GUIDEBOOK

Sedimentary evolution and trace fossils of Carboniferous turbidite systems in the Variscan foreland, Czech Republic

Guide to field trip A8 • 20–22 June 2015

Ondřej Bábek, Radek Mikuláš, Daniel Šimíček

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Sedimentary evolution and trace fossils of Carboniferous turbidite systems in the Variscan foreland, Czech Republic

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Route (Fig. 1): From Brno we drive NE to Vyškov (**Mokrá and Luleč quarries, stops A8.1 and A8.2**) using local roads and then continue to Olomouc using R46 motorway. In Olomouc we turn N taking road 46 to Šternberk and then taking various local roads we drive to **Bělkovice Quarry (stop A8.3)**, then to **Malý Rabštejn and "Railway section" near Domašov nad Bystřicí (stop A8.4)** (about 15 – 20 km NE of Olomouc) and finally to Hotel Akademie in Hrubá Voda village (**accommodation**). On the second day we use mainly local roads E and NE of Olomouc, in the area between Lipník nad Bečvou, Hranice, Moravský Beroun and Šternberk visiting **Skoky (stop A8.5)**, **Hrabůvka quarry (stop. A8.6)**, **Olšovec (stop. A8.7)**, **Budišov nad Budišovkou (stop A8.8)** and return back to Hotel Akademie (**accommodation**). On the third day, we drive first S to Olomouc and then N and NE using road 46, direction Šternberk and Opava to **Slezská Harta (Stop A8.9)**. From Stop 9 we turn to

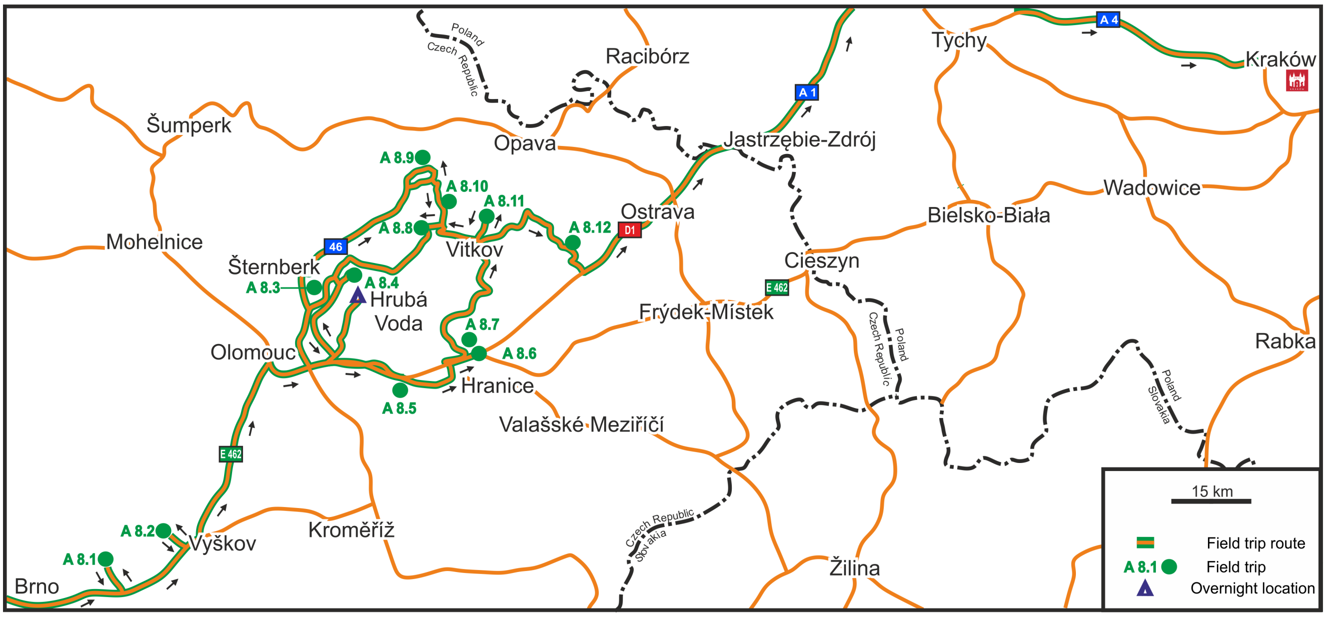

Fig. 1. Route map of field trip A8

Bábek, O., Mikuláš, R. & Šimíček, D., 2015. Sedimentary evolution and trace fossils of Carboniferous turbidite systems in the Variscan foreland, Czech Republic. In: Haczewski, G. (ed.), *Guidebook for field trips accompanying 31st IAS Meeting of Sedimentology held in Kraków on 22nd–25th of June 2015*. Polish Geological Society, Kraków, pp. 115–143.
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S and SE to **Kružberk (stop A8.10), Vítkov – Annina dolina (stop A8.11)** and **Stará Ves (stop A8.12)** using local roads. From Stop 12, we take the shortest way to motorway D1, direction Ostrava, Polish border and then using Polish motorways A1 and A4 to **Kraków**.

Introduction to the trip

Variscan flysch of the Moravo-Silesian Culm Basin

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The term "Culm" ("kulm" in Czech) was first introduced into the geology of the Bohemian Massif in the second half of the 19th century to denote fossiliferous successions of dark shales, siliceous shales, sandstones and rare limestones with *Posidonia* bivalves, goniatites and fossil plants (Roemer, 1860; Wolf, 1863; Zapletal, 2000). At present, it is recommended to use the term "Culm" as an informal term to describe sediments with unique lithology (see above) related to the Variscan plate convergence (Zapletal, 2000).

The Bohemian Massif represents the easternmost outcrop of the Variscan orogene in Europe. Pre-Permian successions of the Bohemian Massif can be subdivided into the Moldanubian, Central Bohemian, Saxothuringian, Lugian and Moravo-Silesian Zones (Chlupáč and Vrána, 1994, Franke and Żelaźniewicz, 2002). The former four zones represent the Armorican Terrane Assemblage with affinity to Gondwana, whereas the Moravo-Silesian Zone belongs to the Brunovistulian Terrane located at the southern passive continental margin of Laurussia. During the Variscan orogeny, the Brunovistulian Terrane acted as a lower plate that was subducted beneath the Armorican Terrane Assemblage (Kalvoda, 1995; Finger and Steyrer, 1995, Kalvoda *et al.*, 2002). For the most part, deposition of the Culm facies was to a certain extent related to the collision events in various geotectonic settings.

There are numerous outcrops of the Culm facies all over the Bohemian Massif including the Ještěd Ridge at the SW edge of the Karkonosze-Izera Massif in the West Sudetes, occurrences in the Nepasice borehole in the basement of the Bohemian Cretaceous Basin, the so-called Mírov Culm Unit in the eastern part of the Bohemian Terrane and Givetian "Culm-like" deposits of the Barrandian area (Central Bohemian Zone (Chlupáč, 1994; Chlupáč *et al.*, 2002; Zapletal, 2003). However, the most extensive occurrence of the Culm facies, traditionally referred to as the Moravo-Silesian Culm Basin, is located in the Variscan foreland of the Moravo-Silesian Zone (Fig. 2).

Moravo-Silesian Culm Basin: geological setting and structure

The Moravo-Silesian Culm Basin (MSCB) is an elongated, SW-NE to SSW-NNE trending structure, bordered by the Moravo-Silesian Fault Zone in the W (Schulmann *et al.*, 1991) and covered by Tertiary to Quaternary deposits of the Carpathian Foredeep to the E. Deposits of the MSCB are preserved in two major outcrops, the Drahany Basin and the Nízký Jeseník Basin (NJB) (Fig. 2). Minor relics of the MSCB are known from the Maleník Horst, Miroslav Horst (Hostěradice), Boskovice Graben and the centre of the city of Olomouc. A great deal of the MSCB is now covered by upper Carboniferous to Neogene deposits of the Upper Silesia Coal Basin, Jurassic platform cover of the Bohemian Massif, the nappes of the Outer Western Carpathians and the Carpathian Foredeep. Relics of the MSCB are also known from the Cracow-Upper Silesia region of Poland and the Polish Sudetes region (Kumpera *et al.*, 1995; Narkiewicz, 2005) and from many boreholes in Moravia.

The MSCB belongs to the system of lower Carboniferous deep-marine basins of the Rhenohercynian Zone of Western and Central Europe (Franke and Engel, 1988; Ricken *et al.*, 2000; Hartley and Otava, 2001). The basin evolved in the Tournaisian to Early Namurian times, in response to the Variscan plate convergence between the Brunovistulian Terrane and the overriding Lugodanubian Terranes encompassing the Moldanubian, Central Bohemian and Lugian Zones (Fritz and Neubauer, 1995; Franke *et al.*, 1995; Grygar and Vavro, 1996; Kalvoda *et al.*, 2003, Bábek *et al.*, 2006). The filling of the MSCB is interpreted as a multiphase geotectonic event, which can be subdivided into an initial, remnant basin phase (Lower to Middle Viséan) and a subsequent peripheral foreland basin phase (Upper Viséan to lowermost Namurian) (Kumpera and Martinec, 1995).

Structure of the MSCB is interpreted as an E-directed, thin-skinned stack of tectonic slices overlying the Proterozoic Brunovistulian crystalline basement and its pre-flysch, Devonian to lower Carboniferous sedimentary cover (Bábek *et al.*, 2006; Čížek and Tomek, 1991). Two major tectonic units were revealed in the southern part of the MSCB (Hladil *et al.*, 1999; Bábek *et al.*, 2006). The western (Protivanov) unit, which is allochthonous, is comparable in tectonic style to the Giessen nappe of the Rhenish Massif in Germany (Kalvoda *et al.*, 2008). Three strongly sliced units, the Němčice Vratíkov, the Northern and Southern Moravian Karst units, constitute the eastern parautochthon (Hladil *et al.*, 1999; Bábek *et al.*, 2006). Structure of the northern part of the MSCB is similar, comprising the western allochthonous unit (Andělská Hora and Horní Benešov formations) and the eastern parautochthonous (Moravice and Hradec-Kyjovice Fm.) unit (Grygar and Vavro, 1996; Hladil *et al.*, 1999). The MSCB shows a distinct W-E to NW-SE polarity in deformation and thermal metamorphism. The intensity of deformation and metamorphic alteration generally decreases to the the E to SE (Franců *et al.*, 2002; Rajlich, 1990). This trend continues further to the E to essentially undeformed Culm strata, which are known only from subsurface of the Outer Western Carpathians.

The Drahany Basin and the Nízký Jeseník Basin are separated by the NW-SE trending Haná Fault Zone, a post-Variscan structure, which accommodates late Cenozoic graben-like basins of the Upper Morava Valley (Fig. 2). During their deposition, the Drahany and Nízký Jeseník basins were connected, as suggested by their similar paleocurrent and clastic provenance patterns showing proximal (Drahany) to distal (Nízký Jeseník) sediment dispersal patterns (Kumpera and Martinec, 1995; Hartley and Otava, 2001).

Drahany Basin

The Drahany Basin consists of three formal lithostratigraphic units (Fig. 3): Protivanov Formation, Rozstání Fm. and Myslejovice Fm. (Dvořák, 1965; Hladil and Dvořák, 1994).

The Protivanov Fm. is the oldest unit of the Drahany Basin, which comprises greywackes with subordinate siltstones, mudstones and conglomerates. The Protivanov Fm. is subdivided into basal Velenov Shale Member and the overlying Brodek Greywacke Mbr. Total thickness of the formation is thought to reach almost 3000 m (Hladil and Dvořák, 1994). The formation is free of body fossils and it is dated only indirectly. The dating is based on limestone pebbles present in the (so-called) Kořenec conglomerate, which contains foraminifers of Lower to Middle Viséan age (V1b-V2a of traditional Belgian division, Kalvoda *et al.*, 1995; Špaček and Kalvoda, 2000). The $^{40}Ar/^{39}Ar$ dating of detrital white micas yielded youngest cooling ages of 350 Ma (Early Carboniferous) in the source area (Schneider *et al.*, 2000). Hartley and

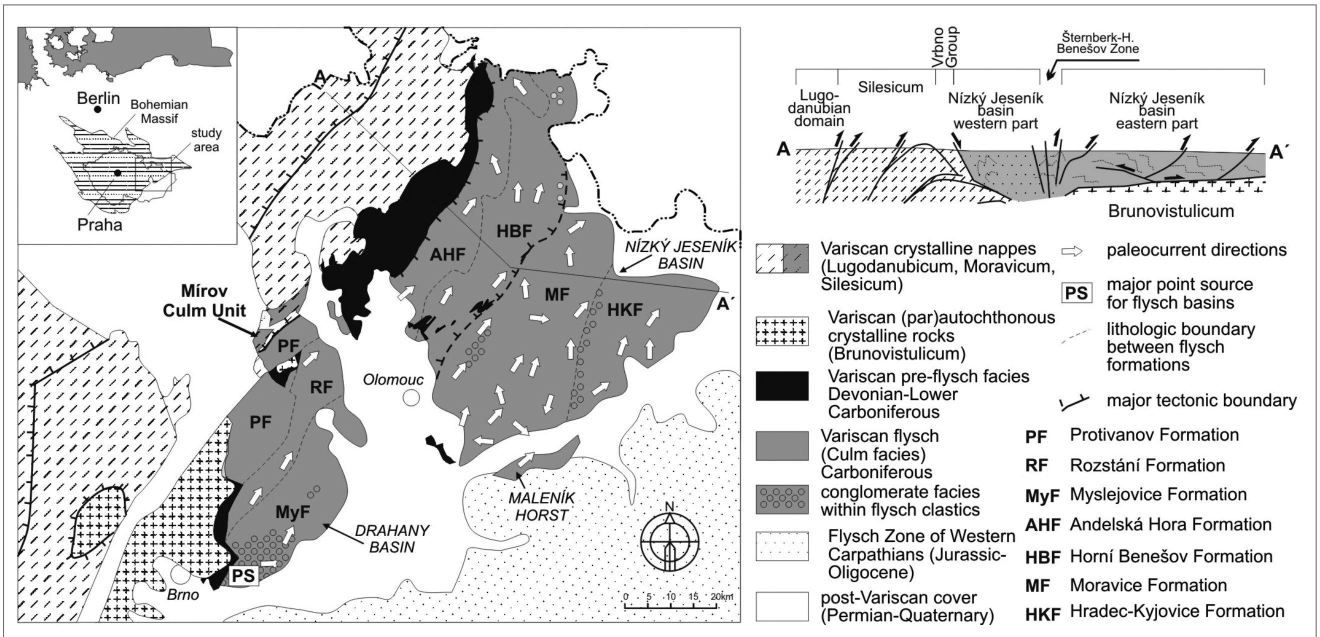

Fig. 2. Moravo-Silesian Culm Basin: major outcrops, lithology, lithostratigraphy and structure (adopted from Bábek *et al.*, 2004).

Otava (2001) defined three Heavy Mineral Zones (HMZ) in the MSCB; each one is confined to a distinct stratigraphic interval. The changes in heavy mineral spectra up-section reflect increasing proportion of high-grade metamorphics at the expense of low-grade metamorphics in the source area, as a result of upper Viséan unroofing of the Moldanubian source area (Hartley and Otava, 2001). In the Lower HMZ (Peγ goniatite Zone to base of Goα goniatite Zone), the heavy mineral assemblages obtained from greywackes and conglomerates are composed mainly of epidote, tourmaline, garnet, sphene and zircon. Spessartine, grossular and almandine predominate in the Middle HMZ (base of Goα Zone to Goβ/Goγ Zone boundary) whereas pyrope and almandine are the predominant constituents of heavy mineral assemblages in the Upper MHZ (Goβ/Goγ Zone boundary to E1 Zone). The whole Protivanov Fm. correlates with the Lower HMZ.

The Rozstání Fm. is about 250 m-thick and it is composed of fine-grained sandstones, siltstones and mudstones with subordinate sandstone and conglomerate layers. Sandy limestone layers and limestone pebbles in conglomerates contain foraminifers of late Early Viséan / early Middle Viséan (V1b-V2a) to Late Viséan (V3a) age (Kalvoda and Bábek, 1995; Špaček and Kalvoda, 2000). Conil (in Holub *et al.*, 1973) described limestone clasts containing Upper Viséan foraminifers (V3a) from conglomerates located near Křtiny. From superposition relationships with the underlying Březina Formation (Tn3c-V1b, ?V2a) in the southern part of the Drahany Upland, the age of the Rozstání Formation can be considered to be post Early- to Middle Viséan. Youngest cooling ages of detrital white micas are 328 Ma (Tournaisian – Early Viséan) (Schneider *et al.* 2000). The whole Rozstání Fm. correlates with the Lower HMZ (Hartley and Otava, 2001). The two basal formations are in tectonic contact with the underlying pre-flysch sediments.

The overlying Myslejovice Fm. is composed of sandstones and conglomerates with subordinate siltstones and mudstones. Maximum thickness of the formation is about 2000 m. The formation is further subdivided into the Studnice Shale Member and two prominent conglomerate bodies, the Račice and Luleč Conglomerate Mbrs (Dvořák, 1965). The siltstones and mudstones yielded relatively rich late Viséan goniatites, bivalves, nautiloids, trilobites as well as trace fossils (Kumpera, 1973; Kumpera and Lang, 1975, Lang and Chlupáč, 1975; Lang *et al.*, 1979). The goniatites indicate Goα to Goγ1 goniatite zones (Upper Viséan). Foraminifers in limestone pebbles of the Račice Mbr indicate late Viséan ages

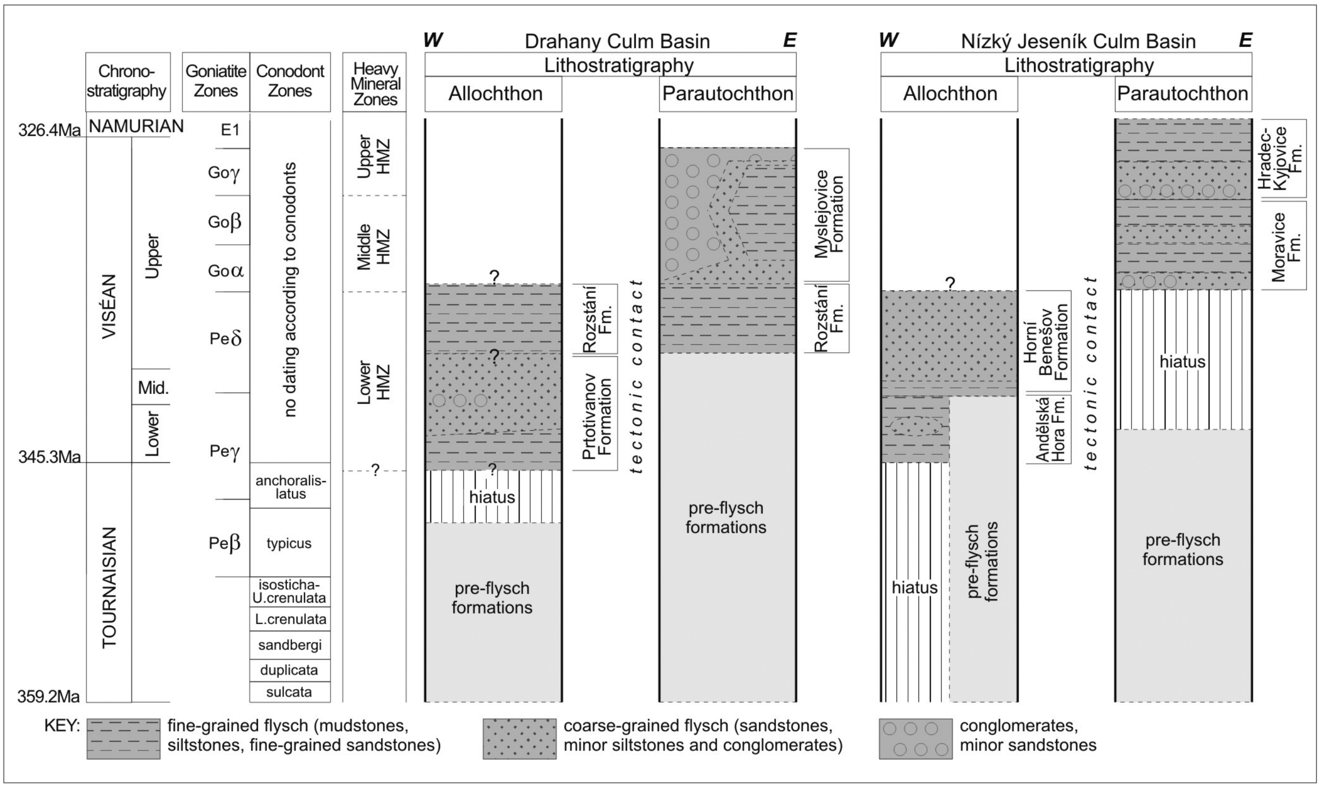

Fig. 3. Lithostratigraphy and chronostratigraphy of the Drahany and Nízký Jeseník Culm Basins (adopted from Kalvoda and Bábek, unpublished).

(V2a-V3b) (Špaček and Kalvoda, 2000). Rich floristic remains include 50 species (Purkyňová and Lang, 1985). Youngest detrital white micas yielded 332 Ma cooling ages (Late Viséan) $^{40}Ar/^{39}Ar$ cooling ages (Schneider *et al.*, 2000). Lower part of the Myslejovice Fm (Račice Mbr) correlates with the Middle HMZ, whereas its upper part (Luleč Mbr.) correlates with the Upper HMZ (Hartley and Otava, 2001. Lateral equivalents of the Myslejovice Formation are known from subsurface below the Western Carpathians, but they wedge out rapidly to the E.

Nízký Jeseník Basin

The Nízký Jeseník Basin is subdivided into four lithostratigraphic units, Andělská Hora, Horní Benešov, Moravice and Hradec – Kyjovice Formation (Patteisky, 1929; Kumpera, 1966; Zapletal *et al.*, 1989).

The Andělská Hora Fm is about 1000 to 2000 m-thick succession of thin, fine-grained sandstones, siltstones and mudstones with thicker, 1m to several hundred m-thick bodies of sandstones, fine-grained conglomerates and pebbly mudstones. The formation is free of body fossils, but Famennian and Tournaisian conodonts were found in limestone interlayers within the basal parts of the formation (Dvořák *et al.*, 1959; Koverdynský and Zikmundová, 1966; Zikmundová and Koverdynský, 1981). However, the same limestone layers have been interpreted as conformable sedimentary layers, tectonic slices and limestone pebbles in sheared pebbly mudstone beds by different authors. In the light of this controversy, the Andělská Hora Fm. can be younger than is indicated by conodonts. More recently, lower Carboniferous (Viséan) ages of the formation are preferred, based on the findings of the tree ferns *Asterocalamites* (Purkyňová, 1977) and rugose corals *Lithostrotion* and *Tetraporinus* ex gr. *T. virgatus* in conglomerate pebbles (Otava *et al.*, 1994). The $^{40}Ar/^{39}Ar$ dating of detrital white micas indicate 350 Ma cooling ages (Tournaisian) (Schneider *et al.*, 2000). The Andělská Hora Fm correlates with the Lower Heavy Mineral Zone of Hartley and Otava (2001). Owing to the lack of body fossils, its correlation with the Drahany Basin is uncertain.

The overlying Horní Benešov Fm is about 1500 to 2000 m-thick succession of thick, massive sandstones with subordinate lenses of fine-grained conglomerates and rhythmic successions of siltstones, mudstones and fine-grained sandstones. The formation is subdivided into three members: the Laryšov, Brantice and Dalov members (Kumpera, 1966). The formation is free of fauna and contains only rare fossil plants (*Archaeocalamites*). Based on superposition, its age is inferred to be Early- to Middle Viséan (Zapletal *et al.*, 1989). The only indirect biostratigraphic evidence comes from the boreholes near Moravský Beroun where foraminifers from sandy limestones and breccias underlying the Horní Benešov Fm suggest late Early Viséan to early Middle Viséan (V1b-V2a) age (Dvořák, 1994). The 40Ar/39Ar dating of detrital white micas indicates the youngest ages of 350 Ma (Tournaisian) (Schneider *et al.*, 2000). The whole Horní Benešov Fm correlates with the Lower HMZ (Hartley and Otava, 2001). No lateral equivalents of the Andělská Hora and Horní Benešov Fms are known from subsurface outside their outcrop area.

The Moravice Fm. is an ca. 1800 to 2500 m-thick succession of fine-grained sandstones, siltstones and mudstones with minor proportion of thicker sandstone and conglomerate bodies. The Moravice Fm. is subdivided into four lithostratigraphic units: the Bělá, Bohdanovice, Cvilín, Brumovice and Vikštejn members. Frequent findings of goniatites allowed dating of the Moravice Fm to Late Viséan (Goα2-3 to Goβmu Subzone, Kumpera, 1966, 1983; Zapletal *et al.*, 1989). The most common fossils include *Posidonia becheri*, *Streblochondria*, *Goniatites crenistria crenistria*, *Goniatites crenistria intermedius*, *Goniatites striatus falcatus*, frequent trace fossils and fossil plants including horsetails and seed ferns (Kumpera, 1972a, 1983; Zapletal and Pek, 1999; Mikuláš *et al.*, 2002). The youngest cooling ages of detrital white micas correspond to 330 Ma (Late Viséan) (Schneider *et al.*, 2000). The bulk of the Moravice Fm. correlates with the Middle HMZ of Hartley and Otava (2001) save its lowermost (Bělá Mbr) and uppermost (Vikštějn Mbr) parts, which correspond to the Lower and Upper HMZ, respectively (Hartley and Otava, 2001).

Conformably underlain by the Moravice Fm., the Hradec-Kyjovice Fm. constitutes a ca. 1800 m-thick succession of siliciclastics. The formation is subdivided into two members, the basal Hradec Member composed of thick layers of coarse-grained sandstones with subordinate fine-grained conglomerates, and the overlying Kyjovice Mbr composed of thin layers of fine-grained sandstones alternating with siltstones and mudstones. The Hradec-Kyjovice Fm. contains abundant goniatites, nautiloids, bivalves, brachiopods, trace fossils and fossil plants including lycopods, horsetails and ferns (Kumpera, 1983; Purkyňová, 1981). Based on abundant goniatites, the formation has been dated to Late Viséan to earliest Namurian (Goβspi to E1 Zones, Kumpera, 1983). Findings of fossil ferns and horsetails suggest Namurian age (Purkyňová, 1981). The $^{40}Ar/^{39}Ar$ dating of detrital white micas indicates the youngest cooling ages of 330 Ma (Late Viséan) (Schneider *et al*., 2000). The whole Hradec-Kyjovice Fm correlates with the Upper HMZ (Hartley and Otava, 2001). The Hradec-Kyjovice Fm is overlain by coal-bearing paralic siliciclastics of the Upper Silesia Coal Basin.

Minor outcrops and subsurface of the MSCB

Deposits of the Culm facies are exposed in the Maleník Horst in central Moravia, comprising a ca. 900 m thick succession of thick- and thin-bedded sandstones with minor fine-grained conglomerates, siltstones and mudstones. Based on goniatite fauna, they are dated to the Goγ zone and correlated with the Moravice Fm. and Hradec-Kyjovice Fm. of the Nízký Jeseník Basin, located to the N. Outcrops of the Culm facies are also known from the historical centre of Olomouc and its vicinity. They comprise a several hundred-m-thick succession of massive or thick-bedded sandstones with minor conglomerates, siltstones and mudstones. They are correlated with the basal parts of the Moravice Formation (Bohdanovice and Cvilín Beds) based on general lithology, modal composition of sandstones, and $^{40}Ar/^{39}Ar$ dating of detrital micas (Kumpera, 1983; Schneider *et al*., 2000).

Lower Carboniferous Culm facies has been described from several deep boreholes in SE and NE Moravia and in the subsurface of the Upper Silesia Coal Basin. The deposits belong to the parauthochthonous units and correlate with the Myslejovice, Moravice and Hradec-Kyjovice formations. Thickness of the subsurface Culm deposits vary from ~40 m (Němčičky-1 borehole) to ~290 m (Uhřice-2 borehole), but occasionally may exceed 1000 m (Těšany-1 borehole) (Zukalová *et al*., 1981). Generally, the Culm deposits rapidly wedge out towards E. The Culm deposits in SE and NE Moravia are conformably overlain by Upper Carboniferous (Namurian A) siliciclastic molasse sediments of the Upper Silesia Coal Basin (Dvořák, 1982; Zukalová *et al*., 1981).

Facies, processes and depositional environment

Lithology and facies

The MSCB is essentially composed of rhythmic alternation of siltstones and sandstones, with minor proportion of mudstones and conglomerates. Most of the sediments are considered deep-water in origin, although some previous authors suggested shallow-marine, tidal-flat, deltaic, or even fluvial depositional setting for at least a part of the MSCB (Kukal, 1980; Dvořák, 1994). More recently, detailed facies analysis works have indicated that the MSCB consists essentially of gravity-flow deposits (Tab. 1) including: clast-supported conglomerates (facies *F1*); pebbly/granule sandstones (*F2*); normally graded or massive, coarse-grained sandstones (*F3*); coarse- to fine-grained sheet sandstones and sandstone-mudstone couplets; fine-grained sandstone – silstone – mudstone couplets *(F5*) and mudstones with rare siltstone laminae (*F6*). These sediments are thought to be deposited from high-density turbidity currents, sandy debris flows, low-density turbidity currents (sometimes “quasi-steady”) and hemipelagic fall-out (Nehyba and Mastalerz, 1995; Zapletal, 1991; Hartley and Otava, 2001; Bábek *et al*., 2004).

High-density turbidity current deposits

Clast-supported conglomerates with sandy matrix (facies *F1*) and pebbly sandstones of facies *F2a* are normally or sometimes inversely graded (Tab. 1). Both facies are thought to be deposited from high-density turbidity currents (Lowe, 1982) as their normal grading indicates suspension settling and high flow concentration is required for transport and deposition of sediment particles larger than coarse sand (Middleton and Hampton, 1973; Lowe, 1982; Mulder and Alexander, 2001). In contrast to the typical features of cohesive debris-flows, the beds of facies *F1* have sometimes basal erosive scours, flat upper bed contacts (cf. Plink-Björklund *et al*., 2001) and low to zero content of clay matrix (cf. Mulder and Alexander, 2001). Most beds of facies *F1* correspond to *R3* beds of Lowe (1982). In several beds of facies *F1*a there is a basal massive layer sometimes showing clast imbrication, which is followed by a normally graded conglomerate layer. This sequence suggests flow transformation from a basal layer deposited by friction freezing from non-turbulent hyperconcentrated flow (cf. Sohn, 2001) to an upper layer deposited by suspension settling from concentrated (high-density) turbidity flow (division *R3*). High-density flows that deposited the pebbly sandstones of facies *F2a* were highly erosive as suggested by abundant basal scours and mud intraclasts distributed near bed bases (Tab. 1). The beds show abrupt grain size jumps from basal pebbly/granule sandstone layer (division *R3*) to upper, usually parallel-stratified sandstone layer (*S1* of Lowe, 1982).

Sandstone beds of facies *F3a* have a thick (up to 4m), often normally graded and/or parallel stratified, interval of coarse-grained sandstone, which is usually overlain by a relatively very thin $T_{b,c,d}$ Bouma sequence (up to 30cm). The normal grading, basal and internal scours, and coarse sand lithology in the basal interval, all indicate deposition from turbulent density flows and this facies can be interpreted as deposited from sand-dominated high-density turbidity currents (the *S1* and *S3* divisions of Lowe, 1982; concentrated flows of Mulder and Alexander, 2001). High erosive efficiency of these flows is indicated by abundant mud intraclasts distributed near the bed bases and by frequent basal scours. Beds of facies *F3b* share similar succession of sedimentary structures with facies *F3a* and can thus be interpreted as sediments of high-density sandy turbidity flows. However, individual beds are very thick (usually about 8 to 10m, occasionally up to 15m, Table 1) and show frequent traces of amalgamation such as internal scours and rip-up clasts (cf. Mattern, 2002; Plink-Björklund *et al.*, 2001) distributed in discontinuous layers at variable heights above the bed bases. Facies *F3b* is therefore assumed to represent amalgamated layers consisting of several high-density turbidite beds.

Sandy debris flows

Beds of pebbly sandstones of facies *F2b* are ungraded, have non-erosive bases and contain abundant outsized clasts (Tab;le 1). The outsized clasts include both, rounded extraclasts and plastically deformed intraclasts of thin-bedded turbiditic siltstones, mudstones and fine-grained sandstones. They are usually several dm to about 1m in α-axis diameter but outsized clasts as long as 5m were also found. The outsized clasts show random vertical distribution in the bed and they are not aligned in any discrete levels. Absence of bedforms, non-erosive nature and abundance of outsized clasts indicate that these beds were deposited by friction freezing from non-turbulent, high-concentration density flows (Shanmugam, 1996; Mulder and Alexander, 2001). Most likely, these beds were not deposited from cohesive debris flows, as their clay content is very low to zero (macroscopic observation) and no clast projection typical of cohesive debris flows is visible in them (cf. Hiscott and James, 1985; Carter, 2001). The overall bed characteristics of this facies type suggest deposition from cohesionless, sandy debris flows (Shanmugam, 1996; Falk and Dorsey, 1998).

Quasi-steady turbidity current deposits (?)

Up to 17 m thick layers of medium grained sandstone of facies *F3c* are non-erosive and structureless, except for occasional low-angle cross stratification and occasional faint normal grading and convolute lamination in the topmost parts of most beds (Table 1). The layers are unusually thick but they do not show any traces of amalgamation and, therefore, each one probably represents a single depositional event. Great bed thickness is a feature typical of contained (ponded) turbidites, but thick mudstone intervals and upper-flow regime bedforms usually associated with contained deposits (cf. Pickering and Hiscott, 1985; Haughton, 2001) are not present in the beds of facies *F3c*. Lateral pinch-out bed geometry can be observed in some of the beds of facies *F3c*. Absence of grading and great bed thickness may indicate deposition from quasi-steady hyperpycnal flows that may owe their origin to fluvial discharge (Kneller and Branney, 1995), while surges and surge-like turbidity flows, unless ponded, do not produce thick sediment layers (Rothwell *et al.*, 1992). The presence of cross stratification is in contradiction to sandy debris flow interpretation, as such stratification forms solely beneath turbulent traction flows (Hickson and Lowe, 2002, p. 349). Many examples of hyperpycnal flows are known from modern submarine fans (e.g. Kneller and Branney, 1995; Mulder *et al.*, 2001) and the occurrence of such deposits is probably underestimated in the fossil record, partly due to the difficulties with recognition of such flows from the bed characteristics (Kneller and Buckee, 2000). Convex-upward shape and lateral pinch-out geometry of the beds of facies *F3c* can be attributed to deceleration of a hyperpycnal current, loss of momentum and rapid deposition associated with a decrease in slope gradient (hydraulic jump).

Low-density turbidity current deposits

Heterolithic sandstone-siltstone-mudstone beds of facies *F4a* and *F4b* have usually sheet-like geometry and they are organised into well-developed, complete or incomplete Bouma sequences. Frequent basal erosion marks and $T_{a,b,c,d}$ Bouma sequences present in facies *F4a* suggest deposition from low-density turbidity currents (Middleton and Hampton, 1973). The well-developed succession of bedforms expressed in the Bouma sequence indicates a progressive decrease in flow regime and an

Table 1. Facies classification of the Moravo-Silesian Culm Basin (adopted from Bábek *et al.*, 2004).

Facies code / Lithology	Sedimentary structures	Bed thickness	Bed contacts, bed geometry	Intraclasts, outsized extraclasts	Depositional process
F1 Clast-supported conglomerate	Normally graded, occassionally inversely graded, sometimes massive in lower parts of beds, ocassional clast imbrication near bed bases	2 to 13 m	Sometimes basal scours, flat upper contacts, bed geometry unknown	Very rare intraclasts, max. size 10 cm	High-density turbidity currents
F2 Pebbly sandstone to granulestone	*F2a* Normally graded, sometimes parallel-stratified, grain-size jumps from basal pebbly sandstone division to upper sandstone division, internal scours	2 to 4 m	Frequent basal scours, flat upper contacts, bed geometry unknown	Abundant mud intraclasts distributed near bed bases, max. size 40 cm	
	F2b Massive	8 to 12 m	Non-erosive basal contacts, flat upper contacts, bed geometry unknown	Abundant intraclasts and outsized extraclasts distributed throughout the bed thickness, max. size 500 cm	Sandy debris flows
F3 Sandstone	*F3a* Normally graded or massive, parallel-stratified, internal scours, $T_{b,c,d}$ Bouma sequences near bed tops	1 to 4 m	Erosive basal contacts, flat upper contacts, bed geometry unknown	Sometimes mud intraclasts distributed near bed bases, max. size 15 cm	High-density turbidity currents
	F3b Massive, normally graded , sometimes coarse-tail graded, rarely inversely graded near bed bases, sometimes parallel-stratified, internal scours, $T_{b,c,d}$ Bouma sequences near bed tops	3 to 15 m	Erosive basal contacts, flat upper contacts, bed geometry unknown	Abundant mud intraclasts distributed in bed-parallel or irregular zones in variable height above bed base, max. size 50 cm	Amalgamation of high-density turbidity current deposits
	F3c Massive, near bed tops faintly normally graded, convolute-laminated, parallel laminated or low-angle cross-laminated	1.5 to 17 m	Flat, non-erosive basal contacts, sometimes lateral pinch-out geometry, concave-up upper contacts	N/A	Quasi-steady turbidity currents
F4 Sandstone to mudstone	*F4a* $T_{a,b,c,d}$ Bouma sequences, sometimes massive	several cm to 1 m	Abundant tool marks and flute casts, sheet-like bed geometry	N/A	Low-density turbidity currents
	F4b $T_{b,c,d}$ (base-cut-out) Bouma sequences, frequently convolute-laminated	several cm to ca. 50 cm	Non-erosive, flat bed bases, wavy tops	N/A	
F5 Siltstone to mudstone, rarely fine-grained sandstone	Normally graded, parallel laminated, ripple-cross laminated, low-angle cross-laminated	several mm to 20 cm	Basal scours, load casts (load balls), flame structures, wavy tops, lateral pinch-outs of basal siltstone layers	N/A	
F6 Mudstone, rare siltstone	Faintly parallel laminated, sometimes bioturbated	Several cm to several dm	N/A	N/A	Hemipelagic fall-out, low-density turbidity currents

increase in traction during flow passage (Walker, 1965), that is features typical of surges or surge-like flows (Normark and Piper, 1991; Kneller and Buckee, 2000). Base-cut-out $T_{b,c,d}$ Bouma sequences and predominant fine- to medium-grained sandstone lithology represent typical features of facies *F4b*. Prevalence of upper flow regime traction structures and relatively great thickness of individual beds (several dm to 1m) suggest deposition from thick, low velocity turbidity flows, possibly in channel overbank settings (cf. Leverenz, 2000).

Heterolithic siltstone-mudstone beds of facies *F5* typically have an erosive base, a thin (0.5 to 3cm), parallel laminated, ripple-cross laminated and/or normally graded siltstone layer showing frequent lateral pinch-outs, and a thick, sometimes bioturbated, upper mudstone layer (Tab. 1). Bed bases are sharp, commonly highly irregular due to scouring and loading of basal siltstone layers into underlying mudstones. The extreme loading sometimes results in formation of detached load balls. The vertical succession of bedforms, low silt-clay ratio and loading features indicate that these sediments may be classified as fine-grained or silt turbidites with Bouma *A-E* divisions (Shanmugam, 1980; Piper and Stow, 1991), deposited from low-density turbidity currents. Thick successions of more-or-less regular zebra-type repetition of the beds of facies *F5* were previously referred to as the "laminite" in the literature (Lombard, 1963; Kumpera, 1983) and they occur ubiquitously all over the MSCB. For the major part, these successions cannot be interpreted as bottom current deposits (contourites) due to the frequent erosive bases, normal grading and load casts present in individual beds (Stow, 1979).

Deep-water mudstones

Massive black mudstones of facies *F6*, sometimes with thin silt laminae or bioturbated, are very rare in the Moravice Formation. These deposits are difficult to interpret. Due to their common occurrence with silt turbidites (*F5a*) it is possible to interpret these deposits as base-cut-out silt turbidites or mud turbidites (Piper and Stow, 1991). Alternatively, the mudstones may represent hemipelagic deposits of hypopycnal plumes associated with river discharge.

Trace fossil assemblages

The deep-water depositional setting is also supported by relatively abundant trace fossil assemblages. Fine-grained facies are usually associated with low-diversity assemblages including *Dictyodora liebeana*, *Nereites*, and *Planolites* indicating bathyal, aphotic, low-energy dysoxic environments. Upper Viséan sandstone facies are usually associated with higher-diversity assemblages comprising *Dictyodora liebeana*, *Nereites*, *Cosmorhaphe*, *Diplocraterion*, and *Rhizocorallium* indicating relatively higher levels of nutrients and bottom oxygenation (Mikuláš *et al.*, 2004; Bábek *et al.* 2004).

Three types of ichnocoenoses were observed in the Moravice Formation, each reflecting a distinct environmental control: (i) diversified *Dictyodora-Planolites*; (ii) simple *Dictyodora-Planolites*; and (iii) *Diplocraterion-Nereites*.

The diversified *Dictyodora-Planolites* ichnocoenosis consists mostly of fodinichnia (feeding traces) accompanied by agrichnia, pascichnia (grazing traces) and traces showing complex feeding strategies. The most common ichnogenera are *Chondrites, Dictyodora*, *Phycosiphon*, *Zoophycos* and *Planolites*. In the classical Seilacher's (1967) concept, this ichnocoenosis can be considered as a transitional *Zoophycos-Nereites* ichnofacies indicating typically bathyal, aphotic, low-energy, oxygen-depleted environments, which are unfavourable for the benthic communities to live and evolve (Frey and Pemberton, 1984).

The simple *Dictyodora-Planolites* ichnocoenosis shows extremely low diversity, comprising only two nominal ichnogenera. This ichnocoenosis can be assigned to the *Nereites* ichnofacies indicating deep-marine environment with extremely low energy levels (Frey and Pemberton, 1984; Stepanek and Geyer, 1989; Orr, 2001). The relatively highly diverse *Diplocraterion-Nereites* ichnoceonosis comprises abundant domichnia (dwelling traces), fodinichnia, agrichnia-pascichnia type traces and abundant traces of suspension feeders or possible surface-scraping detritus feeders (*Diplocraterion*). The most common trace fossils are *Rhizocorallium*, *Diplocraterion*, *Dictyodora liebeana*, *Cosmorhaphe*, *Protopaleodictyon*, *Furculosus*, etc. The ichnogeneric composition of this ichnocoenosis corresponds to the *Cruziana* ichnofacies mixed with traces of the *Nereites* ichnofacies sensu Seilacher (1967) and Frey and Pemberton (1984) and suggests deposition in environments more favourable to colonisation, compared to the previous ichnocoenoses. Map distribution of the ichnocoenoses in the Moravice Formation is shown in Fig. 4.

Paleocurrent data

Both, unidirectional and bi-directional paleocurrent data were obtained from the orientation of flute casts and tool marks, mostly from low-density turbidity current deposits (F4a, F5). The absolute majority of both published and our own paleocurrent data indicate S-N to SW-NE directions of flow with SSW-NNE frequency maximum (Fig. 4). This direction has been assumed to be parallel to the basin depocentre axis (Kumpera, 1983; Hartley and Otava, 2001). Such paleocurrent patterns are typical of the whole MSCB successions, indicating axial-trough topography at the time of deposition. A much smaller amount of the paleocurrent indicators show alternate W-E and NW-SE directions, which are oblique to perpendicular to the basin axis. Especially in the basal parts of the Moravice Formation the paleoflow patterns are relatively more complex, showing a relatively higher proportion of the oblique to perpendicular W-E to NW-SE directions. In the upper parts of the Moravice Formation,the paleoflow patterns are more uniform and tend to the SSW-NNE frequency maximum.

Depositional model

Five facies associations have been recognised (Hartley and Otava, 2001; Bábek *et al.*, 2004; Nehyba and Mastalerz, 1995). Proximal gravity-flow (fan-delta) deposits are composed of thick accumulations of clast-supported conglomerates (*F1*) locally interbed-

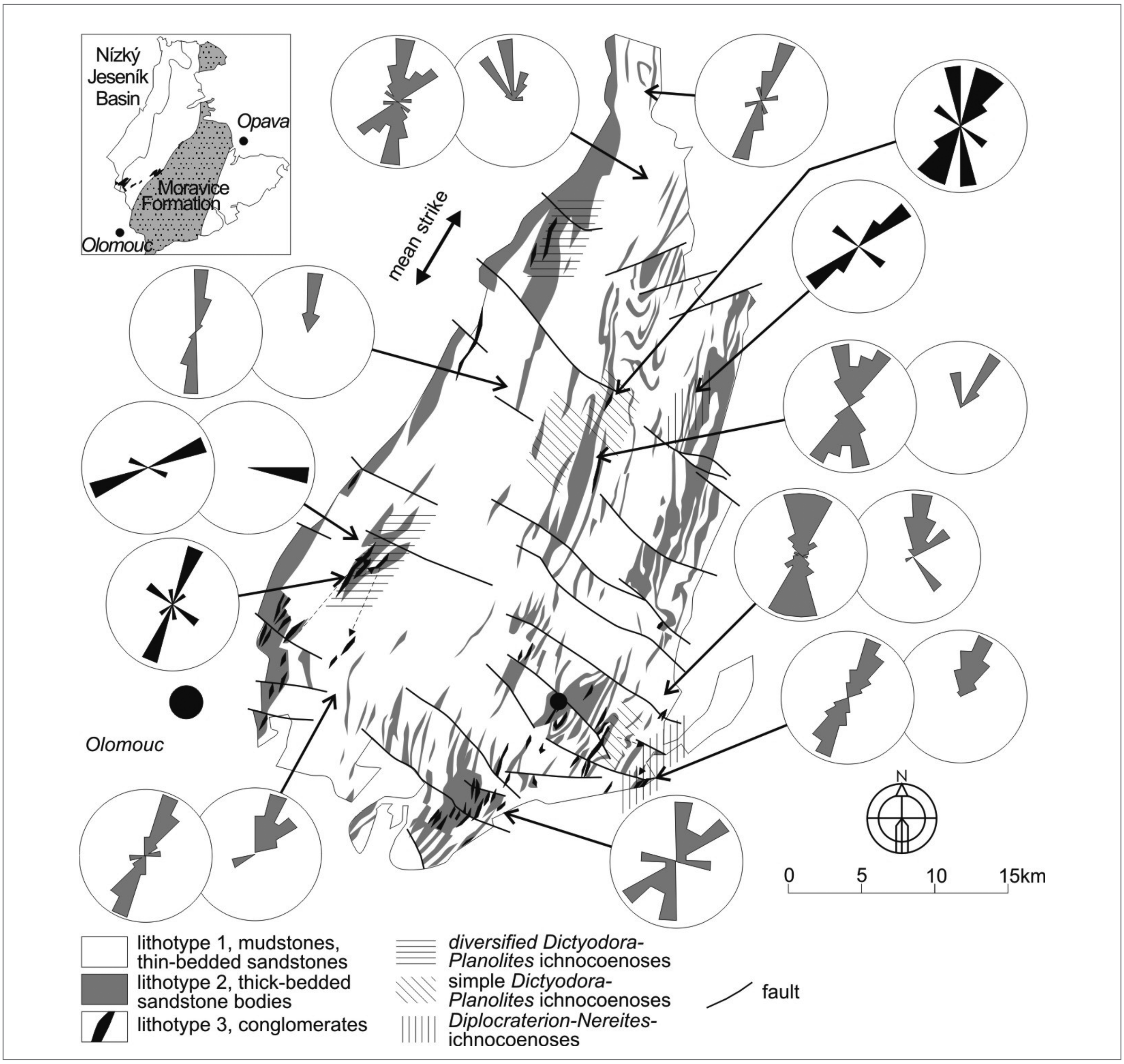

Fig. 4. Basic lithotypes, palaocurrent data and distribution of trace fossils in the Moravice Formation, Nízký Jeseník Culm Basin (adopted from Bábek *et al.*, 2004).

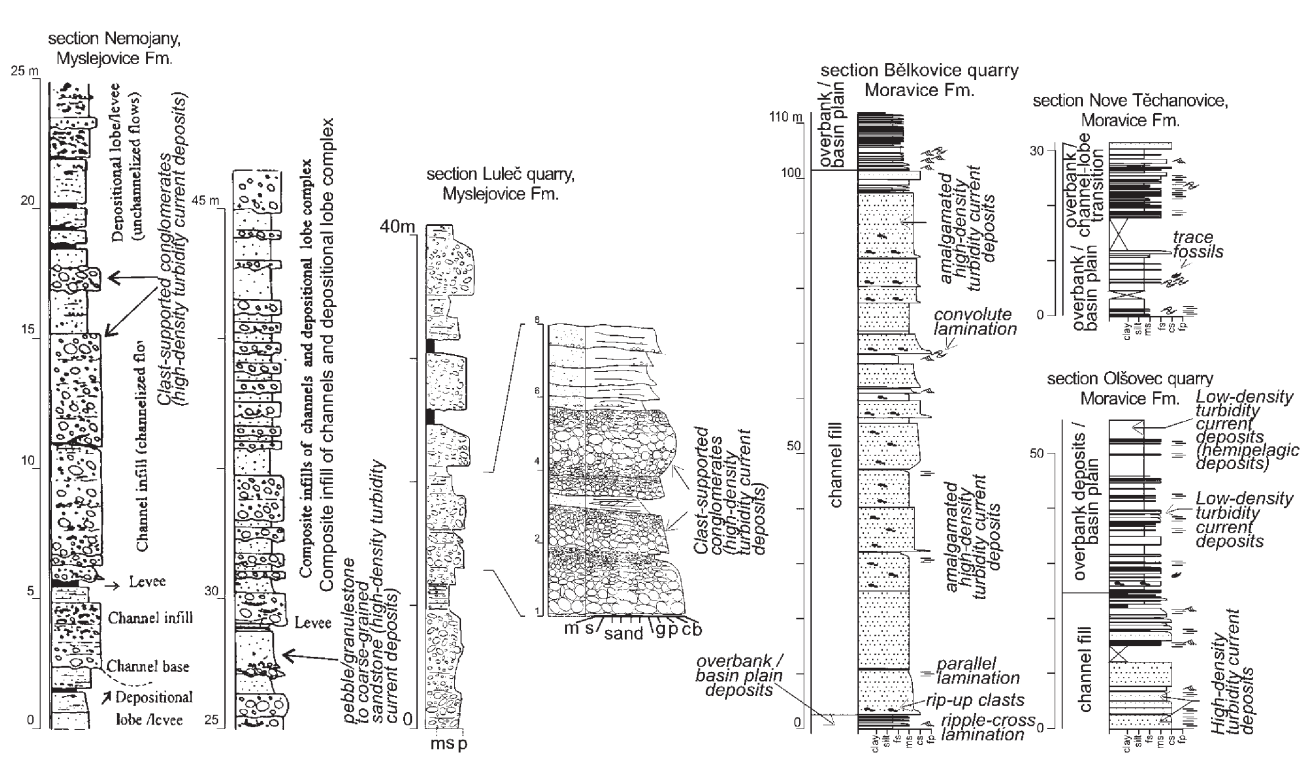

Fig. 5. Selected lihofacies columns across the MSCB in SW – to NE direction representing proximal (left) – to – distal (right) direction (adopted from Nehyba and Mastalerz, 1995; Hartley and Otava, 2001; Bábek *et al.*, 2004).

ded with high-density turbidite sandstones (*F2a*, *F3a*, *F3b*). Channel-fill and channel-lobe transition deposits comprise high-density turbidites (*F1*, *F2a*, *F3a*, *F3b*) interbedded with minor low-density turbidites (*F4a*, *F4b*, *F5*) and occasional sandy debris-flows (*F2b*). Slope apron deposits are composed of quasi-steady turbidity current deposits (*F3c*) interbedded with low-density turbidity currents (*F4a*, *F4b*, *F5*) and occasional sandy debris flows (*F2b*). Lenticular sandstone bodies (depositional lobes) comprise high-density turbidite sandstones (F3a, F3b) interbedded with quasi-steady flow turbidites (*F3c*) and low-density turbidites (*F4a*, *F4b*, *F5*). Basin plain deposits comprise low-density turbidity current deposits (*F4a*, *F4b*, *F5*) and deep-water mudstones (*F6*). The proximal fan-delta deposits are developed almost uniquely in the southern part of the Drahany Basin, whereas the majority of the basin-plain deposits are developed in the Nízký Jeseník Basin, interbedded with the channel and sheet sandstone deposits (Fig. 5). This general grain-size trend, together with the NNE paleocurrent directions and sandstone composition data, indicate a predominant NNE sediment dispersal from point sources located in the Drahany Basin (Hartley and Otava, 2001), with minor sediment supply from the hinterland located in the present-day western direction (Zapletal, 1989; Bábek *et al.*, 2004).

An overall cyclic alteration of the channel and sheet sandstone deposits, and the basin plain deposits, with megacycle thickness reaching several hundred metres, has been interpreted as a result of pulsating tectonic activity associated with switching of major point sources (Bábek *et al.*, 2004).

The Moravice Formation (Nízký Jeseník Basin) comprises two asymmetric megacycles, each about 500 to 900 m thick. In their lower parts, the megacycles are composed of erosive low-efficiency, relatively coarse-grained turbidite systems indicating relative sea-level lowstand. The basal lowstand systems pass up-section into about twice as thick distal, low-efficiency turbidite systems. A combined tectonic-sediment supply model is suggested that explains the cyclic stratigraphy. Periods of increased tectonic activity resulted in slope oversteepening, probably combined with increased rate of lateral, W-E sediment supply into the basin, producing the basal sequence boundary and the subsequent lowstand turbidite systems. During subsequent periods of tectonic quiescence the system was filled mainly from a distant southern point source, producing the thick, low-efficiency turbidite systems (Fig. 6).

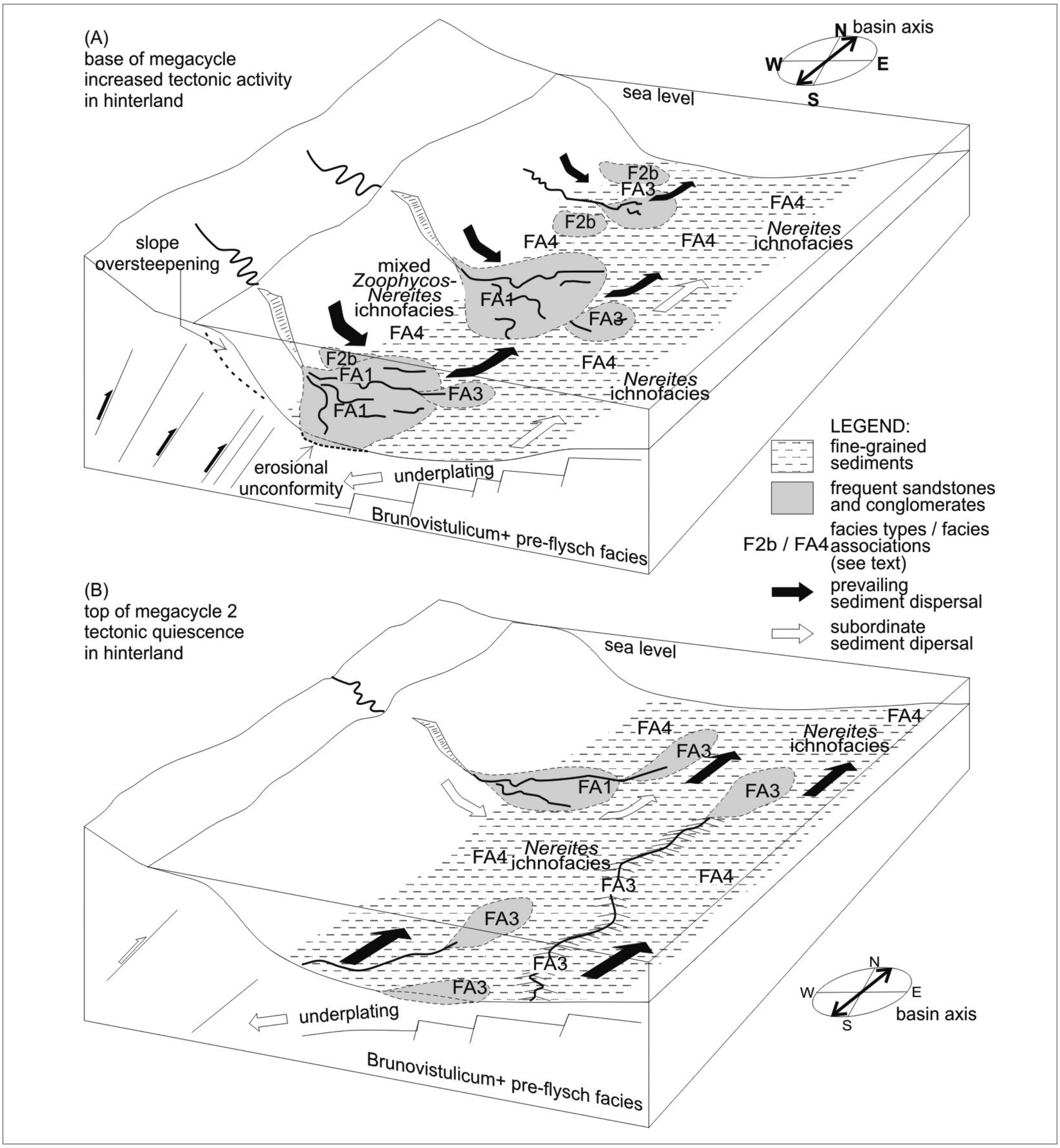

Fig. 6. Depositional model of the Moravice Formation, Nízký Jeseník Culm Basin.Basic lithotypes, palaeocurrent data and distribution of trace fossils in the Moravice Formation, Nízký Jeseník Culm Basin (adopted from Bábek *et al*., 2004).

Sediment composition and provenance

There is a wealth of sediment composition and provenance data in the literature, including modal composition of sandstones, clast analyses of conglomerate facies, heavy-mineral spectra, geochemistry and gamma-ray spectrometry (Hartley and Otava, 2001; Čopjaková *et al*., 2003; Bábek *et al*., 2004; Šimíček *et al*., 2012). The data suggest that the lower part of the MSCB was derived mostly from mixed sedimentary- low-grade metamorphic-plutonic sources with minor proportion of volcanic sources (indicated mainly by potassium feldspars and polycrystalline quartz in the sandstones and volcanic and sedimentary lithic clasts in the conglomerates). The overall trend in this lower part is the up-section increase in concentrations of magmatic lithic clasts and quartz clasts due to increasing proportion of sediment derived from high-grade metamorphic rocks and magmatic rocks and decreasing supply from volcanic/low-grade metamorphic sources.

There is a distinct change towards higher concentrations of potassium feldspars in sandstones, accompanied by higher concentrations of U, Th and U/Th ratios in gamma-ray spectra and high sandstone radioactivity as compared to the mudstones in the Brumovice Beds (Goβ zone, Upper Viséan, Moravice Formation, Nízký Jeseník Basin). This indicates increased supply from plutonic sources, in particular the ultrapotassic plutonites of the Moldanubian nappe pile (durbachites).

Another provenance shift is associated with the onset of deposition of the Luleč Member (Myslejovice Formation, Drahany Basin) and Hradec-Kyjovice Formation (Nízký Jeseník Basin) approximately in the Goβto Goγ interval (boundary between the Middle and Upper Heavy Mineral Zone). The sudden shift towards quartz-rich conglomerate compositions at this boundary is thought to reflect even more significant supply from high-grade metamorphic terrains. This is supported by the published heavy mineral spectra (Hartley and Otava, 2001), in which high concentrations of pyrope and almandine suggest low sediment maturity and derivation from metamorphic sources. The same authors considered this compositional change to reflect a basin-wide progradation associated with sediment oversupply from the source areas. These compositional and GRS changes reflect extremely rapid exhumation of mid- and deep-crustal rocks of the Moldanubian Zone of the Bohemian Massif, which represented the major source area of the Nízký Jeseník Basin foreland basin.

Stop descriptions

A8.1 Mokrá active quarry, eastern part

Active quarry (Českomoravský cement, Heidelberg Cement Group) located 7 km NW of Exit 210 Holubice, D1 motorway between Vyškov and Brno. The Mokrá quarries are situated NE of Mokrá Horákov village. Access to the quarries requires permission from the quarry authorities. Safety hard hats and safety reflective vests are required. (S42: 49°13′39″ N, 16°46′30″ E)

Stratigraphy of the eastern part: Rozstání Formation, Drahany Culm Basin, upper Viséan Račice Member, Myslejovice Formation, Drahany Culm Basin, upper Viséan (Goα to Goβ Zone).

This quarry exposes basal parts of the MSCB at their contact with their pre-flysch formations. Across the MSCB, this contact is considered as diachronous and often modified by basal MSCB thrusts. However, in Mokrá quarry, this transition is syndepositional and relatively well dated by goniatite faunas.

The pre-flysch formations, represented by Devonian and Lower Carboniferous, mostly carbonate sequences of the Macocha Formation (carbonate platform) and Líšeň Formation (calciturbidites), are exposed in the Central and Western Mokrá quarries. Nevertheless, our interest is focused on the Culm Facies developed only in the Eastern Quarry, known also as „Břidla“ (the Shale). The oldest part of the Culm facies in this part of the MSCB belongs to the Rozstání Formation (heterolithics – rhytmic alternation of shales, siltstones and fine-grained sandstones) which is underlain by „transitional facies“ (Buriánek – Gilíková – Otava, 2013). We place the transitional type of sedimentation in time and space between calciturbidites of the Líšeň Formation and the typical Drahany Culm. The most distinct here is the facies of variegated, mostly red-brown shale, rich in trilobites of lower to middle Viséan age. The shale belongs to the Březina Formation, which has variable mineral and chemical composition, in particular the contents of calcium carbonate (CaO = 0.53 to 0.98 wt.%). Compared with the typical Culm facies shales, the clastic component of Březina shale exhibits a higher degree of chemical weathering. The ratio of Al to Na oxides mostly varies between 20 and 30 in the Březina shales, while the values in Culm shales are below 10 (Buriánek –Gilíková – Otava, 2013).

Fig. 7. *Chondrites* trace fossil in siltstones of the basal parts of Rozstání Formation, Mokrá Quarry.

The overlying Culm facies (Rozstání Formation) consists of grey siltstones and distal, thin-bedded turbidite sandstones with occasional trace fossils (*Chondrites*) (Fig. 7). The thickness of sediments of the typical Culm facies exposed in the eastern part of the Mokrá quarry does not exceed 50 m. It is often tectonically sliced and interbedded with carbonates of the Líšeň Formation, especially in its lower part.

Heterolithics of the Rozstání Formation are generally dipping eastwards, composed of interbedded siltstones (with normal grading) and shales mostly 2–5 cm thick, considered generally as distal turbidites.

Upper part of the eastern quarry face exposes fine- to coarse-grained, polymict conglomerates (Račice Member of the Myslejovice Formation), which alternate with the heterolithics. They are dated to Goα goniatite subzone of the upper Viséan, based on goniatite findings in the intercalated shales. The pebble assemblage of the conglomerates includes wide range of metamorphics (mostly gneiss), granitoids, volcanites and sediments (mainly limestones and greywackes) and less frequent quartz grains.

A8.2 Luleč active quarry

Active quarry (Českomoravský štěrk, a.s.) located 2.9 km WNW of Exit 226, D1 motorway between Brno and Vyškov, Czech Republic. The quarry is a property of Českomoravský štěrk, a.s. and it can be accessed only with a permission from the quarry owner. Hard hats and safety vests are necessary. (S42: 49°15′43″ N, 16°56′12″ E)

Stratigraphy and structure: Luleč Member, Myslejovice Formation, Drahany Culm Basin, upper Viséan (Goβto Goγ Zone) Structurally the area of the most important faunistic localities represents two large brachystructures – the Olšany Brachysyncline and the Luleč Brachysyncline.

About 400 m of quarry faces at five storeys expose >60 m thick body of proximal fan-delta deposits (Nehyba and Mastalerz, 1995). They are composed predominantly of coarse-grained, often inversely graded clast-supported conglomerates with sandy matrix. The conglomerate beds are about 2 to 3 m thick, lens like, rapidly pinching-out and containing outsized clasts (rafts) up to 2 m across (!). Conglomerate lenses alternate with several dm thick layers of coarse-grained sandstones in mega cross-bedding fashion. The basal bed contacts are sometimes erosive and associated with flute casts and load casts. Paleocurrent measurements indicate generally N- to NNE transport directions, which is in line with the proximal-distal facies relationships in the Upper Viséan MSCB.

Up-section the conglomerate facies grade into thick-bedded sandstones and finally into thin-bedded and fine-grained heterolithic facies, making up together an approx-

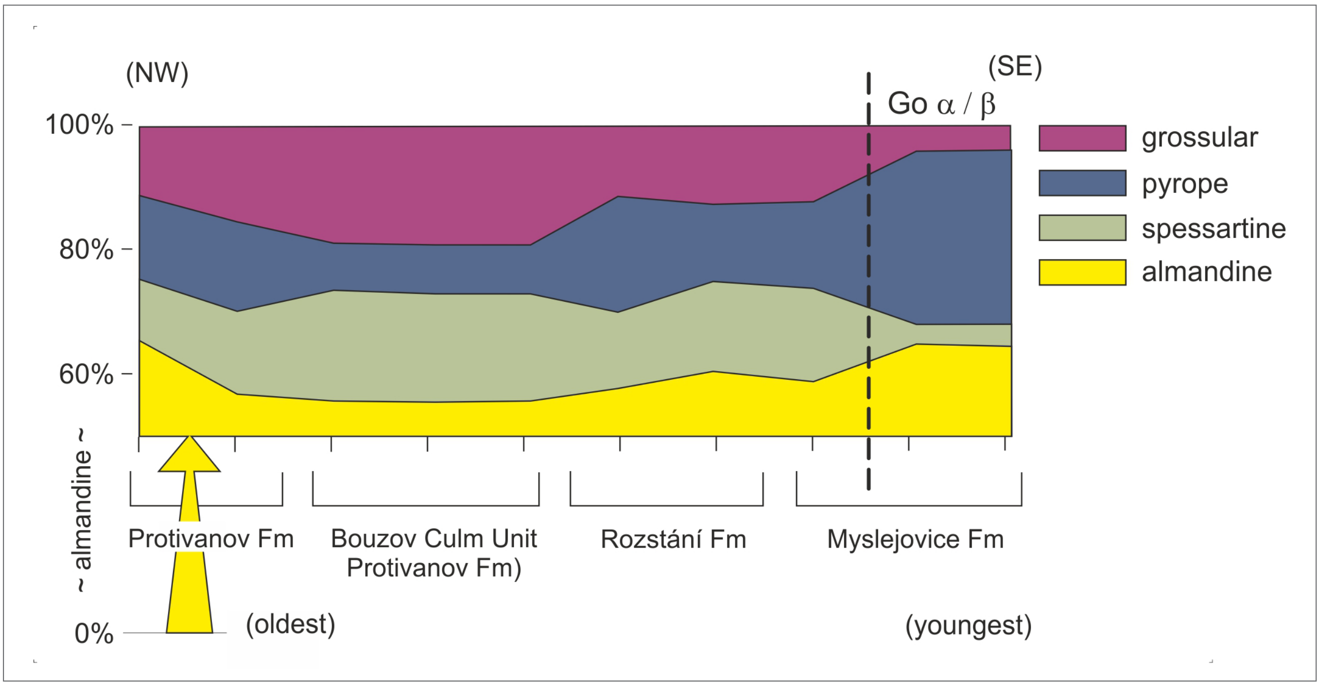

Fig. 8. Change in detrital garnet composition in the upper Luleč Member of the Myslejovice Formation reflects rapid increase in the contents of HT-HP granulites and garnet-bearing gneisses in the source area (Otava, unpublished).

imately 150 m thick succession. The conglomerate facies are interpreted as channel-fill, channel-levee and channel-lobe transition deposits of proximal, coarse-grained fan delta. The sandstone facies are thought to represent depositional lobes (Nehyba and Mastalerz, 1995).

The conglomerates are composed predominantly of igneous and high-grade metamorphic rocks typical of the Moldanubian unit of the Bohemian Massif, including ultrametamorphics (granulites). Heavy mineral spectra from siliciclastics of the Luleč Member in general are dominated by pyrope-almandine garnets poor in LREE, showing enrichment in HREE. Their chondrite-normalized patterns are almost flat from Dy to Lu showing a significant negative Eu anomaly, typical for granulite-grade garnets. Major element compositions of detrital low-grossular pyrope-almandines can only be matched with some granulites and garnet-bearing felsic gneisses of the Bohemian Massif. Garnets from granulites cropping out at the present-day erosion level of the Bohemian Massif usually have higher Ca and/or lower Mg contents (Čopjaková *et al.*, 2005). The Luleč Member therefore sensitively picks up the change in drainage area related to the late Viséan unroofing of the Moldanubian and Moravian nappe pile.

The Luleč conglomerate, which is the youngest member of the Drahany Culm subbasin, is underlain by polymict Račice conglomerates of Upper Viséan Goα age. The gradual change in pebble composition up-section, i.e. from the Račice to the Luleč conglomerate, reflects the following general changes in composition of the source area: (i) decrease in sedimentary rocks; (ii) decrease in effusives and intrusives; (iii) decrease in quartz, and (iv) increase in metamorphics, especially of HP-HT varieties, e.g. granulites. The changes in pebble composition were accompanied by changes in detrital garnet assemblages, form the predominance of spessartine-almandines, grossular-almandines and pyrope-almandines in the Račice Member, to pyrope-almandine in the Luleč Member (Fig. 8)

A8.3 Bělkovice Quarry

Active quarry (Českomoravský štěrk, a.s.) located 5.6 km ESE of the Šternberk railway station, Czech Republic. This is an active quarry, which is normally closed for visitors without permission from the quarry owner. Safety vests and hard hats are necessary. (S42: 49°42′09″ N, 17° 01′30″ E)

Stratigraphy: Bohdanovice Member, Moravice Formation, Nízký Jeseník Culm Basin, upper Viséan (Goα Zone).

The active, six-storey quarry (dimensions ~400 x ~300 m) is open in the Bohdanovice Bed, a basal member of the Moravice Formation. It exposes extremely thick beds of coarse-grained sandstones of facies *F3b* (Fig. 5). Individual beds are massive and usually normally graded at the tops, sometimes coarse-tail graded at the bottom. Thickness of sandstone units may reach up to 15 m, but they often represent multiple amalgamated turbidite events as indicated by occasional erosive basal contacts and abundant mud intraclasts (rip-up clasts) in multiple levels above the unit bases. Nearly one hundred m thick succession of *F3b* beds is exposed in a prominent anticlinal structure at the fourth floor of the quarry. The basal contact of the sandstones with the underlying succession of heterolithics, mostly low-density turbidites and thin mudstone layers, is sharp and emphasized by a layer of rip-up clasts. Upwards, the sandstone succession passes into heterolithics again but this passage is gradual, fining upward. Although the geometry of the sandstone succession is largely unknown due to limited exposure, it is interpreted as a channel-fill succession, owing to the numerous signs of sediment erosion, FU trend in its upper part, abundant internal scours, rip-up clasts and amalgamation implying high erosive competence of the sediment flows.

The Moravice Formation is composed of two megacycles, each about 500 to 900 m thick. The megacycles start with 50- to 250-m-thick, basal segments of erosive channels: overbank successions and slope apron deposits interpreted as lowstand turbidite systems. Up-section they pass into hundred metre-thick, fine-grained, low-efficiency turbidite systems. The Bělkovice quarry exposes basal parts of the lower megacycle, which was supplied from point sources located laterally to the basin axis, in the present-day west.

A8.4 Malý Rabštejn and "Railway section" near Domašov nad Bystřicí

About 60 m high natural cliff in the bend of the Bystřice River located 1.9 km SSE of the Domašov nad Bystřicí railway station. The cliff is situated in the deeply incised valley of the Bystřice River. It forms a natural landmark and a training site for rock climbers. From the cliff we will take a short hike (about 3 km) along the river to observe various turbidite facies in a series of several smaller outcrops and in a big inactive quarry ("railway section" near Domašov nad Bystřicí). (S42: 49°43′21″ N, 17°27′04″ E)

Stratigraphy: Bohdanovice Member, Moravice Formation, Nízký Jeseník Culm Basin, upper Viséan (Goα Zone).

The Malý Rabštejn cliff exposes a succession of massive, coarse-grained sandstones with occasional rip-up clasts and parallel lamination (facies *F3a* and *F3b*), which alternate with normally graded, fine- to medium grained conglomerates and pebbly sandstones (facies *F1* and *F2a*). The conglomerate beds typically have basal layers rich in rip-up mudstone intraclasts

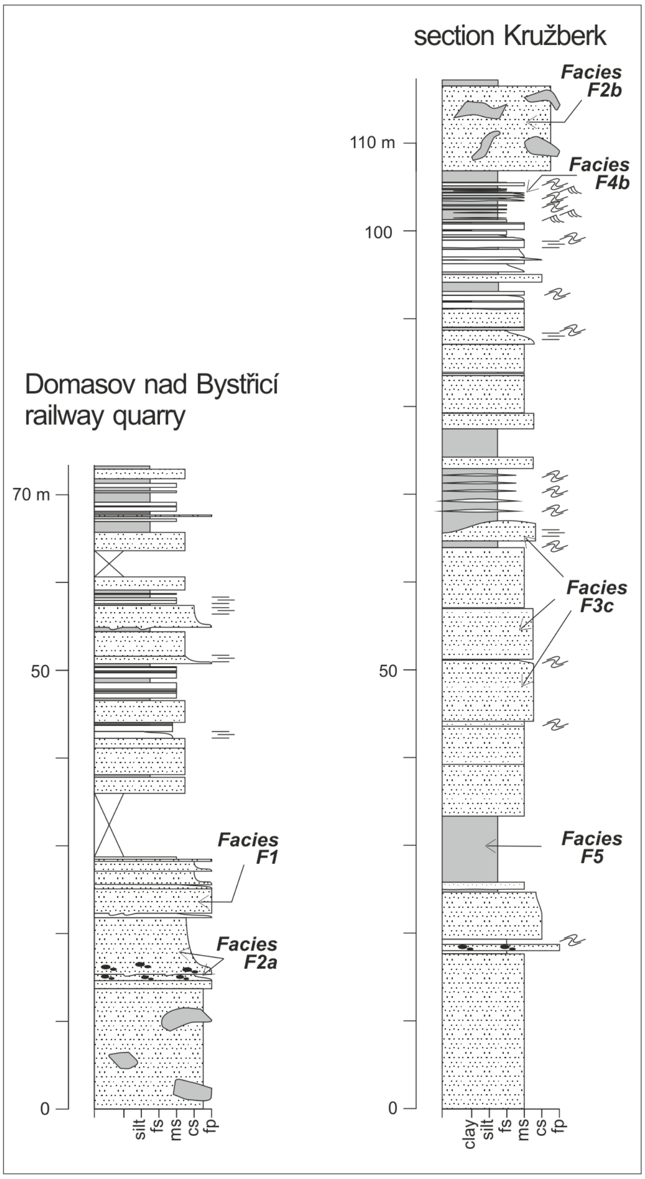

Fig. 9. Representative lithological logs of the "railway section" near Domašov nad Bystřicí (left) and Kružberk dam (right) (adopted from Bábek *et al.*, 2004).

and some of them show erosive bases with large-scale flutes. The abundant evidence for erosion suggests that this is a channel-fill body, composed predominantly of high-density turbidity current deposits. The uppermost part of the cliff shows a fining-upward succession into heterolithics and very thinly laminated siltstones, which are rich in trace fossils of the Zoophycos- and mixed Zoophycos – Nereites ichnofacies. Most abundant are the following ichnotaxa: *Chondrites* isp., *Phycosiphon incertum*, *Planolites beverleyensis*, *Planolites* isp. and more rarely *Cosmorhaphe timida*, *Chondrites* cf. *intricatus*, *Falcichnites lophoctenoides*, *Pilichnus* isp., *Protopaleodictyon* isp, *Spinorhaphe rubra* and *Zoophycos* isp. (Zapletal and Pek, 1998).

The Malý Rabštejn section is a part of large-scale, multi-storey submarine channel body, in which coarse-grained facies alternate with fossiliferous heterolithics and even black shales. A similar succession is exposed in the nearby "railway section" in Domašov nad Bystřicí (Fig. 9). The intercalated fossiliferous heterolithic layers are exposed in the uppermost parts of the Malý Rabštejn section see above) and in section "Bělský mlýn" located about 300 m E of Malý Rabštejn. The channel-fill succession belongs to the same basal segment of the first megacycle of the Moravice Formation, which is exposed in the Bělkovice quarry (stop 3).

A8.5 Skoky

About 260 m long road cut located 3.8 km ESE of Exit 290, D1 motorway between Olomouc and Hranice. This section is situated along a local road with infrequent traffic. Reflective vests will be provided for safety. (S42: 49°32′56″ N, 17°32′03″ E)

Stratigraphy: Brumovice – Vikštejn members, Moravice Formation, Nízký Jeseník Culm Basin, upper Viséan (Goβ Zone).

This outcrop exposes nearly 200 m thick succession at the passage from coarse-grained facies to very thick succession of fine-grained heterolithics and shales. The basal parts of the section consist of several-m thick layers of massive and/or normally graded, coarse-grained sandstones (facies *F3a*). They may represent outer reaches of distributary channels or sandstone lobe deposits. In this particular case, closer interpretation is extremely difficult. This succession passes upward into dm-thick layers of medium-grained sandstones, often parallel-laminated, wavy-laminated and convolute-laminated (*F4b*), alternating with thin siltstone interlayers. The sandstone beds often exhibit base-cut-out Bouma sequences ($T_{b,c,d}$). Frequent convolute lamination present in facies *F4b* suggests rapid suspension settling and water escape, which may be associated with deposition in proximal, high-energy channel-overbank environments. Upwards, this succession passes into monotonous unit composed almost solely of siltstones and shales, which is crosscut by several faults. The whole section is a good example of fining- and thinning-upward trends, which occur ubiquitously throughout the Moravo-Silesian Culm Basin. Of special interest is the variety of wavy and convolute lamination in facies *F4b* and the overlying thick shale succession.

Modal composition of sandstones reveals their relative low mineral and textural maturity, which is characteristic for synorogenic siliciclastics. Average contents of framework components (quartz, feldspars and lithic clasts), recalculated to sum 100%, show dominancy of quartz grains (59%) over feldspar grains (33%) and lithic clasts (8%). Ratio of polycrystalline/monocrystalline quartz is up to 2:1. Potassium feldspars strongly dominate. Plagioclase grains, mainly albite, are rare and usually altered. Lithic clasts group contains mainly fragments of plutonic and high-grade metamorphic rocks, such as gneisses, granitoids and durbachites. Clasts of acid volcanic rocks and sediments (mainly siltstones and shales from older Culm strata) are rare. In addition, micas are abundant non-framework minerals (more or less chloritized biotite flakes prevail over muscovite). Silty-to-clayey sandstone matrix is fine-grained derivative of framework grains (quartz, feldspars), supplemented with chlorite, sericite, clay minerals and heavy minerals. In QFL ternary diagrams of Dickinson *et al.* (1983) most of samples plot near the boundary between transition continental and recycled orogeny provenance field. Relative low mineral maturity and preservation of less stable components in sandstones indicate rapid deposition and short transport of clastic material due to high topographic gradient, which eliminated effects of chemical weathering and selective hydrodynamic sorting (Šimíček *et al.*, 2012).

Relatively high contents of less stable components of sandstones, which can carry radioactive K (K-feldspars, micas, components of sandstone matrix) and U and Th (especially heavy minerals such as zircon, thorite, monazite, xenotime and secondary REE-minerals contained in durbachite clasts and within the sandstone matrix) are responsible for "inverse" nature of spectral gamma-ray signal in siliciclastic sediments. Gamma-ray spectrometry was originally utilized as indicator of fine-grained lithology with high contents of clay minerals, which usually reveal higher values of radioactivity compared to sandstone facies. However, greywackes of the Brumovice member are more radioactive than mudstones from the same stratigraphic levels. The average concentrations of radioactive elements in sandstones at Skoky are 19.8 ppm of Th, 6.7 ppm of U and 2.9% of K. Average values in mudstones are 16.2 ppm of Th, 4.9 ppm of U and 4% of K (Šimíček *et al.*, 2012).

Fossils are rare and usually not well preserved in Skoky. Lehotský (2002) described bivalve *Posidonia becheri* and horsetail *Archaeocalamites scrobitulatus*. More frequent are trace fossils, which belong to the simple Dictyodora–Planolites ichnocoenosis (*Dictyodora liebeana*, *Planolites* isp. and *Planolites beverleyensis*). This ichnocoenosis is characteristic for deep marine environment with extremely low energy and low content of nutrients (Bábek *et al.*, 2004).

A8.6 Hrabůvka quarry

Active quarry (Českomoravský štěrk, Heidelberg Cement Group) located 2.5 km E of Exit 308 Hranice, D1 motorway between Hranice and Lipník nad Bečvou. This is an active quarry – permission from quarry owner is required. Hard hats and reflective vests are necessary. (S42: 49°34′38″ N, 17°41′51″ E)

Stratigraphy: Vikštejn Member, Moravice Formation – or perhaps basal parts of Hradec–Kyjovice Formation, Nízký Jeseník Culm Basin, upper Viséan (Goβel to Goβmu or even Goγ).

The active, six-storey quarry (dimensions ~800 x ~ 350 m), which exposes the uppermost part of the Moravice Formation, is situated near the fault line separating outcrop area of the Nízký Jeseník Culm and Moravian Gate trough.

Several species of goniatites have been described at this locality (*Nomismoceras vittiger*, *Goniatites* sp., *Arnsbergites falcatus* and *Paraglyphioceras elegans*) and they mostly indicate goniatite sub-zones Goβel to

Goβmu, which correspond with the Vikštejn Member of the Moravice Formation. However, the presence of *Neoglyphioceras spirale* indicates, that part of the section may belong to the goniatite sub-zone Goγ and so to the Hradec Member of the Hradec-Kyjovice Formation (Lehotský, 2008). However, goniatites are rare and usually not well preserved. More frequent are trace fossils at the surfaces of greywacke lenses. Similarly to the Olšovec quarry, species of relatively shallow water, Cruziana (*Diplocraterion* isp. and *Rhizocorralium* isp.) and deep water, Nereites (*Dictyodora liebeana* and *Planolites* isp.) ichnofacies are present (Bábek *et al*., 2004).

The dominant part of the section is formed by ~10 m thick lenticular coarse-grained sandstone bodies (facies *F3a–b*) interbedded with fine-grained sandstones and mudstones (facies *F4a–b* and *F5*). The lack of amalgamation surfaces, lower average bed thickness, small size of mudstone rip-up clasts, absence of internal compensation cycles and dominance of sandy-rich facies over mud-rich facies allow to interpret this facies stacking pattern as channel-lobe transition deposits (Mutti and Ricci Lucchi, 1972) or infills of shallow channels parallel with basin axis (Bábek *et al*., 2004). Near the base of the section is present a sedimentary succession predominantly formed by low-density turbidites (facies *F4a–b* and *F5*) and deposits of hemipelagic suspension (facies *F6*). They represent outer submarine fan settings (lobe fringe) or channel levee environment. In the upper part of the section we can observe ~10 m thick facies stacking patterns formed by facies *F1*, *F2* and *F3a–b*. Facies *F4a–b* and *F5* are in minority. Blocky-to-fining upward cycles, overall coarse-grained lithology, frequent basal scours, amalgamation surfaces and large mudstone rip-up clasts indicate deposition within proximal, erosional or mixed erosional-depositional channels during their progressive migration (Mutti and Ricci Lucchi, 1972; Reading and Richards, 1994; Shanmugam, 2006).

Analyses of pebble assemblages in fine-grained conglomerates reveal high contents of metamorphic rocks (47%), supplemented with magmatic (29%) and sedimentary (24%) rocks (Gilíková *et al*., 2003). The most abundant metamorphic rocks are orthogneiss, phyllite and quartzite. Pebbles of granites predominate among the magmatic rocks. However, clasts of acid-to-intermediate volcanic rocks are also abundant. Pebbles of sedimentary rocks are usually represented by rocks from older Culm strata (basin cannibalism). The arenites can be characterized as lithic and litho-feldspathic greywackes. Composition of lithic fragments in greywackes corresponds with the above mentioned composition of pebble assemblages. Matrix of the greywackes is a mixture of detrital quartz, feldspars, sericite and clay minerals. Arenites from Hrabůvka quarry are characteristic by variable textural and low mineral maturity which is typical for sediments of the Brumovice and Vikštejn members of the Moravice Formation. From the geotectonic point of view, the main sources of clastic material were identified in the recycled orogene (Maštera, 1997; Gilíková *et al*., 2003).

Paleocurrent data correspond with direction from SW to NE, which is consistent with elongation of the MSCB and the confirm the axial-trough topography of the basin (Hartley and Otava, 2001; Bábek *et al.* 2004).

Hydrothermal polymetallic mineralization (galena, sphalerite, chalkopyrite, tetraedrite and Ag-minerals) was previously described in the quartz-dolomite veins (Slobodník and Dolníček, 2001).

A8.7 Olšovec

Abandoned quarry located about 600 m NW from the chapel in Olšovec, about 2.9 km NNW of Exit 308, D1 motorway between Olomouc and Ostrava. This section is located in an abandoned quarry, which is partly filled with water, providing a favourite bathing and fishing place for local people. (S42: 49°35′56″ N, 17°42′39″ E)

Stratigraphy: Vikštejn Member, Moravice Formation – or perhaps basal parts of Hradec – Kyjovice Formation, Nízký Jeseník Culm Basin, upper Viséan (Goβel to Goβmu or even Goγ).

The lowermost 12 m of the section is submerged. Above the water level, an about 15 m thick succession of several m thick beds of coarse-grained, massive sandstones (*F3a* facies) is exposed, which is assumed to represent high-density turbidity current deposits. They are intercalated by thin layers of medium- to fine-grained, cross and convolute stratified sandstones deposited from low-density turbidity currents. These facies are characterized by a relatively lower proportion of amalgamation surfaces and a lack of mudstone intraclasts. The facies architecture and lithological marks probably document deposition at the mouths of distributary channels or as axial channel fills. From the middle to the upper part of the section, a fining-upward trend can be observed in the vertical facies succession. The predominant heterolithic sediments are intercalated with thin layers of massive and normally graded fine- to medium-grained greywackes, sometimes with cross- or wavy lamination. Flute marks, groove marks and load casts are frequent at the bases of the greywacke beds. Heterolithic sediments represent deposition from low-density turbidity currents and bottom currents at distal parts of continental slopes. Greywacke beds can be interpreted as sandstone lobes of an outer submarine fan (Bábek *et al*., 2001).

Gamma-ray logging of the Olšovec section (Fig. 10) revealed that the facies dependence of the gamma-ray signal (in particular Th and K) is weak. This is a typical pattern for the lower parts of the Moravice Formation, which is caused by low compositional contrast between framework grains and matrix in greywackes and, in general, low chemical maturity of the siliciclastic material.

The fine-grained upper parts of the section are rich in paleontological material. In spite of their generally low preservation, several species of goniatites (*Neoglyphioceras spirale, Hibernicoceras kajlovencense, Sudeticeras crenistriatum*), bivalves (*Posidonia becheri*) and crinoids (*Cyclocaudiculus edwardi*) were described from the locality. Fossil flora predominantly includes fragments of horsetail *Archaeocalamites scrobitulatus* (Zimák *et al*., 1995). Trace fossils are frequently preserved on the contacts of greywacke beds and include the ichnospecies: *Cosmoraphe kettneri*, *Rhizocorallium* sp., *Diplocraterion parallelum* (U-shaped burrows), *Dictyodora liebeana* (meandering), *Nereites missouriensis*, *Chondrites indricatus* and *Planolites* sp. (Lehotský, 2008). The presence of specimens typical for both relative shallow-water, Cruziana ichnofacies (*Rhizocorallium*, *Diplocraterion*) and deep-water, Nereites ichnofacies (*Dictyodora, Cosmoraphe, Nereites*) can be explained by either characteristics of the environment, which allowed existence of both groups or by periodic oxygenation of bottom, coupled with supply of nutrients and coarse-grained clastic material.

Hydrothermal mineralization occurs in cracks and contains mainly calcite and quartz. Chlorite (clinochlore-chamosite) and pyrite were also described, but their occurrence is rare.

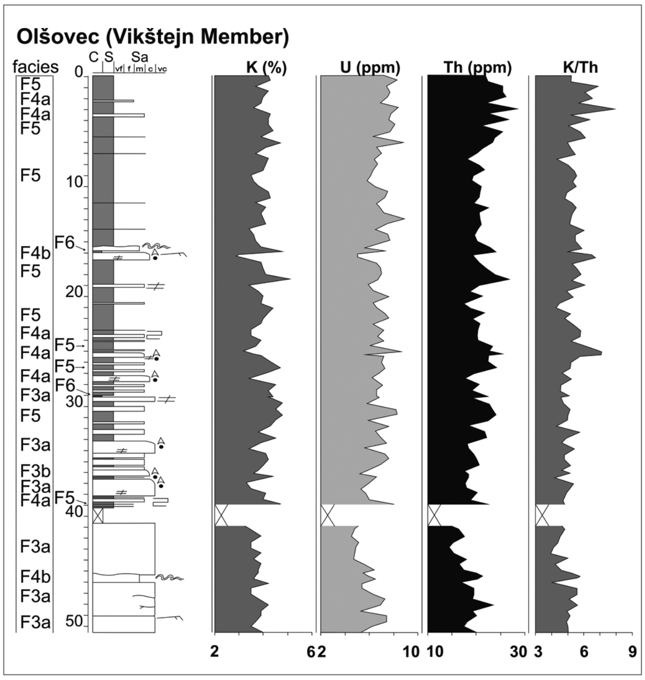

Fig. 10. Lithological and gamma-ray spectrometry logs of the Olšovec quarry (Šimíček *et al*., 2012). Note relatively poor gamma-ray representation of the prominent fining-upward trend.

A8.8 Budišov nad Budišovkou

Abandoned quarry on the right side of a local road from Budišov nad Budišovkou to Stará Libavá, about 26 km SW of the centre of Opava. The quarry is used as a shooting range and it is closed for public. Permission for access is required. (S42: 49°48′03″ N, 17°36′10″ E)

Stratigraphy: Cvilín Member, Moravice Formation, Nízký Jeseník Culm Basin, upper Viséan (lower part of Goβ subzone).

A succession of thin-bedded, sheet-like turbidite beds is exposed in this abandoned quarry. The predominating facies type is fine-grained, normally graded sandstone with $T_{a,b,c}$ Bouma sequences or incomplete (base-cut-out) Bouma sequences, which are interpreted as sediments

Fig. 11. Example of tool marks from basin-plain deposits at the Budišov nad Budišovkou section.

of distal low-density turbidity currents, deposited in a basin plain environment. Bed bases are exposed in several instances, showing well-developed tool marks, flute casts and bounce casts (Fig. 11). The paleocurrent data show predominant SSW to NNE flow directions, often combined with S to N directions. These patterns can be observed throughout the MSCB, indicating axial-trough topography of this deep marine foreland basin.

A8.9 Slezská Harta

A road-cut ca. 260 m long along road 452 between Leskovec nad Moravicí and Bílčice. This section is situated just next to the dam of the Slezská Harta reservoir – one of the biggest reservoirs in North Moravia. The section itself is situated along one of the main roads and caution is needed when moving along the section. Reflection vests will be provided. Coordinates (S42: 49°53′29″ N, 17°35′06″ E)

Stratigraphy: Bohdanovice Member, Moravice Formation, Nízký Jeseník Culm Basin, upper Viséan (Goα Zone).

This section exposes a fine-grained succession of the Bohdanovice Member, comprising dark grey siltstones and mudstones alternating with thin laminae of fine-grained turbiditic sandstones, facies F5 and F6. The fine-grained sediment is very well preserved including mm-thick lamination. The turbiditic laminae are typically 0.5 to 2.5 cm thick, normally graded, parallel- or ripple-cross laminated. The bed bases are sharp and often associated with very prominent load casts. The extreme sediment loading results in numerous cases in bed contortion, thinning of laminae and development of load balls. This is a good example of synsedimentary and early post-sedimentary deformation due to loading in distal fine-grained turbidites. This facies is devoid of body- and trace fossils, presumably due to high sediment accumulation rates.

Situated several kms from the locality there are young, Plio-Pleistocene volcanic rocks, which include lava flows of alkali basanite and related rocks, thick layers of pyroclastic material (scoria) and lacustrine volcaniclastic sediment (including relics of maars). They are related to the deep-seated faults of the upper Elbe fault system and represent one of the youngest volcanic rocks in the Bohemian Massif. A big quarry in Bílčice, about 2 km away from the locality, exposes an instructive lava flow with thick columnar jointing.

A8.10 Kružberk

Natural outcrop in the Moravice River valley, about 400 m ENE of the Kružberk reservoir dam. The section is located in a scenic valley. Cliffs at the section are frequently used by rock climbers. Coordinates (S42: 49°49′28″ N, 17°40′3″ E)

Stratigraphy: Basal part of the Brumovice Member, Moravice Formation. Nízký Jeseník Culm Basin, upper Viséan (lower part of Goα subzone).

This section exposes a somewhat unusual sedimentary succession in the MSCB, comprising up to several m thick, massive, granulometrically uniform sandstones with occasional convolute- and parallel lamination in the upper parts of beds (facies *F3c*) (Fig. 9). The beds have flat, non-erosive contacts and sometimes lateral pinch-out geometry with concave-up tops. The absence of grading and unusual bed thickness may indicate deposition from quasi-steady hyperpycnal flows that may owe their origin to fluvial discharge (Kneller and Branney, 1995), in contrast to surges and surge-like turbidity flows, which, unless ponded, do not produce thick sediment layers (Rothwell *et al.*, 1992). Convex-upward shape and lateral pinch-out geometry of the beds of facies *F3c* can be attributed to deceleration of hyperpycnal currents, loss of momentum and rapid deposition associated with a decrease in slope gradient (hydraulic jump). Any alternative hydrodynamic interpretation of these beds is open to discussion at the locality and will be highly welcome.

These beds occur in association with conglomerates rich in outsized clasts (*F2b*), interpreted as sandy debris flows and heterolithic facies including sediments of low-density turbidity flows (*F4b*). This facies association is present in laterally continuous sand-rich units. Thicker mudstone-dominated successions, the presence of sandy debris flows and their distribution in form of laterally incoherent bodies, have been reported as indicative of slope or base-of-slope deposition (*cf.* Shanmugam and Moiola, 1995). Similarly, deposits of quasi-steady turbidity currents have been reported from slope apron settings (Plink-Björklund *et al.*, 2001) or indicating a close link to shelf-edge river systems (Sinclair, 2000; Mulder *et al.*, 2001). The blocky cycle and fining-upwards cycle organisation of these deposits reflect filling of smaller-scale channels probably connected to a shelf-edge river system. Unusually high bed thickness and pinch-out geometry of the quasi-steady turbidity current deposits of *F3c* (see above) may reflect deposition in settings with significant decrease in bathymetric gradient, where the turbidity currents underwent hydraulic jumps (*cf.* Mutti and Normark, 1987; Weimer *et al.*, 1998). Deposition in lower reaches of a slope apron setting or in a topographically complex slope setting (slope basins) is inferred for the Kružberk section.

The basal parts of the Brumovice Member in Kružberk are characterized by extremely high concentrations of radioactive elements, U, Th, K, especially in the sandstone facies. The major carriers of the GRS signal, observed in optical microscopy, CL microscopy and WDX SEM include K-feldspars, muscovite, sericite, biotite and albite for K; zircon, apatite, monazite and xenotime for U and monazite, thorite, REE secondary minerals, xenotime, apatite and zircon for Th.

This particular stratigraphic level reflects a sudden, early Late Viséan (330 – 335 Ma; Fig.12) shift from low-grade metamorphic, volcano-sedimentary provenance to predominantly magmatic sources with ultrapotassic plutonites (= durbachites) showing Moldanubian (Lugo-Danubian) affinity (Šimíček *et al.*, 2012). This change is associated with facies shift to coarse-grained turbidite systems at the base of the second megacycle of the Moravice Formation (Bábek *et al.*, 2004).

A8.11 Vítkov – Annina dolina

Abandoned quarry + several outcrops along the quarry access road, located about 4 km NE from the crossroads of 442 and 462. (S42: 49°48′24″N, 17°46′43″ E)

Stratigraphy: Hradec Member, Hradec–Kyjovice Formation, Nízký Jeseník Culm Basin, upper Viséan to lower Namurian (Goγ to E1).

Abandoned shelf quarry (dimensions ~ 170 x ~ 50 m) is located in the central part of the Moravice river Natural Park. It is lectostratotype locality of the coarse-grained facies stacking patterns in the basal part of the Hradec–Kyjovice Formation, which is known as "Nýtek conglomerate horizon" (Kumpera, 1976). In the quarry, and on numerous outcrops along its access road, binominal conglomerate-greywacke rhythmic interbedding can be seen. The thickness of conglomerate beds varies from several dm up to 5 m. We can observe medium- to fine-grained clast-supported conglomerates (facies *F1*) and fine-grained matrix-supported conglomerates to pebbly sandstones (facies *F2a–b*). All conglomerate facies have unsorted coarse-grained greywacke matrix. The average size of clasts varies between 3 and 5 cm in α clast-axis. However, you can find floating outsized clasts up to 20 cm in the longest clast-axis, especially in facies *F1*. Also large mudstone rip-up clasts (up to 80 cm) are present

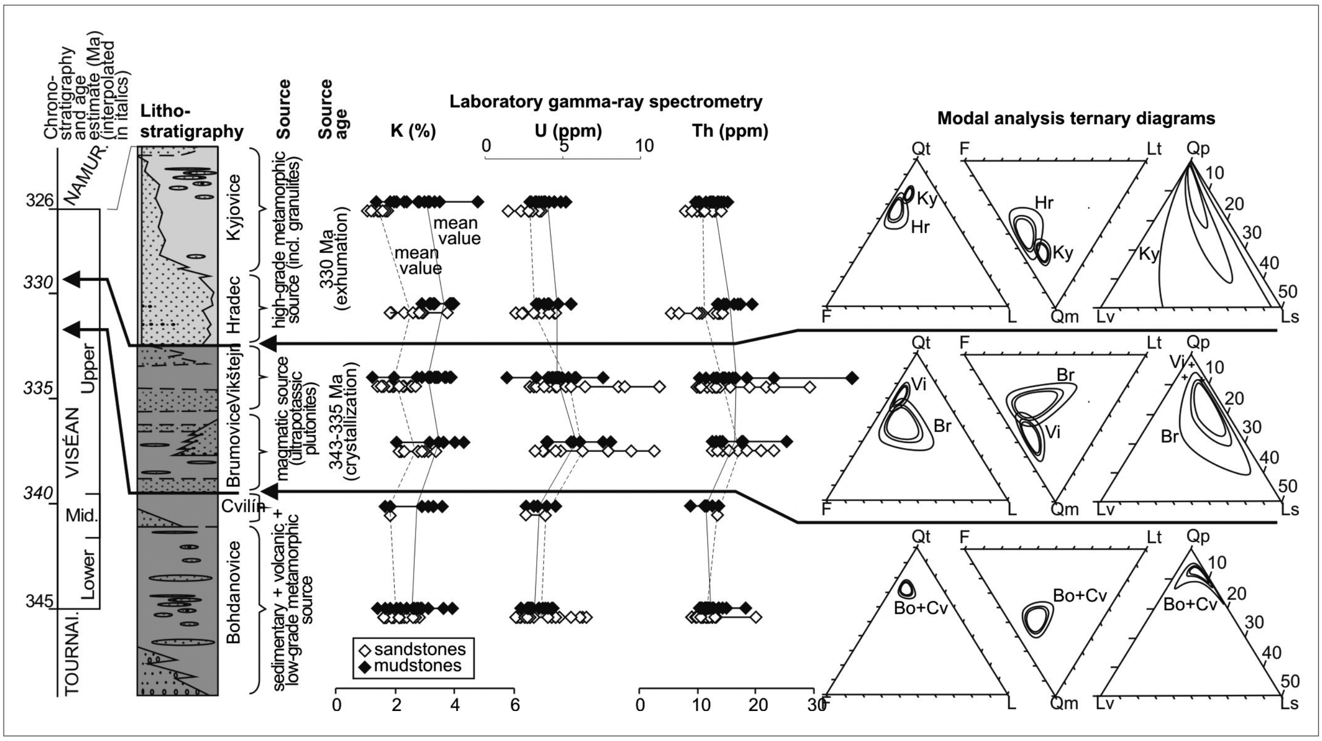

Fig.12. Stratigraphic distribution of gamma-ray spectrometric concentrations in sandstones (white diamonds) and mudstones (black dots) of the MSCB. (Šimíček *et al.*, 2012).

in facies *F2a–b*. Roundness of clasts can be described as subangular to subrounded. The beds are usually massive or normally graded. Occasionally, inverse grading can be observed above the base and planar stratification near the top of some beds. The load casts (up to 20 cm deep) are often developed at the base of conglomerate beds. The thickness of arenitic beds ranges from several dm to 10 m. They are mostly coarse- to medium-grained, massive (facies *F3a*) or normally graded with planar, cross or convolute stratification near the top of beds (facies *F3b*). Mudstone rip-up clasts can be observed above the base of some beds. Traction carpets are developed at the base of some greywacke beds. The presence of internal erosional surfaces and mudstone rip-up clasts within some beds indicates amalgamation. Packets of sandstone-conglomerate beds are separated by thin fine-grained sedimentary successions formed by mudstones (facies *F6*), heterolithic facies (facies *F5*) and thin bedded fine-grained sandstones corresponding to the Tcd division of Bouma sequence (facies *F4b*) (Šimíček *et al.*, 2012).

This sedimentary succession is an example of channel-fill sedimentation, which is characterized by presence of coarse-grained sedimentary facies, several m thick, sometimes amalgamated beds and deep load casts at the base of beds. Higher portion of normally graded sandstone facies indicates deposition in the proximal part of a distributary channel, close to the boundary between the inner and central parts of a submarine fan system (Mutti and Ricci Lucci, 1972; Reading and Richards, 1994; Shanmugam, 2006). Paleocurrent data indicate dominant directions from

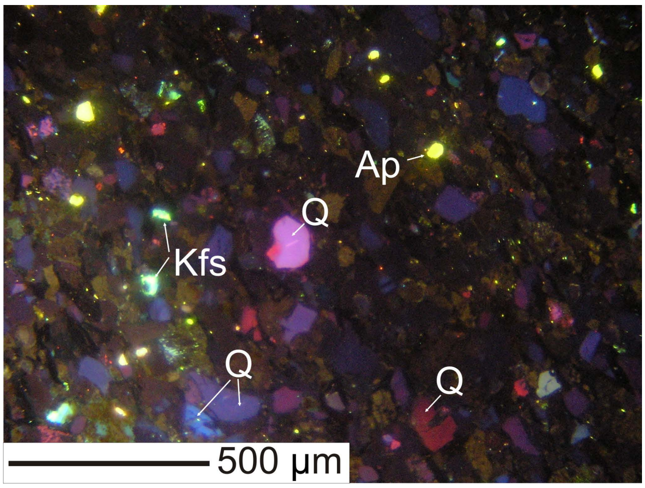

Fig. 13. Photomicrograph from cathodoluminescence microscope which shows relative abundance of quartz grains with red-to-pink CL-colour indicating their volcanic source.

NNW to SSE, which roughly correspond with the N–S elongation of the MSCB, but some paleocurrent indicators in conglomerate facies show almost perpendicular, W to E direction (Dvořák, 1994). Composition of rock pebbles is strongly polymict. Most pebbles belong to quartz, garnet and muscovite-biotite gneisses, biotite granodiorites and acid-to-intermediate volcanic rocks, supplemented with quartzites, mica-schists and greywackes (Maštera, 1975). Arenites can be generally described as sublitharenite, but sandstones with subarcose composition are also abundant. The average content of quartz is 60%, feldspars 29% (K-feldspars prevail over plagioclases) and lithic clasts 11%. Among the lithic group, clasts of gneiss, granite and acid volcanic rocks predominate, which is consistent with the above-mentioned composition of pebble assemblages from conglomerates (Maštera, 1975; Šimíček *et al.*, 2012). Cathodoluminescence microscopy revealed abundant contents of volcanic quartz in sandstones of the Hradec Member (red-to-pink CL-colour; Fig. 13). The QFL data plot mainly within the recycled orogene provenance field in ternary diagrams of Dickinson *et al.* (1983).

Minerals of garnet group form the dominant portion in the heavy mineral assemblages. In several samples, garnets form up to 80% of all grains (cf. Maštera, 1975; Hartley and Otava, 2001). Apatite, tourmaline, zircon and sphene are also relatively abundant heavy minerals. Whole-rock chemical analyses of mudstones revealed high contents of Al_2O_3 (20–25%), MgO (4.5%) and MnO (up to 1%). The ratio of Al_2O_3/Na_2O indicates deposition of mainly fresh, chemically unweathered material (Maštera, 1975). The spectral gamma-ray logging shows only a weak effect of facies changes on variations in K, U and Th concentrations. It is most probably due to low compositional contrast between different facies related to the low mineral, chemical and textural maturity of sediments. High contents of feldspars, lithic fragments, silty-to-clayey matrix and low contents of non-radioactive quartz grains are responsible for relatively high radioactivity of sandstones, which is very close to values obtained from the mudstones (Fig. 12). Hence, usefulness of gamma-ray spectrometry as indicator of lithological changes is very limited at the base of the Hradec–Kyjovice Formation. Overall coarse-grained nature of sediments, low maturity of sandstones and mudstones in combination with low spectral gamma-ray contrast between different facies indicate short transport and rapid deposition of clastic material due to extreme uplift and erosion of the source area (cf. Hartley and Otava, 2001; Šimíček, *et al.*, 2012).

The frequent hydrothermal veins, which penetrate greywacke beds are composed of quartz, calcite and chlorite, sometimes even minerals of clinochlore–chamosite series occur. The thickness of veins is up to 10 cm. An interesting technical relic – a wooden discharge hopper – is preserved in the quarry .

Stop 12 Stará Ves

Abandoned quarry located about 520 m E of the chapel in Stará Ves near Bílovec, about 5.4 km NNW of Exit 336, Dl motorway between Olomouc and Ostrava. This is an easily accessible abandoned quarry. (S42: 49°46′14″ N, 17°58′56″ E)

Stratigraphy: Kyjovice Member, Hradec Kyjovice Formation, Nízký Jeseník Culm Basin, upper Viséan (Goγ subzone) to Namurian A (Goy subzone).

This abandoned quarry, 200 x 150 m in size, is an excellent exposure of the Kyjovice Member of the Hradec-Kyjovice Formation. The locality is important from sedimentological, mineralogical and tectonical points of view.

Sedimentary succession is characterized by a rhytmic alternation of fine-grained turbiditic sandstones (low-density turbidites, facies *F4a* and *F4b*) with siltstones and silty shales (*F5* and *F6*). Thickness of greywacke beds ranges from 10 to 60 cm. They are massive or parallel stratified, normal grading is less common. Flute marks and other sole marks are frequently present at the lower contacts of the beds, and their orientation documents dominant axial (S to N) filling of the Variscan foreland basin. The average modal composition of the greywackes comprises: 50% of quartz, 20% of plagioclases, 10% of volcanic lithic clasts and 20% of sedimentary and meta-sedimentary lithic clasts, mostly silty shales, phyllites and gneisses (Dvořák, 1999). Black-greyish micaceous siltstones and silty shales with parallel lamination form cm to dm thick layers. Locally abundant plant debris includes typical Lower Carboniferous genera *Lepidophloios* sp., *Archaeocalamites* sp. and *Calamites* sp. A thin horizon of acid volcaniclastics was described by Dvořák (1999) in the face of the northern quarry.

Gamma-ray spectrometric (GRS) logs show generally lower K, U and Th concentrations and total gamma-ray counts than the underlying Moravice Formation. In addition, there is a marked contrast between low-radioactivity sandstones and high-radioactivity mudstones/heterolithics (Fig. 14). This reflects a compositional shift towards highly mature, quartz-rich sandstones derived from high-grade metamorphic sources with granulites in the late Viséan (approximately at 330 Ma level, Fig. 12). These compositional and GRS changes reflect extremely rapid exhumation of mid- and deep-crustal rocks of the Moldanubian Zone of the Bohemian

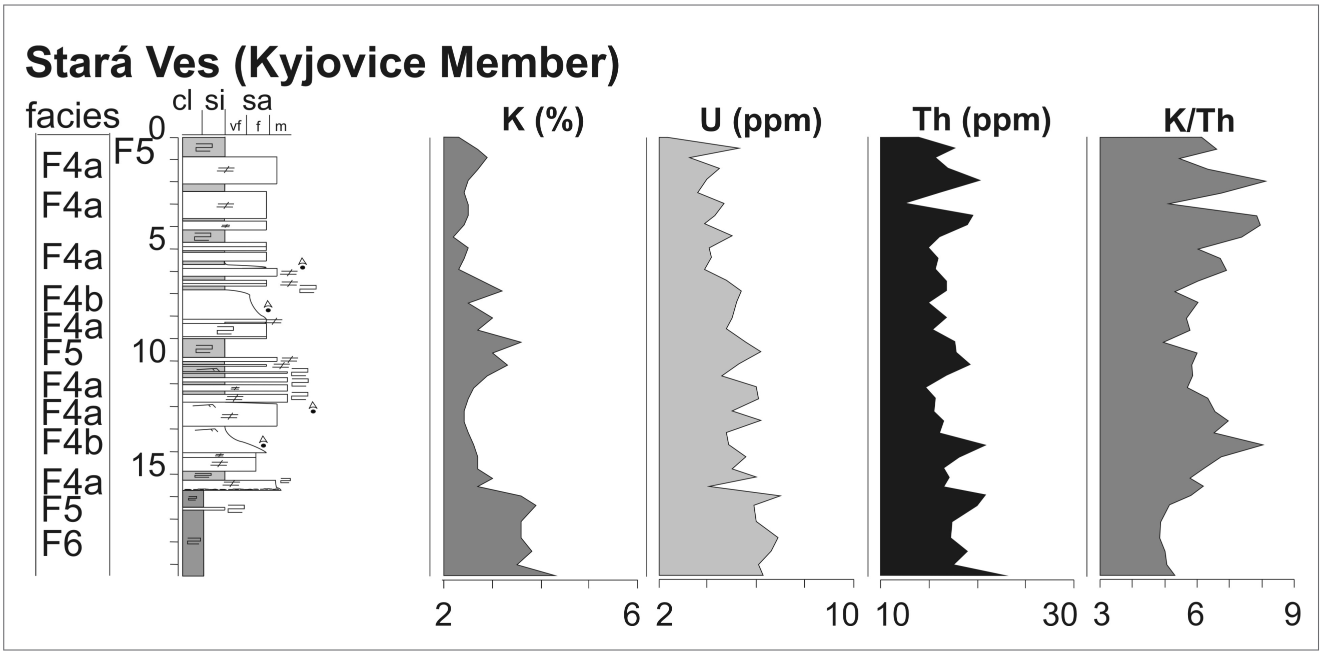

Fig. 14. Facies and gamma-ray spectrometry logs at the Stará Ves section. Note good correspondence between K log and facies stacking patterns, which indicate well-developed grain size dependence of gamma-ray data (Šimíček *et al.*, 2012)

Massif, which represented the major source area of the Nízký Jeseník Basin foreland basin. In this respect, the base of the Hradec – Kyjovice Formation is well correlatable with the base of the Luleč conglomerate indicating a sudden influx of granulite-rich Moldanubian-type material.

The sandstone beds are frequently cut by small hydrothermal veins containing quartz (so called Bristol diamond) and carbonate minerals (calcite and dolomite-ankerite). In addition, sage-green aggregates of chlorite (clinochlore-chamosite) and rare barite, pyrite, chalcopyrite and sphalerite were described. Secondary minerals include relative abundant limonite and rare malachite (Zimák *et al*., 2002).

The north face of the quarry presents one of the best exposures of fold-and-thrust tectonics in the Moravo-Silesian Culm Basin (Grygar, 1997). The architecture of the quarry is characterized by presence of inverted to recumbent east-vergent folds, which are cut by faults dipping towards WNW. Asymmetric flexures (kink folds) are accompanied by intra-stratal dislocations, subparallel with flat flexure limbs.

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