east and by five basins: Rajec, Žilina, Púchov, Ilava and Trenčín basins in NE, N and W.

The geological structure of the Strážovské Vrchy Mts. traceable on 300 square kilometers large area is asymmetric with a crystalline "core" situated far on the SE periphery. The 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. 9).

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 Variscan crystalline basement is dominated by the high-grade metamorphic rocks (migmatites, paragneisses, less amphibolites); granitoids form small intrusive bodies only. The Tatric Mesozoic cover sequence commences with Scythian quartzose sandstones of the Lúžna Fm. overlain by Middle Triassic carbonates (Gutenstein Limestone, Ramsau Dolomite). The Carpathian Keuper Fm. 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 Upper Hauterivian in Manín, but as late as in Aptian in the Butkov area). The sequence is covered by Upper Albian – Cenomanian marls and by Upper Cretaceous flysch facies.

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 Fm., Lower Jurassic "Fleckenkalk", Adnet limestone, Middle Jurassic silicites of the Ždiar Fm., and by Upper Jurassic dark marlstones of the Jasenina Fm. 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 Fm.) and spotted Valanginian to Aptian limestones (Mráznica Fm.) with small volcaniclastic bodies represent Lower Cretaceous sequence of the Zliechov Unit. Albian and Cenomanian strata are represented by the 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 characterized 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 the Upper Triassic dolomites.

Paleogene sequences fill rest of basins both in the Paleoalpine 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 the outer zones towards the S. 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.

Biele Karpaty Unit s.l.

M. Potfaj

Geological mapping in the last 15 years in the Klippen Belt and the related flysch area of western Slovakia allowed us to reinterpret the subdivision and arrangement of some tectonic units of the Outer Western Carpathians (Potfaj, 1993; Stráník et al., 1997; Mello ed., 2005). One of the most important changes was the distinction of the Biele Karpaty Unit s.l. from the group of Magura units and establishing the Biele Karpaty group of nappes (Fig. 10; Bezák ed., 2004). Also the changes in the inner division of the Klippen Belt sequences were made, such as the cut off of the flysch Snežnica Formation (and younger formations) from the rest of the Kysuca sequence and detection of the new Mariková Klippen Sequence (Mello ed., 2005).

Application of criteria commonly used for the division of other Flysch Belt units to the former Biele Karpaty Unit showed a higher degree of independency of the latter (Potfaj, 1993). In conclusion, the formerly declared equivalency of the Biele Karpaty Unit to the Oravská Magura and Krynica (Čerhov) partial units of the Magura nappe was denied, as the composition and lithostratigraphic succession of the Biele Karpaty Unit is fundamentally different from the other Magura units. One of the main arguments is the large amount of dolomitic clasts in some of the Biele Karpaty formations.

Two main groups were described within the Biele Karpaty Unit: The **Hluk** and the **Vlára Groups** (Fig. 11).

The **Hluk Group** (Stráník et al., 1989; Potfaj, 1993) consists of the Hluk Fm., Gbely Fm., Púchov Fm., Antonínek Member, Svodnice Fm. with Filipov and Suchov facies, Nivnice Fm. and two horizons of variegated claystone sequences. It is overlain by Kuželov Fm. In the borehole Blatnička-1 (Menčík and Pesl, 1966) also a flysch sequence of Middle Eocene age was identified.

The Campanian to Lower Eocene succession of the **Vlára Group** consists of the **Lopeník Formation** with the **Ondrášovec, Javorina** and **Drietomica Members**, overlain by the **Rajkovec** and **Chabová Members**.

Lopeník Fm. (Campanian – Maastrichtian) is composed of sandy flysch, with the predominance of calcareous well-sorted sandstones, intercalated with thin claystones. The bottom of the Lopeník Fm. is formed by the variegated violet-red claystones with red and yellowish marls belonging to **Ondrášovec Mb**. Sandstones are not abundant in this part. The maximal observed thickness of the member is 340 m and it is laterally interfingering with the strata of the **Javorina Mb**.

Javorina Mb. (Upper Campanian – Maastrichtian) consists of thin-bedded flysch sequence with predominance of fine- to medium-grained sandstones. Rare bodies of microconglomerates with rare large foraminifers *Lepidorbitoides* cf. *kampanensis* VAN GORSEL were located in the higher part of the member. Sandstones are composed of quartz, metamorphic rocks and large amount of carbonate clasts (up to 45 %). Claystones are greenish-grey, more or less silty, intercalated by a few calcareous beds and sporadically occurring white-grey pelocarbonate layers. The formation thickness is about 600 m.

Drietomica Mb. forms a top of the Lopeník Fm. It is characterized by domination of thick-bedded, fine- to coarse-grained sandstones with no, or only a few thin claystone intercalations. Sandstones have a mixed, carbonate-siliciclastic composition. Maximum thickness of

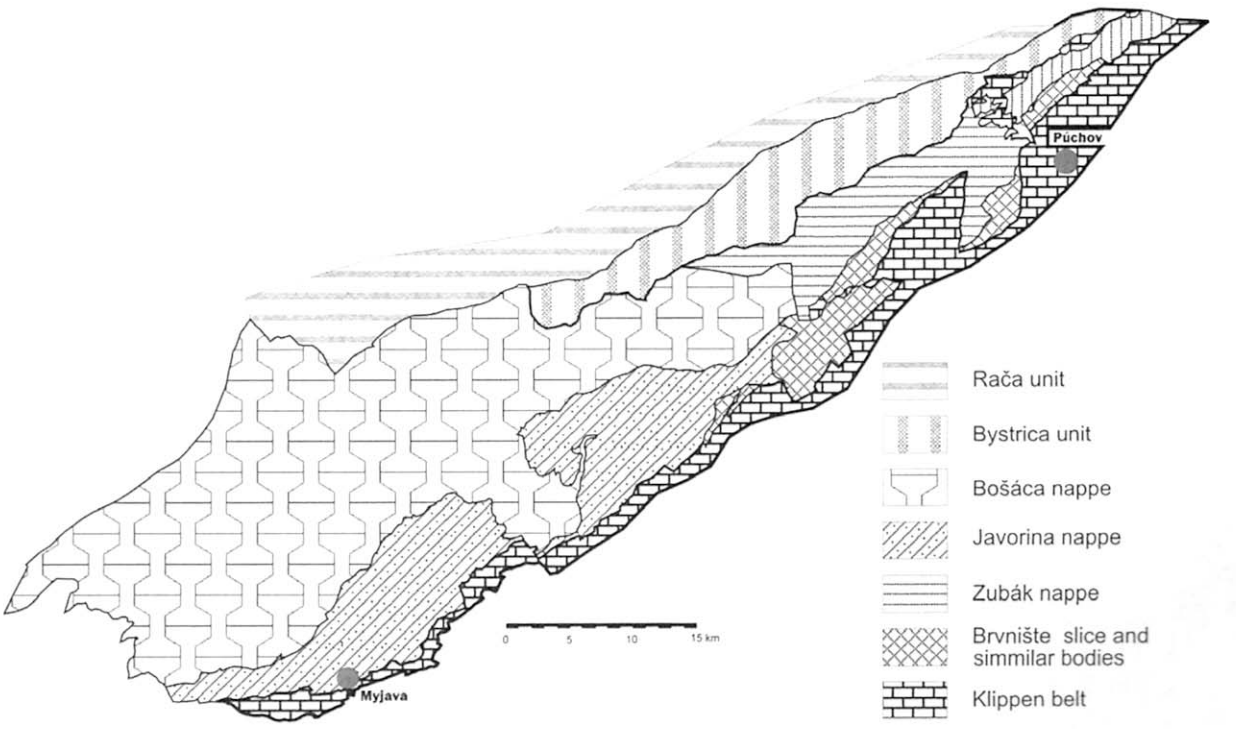


Fig. 10. Tectonic scheme of the Biele Karpaty and adjacent units (Potfaj, modified after Bezák ed., 2004).

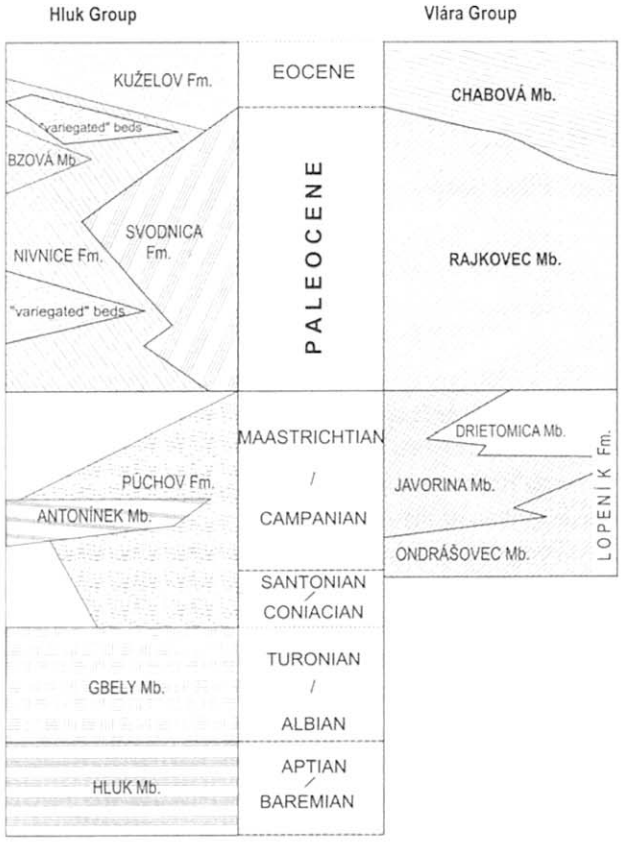


Fig. 11. Lithostratigraphic scheme of the Biele Karpaty s.l. (Potfaj, modified after Potfaj, 1993).

the Drietomica Mb. was estimated to 200 m, diminishing towards the SW. The presumed age is Maastrichtian, without biostratigraphic control.

Rajkovec Mb. (Paleocene – Lower Eocene?) consists predominantly of sandstone flysch sequence with thin intercalations of silty claystones and mudstones with mica admixture. The sandstones are fine- to medium-grained with mixed carbonate-siliciclastic composition with muscovite. Individual beds are 7–30 cm thick, but layers up to 1.5 m are present as well. The maximum thickness of the Rajkovec Mb. is estimated to about 500 m. We presume their close lithological relation to the Javorina Mb.

Chabová Mb. (Upper Paleocene – Lower Eocene) is formed by thick beds (20–200 cm) of medium- to coarse-grained grey siliciclastic sandstones with carbonate clasts share up to 25 %, accompanied by several beds composed of fine-grained conglomerates, rare silty mudstones and 5-10 cm thick claystone beds. Erosion and incised channels are the common features of thicker layers. The 1-2 m thick packets of thin-bedded flysch locally occur. The member thickness is about 50–150 m.

From the tectonic point of view, the Biele Karpaty Unit s.l. consists of three partial nappes: the **Javorina, Zubák** and **Bošáca nappes** (Fig. 10). The upper **Javorina nappe** is composed of sequence of the Vlára Group, the lower **Bošáca nappe** contains mostly deposits belonging to the Hluk Group. The **Zubák nappe** in the northern part of region is still not well territorially defined; it contains mainly deposits of the Lopeník Fm. (compare also with the tectonic map of Bezák ed., 2004).

Inner structure of the Biele Karpaty Unit s.l. has a fold-and-thrust character in the western part. The Javorina nappe occupies the zone along its southeastern bor-

der. It is a flatly lying body about 900 m thick and 50 km long. It was displaced northwestward from its "inner" paleogeographic position in the southern part of the Biele Karpaty realm.

The present day relationship of the Biele Karpaty Unit s.l. to northern Magura units (Rača and/or Bystrica) is tectonic. Southwest of the Nezdenice fault, the Rača Unit stretches at least as far as the front of the Klippen Belt, as it was proved by the borehole KLK-1 between Strání and Moravské Lieskové villages (Potfaj, 1993). Here the Biele Karpaty nappes directly overthrust the Rača Unit at a distance of at least 25 km, but the Bystrica Unit is missing between them. A similar situation seems to be present also in the Vienna Basin subcrop (Buday et al., 1966).

Similarly, the relations of the Biele Karpaty Unit s.l. to the Klippen Belt are tectonic all along their contact. Analysing the paleocurrent arrangement, it was stated that in the Bošáca partial nappe (mainly built by the Hluk Group) a longitudinal transport is preserved, whereas in the inner part built by the Vlára Group sediments, a radial array of paleotransport dominates. This invokes the idea that carbonate clasts were derived from the present southeastern neighbour of the Biele Karpaty Unit – from the PKB, or even Central Carpathian units. However, several facts are in contradiction with this presumption:

a) The PKB successions generally do not contain dolomites, nor they contain metamorphics and quartz enough to supply the sandstones in the Biele Karpaty Unit.

b) Heavy-mineral associations of the Biele Karpaty Unit on one hand and the PKB and Central Carpathians on the other are so different that connection between these units was not accepted (Potfaj, 1993).

Resulting interpretation of the present position of the Biele Karpaty Unit s.l. is its lateral emplacement with respect to the PKB. Therefore the idea of "transgressive" relation of the Biele Karpaty sediments to the Klippen Belt, as proposed by Andrusov (1931) as well as Matějka and Roth (1956), is not tenable. The tectonic deformation of the Biele Karpaty group of nappes is post-Eocene in age.

STOP 1

Hatné Klippe – cross bedded crinoidal limestones (Czorsztyn Succession)

Roman AUBRECHT and 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 Lst. Fm.**) passing upwards, in the uppermost preserved part, to red nodular limestone (**Czorsztyn Lst. Fm.**). 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 in detail. He reported the following Bathonian 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 examined by him in described area. The latest paper published about the locality was that of Aubrecht and 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 Lst. Fm. The red crinoidal limestones are thick bedded, with frequent cross-beddings (Figs. 12 and 13), 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 Lst. Fm. 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

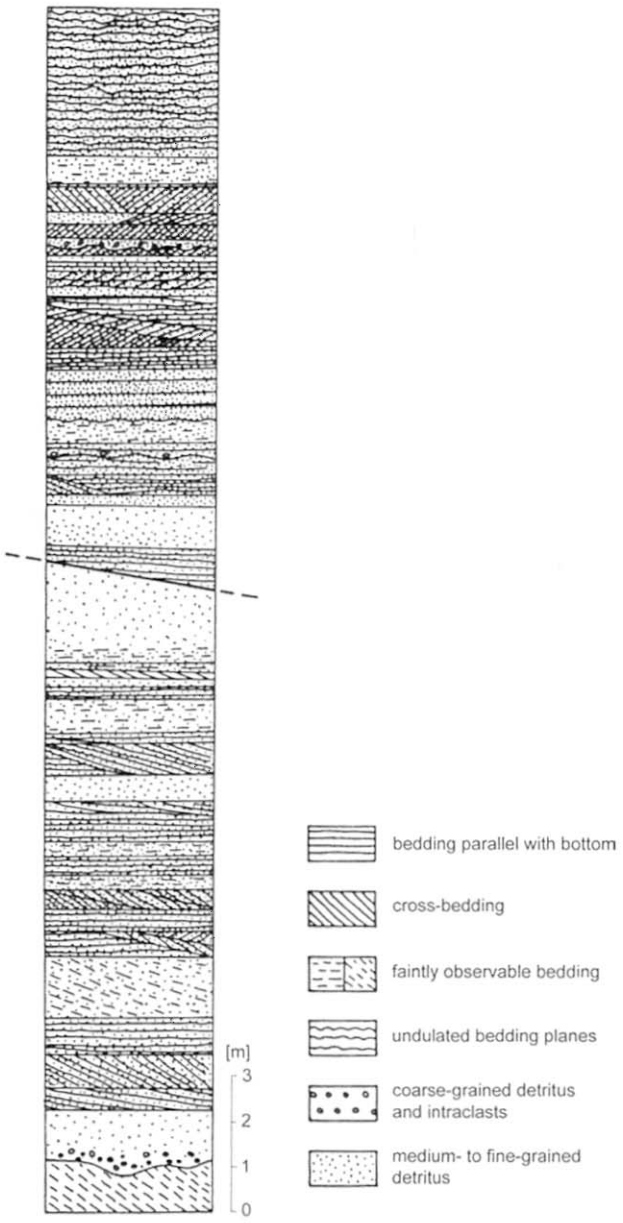


Fig. 12. Lithological and sedimentological section through middle part of the quarry wall (after Aubrecht and Sýkora, 1998).

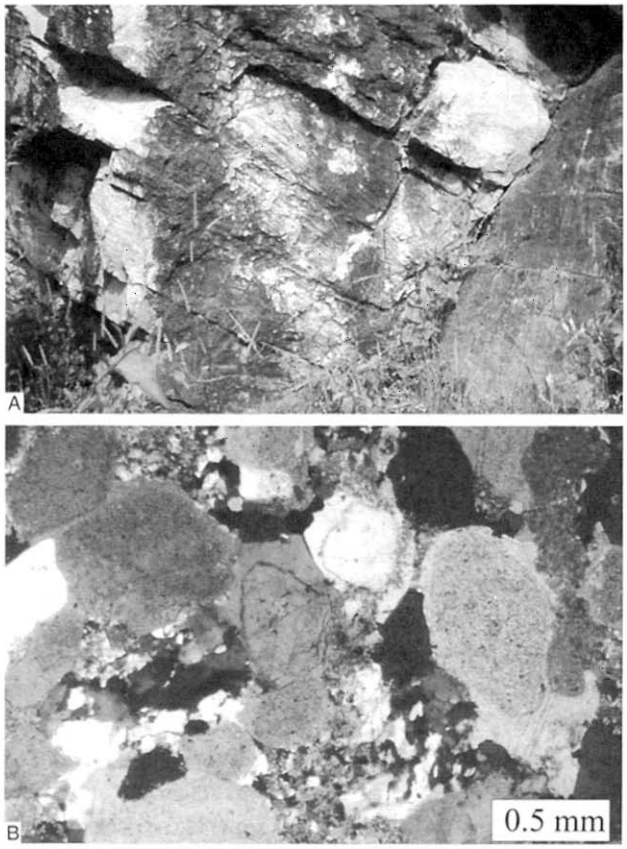


Fig. 13. A. Detail on a cross bedding in the Krupianka Lst. Fm. in the middle part of the quarry wall. **B.** Two close detrital quartz grains with syntaxial rims forming a compromise boundary between them.

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.

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 are 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 Gluchowski (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 pres-

sure-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 the 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. 13B). 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 the 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 pre-dating 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.

Red, partly nodular limestone (base of the **Czorsztyn Lst. Fm.**) is preserved only at the 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 the absence of siliciclastic admixture is indicative of deepening of the sedimentary area and flooding of land areas of the Czorsztyn Swell. The sediment itself is penetrated by veinlets filled with clear blocky calcite. These veinlets are, however, cut by numerous stylolites, which then appear to be the latest diagenetic phenomenon in the limestone.

STOP 2

Stupné locality (Klape Succession)

Milan SÝKORA, Peter IVAN, Pavel UHER and Dušan PLASIENKA

Polymict conglomerates outcrop in a small abandoned quarry south of the elevation point 637 m, at the western edge of the Stupné village. It is one from numerous bodies of psephitic rocks in the Cretaceous flysch sequences of the Klape Unit and in the western segment of the Pieniny Klippen Belt and Kysuca and Manín units. Flysch sequences with conglomerates in the territory of Stupné and Prosné villages were regarded as costituents of Kysuca Unit of Santonian age. According to recent data (Mello ed., 2005), these conglomerates belong to the Klape Unit and are of Albian to Lower Cenomanian age. Formerly they were named "Upohlav" conglomerates. In Mello ed, l.c., the term Upohlav Formation was used for the polymict conglomerates of the Klape Unit (Albian – Cenomanian); for the conglomerates with similar composition in the Kysuca Unit (Coniacian, Santonian, Maastrichtian) the name exotic conglomerates was used.

The conglomerates of the Kysuca, Klape and Manín units have a very variable composition in general. The conglomerates from the Stupné locality are composed of countless types of rocks; the most frequent are sedimentary and volcanic rock pebbles. Abundance of dominant rock pebbles is following: carbonates (limestones + dolomites) 50–58 %, clastic (mainly siliciclastic) sedimentary rocks 13–16 %, volcanic rocks (acid, intermediate and basic) 23–33 %, granitoids about 2 % and metamorphics 2 %.

Data concerning the conglomerates composition of the Upohlav Formation mentioned in the following text were obtained from several localities (not only from Stupné quarry).

Clasts of sedimentary rocks in the Upohlav conglomerates

According to Mišík and Sýkora (1981), the most frequent pebbles were limestones of very variable facies (shallow-water, pelagic and less common fresh-water), ranging from the Lower Triassic to the Cenomanian.

Triassic is represented by the facies of Gutenstein, Steinalm, Wetterstein, Reifling and Hallstatt limestones with foraminifers, conodonts, holothurian sclerites, *Osteocrinus*, etc.

Among the Jurassic pebbles, pink crinoidal limestones and pink limestones with foraminifers of the Liassic age were found. Dogger pinkish crinoidal limestones, "filamentous" coquina limestones and limestones with "Protoglobigerinids" were also found. The Upper Jurassic carbonate pebbles are very diverse, e.g. limestones with *Protopeneroplis striata, Conicospirillina basiliensis, Nautiloculina oolitica*; limestones with *Saccocoma*, *Cadosina*, radiolarians, sponges, filaments and *Globochaete*; microoncoidal limestones with *Saccocoma*; coral limestone with *Calamophylliopsis cf. stokesi*; limestones with *Cladocopsis mirabilis*, *Teutloporella obsoleta, Clypeina jurassica, Tubiphytes*; limestones with *Calpionella alpina* and *Crassicollaria*.

Pebbles of Berriasian and Hauterivian carbonates are represented by limestones with *Campbeliella striata*; oolitic limestones with *Bacinella irregularis*, *Tubithytes* and *Cayeuxia anae*, together with pelagic limestones containing microfossils like *Tintinnopsella carpathica, Calpionella elliptica, Cadosina heliosphaera* and marly limestones with *Pseudothurmannia angulicostata.* Sponge-radiolarian limestones with turbidite intercalations are of the Upper Hauterivian age.

Barremian and Aptian rocks are represented by limestones with *Orbitolinopsis flandrini*, *O. buccifer*, *Paracoskinolina sunnilandensis*; Urgonian-type limestones with *Palorbitolina lenticularis*, rudists, corals, miliolids, *Sabaudia minuta*, *Cylidroporella sugdeni* (sometimes containing clastic admixture of Cr spinels, small lithoclasts of serpentinites and blue amphiboles); limestones with *Mesorbitolina texana* and *Orbitolinopsis kiliani*.

Albian is represented by fine-grained conglomerates, sandstones and sandy limestones with *Pithonella ovalis.* Marly limestones with *Stomiosphaera sphaerica*, *Colomiella recta* and *Rotalipora ticinensis* are of the same age.

The youngest Mesozoic rocks in the conglomerates are Cenomanian limestones with *Orbitolina concava*, calcarenites with *Rhynchostreon suborbiculatum* ("*Exogyra columba*"), brackish and fresh-water limestones and calcareous sinters. Marls with *Rotalipora appenninica* were found, too.

Along with the mentioned limestones, metamorphosed limestones, like white and grey marbles were also identified in the conglomerates. They are supposedly of the Paleozoic age.

The conglomerates of Upohlav Formation contain also pebbles of siliciclastic and silicitic sedimentary rocks, which are known from many other localities. These rocks sandstones and conglomerates were analysed in detail by Zaťko and Sýkora (2006). According to the degree of mineralogical maturity, diagenesis and sometimes low degree of metamorphism they are of pre-Mesozoic age. No fossils were found in the examined rocks. Some of them were turmalinized. Along with the clastic sediments, radiolarites, lydites (rarely with silicified plant tissues) and jaspers were identified, too. The sandstones and conglomerates mostly consist of quartz, feldspars, lithoclasts, heavy minerals and often chloritic matrix. The arenites represent mostly quartz wackes, quartz metawackes, feldspatitic greywackes, lithic greywackes, arkosic wackes and oligomict orthoconglomerates and ortho metaconglomerates

Clasts of volcanic rocks in the Upohlav conglomerates

Some localities with the conglomerates of the Upohlav Formation contain pebbles of blueschist rocks facies with variable lithology. According to Ivan et al. (2006), three groups of original rocks can be discerned except of typical blueschists: pelagic sediments, metamorphic rocks (amphibolites, gneisses) and volcanic rocks. Based on immobile trace elements (HFSE, REE) distribution, two petrogenetic types of volcanic rocks have been identified: basalts with BABB signature and calc-alkaline basaltic andesites to rhyolites. Protolith of the BABB- type blueschists was generated in the back–arc basin setting as an upper part of its ocean crust composed of basalts, dolerites and gabbro dolerites. The source of all these rocks was probably an Upper Jurassic nappe stack situated in the Carpathian interior.

Another important group of rocks in conglomerates of the Upohlav Formation are LP/LT metamorphosed acidic, intermediate and basic calc-alkaline volcanics. Information about them was published by Ivan et al. (1999) and a summary report was presented by Demko (2006). Basic varieties of these rocks are petrographically and geochemically identical with metabasalts and basaltic andesites from the Hronic Superunit (the Malužiná Formation).

Clasts of granitic rocks in the Upohlav conglomerates

Occurrences of granitic rocks belong to widespread lithologic types in polymict Upohlav flysch conglomerates of the Klape, Pieniny-Kysuca and Proč Units (Lower Cretaceous to Eocene) through a long distance from SW Slovakia to Carpathian Ukraine. The granitic clasts form usually well-rouded pebbles, usually between 2 and 30 cm, rarely blocks up to 1.5 m in diameter. Two different petrographic and genetic types of the granitic rocks could be distinguished: Tatry versus "exotic" type (Zoubek, 1931) or granites I vs. II (Šímová, 1985), or Upohlav vs. Krivá type (Uher and Marschalko, 1993; Uher et al., 1994).

The Krivá type granitic rocks (KG) represent usually two-mica granites, granodiorites to leucotonalites, locally pegmatitic granites to pegmatites. KG displays equigranular texture, an average composition contains (in vol. %): quartz 35.8 ± 1.8, plagioclase 45 ± 9.2, K-feldspar 11.5 ± 5.7, biotite 4.4 ± 2.7 and muscovite 1.0 ± 0.5 (Uher et al., 1994). Zircon, almandine, apatite, monazite-(Ce) and locally also allanite-(Ce) belong among typical accessory minerals (Uher, 2004). Zircon composition and typology (dominant S_{1-2}, S_{6-7} subtypes), as well as geochemistry of main and trace elements indicate peraluminous, calc-alkaline and orogenic S/I-type character of KG (Uher and Marschalko, 1993; Uher et al., 1994). Electron-microprobe dating of monazite-(Ce) revealed Lower Carboniferous age of KG magmatic crystallization (348 ± 22 Ma; Finger et al., 2003). Consequently, KG or Tatry type granites represent typical Hercynian magmatic suite derivated from the Tatric or Veporic crystalline basement.

On the contrary, the Upohlav type granitic rocks (UG) correspond to biotite granites and granite porphyries with pinkish, commonly porphyric K-feldspar. Hypersolvus to transsolvus alkali feldspars, microgranitic groundmass or dactylitic (micrographic) K-feldspar + quartz intergrowths are common. Average modal composition of UG is the following (in vol. %): quartz 34.4 ± 6.7, plagioclase 23.3 ± 11.9, K-feldspar 36.9 ± 13.2 and biotite 4.8 ± 2.7 (Uher et al., 1994). Zircon, allanite-(Ce), magnetite, locally ilmenite, apatite and almandine form characteristic accessory assemblage of UG (Uher, 2004). Late-magmatic to subsolidus fluid-driven breakdown of primary magmatic allanite-(Ce) led to formation of gadolinite-(Y), synchysite-(Ce) and other secondary REE fluoro-carbonate phases (Uher, 2004, unpubl. data). Zircon composition, typology (dominant P_{4-5} subtypes) and saturation temperature, hypersolvus to transsolvus character of alkali feldspars, biotite composition (Fe/Mg- and Fe^{3+}-rich green anhedral to subhedral annite aggregates) and especially main + trace-element geochemistry (high Si, Fe/Mg, Ga/Al, Zr, Rb, REE, Nb, and low Al, Ca, Mg, P, Sr, Ba and V) reveal alkaline, post-orogenic to anorogenic A-type tendency of UG (Uher and Marschalko, 1993; Uher et al., 1994; Uher and Broska, 1996; Broska and Uher, 2001). The Zr/Hf whole rock and zircon ratio as well as oxygen isotope geochemistry of zircon indicates mainly crustal protolith of UG ($\delta^{18}O_{(VSMOW)}$ = 7.6 to 8.6 ‰, Uher, Bojar and Ondrejka, in prep.). Rare occurrences of mafic microgranular enclaves in UG show a presence of restricted interaction and mixing/mingling between felsic and mafic (upper mantle?) magma.

Therefore, UG represent hot and dry (F-rich and H_2O-undersaturated) magmatic suite, solidified at medium to low pressure and depth; zircon saturation temperature (Watson and Harrison, 1983) indicates 820–890 °C, whereas the biotite geobarometry calculations (Uchida et al., 2007) gave solidification pressure ca. 2.2 to 3.3 kbar, which correspond to approx. 8 to 12 km depth. A conventional zircon U-Pb isotope dating yielded Middle/Upper Permian age of BP magmatic crystallization (upper intercept at 274 ± 13 Ma; Uher and Pushkarev, 1994). The source rocks and provenance of the "exotic" Upohlav-type granitic suite is a long-time enigma. However, recent geochemical and geochronological data indicate their similarity to Permian/Triassic A-type granites of the Central to Inner Western Carpathians, especially to Turčok and Velence granitic massifs (e.g. Uher et al., 1994; Uher and Broska, 1996; Broska and Uher, 2001). UG probably originated under extensional/transtensional tectonic regime in strike-slip fault zones of thinning continental crust during anorogenic stage after Hercynian and before Alpine orogeny.

Beside of the granitic rocks, pebbles of rhyolites are widespread in the flysch conglomerates. At least part of them reveal A-type geochemical signatures and probably also belong to the UG-related Permian/Triassic alkaline suite (Uher et al., 1994).

Granitoid pebbles from Cretaceous flysch conglomerates of the PKB were studied also by means of fission-track (FT) measurements on zircon grains with the aim to reveal their low-temperature thermal, i.e. cooling history (Kissová et al., 2006). Generally, the zircon FT ages are close to the depositional ages of the host conglomerates. The central age of one granite sample from the Albian–Cenomanian conglomerates of the Klape unit is 92.1 ± 6.0 Ma, nine samples of the Coniacian–Santonian conglomerate pebbles from the Kysuca and/or Klape unit provided ages ranging from 89.5 ± 7.2 to 120.8 ± 8.8 Ma. Three pebbles from the Stupné locality gave ages 91.5 ± 7.1, 97.2 ± 6.5 and 101.2 ± 6.1 Ma. The very short time lag of the cooling ages relative to the depositional ages of conglomerates, as well as large sizes of granitoid and various other clasts and synorogenic, thickening- and coarsening-upward character of conglomerate-bearing wildflysch formations collectively indicate that this source area was an actively deforming, exhuming and

rapidly eroding mountain range with a complex geological structure.

Most pebbles are of exotic origin – they do not occur in the adjacent geological and tectonic units. The problem of the Pieniny Klippen Belt conglomerates source area has been for a long time the subject of discussions. The first and older idea considered the pebbles as being derived from an "Exotic Ridge " or "Andrusov Ridge ". The second theory interprets the source area to be situated south of the Western Carpathians. Indeed, the conglomerates show northward transport directions (Marschalko, 1986). The petrographic variety of pebbles shows that the source area was tectonically very complicated mountain range. According to Marschalko l.c. – "Cretaceous flysch sequences of the Pieniny Klippen Belt were formed in the basin conditions with continuous subsidence of the sea floor and in a stable basin-margin-source system for 30–40 Ma without interruptions".

STOP 3
Vršatec area – group of klippen of various paleogeographic origin

Ján SCHLÖGL, Roman AUBRECHT, Jana BUČOVÁ and Vojtech MIKUŠ

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

The group of the main Vršatec Klippen is the largest in Slovak territory as well as 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. 14 and 15). They are formed by a succession of the Middle Jurassic–Lower Cretaceous carbonates that are capped by the Upper Cretaceous marls. Importantly, this locality exposes relatively thick, coral-dominated biohermal deposits, which are missing or very rare in other Jurassic successions of the PKB. Mišík (1979) described in detail sedimentological features of the two blocks in an E-W oriented transect based on seven stratigraphic sections. He suggested that the blocks consist of two tectonic slices with different stratigraphic successions.

According to this hypothesis, the first slice contains the Upper Jurassic biohermal limestones (**Vršatec Lst.**) that are overlying the Middle Jurassic crinoidal limestones (**Smolegowa** and **Krupianka Lst. Fm.**). In the second slice, the Middle Jurassic crinoidal limestones are overlain by the Czorsztyn Lst. Fm. The contact between two slices should lie within the crinoidal limestones of Middle Jurassic age. However, this hypothesis is contradicted by the new litho- and biostratigraphic data that indicate that only one succession is present in the blocks, probably with high horizontal and lateral variations in facies composition. Firstly, based on geopetal infillings within brachiopod shells, the crinoidal limestones are *overlying* the biohermal limestones. Secondly, biostratigraphic data indicate that the biohermal limestone is older than thought before, probably of Middle Jurassic age (Figs. 15 and 16).

The stratigraphy of the Vršatec Klippen. The beds are in overturned stratigraphic position (Fig. 15B):

The Vršatec Lst. 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 Lower Bathonian age. Moreover most of the dykes show filamentous microfacies, 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 Lower Bajocian. The exposed part of the limestones is at least 15 metres thick.

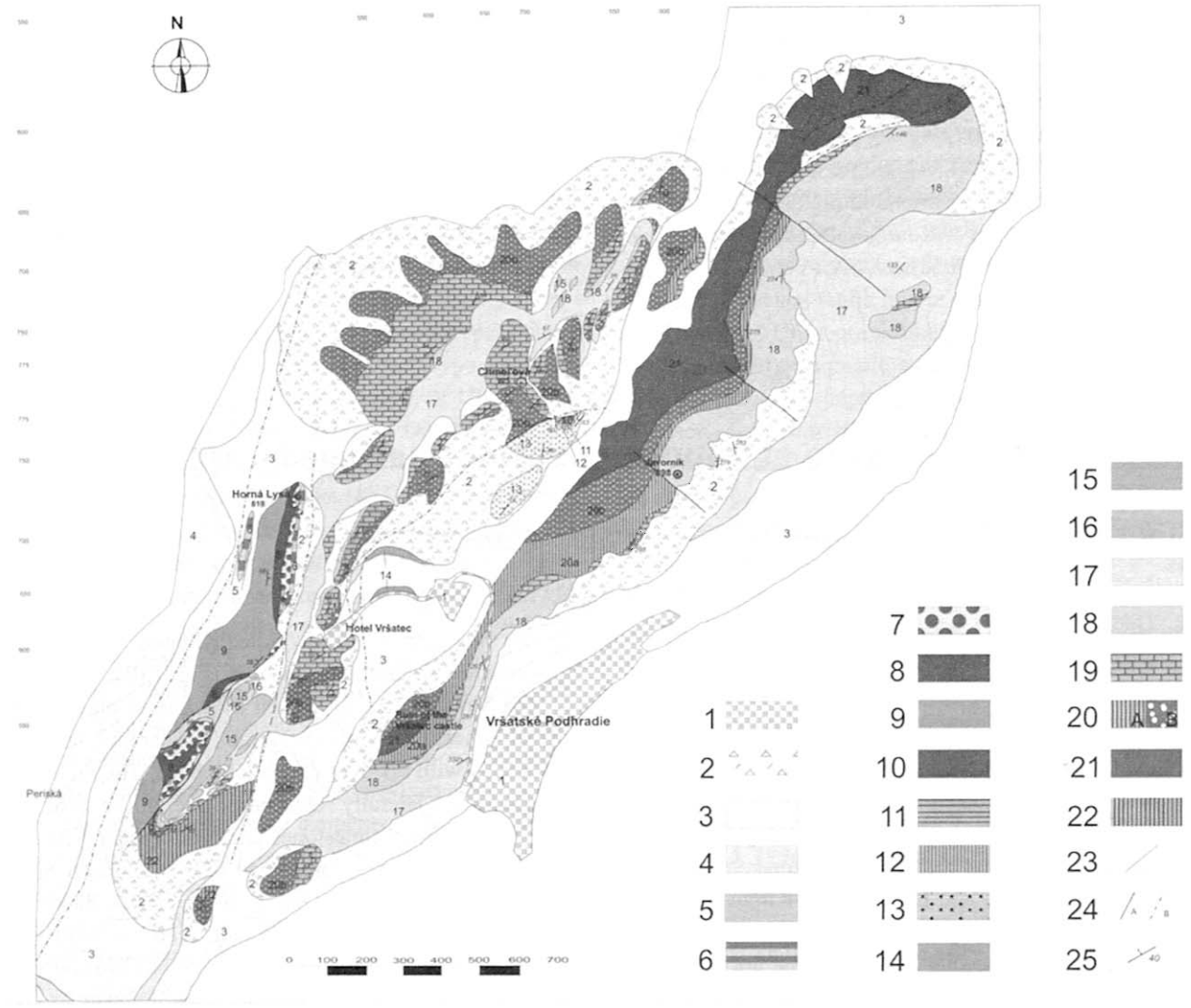


Fig. 14. Geological map of the Vršatec–Chmeľová area (Bučová and Mikuš, 2006). 1 - Holocene anthropogenic deposits. 2–3 - Pleistocene – Holocene. 2 - Deluvial loamy-stony and sandy-stony deposits and debris. 3 - Undivided deluvial slope sediments. 4 - Biele Karpaty Unit, Lopeník Fm., Javorina Mb.: thin bedded flysch with sandstone domination (Campanian – Maastrichtian). 5–9 - Kysuca Unit, Pieniny Klippen Belt. 5 - Lalinok Fm.: variegated marls (Cenomanian – Middle Turonian). 6 - Horná Lysá Lst.: micritic limestones with crinoidal debris and small lithoclasts (Tithonian – Barremian). 7 - Czorsztyn Lst. Fm.: red nodular limestones (Kimmeridgian). 8 - Czajakowa Radiolarite Fm.: radiolarites and radiolarian limestones (Callovian – Oxfordian). 9 - Harcygrund Shale Fm. and Podzamcze Lst. Fm.: dark marly shales, dark spotty marly limestones (Allenian - Callovian). 10–14 - Niedzica and/or Pruské Units. 10 - Czajakowa Radiolarite Fm.: red radiolarites and radiolarian limestones (Oxfordian). 11 - Niedzica Lst. Fm.: red nodular limestones (Upper Bajocian – Callovian). 12 - Krupianka Lst. Fm.: red crinoidal limestones (Upper Bajocian). 13 – Smolegowa Lst. Fm.: light crinoidal limestones, silicified spotty limestones (Lower–Upper Bajocian). 14 - Skrzypny and Krempachy Shale Fms.: 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 xenoliths of carbonates (Cenomanian – Maastrichtian). 17 - Púchov Fm: variegated marls (Lower Albian – Lower Campanian). 18 - Dursztyn Lst. Fm.: yellow to reddish massive limestones (Tithonian – Hauterivian). 19. Czorsztyn Lst. Fm.: nodular limestone (Callovian – Kimmeridgian). 20 – a - Krupianka Lst. Fm.: red crinoidal limestones (Bajocian); b - Smolegowa Lst. Fm.: white limestones (Bajocian). 21 - Vršatec Lst.: light biohermal limestones (Lower Bajocian). 22 - Skrzypny and Krempachy Shale Fms.: 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.

The Smolegowa and Krupianka Lst. Fms. are formed by grey to reddish crinoidal grainstones that are overlying the biohermal Vršatec Lst. (Fig. 15D). The top of the biohermal facies is marked by thin Fe/Mn crusts and impregnations. In contrast, the boundary between the peribiohermal facies and crinoidal limestones seems to be gradual in most sections. Only some brachiopods were collected from the base of the formation, including long-ranged taxa such as *Acanthothiris spinosa* (Linnaeus), *Striirhynchia subechinata* (Oppel), *Apringia* aff. *poly-*

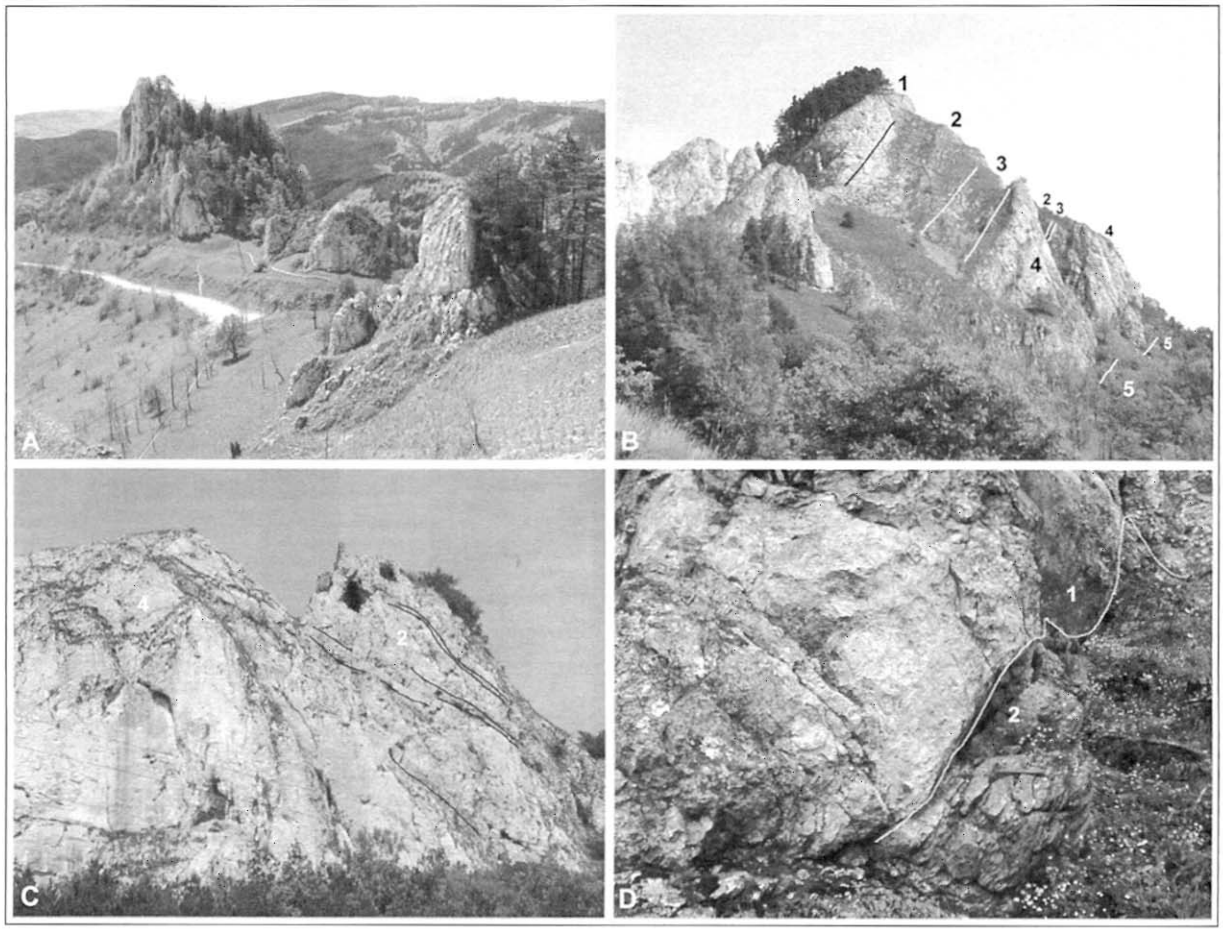


Fig. 15. A. General view on the Vršatec Castle Klippe (photographed from the peak Javorník. **B.** Javorník Klippe, view from the castle. 1 - Vršatec Lst. 2 - Smolegowa Lst. Fm. 3 - Bohunice Fm. 4 - Dursztyn Lst. Fm. 5 - Púchov marls. **C.** Detailed view on the SE wall of the Vršatec Castle Klippe. 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.

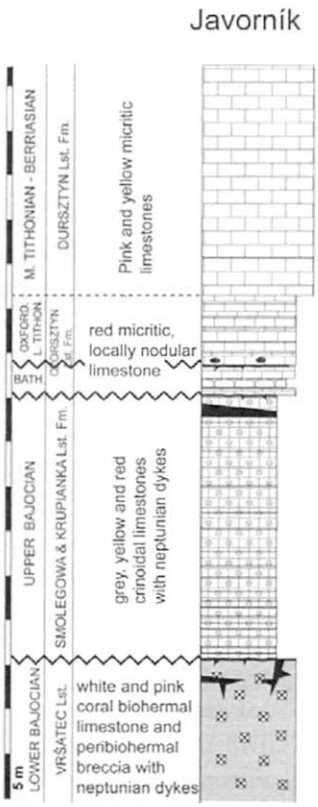
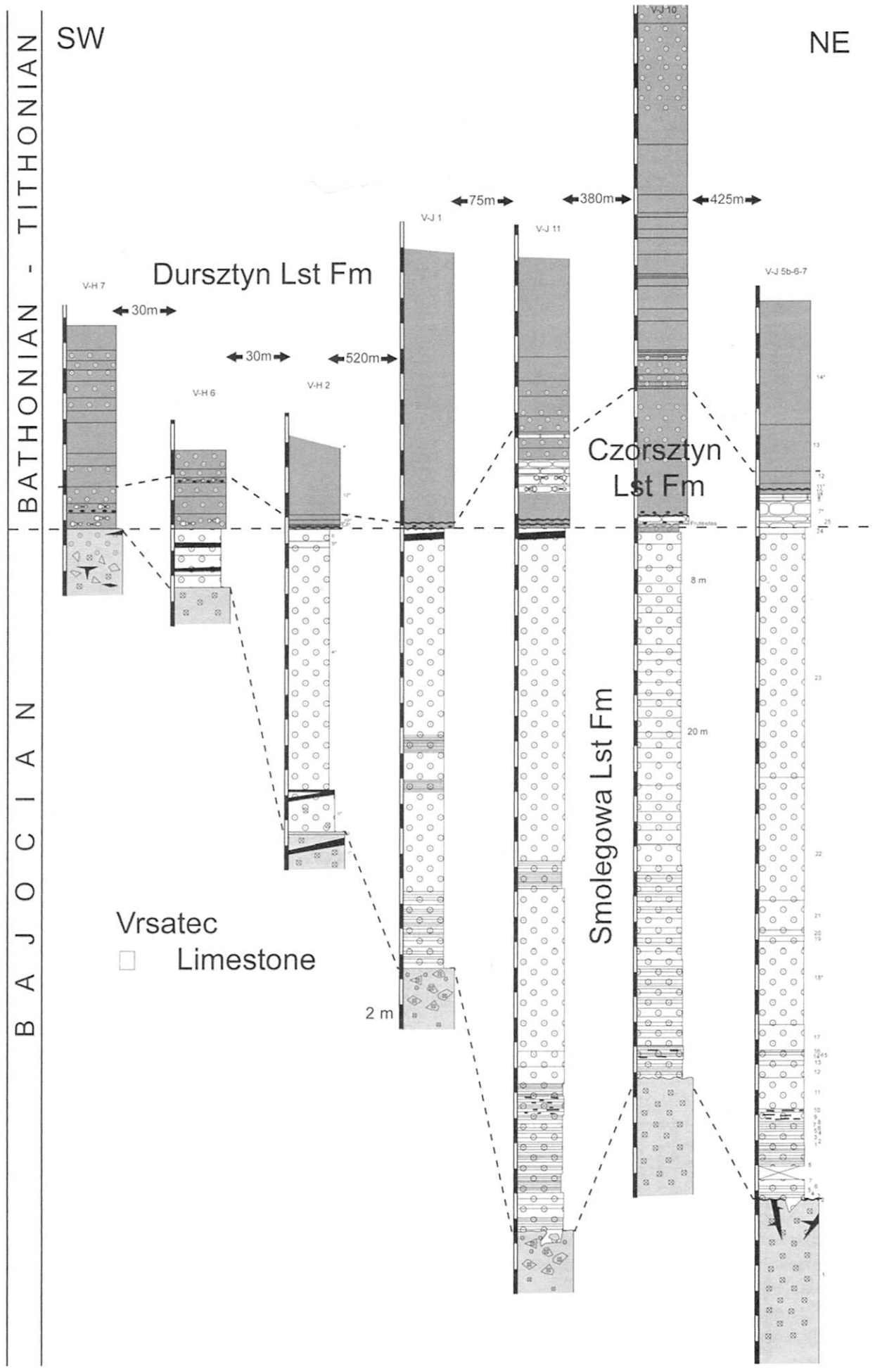


Fig. 16. Simplified section through the Middle Jurassic–Lower Cretaceous succession of the Javorník Klippe (after Schlögl et al., 2006, modified).

morpha (Oppel) with possible stratigraphic range Bajocian – Callovian. Because of lack of the stratigraphically more valuable fauna, the age of crinoidal limestones is based on the dating of the equal crinoidal deposits in the area as Bajocian. The thickness is around 35 metres.

The Czorsztyn Lst. Fm. consists of red micritic, locally nodular limestones. Based on ten detailed stratigraphic sections along both blocks, the thickness of this formation can vary between 20 cm and more than 15 metres. There are 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 Lower Tithonian. The thickness of the Bathonian–?Callovian deposits, which are separated from the overlying red micritic limestones by another Mn/Fe hardground, attains few cm up to 3.5 metres. The deposits contain mainly filaments (filamentous packstones), juvenile gastropods, benthic forami-


BAJOCIAN - BATHONIAN - TITHONIAN
SW
NE
Dursztyn Lst Fm
Czorsztyn Lst Fm
Smolegowa Lst Fm
V-H 7
V-H 6
V-H 2
V-J 1
V-J 11
V-J 10
V-J 5b-6-7
30m
30m
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2 m
Vrsatec
Limestone

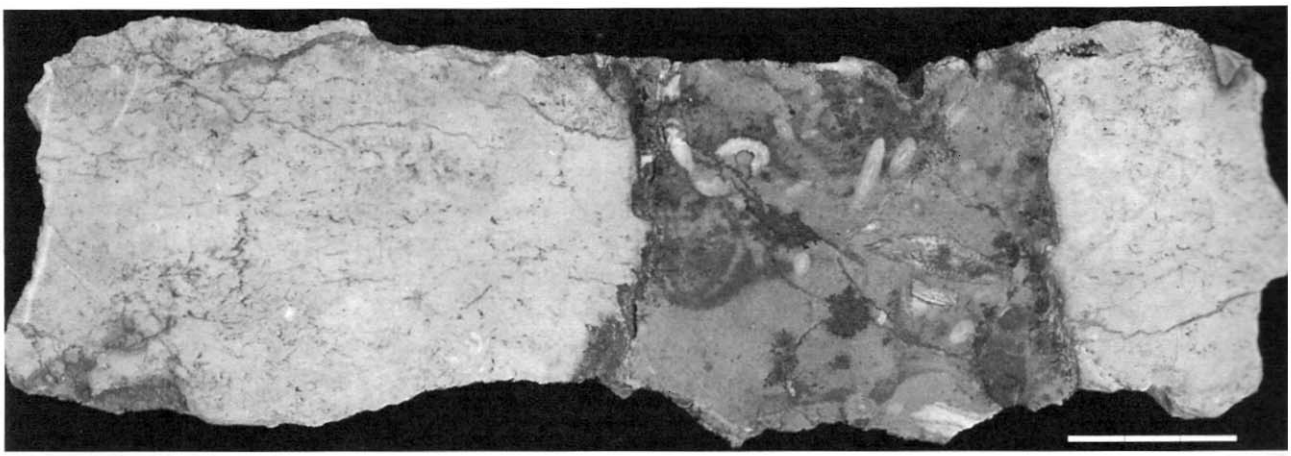


Fig. 17. Detail of the Lower Cretaceous paleokarstic surface with the transgressive Albian lag deposits with abundant belemnite rostra, coral fragments and oncoids. Scale bar 3 cm.

nifers and crinoidal ossicles. The overlying massive limestones show the *Protoglobigerina* microfacies, suggesting their Oxfordian age. The massive limestones pass gradually into massive red micritic limestones with the *Saccocoma* microfacies. Ammonite fauna including *Orthaspidoceras uhlandi* (Oppel) and *Hybonoticeras hybonotum* (Oppel) indicates Kimmeridgian and Lower Tithonian age.

The Dursztyn Lst. Fm. consists of massive, red, pinkish or yellowish micritic limestones. Locally, they can be rich in crinoidal ossicles (forming lenses of crinoidal packstones) and fine shelly debris. The *Saccocoma* microfacies passes gradually into the *Crassicolaria* and *Calpionella* microfacies. The Middle Tithonian to Lower 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 Lst. Fm. 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. 17). The marls are of Upper Cenomanian to Campanian age.

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 paleogeographic position. Aubrecht and Túnyi (2001) analysed neptunian dyke orientations in four sections in the PKB. They include 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 Lst. Fms., Fig. 15C) and consist of red micrites or biomicrites. They contain mainly juvenile bivalves or rarely the *Globuligerina* microfacies. These microfacies indicate that the dykes range from the Bathonian to Oxfordian. Exceptionally, neptunian dykes of Tithonian and Albian age were found at the Vršatec locality. However, they represent rejuvenation of the older dykes (Mišík, 1979).

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

Surrounding klippen

The klippen situated between Vršatec Klippen and the Váh valley belong to various klippen as well as periklippen units, actually mixed together. The closest coulisse of small klippen between village and the saddle below Chotúč Klippe are built of deposits of deep-water Orava Unit (Schlögl et al., 2000). Succession is well outcropped on the steep slopes of **Strapková and Dúbravka Klippen** and can be summarized as follows: bedded Fleckenmergel/Fleckenkalk of Upper Sinemurian age, thin-bedded greenish-grey and red marly limestones, yellowish-greenish marly limestones of late Upper Sinemurian–Pliensbachian age, red nodular limestones of Toarcian age, spongolites and cherty limestones of Aalenian–Lower Oxfordian age, lower red

nodular limestone and green and red radiolarites of Middle Oxfordian to Lower 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 cherts of Upper Tithonian to Upper Berriasian age. It is to note, that these klippen represent 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 the Allgäu and Podzamcze Fms., which is of 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 Lower Cretaceous (Lower Hauterivian) age (Schlögl, 1998). It is to note, that older lithostratigraphic units are outcropping in the close vicinity of the Chotúč Klippe and were formerly 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 east of Chotúč Klippe: white to pink quartzites and Q conglomerates, carbonate micro-conglomerates probably belonging to Karpatian Keuper; dark shales, calcareous sandstones and bioclastic limestones (Rhetian); 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 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 Bajocian biohermal facies and without it are present here. 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 (**Chmeľová coulisse**) belong to the classical Czorsztyn Unit without biohermal limestones and to some type of Niedzica-like transitional units (Bučová, 2006). A newly discovered body of volcanic rocks occurs in a core of macroscopic syncline above the Upper Cretaceous red marls (Fig. 14). The volcanic body is about 50 m wide and over 250 m long and consists of hyaloclastites of leucitic tefrit composition, which are partly mixed with surrounding sediments. Consequently, the volcanics originated most probably in the time range from Cenomanian to Maastrichtian. The age was defined by keeled planktonic foraminifers. They are embedded in earlier marlstones, which fill small pockets in the hyaloclastites (for further details see abstract of Spišiak et al., in this volume). In the most external position in the Chmeľová region, a narrow strip of the Kysuca Unit was discerned (Horná Lysá, variety of Kysuca Unit with more or less crinoidal Lower Cretaceous Horná Lysá Lst.; Mišík et al., 1994). To the NW, it is juxtaposed to the Maastrichtian – Paleocene flysch sediments of the Biele Karpaty Unit of the Carpathian Flysch Belt. This contact is most probably followed by a large wrench fault that forms the northern boundary of the PKB.

STOP 4

Samášky – Pruské unit; Horné Sŕnie quarry – Czorsztyn Unit with Lower Cretaceous paleokarst

Roman AUBRECHT and Ján SCHLÖGL

Samášky – Bajocian to Lower Cretaceous development of the Pruské Unit

GPS coordinates: N 48°59'52.1" E 18°7'7.8"

The section belonging to Pruské Unit outcrops in the roadcut along the road connecting the main transport road with an abandoned quarry at Samášky, within the area of the local cement factory quarries. The section is 400 m long with layers generally dipping about 30° SSW. The following lithostratigraphic units can be recognized (Fig. 18; Aubrecht and Ožvoldová, 1994).

Harcygrund Shale Fm. Poorly outcropping, it is represented by grey spotted marlstones with abundant *Bositra buchi* shells, locally with sandy crinoidal limestone turbiditic intercalations up to 5 cm thick. The sediment is faintly laminated. Thin sections revealed the presence of frequent sponge spicules and some lenticulinid foraminifers. The preserved part of the formation attains 50 m in thickness. Based on the analogy with different sections, the age is supposed as Middle Bajocian.

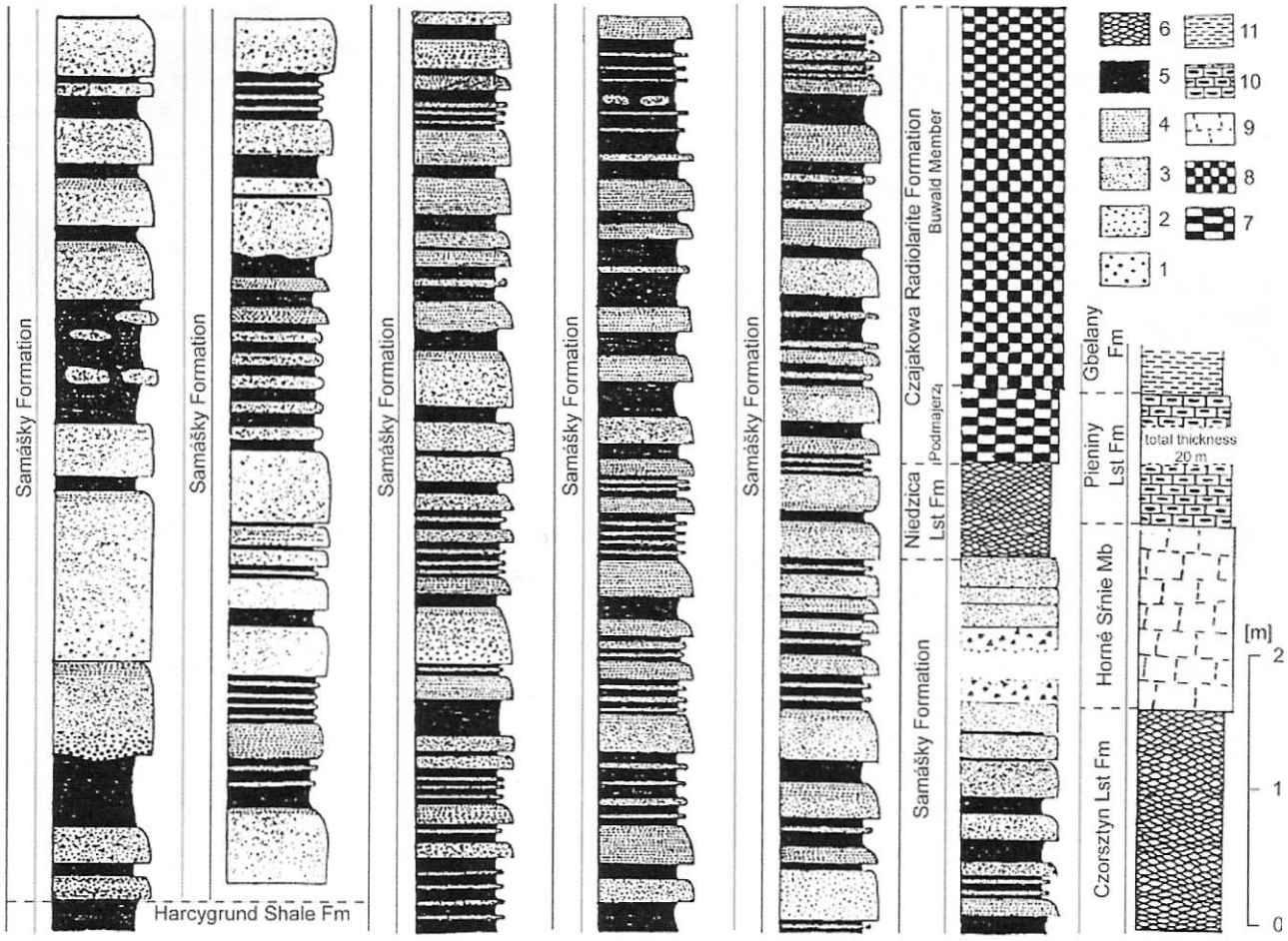


Fig. 18. Lithostratigraphic scheme of the examined profile. 1–4. Sandy crinoidal limestone: 1 - Clasts 2–5 cm. 2 - Clasts 1–2 cm. 3 - Clasts < 1 cm. 4 - Laminated bedding. 5 - Dark shales. 6 - Red nodular limestone. 7 - Green radiolarites. 8 - Red radiolarites. 9 - Massive limestone. 10 - Bedded cherty limestone. 11 - Red marls. (Taken from Aubrecht and Ožvoldová, 1994.)

Samášky Fm. Regular alternation of crinoidal turbiditic layers and marlstones to claystones is the most characteristic feature of the formation. The thickness of the formation is 35–40 m. This crinoidal flysch begins with relatively thick turbiditic layers with thick sandy shale intercalations, but it becomes more regular higher in the section. Slump structures are rare. Several thickening-upward cycles can be distinguished, indicating prograding of the turbiditic fan. Many of the turbiditic layers contain A and B Bouma intervals; the C interval is absent, which suggests a relatively high proximality indice. The crinoidal beds are white to light-grey in colour. Apart from crinoidal detritus, these sandy crinoidal biosparites contain bivalves, thick-shelled ostracods, echinoid spines, punctate brachiopods, bryozoans, nodosariid and lenticulinid foraminifers and sponge spicules. Crinoidal particles are often silicified. Quartz grains up to 3 cm in size are abundant, accompanied by feldspar and intraclasts of dolomites, marlstones, spongolites and sandstones. The marls are grey, rich in sponge spicules and with rare crinoidal particles and lenticulinid foraminifers. The envisaged stratigraphic age is Bajocian to Bathonian.

Niedzica Lst. Fm. is represented by about 75 cm thick layer of red nodular limestone. It is wackestone with filament microfacies, the filaments being the cross-sections of thin-shelled bivalve *Bositra*. Based on microfacies data, the age can be specified as Bathonian.

Czajakowa Fm. is represented by approx. 60 cm thick complex of green radiolarite beds (5–15 cm of individual thickness), locally with manganeous impregnations and two thin clayey intercalations, followed by 4 m thick complex of red radiolarite beds (up to 15 cm thick), with several thin red shale intercalations in its upper part. Rich radiolarian fauna indicates time span from Middle Bathonian-Lower Callovian to Kimmeridgian, but it is necessary to note, that the uppermost part just below the red nodular limestones are not true radiolarites but silicified *Saccocoma* limestone. The abundance of the *Saccocoma* is characteristic for Kimmeridgian.

Czorsztyn Lst. Fm. is represented by about 170 cm thick red nodular limestone with Saccocoma packstones in its lower part, passing upward to wackestones with frequent *Calpionella alpina* and less frequent *Crassico-*

llaria intermedia. Stratigraphic age is Kimmeridgian to Upper Tithonian.

Horné Sŕnie Lst. Mb. is represented by massive 140 cm thick layer of pink micritic limestone with calpionellids, radiolarians, benthic but also relatively abundant planktonic foraminifers, bryozoans, bivalves and the later indicates Upper Berriasian age.

Pieniny Lst. Fm. is represented by about 20 m thick, bedded white micritic limestone with dark chert layers or chert nodules mainly in the upper part. The limestones are mudstones with rare microfauna. Rich radiolarian assemblage extracted from the chert layer 2 m above the base indicates Upper Valanginian age.

The section is in tectonic contact with red Púchov Marls with abundant planktonic foraminifers of Lower Campanian age.

The importance of the section is in fact, that it confirms the transitional character of the Pruské Unit already during the Bajocian–Bathonian (Fig. 19) Samášky Fm, represented by distal crinoidal turbidites is the transitional link between the Smolegowa and/or Krupianka Lst. Fms. deposited on the elevated Czorsztyn Swell and the Flaki Fm. from the deep-water Kysuca-Pieniny Unit.

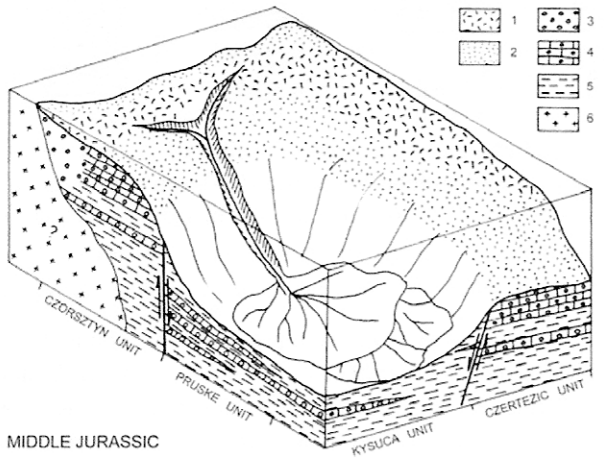


Fig. 19. Schematic view of the Pieninic units in Middle Jurassic. 1. Crinoidal meadows. 2. Crinoidal detritus. 3. Massive crinoidal limestone. 4. Bedded crinoidal limestone. 5. Marly and clayey shales. 6. Basement. (after Aubrecht & Ožvoldová, 1994)

Horné Sŕnie – Czorsztyn Unit and Lower Cretaceous paleokarst

The locality is situated in the highest level of the active quarries of a cement factory at the northern margin of Horné Sŕnie village in Middle Váh valley. Contact of the Albian sediments with their basement was observed at SW margin of the highest step of the quarry and its continuation was found below, in the lower part of the quarry. The locality is unique by depth of pre-Albian erosion and by preserved paleokarst phenomena (Aubrecht et al., 2006). In an overturned position, contact of Upper Bajocian crinoidal limestone (**Smolegowa Lst. Fm.**) and Albian sediments is visible (Figs. 20 and 21). Along with crinoids and brachiopods, the limestones also contain numerous bivalves. Except the crinoidal limestones, some relics of younger organodetritic limestones with "filamentous" microfacies (Bathonian–Callovian) were found in the basement rocks, mainly as filling of fissures in the crinoidal limestones. The rest of Jurassic sediments is missing. The Albian rocks, as a rule, represent both, the organodetritic limestones with crinoids, belemnites, bivalves and siliciclastic admixture (up to size of small pebbles) and somewhat younger, more pelagic red marlstones to marly limestones containing only planktonic fauna. At the base of the Albian deposits, greenish-yellow, brown to black P-Fe-Mn stromatolites and oncoids occur. Locally, white marly limestones fill the karstic depressions, containing Middle Turonian microfauna. This is a further evidence of continuous episodes of non-deposition and/or erosion still after flooding (Fig. 22).

The complete lack of the Bathonian to Lower Cretaceous sediments points to a deep-reaching erosion that so far was not found in the Czorsztyn Unit. Field observation showed that inclination of geopetal fillings of brachiopod shells both, in the Albian limestones and in the underlying crinoidal limestones displays no difference. That implies that no large tilting took place between Bathonian and Albian. Deep erosion thus cannot be explained by a large-scale tilting-induced emergence. The erosional surface is irregular due to karstification. Rainwater grooves perpendicular to the basement and karren surface as deep as 1 m can be seen at the contact (Fig. 21). Pre-Albian calcite veinlets penetrate several meters down to the underlying rocks. However, they are irregular and filled with polyphase fibrous calcite that can be suspected to represent a fresh-water sinter. The bizzare course of the veinlets suggests their origin by karstic leaching. Some wider veinlets, however contain remnants of neptunian dyke fillings of beige micritic limestone.

Fig. 21. Field photos of the paleokarstic surfaces at the Horné Sŕnie locality. A, B. Deep karren landform (all photos are in the recent position, i.e. tectonically overturned) artificially exhumed in the year 2000. Bizarre phalloidal promontories are formed by the Bajocian crinoidal limestone; the depressions contain multiphase filling, involving Upper Aptian up to Turonian sediments. Note the grooves (arrows) perpendicular to the former basement, originated by rain water. C. Other instance of the vertical grooves, testifying the subaerial origin of the karstic surface; hammer for scale (arrow). D. Paleokarstic surface filled with Middle Turonian white marly limestones (seemingly darker) (t).

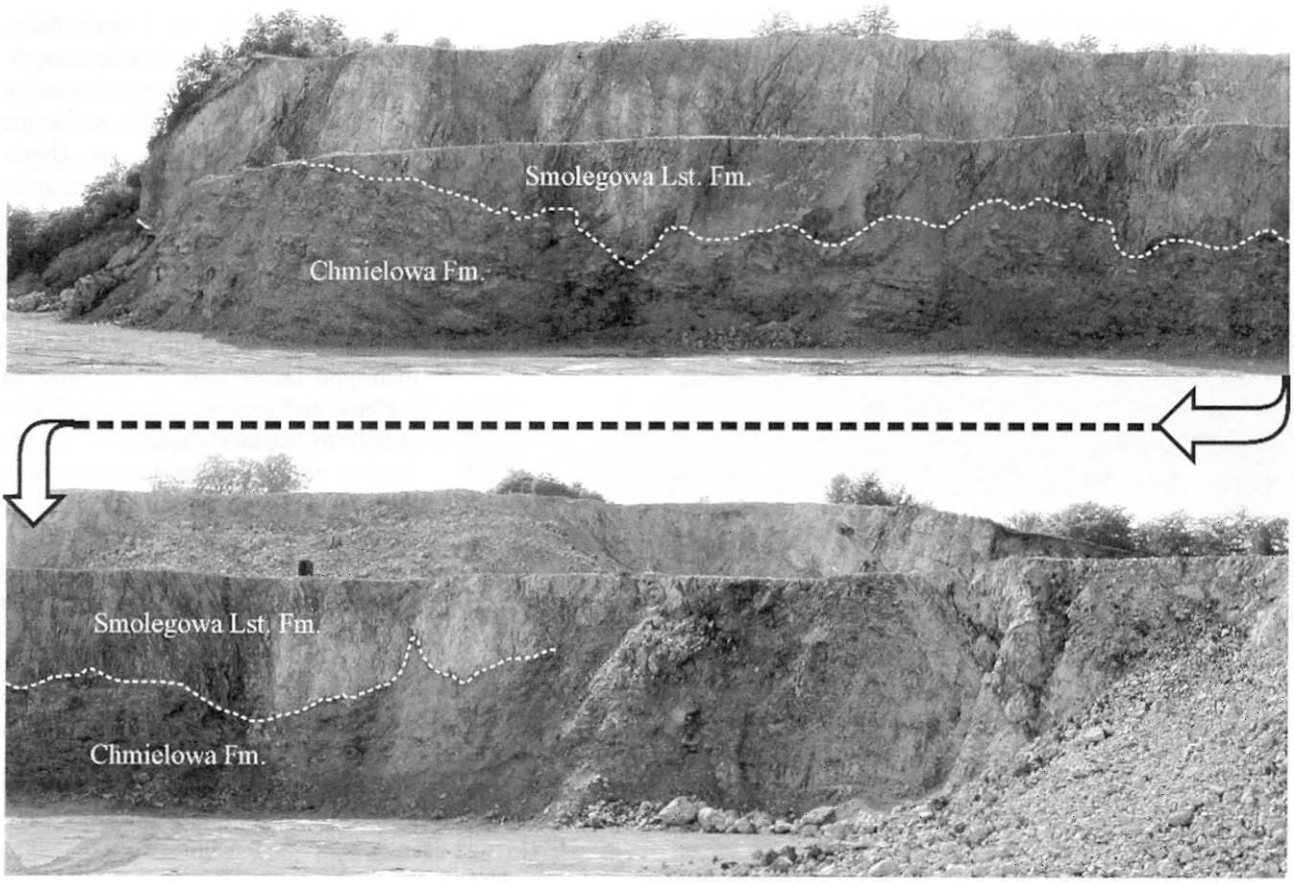
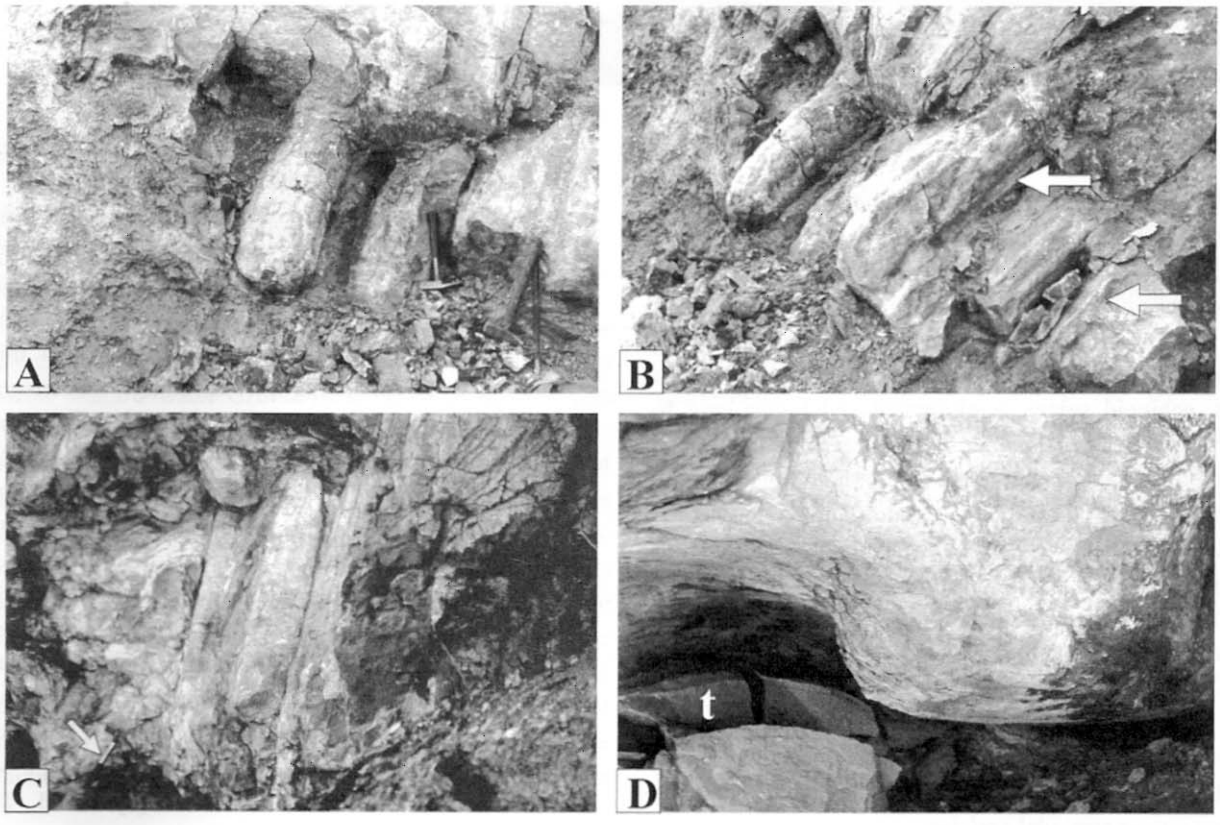


Fig. 20. Field view showing the uppermost steps of the quarries at Horné Sŕnie. Sharp irregular boundary (dashed line) between the Bajocian crinoidal limestone (Smolegowa Lst. Fm.) and the Upper Aptian/Albian marly limestones and marls (Chmielowa Fm.) originated by deep erosion and karstification that removed all the Bathonian to Hauterivian sediments. The succession is in stratigraphically overturned position. State from the summer 2003.



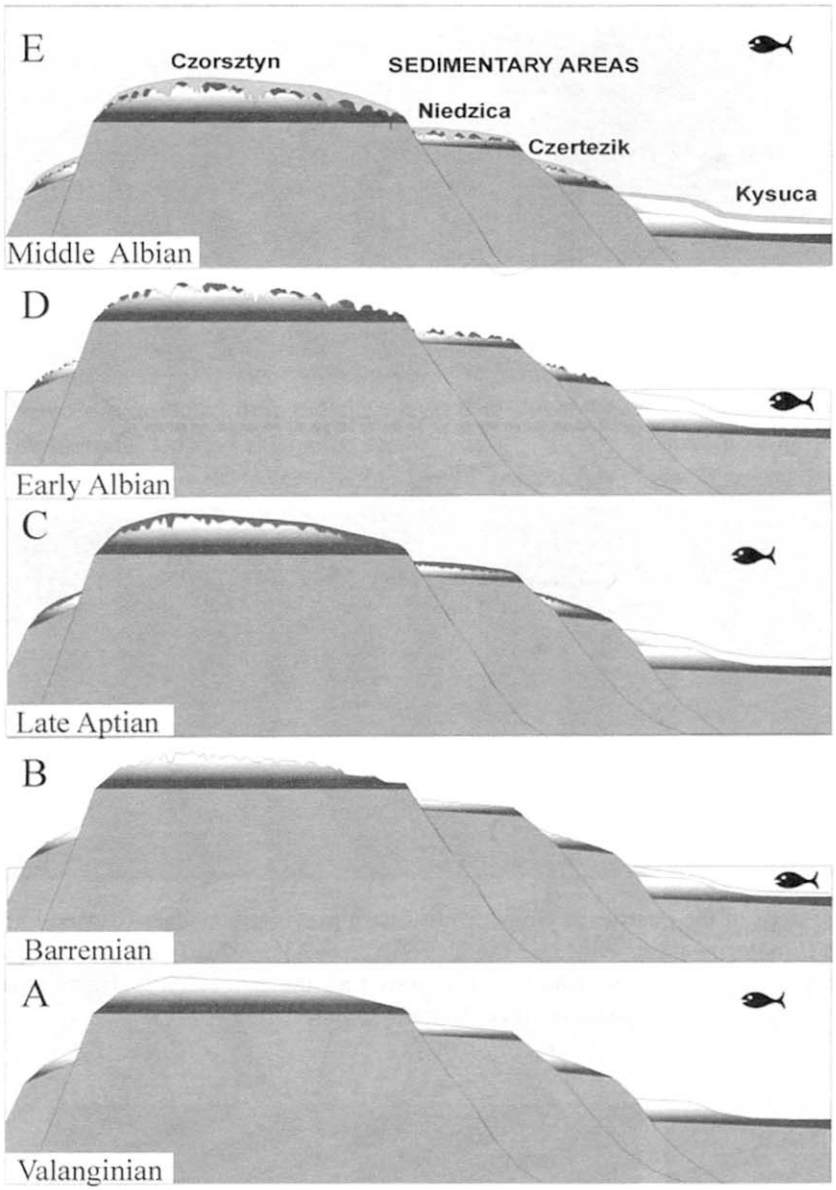


Fig. 22. Model of the Lower Cretaceous evolution of the Oravic area. A. Valanginian: the Czorsztyn elevation was flooded and subtidal to neritic sedimentation took place; B. Barremian sea-level drop resulted in emersion of the more elevated Pienidic units as far as the margin of the Kysuca-Pieniny Trough (sedimentary area of the Nižná Succession), where a shallow-water deposition of the Urgonian-type facies took place; most of the emerged land was eroded and karstified to various depths; C. Upper Aptian new flooding occurred with deposition of organodetritic limestones on the Czorsztyn Swell; D. Lower Albian a new sea-level drop resulted in new karstification also involving the new Upper Aptian limestones, forming thus a polyphase karst; E. Middle Albian: rapid flooding, with deposition of red pelagic marls that covered the karstified areas (after Aubrecht et al., 2006).

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

Relics of micritic limestone represent packstones with "filamentous" microfacies (cross-sections of thin shelled epiplanktonic bivalves *Bositra buchi*) and dispersed bigger crinoidal ossicles.

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

"Organodetritic Albian" represents wackestone with planktonic and agglutinated benthic foraminifers, crinoidal ossicles, echinoid spines, bivalve fragments (mostly *Aucellina* sp.), fish teeth, some tiny gastropods, bryozoan fragments, ostracods and silicisponge spicules. Radiolarian tests were preserved only if impregnated by Fe-Mn oxides. The benthic biodetritus is strongly bored. The

foraminifer assemblages are dominated by planktonic genera, but nodosariid and sessile nubeculariid foraminifers occur, too. The foraminiferal assemblages indicate Upper Aptian–Lower Albian age. At the base of the "organodetritic Albian", clastic admixture is commonly concentrated, mostly represented by sandy quartz grains up to small pebble size. The quartz grains are angular and strongly corroded. Along with them, lithoclasts of Triassic dolomites and dedolomites, as well as tiny lithoclasts of Upper Tithonian micritic limestones with *Crassicollaria* occur. From accessoric minerals, some grains of chromspinelids, rutile, garnet and epidote were found. Authigenic glauconite is scarce but ubiquitous.

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

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

STOP 5

Krasín Klippe – Middle Jurassic syntectonic cliff breccia

Roman AUBRECHT

GPS coordinates: N 48°57′47,2″, E 18°1′24,1″

Locality called Krasín Klippe is situated in an abandoned quarry west 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. 23**): 1. presence of the submarine breccias of the Middle Jurassic age, 2. Upper Jurassic limestones removed by erosion (except the Oxfordian bioherm limestone filling a cleft), 3. Lower Cretaceous sediments overlying the Middle Jurassic limestones in the large clefts. The Krasín Breccia is an example of Jurassic syntectonic sedimentary breccia, 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. 24**).

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

Smolegowa Lst. Fm. 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, mainly 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,

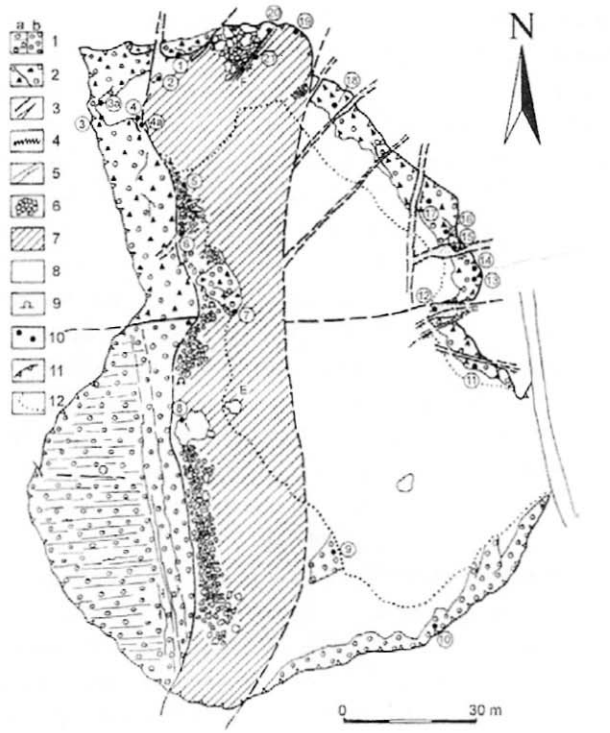


Fig. 23. Geological situation in the quarry (scheme). 1 - Bajocian white and slightly grey crinoidal limestones (a – bedded, b – massive). 2 - Bathonian–Callovian Krasín Breccia (blocks of crinoidal limestone in a similar matrix). 3 - Neptunian dykes with filling of Middle Jurassic age ("O" indicates 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. (Taken from Mišík et al., 1994.)

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 remaining void filling starts with the crinoidal detritus, which indicates that the breccia was formed due to synsedimentary tectonics occurring during the deposition of crinoidal limestones. Next infilling step is represented by micritic limestone with filamentous microfacies (Bathonian – Callovian) and by almost sterile micrite with cavity-dwelling ostracods. The breccia bears evidence of numerous instances of disturbance, resedimentation and recementation. Moreover the isotopic composition of some early generations of stromatolites and early cements indicate possible fresh-water diagenesis.

Krupianka Lst. Fm. 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 Callovian.

?Vršatec Lst. 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).

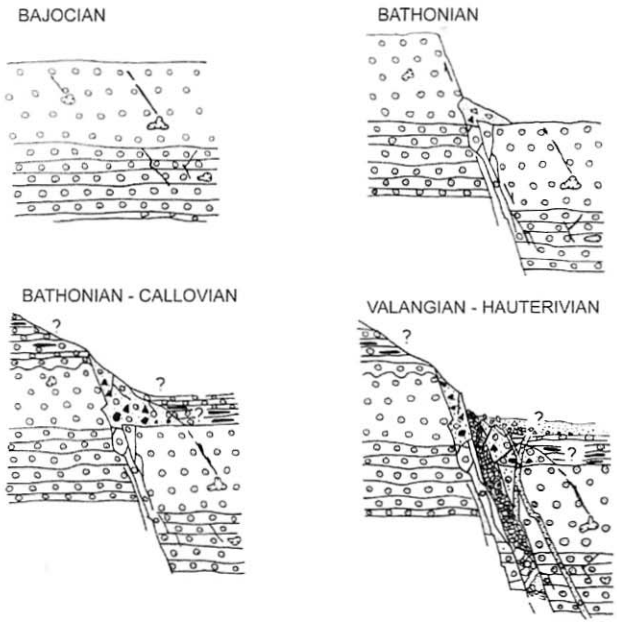


Fig. 24. Suggested geological development in the examined locality (legend as in Fig. 20; after Mišík et al., 1994).

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