Sbor. geol. věd	Geologie 44	Pages 117—153	4 figs.	2 tabs.	9 pls.	Praha 1989 ISSN 0581-9172

Králodvor/Kosov boundary and the late Ordovician environmental changes in the Prague Basin (Barrandian area, Bohemia)

Hranice králodvor/kosov a změny prostředí ve svrchním ordoviku v pražské pánvi

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Received March 19, 1986

Štorch P. - Mergl M. (1989): Králodvor/Kosov boundary and the late Ordovician environmental changes in the Prague Basin (Barrandian area, Bohemia). — Sbor. geol. Věd, Geol., 44, *117—153*. Praha.

Abstract: Strong changes in facies and faunal assemblages at the Králodvor/Kosov boundary are described from the Prague Basin. This boundary as well as the whole sequence of the Kosov Series are influenced by large late Ordovician glaciation of Gondwanaland. We explain the changes in lithology and fossil biota by glacio-eustatic changes in sea-level and we try to use it for chronostratigraphic correlation. Sudden extinction of high-diversified, relatively deep-water Proboscisambon Community, succeeding Mucronaspis Community and pronounced change in lithology permit to correlate Králodvor/Kosov boundary interval with that of Anglo-Scandic Rawtheyan/Hirnantian boundary. This interval coresponds to the start of glacio-eustatic drop in sea-level and associated environmental changes. Overlying flysch-like sequence of the Kosov Formation deposited during further glacio-eustatic lowering of the sea-level. Regression culminated by deposition of thick banks of shallow-water clastics with monotonous bivalve fauna. The uppermost part of the Kosov Formation means starting transgression which also brought the rich Hirnantia fauna to the Prague Basin.

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Introduction

Global changes in lithology and fossil biota on the Ordovician/Silurian boundary recently have attracted attention of many geologists and paleontologists. The first symptom of such revolutional changes could be identified in the upper Ashgill and corresponds to the Králodvor/Kosov boundary in the Prague Basin. It is connected with strong changes in sedimentation and faunal assemblages.

The first sections through the boundary between the Králův Dvůr and Kosov Formations were described by Chlupáč (1951a, 1951b, 1953) and Marek (1952). Major attention has been paid to stratigraphy and faunal associations. The biostratigraphy and fauna were described by Havlíček - Vaněk (1966) in detail. Due to difficulties in stratigraphic correlation of the Mediterranean region (Spjeldnaes 1961) with the British standard scale, new chronostratigraphic units (Králův Dvůr Series and Kosov Series) were introduced by Havlíček - Marek (1973). Sedimentology of the uppermost Ordovician strata was studied by Bouček - Přibyl (1958) and Kukal (1961, 1963).

A new conception of the Prague Basin as a linear sedimentary depression was given by Havlíček (1981). According to him, gradual synsedimentary deformations of the basin during the Ordovician time control both the lithofacies and the distribution of benthic communities (Havlíček 1980, 1981, 1982). Pronounced change in sedimentation at the Králův Dvůr/Kosov boundary was explained in the same sense (Havlíček 1981). Both the change in sedimentation and extinction of shelly fauna and trilobites during this event was thought to be caused mostly by synsedimentary tectonic activity (Havlíček 1982). Also substantial shallowing of the basin during Kosov age has been explained by tectono-eustatic mechanism although the glacial influence had formerly been assumed (Havlíček 1974).

A new investigation in the uppermost Ordovician of the Prague Basin has been initiated by the worldwide discussion about the Ordovician/Silurian boundary and late Ordovician glaciation.

The present authors accepted Havlíček's (1980, 1981) model of linear sedimentary depression of the Prague Basin but they assumed the late Ordovician facies and faunal changes to have chiefly been controlled by glacio-eustatic causes. The authors are aware of the possibility of somewhat different explanation of these changes. However, the glacio-eustatic conception of the late Ordovician environmental changes presented by Berry - Boucot (1973), Brenchley (1984) and Brenchley - Newall (1984) best fits with the data from the upper Ordovician of the Prague Basin.

Glacio-eustatic environmental changes can be recognized on separate continents and plates (Berry - Boucot 1973). The resulting facies and faunal changes have often been precisely identified in the stratigraphical record (Berry - Boucot 1973, Brenchley - Newall 1980, Cooper 1980, Brenchley - Cocks 1982, Brenchley -

Cullen 1984) and could well be correlated with those recorded from the Prague Basin.

Sudden extinction of relatively deep water trilobite-ostracode assemblage with common brachiopods, cystoids and gastropods (topmost Králodvor Proboscisambon Community in the sense of Havlíček 1982 and Havlíček - Mergl 1982) is correlated in this paper with the extinction of trilobite-cystoid-gastropod faunas in the outer shelf conditions which is described by Brenchley (1984).

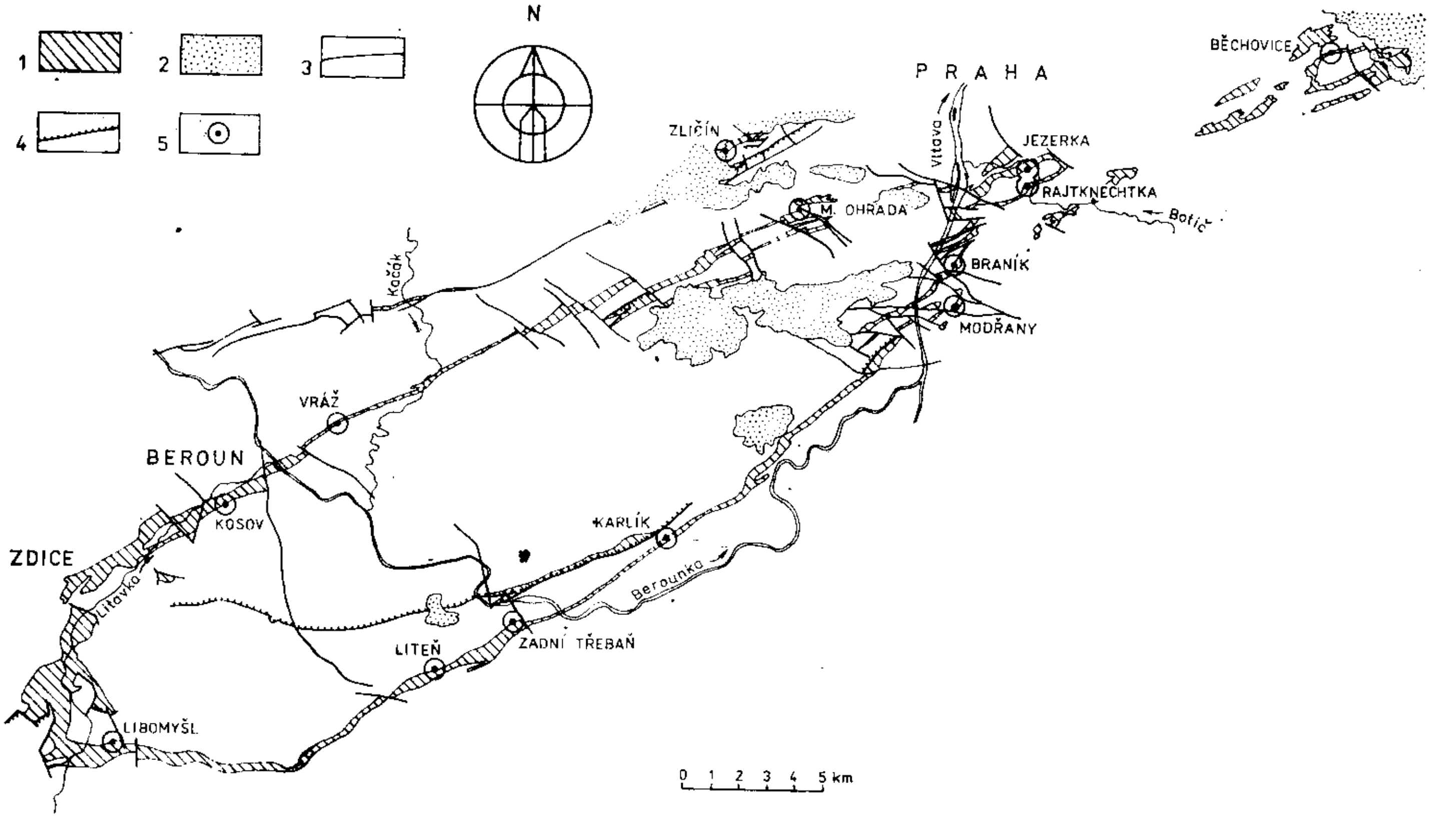
The drastic change in sedimentation at the Králodvor/Kosov boundary and regressive sequence of the Kosov Formation could well be compared with a sequence controlled by glacio-eustatic phenomena summarized by Brenchley - Newall (1984).

Recent correlation of the Králodvor and Kosov with the British standard stages proposes a synchronous nature of environmental changes caused by extensive late Ordovician glaciation (Beuf - Biju-Duval - Stevaux - Kulbicki 1966, Hambrey - Harland 1981) and related glacio-eustatic changes in sea-level (Berry - Boucot 1973). The accurate biostratigraphical correlation of the Králodvor and Kosov with the British standard scale is complicated by both scarce occurrence of graptolites and different composition of benthic assemblages.

In the Prague Basin, glacio-eustatic effect seems to coincide with the synsedimentary tectonic activity noted by Havlíček (1980, 1981, 1982) and Kukal (1961, 1963). The similar situation was described also by Brenchley - Cocks (1982) from the Oslo region. According to Brenchley - Cocks (1982), soon after beginning of the Hirnantian, there were radical changes in the palaeogeography, which were probably initiated by differential block movement within the region, but emphasized by the significant late Ordovician glacio-eustatic regression.

Thirteen sections were studied during the recent investigation. They are nearly regularly distributed around the whole Prague Basin (text-fig. 1). They cover the Králův Dvůr/Kosov boundary interval. The Králův Dvůr/Kosov boundary sequence is subdivided here into several informal lithostratigraphic units (levels A1, A2, A3, B1a, B1b, B2, C, D, E, F, G, H). All the levels are characterized by single type of sediment and corresponding faunal assemblage. All metric data in the description of the sections refer to distances above the first layer of coarse-grained subgraywacke at the base of the Kosov Formation (level D). This layer has been found at all the sections in nearly the same thickness and indicates a considerable change in sedimentation. It is considered to be synchronous and referring to the base of the Kosov Series.

Because of strongly similar character of all the sections, one ideal section summarizing all the measurements is being described in detail.



1. Location of the sections on sketch map of the outcrop area of Králův Dvůr Formation in the Prague Basin
1 — outcrops of the Královdvor sequence, *2* — post-Paleozoic platform sediments (Upper Cretaceous, Neogene), *3* — fault, *4* — overthrust, *5* — section

Individual levels are discussed in this ideal section. All the localities of the sections measured are only briefly commented.

This work forms a contribution to the International Geological Correlation Programme (IGCP), project no. 216 — BIO-EVENTS. We would like to thank M. Šnajdr who kindly gave us unpublished list of trilobites from the Královdvor/Kosov Boundary interval which completed our findings. We would like also to thank I. Chlupáč who kindly lent us upper Královdvor graptolites from Liteň, Zadní Třebaň and Velká Chuchle localities.

Localities

This chapter attempts to give a brief characterization of the localities. More complete data are presented in pl. 1, locations of the sections are depicted by text-fig. 1.

Malá Ohrada

Deep excavations about 300 m northeast of the Malá Ohrada exposed a large section through the uppermost Ordovician including Králův Dvůr/Kosov boundary interval. Due to tectonic disturbance it was impossible to study certain parts of the section (pl. 1). The topmost Králův Dvůr Fm. (level B2) yields many fossils. Some graptolites were collected in the level A1.

Zličín

Similar excavations 200 m southeast of the Zličín railway station exposed complete Králův Dvůr/Kosov boundary interval. The last Královdvor fossils (*Mucronaspis grandis* and some undetermined gastropods) have been found in nodular limestone bed near the top of the formation (level C). The main subgraywacke sequence (level F) yields numerous well rounded pebbles of sandstones and subangular pebbles of green shales.

Vráž

A highway cut on the northern slope of the Herinky hill between Vráž and Beroun shows another outcrop with Králův Dvůr/Kosov boundary interval. There are the two formations developed in a relatively small thickness. Richly fossiliferous level B1 is formed by brown-grey silty-clayey shale, probably decalcified (the typical B1b development). Level B2 is poorly developed.

Table 1

Percentage presence of brachiopods in samples JE-1 and VR-1 (Jezerka and Vráž localities)

species	JE-1	VR-1
"Lingula" incongrua Barrande	0.1	—
Acanthambonia sp.	0.1	—
Conotreta sp.	0.1	—
Orbiculoidea squamosa (Barrande)	1.5	—
Jezercia ostiaria Havlíček & Mergl	5.0	5.7
Ravozetina opima Havlíček & Mergl	0.5	14.4
Salopina slehoferi Havlíček & Mergl	0.5	1.5
Epitomyonia dorsicava Havlíček & Mergl	4.1	1.0
Cliftonia sp.	1.5	0.5
Aegironetes tristis (Barrande)	32.0	51.7
Kozlowskites regnari Sheehan	8.0	4.4
Anoptambonites moneta (Barrande)	17.0	17.7
Proboscisambon quaesitus (Barrande)	28.0	2.1
Leptaena cf. *rugosa* (Dalman)	1.4	0.5
Eoanastrophia sp.	0.1	0.5
Hindella sp.	0.1	—

Kosov

Nearly complete section through the Kosov Formation is exposed in a large abandoned quarry at the northern slope of Kosov hill, just above the cement works at Beroun - Králův Dvůr. The outcrop represents the type section of the Kosov Formation and the Kosov Series. Marek's (1952) description is used to draw the section through the Králův Dvůr/Kosov boundary (pl. 1). Great old collections of fossils from richly fossiliferous levels B1a, B1b, B2 and even C are deposited in the National Museum in Prague. At present the section is not well preserved and it is difficult to obtain additional fossils there. Nearly complete section of the Kosov Formation was briefly described by Bouček - Přibyl (1958) from this quarry.

Libomyšl

The westernmost section was exposed by a trench about 150 m north of gamekeeper's lodge east of Libomyšl. Just below the well developed fossiliferous level B1a grey silty shales with irregular disintegration have been recorded. A small part of the section is tectonically disturbed.

Liteň

The section is exposed in the railway cut about 1 km northeast of Liteň. The section figured on pl. 1 corresponds to that presented by

Chlupáč (1953). Graptolites both of Glyptograptus cf. teres Horizon and Climacograptus angustus Horizon are fairly common there. List of fossils was published by Chlupáč (1953).

Zadní Třebaň

The section exposed in a railway cut near a small railway bridge southwest of Zadní Třebaň, originally described by Chlupáč (1951b). The boundary interval appears to be nearly the same as in Liteň section except for the presence of muddy limestone of the level B1a.

Karlík

Steep southern slope about 600 m northeast of Karlík shows nearly complete section from the upper Bohdalec Formation up to the lowermost Silurian. The interval between the uppermost layers of Bohdalec Fm. through the complete Králův Dvůr Fm. and the lowermost Kosov Fm. was described by Chlupáč (1951b). The present section of boundary interval (pl. 1) was more precisely defined and slightly adapted to our purpose. A list of fossils from the fossiliferous layers corresponding to the present A1 and B1a levels was published by Chlupáč (1951b).

Modřany

A complete section through the Kosov Fm. including the lower boundary interval was exposed by large road excavations between the Lhotka housing estate and the Vltava River, about 100 m northwest of "Ke schodům" street. A distinct part of boundary sequence including the fossiliferous level B1b and basal Kosov subgraywacke (level D) repeat twice in the section due to the presence of a flat longitudinal fault. There are thin sandy intercalations present inside the level E in the Modřany section. Sparse trilobite fragments, bivalves and trace fossils *(Bifungites)* were recorded there in the lower part of the level E.

Braník

The outcrop in the road cut of "Údolní" street about 500 m southeast of Braník brewery shows another important section. There occurs only thin and poorly developed fossiliferous level B1b. Nevertheless, scarce fossil remains (trilobites, bivalves) and trace fossils were found throughout the whole level E. The main subgraywacke sequence (level F) consists of large number of mudflows mostly separated by thin clay lamines. Well developed slump layer recorded inside the sequence is figured in pl. II. The section continues up to a well exposed flysch-like sequence of the middle part of the Kosov Formation (level H).

Jezerka

The present section was exposed by a trench in the Jezerka park (district of Prague-Michle). The first description of the locality and of the highly diversified uppermost Králodvor faunal assemblage (level B1a) was given by Havlíček - Mergl (1982). Recently we have studied the complete section. Muddy limestone nodules yield rich and highly diversified fauna, nevertheless, the level B2 is much less fossiliferous and only weakly developed. Level E is characterized by increase of silty and sandy intercalations.

Rajtknechtka

The section was exposed by excavations 80 m southeast of former farmhouse Rajtknechtka (district of Prague-Michle). It differs from the Jezerka section in having less fossiliferous level B1a and not developed level B2.

Běchovice

Great part of the Králův Dvůr/Kosov boundary sequence (the strata between A2 and E levels) was exposed by a new road cut about 1200 m northeast of "Počernický" pond. Poorly fossiliferous level B1a is formed by a thin bed of nodular limestone. Several thin beds of similar limestone, but without fossils, are developed inside the lower part of the level C. The basal Kosov subgraywacke consists of four beds separated by several centimetres of clay shale. Levels F, G and H were exposed in large excavations on the elevation about 300 m northeast of the pond. Coarse-grained subgraywackes yield there a lot of pebbles of quartz, cherts, quartzites, sandstones, siltstones, green shales (upper Proterozoic ?) and weathered granitoid rocks.

Description of the ideal section

Králův Dvůr Formation

The total thickness of the Králův Dvůr Formation varies between 25 and 200 m (Havlíček 1981). It is mostly developed as grey or green clayey shales with silt admixture and contains low-diversified Rafanoglossa leiskowiensis Community (Havlíček 1982). Beyond the shelly fauna and trilobites, rare graptolites occur through the whole thickness of the formation.

Only the uppermost part of the Králův Dvůr Fm. is the subject of present sections. Most of the measured sections start from yellow-green clayey shales or claystones (text-fig. 2, level A1) with occassional limestone nodules (e.g. Zličín, Liteň, Zadní Třebaň and Braník, pl. 1). Beyond rare trilobites and brachiopods (Rafanoglossa leiskowiensis Community) fairly common graptolites occur in this layer (recorded from Zličín, Liteň, Zadní Třebaň, Malá Ohrada).

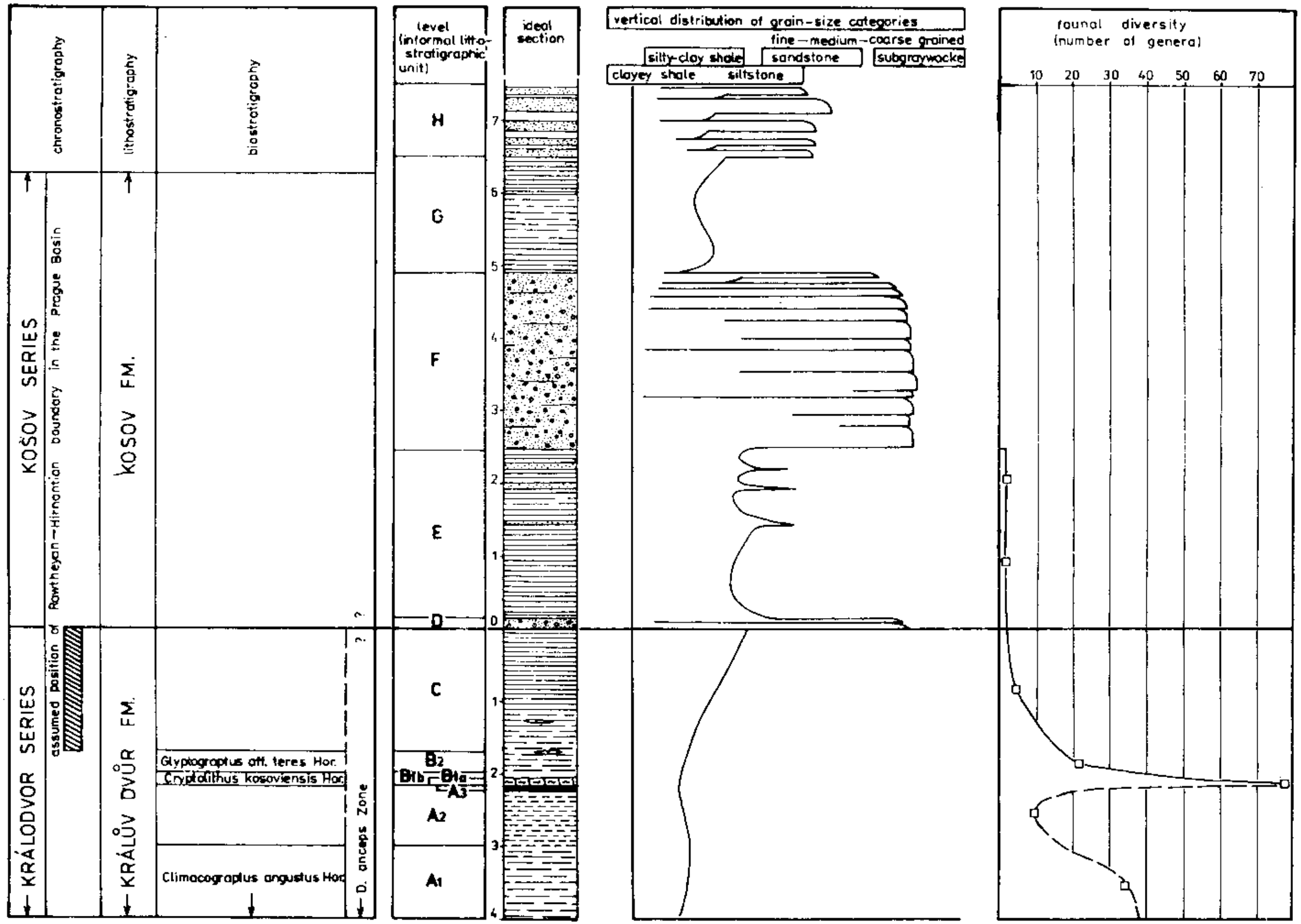
Subsequent 1—2 thick layer of dark-spotted bioturbated clayey shale of level A2 is commonly overlain by a thin (1—4 cm), dark blue-green tuffitic intercalation of the level A3 (text-fig. 2) which permitted a correlation between the sections of Malá Ohrada, Zličín, Vráž, Kosov, Zadní Třebaň and Karlík. The most prominent tuffitic intercalation was recorded at Zličín. The Libomyšl section shows some differences in lithology in this part of the sequence. The above mentioned A levels are developed as grey silty shales with irregular disintegration in Libomyšl.

A well recognizable 0.01—0.2 m thick calcareous layer of the level B1 follows in all the sections. It contains prominent, high-diversified faunal assemblage described in part by Chlupáč (1951a, 1951b, 1953), Marek (1952) and Havlíček - Mergl (1982).

The B1 level is formed by light olive-green calcareous shale with increased silt admixture. It is indicated as the level B1b and recorded at Vráž, Liteň, Modřany and Braník. Alternatively, the level B1 is formed by bioturbated, occasionally rather nodular, light brown-grey muddy limestone. It is indicated as level B1a in this case. It occurs at Malá Ohrada, Zličín, Zadní Třebaň and Karlík. At Kosov and Libomyšl sections the brown-grey muddy limestone (level B1a) is overlain by olive-green calcareous shale (level B1b). At the northeastmost Jezerka, Rajtknechtka and Běchovice localities grey (sometimes reddish-coloured by weathering) muddy limestone nodules occur in this level.

Different structures can be produced diagenetically. Well compactable shales with lesser carbonate content (B1b level) bear flattened and deformed organic remains with dissolved calcareous shells replaced by Fe oxihydroxides. In the case of higher carbonate/clay ratio (55 % of carbonate at Libomyšl, 45 % of carbonate at Levín near Zdice), cementation not allowed greater gravitational compaction and produced massive texture of muddy limestone (level B1a). There are slightly deformed carbonate shells of fossils preserved. The limestone nodules with the highest carbonate/clay ratio contain undeformed but sparse and low-diversified faunal remains (Běchovice).

The above described calcareous layer is overlain by brown-grey silty-clayey shale of the level B2 which contains rich but low-diversified trilobite-dominated fauna in most of the sections (Malá Ohrada, Zličín, Vráž, Kosov, Libomyšl, Liteň, Zadní Třebaň and Jezerka). The youngest Králodvor graptolites occur in this level (Zličín, Liteň, Zadní Třebaň).



2. Ideal section through the Králodvor/Kosov boundary in the Prague Basin; stratigraphy, lithology, **faunal diversity**

The level B2 attains its maximum thickness of 0.5 m at Kosov and Zadni Třebaň. On the other hand, it has not been recorded in the sections with weakly developed calcareous layer (pl. 1).

Grey silty shales of the level C occasionally containing thin beds of nodular limestone follow in all the sections and finish the sequence of the Králův Dvůr Formation. The thickness of the level C greatly varies between 0.2 m and more than 5 m (pl. 1). Sparse and monotonous trilobite fragments (*Mucronaspis grandis*) were found in this shale at Zličín and Kosov. More diversified, mostly bivalve association was solely recorded from the Kosov section by Marek (1952).

A drastic reduction of fossils in both diversity and abundance could be observed during the topmost Králodvor Series. Most of the groups — trilobites, brachiopods, cystoids, ostracodes, gastropods, conulariids and graptolites disappear and a sole trilobite and several bivalve species continue up to the basalmost Kosov Series. Bioturbation was reduced together with shelly fauna during the topmost Králodvor.

Kosov Formation

The basal part of 40—120 m thick Kosov Formation consists of silty shales with two layers of coarse-grained subgraywackes. Middle part is formed by flysch-like sequence of alternating quartzose sandstones, graywackes, siltstones and shales. The upper part begins with thick banks of badly sorted pebbly subgraywackes and petromictic conglomerates and coarse-grained sandstones and terminates by silty shales and claystones. The rest of Králodvor fauna contained in the Mucronaspis Community disappears during the lowermost shaly layer of the Kosov Fm. (level E). Middle part of the Kosov Formation contains only uncommon trace fossils. Quite new Hirnantia fauna accompanied by *Glyptograptus bohemicus* Marek appears in the uppermost silty-clayey layer of the formation.

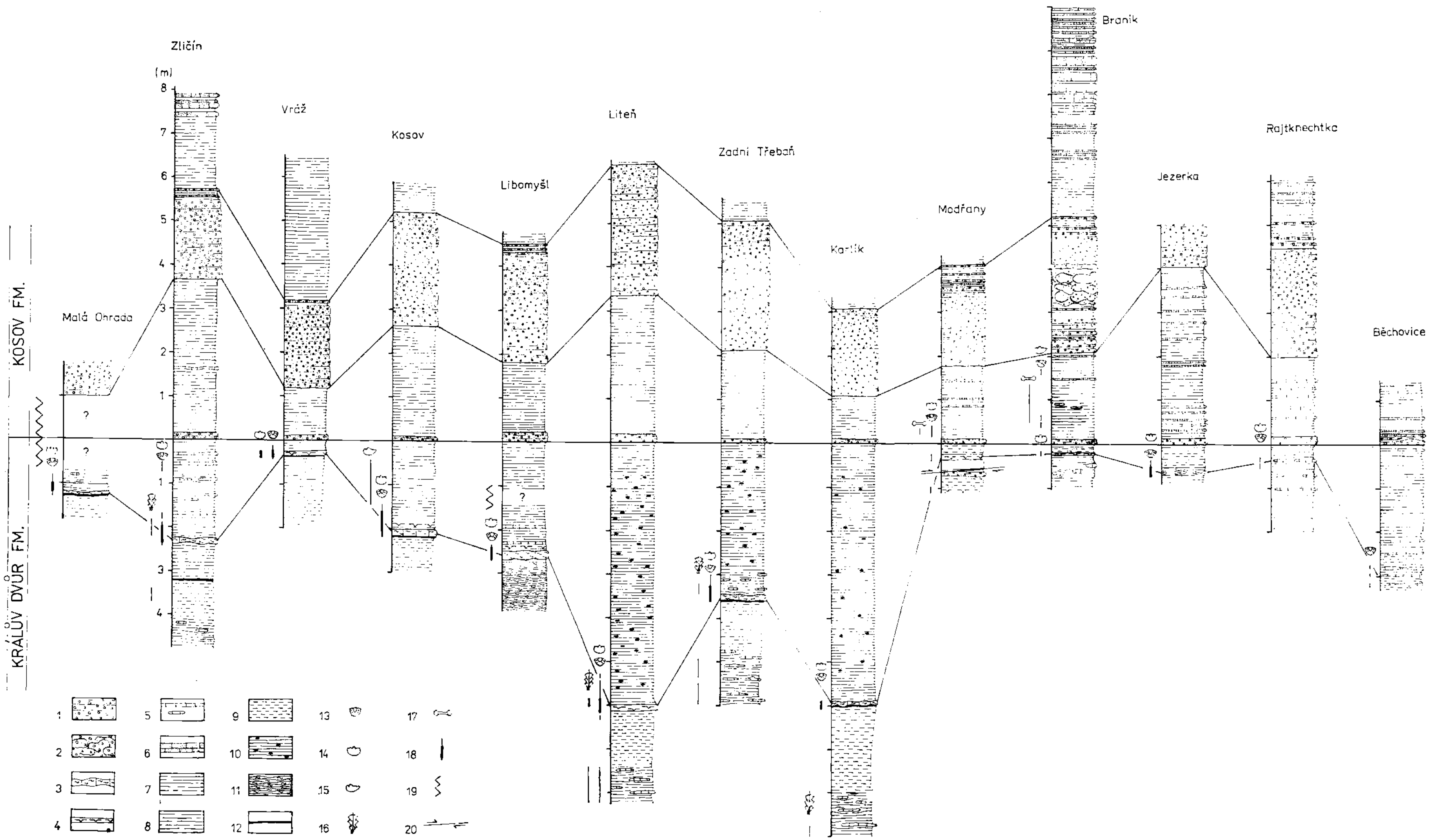
A sudden influx of coarse-grained sandy material appears just above the grey silty shales of the level C at all the sections. It is considered to mark the base of the Kosov Formation. Everywhere in the basin it was deposited as a layer of coarse-grained subgraywacke of nearly the same thickness (0.1—0.2 m) and nature. It is indicated as level D (text-fig. 2). It contains 60—70 % of silty-clayey matrix. Sand fraction consists almost exclusively of quartz grains, accompanied by rare quartzites, silicites and fragments of chloritized volcanic clasts. Common subangular clayey fragments (up to 12 mm in size) originate from the underlying shaly beds of the Králův Dvůr Formation. Flakes of clastic mica are scarce. Feldspars and additional rock fragments are extremely rare in sand fraction. Well rounded mostly izometric quartz of mean grain size of 0.6 mm (max. 1.2 mm) is commonly undulous. Dispersed imperfectly rounded quartz pebbles rarely accompanied by pebbles of siltstones, sandstones and some other rocks attain up to 10 mm in diameter. The pebbles were recorded in all samples.

Subgraywacke layer of the level D consists of up to five beds, often separated by thin (about 1 mm) clay laminae. Flat and sharp lower contact and distinct gradation of topmost parts of separate beds are mostly well visible. Layer of coarse-grained subgraywackes with pebbles is supposed to be deposited by mudflows.

After mudflow deposition at the base of the Kosov Formation, the sedimentation came back to silty shales (l e v e l E). Brown-grey or green-grey silty shales contain several intercalations of hard micaceous quartz siltstones or fine-grained sandstones (about 0.02—0.03 m in thickness) in the south-eastern part of the basin (Modřany, Braník, Jezerka, Rajtknechtka and Běchovice). Occasionally laminated sandy or silty intercalations were deposited probably in a rather different way than subgraywackes. Silty shales of level E, 1—4 m thick, were only sparsely bioturbated. At Modřany and Braník has been detected a trace fossil *Bifungites* accompanied by rare bivalves and fragments of trilobites *(Mucronaspis)*. B o u č e k - P ř i b y l (1958) noted rare bivalves and trilobites in this level from Malá Chuchle.

Silty shales of the level E are overlain by 2—3 m thick sequence of subgraywackes of the l e v e l F throughout the whole basin. The sequence is composed of coarse-grained subgraywackes with pebbles. It differs in some details from a thin layer of subgraywackes of the level D. The so called main basal subgraywacke layer (level F) contains 45—55 % silty-clay matrix. It shows sparsely distributed clayey fragments while the clastic mica flakes become more common. Sand fraction is composed almost exclusively of well rounded quartz grains of mean size 0.5—0.7 mm (max. 1.3 mm). Quartz, siltstone and sandstone pebbles are fairly common (up to 5 %). They are rarely accompanied by pebbles of black silicites, quartzites, green clayey fragments and granitoid rocks. Often not well rounded pebbles attain about 15 mm in diameter. The maximum of 30 mm has been attained by siltstone and sandstone pebbles at Zličín, Braník and Běchovice.

The sequence of the level F consists of large number of subgraywacke beds. Some attain up to 0.3 m in thickness. The beds become much thinner in the upper part of the sequence (0.01—0.05 m in thickness). The uppermost one or two are separated by several centimetres of clayey shales. Similarly to the level D, clastic subgraywacke beds of



COMPARISON OF THE SECTIONS THROUGH THE KRÁLODVOR/KOSOV BOUNDARY IN THE PRAGUE BASIN; LITHOLOGY AND FAUNAL DISTRIBUTION

1 — coarse-grained subgraywacke; *2* — slump layer within the subgraywacke sequence (Braník section); 3 — muddy limestone of level B1a; *4* — olive-green calcareous shale of level B1b; *5* — limestone nodules and lenses; *6* — sandstone; *7* — shale, silty shale; *8* — clayey shale, claystone; *9* — bioturbation (dark spotted shale); *10* — small nodules of hydrous ferric oxide; *11* — silty shales with irregular disintegration (Libomyšl section); *12* — blue-green tuffitic clay intercalation; *13* — trilobites; *14* — brachiopods (restricted to A1 and B1 levels); *15* — bivalves, *16* — graptolites; *17* — trace fossils (Bifungites); *18* — vertical distribution and richness of mentioned principal faunal groups; *19* — tectonic disjunction; *20* — dislocation (longitudinal fault at Modřany section).

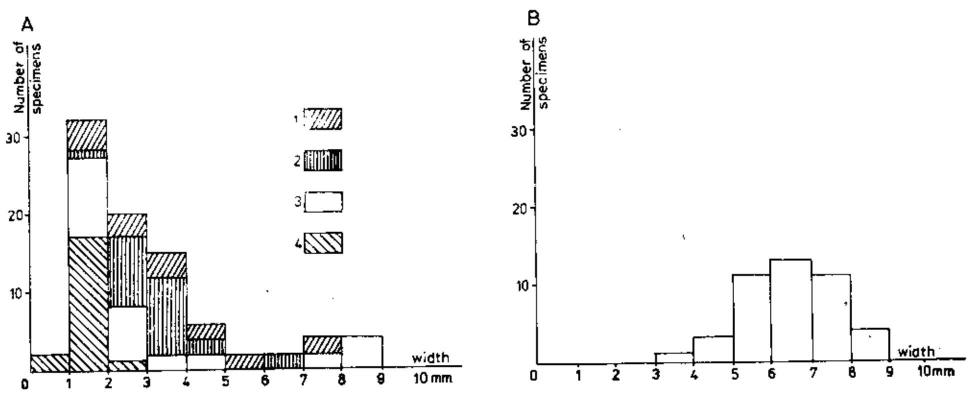
128

the level F lack graded bedding except for the uppermost few millimetres of their thicknesses, just below clay interbeds. Sharply defined bottom surfaces of individual mudflow beds appear to be mostly flat or slightly undulous in some cases. The clayey interbeds were often damaged by erosional effect of younger mudflow, they were preserved mostly between thinner subgraywacke beds in the upper part of the sequence.

In Braník section additional slumping of previously deposited subgraywacke bed or beds including their top clay laminae (clay interbeds) has been observed. There is 0.8 m thick slump layer consisting of tightly infolded slump-balls (in the sense of D z u l y n s k i - W a l t o n 1965) inside the mudflow sequence (pl. I-II).

Subsequently, the subgraywacke beds were diminished and replaced by light grey or brown-grey clayey shales with variable silty admixture. The shales were indicated as the l e v e l G. Such a change could be observed at all the sections (pl. 1) but somewhere several thin (up to 0.05 m) fine-grained sandy intercalations are present (Braník, Rajtknechtka, Běchovice). The shales of the level G lack any bioturbations and macrofossils.

The first fine-grained quartz sandstones of typical flysch-like sequence of the middle part of the Kosov Fm. (l e v e l H) appear just above the shales of the level G. The lowermost part of flysch-like sequence is formed by alternating fine-grained quartzose sandstones, siltstones and shales. According to the presence of great amount of structures typical



3. Size-frequency distribution of valves of selected brachiopods
A — strophomenids and plectambonitids: *1* — *Anoptambonites moneta* (Barrande); *2* — *Aegironetes tristis* (Barrande); *3* — *Proboscisambon quaesitus* (Barrande), *4* — undeterminable minute valves. B — orthids: *Epitomyonia dorsicava* Havlíček & Mergl. A = 81 specimens, B = 43 specimens. Jezerka locality, sample JE-1

of turbidites and described by Bouček - Přibyl (1958), turbidity currents appear to have played an important role in the forming of the sequence.

At present, great attention is paid to the problem of correlation of the Králův Dvůr/Kosov boundary with the initial phase of the glacio-eustatic falling of sea-level in the early Hirnantian. The sections are interrupted after the base of monotonous flysch-like sequence (level H) has been attained.

The flysch-like sequence as well as the topmost Ordovician, including the main drop in sea-level during the upper Kosov, are only briefly commented in this paper. The very end of the Ordovician and the basal-most Silurian which show substantial changes in sedimentation and faunal assemblages reflecting a rapid rise in sea-level were described by Štorch (1986).

Faunal assemblages near the Králodvor/Kosov boundary

Sampling methods

The poor preservation of fossils in the majority of the sections influenced our sampling methods. Bulk samples have been obtained at Jezerka and Vráž localities only (samples JE-1 and VR-1) but the species percentage in these samples has partly been affected by prominent fragmentation. The mode of preservation of the fossils and/or poor out-cropping of fossiliferous layers allowed only limited collecting at other localities. These samples yielded mainly large fossils whereas minute fossils (ostracodes, minute brachiopods) were scarce. Nevertheless, when we compare samples JE-1 and VR-1 with other ones we consider a taxonomic composition of assemblages to be roughly uniform and the sample JE-1 reflects the average taxonomic composition.

Preservation

The essential part of fossils is preserved as internal and external moulds, only specimens from muddy limestone have preserved original shells. Fossils display no preferred orientation, they are usually equally dispersed in the rock. Wide range of fragmentation occurs in one layer or in a single bedding plane: from finely crushed trilobite exoskeletons and shells through isolated parts (cephalons, pygidia, isolate valves, single pelmatozoan plates) to complete, almost undisturbed specimens (complete trilobite exoskeletons, entire cystoid thecae, articulated brachiopod shells), but the latters are rare. Conjoined brachiopod valves occur solitarily they never form clusters or a distinct single bedding assemblage. We consider preserved assemblages to be essentially local or slightly transported ("disturbed neighbourhood assemblages"). Intensive fragmentation was caused by slow sedimentation rates probably accompanied by weak current activity; biogenic activity was less significant (amount of bioturbations is low). The lateral differences in lithology and frequency of fossils indicate that shells, exoskeletons and their fragments form large, flat, lense-like accumulations at the bottom. Taxonomic composition of the community and lithological features of the sediments indicate off-shore, deep-water environment, corresponding to benthic assemblages 5 to 6 in sense of Boucot (1975), Havlíček (1982), Havlíček - Mergl (1982). Therefore, the fragmentation of shells and skeletons by a wave action in a shallow environment and succeeding washing down to deeper basinal floor is unlikely.

Taxonomic composition

Two distinct communities appear in the latest Králodvor: high-diversified Proboscisambon Community, occupying levels B1a and B1b, and poorer Mucronaspis Community, ranging from the level B2 up to the level E.

Among sedentary benthic elements of Proboscisambon Community minute, thin-shelled strophomenid and orthid brachiopods dominate. Species proportions differ in particular localities and also significantly vary in different levels within a single section. In sample JE-1 (level B1a), *Aegironetes* (32 %) together with slightly less abundant *Proboscisambon* (28 %) and *Anoptambonites* (17 %) dominate. *Epitomyonia, Jezercia* and *Kozlowskites* are less common (all less than 8 %). *Leptaena, Orbiculoidea* and *Ravozetina* are rare, and *Cliftonia, Cyclospira, Eoanastrophia, Hindella* and *Salopina* are very scarce. Brachiopods are accompanied by common pelmatozoans (*Echinosphaeronites, Mespilocystites*) and rare bryozoans. Other sedentary elements are absens in the sample. Vagile organisms are common and highly diversified. Ostracods are represented by more than 20 species, trilobites by 18 species. *Cryptolithus, Duftonia, Mucronaspis, Stenopareia* and *Kloucekia* are the most abundant, *Staurocephalus,* odontopleurids and proetids are less frequent of the trilobites. Unfortunately, prominent fragmentation prevents more exact estimation of quantity of particular species in original trilobite

Table 2

Fauna of the Proboscisambon and Mucronaspis Communities

COMMUNITY	Proboscisambon							Mucronaspis					
LEVEL	B1a				B1b			B2				E	
LOCALITY	Jezerka - lower part	Jezerka - upper part	Libomyšl	Rajtknechtka	Malá Ohrada	Vráž	Kosov	Jezerka	Libomyšl	Zličín	Malá Ohrada	Modřany	Braník
"Lingula" incongrua (Barrande)	•												
Acanthambonia sp.	•												
Orbiculoidea squamosa (Barrande)	●												
Conotreta sp.	•												
Jezercia ostiaria Havlíček – Mergl	●	•	○	•	●	●							
Ravozetina opima Havlíček – Mergl	•	●	○	●	●	●							
Ravozetina honorata (Barrande)							○						
Epitomyonia dorsicava Havlíček - Mergl	●	•		●	•	•	○						
Salopina stehoferi Havlíček – Mergl	•	●				•							
Boticium boticum Havlíček – Mergl		•											
Cliftonia sp.	•												
Kozlowskites ragnari Sheehan	●	●	○	●	•	•	○						
Aegironetes tristis (Barrande)	●	●	○	●	●	●	○		•				
Anoptambonites monetus (Barrande)	●	•		●	•	●	○						
Proboscisambon quaesitus (Barrande)	●	•	○	●	●	•	○						
Leptaena cf. *rugosa* Dalman	•	•		•		•							
Fardenia scotica Lamont							○						
Eoanastrophia sp.	•			•		•							
Hindella sp.	•	•											
Cyclospira sp.	•												
Gelidorthis sp.									●				
Stenopareia oblita (Barrande)	●	●	○	●	●	●	○						
Bumastus sp.	•												
Bronteopsis sola (Barrande)							○						
Alceste latissima (Barrande)							○						
Zetaproetus michle Šnajdr	●					•	○						
Decoroproetus mergli Šnajdr	●	•				•	○						
Phillipsinella parabola (Barrande)	•					•	○						
Cryptolithus ? kosoviensis Marek	●	●	○	●	●	●	○						
Actinopeltis carolialexandri Hawle – Corda	•					●	○						
Dindymene fredericiangusti Hawle – Corda	•					•	○						
Staurocephalus clavifrons Angelin	●					•	○						
Gravicalymene asperula Vaněk	•					●	○						
Mucronaspis grandis (Barrande)	●	●	○		●	●	○	●	●	●	●	○	○
Mucronaspis ganabina Šnajdr	●	●				●	○		●	●	●		
Kloucekia ruderalis Hawle – Corda	●					●	○						

Table 2

COMMUNITY	Proboscisambon							Mucronaspis					
LEVEL	B1a				B1b			B2				E	
LOCALITY	Jezerka - lower part	Jezerka - upper part	Libomyšl	Rajtknechtka	Malá Ohrada	Vráž	Kosov	Jezerka	Libomyšl	Zličín	Malá Ohrada	Modřany	Braník
Kloucekia sp.						●	○						
Duftonia morrisiana (Barrande)	●	●				•	○			•			
"Harpes" sp.	•												
Trochurus sp.	•												
Primaspis (*Bojokoralaspis*) sp.						●							
Acantholoma mirka (Marek)	●					•	○						
"Miraspis" sp.	•												
Decipilites decipiens (Barrande)	•	•					○	●	●	●	●		
Mimospira sp.	●					•							
Temnodiscus evolvens (Perner)									●	●	●		
Sinuitopsis sp.	•												
Turbonitella infida (Barrande)	•	●				●	○						
orthoceratids div. sp.	•	●											
Praearca kosoviensis (Barrande)	•	●				●	○	●	●	●	●		
Ctenodonta sp.		•						•	•	•	•		
bivalves div. sp.								⬤	⬤	⬤	⬤	○	○
bryozoans (2 species)	•												
conulariids (2 species)	•	●				•		●	●	●	●		
ostracods (about 20 species)	⬤	⬤	○	⬤	⬤	⬤	○		●	•			
machaeridians (2 species)	●	●				•	○		•				
Cornulites sp.						•							
Sphenothallus sp.		•											
Gochtia ? sp.									●				
Mespilocystites tragervanicus LeMenn	●	•			•	•	○						
crinoid columnars	●												
Echinosphaeronites sp. 1	●												
Echinosphaeronites sp. 2	⬤	●	○	●		●	○						
Cheirocrinus sp.	•												
Anatiferocystites sp.									•				
Glyptograptus cf. *teres* Perner									•	●			

• - rare species
● - common species
⬤ - frequent species
○ - documented occurrence only

position of the Rawtheyan/Hirnantian boundary cannot be identified on biostratigraphical basis in Bohemia.

The evidence of widespread late Ashgill glaciation suggests that it was extended from the Ordovician south pole through about 40° latitude (Brenchley 1984, Hambrey - Harland 1981, Havlíček 1989). The significant changes in ocean temperature, contemporaneous glacio-eustatic sea-level changes and other ensuing environmental changes have been recognized on separate continents and plates (Berry - Boucot 1973). They could be considered a synchronous world-scale event. Thus, synchronous, causally connected facies changes and faunal extinction could also serve for alternative stratigraphic correlation between the Rawtheyan/Hirnantian and Králodvor/Kosov boundaries.

The original term Hirnantian was introduced by Bancroft (1933) for the topmost Ordovician sequence in the Bala district. In their revised classification of the Ashgill Series, Ingham - Wright (1970) included to the base of Hirnantian also Cystoid Limestones of Cautley area in spite of their Rawtheyan-like fauna. Calcareous nature of that layer is well comparable with underlying sequence of the Rawtheyan Stage and clearly differs from usual suite of the Hirnantian sediments.

We follow the widely accepted conception of the base of the Hirnantian marked by a sudden replacement of warm water faunas of Rawtheyan type by eurytopic brachiopod-dominated Hirnantia fauna. Such a change reflects world-scale environmental change described by Berry - Boucot (1973), Brenchley - Newall (1980, 1984), Brenchley (1984) and others and is followed by changes in sedimentation.

Bohemian Králodvor Proboscisambon Community is related to relatively deep-water communities of Rawtheyan age of the Anglo-Scandic province. On the other hand, the first Hirnantian regressive phase is assumed to be documented by the first mudflows (subgraywackes of level D). Therefore, the question of exact position of Rawtheyan/Hirnantian boundary could be restricted to the interval between the richly fossiliferous calcareous layer (level B1) and the first subgraywacke layer. In the course of the discussed interval, the rich fauna became almost totally extinct. Its extinction supports our judgement. Brenchley (1984) noted some principal changes at the base of Hirnantian in Cautley area. Conspicuous disappearance of limestone nodules, decreased bioturbation and extinction of diversified trilobite fauna were also recorded at all Bohemian sections in the course of B2 - C level interval.

For these reasons, in the Prague Basin the position of Rawtheyan/Hirnantian boundary is assumed within poorly fossiliferous silty shales of the level C. In this sense, the Rawtheyan/Hirnantian boundary lies there

assemblage. Other vagile elements are represented by gastropods (2 species) and machaeridians (2 species). Bivalves, nautiloids and hyolitids are very scarce.

Slightly different fossil assemblage has been obtained from sample JE-2 (upper part of level B1a). *Kozlowskites* and *Aegironetes* together with *Ravozetina* and *Salopina* dominate, *Boticium, Epitomyonia* and *Jezercia* are less common. In contrast to the lower part of B1a, *Proboscisambon* and *Anoptambonites* become very rare. Among brachiopods orthids form 50—60 % here, in contrast to 10 % presence in the lower part of B1a. The amount of strophomenids decrease (40—50 % in the upper part of level B1a against up to 90 % in the lower part). Trilobites and pelmatozoans are uncommon, gastropods, bivalves and nautiloids become more abundant in the upper part of B1a.

Overlying layers (level B2) bear poorer fossil assemblage, composed of the trilobite genus *Mucronaspis,* bivalves, uncommon gastropods and conulariids. These elements form a significant new faunistic assemblage (Mucronaspis Community).

At Vráž (sample VR-1) the brachiopod composition of *Proboscisambon* Community is slightly different. *Aegironetes* is dominant (52 %), *Anoptambonites* (18 %) and *Ravozetina* (14 %) are less common. Additional species are rare *(Cliftonia, Eoanastrophia, Epitomyonia, Jezercia, Leptaena, Proboscisambon).* Other sedentary benthic elements are represented by uncommon pelmatozoans, bryozoans and cornulids. In contrast to Jezerka, trilobites are more abundant and prevail significantly in the sample. Taxonomic composition of trilobite association is slightly different from that of Jezerka. *Cryptolithus, Gravicalymene, Actinopeltis, Kloucekia, Mucronaspis* and *Stenopareia* are abundant, *Staurocephalus,* odontopleurids and proetids are rare. Other trilobites are very scarce *(Phillipsinella, Duftonia).* Ostracodes, gastropods and machaeridians are abundant as at Jezerka.

Size-frequency distribution of fossils

Size-frequency distribution has been studied in the sample JE-1 only, because minute shells are poorly preserved in other localities. Size-frequency distribution is distinct in brachiopods; trilobites are represented by both meraspid and early to late holaspid specimens but their more exact distribution could not be assessed due to their fragmental state of preservation.

Selected brachiopods display two groups of size-frequency distributions.

a-group comprizes brachiopods characterized by a high percentage of juvenile and small valves in the sample. Here strophomenids *Aegironetes, Anoptambonites, Proboscisambon,* and orthid *Jezercia* belong.

b-group comprizes remaining orthid brachiopods *Epitomyonia, Ravozetina* and *Salopina.* They are represented mostly by medium-size and adult specimens; the amount of juveniles and minute shells is generally very small or they are absent altogether. Similar size-frequency distribution display *Kozlowskites* in the sample.

Size-frequency distributions of additional species (*Boticium, Cliftonia, Eoanastrophia, Hindella, Leptaena* etc.) could not be studied due to their paucity. Explanation of the different juvenile mortality rate is difficult. According to our opinion this could be caused by a different life habit of minute strophomenids and orthids, and/or their different sensitivity to the fluctuations of environmental parameters. Other explanations, however, may be accepted, too (style of recruitment, brooding etc; Brookfield 1973, Cadée 1982, Richards - Bambach 1975 etc.).

Relationships of Proboscisambon and Mucronaspis Communities

The Foliomena Community and similar deep-water brachiopod assemblages of Ashgill age have been recognized in Southern Sweden (Sheehan 1973, 1979), Gaspé, Quebec, Canada (Sheehan - Lesperance 1978), Scotland (Harper 1979), Ireland (Harper 1980), and Bohemia (Havlíček - Mergl 1982). The Late Ashgillian plectambonitid — orthid assemblage with the dominance of *Christiania, Dedzetina* and other minute brachiopods was collected by one of us (MM) at the Holy Cross Mountains, Poland. The Foliomena Community and similar shelly deep-water assemblages are accompanied by rich vagile benthos in which trilobites and ostracods prevail. Apart from minute brachiopods, other sessile benthic elements are scarce.

The Proboscisambon Community shares many features with other contemporaneous deep water benthic communities: vagile elements (trilobites, ostracodes) dominate, and small thin-shelled brachiopods form characteristic strophomenid — orthid assemblage; pelmatozoans are significant, too. However, the Proboscisambon Community is unique in several aspects: genera *Chonetoidea, Christiania, Dedzetina* and *Sericoidea,* although frequent in other deep-water shelly assemblages in Anglo-Scandic Province, are absent in Bohemia. Additional genera appear in Bohemia: *Cliftonia, Eoanastrophia, Epitomyonia, Fardenia, Hindella, Jezercia* and *Leptaena.* Their occurrence indicates either more shallow environment and/or imperfectly developed depth-controlled, zonation of benthic assemblages, which is common in platforms. The rather steep basin slopes prevented the rise of distinct depth-controlled communities; originally deep-water communities pass here to the shallower benthic zones without significant changes during the Ordovician (Havlíček 1982). Therefore, the Proboscisambon Community is referred to benthic assemblage 5 to 6 in classification of Boucot (1975). The presence of *Cliftonia, Eoanastrophia, Epitomyonia, Hindella* and *Leptaena* however does not essentially change the minute strophomenid — orthid composition of the Proboscisambon Community, which is close to other contemporaneous deep-water shelly assemblages, but indicates an invasion of new elements into the Prague Basin.

Trilobites, characteristic of the Proboscisambon Community, indicate also an invasion of new, warmer water elements from Anglo-Scandic Province. Proetids *Decoroproetus* and *Zetaproteus,* minute odontopleurids *Leonaspis* and *Miraspis, Staurocephalus, Trochurus* and *"Harpes"* appear for the first time in the Prague Basin. They are close to the contemporaneous trilobite faunas of Poland (Kielan 1959), Sweden (Bruton 1966, Owens 1973), British Isles (Dean 1971, 1974, 1978; Ingham 1974, 1977), and Quebec, Canada (Lesperance 1968). The topmost part of the Králův Dvůr Formation differs with these new elements from the remaining part of the formation, where, despite the occurrence of some genera *(Amphitrion, Lonchodomas, Phillipsinella, Tretaspis* a.o.), proetids, odontopleurids, lichids, harpids and *Staurocephalus* are absent.

The vertical changes in the taxonomic composition of the Proboscisambon Community, its disappearance and substitution by the Mucronaspis Community, ban be explained by the deterioration of environment in the basin at the end of the Králodvor, connected with beginning of the late Ordovician glaciation. Originally rich *Proboscisambon* + *Leptaena* — plectambonitid — orthid assemblage passes through plectambonitid — orthid assemblage to poor, purely orthid assemblage. The successive deterioration of environments destroyed branchiopod-dominated sessile benthic assemblages, significantly reduced trilobite diversity, and facilitated a rise in the poor Mucronaspis Community.

The Mucronaspis Community is recorded from Gaspé, Quebec, Canada, in the rocks of Hirnantian age (Lesperance - Sheehan 1976), Dalmanitina assemblage in Rawtheyan-Hirnantian boundary interval in Wales (Brenchley - Cullen 1984), Dalmanitina beds are widely distributed in the late Ashgill in Sweden and Poland (Bergström 1968, Kielan 1959), and assemblage with dominant *Mucronaspis* of the late Rawtheyan or Hirnantian age is even known from South Africa

(Cocks - Fortey 1986). All these dalmanitinid trilobite assemblages are taxonomically poor and stratigraphically precede or accompany Hirnantian faunas. In the benthic zonation of assemblages the Mucronaspis Community shows seaward position to the Hirnantia Community and is assigned to the benthic assemblage 4 (Lesperance - Sheehan 1976). In the Prague Basin, the Mucronaspis Community is attributed by us to benthic assemblage 5 to 4. This community is taxonomically poorer than the preceeding Proboscisambon Community; two or three trilobite species *(Mucronaspis, Duftonia)* are accompanied by bivalves, gastropods, hyolithids and conulariids. Brachiopods and other groups (ostracodes, mitrates, machaeridians) are scarce and occur in the basalmost layers of the sequence bearing the Mucronaspis Community. Locally graptolites appear. At the base of the Kosov Formation the Mucronaspis Community becomes even poorer. The rare fragments of trilobites and shells of bivalves are accompanied by the trace fossil *Bifungites.* Occurrence of *Mucronaspis,* bivalves and *Bifungites* is the latest evidence of the Mucronaspis Community in the basin and reflects further deterioration of the environment.

Glacio-eustatic model of Králodvor/Kosov environmental changes in the Prague Basin

The glacio-eustatic model of Rawtheyan/Hirnantian environmental changes presented by Berry - Boucot (1973), Brenchley (1984) and Brenchley - Newall (1984) is applied to rather spefic conditions of graben-like linear depression of the Prague Basin in this paper. Narrow, tectonically predisposed linear depression of a rift character (Zeman 1978, Havlíček 1981) is marked by synsedimentary tectonic activity, by occurrence of shallow marine areas in marginal segments (containing Tigillites Community, Havlíček 1982), by rather steep, tectonically predisposed basin slopes and by relatively flat and deep basin floor in narrow central segment.

The late Ordovician sedimentary sequence of the Prague Basin more or less represents only basinal environment of the central segment (in the sense of Havlíček 1980, 1981). Shallow-water sediments of marginal segments, perhaps including complete basin slopes, were lost due to Hercynian deformation of the basin and subsequent erosion. We lack direct evidence of the environmental changes in marginal segments. Our conslusions are based solely on direct observations of changes of sediments and faunal assemblages in basinal conditions. The shallow--water environment in marginal parts could be assumed by analogy with

Lower Ordovician shallow water facies preserved in the Prague Basin.

Comparatively deep-water environment persisted in the central part of the Prague Basin during the Králodvor. It is characterized by sedimentation of grey-green clayey shales and/or mudstones containing a sequence of low-diversified deep water faunal assemblages. The Rafanoglossa leiskowiensis Community, assigned by Havlíček (1982) to the benthic assemblage 6, was replaced by Dedzetina macrostomoides Community confined to silty shales and proposed to indicate a temporary shallowing of the sea (in about benthic assemblage 4—5; Havlíček 1982). The Dedzetina Community in some aspects recalls the Foliomena Community assigned by Sheehan (1973, 1979) to benthic assemblage 6.

The following sequence of the Králův Dvůr Formation contains graptolites, trilobites, ostracodes and nautiloids accompanied by minute lingulids *(Anx)* and plectambonitids *(Chonetoidea)* which belong to the reappeared Rafanoglossa leiskowiensis Community. Upper part of this sequence corresponds to our level A1. Clayey sediments of the level A1 with few brachiopods and nearly no other sessile organisms are supposed to be equal to deep-water assemblage 6 and laterally might tend to pass into graptolitic shale facies (not developed at the present area of the basin).

In the latest Králodvor appears a layer of silty-clay shale with increased carbonate content, locally passing into a thin bank of muddy limestone (level B1). It contains distinct deep-water Proboscisambon Community across the whole basin. The layer with Proboscisambon Community bears prolific, in many aspects unique association in comparison with underlying sequence containing large amount of sessile elements (cystoids, brachiopods, blastoids, rare bryozoans). However, vagile organisms remain dominant in the community, represented mostly by trilobites and ostracodes; gastropods are less common, many other groups occur sparsely. Among brachiopods, minute strophomenids (especially plectambonitids) and orthids dominate, other brachiopod groups (triplesiids, inarticulates) are rare.

Sudden appearance of high-diversified Proboscisambon Community might be caused by moderate shallowing of the basin (still in the depth range of benthic assemblages 6—5) and was probably accompanied by an improvement of some other environmental factors. Bathymetrically controlled ameliorating of basin floor water layers temperature, increase of oxygen content and higher food supply allowed immigration of rich benthic assemblage (in part of Anglo-Scandic origin) from extra-basinal area and formed distinct deep-water basin floor Proboscisambon Community.

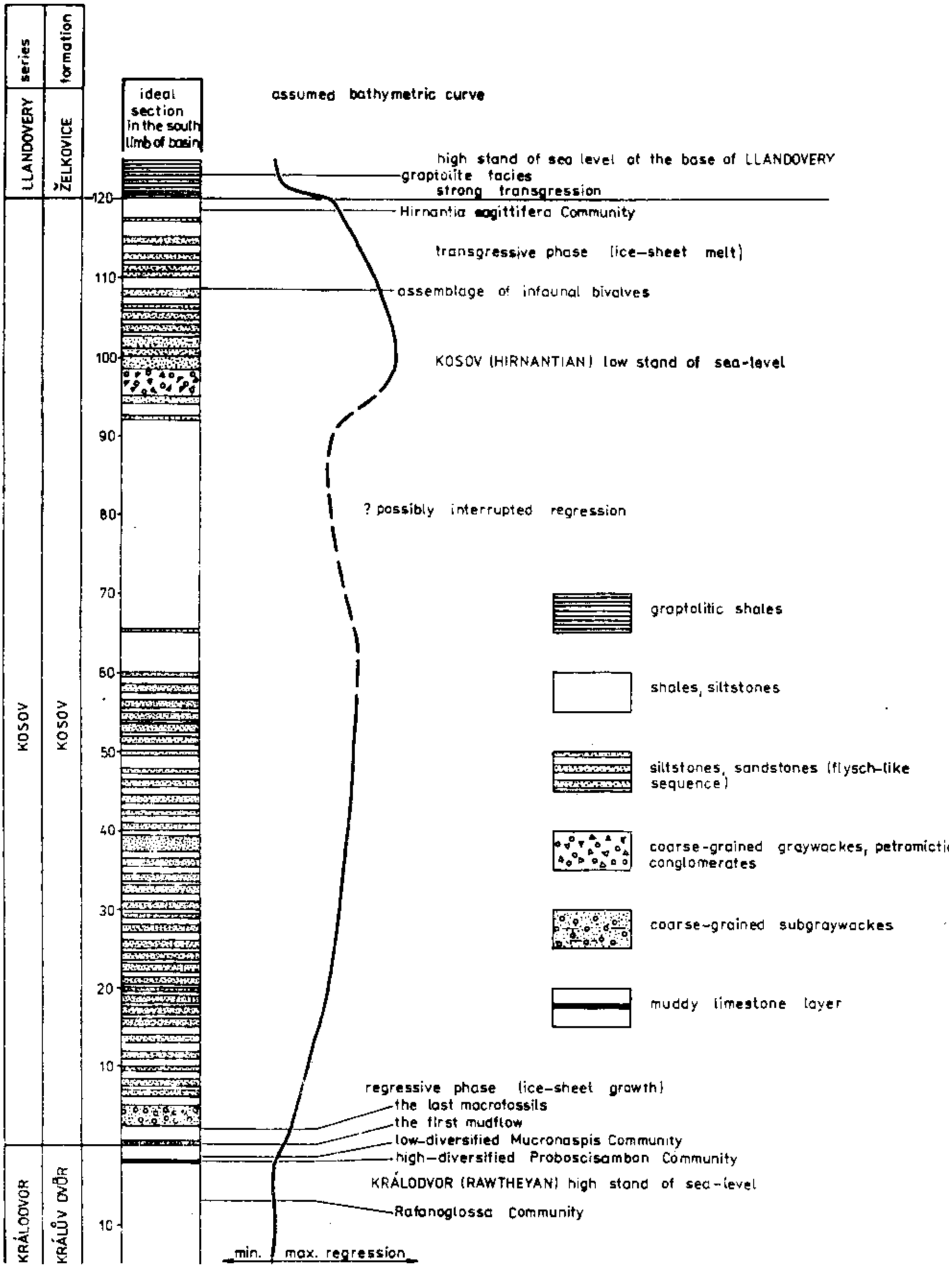
During a short time however, the continuous shallowing of the Prague Basin accompanied by water cooling due to the beginning glaciation of Gondwanaland stopped immigration and destroyed the deep water assemblage with Anglo-Scandic elements. The sudden disappearance of rich Proboscisambon Community is correlated with the initial extinction phase (Brenchley 1984) which affected mainly the deeper shelf communities, chiefly inhabited by trilobites, cystoids and gastropods.

Destroyed Proboscisambon Community was replaced by less diversified, trilobite dominated Mucronaspis Community, inhabiting more shallow environments (benthic assemblage 4—5 according to Lesperance 1974). Mucronaspis Community is confined to several tens of centimetres of clayey shale with increased silty admixture (level B2). The Mucronaspis Community is composed of two trilobite species of *Mucronaspis,* rarely accompanied by the third one of *Duftonia.* Minute smooth bivalves and hyolitids are common, gastropods, conulariids and graptolites of one species occur scarcely. Brachiopods and other sessile organisms are missing.

All the sections continue by silty shales (level C) with unusually sparsely disseminated organic remains (*Mucronaspis* and bivalves) that give evidence of continued extinction within the Mucronaspis Community. Increased supply of silty material reaching the basin floor is explained by shore-line progradation caused by the developing glacio-eustatic regression.

High sedimentation rate during the following strong regressive phase led to the instability of sedimentary accumulations at the more or less oversteepened basin slopes. Ensuing slumps and gravity flows could well be initiated by tectonic quakes which are not unusual in such a tectonically controlled basin. Originally nearshore material was removed by slumps and mudflows down the slope and across the basin floor. Coarse-grained near-shore deposits mixed with relatively deep water silty-clayey material gave origin to subgraywackes with high content of silty-clayey matrix (levels D and F). Epecially the first subgraywacke sequence (level D) bears a lot of subangular fragments of underlying clayey shales of the Králův Dvůr Formation and demonstrates erosional ability of mudflows. Common appearance of gravity flow deposits of Hirnantian age was discussed by Brenchley - Newall (1984). According to them, unusually widely distributed gravity flow sediments marked deeper-water regressive sequences while the regressive sequences in shallow-water conditions are marked by massive sandstones filling the channels and by erosional surfaces. Cross stratifications are common in these sandstones.

Both subgraywacke sequences (levels D and F) are characterized by



4. Ideal section from the Králodvor/Kosov boundary up to the Kosov/Llandovery (Ordovician/Silurian) boundary in the Prague Basin
The diagram shows assumed bathymetric curve related to principal environmental and biotic changes

nearly constant thickness, grain size distribution and content of silty-clayey matrix over the whole basin. For that reason we judge that the clastic material was supplied from the whole basin periphery, in fact from both marginal segments. Constant nature of mudflow beds contradicts the possibility of local supply or asymmetrical influx of gravity flow deposits from the only side and/or marginal segment of the basin. The Králodvor/Kosov boundary sections unusually resemble each other around the whole basin and seem to be originated under basin floor conditions, at least several kilometres away from the sources of mudflows. The distance should not have been too long according to the Havlíček's (1980, 1981) conception of the Prague Basin as a linear depression.

Subgraywacke sequences (level D and F) are interpreted as being composed of high-density proximal turbidites, and/or low-energy mudflows. It is suggested by their sedimentary structures, bed thickness, ungraded beds, clay "pelagic" intercalations, sharp and/or erosional surfaces of individual beds, associated slumps, grain size distribution.

Grey silty shales of the level E have been recorded between the subgraywacke sequences in all sections. They could represent possible interruption of rather strong regressive phase which is marked by gravity flow deposition. Increased supply of silty and sandy material (sandy intercalations of level E) is explained by shore line progradation which accompanied glacio-eustatic regression.

Last elements of Mucronaspis Community (*Mucronaspis* fragments and bivalves) have been rarely recorded in shales of the level E. The last fauna appears to be totally destroyed during the second gravity flow deposition (level F). The subgraywacke sequence of the level F documents the continuing drop in sea-level. The rest of incoherent, coarse-grained, originally near-shore sediments was displaced over the marginal shallows edge and transported by mudflows across the basin slope into the basin floor environment.

Repeated calming of sedimentation could be observed after deposition of the second subgraywacke sequence. It is illustrated by deposition of clayey shales with variable silty admixture. The reason could be found in interrupted regression, perhaps accompanied by tectonic quieting.

The Kosov sequence of the Prague Basin seems to be influenced by specific conditions of the linear sedimentary depression. Early Hirnantian increase of tectonic activity recorded by Deynoux - Trompette (1981) from Moroccan Sahara was reported later from the Oslo Region (Brenchley - Cocks 1982). The similar increase of tectonic activity could have been reflected also in the Kosov sequence of the Prague Basin.

The most of the Kosov Formation is formed by flysch-like sequence (beginning in level H). It could be explained by further glacio-eustatic drop in sea-level. Marginal segments of the basin emerged. Silty and sandy material appears to have been mainly eroded from widely exposed Early Paleozoic sediments. It was recycled and carried by channels into the basin as gravity flows and slumps. Flysch-like sequence is considered to have originated with the contribution of earthquakes (Kukal 1963 and Havlíček 1982) and/or storms.

Within the flysch-like sequence, the shaly member (well exposed at Hlásná Třebaň locality, Bouček - Přibyl 1958) seems to support the idea of sea-level oscillation within the glacial period (Brenchley - Newall 1984). However, this consideration should be further confirmed. The flysch-like sequence culminated by banks of ill-sorted coarse-grained pebbly, subgraywackes, sandstones and fine-grained petromict conglomerates of several meters in thickness. Coarse clastics are supposed to correspond to shallow water conditions and to reflect maximum regression during the Hirnantian (Kosov) low stand of sea--level. Emerged marginal segments were deeply notched by channels. The channels carried a lot of clastic material that was quickly deposited in conspicuously shallow water environment. The shallow water environment during the deposition of subgraywackes and conglomerates was also assumed by Kukal (1985). Another evidence of shallow water conditions is given by monotonous assemblages of infaunal bivalves which occur in these clastics (according to Havlíček 1982, they account for intertidal environment).

The subsequent large transgression reflects ice-sheet decay during the Ordovician/Silurian boundary interval. In the Prague Basin the transgression was described by Havlíček (1982) and Štorch (1986). Evidence suggests that the Hirnantia fauna inhabited the Prague Basin during the initial phase of this transgression in the uppermost Kosov Formation.

Stratigraphy and correlation

The exact correlation of Králodvor-Kosov sequence with standard British stages on biostratigraphical basis is still uncertain. The typical Rawtheyan faunas have been discovered only in Anglo-Scandic Province up to this time. They could be compared with the upper Králodvor communities. However, widely distributed Hirnantia fauna appears only at the top of the Kosov (Hirnantian) sequence in Bohemia. For this reason, we must follow the Brenchley's (1984) opinion that the exact just on, or somewhat below, the Králodvor/Kosov boundary. Maximum interval between assumed Rawtheyan age strata and the strata of Hirnantian varies from 0.2 m up to 5 m in the Prague Basin. The Králodvor/Kosov boundary is drawn at the base of the first subgraywacke (level D) according to Havlíček - Vaněk (1966) and Havlíček - Marek (1973) and corresponds to the boundary between the Králův Dvůr and Kosov Formations.

Uncommon and rather monotonous graptolite fauna occurs through the whole Králův Dvůr Fm. Five species have been recorded up to now: *Climacograptus angustus* (Perner), *Glyptograptus teres* Perner, *Rectograptus truncatus fritschi* (Perner), *Plegmatograptus* (?) *chuchlensis* Přibyl and *Dicellograptus anceps* (Nicholson). The graptolites have not yet been applied in detailed stratigraphy of the formation. Precise stratigraphic determination of old collections is mostly impossible.

The recent findings of graptolites in the sections studied are demonstrated in pl. 1. *Dicellograptus* cf. *anceps* (Nicholson) rarely occurs up to the level A1. The A1 is characterized by common *Climacograptus angustus* (Perner) across the whole basin and is signed here as Climacograptus angustus Horizon. The B2 level contains the last graptolites. *Glyptograptus* cf. *teres* Perner is common in some localities (Glyptograptus cf. teres Horizon). The next graptolites were found in the topmost Kosov together with Hirnantia fauna (Marek 1954, Štorch 1982).

Conclusions

Considerable changes in lithology and fossil biota at the Králodvor/Kosov boundary and the complete Kosov Series could be well explained by glacio-eustatic model presented by Brenchley - Newall (1984) and Brenchley (1984). Originally, this model was chiefly based on data from the Anglo-Scandic Province. Recently, analogous data have been also obtained from the Prague Basin (Bohemia).

The upper part of the Králův Dvůr Formation (Králodvor) is characterized by the deposition of shales with occasional limestone nodules or lenses (level A). Comparatively deep water and rather monotonous faunal assemblage of the level A is followed by rich and high-diversified Proboscisambon Community in the calcareous layer (level B1) developed in the uppermost part of the Králodvor. The Proboscisambon Community contains more than 70 genera, mostly trilobites, ostracods, brachiopods, cystoids, gastropods. Some trilobites resemble warm water Rawtheyan faunas (*Leonaspis, Miraspis, Decoroproetus, Zetaproetus, Staurocephalus,*

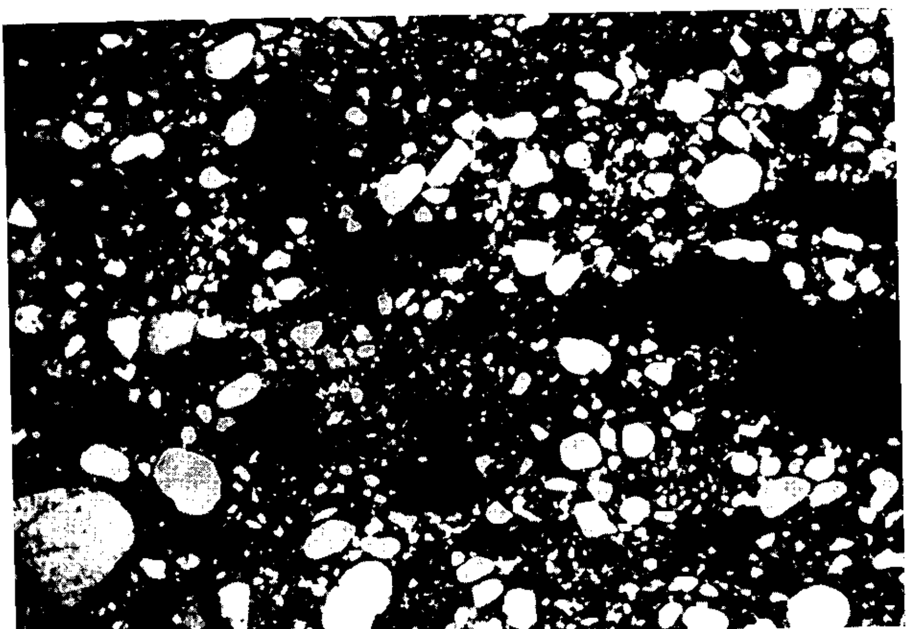
Branik section. Main subgraywacke sequence of the lowermost Kosov Formation (level F) with the slump layer in the middle part (between white arrows). The sequence of level F is overlain by shales of level G (above the white bar). The base of level F is marked by white bar in the lower right corner.

Photo by P. Štorch

Braník section. Tightly infolded slump balls of the slump layer (subgraywacke sequence of level F).

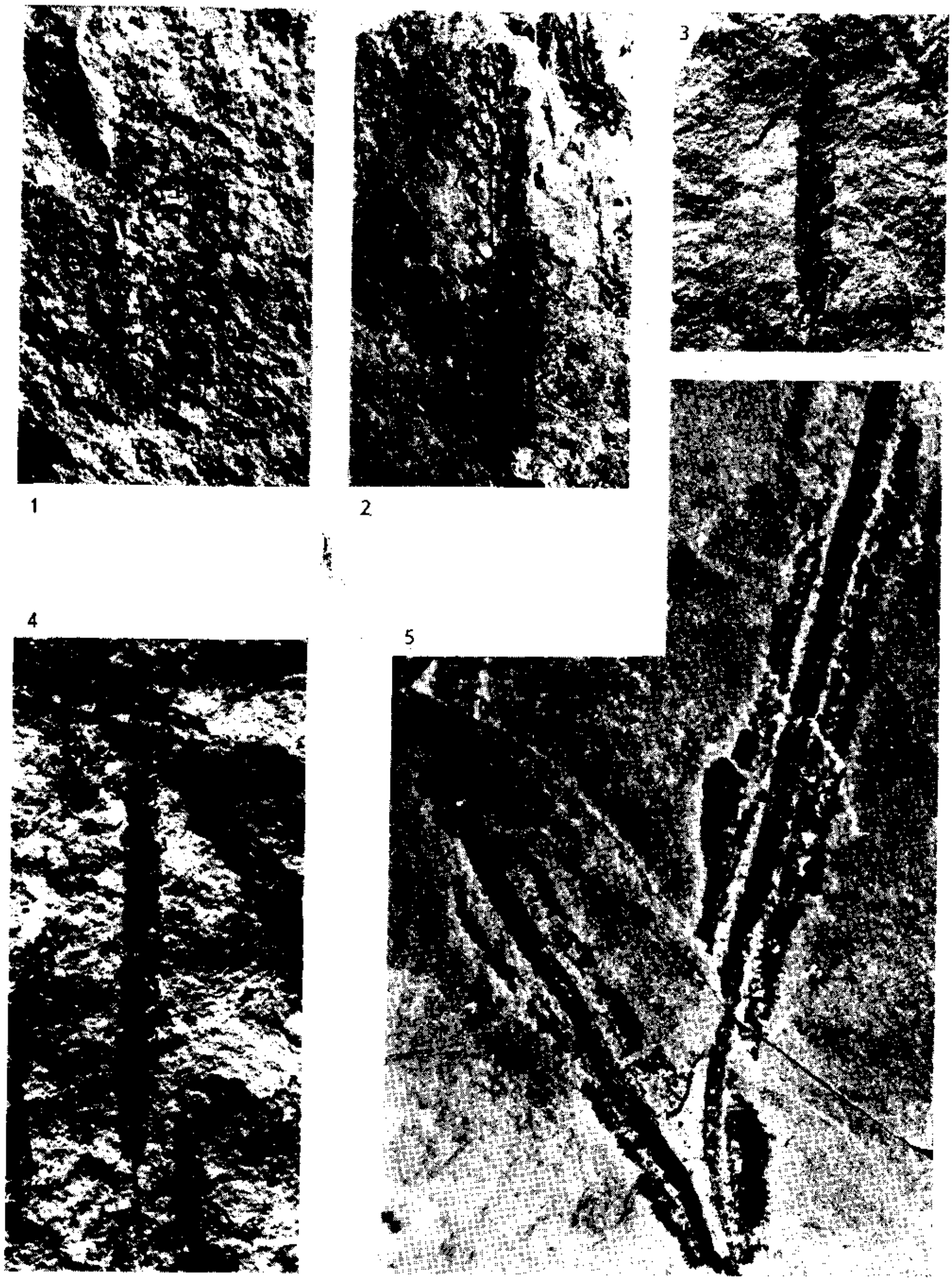
Photo by P. Štorch

1. Muddy limestone with fragments of cystoids and trilobites. Thin section. Libomyšl. Calcareous layer in the upper part of Králův Dvůr Formation (level B1a). ×18.



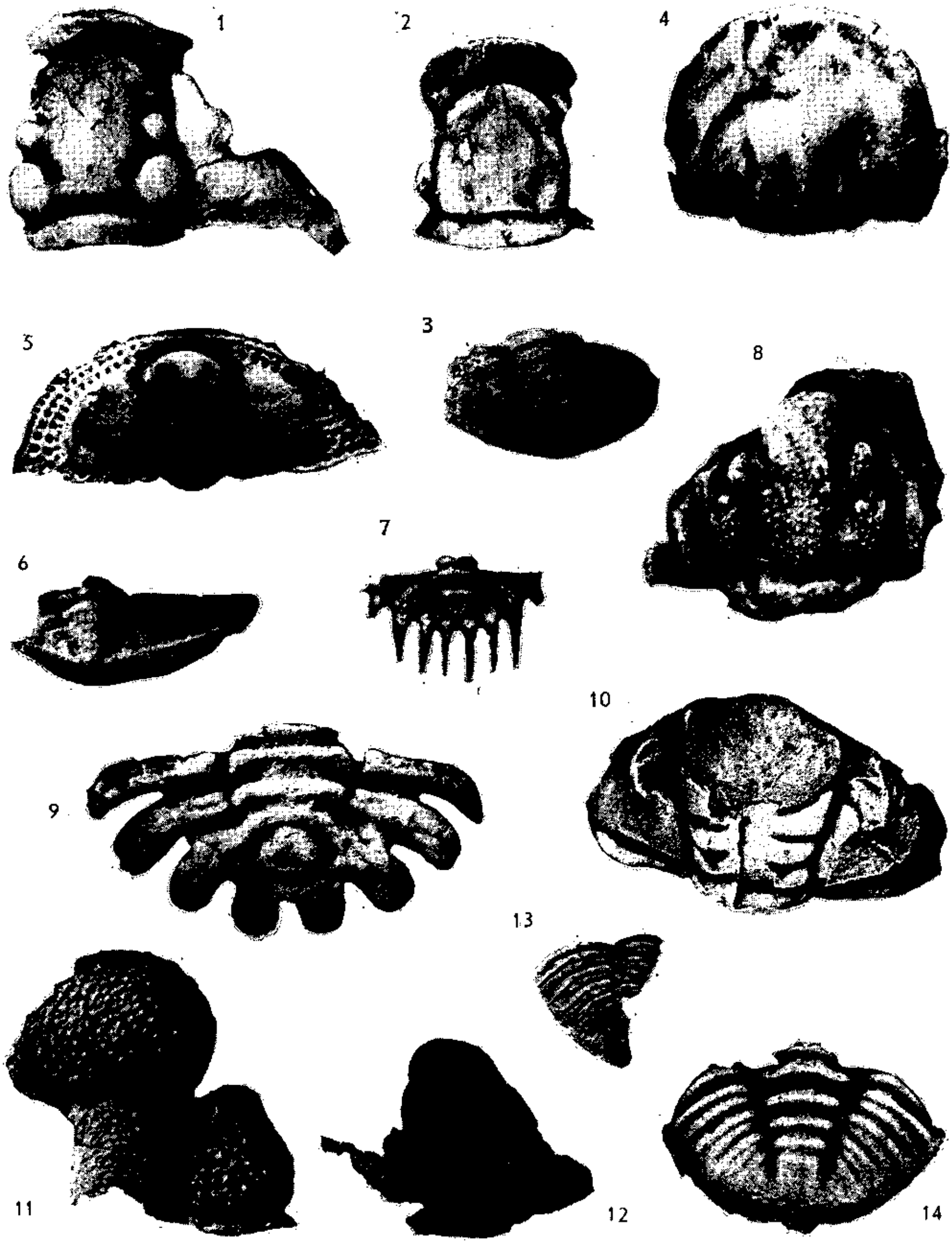
2. Coarse-grained subgraywacke with subangular clay fragments. Thin section. Zličín. The base of Kosov Formation (level D). ×14.6.

Photo (1) ÚÚG — N. Hrdličková, (2) P. Štorch



Graptolites of the upper Králův Dvůr Fomation. 1. *Plegmatograptus* (?) *chuchlensis* Přibyl, ×4. 2. *Glyptograptus* cf. *teres Perner,* ×4. 3,4. *Climacograptus angustus* (Perner), ×4. 5. *Dicellograptus* cf. *anceps* (Nicholson), ×3. Localities: 1,2 — Liteň; 3,4,5 — Malá Ohrada.

Photos by P. Štorch



Proboscisambon Community. 1. *Gravicalymene asperula* Vaněk, ×2.5. 2,3. *Decoroproetus mergli* Šnajdr, ×4. 4. *Stenopareia oblita* (Barrande), ×3.5. 5,6. *Cryptolithus kosoviensis* Marek, ×4.5; ×4. 7,8. *Bojokoralaspis* sp., ×4. 9. *Actinopeltis carolialexandri* (Hawle & Corda), ×3.5. 10,14. *Kloucekia* sp., ×3; ×4. 11. *Staurocephalus clavifrons* Angelin, ×6. 12. *Trochurus* sp., ×10. 13. *Zetaproetus michle* Šnajdr, ×4.7. Localities: 1,3,11,12,13 — Jezerka; 2,4—10,14 — Vráž.

Photos by M. Mergl and P. Štorch

of the new transgression at the end of the glaciation. The assumed bathymetric curve is shown in text-fig. 4.

K tisku doporučil V. Havlíček
Přeložili autoři

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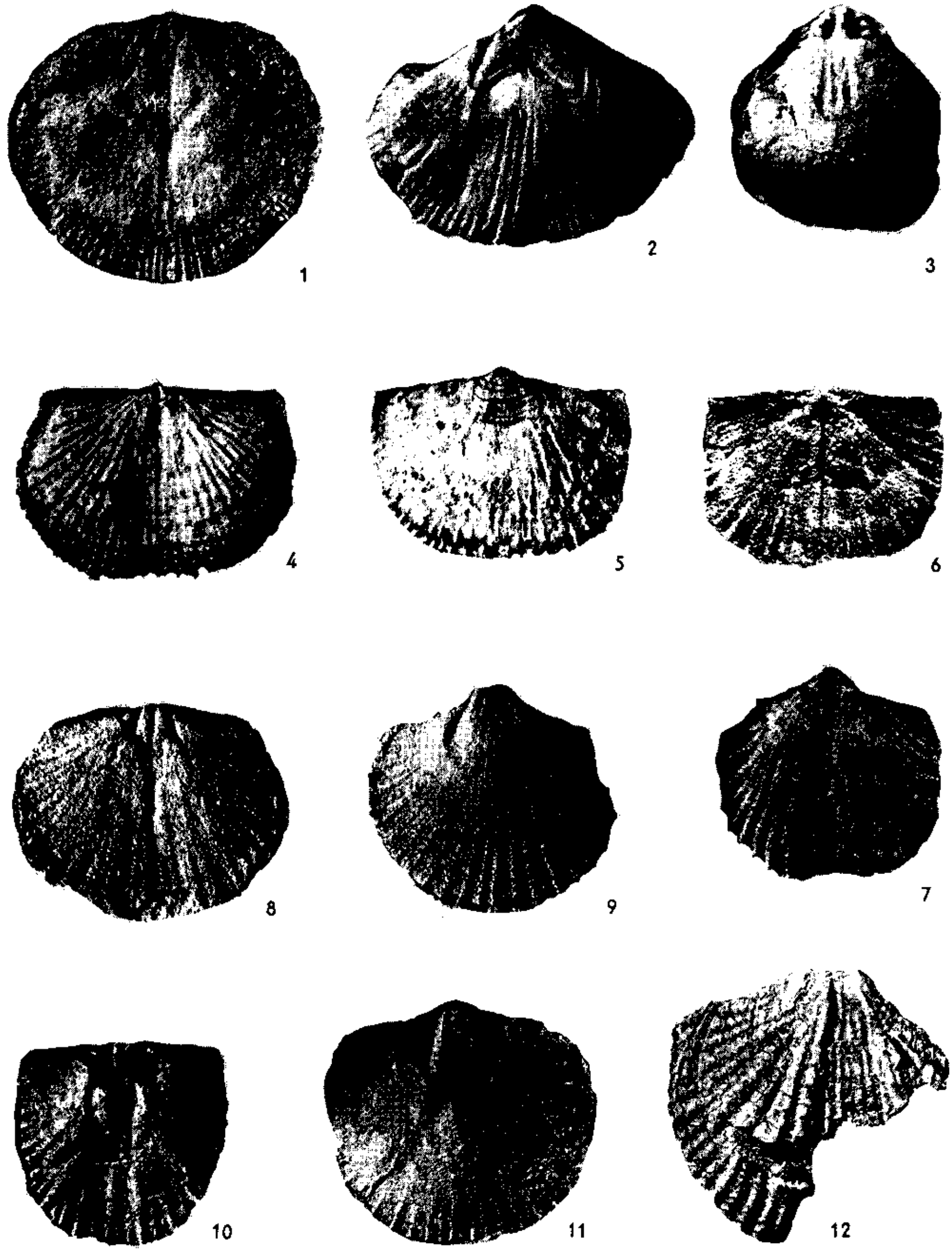
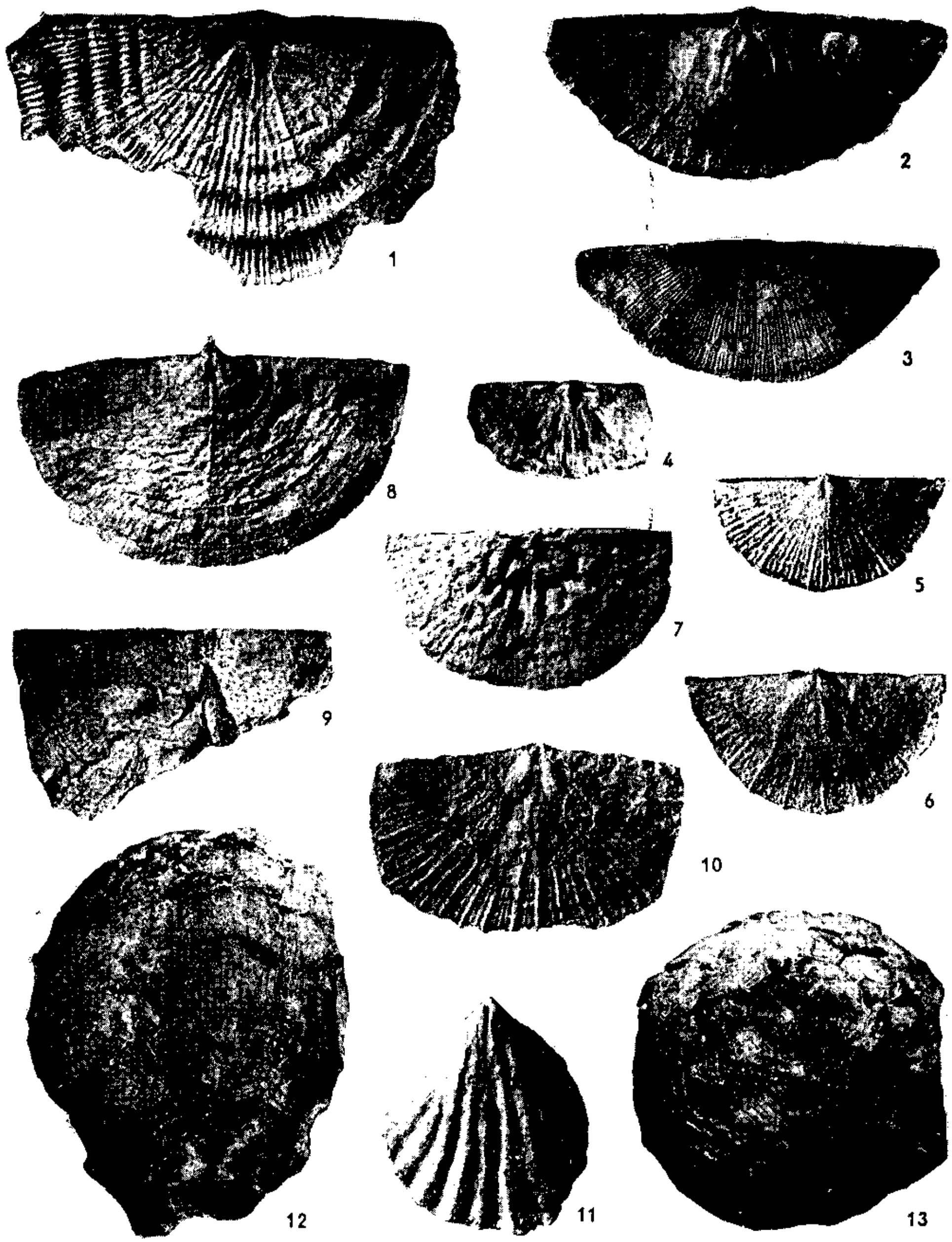


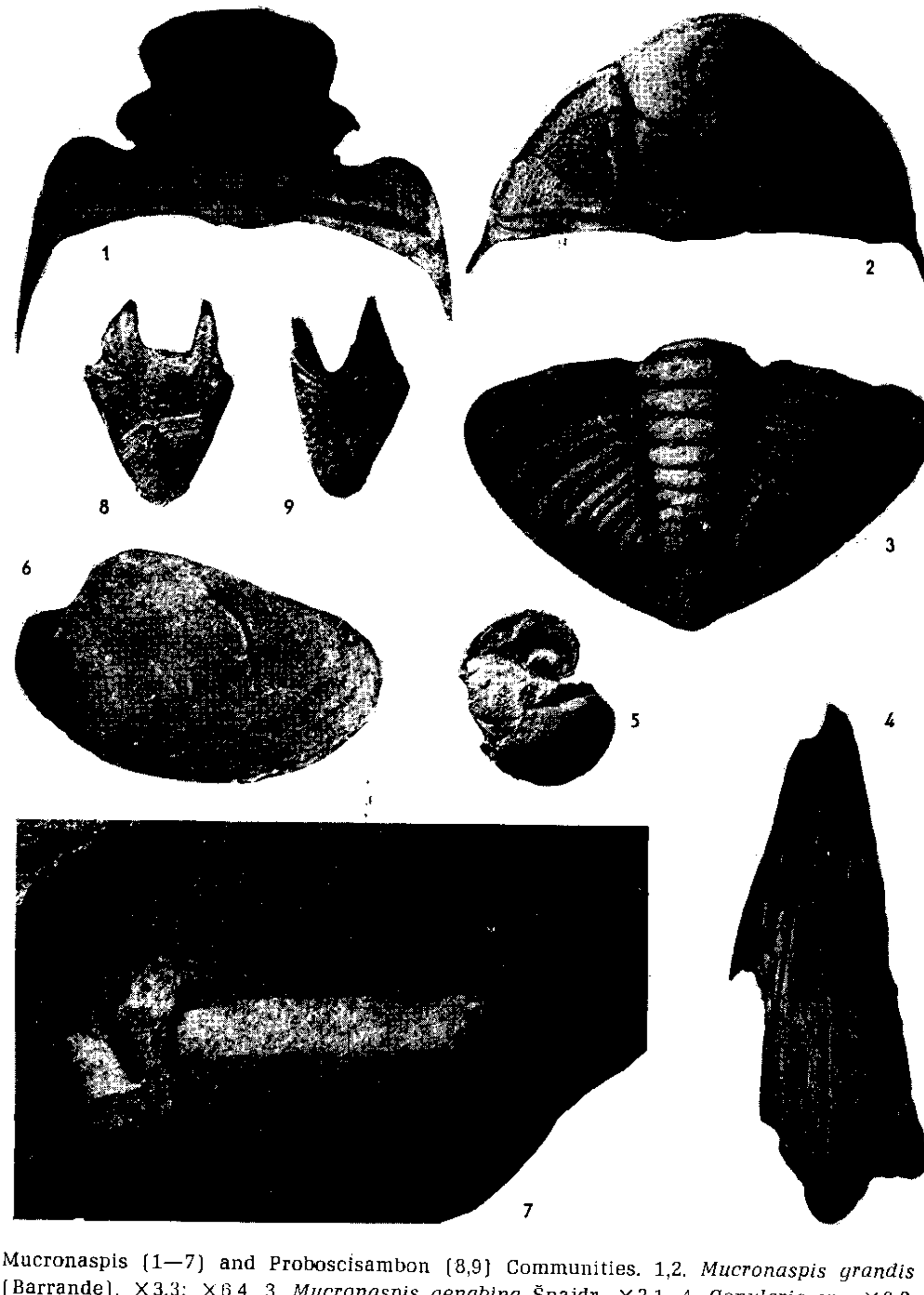
Proboscisambon Community. 1,2. *Boticium boticum* Havlíček & Mergl, ×3.6. 3. *Hindella* sp., ×7.2. 4,5. *Jezercia ostiaria* Havlíček & Mergl, ×3.2. 6,7. *Epitomyonia dorsicava* Havlíček & Mergl, ×4. 8,9. *Salopina slehoferi* Havlíček & Mergl, ×5.1; ×5.3. 10,11. *Ravozetina opima* Havlíček & Mergl, ×6. 12. *Cliftonia* sp., ×4. Locality: 1—12 — Jezerka.

Photos by M. Mergl



Proboscisambon Community. 1. *Leptaena* cf. *rugosa* (Dalman), ×5.3. 2—4. *Kozlowskites ragnari* Sheehan, ×4. 5—7. *Aegironetes tristis* (Barrande). ×8.7; ×6.6; ×7.4; ×8,9. *Proboscisambon quaesitus* (Barrande), ×6; ×5.5. 10. *Anoptambonites monetus* (Barrande), ×9.1. 11. *Boanastrophia* sp., ×10. 12. *Echinosphaerites* sp. A, ×2.6. 13. *Echinosphaerites* sp. B, ×2.6. Locality: 1—13 — Jezerka.

Photos by M. Mergl



Mucronaspis (1—7) and Proboscisambon (8,9) Communities. 1,2. *Mucronaspis grandis* (Barrande), X3.3; X6.4. 3. *Mucronaspis genabina* Šnajdr, X3.1. 4. *Conularia* sp., X3.2. 5. *Sinuites* sp., X4. 6. bivalve sp. indet., X4.5. 7. *Bifungites* sp., X1.8. 8,9. *Mespilocystites tragervanicus* LeMenn, X7. Localities: 1,3,6 — Zličín; 2,4 — Malá Ohrada; 5 — Libomyšl; 7 — Modřany; 8,9 — Jezerka.

Photos by M. Mergl

"Harpes", Trochurus); brachiopods are well comparable with the brachiopods of Jerestadt Mudstones from South Sweden.

Both the fauna and the deposition of sediments changed at the Králodvor/Kosov boundary. These changes are characterized by:

1) Sudden disappearance of the Proboscisambon Community at the top of the B1. This appears to correspond to the earliest phase of the glacially induced extinction of deep shelf trilobite-cystoid-gastropod faunas as described by Brenchley (1984).

2) Replacement of the Proboscisambon Community by much less diversified Mucronaspis Community (levels B2,C). The latter is quickly reduced (level C) and totally destroyed during the basal Kosov Fm. (levels D, E, F). The extinction is supposed to be caused by cooling accompanied by a distinct drop in sea-level.

3) Distinct change and decrease in bioturbation even though the sediments are of the same nature (shales of the levels A, E, G).

4) Disappearance of calcareous nodules. The last calcareous layer, muddy limestone of level B1, is followed by shales (B2) and silty shales (C).

5) Suggested subsequent glacio-eustatic regression triggered mudflows depositing subgraywackes of the levels D,F.

Considerable and analogous changes in lithology and faunal assemblages allow to correlate the Králodvor/Kosov boundary interval with that of Rawtheyan/Hirnantian in terms of the event stratigraphy. Rawtheyan/Hirnantian boundary is referred to the level exactly on, or somewhat below (within the level C), the Králodvor/Kosov boundary in Bohemian sections (text-fig. 2). Nevertheless, there is comparatively small difference between the setting of the boundary of British standard stages and the boundary of Bohemian units (max. difference 0.2—5 m), as related to the thicknesses of Bohemian sequence (50—150 m for Králodvor sequence, 40—120 m for Kosov sequence).

Glacio-eustatic concept is also supported by the character of the overlying Kosov sequence. A distinct flysch-like nature of the Kosov Formation is supposed to reflect continuing glacio-eustatic regression. Brenchley (1984) proposed a low stand of sea-level in the upper Hirnantian. It well fits the deposition of shallow water pebbly subgraywackes, sandstones and conglomerates in the upper Kosov Fm.

Coarse-grained clastics passed subsequently into overlying sandstones and siltstones. The sequence culminates with shales containing the rich Hirnantia fauna (benthic assemblage 3—4 according to Havlíček 1982). The Hirnantia fauna is supposed to accompany the initial phase

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Hranice králodvor/kosov
a změny prostředí ve svrchním rdoviku v pražské pánvi

(Résumé anglického textu)

Petr Štorch - Michal Mergl

Předloženo 19. března 1986

Předložená práce se zabývá vývojem sedimentace a faunistických společenstev v pražské pánvi na konci ordoviku. Výrazné litologické a faunistické změny na hranici králodvorského a kosovského souvrství dávají autoři do souvislosti se vznikem rozsáhlého zalednění Gondwany. V souladu s glacio-eustatickou koncepcí vycházející ze studia profilů ve Velké Británii, Skandinávii, v USA a v dalších oblastech (Berry - Boucot 1973, Brenchley 1984, Brenchley - Newall 1984) je vysvětlován i celý vrstevní sled kosovského souvrství.

Rozsáhlé svrchnoordovické zalednění Gondwany se projevilo globálním ochlazením a značným poklesem mořské hladiny v důsledku růstu obrovského kontinentálního ledovce pokrývajícího značnou část Gondwany. Glacio-eustaticky podmíněné faciální a faunistické změny se projevily logicky nejen na zahraničních profilech, ale můžeme je sledovat i ve svrchním ordoviku pražské pánve. Z časového hlediska lze navíc považovat nástup těchto změn za synchronní událost („event"). Projevy glacio-eustatické regrese jsou v pražské pánvi ovlivněny jednak paleogeografickou pozicí pánve na severním předpolí zaledněného jižního kontinentu (Havlíček 1989) a jednak geotektonickým postavením a charakterem pánve.

V předložené práci vycházíme z Havlíčkovy (1980, 1981, 1982) koncepce pražské pánve jako tektonicky založené lineární sedimentační deprese s příkře upadajícími svahy, úzkým a relativně plochým dnem a s mělkými plošinami na křídelních segmentech. Ve svrchním ordoviku máme k dispozici přímé doklady pouze o vývoji dna pánve, neboť sedimenty většiny svahu a plošin se nezachovaly.

Naše výzkumy navazovaly rovněž na sedimentologické studie Boučka - Přibyla (1958) a Kukala (1961, 1963), na výzkumy profilů a faunistických společenstev prováděné Chlupáčem (1951a, 1951b, 1953) a Markem (1952). Při studiu stratigrafie a společenstev jsme dále vycházeli především z prací Havlíčka a Vaňka (1966), H a v l í č k a a M a r k a (1973) a H a v l í č k a a M e r g l a (1982).

Naše závěry vycházejí hlavně z komplexního studia třinácti profilů hranicí králodvor/kosov (příl. 1). Profily byly situovány téměř rovnoměrně po celém obvodu pánve (obr. 1). Všechny jsou si natolik podobné, že mohly být popsány ve formě jednoho souhrnného ideálního profilu. Jeho vrstevní sled byl pro lepší přehlednost rozdělen do několika neformálních litostratigrafických jednotek (poloha A1, A2, A3, B1a, B1b, B2, C, D, E, F, G, H), znázorněných na obrázku 2.

Ve svrchním králodvoru probíhala v dochované části sedimentačního prostoru klidná, jílovitá až prachovito-jílovitá sedimentace. Ukládaly se šedé nebo zelenošedé, často bioturbované břidlice s rozptýlenými karbonátovými konkrecemi. Dno pánve bylo osídleno chudým hlubokovodním bentickým společenstvem (Rafanoglossa leiskowiensis Community). Kromě trilobitů, brachiopodů a dalšího, převážně vagilního benthosu byli zastoupeni i graptoliti (zóna Dicellograptus anceps).

Nad břidlicemi a jílovci je vyvinuta tenká poloha hnědozelené vápnité břidlice (poloha B1a), často až jílovitého či prachovitého vápence, s bohatým bentickým společenstvem (Proboscisambon Community) s hojnými trilobity, ostrakody, brachiopody, ostnokožci a dalšími bentickými organismy. Náhlý růst diverzity fauny je dobře patrný na obrázku 2. Společenstvo obsahuje řadu druhů či rodů známých z anglo-skandinávské provincie (ve smyslu S p j e l d n a e s e 1961) a je obdobou bohatých faun rawtheyanského stáří.

Ve vyšších polohách společenstvo náhle mizí a v poloze B2 je nahrazeno mnohem chudším, převážně trilobitovým společenstvem (Mucronaspis Community). Kromě převládajících trilobitů rodu *Mucronaspis* se vyskytují ostrakodi, konulárie, mlži, gastropodi a poslední králodvorští graptoliti (*Glyptograptus* cf. *teres*). Výměna společenstev je po srovnání se zahraničními profily spojována s ochlazením v počáteční fázi zalednění.

Následující glacio-eustatická regrese způsobila kromě další redukce a posléze úplného zničení mucronaspisového společenstva také změnu sedimentace. Pokles hladiny vedl k rychlému přemísťování nezpevněných písčitých mělkovodních sedimentů na hranu svahu a svah pánve. Příliš rychlá sedimentace na příkrých svazích pánve vedla ke vzniku gravitačních skluzů a bahnotoků. Pravděpodobné je i spolupůsobení synsedimentárních tektonických pohybů a otřesů uvažovaných K u k a l e m (1961, 1963) a H a v l í č k e m (1982). Na všech studovaných profilech vytvořily husté proudy v nejspodnějším kosovu dvě sekvence hrubozrnných drobovitých pískovců s vysokým obsahem prachovito-jílovité základní hmoty. Pískovce mají na všech profilech téměř konstantní zrnitostní složení i obdobnou mocnost. Spodní tenká poloha, tvořená několika po sobě následujícími proudy, představuje bázi kosovského souvrství a zároveň hranici mezi sériemi králodvor a kosov. Mezi oběma sekvencemi je všude vyvinuta poloha prachovitých břidlic s posledními zbytky mucronaspisového společenstva (úlomky trilobitů, mlži) a význačnými stopami *(Bifungites)*.

V úseku mezi břidlicemi polohy B2 a prvními drobovitými pískovci (poloha D) mizí poslední karbonátové konkrece a čočky, téměř mizí bioturbace, přibývá prachové frakce v břidlicích a je drasticky redukována fauna. Po těchto změnách následuje sedimentace z gravitačních skluzů a bahnotoků (poloha D a později F). U glacio-eustaticky determinovaných sekvencí byly obdobné jevy popsány více autory (Brenchley - Newall 1984, Brenchley - Cocks 1982, Brenchley - Cullen 1984, Brenchley 1984). Vzhledem k synchronnímu charakteru glacio-eustatických změn lze poměrně přesně korelovat hranici králodvor/ /kosov v mediteránní provincii s hranicí stupňů rawtheyan/hirnantian v anglo-skandinávské provincii (obr. 2).

Následující flyšoidní vrstevní sled kosovského souvrství je pokládán za regresívní sekvenci vrcholící ve svrchním kosovu sedimentací mělkovodních (Kukal 1985), nevytříděných hrubozrnných drobovitých pískovců a jemnozrnných slepenců, obsahujících na více lokalitách mělkovodní monotónní mlžová společenstva (Havlíček 1982). Postupné zjemňování sedimentů doprovázené v nejvyšším kosovu invazí bohaté hirnanciové fauny do pražské pánve je možno spojovat s počínající glacio-eustatickou transgresí na konci zalednění. Batymetrická křivka odvozená z tohoto vrstevního sledu (obr. 4) odpovídá batymetrické křivce dedukované Brenchleym (1984).

Vysvětlivky k tabulkám

Tabulka 1. Procentuální zastoupení jednotlivých druhů brachiopodů ve vzorcích JE-1 a VR-1 (lokality Jezerka a Vráž).

Tabulka 2. Seznam fauny (Proboscisambon Community a Mucronaspis Community).

Vysvětlivky k obrázkům

1. Schematická mapa současného rozšíření králodvorského souvrství v pražské pánvi s vyznačením studovaných profilů.
   1 — výchozy králodvorského souvrství; *2* — popaleozoické platformní sedimenty (svrchní křída, neogén); *3* — zlom; *4* — přesmyk; *5* — profil.
2. Ideální profil hranicí králodvor/kosov v pražské pánvi; stratigrafie, litologie, diverzita fauny.
3. Velikostní distribuce misek u vybraných brachiopodů.
   A — strophomenidy a plectambonitidi: *1* — *Anoptambonites moneta* (Barrande);

2 — *Aegironetes tristis* (Barrande); 3 — *Proboscisambon quaesitus* (Barrande); 4 — neurčitelné drobné misky. B — orthidy: *Epitomyonia dorsicava* Havlíček & Mergl. A = 81 kusů, B = 43 kusů. Lokalita Jezerka, vzorek JE-1).

4. Ideální profil vrstevním sledem v pražské pánvi od hranice králodvor/kosov po hranici kosov/llandover (ordovik/silur). Diagram ukazuje předpokládanou batymetrickou křivku ve vztahu k hlavním změnám prostředí a faunistických společenstev.

Vysvětlivky k přílohám

Příl. 1

Korelace litologického vývoje a rozšíření fauny na profilech hranicí králodvor/kosov v pražské pánvi.
1 — hrubozrnný drobovitý pískovec; *2* — skluzová vrstva uvnitř sekvence drobovitých pískovců (profil Braník); *3* — jílovitý vápenec polohy B1a; *4* — hnědozelená vápnitá břidlice polohy B1b; *5* — vápencové konkrece a čočky; *6* — pískovec; *7* — prachovitá břidlice; *8* — jílová břidlice, jílovec; *9* — bioturbace (tmavě skvrnité břidlice); *10* — drobné limonitové konkrece; *11* — nepravidelně odlučné prachové břidlice (profil Libomyšl); *12* — vložka modrozeleného jílu (tufitu); *13* — trilobiti; *14* — brachiopodi (omezeni pouze na polohu A1 a B1); *15* — mlži; *16* — graptoliti; *17* — stopy (Bifungites); *18* — vertikální rozšíření a četnost zastoupení hlavních faunistických skupin; *19* — tektonické porušení; *20* — dislokace (podélný zlom na profilu Modřany).

Příl. I

Profil Braník. Hlavní sekvence drobovitých pískovců nejspodnějšího kosovského souvrství (poloha F), ve střední části se skluzovou vrstvou (mezi bílými šipkami). Vrstevní sled polohy F následují břidlice polohy G (nad bílou čarou). Báze polohy F je označena bílou čarou v pravém dolním rohu záběru.

Foto P. Štorch

Příl. II

Profil Braník. Textury hrnutí ve skluzové vrstvě (vrstevní sled drobovitých pískovců polohy F).

Foto P. Štorch

Příl. III

1. Jílovitý vápenec s úlomky cystoidů a trilobitů. Výbrus. Libomyšl. Vápnitá vrstva v nejvyšší části králodvorského souvrství (poloha B1a). 18×.
2. Hrubozrnný drobovitý pískovec s nedokonale zaoblenými jílovitými útržky. Výbrus. Zličín. Báze kosovského souvrství (poloha D). 14,6×.

Foto (1) ÚÚG — N. Hrdličková, (2) P. Štorch

Vysvětlivky k Příl. IV—VIII na obrazových přílohách

Граница между краладворским и косовским ярусами и изменения среды обитания в Пражском бассейне в верхнеордовикское время

В Пражском бассейне описаны выразительные смены фаций и зооценозов на границе между краладворским и косовским ярусами. Отложения в приграничном промежутке, а также вся толща косовского яруса, находились под влиянием обширного верхнеордовикского оледенения Гондваны. Изменения литологического и фаунистического состава объясняются, прежде всего, гляцио-эвстатическими колебаниями уровня моря и из этого выводится возможность их использования для хроностратиграфической корреляции. Внезапно вымершее, очень разнообразное и относительно глубоководное сообщество с родом Proboscisambon, вновь появившееся сообщество с родом Mucronaspis и следующее выразительное изменение литологического состава позволяют сопоставить приграничный промежуток между кралодворским и косовским ярусами с приграничным промежутком между ярусами Rawtheyan и Hirnantian в англо-скандинавской области. Этот промежуток соответствует началу гляцио-эвстатического понижения уровня моря и связанным с ним изменениям среды обитания. Вышележащая флишоидная толща косовского яруса отлагалась в течение дальнейшего гляцио-эвстатического понижения уровня моря. Отступание моря завершилось отложением мощных толщ мелководных обломочных пород, содержащих однообразную фауну двустворчатых моллюсков. Наиболее верхняя часть косовского яруса представляет начало новой трансгрессии в конце оледенения, которая принесла в Пражский бассейн изобильную фауну с родом Hirnantia.

Přeložil A. Kříž