Ordovician of the Barrandian area: Reconstruction of the sedimentary basin, its benthic communities and ichnoassemblages

Ordovik Barrandienu: rekonstrukce sedimentární pánve, benthických společenstev a ichnospolečenstev (Czech summary)

(*11 text-figs.*)

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Reconstruction of the development of the Barrandian area during the Ordovician (presented in a form of a series of block-diagrams) enables us to presume: 1, there is a different pattern of development of body fossil assemblages compared to ichnoassemblages; 2, the linear sedimentary basin went through a stepwise change into an open marginal sea; 3, main mechanisms of sedimentation changed in a time (e.g., increase of tempestites towards the end of the Ordovician); 4, the clastic material had been transported mostly from the North in the Late Ordovician; 5, the hitherto published conclusions on the palaeogeography of the Prague basin during the Ordovician do not show substantial inconsistencies if translated into a series of linked three-dimensional models.

Key words: Ordovician, Czech Republic, Barrandian area, palaeogeography, benthic assemblages, trace fossils

Introduction

One of the peculiar features of the Ordovician of the Barrandian area consists in a joint occurrence of rich ichnoassemblages and benthic shelly fauna. As a direct comparison of ichnofossils and benthic macrofossils has been rarely published, I have done an attempt to syntethise the trace- and body-fossil data from the Barrandian Ordovician (Mikuláš 1997b and a paper in progress). To compare the trace fossil assemblages to the benthic communities, I have decided to use as „graphic" palaeogeographical background as possible, i.e. a series of three-dimensional block-diagrams showing the development of the Prague basin.

The already published data and some new observations and interpretations have been used for the construction of the block-diagrams. Obviously, some features of the presented reconstructions remain speculative. Degree of the uncertainty increases from the Early Ordovician to the Late Ordovician, because the preserved horizontal extent of the younger sediments is limited and therefore there is the lack of the information on the presumed shoreline and/or the most shallow-water facies.

Regardless the orginal sense of the block-diagrams was to demonstrate joint occurrences of particular body- and trace fossils assemblages, their construction have brought my attention to regional problems. The aim of this contribution, therefore, is to present the reconstruction with the focus of the regional geological interest.

Geological settings

Several referative papers providing a brief or thorough information on the geological settings of the Barrandian Ordovician have been published recently (e.g., Chlupáč 1988, 1993, Havlíček 1992b, Havlíček – Fatka 1992, Štorch et al. 1993, Mikuláš 1993a, Fatka et al. 1995). Within the framework of the Barrandian (Late Proterozoic to Middle Devonian) sedimentary basins, the Prague basin had originated at the beginning of the Ordovician as a linear depression produced by a disruption of the pre-Palaeozoic basement. Later the basin became much broader. The continuous sedimentation terminated there in the Middle Devonian. The stratigraphy and rock composition of the Ordovician of the Prague basin are shown on Fig. 1.

Descriptive part

The block-diagrams represent the area between Rokycany in the south-west and Úvaly in the north-east (Fig. 2).

The depicted sedimentary and volcanic bodies are shown, if possible, to the scale of the diagrams. The individual patterns (depicting, e.g., sandy bottom, or sandy to muddy sediments of deltas) are adapted to suggest presumed main directions of transport, daily or storm wave activity, currents, slumping etc.

The symbols of benthic assemblages are explained on Fig. 3. When possible, names of the benthic communities are put to the diagrams; trace fossil symbols have always given the ichnogeneric names.

Lower Tremadocian

Fig. 4

Main sources of the information: Havlíček (1981, 1992b) – the course of the shoreline, synsedimentary tectonics and volcanism; Havlíček (1971, 1992a) – presumed extent of the Cambrian sediments; Štorch (1992) – extent of the Late Cambrian volcanism; Kukal (1963) – sedimentological data; Havlíček (1982) – benthic assemblages; Mikuláš (1993b) – ichnofossils.

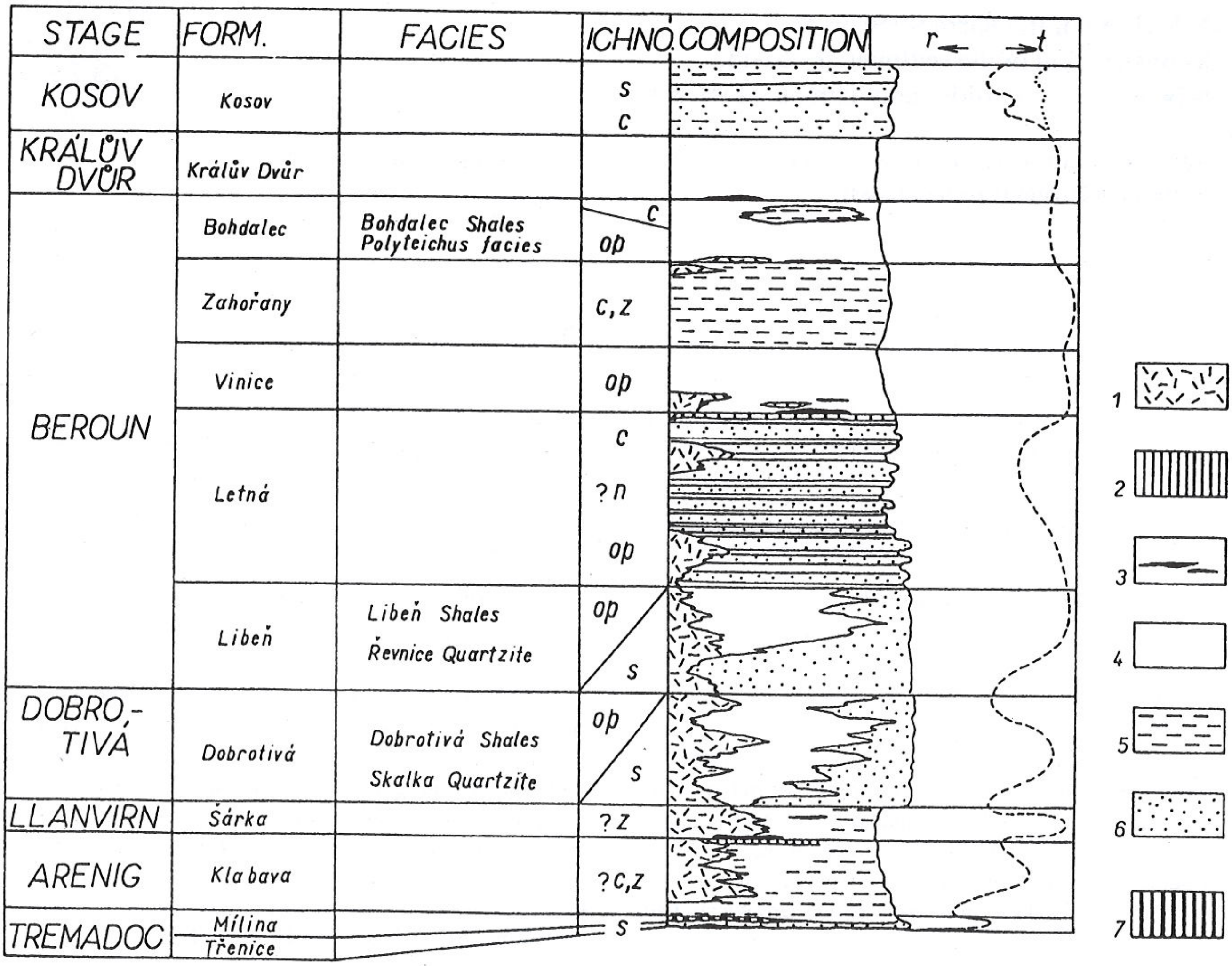

Fig. 1. Schematic stratigraphic section and succession in the Ordovician of the Barrandian area. The thickness ranges from several hundred to 2 500 m. After Mikuláš (1993a) who used data by Havlíček (1977), Chlupáč – Kukal (1988), and Štorch (1986).
ICHNO. – ichnofacies; S – Skolithos, c – Cruziana, z – Zoophycos, n – Nereites, op – oxygen-poor conditions assemblages.
Sea level changes: r – regression, t – transgression; *stroked line* adapted after Chlupáč and Kukal (1988), *dotted line* after Štorch (1986).
Rock composition: *1* – diabase tuff, diabase; *2* – variegated tuff and tuffite; *3* – oolitic iron ore; *4* – clayey shale; *5* – siltstone and silty shale; *6* – sandstone, greywacke; *7* – cherts.

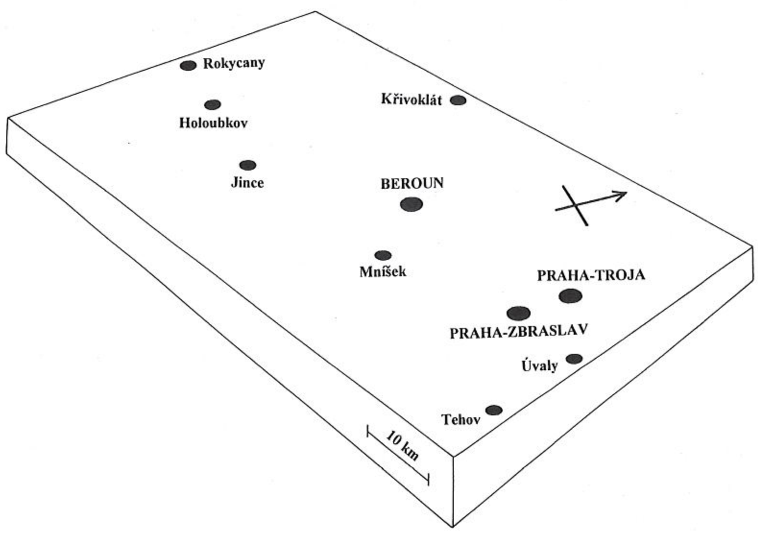

Fig. 2. Extent of the area presented by the block-diagrams.

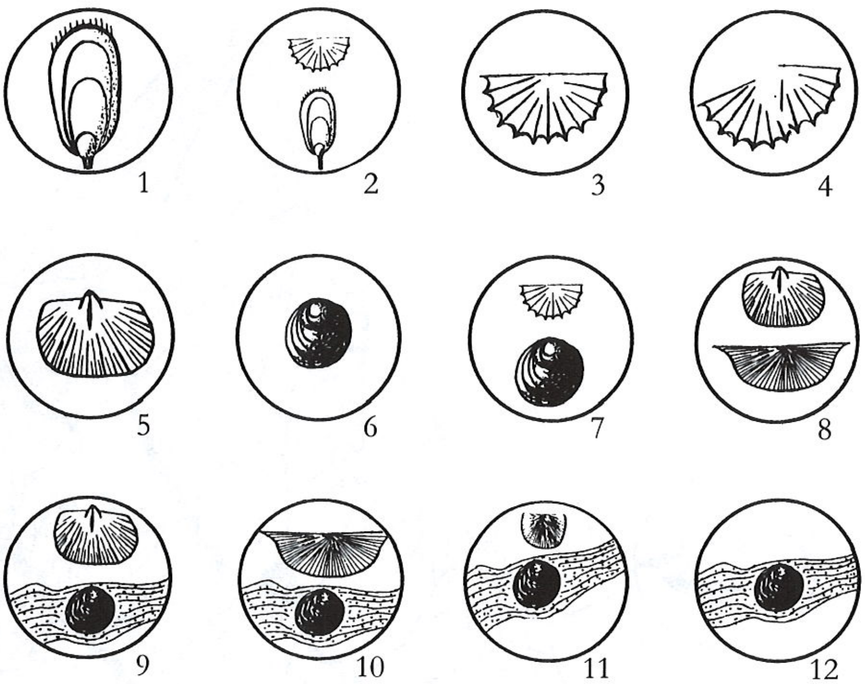

Fig. 3. Explanation of brachiopod benthic assemblages symbols.
1 – Benthic Assemblage (B.A.) 1; *2* – B.A. 1–2; *3* – B.A. 2; *4* – B.A. 2 (damaged specimens); *5* – B.A. 3 (articulate brachiopods prevail); *6* – B.A. 3 (inarticulate brachiopods prevail); *7* – B.A. 2–3; *8* – B.A. 3–4 (the *Drabovia–Aegiromena* fauna); *9* – B.A. 3–5; *10* – B.A. 4–6; *11* – B.A. 5–6 (articulate brachiopods present); *12* – B.A. 5–6 (inarticulate *Paterula* communities).

Description of the model: The Lower Tremadocian sediments (represented by the Třenice Formation) originated after a break in the marine sedimentation in the Upper Cambrian. The horizontal, probably mostly moderately lithified Lower and Middle Cambrian sediments (left below), moderately folded Late Proterozoic sedimentary and volcanosedimentary rocks (above right), and Upper Cambrian, partly still active volcanic belts (above) represented a geological background for an origin of the new sedimentary basin [the Prague basin according to Havlíček (1981)]. The basin originated as a narrow, tectonically controlled depression bordered by conspicuous elevations. Most of the sedimentary content of the basin can be attributed to alluvial fans and fanglomerates, represented by polymictic fine-grained conglomerates passing to coarse-grained greywackes. The grain composition reflects the local source of products of weathering. In places, variegated fine-grained sandstones suggest to represent short belts of sandy shores outside the fans, modelled by a daily waving. In the eastern part of the basin, quartzose sandstones represent larger and more presistent sandy shores (right below), and intercalations of dark grey shales rarely with graptolites (right) suggest a deepening of the basin to the East. Lens of haematite indicates a locally suppressed influx of the coarse-grained material and resulting chemogenetic sedimentation in lagoonary settings (left).

The coarse-grained layers and lenses yielded in places attributable to a surface of alluvial fans and fanglomerates the *Hyperobolus feistmanteli* Community which may be correlated with Benthic Assemblage 1 of the Boucot's (1975) classification. One locality only has provided a trace fossil assemblage, consisting of unusually thick-lined *Bergaueria* and rare *Skolithos*.

Also the sandstones contain in places similar, inarticulate brachiopod benthic assemblages. The local lagoonar settings with chemogenic iron ore sedimentation at Holoubkov provided much more diversified brachiopod, cystoid, and trilobite assemblage, attributable to Benthic Assemblage 1–2. These sediments have yielded no trace fossils so far.

Arenigian
Fig. 5

Main sources of the information: Havlíček (1981, 1992b): the course of the shoreline, synsedimentary tectonics, volcanism; general distribution, thickness and extent of main lithofacies; Havlíček (1971, 1992): pre-Ordovician geology of the area; Kukal (1959): sedimentological data; Havlíček (1982): benthic assemblages; Mergl (1983) – zoopalaeontological data; Mikuláš (1995a, 1996) – ichnology.

Description of the model: After a short period of a chemogenetical, lagoonary sedimentation in the Upper Tremadocian, the basin extended in the Arenigian. Stepwise transgression, tectonic and volcanic activity had provided very variable sedimentary settings represented by the Klabava Formation. The palaeogeographical backround had changed by a general lowering of the landscape elevations, with the exception of the south-eastern shoreline where the new tectonical elevation zone had originated. The basin had been prolonged to the west, and a new, at present rudimentaly preserved trench had opened in southwest. The basin was differentiated to narrow, longitudinal segments, forming the deep depression in the central part. In the central to western-central part, a new, effusive and pyroclastic basaltic complex had originated, copying a direction of older (Late Proterozoic) tectonical structures.

The central depression of the basin had been filled mostly by a clay material locally with increased share of

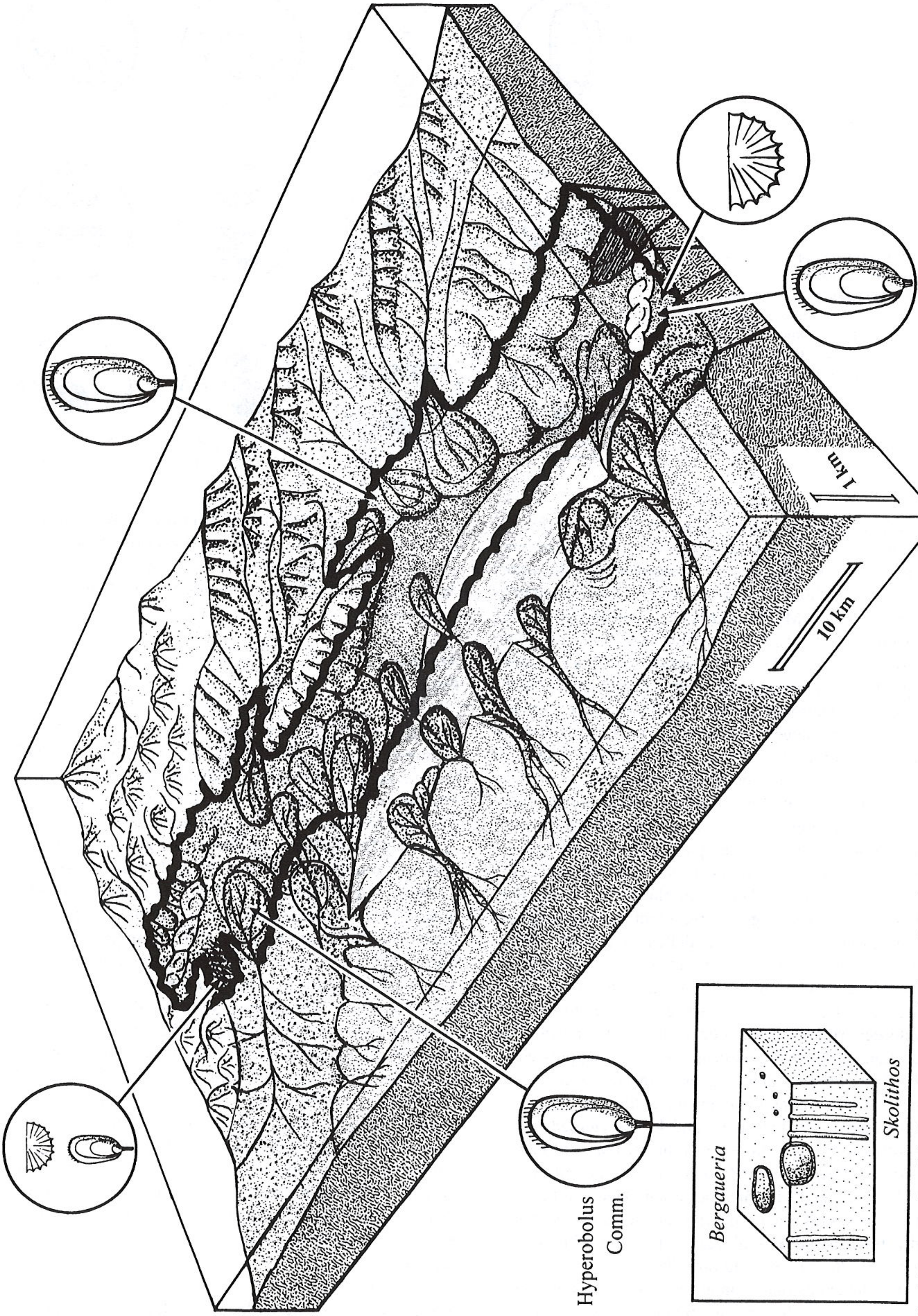

Fig. 4. Reconstruction of the Barrandian area in the Lower Tremadocian.

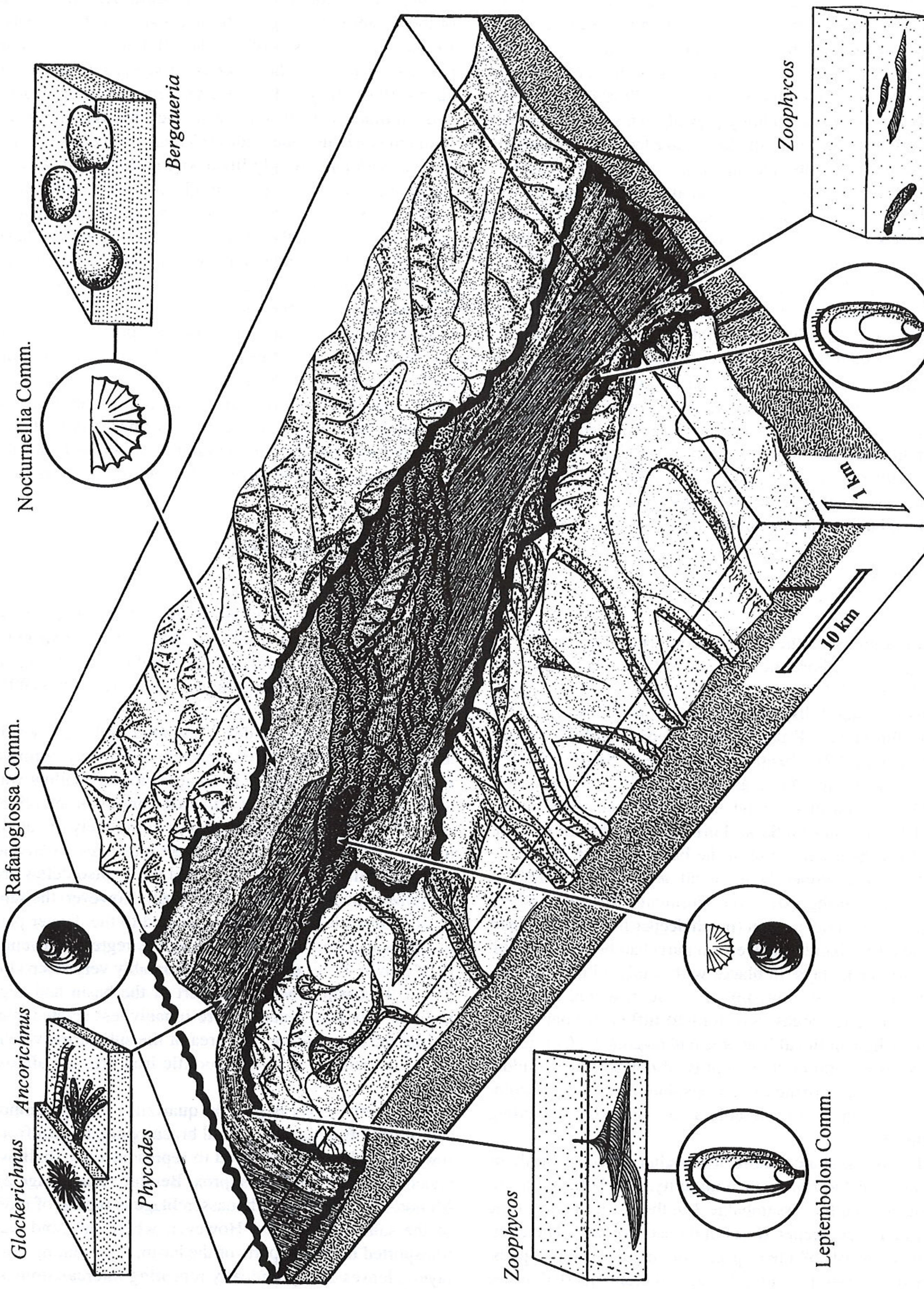

Fig. 5. Reconstruction of the Barrandian area in the Arenigian.

coarser-grained terrigenous detritus and/or tuffaceous admixture. The low-diversified benthic assemblage consists of small obolids and several trilobite taxa (the *Rafanoglossa* Community), representing presumably Benthic Assemblage 3. Trace fossils are very common in places. Variable subsurface fodinichnia (e.g. *Phycodes, Glockerichnus, Ancorichnus*) higly prevail. In a spatial connection with the volcanism, shallow-water facies (i.e. tidal flats and more often subtidal plains) had a substrate of reworked tuffs. This setting hosted an almost monospecific orthid brachiopod *Nocturnellia nocturna* Community (Benthic Assemblage 2), which is in places joint with dense assemblages of unlined *Bergaueria*. Other peripheral parts of the basin are mostly occupied by red greywackes and shales, which provide a *Leptembolon insons* Community (Benthic Assembalge 1 to 2). The red sediments yielded in few localities poorly diversified ichnoassemblages of *Zoophycos* and *Planolites*. The debris cones resulting from the rising zones provided no ichnofossils. Elevations of pyroclastics had provided timely and spatially limited suitable conditions for a development of more diversified orthid and inarticulate brachiopod, trilobite and gastropod assemblages (Benthic Assemblage 2 to 3), but no trace fossils have been found there.

Llanvirnian

Fig. 6

Main sources of the information: Havlíček (1992b) – course of the shoreline in the western part of the basin; Havlíček (1982, 1992b) – synsedimentary tectonics, volcanism, general distribution, extent and thickness of the main lithofacies; Kukal (1962) – sedimentological data; Havlíček (1982) – benthic assemblages; Šnajdr (1957) – illaenid trilobites; Mikuláš (1991, 1993b) – ichnofossils.

Description of the model: The sedimentation during the Llanvirnian (the Šárka Formation) had been influenced by further extension of the basin after a transgressive event. Consequently, the local detritus represented no more a prevailing part of the sediments. The rapidly deepening central depression (much deeper in the eastern part of the basin than in the western part) had been filled with grey to black clays, in places with sandy admixture. The marginal parts are in many places represented by more-or-less isolated areas with limited influx of coarser detritus, where oolitical iron ores had originated. Clastic flat shores were limited to a vicinity of deltas (upper middle part of the reconstruction). The submarine volcanic complex had kept a considerable area, somewhat extending to the east.

The black shale lithofacies is characterized in all its area by the *Euorthisina* Community. It is believed to inhabit the Benthic Assembalge 3 in the western part of the basin but also deeper zones in the eastern part. The community consists of a few species of articulate brachiopods, very diversified presumably vagrant elements (trilobites, ostracods, gastropods, bivalves, hyolithids) and inarticulate brachiopods *Paterula* and *Palaeoglossa*. The difference in depth between the western and the eastern part is suggested also by a study of illaenid trilobites: those of the western part [e.g., *Ectillaenus katzeri* (Barr.)] have well developed eyes, whereas the trilobites of the eastern part are blind [e.g., *Ectillaenus sarkaensis* (Novak)] or have very small eyes. From the western part of the described lithofacies, well-preserved trace fossils have been found in siliceous concretions (*Chondrites, Palaeophycus, Rhizocorallium*, strongly lined *Arenicolites*, and *Brdichnus*). The last-named trace might represent uppermost parts (i.e. openings of vertical shafts) of extraordinarily large *Zoophycos*. In the eastern part, the concretions have not yielded this ichnoassemblage; instead, *Spirophycus* and *?Urohelminthoida* joined with common *Chondrites* have been found in the shales.

The oolitical iron ores are very poor in fossils and ichnofossils. Only fragments of inarticulate brachiopods, indicating the Benthic Assemblage 1 to 2, numerous *Planolites* and *Bergaueria* in the basal part of the iron ore lens, have been found. The deltaic or linear sandy shores provided no macrofossils; common ichnofossils are represented by *Helminthopsis, Asterichnus*, and *Didymaulichnus*.

Dobrotivian („Llandeillian“)

Fig. 7

Main sources of the information: Havlíček (1982) – benthic assemblages; Havlíček (1992b) – general distribution, thickness and extent of main lithofacies, volcanism; Kukal (1957) – sedimentological data; Mikuláš (1991, 1993b) – ichnofossils.

Description of the model: Compared to the Llanvirnian, the Dobrotivian Stage (represented by the Dobrotivá Formation) differs mainly in composition of shallow-water facies. The Dobrotivá Formation consists in marginal parts of the basin from most part or completely of supermature, medium-grained quartzose sandstones. Tidal and subtidal plains, sandy barriers, and partly also deltas are presumed environments of their origin. However, the sandy sedimentation had often prograded to the deeper part of the basin, either as a result of eustatic regressive events, or of gravity flows effective in presumably very steep slopes of the basin. The central part of the basin had kept the dark clay sedimentation, presumably less aerated than during the Llanvirnian. The area of the submarine volcanism had decreased, and the oolitic iron ores are almost lacking.

The shelly fauna is poor in quartzites, being composed of only fragmentary orthid brachiopods known from few sites, which are believed to represent truly shallow-water (subtidal) settings (approx. Benthic Assemblage 2). Monotonous *Skolithos* ichnoassemblage is typical of most of the sandy lithofacies. However, where the sand was transported to deeper parts of the basin, representing only layers, lenses or rhythmically repeating intercalations in the black shales, the ichnofossil content is different. In the western part, presumably shallower, the rhythmical

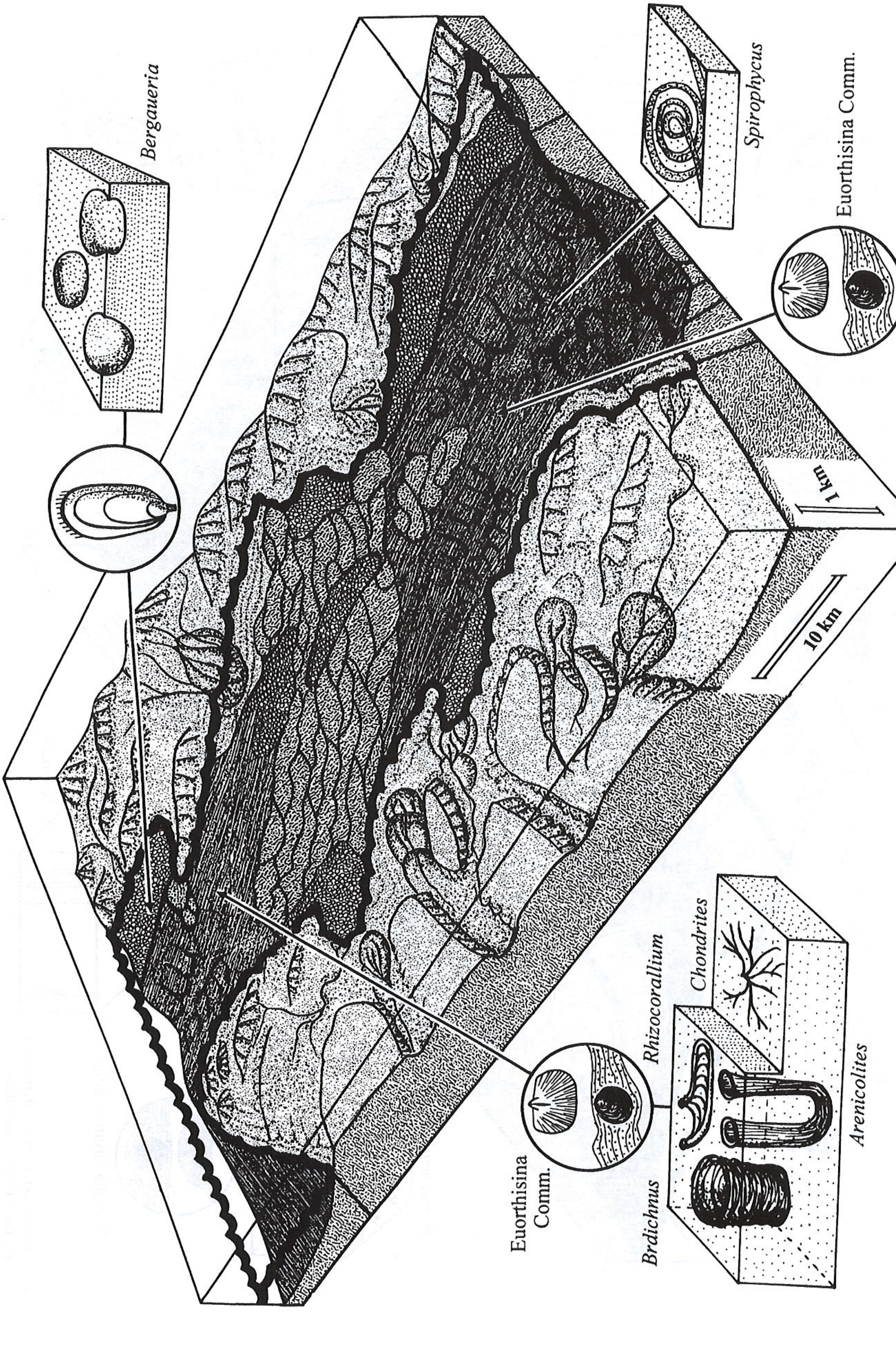

Fig. 6. Reconstruction of the Barrandian area in the Llanvirnian.

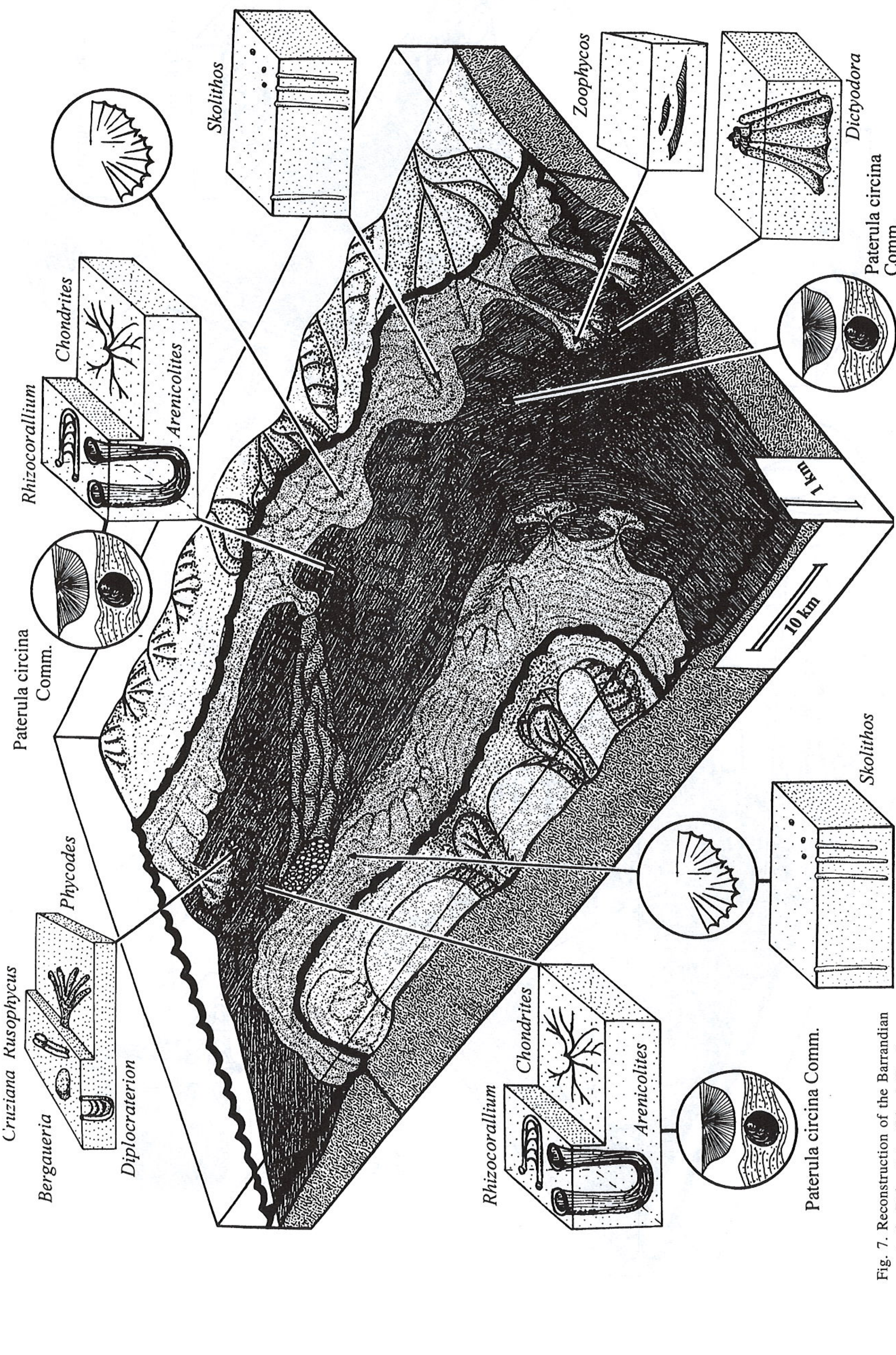

Fig. 7. Reconstruction of the Barrandian area in the Dobrotivian (Llandeillian).

layers have *Phycodes*, *Diplocraterion*, *Cruziana* and *Rusophycus*. In the eastern part of the basin, the lithologically comparable rocks yielded locally dense assemblage of *Dictyodora*, and mixed sediments of clays and sands immediately above the layers with *Dictyodora* have common *Zoophycos*.

In the black shales, the shelly fauna is represented by the *Paterula circina* Community, which is believed to cover with only minor changes the Benthic Assemblages 3 to 6. There are relatively diverse assemblages in the western part of the basin. The brachiopods are dominated with small inarticulates and two strophomenids (*Benignites* and *Brandysia*), strongly diversified trilobites are common in places. Gastropods, molluscs, hyolithids, carpoids and crinoids are also locally common. Towards the eastern part, the fauna is less frequent and presumably planktonic forms (graptolites, conulariids, phyllocarids) are more common. Trace fossils are known from siliceous concretions of the western and central part (*Chondrites*, thickly lined *Arenicolites*, *Palaeophycus*, *Rhizocorallium*) but similar concretions from the eastern parts have only *Chondrites*.

Lowermost Berounian („Lowermost Caradocian")
Fig. 8

Main sources of the information: Havlíček (1982) – benthic assemblages; Havlíček (1992b) – distribution, thickness and extent of main lithofacies; volcanism; Kukal (1957) – sedimentological data and interpretations; Chlupáč (1987) – ichnofossils; Mikuláš (1993a, 1997a) – ichnofossils.

Description of the model: Further extension of the basin is expected in the Lowermost Berounian, represented by the Libeň Formation. Configuration of main lithofacies had remained similar as in the Dobrotivian. The quartzose sandstones lithofacies represents linear sandy shorelines and deltas. Share of the sandy and clayey sediments changes substantially during the time, reflecting presumed eustatic events. Newly the rhythmical alternation of laminated sandstones and shales occupies a substantial part of the basin namely in its western part. It is believed to represent mostly tempestites, which are poorly recorded from the older formations. It is probably because the basin had gradually lost its isolation and became a part of an open marginal sea. Also a gradual flattening of the relief of the basin, caused rather by extremely rapid sedimentation (the Berounian sediments represent usually more than 50 % of thickness of all the Ordovician), increased the space modelled by storm waving but protected from daily waving; before, only the steep, tectonically active slopes occuppied the depths otherwise characteristic of the storm sedimentation.

The *Drabovia dux* Community with abundant articulate brachiopods and trilobites occupied only some (presumably deeper) parts of the sandy substrates including the presumed tempestites. It has been attributed to the Benthic Assemblage 3. The tempestites have rich ichnofossils in places (*Asteriacites*, *Diplocraterion*, *Planolites*). Tidal to shallow subtidal linear sandy shores have common *Skolithos*, and presumed deltas prograding to deeper parts of the basin, represented by irregular alternation of sandy and clay sediments, yielded also unusual trace fossil *Pragichnus*. Both the shelly fauna and the ichnofossils of the black shales are poor, represented by the *Paterula* Community (Benthic Assemblage 5 to 6) and by small *Chondrites*.

Lower to Middle Berounian
Fig. 9

Main sources of the information: Havlíček (1982) – benthic assembalges; Havlíček (1992b): synsedimentary tectonics, thickness of the sediments; Kukal (1958) – sedimentological data; Mikuláš (1993a, 1998) – ichnofossils.

Description of the model: In the central and eastern part of the basin, the Letná Formation is, by far, the thickest formation of the Barrandian Ordovician (locally more than 600 m). The main lithofacies consists of sandstones and subgreywackes intercalated with greywackes, siltstones, and clay shales. There are no typical features of turbidites in any part of the sequence, and boundaries in the rhythmically developed sections are often unsharp; therefore it has been usually argued for a mostly deltaic origin of the Letná Formation. However, sharply limited layers with prominent palaeolamination occur in most localities, too; they refer to a storm influence on the sedimentation. Sparse occurrences of black shales point to their origin below the storm wave base.

The strong influx of the mature terrestrial material by a river (or rivers) equalized more-or-less the before-existing bathymetrical differences in the basin. Only spatially and temporarily limited areas had been under an influence of prograding sandy shoreline. Otherwise there is no direct record of the shoreline facies. The terminal phase of the origin of the Letná Formation is joined with an origin of large lenticular bodies of oolitical iron ores. The area of the oolitical substrate put to the model shows this phase of development of the basin.

The *Drabovia redux* Community, referred to Benthic Assemblage 3, is limited mostly to the area with prevailing sandstones and subgreywackes; it is rich in orthid brachiopods and diversified dalmanitid, trinucleid, asaphid and calymenid trilobites; unusual are xiphosuran arthropods. This community is accompanied by a moderately diversified ichnoassemblage (e.g., *Phycodes*, *Arenicolites*, *Rosselia*).

In contradiction with the previous interpretations, the rhythmical sediments rich in ichnofossils but poor in shelly fauna are interpreted to be mostly deeper-water than the facies bearing the *Drabovia redux* Community. The rich ichnoassemblages, containing, e.g., *Cruziana*, *Rusophycus*, *Didymaulichnus*, *Fustiglyphus*, *Gyrochorte*, *Phycodes*, *Chondrites*, *Teichichnus*, *Squamodictyon*, correspond well with the „classical" *Cruziana* Ichnofacies typical of storm-influenced substrates. Some parts of the basin have much less diversified ichnoassemblages (dense

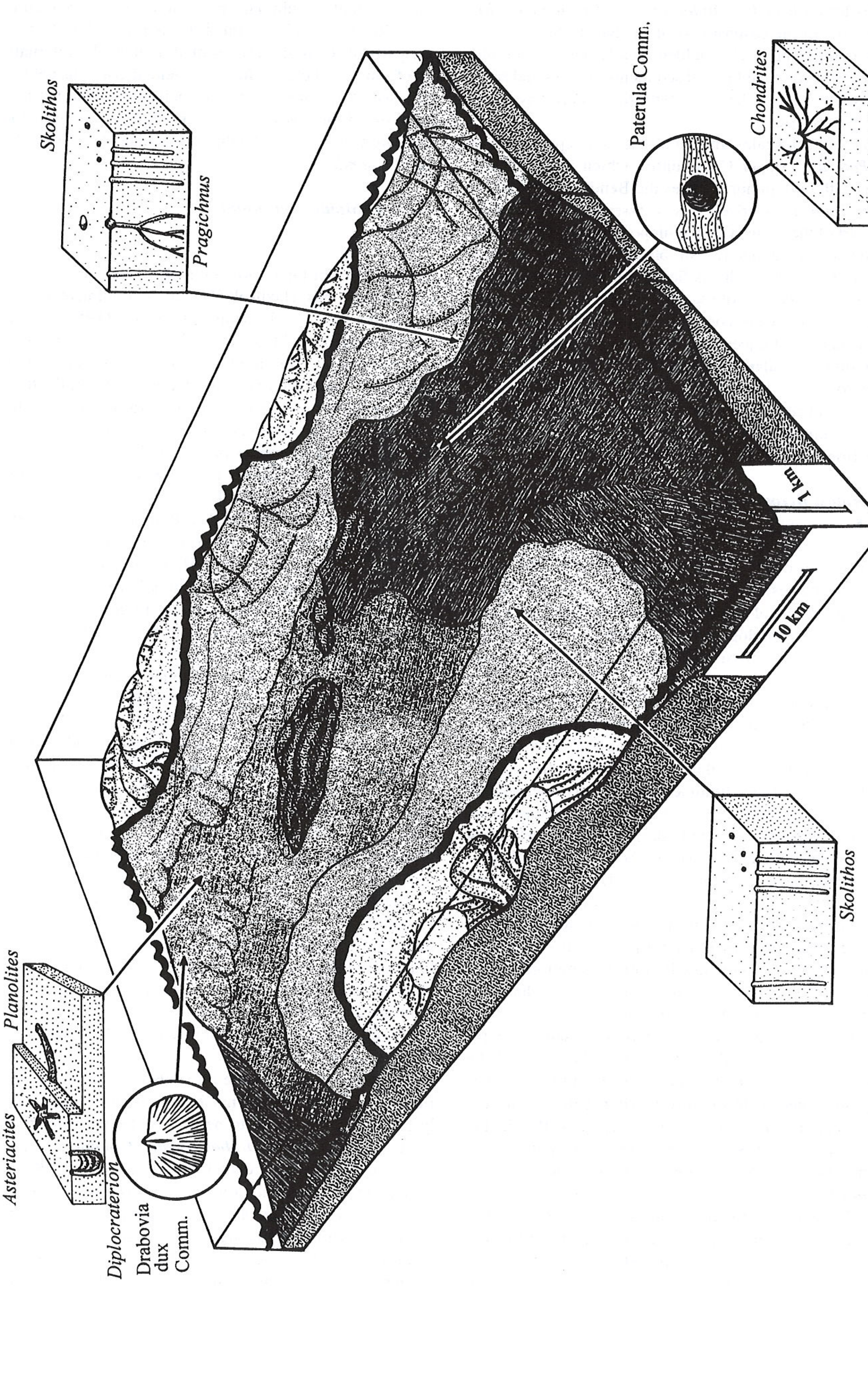

Fig. 8. Reconstruction of the Barrandian area in the Lowermost Berounian (Lowermost Caradocian).

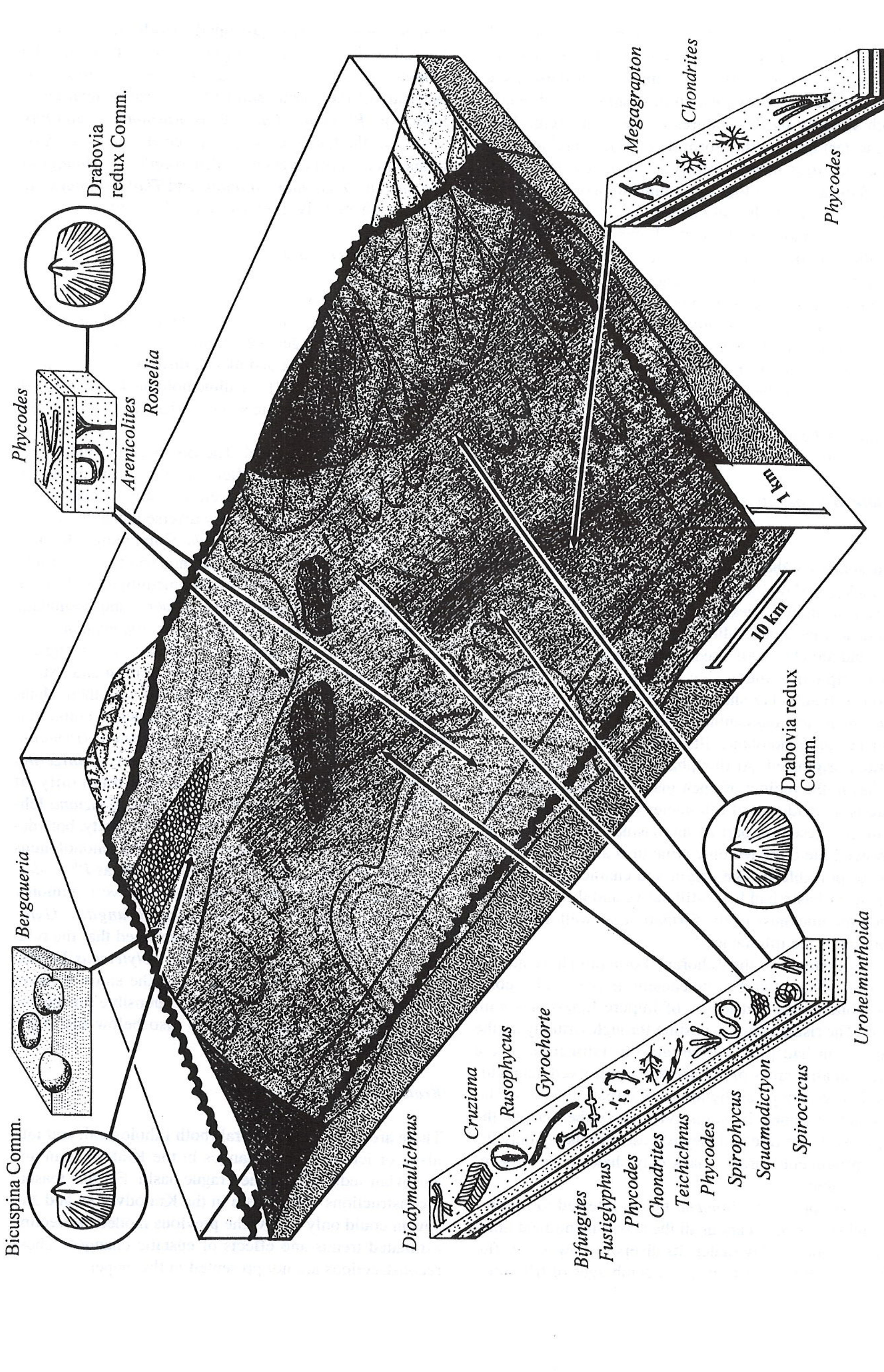

Fig. 9. Reconstruction of the Barrandian area in the Lower to Middle Berounian.

accumulation of *Chondrites*; *Megagrapton*, *Phycodes*), pointing to a periodical appearance of dysoxic conditions. It is, however, difficult to distinguish these facies from the presumed area which had had to be influenced much strongly by the features of the deltas (e.g., brackish water) than by the storm regime. It is probably that some localities having mostly *Chondrites*, *Planolites*, *Teichichnus* or few other opportunistic taxa might originated in the brackish water of the deltas.

The uppermost layers of the Letná Formation provided the benthic shelly fauna referred to the *Bicuspina* Community (Benthic Assemblage 3 to 4; diversified orthid brachiopods, locally common trilobites, frequent carpoids, less frequent cystoids, mollusks, and bryozoans). The fossiliferous strata are in places directly overlied by the Zdice–Nučice Iron Ore Horizon. Rhythmical layers close to the strata bearing the *Bicuspina* Community provided a dense assemblage of the ichnofossil *Bergaueria perata* at Zdice, i.e. at the type locality of this prominent ichnospecies.

Middle to Upper Berounian
Fig. 10

Main sources of the information: Havlíček (1982) – benthic assemblages; Havlíček (1992b) – synsedimentary tectonics, volcanism, and thickness of the sediments; Kukal (1960) – sedimentological data; Mikuláš (1992) – ichnofossils; Havlíček and Štorch (1990) – sedimentological data.

Description of the model: After a period of sedimentation of black clay shales with very poor *Chondrites–Tomaculum* ichnoassemblage (the Vinice Formation), a sequence of monotonous siltstones, i.e. the Zahořany Formation, originated. At this phase of the development of the basin, the regime of open marginal sea is presumed; there is no evidence of lithofacies joined with a shoreline in the preserved part of the basinal sedimentary fill. However, the older tectonic structures and volcanic centres, responsible for the origin and character of the former linear basin had been still active and they had influenced the thickness of the formation, as well as the distribution of the lithofacies.

The siltstones of the Zahořany Formation have always a certain share of carbonate cement, in places also common concretions and lenses of impure limestones with fauna. The rising zones persisting through virtually all the Ordovician had provided certain diversification of the space: smaller areas of the presently preserved denudation relict show typical rhythmical alternation of storm layers and siltstones. In a close vicinity of these areas, the storm layers are rare and they represent probably only the most prominent storms. Black clay shales have very reduced extent.

The *Drabovia–Aegiromena* fauna, referred to Benthic Assemblage 3–4, occurs in all the above-mentioned lithofacies except the clay shales. Its diversity, however, is fluctuating, and the most diverse assemblages of trilobites, brachiopods, bivalves, gastropods, hyolithids etc. fall to the rather shallow-water settings. On the other hand, the ichnofossils reflect very strongly the presence/absence or the share of the storm sediments. The rhythmical layers have, e.g., *Phycodes*, *Teichichnus*, *Rusophycus*, and *Phycosiphon*; the localities with reduced share of the palaeolaminated storm layers provided *Zoophycos*, *Bifungites*, *Teichichnus*, *Phycodes*, *Nereites*, and *Thalassinoides*; the siltstones have only *Zoophycos* and *Planolites*.

Uppermost Berounian
Fig. 11

Main sources of the information: Havlíček (1982, 1992b) – benthic assemblages, synsedimentary tectonics, volcanism, thickness of the sediments, distribution of main lithofacies; Kukal (1963) – sedimentological data; Röhlich (1957) – sedimentological data; Mikuláš (1988, 1989, 1995b) – ichnofossils.

Desciption of the model: The Bohdalec Formation, representing the Uppermost Berounian, consists mostly of grey clay shales. They, however, do not resemble typical anoxic facies, having a relatively diverse fauna; though refered by Havlíček to the *Paterula* Community (Benthic Assemblage 3–6), it contains common trilobites, cystoids, mollusks, gastropods, and strophomenidinid and orthid brachiopods. This lithofacies has a poor ichnoassemblage (*Chondrites*, *Palaeophycus*, *Planolites*, *Tomaculum*).

Compared to the Zahořany Formation, the rising zones had changed substantially their position and extent; however, the faunal assemblages joined with them changed a little only. There are several distinctive communities based on orthid brachiopods (*Drabovia* or *Hirnantia* Community of Benthic Assemblage 3–4; *Onnizetina* Community of B.A. 4; *Svobodaina* Community of B.A. 3), all of them accompanied by the „*Cruziana* Ichnofacies" traces of variable density and diversity, both dependant apparently on taphonomic regime (monotonous siltstones preserved mostly the inner traces as *Phycodes*; storm-generated rhythmical sediments have commonly *Cruziana*, *Rusophycus*, *Asteriacites*, *Bifungites*, *Gyrochorte*, *Monomorphichnus*). It is presumed that the related lithofacies (generally called the *Polyteichus* Facies) corresponds roughly to the extent of the storm influence; locally the gravity flows were responsible for the origin of coarse-grained substrates also below the storm wave base.

Kralodvorian and Kosovian

There are very limited lateral (both lithological, and faunistic or ichnological) changes in the Kralodvorian and Kosovian sediments of the Prague basin. For this reason, reconstructions of the basin in the Kralodvorian and Kosovian could only follow the previous models, reflecting estimated trends and effects of eustatic changes. These reconstructions are not presented in this paper.

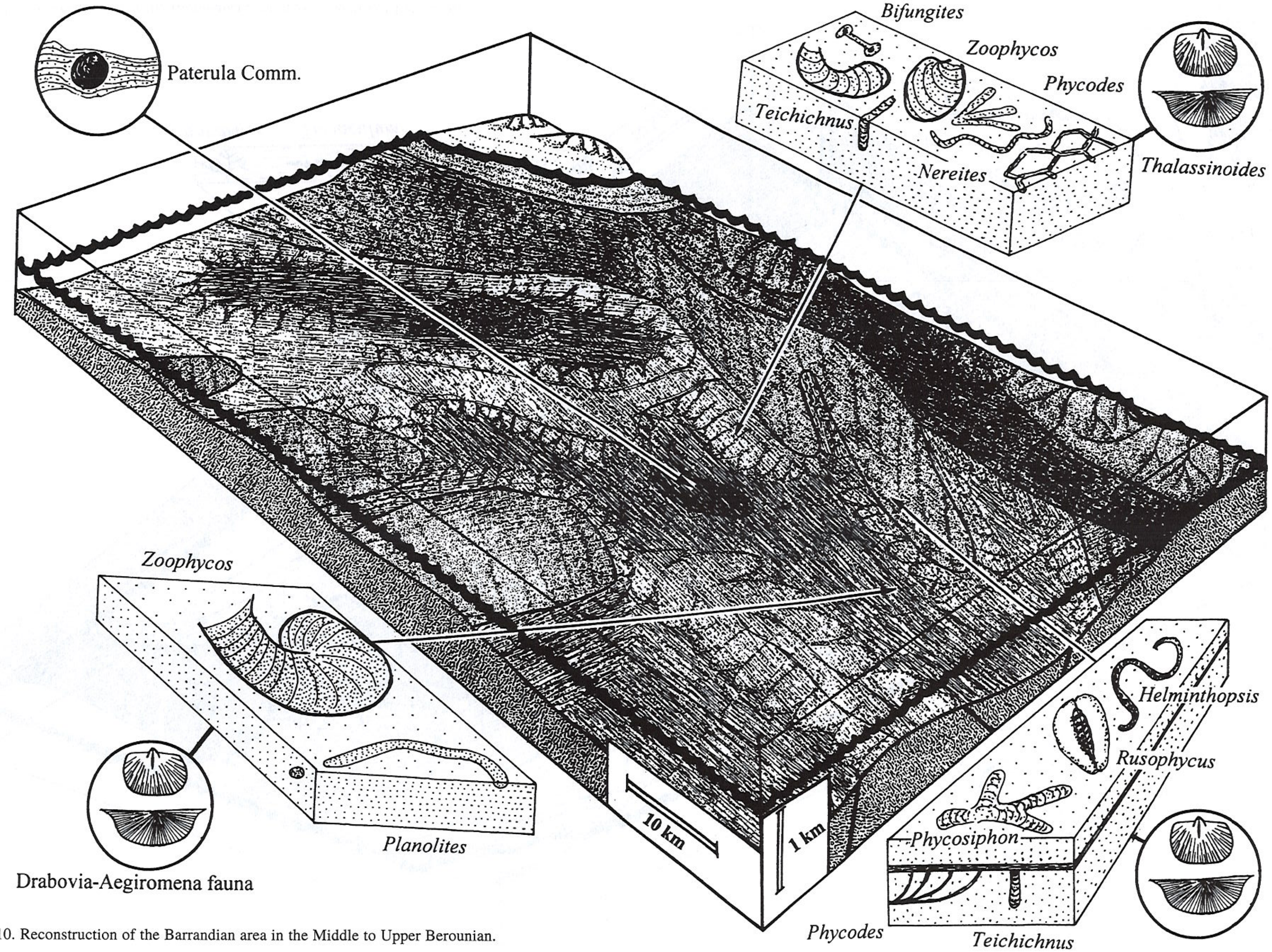

Fig. 10. Reconstruction of the Barrandian area in the Middle to Upper Berounian.

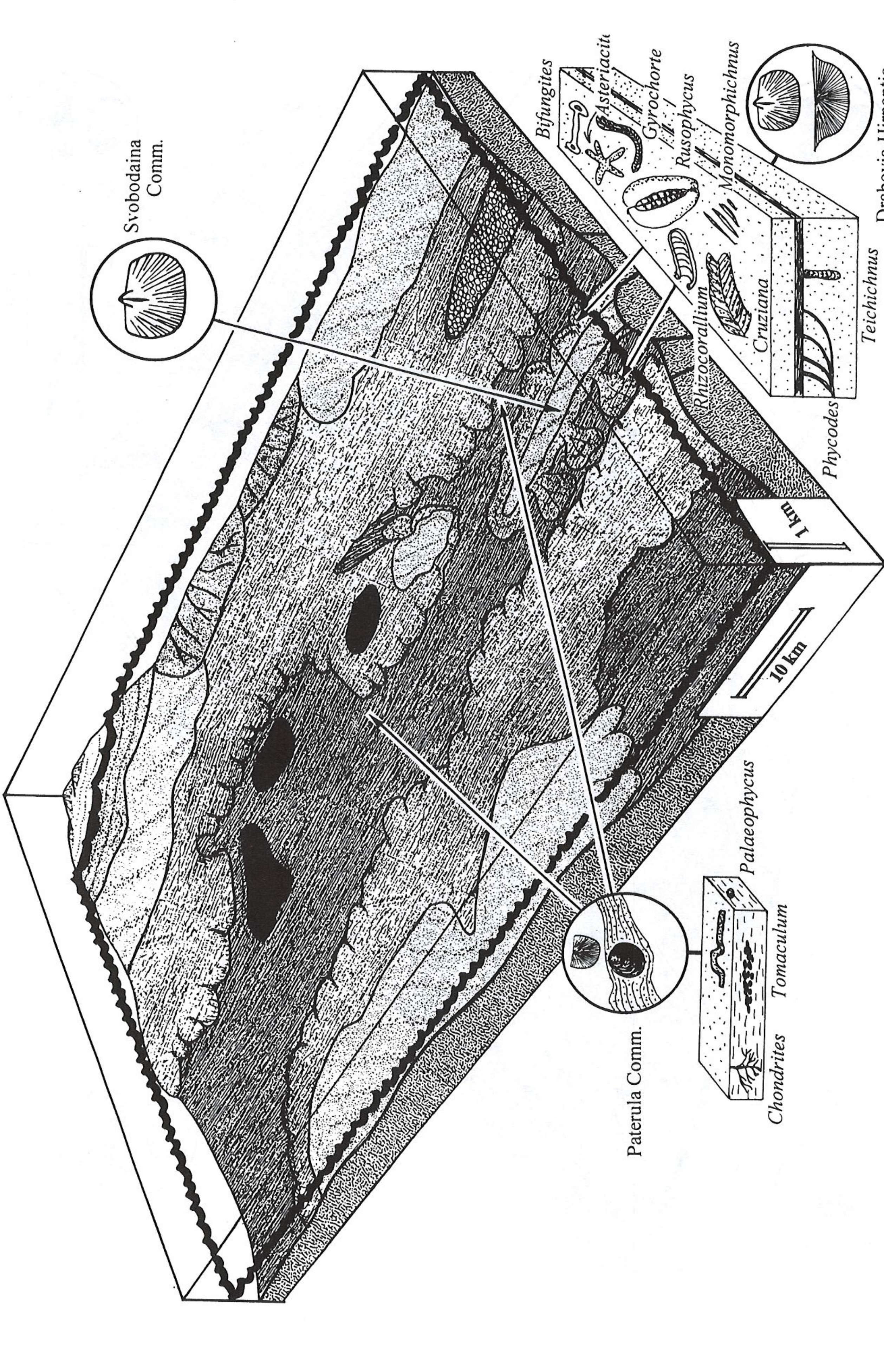

Fig. 11. Reconstruction of the Barrandian area in the Uppermost Berounian.

Trace fossils and presumed eustatic changes in the Ordovician of the Barrandian area

If we consider a detailed ichnogeneric composition of the ichnoassemblages in the Barrandian Ordovician and not merely their appurtenance to some of the recurring ichnofacies, a few of them are really observable to pass boundaries of the formations. These rare cases are rather trivial examples of *Skolithos* assemblages of sandy facies of the Dobrotivá and Libeň Formations, and the *Chondrites–Planolites* assemblages involved in most of the black shales. Most of the ichnofossils assemblages are limited to one member. For example, typical lobate forms of *Zoophycos*, showing a mass occurrence in many localities of the Zahořany Formation, have not been found in any other formation. Other occurrences of *Zoophycos* differ by a minor density of finds and by a morphology of the traces. Also the individual occurrences of the *Cruziana* Ichnofacies are mostly clearly distinguishable. In the Kosov Formation, *Cruziana* and *Rusophycus* are rare and they are represented only by small forms described formerly as *Isopodichnus*. However, *Asteriacites* is very common, as well as *Nereites*, *Neonereites*, *Fustiglyphus*, a.o. In the *Polyteichus* Facies of the Bohdalec Formation, large and quite common *Rusophycus* and *Cruziana* are accompanied, e.g., by *Asteriacites*; in the Letná Formation, these taxa occur altogether, e.g., with networks, as *Squamodictyon*.

Therefore, the above-mentioned facts point that the changes of ichnoassemblages and the responsible changes in environment (at least in the part of the Prague Basin defined by the present-day area of denudation relict of its sediments) were influenced more strongly by events of broader scale than by the local synsedimentary tectonics and volcanism. It should be, however, emphasized, that most of the boundaries of the formations are the prominent lithological boundaries, therefore, the changes of preservational potential of the traces are recorded altogether with the presumed patterns of the fossil behaviour. I have had a possibility to study a temporarily exposed Arenigian–Llanvirnian boundary (which is believed to represent an important transgressive event) at the locality Drahouš at Rokycany. At this site, there is a slight difference between the rock composition of the uppermost Arenigian and the lowermost Llanvirnian strata. Here the ichnological difference across the boundary is moderate only.

Events in the geological record of the Barrandian area were studied by Chlupáč and Kukal (1988), who recognized the following turning points of event character in the Ordovician of the Prague Basin: 1, the Tremadocian transgression; 2, the Llanvirnian transgression; 3, the suite of Middle Ordovician (Llandeilian–Lower Caradocian) transgressive and regressive events; 4, the Lower Caradocian transgressive event; 5, the basal Kosov event; and 6, the Ordovician–Silurian boundary transgressive event. Among them, the events ad 1, 2, 4, and 6 show a global character when compared with worldwide geological record (Chlupáč – Kukal 1988). Present-day authors (e.g., Schenck 1991) consider also the glacioeustatic regressive event at the base of the Kosov Stage to have a global character.

Changes of ichnoassemblages attached to these events in the Barrandian Ordovician are described below.

1. The Tremadocian transgression. The transgression enabled a local development of simple shallow-water ichnoassemblages after a long period of subaerial settings with no preserved sediments (the Tremadocian sediments overlie mostly the Upper Proterozoic strata with pronounced angular unconformity, partly in Middle Cambrian strata). Therefore, ichnological record of this event is highly subordinated with the overall geological record.

2. The Llanvirnian transgression. The Arenigian/Lanvirnian boundary has been studied in detail at the Drahouš locality (Kraft – Kraft 1993 – geology and zoopaleontology; Mikuláš 1994 – ichnology). Regardless the presumed global character, the changes observable in the profile are not very prominent and they seem be influenced also by a local event, i.e. sedimentation of a thin volcanoclastic layer. Changes of ichnological content at the Klabava Fm/Šárka Fm. (= near the Arenig–Llanvirn boundary) consist mostly in decrease of diversity of ichnotaxa and in diminution of intensity of bioturbation. Trace fossil assemblages in clay shales of uppermost part of Šárka Fm., compared with those from the Klabava Fm., do not differ much both in ethological spectrum of traces and in occurrence of individual ichnotaxa. Overall intensity of bioturbation is somewhat smaller in lower part of the Šárka Fm. than in uppermost layers of Klabava Fm., which might represent the developing dysoxia in the basin.

3. Llandeillian to Lower Caradocian transgressive and regressive events. These events are expressed by changes in proportions of the sandy (i.e. quartzose sandstones) and clay (i.e. blach shales) facies of the Dobrotivá and Libeň Formations. Most of the area of the basin has quartzose sandstones on the bases of both the formations, and the clay shales prevail in the upper parts. Therefore, we can recognize alternations of sandstones and shales at this area, each layer showing thickness approx. several tens of metres. According to Chlupáč and Kukal (1988), transgression caused anoxic regime in the centre of the basin. As the basin had been semi-isolated during the Llandeillian and Lower Caradocian, the anoxia is supposed to be augmented by the salinity or temperature stratification of water. During the regressions, the sandy sediments spread towards the central part of the basin as the prograded sandy shoreline. The ichnological record of these events is rather trivial, subordinated to the sedimentological record; the black clay shales locally with *Chondrites* alternate white quartzose sandstones with common *Skolithos*, in places *Diplocraterion* and *Pragichnus*. The last-mentioned ichnogenus is limited to the facies where the shales and the sandstones alternate in layers several decimetres thick (Mikuláš 1997a).

4. The Lower Caradocian trasngressive event. This event is expressed on all the area of the basin by termination of rhythmical, greywacke-shale sediments of the Letná Formation. These sediments are locally overlied by thick layers and lenses of oolitical iron ores, and then followed by black clay shales. Also in this case, the ichnological record of the event is subordinated to the lithological change. The rhythmical greywacke-shale sediments of the Letná Formation (Lower Caradocian) have common ichnofossil of the „classical“ *Cruziana* Ichnofacies. Before the oolitical sedimentation had occurred, a dense population of the *Bergaueria* tracemaker had developed at the locality Zdice (Prantl 1946). There is a clear analogy with the Arenigian–Llanvirnian boundary at the locality Ejpovice (Havlíček 1982, Mikuláš 1995a), where *Bregaueria* is abundant also below the iron ore lense. The oolitical lenses at the base of the Middle Caradocian (the Vinice Formation) have poor *Skolithos–Planolites* ichnoassemblage, the overlying black shales have normally no ichnofossils or bioturbation (locally *Tomaculum* and *Chondrites*).

The basal Kosov event and the Ordovician–Silurian transgressive event fall from the stratigraphical range of the studied sediments.

Discussion

The presented reconstructions are not an attempt to give a final answer to the questions of the palaeogeography of the Ordovician of the Barrandian area. However, I believe that their „vividity“ will make some persisting problems more intelligible; in this way, the knowledge involved in the recostructions will be more open to discussion and criticism.

The present-day knowledge of the Barrandian Ordovician is supported mostly by palaeontological data, and by a thorough geological mapping. A detailed sedimentological research was done in 50‘s and 60‘s by Z. Kukal; a new phase of the sedimentological investigations is just beginning. Determination of some sedimentary environments is complicated by the fact that the presence, share and character of tempestites has not yet been assessed in most of the formations. A lack of large outcrops (tens to hundred metres in size) is critical for a recognition of large slumps, channel fills, and other structures of a comparable size order.

Course of shoreline

The area of the „metamorphic islet zone“ on the Central Bohemian Pluton, lying at present (and probably also in the pre-Hercynian period) in a distance of a few dozens of kilometres SE from the Prague basin, had functioned undoubtedly as a sedimentary basin since the Ordovician (e.g., Chlupáč 1992). Therefore, the south-eastern shoreline of the Barrandian Upper Ordovician sea is expected to lie „beyond the islet zone basin“. But the extent of the islet zone basin to SE (i.e. to the present-day Moldanubian zone) is very uncertain. The elevated block of Cambrian sediments (approx. SE of the Hřebeny hills) had functioned as an island or a peninsula during the Early Ordovician; it was a source of a local clastic material. From the upper part of the Letná Formation, no lithological or palaeontological evidence indicates a substantial shallowing of the basin from its axis to SE.

A reconstruction of the NW shoreline of the basin is even more difficult. There are no Ordovician sediments in the NW neighbourhood of the preserved sedimentary fill of the basin. However, the NW remains the only direction of a probable strong influx of a clastic material from remote sources. The presumed existence of big rivers requires to presume also a correspondingly big landmass.

Sedimentary environments

For the reconstruction of the Lower Tremadocian (Fig. 4), episodic floods and a daily waving are presumed to be the main mechanisms of the transport and sedimentation (cp. Kukal 1963). The presence of the clay sediments in the eastern part of the basin (Havlíček 1992b) points to existence of deeper settings, which may fall to a zone usually dominated by tempestites. However, the tempestites have not yet been reported from the Třenice Formation.

As the sedimentary environments and mechanisms are concerned, the Letná Formation seems to remain problematic. Kukal (1963) presumed deltaic sediments and reported one sample interpreted by him as rill marks and he found an alteration of the grain-size in a suspension to cause the rhythmical character of the formation. However, there are substantial vertical and lateral changes of the ichnological record; many outcrops of the formation show a certain share of well-sorted, horizontally laminated sandstones to subgreywackes probably of a storm origin. I assume there were several mechanisms competing for the most influence in the Letná Formation; their extent, as depicted on Fig. 9, should be considered only approximate and speculative.

Acknowledgement. I thank The Royal Society, London, for a financial support of my stay at The University of Liverpool. I am obliged to Dr. T. P. Crimes, Dr. P. Brenchley (University of Liverpool), Prof. I. Chlupáč, Dr. O. Fatka (Charles University, Prague) and Dr. P. Štorch (Geological Institute, Academy of Science, Prague) for valuable comments.

Submitted October 21, 1997

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Ordovik Barrandienu: rekonstrukce sedimentární pánve, benthických společenstev a ichnospolečenstev

Rekonstrukce vývoje barrandienského sedimentačního prostoru během ordoviku (prezentovaná ve formě série blokdiagramů) umožňuje konstatovat, že: 1. změny společenstev benthické shelly-fauny a ichnofosilií jsou často nesoučasné, 2. pánev se postupně měnila z lineární deprese v otevřené okrajové moře, 3. hlavní mechanismy sedimentace se v čase zásadně měnily (např. podíl sedimentů přepracovaných bouřemi se postupně zvyšoval; vliv delt velkých řek byl maximální ve středním berounu), 4. ve svrchním ordoviku je nejpravděpodobnější přínos klastického materiálu od severu, 5. dosud publikované závěry o paleogeografii pražské pánve v ordoviku nejsou převedením do série trojrozměrných, navzájem na sebe navazujících modelů vystaveny závažným protikladům.