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Stratigraphic reconstruction of tectonically disturbed carbonate sequences along the western margin of the Brno batholith: a need of multidisciplinary approach

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Abstract. Extremely complicated evolution of the western margin of the Brno batholith resulted in a poor preservation of the Devonian and Lower Carboniferous in several fragments of a different stratigraphic range and deformational degree. The research of geological development has shown that sedimentological interpretations of such tectonically disturbed carbonate sequence require a multidisciplinary approach. After describing the most important transformations of limestone microfabric during the low-temperature ductile deformation, new data on biostratigraphy and facies of these relics of sedimentary successions are presented. The outcrop data are supplemented with facies and biostratigraphic information on eroded levels of carbonates that come from the limestone pebbles in the adjacent Permian alluvial fans of the Rokytná Member conglomerate.

Three stratigraphic horizons are present, distinctly separated from one another by two gaps without any lithological content:

1. Eifelian to lowermost Givetian reef limestones, which can be paralleled to the Čelechovice Cycle of the Moravian Karst Development.

2a. A thick succession of Middle Givetian to Lower Frasnian reef limestones with the development analogous to the Macocha Formation of the Moravian Karst.

2b. Calciturbidites overlying succession *2a* in the Chudčice-Hůrka-Dálky area, in which Lower Frasnian conodont assemblages were identified.

3. Uppermost Famennian to Middle Viséan complex of limestones facially close to the Konice Palaeozoic or to the southern Moravian Karst limestones.

In spite of the good correspondence of the limestones in horizons *1* and *2a* with the Moravian Karst Development, the Lower Frasnian calciturbidites (horizon *2b*) have not been reported from other typical exposures of the Macocha Formation in Moravia yet; their relation to Moravian Karst Development is thus not clear.

Key words: Moravo-Silesian pre-Variscan Palaeozoic, Brno batholith, Moravian Karst

Introduction

Complicated geological situation on the western margin of the Brno batholith makes the stratigraphic and sedimentological research of its Palaeozoic carbonate cover very difficult. The major problems include:

1. strong ductile deformation of limestones, which is markedly higher than in the eastern part of the Brno batholith;
2. complex post-ductile tectonic development, which destroyed the stratigraphic continuity of carbonate sequences;
3. significant erosion of the upper levels of the Brno batholith and its sedimentary cover, which reduced the occurrence of the Palaeozoic into isolated relic bodies;
4. primary lack of fossils at some stratigraphic levels, namely the types which could resist higher strains.

The correct understanding of the architecture and genesis of such complexly dislocated sedimentary sequences necessitates a comprehensive approach with the use of microtectonics, mesostructural geology, sedimentology and palaeontology. In the presented paper we summarize the available significant data, which were obtained from these fields of geology and try to draw some conclusions on the stratigraphy of the Devonian and Upper Carboniferous limestones along the western margin of the Brno batholith. Several typical problems, which can be encountered during this type of study, are discussed.

Tectonic setting

The Devonian and Lower Carboniferous limestones in the sedimentary cover of the Brunovistulicum are exposed at several distinct positions with different degrees of tectonization. Within the Devonian, three types of facies developments are traditionally distinguished: the Drahany Development, dominated by deeper water facies and basic volcanism; the Moravian Karst Development with typical coral-stromatoporoid carbonate platform limestones, which were replaced by deeper facies during the Late Frasnian and Lower Famennian; and the Transitional Development, combining platform and basin features (e.g. Chlupáč 1964, Kettner 1966). In all these developments the pre-flysch sedimentation continued to the Lower Carboniferous.

In the westernmost part of the Brunovistulicum, the Devonian and Lower Carboniferous sediments are incorporated into the nappe sequence of allochthonous Moldanubian and Moravian units, which are thrust over the Brunovistulicum. Palaeozoic limestones and Lower Carboniferous flysch sediments (mainly greywackes) are

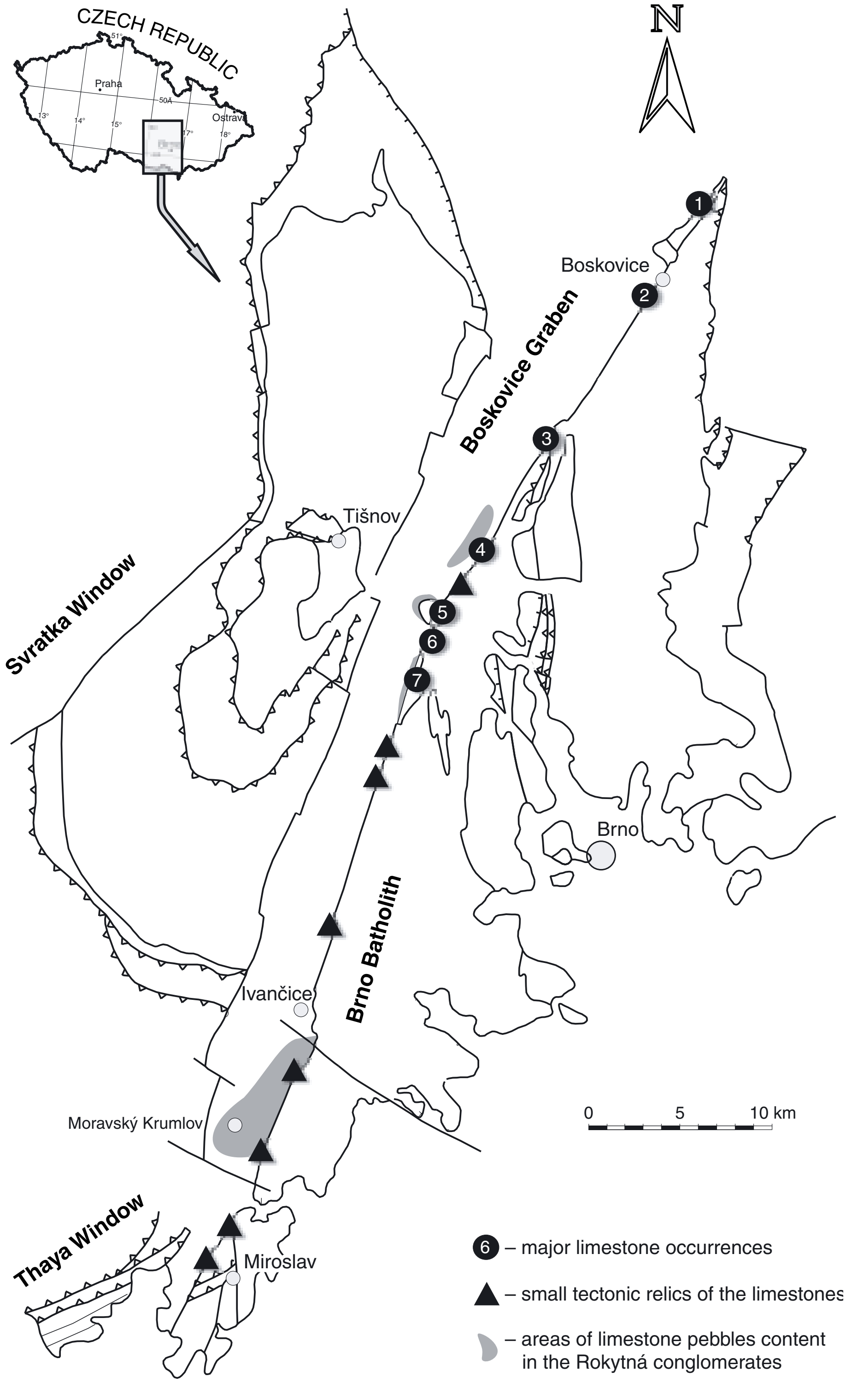


Fig. 1. Schematic geological map of the study area. Major localities of stratigraphic research are shown together with minor relics of the limestones and areas of limestone pebbles content in the Rokytná Member conglomerates. 1 – Šebetov-Vážany section, 2 – Újezd u Boskovic, 3 – Černá Hora, 4 – Lažany, 5 – Malhostovice and Čebín, 6 – Dálky and Hůrka hills, 7 – Chudčice-Veveří Belt.

preserved in tectonic relics in a close foreland of these crystalline nappes, on the western margin of the Brno batholith (Fig. 1). During a ductile event of probably Late Viséan to Namurian age, the limestones were intensely mylonitized, folded and tectonically imbricated. The temperature reached during the deformation was as high as 300 °C and the strain markers indicate a large stretch of up to 500 percent (Špaček et al. 2001).

This mylonitized sequence was further affected by post-ductile tectonic deformations related to the formation of the Boskovice Graben and later thrusting of the Brno batholith over the Upper Carboniferous-Permian sediments of the graben. Brittle deformations resulted in a strong cataclasis of the sediments and pulling-up of their fragments along the whole western margin of the Brno batholith. The age of the thrusting of the batholith is probably of pre-Mesozoic age, as indicated by the absence of similar faults in the Jurassic and Cretaceous sediments (Zapletal 1924). The Klemov Fault, which runs across the Cretaceous sediments of the Blansko Trough parallel to the margin of the Boskovice Graben, shows an opposite sense of displacement: it is a normal fault (Jaroš 1958). A system of transversal WNW-ESE-striking faults developed during the later tectonic phases.

The evolution described above resulted in the present-day occurrence of several fragments of sedimentary sequences, each of different size, stratigraphic range and intensity of deformation. Nevertheless, in spite of this extremely complicated structure, these remains give us some chance for stratigraphic reconstruction of the original pre-orogenic situation.

Microfabric changes resulting from tectonization

The lack of fossils in the Devonian to Lower Carboniferous limestones covering the western part of the Brno batholith and their poor preservation has often led to preferential usage of lithostratigraphic criteria for the classification and correlation of the carbonate successions. However, due to the lithological similarity of the limestones at different stratigraphic levels and their significant tectonic transformation, the lithostratigraphic approach can result in a simplified and erroneous view of sedimentary successions. In the collisional area of the orogen, mylonite zones in the limestones can be very thick and if the strain-induced changes of their internal structure are disregarded, petrological misinterpretations are inevitable.

In the following paragraphs we describe two typical examples of deformational processes, which can lead to a significant damage of sedimentary structures.

Grain boundary sliding

Fine-grained polycrystalline aggregate can be deformed by a mechanism, which is referred to as grain boundary sliding (GBS). It is a ductile mechanism during which strain is accomplished by sliding along grain boundaries of essentially rigid crystallites. Minor changes in shape that the grains have to undergo in order to slide past each other are accommodated by other mechanisms (mainly diffusional mass transfer), but this does not result in a significant change in grain size or in grain shape (Schmid et al. 1977, Schmid 1982, Burkhard 1990). In classical microtectonic studies it is often concluded that no substantial change in microstructure occurs in homogeneous aggregates deformed by GBS, but this is not true in the case of inhomogeneous sediments with architecture based on fine-grained components. For example, a rock with small-scale rapid alternation of lime mudstone and packstone with peloids, ooids, intraclasts and foraminifers as basic constituents can be transformed, due to high strain, into a rock with the appearance of micritic sediments of monotonous and uniform composition.

An example of tectonic transformation of a peloid packstone with echinoderms into "laminated mudstone" is demonstrated in Figures 2A–C. Residual syntaxial overgrowths of crinoid fragments enclose nearly intact peloids, which are stretched into thin laminae in the external parts of the structure. In most mylonitized fine-grained limestones, such lamination is of tectonic origin, resulting from intimate folding and multiple recurrence of several small-scale lithological sequences. High-stress dynamic recrystallization, which is discussed in the following section, usually makes the lamination even more pronounced. When interpreting such lithology, we often have to rely only on the occurrence of rare markers such as pressure fringes around quartz clasts; these may indicate high strains and probable damage of all minute sedimentary structures (Fig. 2D).

When micritic matrix of inhomogeneous limestone is deformed by GBS mechanism, its strength is much lower than that of relatively coarse-grained clasts. Consequently, the preservation of primary sedimentary structures in limestones mylonitized in low-temperature conditions is most probable in coarse-grained domains "floating" in fine-grained matrix.

Dynamic recrystallization

Intracrystalline deformation leads to the increase in dislocation density, which inhibits free movement of dislocations through the crystal lattice (e.g. Guillopé and Poirier 1979). If the temperature during the deformation is high enough, the processes activated lead to the reduction of dislocation density, and, consequently, to the reduction of Gibbs free energy. These mechanisms are referred to as recovery, subgrain rotation recrystallization and migration recrystallization (e.g. Guillopé and Poirier 1979) and often lead to significant changes in rock microstructures.

In the inhomogeneous limestones of the area studied, the dynamic recrystallization led to an outstanding grain-size reduction of the coarse-grained clasts, while the grains of originally micritic matrix increased their size only negligibly. It has been demonstrated by many authors that there is an inverse proportionality between stress and recrystallized grain size (e.g. Twiss 1977, Kohlstedt and Weathers 1980, Rutter 1995). As a result of high-stress conditions of the deformation under low temperature, the size of dynamically recrystallized grains is similar to the size of the matrix grains (6–10 μm). Rocks affected by the dynamic recrystallization show transformation of clasts into apparent "microspar", which is actually mainly secondary (tectonogenic; Figs 2E, F). Progressive syn-deformational (or post-deformational) temperature increase can lead to the recrystallization under lower stress, and consequent grain growth. If the dynamic recrystallization is underestimated, one could confuse such microstructure with normal diagenetic sparite of static environment. In most cases, a detailed analysis of the microfabric leads to the identification of genetic processes. Nevertheless, if the interpretation of the processes is to be true, a complex view is necessary.

For a more detailed analysis of the ductile deformation of the limestones in the western margin of the Brno batholith see the paper of Špaček et al. (2001).

Brittle-plastic and brittle deformations can result in even more catastrophic devastation of the primary microstructures of rocks. Large displacements occurred on the eastern marginal fault of the Boskovice Graben during the Permian. The blocks of carbonates whose structure was completely destroyed by cataclasis and penetrative veining are commonly found along the whole western margin of the Brno batholith, particularly in its southern part (Fig. 1).

Biostratigraphic record and sedimentary facies

The carbonate rocks exposed on the western margin of the Brno batholith often show lithological features, which are representative of Givetian and Frasnian limestones of the Macocha Formation in the Moravian Karst. Therefore, the two regions have been frequently compared from both stratigraphic and sedimentological points of view. Nevertheless, strong mylonitization resulted in a significant change of internal architectures of the limestones, and, consequently, lithological parallelization with the limestones of the Moravian Karst can be misleading. Finds of fossils in the area of interest are restricted only to several stratigraphic horizons. In other places, fossils are absent primarily or due to their low resistance to high strains, mainly in the ductile phases of the deformation. A mere extrapolation of stratigraphic meaning of such scarce palaeontological data would be obviously misleading.

The casual analytical research of the last two decades has shown the presence of the Eifelian limestones with faunal affinity to the Čelechovice Development (the lowermost part of the Moravian Karst Development) within the successions of the Moravian Karst-type limestones (Hladil and Lang 1985, Hladil 1991, Hladil et al. 1994). Famennian to Viséan facies were also found, which are similar to calciturbidites of the Líšeň Formation (Moravian Karst), Jesenec Limestone (Drahany Development) or some facies of Transitional Development (Bábek et al. 1995, Kalvoda et al. 1995). Kalvoda et al. (1995) suggested that the limestones of the western margin of the Brno batholith could represent a mosaic of tectonically juxtaposed relics of sedimentary areas with different features, originally distant from one another. A similar scheme is supported by new biostratigraphic and sedimentological data, which were obtained during the current research. The results of biostratigraphic research based primarily on the analysis of conodont assemblages, are summarized in Table 1 and Figure 3, together with older existing data.

Due to the generally poor state of preservation, a detailed stratigraphic analysis of limestones was possible in only six areas, which are briefly described below. Further information on the localities can be found in Špaček (2001).

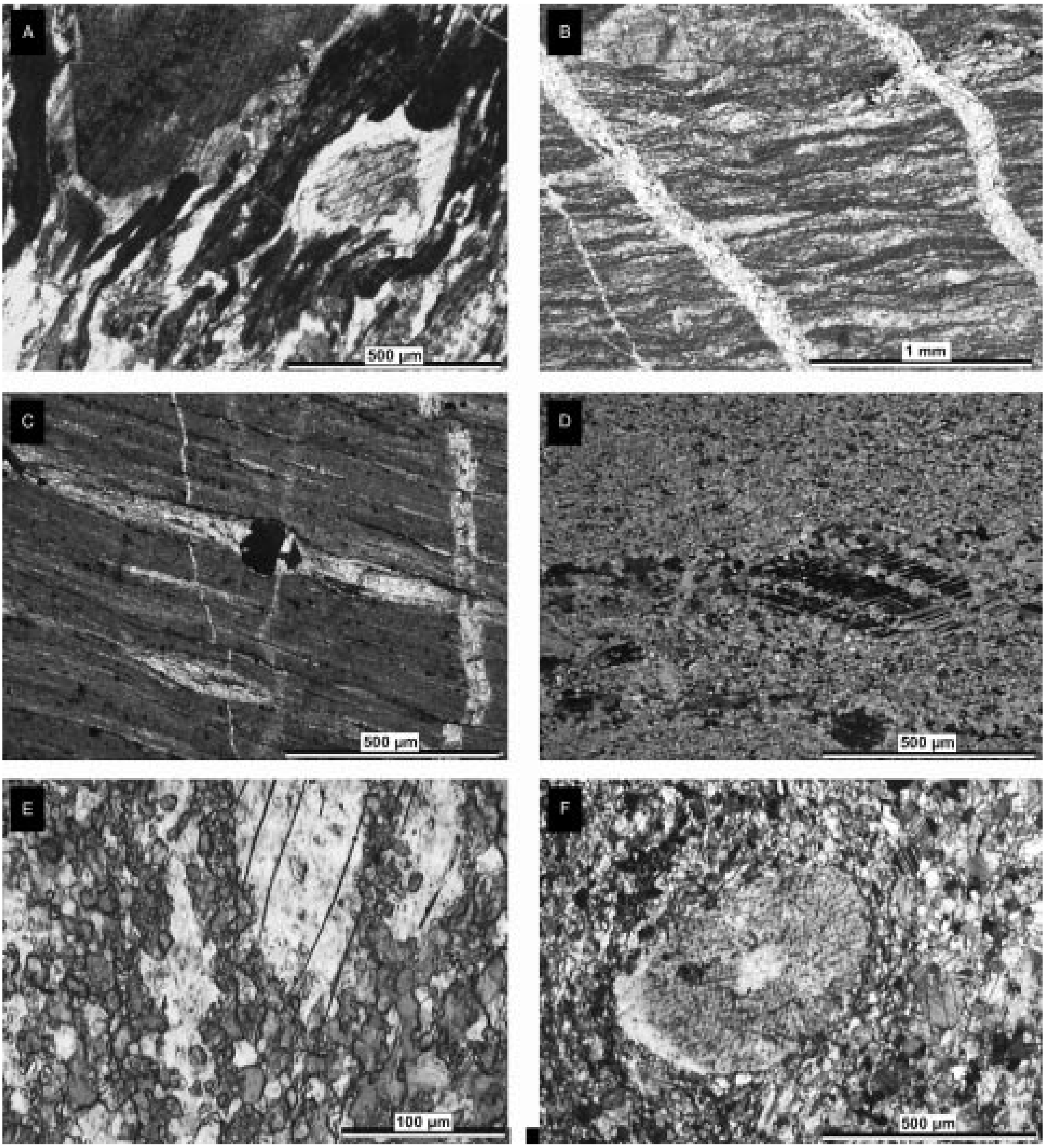
Šebetov area

In the area of Šebetov, the limestones are exposed in a more or less continuous, c. 4-km long belt, and are associated with quartzose and quartzo-feldspathic sandstones/conglomerates and Lower Carboniferous greywackes. The major part of their volume is represented by calcitic mylonites with micrite and microsparite as dominant components. These domains are characterized by the absence of any traces of macroscopically visible fossils and conodonts. Scarce and poorly preserved relics of fossils were obtained only from the northern and southernmost parts of the limestone belt. In the south, light grey, clay-rich, laminated lime mudstones yielded a poor assemblage of fragmented and often strongly ductile-deformed conodonts. Only one 5-kg sample contained a relatively rich assemblage of the palmatolepid-icriodid-polygnathid biofacies of Upper Frasnian age. In the northernmost tip of the belt, a Famennian conodont assemblage was described from dark micritic limestones with shale intercalations (unpublished dT of G. Freyer in the archive of J. Dvořák). However, the tectonostratigraphic correlation of these sediments is problematic because the Šebetov Belt in this area comes into tectonic contact with the Němčice-Vratíkov Belt of the Transitional Development (Kettner 1966). Thus, the only biostratigraphic data from the northern part of the Šebetov section are represented by rare finds of dark dolomites with heliolithoid corals and other taxa indicating the Eifelian age. Unfortunately, due to the poor exposure of these successions, the only available data come from the scree that does not allow for a sufficiently good recognition of structural relations.

Újezd u Boskovic "islet"

At this locality, a limestone body 0.8 × 0.3 km in size crops out in association with the Culm greywackes. Two well-exposed sections were studied where analyses of conodont assemblages enabled a relatively good assessment of their stratigraphic position. The micritic limestones with shale intercalations contain a poor upper Famennian conodont assemblage while peloidal packstones and grainstones with crinoids associated with quartz-feldspathic clastic sediments contain the assemblage of the Upper *Palmatolepis expansa* Zone. Nevertheless, similar lithological types contained also Tournaisian conodont fauna of Tn2 age and Tn2c-Tn3c age, which raises the question of the resedimentation of conodonts. The Middle Tournaisian *Siphonodella crenulata* Zone and Upper Tournaisian *Gnathodus typicus* Zone were recognized in the western section. Conodont assemblage from the eastern section was recently described also by Malovaná (1997) who reported the Middle and Upper Tournaisian conodonts with the youngest sample being attributed to the uppermost Tournaisian *Scaliognathus anchoralis* Zone (Figs. 4A–D, F). The facies of the limestones, namely the pronounced content of siliciclastic material in the Middle Tournaisian facies, the predominance of peloids and only rare occurrence of foraminifers indicate their affinity to the Konice Palaeozoic (Basinal Development).

→ Fig. 2. Examples of transformations of sedimentary structures in limestones due to ductile deformation. A-C – damage of the primary structures via high-stress dynamic recrystallization of coarse grains.
A – core-and-mantle structure of a relic porphyroclast in matrix resulting from the dynamic recrystallization of coarse calcite grain. Independent thermometers indicate the maximum temperature of the deformation of c. 250 °C. As the temperature of recrystallization was low, the size of newly formed recrystallized grains is very close to that of the micritic matrix. In such sediments it is often difficult to decide what part of the fine-grained matrix volume represents the original micrite and what part was formed during the deformation. Locality Lažany Š52a. Ultra-thin section, crossed polarizers.



B – a detail of a porphyroclast with small recrystallized grains growing along twin planes. Locality Čebín 88b. Polarizers at 45°. C – when the temperature of deformation is higher, the differential stress often decreases, resulting in larger size of recrystallized grains. In this photograph the sparite-like matrix surrounding the fragment of an echinoderm probably represents a result of grain growth of originally much finer, possibly micrite grains. The rock was stretched by more than 600% under the temperatures between 250–300 °C. Locality Květnice, Š170. Polarizers at 45°.

D-F – the damage of primary structures as a result of grain boundary sliding in fine-grained domains. D – peloid-crinoidal grainstone after c. 150% extension gives an example of contrasting rheological behaviour of coarse-grained and fine-grained constituents. Syntaxially overgrown crinoids behave as non-deformed rigid bodies flowing in ductile "matrix" of micritic peloids. Locality Újezd u Boskovic, Ú95/9. E – continuing deformation leads to the formation of tectonogenic "lamination" - alternation of fine-grained and relatively coarse-grained calcite in thin layers. In this sample, dynamic recrystallization was taking place in addition to grain boundary sliding, and the sedimentological interpretation of such rocks is highly problematic. Locality Čebín, Š87/3b. F – in the case of sediments, which would be called "lime-mudstone" but in which strong foliation is developed, it is useful to look for the structures which could be a result of large strains, e.g. relic hinges of drag folds or pressure shadows around rigid grains. On this photograph the calcite-filled pressure fringe of quartz grain indicates 400% extension; here, it is impossible to speculate about sedimentological interpretation. The protolith of this rock could be both micrite-rich limestone or biodetrital limestone which was completely dynamically recrystallized. Locality Šebetov, Š193/2. Crossed polarizers.

Černá Hora "islet"

Another interesting section through the ?Devonian and Lower Carboniferous sediments is exposed in a small quarry SW of the town of Černá Hora. In spite of the strong ductile deformation with dynamic recrystallization of calcite, relatively rich faunal assemblages were found locally. In the lowermost part of the section, calcitic mylonites carry structurally puzzling domains with relatively frequent relics of *Scoliopora denticulata*, indicating probably the Lower Frasnian age. Within a few metres of thickness, peloid grainstones/packstones with crinoids and foraminiferal assemblages of probably Tournaisian age (but not older) were found in the same section (Bábek et al. 1995). Finds of such fauna in the upper part of the section indicate that the Tournaisian age counts for the major portion of limestones and quartzose sandstones at the locality. In the central part of the quarry, a body of folded Lower Carboniferous greywackes and siltstones is incorporated into the structure with limestone intercalations at its base. These decimetre-scale beds of intraclast-rich packstones with quartz and feldspar clasts provided an assemblage of foraminifers and algae indicating Lower to Middle Viséan age (*Viseidiscus eospirillinoides – Glomodiscus oblongus* Zone, Bábek et al. 1995). Similarly as those from the Újezd locality, these limestone facies can be compared with those of the Konice Palaeozoic or with the types exposed in the southern part of the Moravian Karst. The Viséan age of the carbonates indicates their affinity to the Moravian Karst Development, because the Viséan sedimentation was siliciclastic in the other two developments. Alternation of the Viséan limestones with greywackes and siltstones represents a transition to the flysch facies thus resembling the Březina Shale Member in the Říčka Valley in the southern part of the Moravian Karst.

Lažany-Malhostovice-Čebín section

Strongly mylonitized limestones with advanced dynamic recrystallization of calcite are exposed in several "islets" between the villages of Lažany and Čebín. Strong to almost complete grain-size reduction of coarse-grained components makes the stratigraphic and sedimentological interpretations impossible in most of the volume of limestones. Nevertheless, rich assemblages of deformation-resistant coral and stromatoporoid macrofauna have been found in the uppermost parts of the succession. The taxa from the reef rudstones of Malhostovice Hill and the uppermost levels of the Čebínka quarry indicate the uppermost Frasnian age (Galle in Hladil 1979, Bosák 1980). Based on their lithological composition and presumed stratigraphic continuity, the rest of the mylonitized succession has been attributed to the Frasnian as well. Nevertheless, two cases of significant tectonic disturbance of the sedimentary succession were described in this area. Hladil and Lang (1985) reported a sharply bounded domain of dark facies with Eifelian/Givetian fauna of the Čelechovice type from the siliciclastic sediments reached by borehole Újezd V-1 (near the Lažany quarry). Two tectonic slices of similar limestone facies with Eifelian fauna were described from the siliciclastics of the Čebínka quarry (Hladil 1991). In these cases the lithological contrasts and faunal content allowed the identification of tectonic juxtaposition, however, the existence of structures lacking obvious contrasts can be neither excluded even in other portions of the limestones.

Hůrka and Dálky hills and Chudčice-Veveří section

The 5 km long and up to 800 m wide belt of limestones in the Chudčice-Veveří section provides the most extensive series of outcrops in the region. Two small bodies (0.5 × 0.3 km) of limestones showing the same stratigraphy as the Chudčice-Veveří Belt crop out on Hůrka and Dálky hills. The major portion of the section is built mainly of Givetian to Lower Frasnian platform facies with horizons of fossil-rich bioherms. Stromatoporoids, corals and brachiopods characteristic of the Macocha Formation of the Moravian Karst were found within the whole succession (Fig. 5a).

Hladil et al. (1994) described rich coral palaeofauna from an old collection sample, which was probably found in this area. The fauna indicates Eifelian age and affinity to the Čelechovice Development. Despite our strong effort we were not successful in re-discovering such facies. Similarly, the presence of the limestones with Famennian conodonts, described by G. Freyer (unpublished data in the archive of J. Dvořák) from the uppermost parts of the Dálky locality, could not be confirmed either.

In the northernmost part of the belt and in the Hůrka and Dálky areas, macroscopically distinctive facies are developed overlying the platform types. Because of the lack of palaeontological data, the stratigraphic correspondence of these limestones has always been a subject to discussions. The samples show mostly very similar lithology – fine-grained micrite-rich dark limestones locally containing thin shale intercalations. Rapid alternations of limemudstones containing radiolarians and packstones with bioclasts can be often observed in thin sections (Figs 5B, C). On the basis of sedimentological features these sediments are interpreted as calciturbidites.

The current results of the analysis of conodont assemblages evidence the Lower Frasnian age (Fig. 4G). The conodonts are often fragmented, poorly preserved and sometimes also ductile-deformed. The number of conodonts in the samples is very low (less than 10 per kg). Nevertheless, the marked predominance of *Polygnathus*, the absence of *Palmatolepis*, and only rare presence of *Ancyrodella* and *Icriodus* seem to be a characteristic feature. In most samples the assemblage corresponds to the polygnathid biofacies (Klapper and Lane 1985, Sandberg et al. 1989). *Polygnathus* cf. *robustus* Klapper and Lane (Hůrka locality) represents the

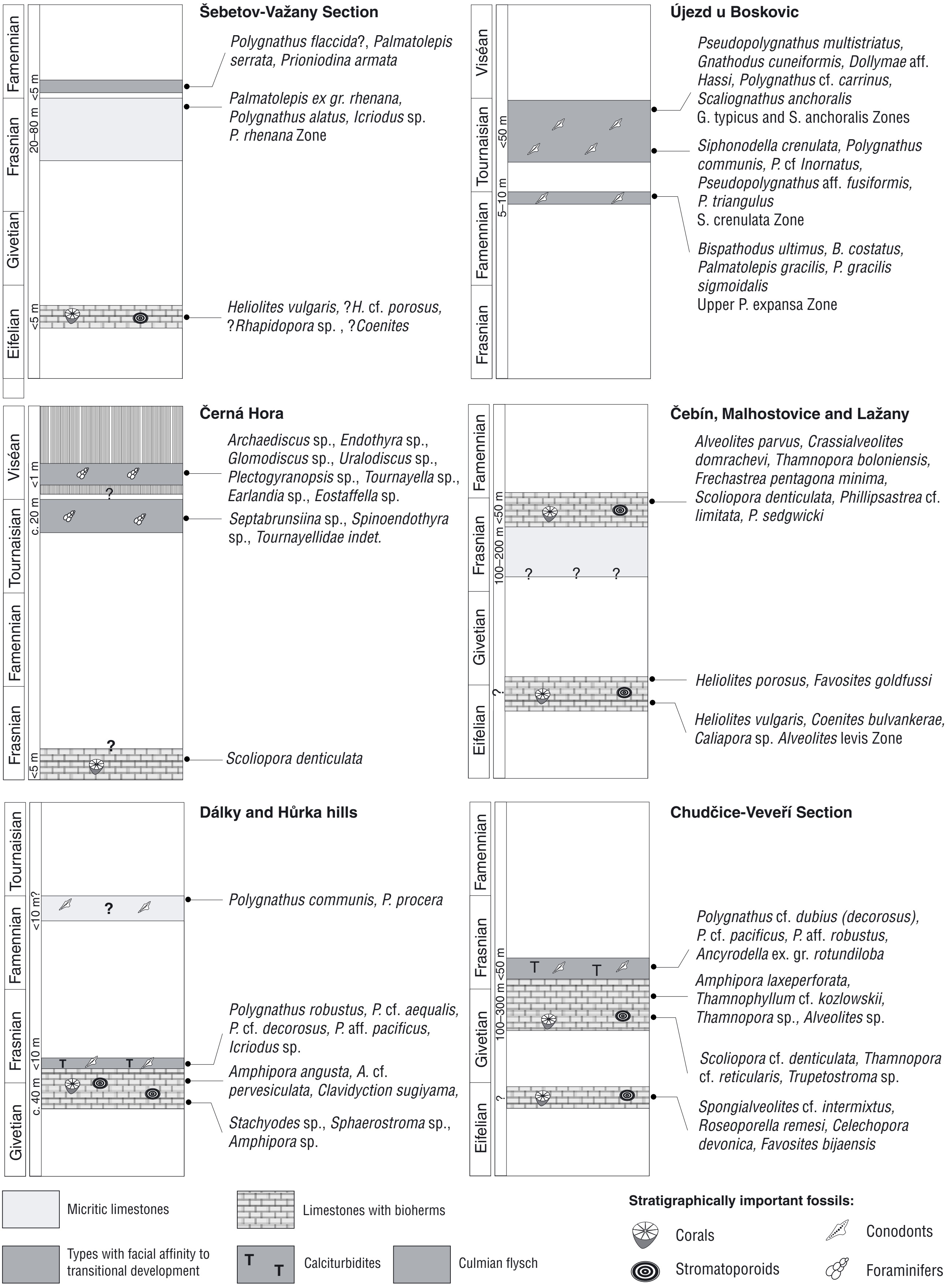


Fig. 3. Stratigraphic columns of the key sections through the Palaeozoic limestones. Main lithotypes and the content of stratigraphically important fossils are expressed with hachures and symbols, respectively.

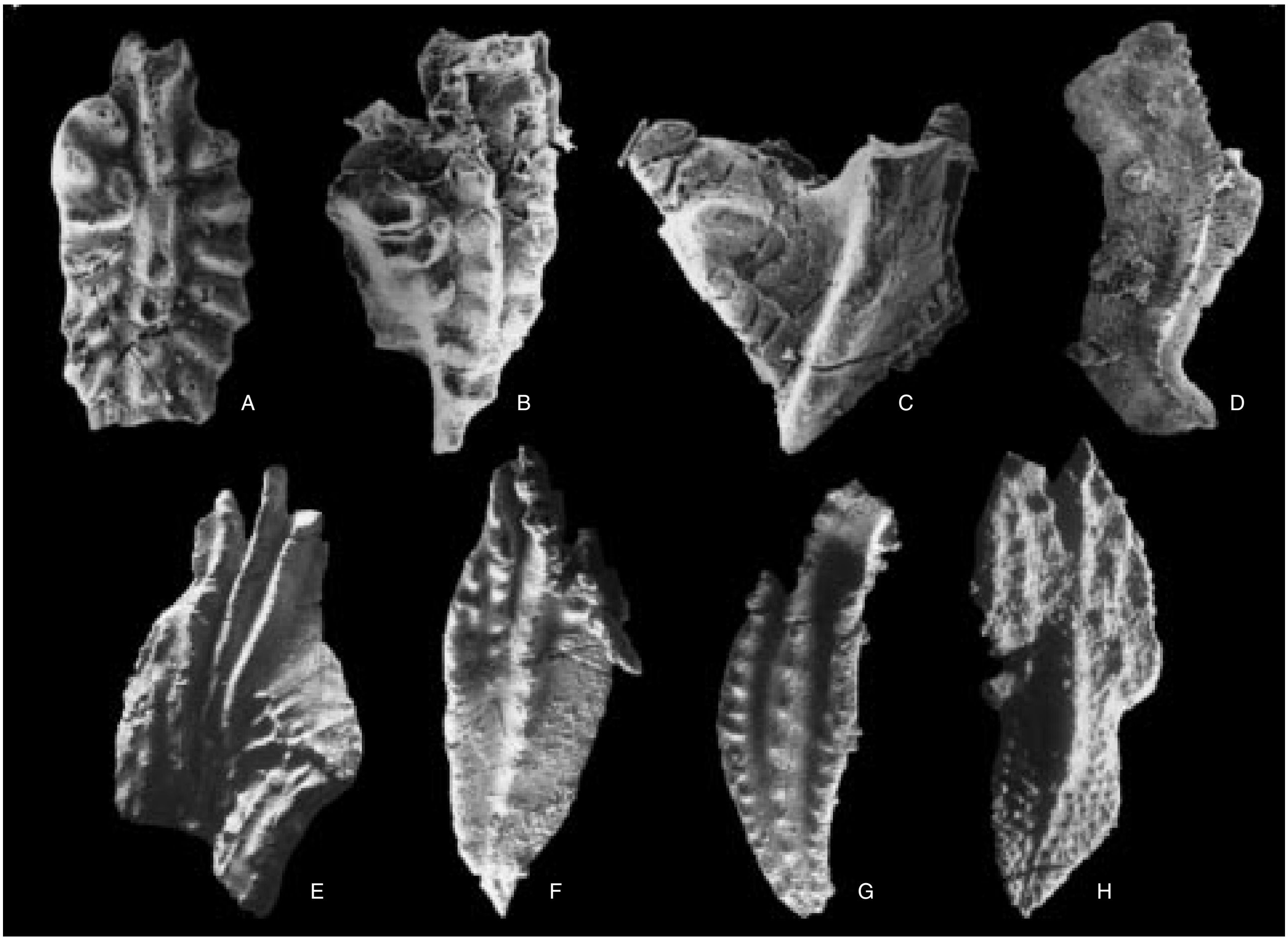


Fig. 4. Examples of conodonts from the studied limestones; A – *Pseudopolygnathus multistriatus* Mehl et Thomas, locality Újezd u Boskovic M1; B – *Gnathodus cuneiformis* Mehl et Thomas, locality Újezd u Boskovic M16; C – *Scaliognathus anchoralis* Branson et Mehl, locality Újezd u Boskovic M16; D – *Palmatolepis glabra distorta* Branson et Mehl, locality Újezd u Boskovic M11; E – *Siphonodella* cf. *duplicata* Branson et Mehl, locality Čebín Š205 (pebble); F – *Polygnathus communis carinus*, locality Újezd u Boskovic Š169; G – *Polygnathus* cf. *dubius* Hinge, locality Hůrka Š161; H – *Polygnathus triphyllatus* (Ziegler), locality Čebín Š205 (pebble).

stratigraphically most important species. Klapper and Lane (1985) described *P. robustus* from Middle to Upper *M. asymmetricus* Zone in NW Territories in Canada. Forms described by Szulczewski (1971) as *Polygnathus* sp. B from the Middle *M. asymmetricus* Zone in the Holy Cross Mountains are included in the synonymy of the species. Later, it was also described from Zone 2 in Alberta (Klapper and Lane 1989). Other important forms in the area seem to belong to *P. dubius* and specimens similar to *P. dubius* from which they differ by the lack of markedly developed rostrum and shorter platform. Similar transitional forms have been described from the lower part of the Long Rapids Formation in northern Ontario by Norris et al. (1992) as *P.* cf. *decorosus*. The formation was correlated with conodont Zone MN 10 to lower MN 11 (Klapper 1989) or with Zone 4b by Klapper and Lane (1989). In one sample, a relatively rich conodont assemblage of the *Polygnathus* biofacies contained very well sorted juvenile elements. As *Polygnathus* preferred shallow-water environment (Sandberg et al. 1992), their sorting and presence in laminite facies may indicate a role of current activity. The absence of *Palmatolepis* from the samples may be facies-controlled, and ancyrodellids are either fragmented or represented by juvenile specimens, which prevent a closer determination. Since most of the determinations are only “cf.” and the relation of *Polygnathus*-based zonation (Klapper 1989, Klapper and Lane 1989) to the standard conodont zonation (Sandberg and Ziegler 1990) is not quite clear, we may attribute these limestones only to the lower part of the Frasnian without closer zone determination.

In Moravia, similar deformed and corroded conodont assemblages of lower Frasnian age were described from the Karlov borehole (SW Jeseníky Mountains) by Dvořák et al. (1973). Only few data are available on conodont biofacies in Moravia, and purely polygnathid biofacies with no palmatolepids have not been described yet. Conodont biofacies of a similar stratigraphic interval were studied in the lowermost part of the Hranice cement quarry (Krejčí 1991). These correspond to the mesotaxid-ancyrodellid and mixed polygnathid-ancyrodellid-palmatolepid conodont biofacies. Lithologically, the

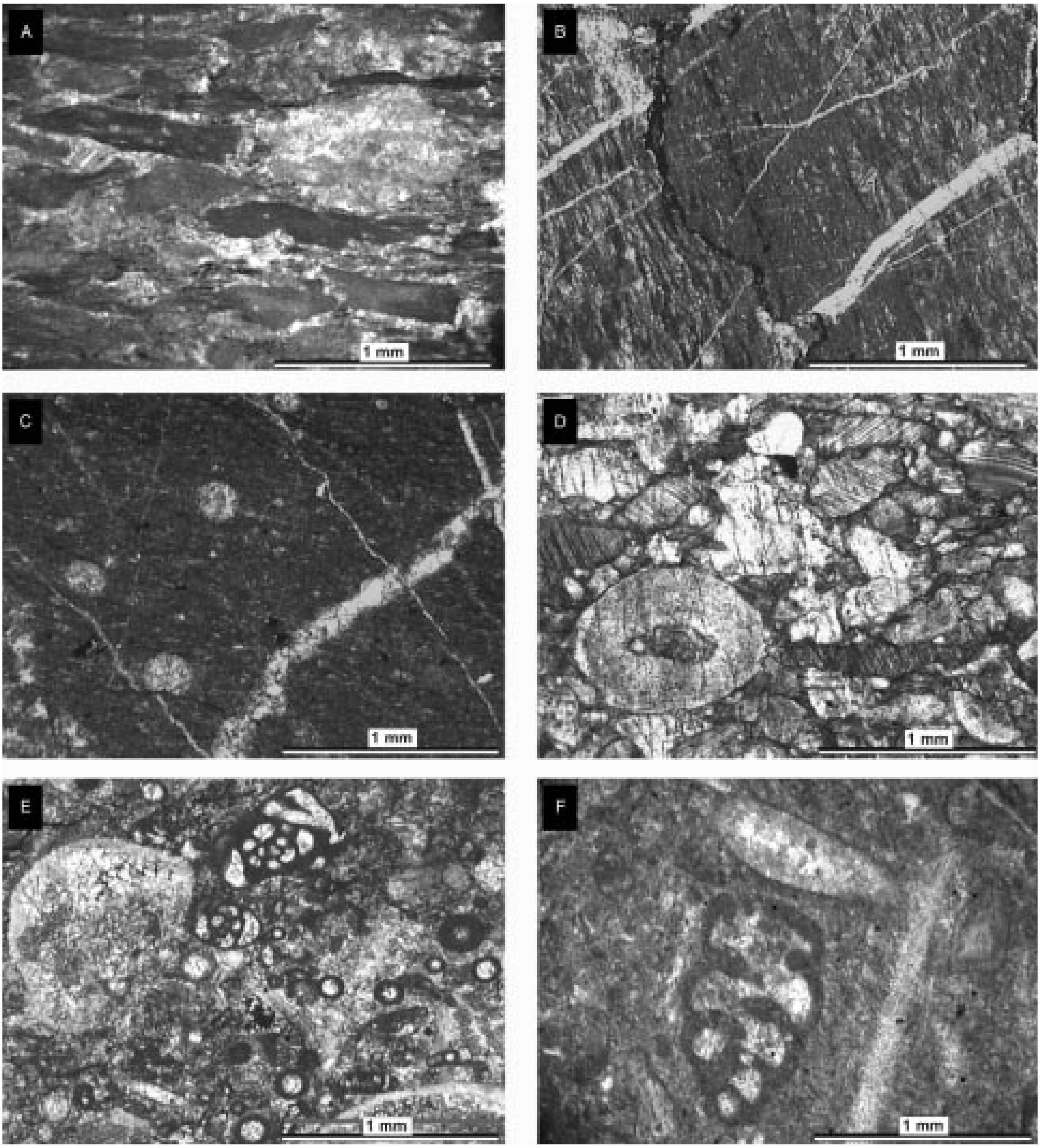


Fig. 5. Selected microfacies of the Lower Frasnian limestones on the western margin of the Brno batholith (A-C) and of the Lower Carboniferous limestones in the pebbles of the Rokytná Member conglomerates (D-F).
A – intraclast-peloidal packstone with fragments of Lower Frasnian *Amphipora laxeperforata* stems. Locality Hůrka, Š179c. B – Lower Frasnian calciturbidites from the northern part of the Chudčice-Veveří belt. Thin layers of mudstones and biodetrite-rich packstones with peloids are rhythmically alternating. Locality Chudčice Š2123. C – another example of Lower Frasnian calciturbidites from the Chudčice-Hůrka area. A detail of lime-mudstone layer with radiolarians. Locality Chudčice Š77. D – typical facies from the pebbles of the Rokytná conglomerate in the Čebín-Chudčice area – encrinitic rudstone with rich assemblage of Tournaisian conodonts. E – Middle to Upper Viséan shallow-sea packstones with foraminifers and green algae typical of the limestone pebbles of the Rokytná Member conglomerates in the southern part of the Boskovice Graben. Locality Š222/5e. F – a detail of the foraminifer *Konskinotextularia* characteristic of the *Pojarkovella nibelis – Koskinotextularia* Zone of the uppermost Middle Viséan to lowermost Upper Viséan. Locality Rokytná Š222/2.

limestones of the Hůrka-Dálky-Chudčice area are very similar to the Upper Frasnian calciturbidites recently reported from the southernmost parts of the Moravian Karst (locality of Bedřichovice, Synek 2000).

The study of eroded portion from proximal pebble material

The Lower Permian Rokytná Member conglomerates, developed in the eastern part of the Boskovice Graben, show features indicating proximal provenance of their pebble material:

1. the dominance of greywacke and limestone pebbles and the absence of clastic material from the units from the western vicinity of the basin (Petránek and Pouba 1953),
2. large sizes of the pebbles (greywackes – up to 2.5 m, limestones – up to 0.5 m), their poor roundness and sorting, and in particular
3. close correlation of pebble content in conglomerates with the occurrences of Palaeozoic limestone outcrops (Suess 1905, Augusta and Čepek 1947, Fig. 1).

All these data indicate that the source of the limestone pebbles in the Rokytná Member conglomerates must have been represented by sedimentary bodies located in the close eastern neighbourhood of the conglomerate alluvial fans – the Palaeozoic limestones whose relics are the subject of this study (Suess 1907, Havlena and Pešek 1980). The limestone pebbles of the Rokytná Member conglomerates can thus give us helpful information on the eroded levels of the sedimentary successions studied.

For the purpose of this work, all mesoscopically distinguishable lithotypes of pebbles were collected from each locality. Thin-section analyses of rocks from most of the localities revealed limestones analogous to adjacent outcrops mixed with such types that are not present on the surface nowadays. Pebbles of the Upper Frasnian reefoid facies with *Alveolites parvus* found in the vicinity of the Lažany limestone body are identical with the limestones from Malhostovice Hill. Within the same conglomerate horizons, pebbles of mylonitized grainstones with peloids and crinoids are present, which are similar to the facies of Újezd u Boskovic or Černá Hora "islets".

A substantial proportion of limestone pebbles in the Permian conglomerates of Čebínka Hill is represented by coral and stromatoporoid fauna-bearing types (with *Phillipsastraea* sp., *Alveolites* sp., *Frechastraea* sp.) corresponding with the adjacent Frasnian facies exposed in the limestone quarry. Other common types of limestone pebbles in this area are encrinites with phosphatized clasts, in which the assemblage of reworked Famennian and probably Tournaisian conodonts (*Siphonodella* aff. *duplicata*) was found, *Gnathodus* cf. *punctatus* representing the youngest age (most probably Tn2c-Tn3 of the Belgian division, Figs 4E, H and 5D). Pebbles of similar facies are present in a close vicinity of the northernmost part of the Chudčice-Veveří Belt; however, no analogous source rocks have been found in the outcrops. These limestones do not contain foraminifers at all and can be compared with some limestone facies of the Konice Palaeozoic.

Adjacent to the southernmost part of the Chudčice-Veveří section, the Rokytná Member conglomerates contain pebbles of facies that can be paralleled with outcropping limestones as well as pebbles of packstones with foraminiferal assemblages indicating the uppermost Tournaisian to lowermost Viséan (Tn3c-V1a) age, which can be well paralleled with the southern part of the Moravian Karst (V1a).

In the area where the sedimentary cover of the Brno batholith was removed by erosion, limestone pebbles of the Rokytná Member conglomerates represent the only source of data on its nature. In the southern part of the Boskovice Graben, where the limestones were preserved in several small brecciate bodies only, the Rokytná Member conglomerates contain rich coarse limestone pebbles. Microscopic analysis has shown that the major part of these pebbles is represented by unstrained Viséan platform facies, which are typical in the pebbles of the Račice Member conglomerates of the Drahany Culm (mainly V2b-V3a age, usually packstones with green algae, corals, bryozoans and foraminifers, see Table 1 and Figs 5E, F).

In the case of these pebbles, their resedimentation from Culm conglomerates cannot be excluded, but such a scenario is less plausible due to the lack of other pebbles typical of the Culm conglomerates in this region. The Rokytná Member conglomerates are composed mainly of greywacke and limestone pebbles, the size of which often exceeds 25 cm. Conglomerates in the Culm relics in this area always contain pebbles of crystalline rocks (granitoids, gneisses) and their usual size is only several centimetres (e.g. Hostěradice Conglomerate, Dudek 1963). Thus the direct formation of limestone pebbles from the limestone bodies seems to be more likely than their resedimentation from the Lower Carboniferous sediments.

Important faunal data are included in Table 1. For a more detailed description of the facies, see Špaček (2001).

Stratigraphic reconstruction

Stratigraphic data obtained from the studied localities on the western margin of the Brno batholith complemented with data on limestone pebbles of the Rokytná Member conglomerates can give us a general view of the sedimentary sequence architecture in a regional scale. All available stratigraphic data are summarized in Fig. 6 showing the variability of distribution of facies of different age in a NNE-SSW-orientated cross-section. At a first sight, the presence of three separate stratigraphic limestone horizons is obvious in the Palaeozoic outcrops:

1. Eifelian to lowermost Givetian limestones with reef-rich palaeofauna with affinities to the Čelechovice Development,

2a. a thick succession of Middle Givetian to Lower Frasnian limestones with the development analogous to that of the Macocha Formation of the Moravian Karst,

2b. Lower Frasnian calciturbidites overlying horizon 2a in the Chudčice-Veveří section and Dálky-Hůrka hills, and

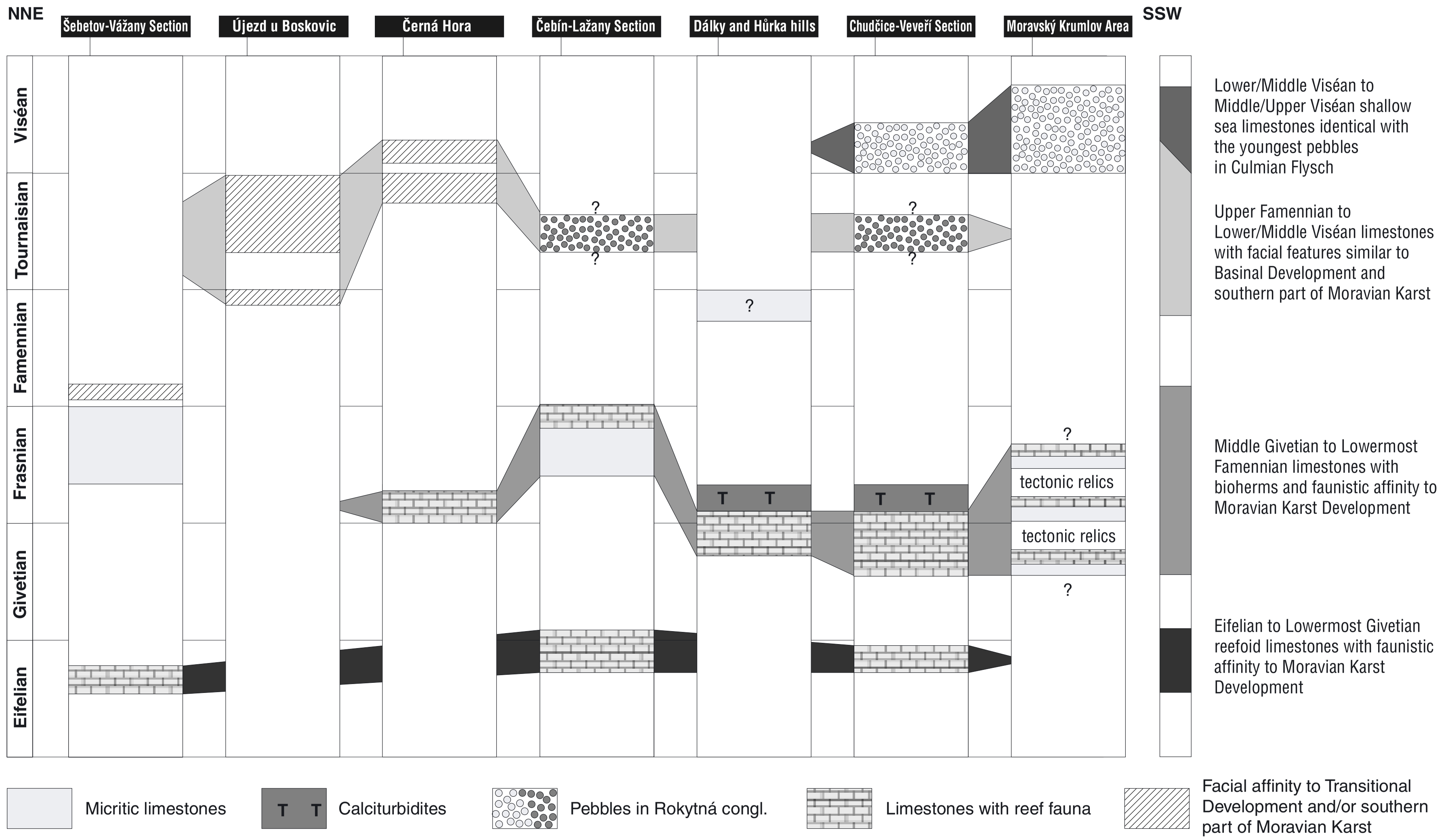


Fig. 6. Suggested stratigraphic correlation of the main sections through the limestones of the western margin of the Brno batholith completed with the data from the limestone pebbles.

Tab. 1. A summary of faunal data on the studied limestones and their stratigraphic significance. Both the previously published and newly found fossils are included.

Locality	Taxa described	Stratigraphical significance	Note	References
Moravský Krumlov area	*Koskinotextularia* sp., *Mediocris* sp., *Endothyra* sp., *Pojarkovella nibelis, Archaediscus* sp., *Eostaffella* sp., *Archaesphaera* sp., *Brunsia* sp., *Globoendothyra* sp., *Forschia* sp., *Eoendothyranopsis* sp., *Koninckopora* sp.	VISÉAN 2b/3a, Pojarkovella nibelis – Koskinotextularia Zone	limestone pebbles from the Rokytná Member conglomerate	J. Kalvoda in this paper
	Endothyra sp., *Eoendothyranopsis donicus, Eoparastaffella* sp., *Moravamminidae* indet., *Koninckopora* sp.	VISÉAN 1a, Eoparastafella simplex Zone	limestone pebbles from Rokytná Member conglomerate	J. Kalvoda in this paper
Veveří-Chudčice section	*Polygnathus* cf. *dubius* (or *P.* cf. *decorosus*), *P.* cf. *pacificus, P.* aff. *robustus, Ancyrodella* ex. gr. *rotundiloba*	EARLY FRASNIAN	northernmost occurrences	J. Kalvoda in this paper
	Calamophora filiformis			Makowsky-Rzehak (1883)
	Stringocephalus burtini	GIVETIAN?		Polák (1954, 1959)
	Amphipora cf. *angusta*	GIVETIAN or FAMENNIAN		Zukalová in Dvořák (1963)
	Amphipora ramosa, Alveolites sp.	GIVETIAN or FAMENNIAN		Polák (1959)
	Amphipora laxeperforata Lecompte, Thamnophyllum cf. *kozlowskii*	EARLY FRASNIAN?	southern part of the belt	Hladil (1985)
	Pseudamplexus sp., *Spongioalveolites* cf. *intermixtus, Coenites fascicularis, Roseoporella remesi, ?Scoliopora* sp., *Favosites bijaensis, ?Mariusilites* sp., *Celechopora devonica kettnerae, ?Heliolites vulgaris, ?H. intermedius*	LATE EIFELIAN	older collection sample from surroundings of Veverská Bítýška	Hladil et al. (1994)
	Scoliopora cf. *denticulata* (*Sc.* cf. *dubrovensis*?), *Thamnopora reticularis, Dendrostroma* sp. *Trupetostroma* sp., *Thamnophyllum* sp., *Alveolites* sp.	MIDDLE GIVETIAN and FRASNIAN	middle and southern parts of the section	J. Hladil in this paper
	Septabrunsiina sp., *Endothyra* sp., *Eoendothyranopsis* sp.,- *Eotextularia* sp., *Earlandia* sp., *Eoforschia* sp., *Eoparastaffella* sp., *Dainella* sp., *Solenoporaceae* indet.	TOURNAISIAN 3c/VISÉAN 1a	limestone pebbles from the Rokytná Member conglomerate	J. Kalvoda in this paper
Dálky and Hůrka hills	*Polygnathus communis, P. procera, Hindeodella* sp., *Ozarkodina* cf. *regularis*	FAMENNIAN 2-3?	uppermost levels of the Dálky section	G. Freyer (pers. comm. with J. Dvořák)
	Polygnathus robustus, P. cf. *aequalis, P.* cf. *decorosus, P.* aff. *pacificus, Icriodus* sp.	FRASNIAN 1	upper levels of the Hůrka quarry	J. Kalvoda in this paper
	Stachyodes sp., *Clavidictyon* sp., *Amphipora* sp., *Amphipora* ct. *pervesiculata Lecompte, A. angusta*	FRASNIAN 1		V. Zukalová in Habarta et al. (1969)
	Stachyodes sp., *Sphaerostroma* sp., *Amphipora* sp.	LATE GIVETIAN	lower levels of the Hůrka quarry	J. Hladil in this paper
	Clavidictyon sugiyama	FRASNIAN 1		Bosák (1980)
Čebín and Malhostovice	*Cyathophyllum* sp.		Čebínka Hill vicinity	Tausch (1896)
	Smithicyathus lacunosus, Frechastraea pentagona pentagona, Pterorrhiza sp., *Temnophyllum* sp., *Thamnopora boloniensis, Crassialveolites* cf. *smithi, Crassialveolites evidens, Alveolites delhayei*	MIDDLE/LATE FRASNIAN	older collection material from uppermost parts of Čebínka Hill	A. Galle in Hladil (1979) and Hladil in this paper
	Alveolites parvus, Crassialveolites domrachevi, Crassialveolites sp., *Thamnopora boloniensis, Scoliopora denticulata vassinoensis, Frechastraea pentagona minima*	LATE FRASNIAN	Malhostovice Hill	Hladil (1979)
	Phillipsastraea cf. *limitata, P. sedgwicki, Alveolites suborbicularis, Neostringophyllum* sp., *Fasciphyllum* sp., *Striatopora* sp., *Cladopora* sp.	LATE FRASNIAN	uppermost levels of the quarry	Bosák (1980)
	Stachyodes sp.	FRASNIAN?		Zukalová (1971)
	Heliolites porosus, Favosites goldfussi	EIFELIAN/ GIVETIAN	tectonic slices of limestones	Hladil (1991)
	Protognathodus cf. *kockeli, Siphonodella* aff. *duplicata, Gnathodus* cf. *punctatus, Bispathodus costatus, Palmatolepis* cf. *marginifera, Pa.* ex. gr. *glabra, Polygnathus triphyllatus, Po.* cf. *subiregularis, Po.* cf. *perplexus*	TOURNAISIAN 1/2 or younger, redeposited Famennian taxa	limestone pebbles from the Rokytná Member conglomerate	J. Kalvoda in this paper

Tab. 1. – continued

Locality	Taxa described	Stratigraphical significance	Note	References
Lažany	*Heliolites vulgaris, Coenites bulvankerae, Caliapora* sp.	EIFELIAN, Alveolites levis Zone	slice of limestone in clastic sediments, Újezd V-1 borehole	Hladil and Lang (1985)
	Alveolites parvus	LATE FRASNIAN	limestone pebbles from the Rokytná Member conglomerate	J. Hladil in this paper
Černá Hora	*Septabrunsiina* sp., *Spinoendothyra* sp., *Tournayella* sp., *Archaediscus* sp., *Endothyra* sp., *Glomodiscus* sp., *Uralodiscus* sp., *Plectogyranopsis* sp., *Earlandia* sp., *Eostafella* sp.	TOURNAISIAN 3 - VISÉAN 1/2	whole section	Bábek et al.1995
	Scoliopora denticulata	EARLY FRASNIAN?	lowermost part of the section	J. Hladil in this paper
Újezd u Boskovic	*Bispathodus ultimus, B. costatus, Palmatolepis gracilis gracilis, P. gracilis sigmoidalis, Polygnathus* cf. *inornatus*	LATE FAMENNIAN, upper Pa. expansa Zone	northern section	J. Kalvoda in this paper
	Siphonodella crenulata, Polygnathus communis, P. cf. *inornatus, P.* cf. *carrinus, Pseudopolygnathus* aff. *fusiformis, Pseudopolygnathus triangulus, Gnathodus cuneiformis, Dollymae* aff. *hassi*	TOURNAISIAN 2a/b–3a/b, Si. crenulata and Gn. typicus Zones	northern section	J. Kalvoda in this paper
	Endothyra sp., *Spinobrunsiina* sp., *Septabrunsiina* sp., *Tournayellidae* indet., *Earlandia* sp., *Pseudopolygnathus* ex. gr. *multistriatus, Polygnathus* sp.	TOURNAISIAN		Kalvoda et al. (1996)
	Pseudopolygnathus multistriatus, Palmatolepis cf. *gracilis, Palmatolepis glabra distorta, Gnathodus semiglaber, Pseudopolygnathus primus, Scaliognathus anchoralis, Gnathodus cuneiformis, Polygnathus communis carinus*	TOURNAISIAN 1/2–3, up to Sc. anchoralis Zone	southern section	Malovaná (1997)
Šebetov-Vážany section	*Polygnathus flaccida*?, *Palmatolepis serrata, Prioniodina armata, Siphonodella* sp.	EARLY FAMENNIAN	northernmost outcrops	G. Freyer (pers. comm with J. Dvořák)
	Palmatolepis ex gr. *rhenana, Polygnathus alatus, Icriodus* sp.	LATE FRASNIAN, Pa. rhenana Zone	southernmost outcrops	J. Kalvoda in this paper
	Heliolites vulgaris, *H.* cf. *porosus*?, *Rhapidopora* sp.?, *Coenites* sp.?	EIFELIAN	northern part of the section	J. Hladil et al. in this paper

3. the mosaic of uppermost Famennian to Middle Viséan limestones facially close to the Konice Palaeozoic or southern Moravian Karst facies.

These facies and biostratigraphic disjunctions are systematic and typical of the most of the localities studied. However, the explanation of this feature is very problematic. The presence of broad mylonite zones with large strains within the limestones and mesoscopically observed structures indicate tectonic juxtaposition in the scale of individual sections. Nevertheless, significant hiatuses and low sedimentation rates were frequently reported from the Moravian Karst for both time gaps – Famennian and Lower Givetian (Hladil 1986b). Thus the large-scale stratigraphic pattern presented in Fig. 6 can be a result of the interplay of more than one process – the lack of fossils in these horizons, hiatuses, extreme sedimentary condensation or tectonic unconformities. Unfortunately, mesostructural observations do not give us unambiguous markers for the resolution. Even the Frasnian reefoid facies which were found in a close proximity (2–3 metres) of the Tournaisian limestones in the Černá Hora quarry can be explained in two ways: re-sedimentation of Frasnian reefs into Tournaisian limestones and some kind of a tectonic juxtaposition of the two disjunctive facies.

A relatively good correspondence can be found between the Eifelian and lowermost Givetian succession and Cycle 1 of Hladil (1986a, 1994), and between the Middle Givetian to Frasnian succession and Cycles upper 2–3 of Hladil (1994). Slight differences exist between the Eifelian/Givetian sediments of the typical Čelechovice limestones and those we have studied, which have significant content of siliciclastic material and faunal attributes of open-sea environment. As for the Lower Frasnian calciturbidites overlying the Givetian and Lower Frasnian reefoid limestones in the Chudčice-Hůrka-Dálky area, they are rather untypical for the exposures of the Moravian Karst Development. The biostratigraphic range of this sedimentary succession seems to be uninterrupted, which could indicate continuous sedimentation not significantly disturbed by tectonic juxtaposition. If so, this pronounced facies change in the Lower Frasnian apparently differentiates this sedimentary succession from the typical development of the Macocha Formation. However, other important Moravian occurrences of Frasnian deep-sea facies overlying the reef limestones should be mentioned: according to Sedlák (1999), a body of distal calciturbidites is developed above the reef facies in the Cement Works Block of the Hranice Palaeozoic. Krejčí (1991) reported conodont fauna of Upper *Palmatolepis hassi* Zone from the basal part of the calciturbidites. This occurrence probably represents the closest analogy of the situation we can observe in the Chudčice-Hůrka-Dálky area.

The composition of limestone pebbles from the middle and southern sections of the batholith margin indicates pronounced facies bipolarity of the carbonates during the Late Tournaisian/Early Viséan. Nevertheless, the zoning of the degree of erosion and the degree of preservation of limestone bodies can be strongly influenced by an overthrust of the Brno batholith over the Permian sediments of the Boskovice Graben in its southern part (note also the lack of limestone pebbles in the northern part of the Boskovice Graben). As we have observed, the conodont and crinoid-rich facies of the northern section (Újezd u Boskovic, Černá Hora, limestone pebbles near Čebín and Chudčice) are substituted with shallow-water limestones containing green algae in the south (limestone pebbles near Moravský Krumlov and Veveří). A decreasing representation of the limestones of the Macocha Formation is apparent in the outcrops of the northern section compared to the middle section (Malhostovice, Čebín, Dálky and Hůrka, Veveří-Chudčice Belt). Considering the abovementioned problem of erosional zoning, this feature must be treated with care as it may reflect not only the pre-Permian distribution of limestone source-bodies but also the syn- and post-Permian tectonic interferences.

Summary and concluding remarks

Within the Palaeozoic carbonate successions on the western margin of the Brno batholith, the Variscan formation of broad mylonite zones led to the disturbance of sedimentary structures and transformation of coarse-grained components into tectonogenic microsparite. Because of this strong ductile deformation and later veining, cataclasis, faulting and simultaneous erosion, the stratigraphic research becomes extremely complicated and the discontinuous faunal data do not allow a definite interpretation of sedimentary sequence architecture.

A complex research of the limestone relics revealed the presence of three stratigraphic horizons, which are distinctly separated from one another by two gaps without lithological contents, namely Lower Givetian and Famennian. The explanation of this feature is still equivocal. The existence of significant hiatuses and low sedimentation rates in the Famennian and Lower Givetian in tectonically unaffected occurrences of the Devonian in Moravia does not allow for an explicit attribution of the biostratigraphic gaps to tectonic overthrusting.

Conclusive recent data can be summarized into several points:

1. The presence of the uppermost Famennian?-Tournaisian carbonate sediments at the Újezd u Boskovic and Černá Hora localities and pebbles near Čebínka, which show the affinity to the Konice Palaeozoic.
2. The presence of sediments with affinities to the Moravian Karst Development both in outcrops and pebbles.
3. Tectonic juxtaposition of the Tournaisian limestones with the sedimentary complex of Culm flysch sediments and Viséan limestone intercalations in the Černá Hora quarry. In this case the tectonic juxtaposition is unquestionable because the boundary between the two sedimentary complexes is sharp, and different deformation styles were recognized in each of them (Bábek et al. 1995).
4. The presence of limestone pebbles in the Permian Rokytná Member conglomerates, which are of Tournaisian to Middle/Upper Viséan age and which are not analogous to the adjacent outcrops.
5. Facies diversity of the Tn3c/V1a limestones in the northern and southern sections across the western margin of the Brno batholith.
6. The presence of Lower Frasnian calciturbidites developed in the upper parts of the Chudčice and Dálky/Hůrka sections. Until now, calciturbidites of the Lower Frasnian age have not been referred to the Moravian Karst Development and the closest analogy can be found in the Cement Works Block of the Hranice Palaeozoic.

The current research suggested that sedimentological interpretation of limestone successions requires a multidisciplinary approach in the areas where ductile tectonic overprint is possible. In such terrains it is highly advisable to consider strain magnitudes and palaeotemperatures and to understand deformational mechanisms in addition to the analysis of sedimentological content. The use of very thin sections (<10 µm) is recommended, in particular when interpreting the origin of microspar. One has to consider macro-scale tectonic overthrusting, which does not necessarily require a significant change in internal rock architecture (see Melichar and Hladil 1999).

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