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# LOWER CARBONIFEROUS ICHNOFABRICS OF THE CULM FACIES: A CASE STUDY OF THE MORAVICE FORMATION (MORAVIA AND SILESIA, CZECH REPUBLIC)

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**Abstract:** Overall bioturbation of sediments of the Culm facies is much lower compared to the Mesozoic and Cenozoic flysch facies. Totally reworked intervals (up to 1 cm thick) occur locally at the tops of turbiditic beds. Much more frequently, visual equivalents of a “mottled zone” were observed at the two localities which represent a transitional facies between “laminites” and greywacke bodies. Approximately one-half of the turbidite beds studied show a mottled level. *Planolites montanus* Ichnofabric and *Rhizocorallium* Ichnofabric are infrequent. Most of the laminites show no ichnofabric except cross-sections of *Dictyodora,* which are typically observed on bedding planes only (not in vertical sections). Compared to the Mesozoic and Cenozoic flysch (i.e. Rhenodanubian or Carpathian flysches), the Culm facies appears to have formed in less oxygenated settings possibly with shorter and unequally distributed colonization windows. This explains the prevalence of traces with complex feeding strategies comprising chemosymbiosis and gardening (*Chondrites, Dictyodora*). Their effect on the integrity of sediment (i.e. the amount of transported material) was weak.

**Key words:** Carboniferous, Culm facies, turbidites, ichnofabric, paleoenvironment.

## Introduction

The Culm facies, named after the English attribution Culm Measures, represents a specific variety of flysch sediments, characteristic of sedimentary basins bordering active margins of the Variscan Orogen. The facies is characterized by rapid influx of clastic material (e.g. Kumpera 1983). In Europe, regions with Culm flysch facies include South England, Ireland, Massif Central in France, Schwarzwald, Rhenish Slate Mts, Harz Mts and Moravian-Silesian Zone. Due to the relatively large extent of the Culm facies, numerous papers on its trace fossils were published (see Štúr 1875; Patteisky 1929; Štepánek & Geyer 1989; Pek 1986 for further literature sources).

Ichnological studies should not be limited to systematic ichnology and ichnofacies description; it has become clear that parameters of paleoenvironments are much better recognized on the basis of ichnofabric analysis than on the basis of individual ichnotaxa or trace-fossil communities (Uchman 1999). Ichnofabric analysis involves all structural and textural aspects of bioturbation, and describes and interprets determinable forms (i.e. trace fossils) as well as undeterminable biodeformational structures in spatial relation to physical sedimentary structures and textural features (e.g. Ekdale & Bromley 1983; Bromley & Ekdale 1986; Uchman 1999).

Most of the existing studies on ichnofabric concerned shallow-water marine sediments (e.g. Bockelie 1991). The first comprehensive study of the flysch ichnofabrics was included in the volume by Uchman (1999), which concerned the Lower Cretaceous–Eocene Rhenodanubian Flysch of the Alps. The Culm facies represents a much older geological record of benthic life and behaviour, and the paleoenvironments represented are apparently specific. For this reason, a special study of the ichnofabric of the Culm facies is presented herein, based on experience from several localities in the Moravian-Silesian region. The aim of the contribution is to provide a case study to be used in interpreting other occurrences of the Culm facies. This is the first paper about ichnofabrics in deep-sea Upper Paleozoic deposits. We believe that it may contribute to consideration of ichnofabric changes in the Paleozoic, colonization of deep-sea floor, and paleo-ecological conditions in Carboniferous seas.

## Geological setting

The Culm deposits of the Moravian-Silesian region are preserved in an elongated, SW-NE to SSW-NNE-trending structure on the eastern margin of the Bohemian Massif. Generally, two Culm basins are recognized in the Moravo-Silesian Zone: the Drahany Basin and the Nízký Jeseník Basin. The fill of the Drahany Basin has been lithostratigraphically subdivided into three formations: the Protivanov Formation of Lower to Upper Viséan age (Peγ to Peδ Zone), the Rozstání Formation of Upper Viséan age (Peδ to Goniatites Goα Zone) and the Myslejovice Formation of Upper Viséan age (Goα to Goγ Zone), each consisting of several members. The lithostratigraphic succession of the Nízký Jeseník Basin has been subdivided into four formations: the Andělská Hora Formation of Lower Viséan to Middle Viséan age (Peγ Zone), the Horní Benešov Formation of Middle to Upper Viséan age (Peγ to Goα Zone), the Moravice Formation of Upper Viséan age (Goα2–3 to Goβmu Subzone) and the Hradec-Kyjovice Formation ranging from the Upper Viséan to the lowermost part of the Namurian (Goβspi Subzone to E1 Zone) (Kumpera 1983; Dvořák 1994).

Covering the most extensive outcrop area of all formations within the Nízký Jeseník Basin, the Moravice Formation represents a ca. 2500 m thick succession of fine-grained sandstones, siltstones and mudstones alternating with prominent sandstone bodies and small conglomerate bodies. The facies patterns of the Moravice Formation are very complex. The following basic facies types have been recognized and classified according to the facies classes by Mutti et al. (1975) and Pickering et al. (1989): (1) massive and/or normally graded conglomerates and pebbly sandstones of facies class A, several metres thick; (2) beds of massive, coarse- to medium-grained sandstone of facies class B, several tens of centimetres to several metres thick, sometimes featuring coarse-tail grading, repeated grading or parallel stratification, some of them bearing prominent rip-up clasts of black mudstone; (3) beds of fine- to medium-grained sandstone, several centimetres to tens of centimetres thick, with $T_a$, $T_{ab}$ and $T_{abc}$ Bouma intervals frequent parallel lamination, ripple-cross lamination and convolute lamination (facies class C); (4) beds or irregular lenses of massive or faintly normally graded fine-grained sandstone and siltstone, several mm to about 20 cm thick, often with parallel lamination and/or ripple-cross lamination (facies class D), and (5) structureless or bioturbated black mudstones (facies class E). A "zebra"-type alternation of generally light-coloured beds and laminae of facies D and black mudstones of facies E is the most common feature of the fine-grained flysch deposits in all Culm-facies formations, commonly referred to as the "laminite" (Lombard 1963; Zapletal 1970). Lithofacies characteristics, sedimentary structures (erosive bases, flute casts, tool marks, Bouma intervals) and facies stacking patterns observed reflect deposition from high-density turbidity currents (facies A and B), low-density turbidity currents (facies C, D) and possibly also debris flows (certain beds of facies A). Deposition of the fine-grained facies D may have been contributed by bottom currents. Sediments of facies E were deposited presumably from hypopycnal flows (Mulder & Alexander 2001), pelagic suspension, and as the uppermost divisions of the Bouma intervals.

A detailed field facies mapping of the Moravice Formation allowed us to reveal two distinct facies associations to compose this turbidite succession. The first facies association is extremely diverse, comprising facies A, B, C, D and E organized into a few tens to a few hundred metres thick asymmetric fining- and thinning-upward cycles, which alternate with thick successions of the laminites. These cycles are interpreted as channel-fill cycles alternating with overbank sediments, deposited in the inner- to middle-fan environments. The second, overlying facies association comprises thick successions of laminite and beds of facies D and C, which alternate with several tens of metres to about one hundred metres thick sandstone lenses composed of facies C and B. The second facies association was deposited as sandstone lobe to lobe-fringe sediments in the outer-fan environment. As envisaged from the present facies characteristics and supported by paleocurrent data and clastic provenance data (Kumpera 1983; Hartley & Otava 2001), the Moravice Formation evolved as a longitudinal, predominantly fine-grained turbidite system within a remnant foreland basin.

Ichnoassemblages of the first facies association are dominated by *Dictyodora liebeana*, which is accompanied by *Chondrites* isp., *Phycosiphon incertum*, *Planolites beverleyensis*, *Planolites* isp., *Spirodesmos archimedeus* and rare occurrences of *Chondrites* cf. *intricatus*, *Falcichnites lophoctenoides*, *Pilichnus* isp., *Protopaleodictyon* isp., and *Zoophycos* isp. (most of the ichnotaxa were recognized by Zapletal & Pek 1997). The second facies association in the upper part of the Moravice Formation is engaged with peripheries of greywacke lenses and contains *Diplocraterion* isp., *Rhizocorallium* isp., *Dictyodora liebeana*, *Cosmorhaphe* isp. and *Paleodictyon* isp.

For the ichnofacies analysis and ichnofabric description, ubiquitous gradual transitions between laminites of outer fans and mostly lenticular greywacke bodies (the origin of which can be explained as a result of "turning on" and "turning off" individual transporting canals) are exceptionally attractive. These intervals provide the richest finds of distinct ichnofabric, apparently because substrates contrasting in colour and grain size were available, hence also able to preserve biogenic reworking. The ichnofabric described below comes from two localities: Nové Těchanovice-Pollak's galleries (Nové Těchanovice-Pollakovy štoly) (Patteisky 1930; Kumpera 1971) and Olšovec (Zapletal & Pek 1987) (Fig. 1) from the transition between laminites and greywacke beds. The transitional character of this facies enables, in our opinion, general estimation of the biogenic reworking of the Culm facies, both towards the laminites, and the greywackes.

## Terminology and methods

The above cited paper by Uchman (1999) provided a concept, terminology and methods for studying the ichnofabrics of turbidite beds. According to Uchman (op. cit.), who uses his experience from the Mesozoic and Cenozoic flysch sediments, two basic zones can be distinguished: the spotty zone and the elite zone. These zones correspond roughly to the zones of bioturbation in Recent deep-sea sediments, that is to the mixed layer and transitional layer, which can be preserved if "frozen" by burial with turbidite sediments. The uppermost layer (commonly $T_d$–$T_e$ Bouma's interval) is completely bioturbated and usually shows "spotty" ichnofabric. This layer is called the **spotty layer** (Uchman 1999).

Uchman (op. cit.) presented the spotty layer as "... characterized by oval spots visible against the mottled background. The spots are cross-sections of trace fossils, commonly *Planolites* or *Thalassinoides*. The spots differ in colour contrast and sharpness of contours. In some layers the contrast is so low, that the layer seems to be structureless. Additionally, in thin-bedded flysch, some deep-tier trace fossils penetrate from the overlying bed to the spotty layer of the underlying bed ... Lithology of the spotty layer differs from the underlying sediment ...".

A term suggested by Uchman (1999) to describe the bioturbation by elite trace fossils (i.e. the most "eye-catching" traces) is the **elite layer** subdivided into **upper elite zone**, **lower elite zone**, and **exichnial elite zone**. Ichnofabrics in these zones are formed by deep-tier trace fossils.

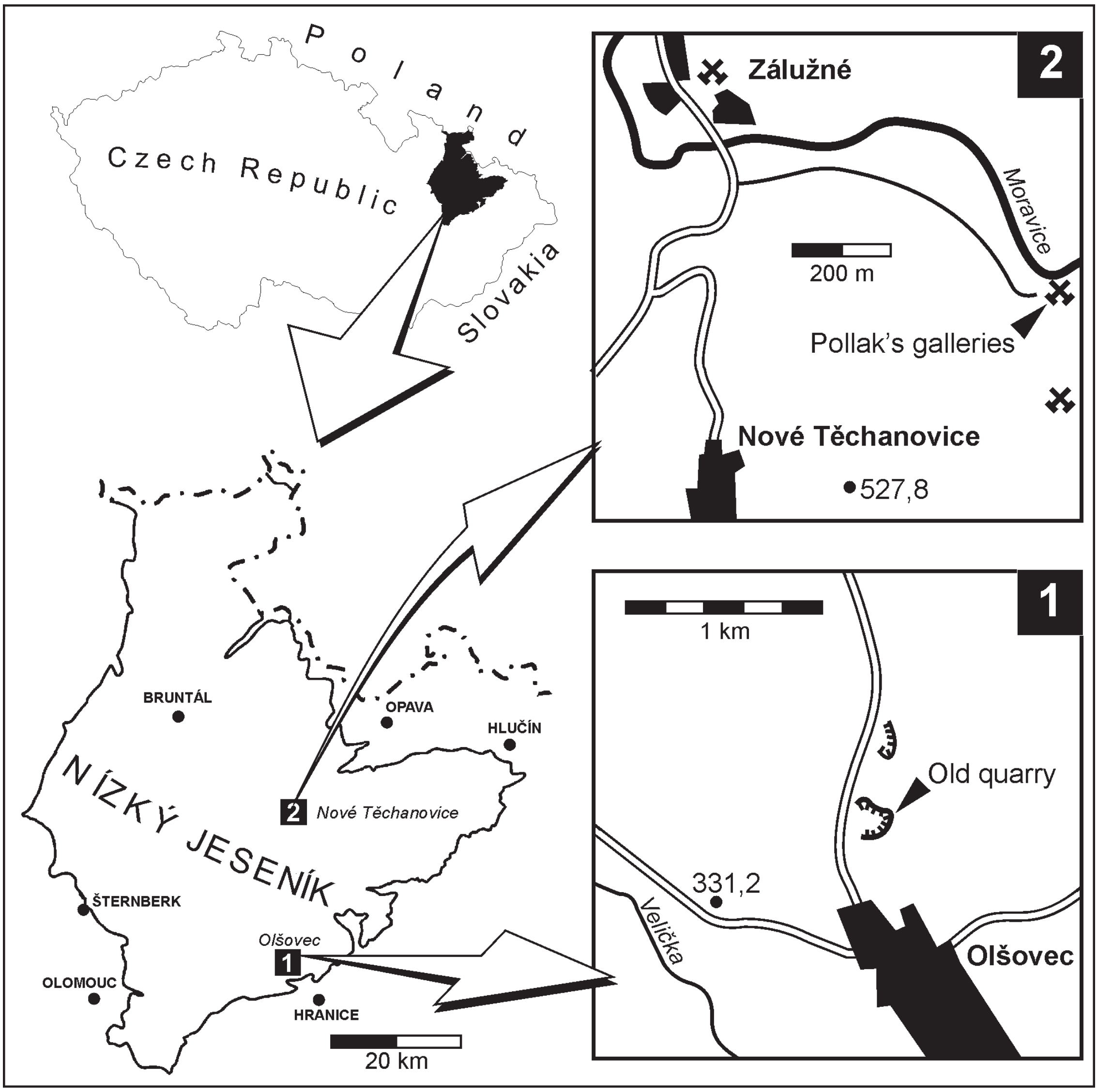


**Fig. 1.** Location map.

Specific features of the Culm facies, that extremely complicate identification and interpretation of the ichnofabrics, resulted from anchimetamorphic processes which made some subtle laminae virtually invisible and, on the other hand, formed new laminae along bedding planes and cleavage planes. The statement of Uchman (1999) that "in some layers the contrast is so low, that the layer seems to be structureless" applies for the whole Culm facies. The "readability" of the structures is further reduced by vertical and oblique synaeresis cracks filled with clay minerals. Finally, strong lithification of the rock also complicates the study, as it is very complicated to impossible to prepare polished sections in the field.

For the purpose of this paper, we distinguish a "**mottled zone**", that is a conspicuously spotted rock, and a "**homogeneous layer**", that is fully homogeneous rock which became non-laminated probably through the effect of bioturbation. In the "List of ichnofabrics" below, we describe individual layers and tiers as distinctive ichnofabrics, because a complete set of tiers can be observed only exceptionally. The studied material includes outcrops and vertical polished sections usually 3–15 cm thick which thereby involve one to several turbidite sequences. Numerous vertically cut samples can be provided from the waste dump of the former "roofing slate" works at the Nové Těchanovice-Pollak's galleries. They represent a majority of the illustrated samples. Commonly, the outcrops do not enable study of the ichnofabric except the "elite" *Rhizocorallium* Ichnofabric, because the rock disintegrates along cleavage planes.

## List of ichnofabrics

*Homogeneous layers*
Figs. 2A, 2C, 3I

**Description:** Silt- and clay-dominated rocks without lamination (though we would expect the lamination considering the rock composition and turbidite character of the sedi-

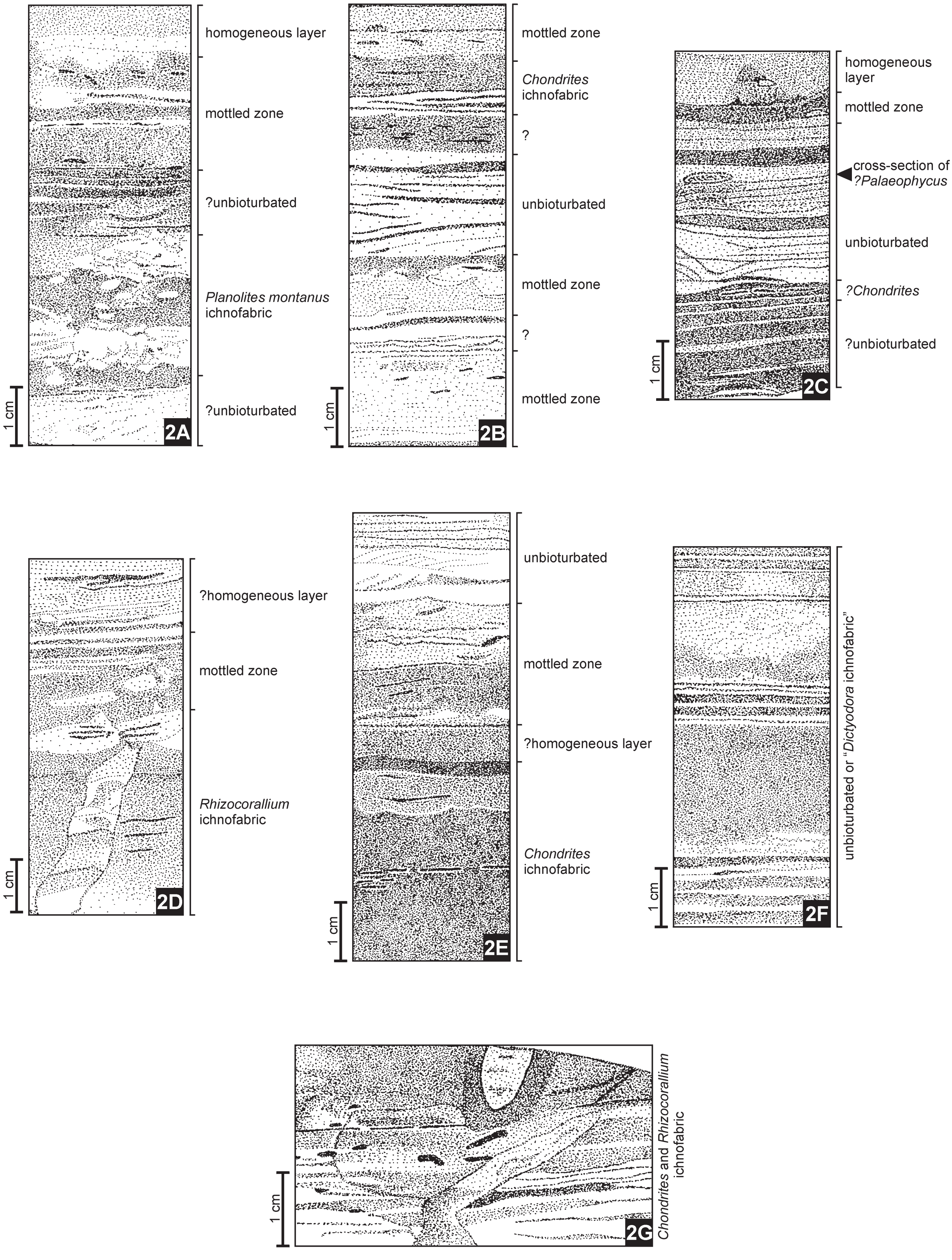


**Fig. 2.** Interpretative drawings of vertical sections of "roofing slate"; Nové Těchanovice-Pollakovy štoly (Nové Těchanovice-Pollak's galleries) locality. Scale bar = 1 cm.

ments). Ichnofabric index (ii; cf. Droser & Bottjer 1986) = 6. These layers are often difficult to distinguish from primarily non-laminated layers. The rock appears to be homogeneous in both vertical and horizontal polished sections. These layers occur either in the uppermost parts of turbiditic beds, or at the top of a sequence of turbidite-hemipelagite beds.

**Vertical extent:** Up to 1 cm, on top of turbidite beds.

**Occurrence:** Very rare at both Nové Těchanovice and Olšovec localities. Absent in most of the observed sequences.

**Relations:** The totally bioturbated rock (ii = 6) is often cut by *Chondrites*, which represents a subsequent colonizer. This produced a conspicuous visual effect. As such, this pattern is described separately within the *Chondrites* Ichnofabric. The reworked zone is occasionally intersected by *Rhizocorallium* isp. and *Arenicolites* isp. which represent the "elite traces" of the Culm facies.

*Ichnofabric of the mottled zone*

Figs. 2A, 2B, 2C, 2D, 2E, 3A, 3B, 3E, 3F, 3H, 3I

**Description:** Silt- and clay-dominated substrates with partially preserved lamination or non-laminated, showing "spots", which can be interpreted as cross-sections of tunnels of *Planolites montanus* or *Chondrites* isp. The former are light, 0.5 to 2 mm in diameter, and the latter are dark, flattened, probably actively filled (cf. Fu 1991 and Uchman 1999). The tunnels ascribed to *P. montanus* are usually filled with greywacke material, and are less deformed because the greywacke mass was less compacted during the diagenesis. Ichnofabric index = 3–6.

**Vertical extent:** 1–2 cm, in the uppermost parts of turbidite beds, occasionally below homogeneous layers.

**Occurrence:** The corresponding interval is observed at one-third to one-half of the turbiditic beds representing a transition between laminites and greywacke part.

**Relations:** Mottled zone is occasionally cut by *Rhizocorallium* isp. or *Arenicolites* isp.

*Planolites montanus ichnofabric*

Figs. 2A, 3E

**Description:** The *Planolites montanus* ichnofabric is a specific case of the mottled zone. Clay- or silt-dominated substrates to greywackes show relics of primary lamination, with "spots" attributable to cross sections of tunnels of *Planolites montanus*. The tunnels are usually filled with greywacke material. Their diameter is close to 2 mm and overall flattening of the tunnels is relatively low. Ichnofabric index = 3–4.

**Vertical extent:** 1–2 cm in sequences representing rapid alternation of clay and greywacke material.

**Occurrence:** Rare, found at the Nové Těchanovice locality.

**Relations:** Because of the rarity of the ichnofabric, no notable relationships to other ichnofabrics were observed.

*Chondrites ichnofabric*

Figs. 2B, 2E, 2G, 3C, 3F, 3G, 3I

**Description:** The *Chondrites* ichnofabric is another specific case of the mottled zone. It appears as clay- to silt-dominated sediments or rarely greywackes, with or without discernible lamination, visually dominated by dark, flattened "spots" which can be best interpreted as cross-sections of *Chondrites* isp. The spots are a maximum of 0.5 mm in height and several millimetres wide; tunnels sometimes look like thin primary laminae when cut by a plane oblique to subparallel to their axes. Ichnofabric index = 2, if lamination is discernible, or ii = 6, if developed in totally reworked background. These two situations are usually difficult to distinguish.

**Vertical extent:** 1–2 cm, in upper part of greywacke beds or thin beds of silt-sized sediment.

**Occurrence:** Approximately one-third of the studied turbidite sequences bear the *Chondrites* Ichnofabric.

**Relations:** The *Chondrites* Ichnofabric sometimes forms gradual transitions to reworked or mottled zone. Occasionally, it is intersected by *Rhizocorallium* isp. or *Arenicolites* isp.

*Rhizocorallium ichnofabric*

Figs. 2D, 2G, 3H

**Description:** Clay- and silt-dominated sediments or greywacke substrates with discernible lamination or, less frequently, with previous bioturbation, containing spreite or tunnels of *Rhizocorallium* isp. or *Arenicolites* isp. Commonest ichnofabric index = 2.

**Vertical extent:** Usually 3–6 cm.

**Occurrence:** The occurrence of *Arenicolites* and *Rhizocorallium* in densities higher than representing isolated individuals is rare (about 1 % of the studied samples).

**Relations:** *Rhizocorallium* isp. or *Arenicolites* isp. were observed to crosscut any of the above described ichnofabrics, as they represent elite traces of the Culm facies.

*Dictyodora ichnofabric*

Figs. 2F, 3D

**Description:** Clay- to silt-dominated sediments showing a conspicuous, virtually undisturbed lamination. Ichnofabric index = 1. Bedding-plane partings, however, show typical sinuous lines having slightly different colour and/or differently orientated clasts of mica; these are generally interpreted as horizontal cross-sections of the ichnogenus *Dictyodora* (e.g. Pek 1986). Even samples rich in clearly visible horizontal "aspect" of *Dictyodora* were several times observed to be virtually unbioturbated in vertical sections. This can be explained by anchimetamorphic processes (e.g. shear-type displacement of clasts in the direction parallel to lamination); as a result, the disturbance of primary lamination by the *Dictyodora* tracemaker was subsequently obliterated.

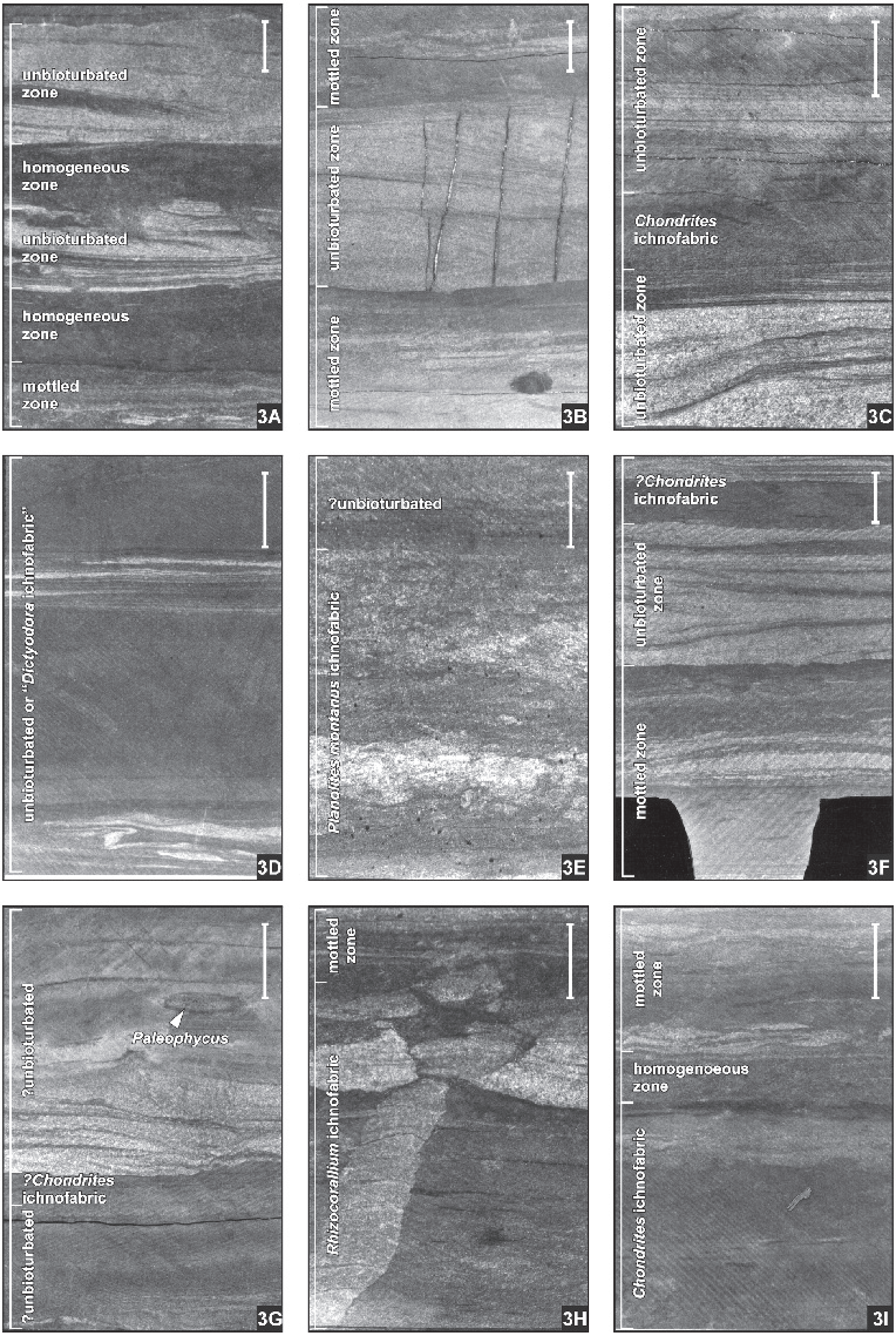


**Fig. 3.** Examples of ichnofabrics in vertical cross-sections from the Culm from the locality of Nové Těchanovice-Pollak's galleries. Scale bar = 1 cm. Fig. 3B corresponds to the drawing on Fig. 2F; 3E = 2A; 3F = 2B; 3G = 2C; 3H = 2D.

**Occurrence:** Relatively frequent in laminites (several per cent of laminites at Nové Těchanovice locality show *Dictyodora* isp. on bedding planes).

**Relations:** *Dictyodora* is most often the only preserved bioturbation structure.

*Unbioturbated layers*

Figs. 2F, 3A, 3B, 3C, 3D, 3F, 3G

**Description:** Greywackes, siltstones and claystones showing undisturbed lamination and no ichnologic features on bedding planes. Ichnofabric index = 1.

**Vertical extent:** Usually several centimetres in the described facies (i.e. transition between laminites and greywackes), depending on the thickness of the turbidite sequence.

**Occurrence:** More than 50 % of samples from the studied localities.

## Conclusions — Sedimentological and paleoenvironmental consequences

Compared to the Rheno-Danubian (Uchman 1999) and to the Carpathian Cretaceous to Eocene flysch (Uchman 1998), the degree of bioturbation of the Culm facies is very low (Fig. 4). Ichnofabrics in deep-sea Paleozoic deposits have not been studied yet, which makes the comparison of the Culm facies to other Paleozoic flysches very problematic. Numerous papers, however, deal with discernible trace fossils collected from Paleozoic deep-sea sediments. Crimes & Crossley (1991) described a very diverse ichnoassemblage from the Silurian flysch of Wales (Aberystwyth area). Besides graphoglyptids, the ichnoassemblage also contains effective bioturbators such as *Planolites* and *Nereites*. Similarly, Clark & Chamberlain (1973) described diverse deep-sea traces from the Paleozoic Oquirrah Basin of central Utah. Pickerill et al. (1988) reported on Late Ordovician-Early Silurian flysch of the Matapedia Group (Canada) and discovered a rich ichnoassemblage showing numerous elements common to the Culm facies (e.g. *Dictyodora*). Therefore, we may presume that the Moravian-Silesian Culm facies are rather less bioturbated than several other deep-sea deposits of the Paleozoic. However, we have to stress that the diversity of ichnoassemblage or density of trace fossils on bedding planes does not necessarily mean a high degree of bioturbation.

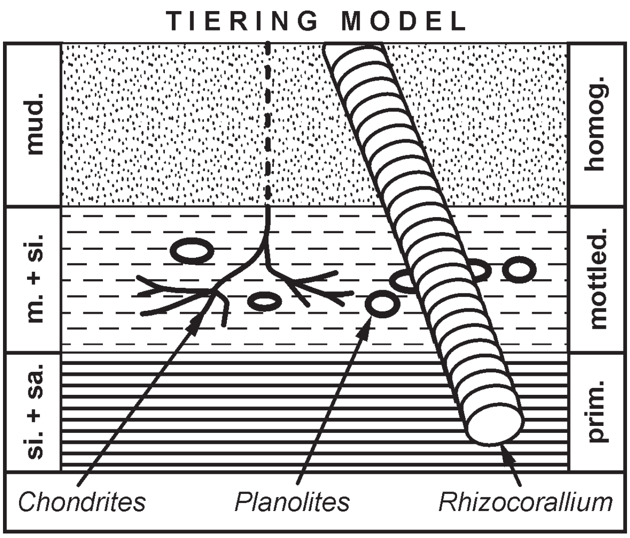


**Fig. 4.** Tiering model for the Culm facies. mud. — mudstones; m. + si. — mudstones + siltstones; si. + sa. — siltstones, sandstones, greywackes; prim. — primary lamination; homog. — homogeneous.

The reasons for a low degree of bioturbation compared to the Mesozoic and Cenozioc flysches may be as follows:

1. Much older age of the Culm facies; invertebrates had not colonized all deep-sea substrates, dysoxic and/or current-exposed settings yet or the depth of bioturbation was low (cf. Bottjer & Droser 1992). This possible explanation should be tested by ichnofabric studies of other Paleozoic flysch sequences, especially those rich in trace fossils.

2. Extreme dynamics of the Culm facies, resulting in shorter and unequally distributed (both spatially and temporally) colonization windows, may be a reason for low bioturbation of some parts of the Culm facies. However, as the recruitment of deep-sea fauna takes several years at maximum (Uchman *pers. commun.* 2002), we cannot presume that the frequency of depositional events was generally higher in all the Culm facies.

3. Low oxygen content. The level of nutrients both in the turbidites and in the background sediment can be presumed relatively high, as the sediments are dark. The problem of oxygenation is commonly applied for dark facies (cf. Mikuláš 1992 and references therein). Layers homogenized by sediment-feeders (cf. Bromley 1996) are rare; nevertheless, feeding on sediment seems to be the most important factor of the overall bioturbation (*Planolites montanus*). Burrows of filter-feeders are rare. The relatively most frequent group falls to the category of opportunistic, complex feeding strategies, which may include chemosymbiosis and gardening (*Chondrites, Dictyodora*; cf. Mikuláš 1997 and references therein).

4. Constraints resulting from metamorphism. No special study dealing with effect of various degrees of metamorphism on preservation of trace fossils have been published yet, but we may presume that the anchimetamorphic processes have reduced both the spectrum of trace fossils visible on bedding planes and the "readability" of subtle ichnofabric features.

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