The Lower Cambrian Paseky Shale: Sedimentology

Sedimentologie spodnokambrických paseckých břidlic (Czech summary)

(3 text-figs. 4 plates)

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The Paseky Shale represents several metres thick part of the huge Lower Cambrian sedimentary complex. It is unique both from the palaeontological and sedimentological viewpoints. It consists of an alternation of claystones and silty claystones and siltstones with several fine grained greywacke intercalations. The Paseky shale belongs stratigraphically to the Holšiny-Hořice Formation and its sediments are sharply separated from the underlying and overlying coarse clastic deposits. These are interpreted as fluvial. The Paseky Shale, on the other hand, represents a product of standing, very shallow waters, as evidenced from the presence of adhesion structures and wrinkle marks. Geochemical criteria (boron content, water extracts, electrical conductivity, trace element contents) speak in favour of brackish conditions, as compared to the true marine Middle Cambrian Jince Formation and fresh water lacustrine Lower Cambrian Sádek Formation and Upper Cambrian Pavlovsko Formation. That is why the sedimentation in the lagoonal environment is supposed which is in context with the palaeogeographic reconstruction of the depositional environment of the Holšiny-Hořice Formation.

The quiet lagoonal sedimentation was interrupted by underwater slump and rapidly deposited greywacke layer contains typical slump structures and sole marks. There is only scarce evidence of palaeocurrents available, linear structures in the lower part of the section showing northward transport whereas load casted flute casts in the upper part of the section indicate opposite - southward transport. Thus irregular current system is supposed. Silty lamination is very abundant, but irregular and probably nonseasonal. Recrystallization of the clayey groundmass is surprisingly slight, because the anchimetamorphic stage is not yet reached. Nevertheless the clay mineral assemblage was converted into homogeneous chlorite-illite mixture. Some initial stages of nonpenetrative cleavage have been observed.

Key words: Lower Cambrian, Paseky Shale, sedimentology, geochemistry, sedimentary environments

Introduction

This paper represents a part of a complex study of the Paseky Shale which was carried out under the project leader prof. Dr. Ivo Chlupáč, DrSc. There are two main reasons why this very thin unit attracted such an attention: a) Palaeontological + stratigraphical and b) sedimentological. First reason is quite clear because the Paseky Shale yielded the oldest Czech macrofauna. Sedimentologically, the Paseky Shale is undoubtedly extremely important from the viewpoint of a paleogeographic reconstruction of the Cambrian sedimentary basin. Last but not least, its pure clayey sediments might evidence not only the palaeosalinity but also the intensity of metamorphic changes.

Sedimentological research of the Paseky Shale was carried out already in sixties by the author of this report. The results were published together with the description of the sedimentology of all the Barrandian Cambrian sediments (Kukal 1971). In the year 1992 the second stage of this researches has started during the initiation of the project called "The Oldest Czech Macrofauna". Stratigraphical and palaeontological studies were completed by sedimentological research carried out by the author of this paper. Original investigations were completed by the study of the cleaned outcrop along Litavka River - Medalův mlýn section, from the artificial outcrop at Kočka Hill and the study of some additional samples from the Tok Hill and Narysov. The sections are thoroughly described in Chlupáč's paper (1995 this volume). The project was sponsored by the Ministry of the Environment (the Division of the Geological Environment Protection).

Geological and stratigraphical backgrounds

The Paseky Shale belongs to the Holšiny-Hořice Formation in which three members are easily distinguishable sedimentologically: Holšiny Conglomerate, Hořice Sandstone and Paseky Shale. Maximum thickness of the Holšiny-Hořice Formation, about 1,100 m, is developed in the western part of the basin and the area of the maximum thickness coincides with the area of the maximum development of the conglomerates. The palaeogeographical reconstruction of depositional environments was published by Kukal (1971, see Fig. 3). In the northwestern parts of the basin fluvial sedimentation prevailed, represented by alluvial fans and river channels. This complex is generally fining southeastwards and alluvial plains, fluvial lakes and flood plain deposits gained more importance in this direction. More southeastwards, in the Rožmitál area, fragments of valves of inarticulate brachiopods have been found in greywackes and tuffitic sandstones (Kukal 1971). As known, brachiopods indicate undoubtedly marine environment and thus this evidence shows that the complex of continental depositional environments passed southeastwards into marine environments (Fig. 3).

The clayey sediments of the Paseky Shale form only negligible volume compared to the conglomerate-sandstone complex, but they might help in reconstruction of sedimentary environment in the basin. The clue sections (Medalův mlýn, Kočka, Tok, Narysov) are situated just along the transition between conglomerate and sandstone area and thus the proper environmental reconstruction might show the exact depositional relations.

Petrographic description of the sediments

The Medalův mlýn section (Litavka River valley) road cut represents the reference section. The section is illustrated in Chlupáč's et al. paper (1995 this volume). 38 thin sections were studied from this section including immediately underlying and overlying beds.

Claystones and silty claystones prevail in this section. Even "pure" claystones contain some admixture of quartzose silt. According to free silica analyses (see below), there are also substantial quantitites of submicroscopic clastic quartz. Clayey groundmass is usually clean, only slightly pigmented by organic matter. Iron oxyhydroxides occur only in weathered claystones. Quartzose silt is either disseminated or forms sharp microscopic laminae, flasers or streaks. Sharp regular or streaky lamination is very abundant and typical for clayey sequences of the Paseky Shale. Together with quartzose silt also less than 10 % of unstable detritus occurs in this fraction. In places, irregular alternation of greenish and greyish portions occurs. This is clearly due to variations of organic matter. Purest claystones exhibit very distinct patching. Pale brown patches, several milimetres up to 2 centimetres accross, are disseminated in the greenish groundmass. Brown patches exhibit slightly higher porosity and contain pigmenting iron oxyhydroxides. The presumption that these patches were primarily carbonate microconcretions, could not be proved. No traces of carbonate have been found. On the other hand, some pyrite grains occur both in the greenish groundmass and in the patches. It is to be supposed that the patches were formed around weathered pyrite nuclea through decomposition of organic matter and discolouring of greenish groundmass. Small (up to 0.01 mm across) pyrite grains of irregular aggregate shape, still unaltered, can be observed in almost all the claystones. That is why we suppose that brownish patches represent bleached and oxidized nuclea around weathered pyrite crystals. It is interesting that mentioned patchy claystones are limited only to certain horizons in the Medalův mlýn sections.

The recrystallization of clayey groundmass is not intensive. Its transformation to cloudy sericite aggregates is visible. Only sometimes larger muscovite individuals result from the recrystallization. Organic matter is still disseminated and does not form films and sharply limited streaks. In purest claystones, only slight traces of crenulation occur and only two samples exhibit initial stages of nonpenetrative cleavage. All this evidence shows that the stage of typical anchimetamorphism is not yet reached which is surprising in the case of Lower Cambrian sediments.

Siltstones form several intercalations in the section. They contain about 40 % of quartzose silt and higher amount of parallelly oriented muscovite flakes. Maximum grain size is 0.15 mm.

One metre beneath the top of the Paseky Shale quartzose sandstone layer can be found. Its medium grain size is 0.17 mm, maximum grain size up to 0.7 mm. This sandstone is strongly silicified with intergrowing quartz grains and neomorphic quartz in the matrix.

Immediately underlying sandstone layer can be characterized as lithic greywacke with 25 % matrix, medium grain size 0.18 mm and maximum grain size 0.5 mm. Clastic grains are angular, sand fraction contains 10 % potassium feldspars and 15 % argillitized unstables. Also several plagioclase grains were found and one larger fragment of mica schist. Among quartz grains polycrystalline quartz prevails over monocrystalline one and also grain of a metaquartzite was found. Several grains of bipyramidal habitus were found indicating possibly a source from the porphyry phenocrysts.

Overlying Hořice Sandstone is formed of quartzose sandstone with medium grain size 0.15 mm and maximum grain size 0.7 mm. The boundary between Paseky Shale and overlying sandstone layer is sharp and erosive.

From the section in the artificial outcrop on the Kočka Hill (see Chlupáč et al. 1995, this volume). Twenty samples were studied microscopically. A difference from the Medalův mlýn section can be observed: Laminites and siltstones are more numerous at Kočka Hill section, "pure" claystones without silty admixture are almost absent. Also the recrystallization is more intensive and reaches anchimetamorphic stage. Crenulation and nonpenetrative cleavage is present nearly in all the clayey samples. "Paper" silty lamination occurs together with flaser lamination. Organic matter is concentrated to films and lenses. Organic matter occurs also in the form of microscopic lumps (0.0X mm across). In silty claystones and clayey siltstones with streaky structure fine sand admixture occurs (maximum grain size 0.20 mm). In sample No. 13 aggregate globular carbonate grains were found, also with zonal structure. Their size is 0.10-0.15 mm and they possibly represent organic remains. Altered very fine pyrite (up to 0.05 mm across) is also present.

Artificial outcrop on the Tok Mt. yielded few partly weathered samples of the Paseky Shale unit and underlying sandstones. Paseky Shale is represented by silty claystones, with quartzose silt and fine sand splinters in streaks (max. grain size 0.09 mm). The underlying Hořice Sandstone is represented by the subarcose (medium grain size 0.18 mm, maximum grain size 0.40 mm, 20 % of unstables in sand fraction - mainly argillitized porphyry grains).

Sedimentary structures

The lamination is of primary importance among sedimentary structures of the Paseky Shale. Two types of lamination can be distinguished:

(a) Silty lamination. Occurs in almost all the silty claystones and can be regular, of "paper" type or irregular, of streaky type. "Paper" lamination is variable in thickness, the thickness of laminae being between 0.2 and 1.0 mm. Mostly the lower and top laminae boundaries are sharp, only in several cases fining upward was observed with gradual transitions of siltstones into overlying claystones. Silty laminae occur individually or in couples and no regularity was found in their vertical distribution. That is why the seasonal origin is improbable and the genesis of lamination can be attributed to coincidental input of the silt into the basin. Due to its quartzose nature and typical grain size its aeolian flux cannot be excluded.

Streaky silty lamination is very abundant and according to general view means the contemporaneous input of clayey and silty fractions into the basin. There are no sharp boundaries between silty and clayey streaks. Typical bioturbation microstructures were not observed.

(b) Lamination due to alternation of colours. In the Medalův mlýn and Kočka sections microscopical colour lamination was observed: 0.2-0.5 mm thick greenish laminae alternate with greyish of the same thickness. The only difference between the laminae is higher amount of streaks and clusters of organic matter in the greyish ones. Such a sort of lamination is often explained as seasonal and it is well known that it might occur in many lacustrine or lagoonal or typically marine sediments of all the geological ages. The greyish laminae richer in organic matter correspond to the seasons of increased organic production.

Ripple marks

Quartzose sandstone (Bed no. 1 in the section of the Medalův mlýn - see section by Chlupáč et al. 1995) exhibits distinct ripple marks on its upper bedding plane. They are slightly asymmetrical with comparatively straight, little undulating ridge direction. Their wave length is 6 cm, amplitude 5 mm. Low ripple index (~12) speaks in favour of underwater current ripples (see Kukal 1986). Asymmetry vergency indicates the S-N heading currents.

Siltstone bed in the section of Medalův mlýn (bed No. 5) exhibits very interesting adhesion ripples (see Pl. I-1, 2). They are known also under the term wrinkle marks or Kinneya's ripples (Kocurek - Fielder 1982). According to these authors this feature is usually formed in extrashallow water during the process of wind driven water layer across unlithified fine grained sediment. This explanation fits suggested depositional model.

Slump and other structures

The layer No 7 (Medalův mlýn section) is deformed by slump and its lower bedding plane exhibits clear slump structures. This 20 cm thick bed contains rolled and curved streaks of silt with fine-grained sand admixture distributed in clayey matrix. Sole bowls and ridges, slightly asymmetric, are developed on the bedding plane (Pl. II-2 and Pl. IV-1). Sudden deposition of this layer due to some extreme event (i.e. storm, landslide) can be supposed.

Underlying bed in the Medalův mlýn section exhibits two types of sole marks: small deformed load casts and small flute casts. This linear structure reveals a current direction from the north to the south.

Some small mechanoglyphs - sole marks were found in the artificial outcrop near Pičín (see Pl. III-1). On the base of coarse grained siltstone bed several skip marks and thin tool marks are oriented in two preferred directions. Transport direction could not be reconstructed. Such structures could be found in a great variety of environments and thus do not contribute to their reconstruction. Ichnofosils were studied separately by Mikuláš (1995 this volume).

Geochemical composition of the sediments

Five complete silicate analysis of the Paseky Shale have been carried out in the Accredited laboratories of the Czech Geological Survey (analyses J. Šikl, M. Mikšovský, E. Černochová, V. Janovská). The results are on the Table 1.

SiO_2/Al_2O_3 ratios are slightly below or above 3.0. Free quartz determinations (analysed by J. Pěnkava, laboratories of the Czech Geological Survey) revealed comparatively high values (Kočka - 25.52 %, Medalův mlýn, sample No. 7 - 46.24 %). These two analyses are from "pure" claystones which means that clastic quartz is mostly of submicroscopic size.

Some additional technical analyses have been carried out, mainly for the calculations of the SiO_2/Al_2O_3 and Al_2O_3/Na_2O ratios.

Al_2O_3/Na_2O ratios were calculated in order to estimate the chemical maturity of clayey sediments. Pure claystones and silty claystones from the Medalův mlýn section exhibit high values - from 66 up to 105 which means that the claystones can be characterized as chemically supermature. In the Narysov and Kočka samples somewhat lower values were found (15-20) which in-

Table 1. Chemical analyses of the Paseky Shale

	Sample				
	1	2	3	4	5
SiO_2	57.38	56.050	59.270	60.760	71.990
TiO_2	0.88	0.870	0.840	0.960	0.840
Al_2O_3	18.70	21.020	20.810	19.980	19.910
Fe_2O_3	3.04	6.320	3.080	4.140	3.770
FeO	4.75	1.520	2.740	1.570	1.890
MnO	0.07	0.033	0.043	0.105	0.028
MgO	2.26	1.770	2.130	1.790	2.000
CaO	0.42	0.040	0.150	0.230	0.080
SrO	-	0.007	0.008	0.008	0.012
BaO	-	0.060	0.055	0.064	0.066
Li_2O	0.02	0.012	0.009	0.013	0.006
Na_2O	0.92	0.200	0.250	0.240	0.180
K_2O	3.81	4.100	4.450	4.340	2.670
P_2O_5	0.17	0.080	0.030	0.030	0.070
CO_2	-	0.080	0.030	0.020	0.020
C	-	0.220	0.360	0.180	0.070
H_2O+	5.22	5.860	5.000	4.810	3.100
F	-	0.068	0.130	0.050	0.041
S	-	0.040	0.030	0.020	0.010
H_2O-	1.65	1.210	0.270	0.290	0.090
F-ekv	-	-0.029	-0.055	-0.021	-0.017
S-ekv	-	-0.010	-0.007	-0.005	-0.002
C_{org}	0.05				
S	traces				
Total		99.520	99.620	99.570	99.820

1 - Medalův mlýn, sample No. 2, pure claystone; 2 - Medalův mlýn, Sample No. 4, pure claystone; 3 - Medalův mlýn, Sample No. 6, pure claystone; 4 - Tok, sample No. 2, pure claystone; 5 - Kočka, No. 1, silty claystone

Table 2. Partial chemical analyses of the Paseky Shale

		SiO_2	Al_2O_3	Na_2O	K_2O
Narysov	No. 1	61.28	16.24	1.14	3.38
	No. 2	68.44	15.23	0.95	3.08
Kočka	No. 4	69.44	15.01	1.03	3.92
Narysov	No. 1	pure claystone			
	No. 2	silty claystone			
Kočka	No. 4	laminite			

dicate lesser maturity. The value of this ratio is generally decreasing with the increasing silt admixture.

Comparing to the middle Cambrian marine Jince Formation, the Paseky Shale claystones exhibit extremely high values of the Al_2O_3/Na_2O ratio. This means that rapid fluvial sedimentation during the Lower Cambrian was stabilized and weathered mature detritus washed to the basin.

The ratio of alkalies exhibit that potassium is strongly overwhelming over sodium.

Organic carbon content varies from 0.05 to 0.360 %. This amount is sufficient for grey colouration of sediments. Moreover this speaks in favour of certain organic productivity of waters. Surprisingly high Fe_2O_3 content in one of the samples (6.320 %) can be explained by the presence of Fe-rich chlorite. Carbon dioxide percentage is negligible and does not reveal presence of carbonate. Sulphur is very low which corresponds to small amount of unaltered pyrite. It can be also supposed that elevated trivalent iron content could originate by the weathering of primary ferrous carbonate (ankerite or siderite). Even though this mineral was not identified in the Paseky Shale, it is rich in the Middle Cambrian Jince Formation (Kukal 1971).

The amount of MgO is slightly lower than the average for claystones.

Trace element analyses were carried out in four samples.

Table 3. Trace elements in the claystones of the Paseky Shale

Element	Sample			
(ppm)	1	2	3	4
Ag	<0.1	<0.1	<0.1	<0.1
B	56.0	70.0	64.0	74.0
Be	2.0	3.0	2.0	2.0
Bi	<2.0	<2.0	<2.0	<2.0
Co	20.0	15.0	70.0	13.0
Cr	95.0	90.0	90.0	48.0
Cu	80.0	70.0	70.0	33.0
Ga	25.0	35.0	25.0	17.0
Mo	1.0	1.0	1.0	1.0
Ni	58.0	32.0	70.0	28.0
Pb	11.0	18.0	13.0	12.0
Sn	5.0	3.0	4.0	2.0
V	120.0	100.0	100.0	52.0
Zn	160.0	210.0	280.0	100.0

Analyzed by E. Mrázová, Laboratories of the Czech Geological Survey

Trace element analyses did not show surprising results. Analysed data were compared to the calculated averages for shales (claystones) by several authors (e.g. Wedepohl in Merian et al. 1991). It can be concluded from this comparison that for most of the elements the ppm contents in the Paseky Shale correspond roughly to the calculated average. The only exceptions are:

Zn - in the Paseky Shale up to 280 ppm, the average for clayey sediments usually calculated below 100 ppm.

Cu - in the Paseky Shale in three clayey samples more than 70 ppm whereas the average for all the clayey sediments 45 ppm.

It is not easy to explain these anomalies, specially that for zinc. It is suggested that the elevated concentration might be caused by the presence of chlorite as prevailing clay mineral. Chlorites according to Adriano (1986) contain up to 1600 ppm Zn. Cu can be bound to iron oxyhydroxides. Its elevated amounts in ferrugineous claystones and soils cannot be considered as exceptions (Bowen 1979, Beneš 1992).

Special attention was given to the trace elements as indicators of the palaeosalinity. Boron contents are used as a main evidence for the palaeosalinity, even though in the recalculated form of so called equivalent boron which means B related to the illite content. Also absolute amounts of boron in pure claystones are sometimes used (see Bouška et al. 1980). For the Paseky Shale the amounts between 56.0 and 74.0 ppm B correspond more to the marine than to freshwater

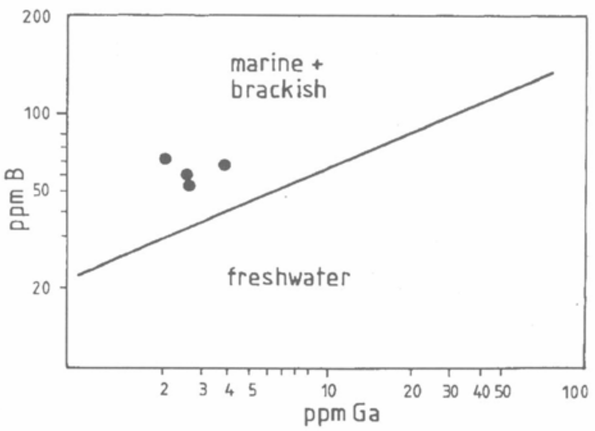

Fig. 1. The diagram showing the plot between the boron and gallium contents in the clayey sediments. The dots indicate four analyses of the claystones of the Paseky Shale. The diagram was suggested by M. L. Keith - E. T. Degens (1959) as a tool for distinguishing marine and freshwater environments

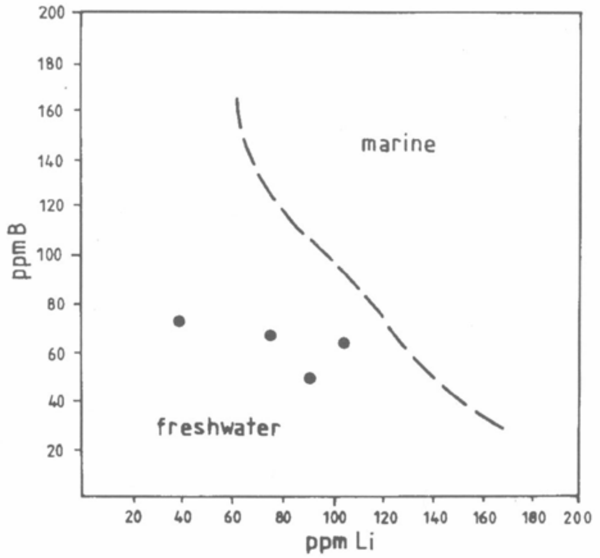

Fig. 2. The diagram showing interrelationship between boron and lithium contents in clayey sediments as a tool for distinguishing between marine and freshwater depositional environments (after M. L. Keith - E. T. Degens 1959). The dots indicate a composition of the claystones of the Paseky Shale

environments. Diagrams of interrelations between element couples B-Ga and B-Li proposed by Keith - Degens (1959) were also used (see Figs. 1, 2).

B-Ga diagram for the Paseky Shale shows that the distribution of values is just between the freshwater and marine environment. For the B-Li plot the values lie in the field of fresh water but not far from the salt water field.

We are aware of the fact that the application of all these methods for the Lower Palaeozoic sediments is somewhat limited but, nevertheless, the results speak neither in favour of marine nor for freshwater environment, thus the brackish environment is most probable.

Unfortunately, the Raiswell - Berner method (1985) of reconstruction by means of C_{org}/S plot could not be used because of extremely low values of sulphur. Almost complete alteration of sulphidic sulphur caused this effect.

Uranium content was analysed in two samples from pure claystones from Medalův mlýn section and Kočka section. The amount 4 ppm U for the two samples was found which corresponds to the world average for clayey sediments. Also radioactivity measurements recalculated to the uranium content give the same results.

Method of the investigation of electrical conductivity and water extract composition was also applied to the Paseky Shale. Electrical conductivity was studied by the method applied by Jansa - Tomšík (1960), even though it is well known that its application to the Lower Palaeozoic sediments is limited. Electrical conductivity of water extract of clayey sediments should rise with the increasing amount of "remanent" ions trapped in the clay structure, i.e. with increasing palaeosalinity. Electrical conductivity and water extract composition were studied in the laboratories of the Czech Geological Survey (J. Pěnkava anal.) and the Laboratories of the Geological Surveying, Ostrava. For 15 samples following minimum, maximum and average values were found (Table 4).

Table 4. Electrical conductivity of the claystones of the Paseky Shale (in $10^{-4}.\Omega^{-1}.cm^{-1}$)

Localities	No. of samples	minim.	maxim.	Average
Medalův mlýn and Kočka	15	1.5	7.6	3.9

The claystones of the Middle Cambrian Jince Formation from the same area, exhibit higher values (Kukal 1971). Some anomalously high values for the Paseky Shale have been found in red and grey sediments enriched in organic matter. Silt and fine sand admixtures have no marked influence.

As compared to younger Barrandian Ordovician, Silurian and Devonian sediments, the Cambrian Paseky Shale exhibits invariably lower values of the electrical conductivity.

Analyses of water extracts have been carried out in the laboratories of the Czech Geological Survey (J. Pěnkava anal.) and also compared to some other Cambrian clayey sediments (Table 5).

According to Spears (1974) marine clayey sediments contain higher amounts of soluble calcium and magnesium in water extracts than freshwater ones. Also total amount of soluble ions should be higher in ma-

Table 5. Analyses of water extracts from clayey sediments in the Barrandian Cambrian

Formation	Number of analyses	Ca2+	Mg2+	K+	Na+	HCO_3'	Cl'
		in milligramequivalents					
Pavlovsko	2	1.80	0.61	0.21	0.09	1.20	0.20
Jince	6	0.25	0.16	0.15	0.18	0.61	0.37
Paseky Shale	4	0.15	0.16	0.15	0.13	0.39	0.25
Sádek	3	0.17	0.15	0.13	0.12	0.28	0.22

rine claystones. As in the case of some other palaeosalinity indicators (boron content, electrical conductivity) the reliability of this method decreases with the increasing age and recrystallization intensity of claystones. In the Lower Palaeozoic sediments diagenetic and anchimetamorphic overprint might completely obscure the primary amount and composition of a sorbed ions. As observed in Table 5, no clear conclusions can be made from the comparison with the true marine Jince Formation and evidently freshwater Sádek and Pavlovsko Formations.

Clay minerals

X-ray analysis of samples by means of the Guinier focusation method after de Wolff was carried out in the Laboratories of the Czech Geological Survey (anal. J. Zoubková). Pure claystones were selected for the analyses and the association of clay minerals proved to be very simple:

Medalův mlýn section (5 samples): chlorite, illite
Kočka Mt. section (3 samples): chlorite, illite
Narysov (2 samples): chlorite, muscovite
Chlorite (basal reflection 14Å) prevails generally over illite. Kaolinite was not identified.

This simple association chlorite+illite corresponds to most of the Lower Palaeozoic claystones as proved from many parts of the world.

Physical properties of the sediments

In order to complete the characteristics of the studied claystones also mechanical properties were identified. The results are shown on Table 6.

Table 6. Mineralogical density and porosity of the claystones of the Paseky Shale

Sample	Mineralogical density	Total porosity
Medalův mlýn section		
No 1	2.726	0.035 %
No 2	2.7016	0.026 %
Narysov	2.7325	0.041 %

(analysed in the Geologický průzkum n.p. enterprise, Prague)

High mineralogical density is caused by the prevalence of iron-rich chlorite (see also increased amounts of trivalent iron in chemical analyses). The porosity is extremely low which means that the claystones from the Medalův mlýn and Narysov sections are fresh and unweathered. That is why the secondary decalcification is impossible. All the younger Cambrian and Ordovician Barrandian clayey sediments exhibit higher total and effective porosities (Kukal 1971).

Discussion and conclusions

The claystones of the Paseky Shale form a thin laterally consistent layer as proved by the geological mapping and successive field and stratigraphical investigations. They are formed mostly of claystones with variable silty admixture, with siltstone interlayers and also with one layer of fine grained sandstone. They are separated both from the underlying and overlying coarse grained sandstones and conglomerates by distinct bounding surfaces.

The claystones are greenish, greyish or patchy, maximum C_{org} content is 0.2 %. Thus certain organic productivity of the Lower Cambrian waters can be proved. Also some traces of primary carbonate (minute aggregates) can be found microscopically but very low porosity speaks against secondary weathering and decalcification.

Recrystallization of clayey matrix is lower than could be expected in the Lower Palaeozoic claystones. In places lower stages of anchimetamorphism can be observed accompanied by crenulation and nonpenetrative cleavage.

All the possible evidences were used in order to identify the depositional environment of the Paseky Shale. "Paper" lamination indicates quiet sedimentary environment, even though the lamination cannot be taken for seasonal. Somewhat elevated amounts of organic matter are also a good evidence for quiet sedimentation and partial anoxia. The discovery of adhesion ripples (Kinneya's ripples) made possible further specification: extremely shallow water. Slump structure in siltstone bed indicate some catastrophic event during the calm history. Linear structures indicate variable current directions. Thus sedimentary structures indicate basin with standing very shallow water and quiet sedimentation only temporary interrupted by aeolian or mudflow events. In order to specify whether these standing waters were marine (lagoonal environment) or freshwater (lacustrine environment) set of geochemical criteria was applied, as the analysis of indicative trace elements, analyses of water extracts, C_{org}/S ratios, etc. Complex of these methods speaks neither in favour of true marine nor typical freshwater environment. All the data cumulate near the boundaries of these two depositional environments. Thus it can be concluded that the basin was filled by brackish water and can be characterized as lagoon bordering continental and marine realms.

As said before (also Kukal 1971) the presence of sea southeastward from the continental Lower Cambrian Barrandian basin is suggested. Temporary rise of sea level could cause the flooding of nearby areas, intrusion of saline waters into alluvial plain and form the brackish lagoonal environment. This assumption is based only on the reconstruction of the character of sediments of the Paseky Shale and founds of the marine brachiopods farther to the southeast in the Rožmitál area in the Hořice sandstones. Thus no detailed image of marine transgressions and regressions during the deposition of the Holšiny-Hořice Formation could be offered. Nevertheless, the reconstruction of lagoonal

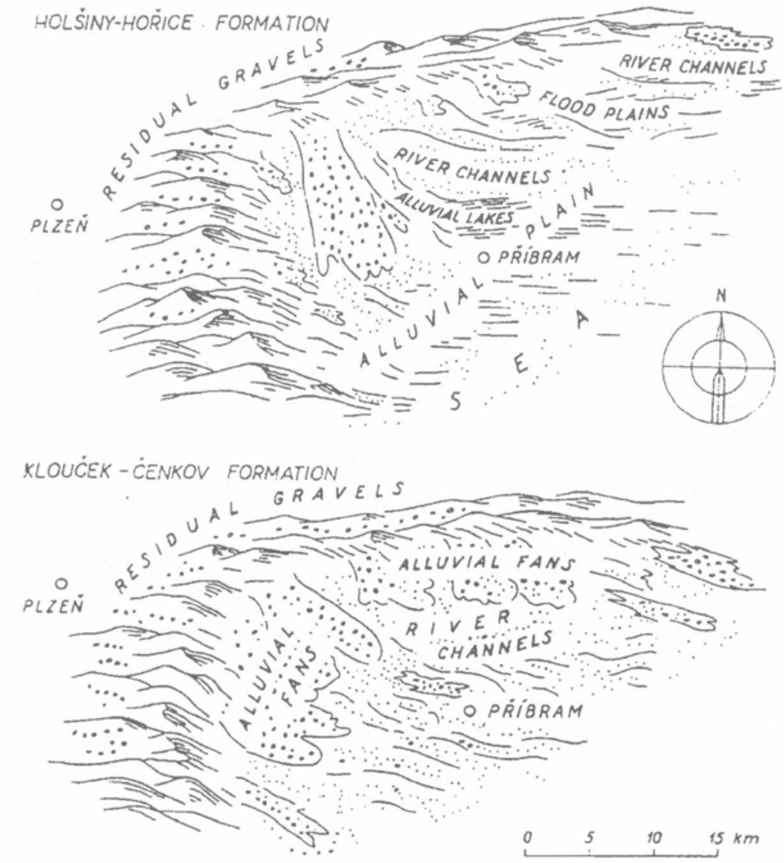

Fig. 3. Palaeogeographic reconstruction of the Lower Cambrian Holšiny-Hořice Formation (including the Paseky Shale) and the overlying Klouček-Čenkov Formation. The occurrences of the Paseky Shale are located mainly around the town of Příbram, i.e. near the possible contact between freshwater and marine environments (reconstruction from Z. Kukal 1971)

environment with brackish waters during the sedimentation of the Paseky Shale is not in contradiction with the palaeontological viewpoints (see Chlupáč et al. 1995). On the other hand, both methodical approaches explained the sedimentary environments of the Paseky Shale in very similar way.

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Translated by the author

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Sedimentologie barrandienských spodnokambrických paseckých břidlic

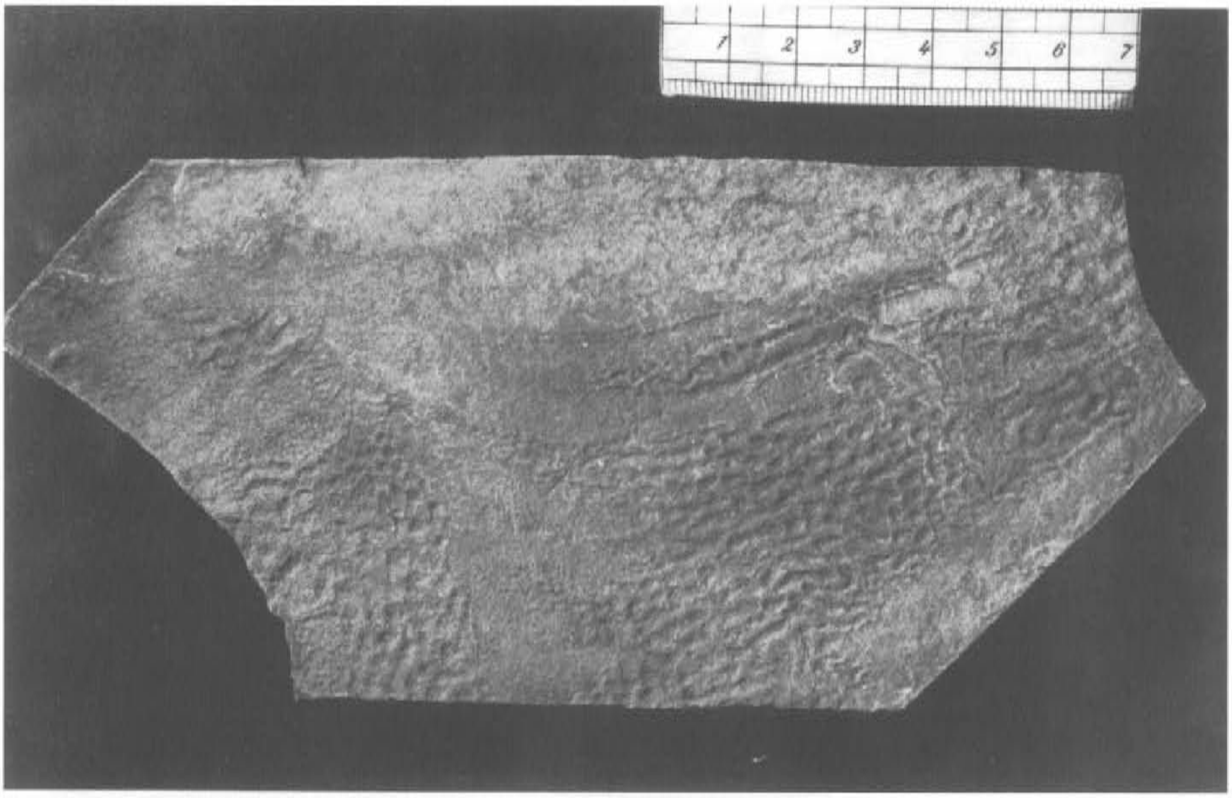
Pasecké břidlice tvoří souvislou, laterálně sledovatelnou polohu jemnozrnných, převážně jílových sedimentů mezi slepenci a pískovci holšinsko-hořického souvrství. Jílové břidlice mají proměnlivou prachovou příměs a přecházejí do prachovců. Vyskytují se i vložky jemnozrnných křemenných a drobových pískovců.

Šedozelené jílové břidlice obsahují až 0.2 % organického uhlíku, který je jednak jemně rozptýlen, jednak koncentrován do čoček a blan. Byly zjištěny i stopy primárního karbonátu ve formě drobných agregátů, zřejmě biogenního původu. Nízká porózita však vylučuje sekundární dekalcifikaci a intenzívnější zvětrávání. Obsah síry je sice minimální, primární pyrit však byl jistě přítomen a vlivem jeho oxidace došlo k odbarvování šedozelených jílových břidlic a vzniku skvrnité textury.

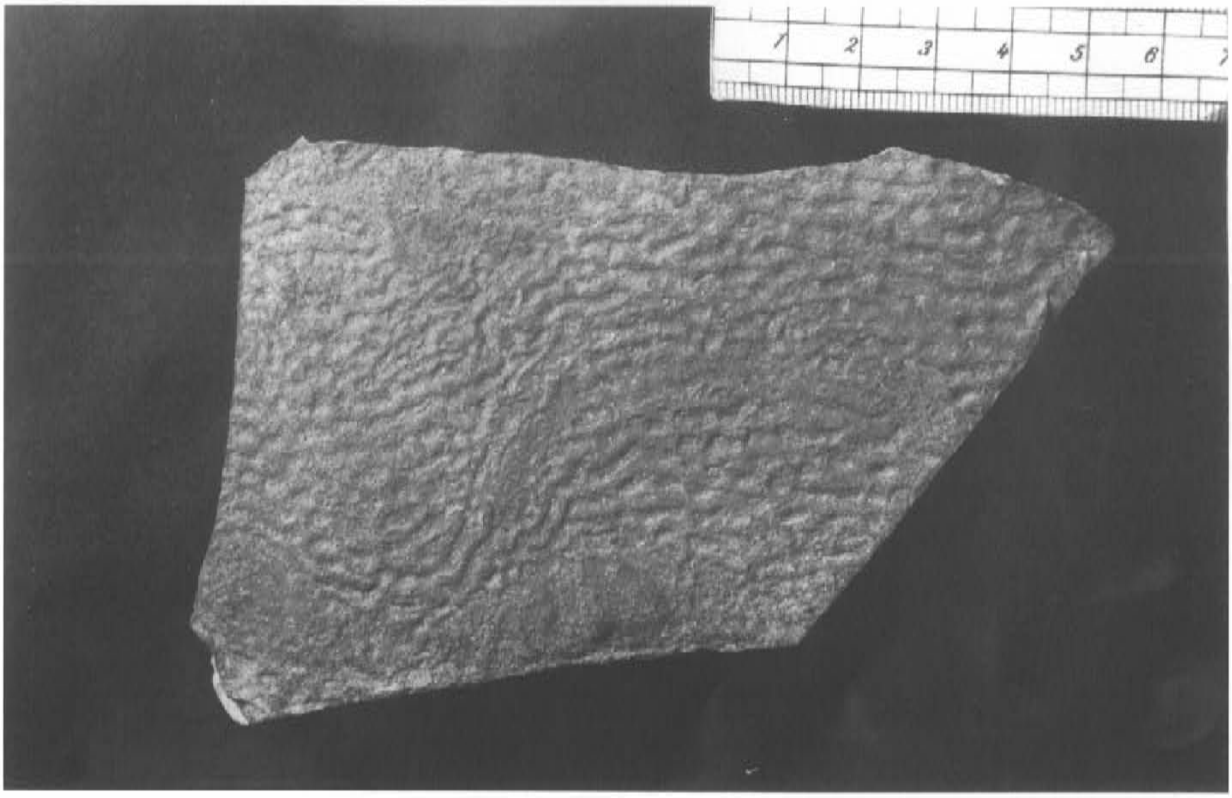
Podle složení jílových minerálů i podle rekrystalizace základní hmoty bylo posouzeno, že horniny jsou ovlivněny nejnižším stadiem anchimetamorfózy. Asociace jílových minerálů je pouze chlorit + illit, ze strukturního hlediska se vyskytuje i vráskování a šikmá nepenetrativní kliváž.

Výrazným texturním znakem je "papírová" laminace, která je však nepravidelná, a tedy nesezónní. Významným kritériem extrémně mělké vody jsou adhezní čeřiny, vznikající pohybem tenké vodní vrstvy, hnané větrem, po nezpevněném sedimentu. Byly zjištěny i skluzové textury, což znamená, že klidná sedimentace byla přerušena katastrofickou událostí. Lineární textury svědčí o proměnlivém proudovém režimu.

Komplex použitých geochemických kritérií, jako obsah boru, galia, lithia, analýzy vodních výluhů, poměr C_{org}/S, neprokázal přítomnost ani normální mořské vody, ani vody sladké. Z toho lze usuzovat, že pasecké břidlice sedimentovaly v lagunárním prostředí s brakickou vodou.



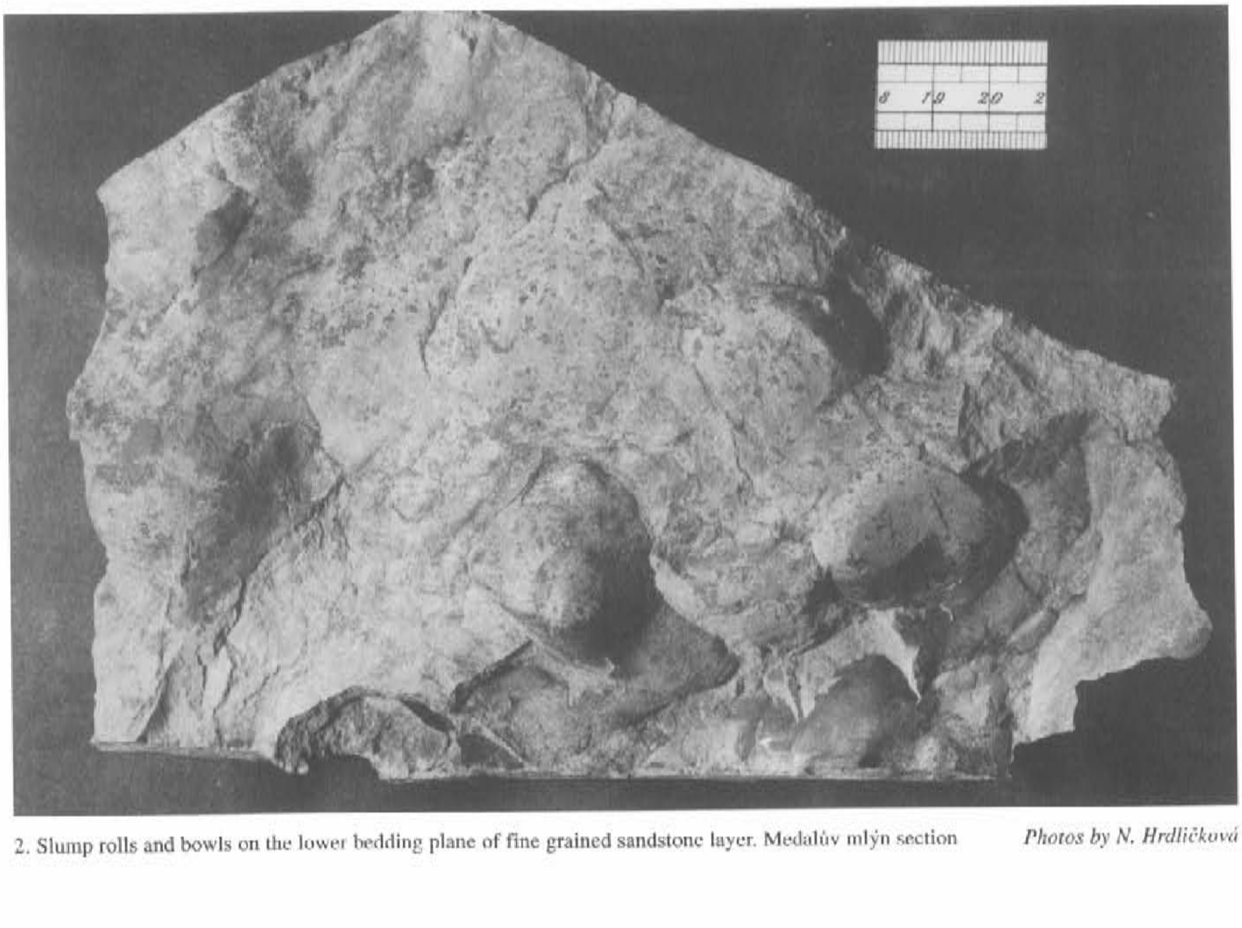
1. Adhesion ripples. Lower bedding plane of the siltstone layer. Medalův mlýn section



2. Adhesion ripples. Upper bedding plane of the siltstone layer. Medalův mlýn section

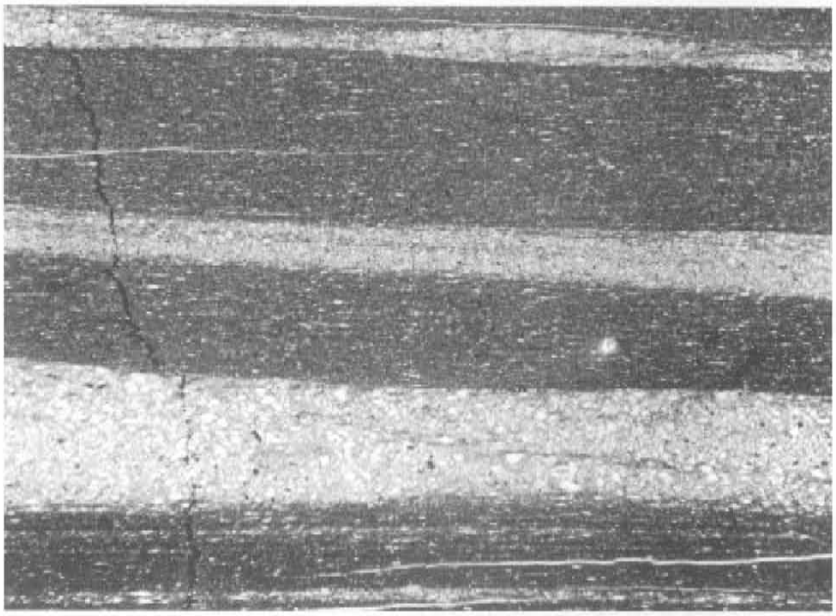
Photos by N. Hrdličková

1. Patchy claystone. "Pure" grey-greenish claystone with rusty patches which were formed by bleaching due to pyrite oxidation. Medalův mlýn section

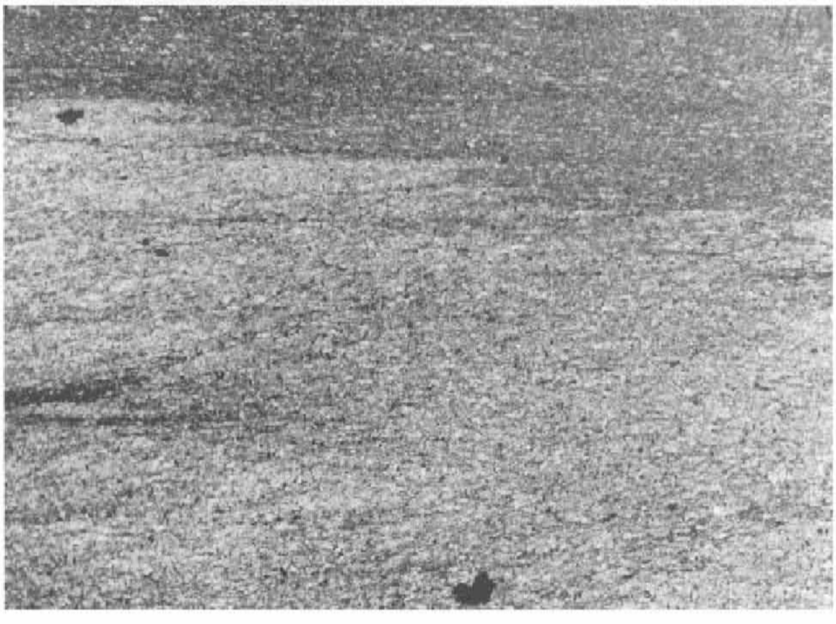


2. Slump rolls and bowls on the lower bedding plane of fine grained sandstone layer. Medalův mlýn section *Photos by N. Hrdličková*

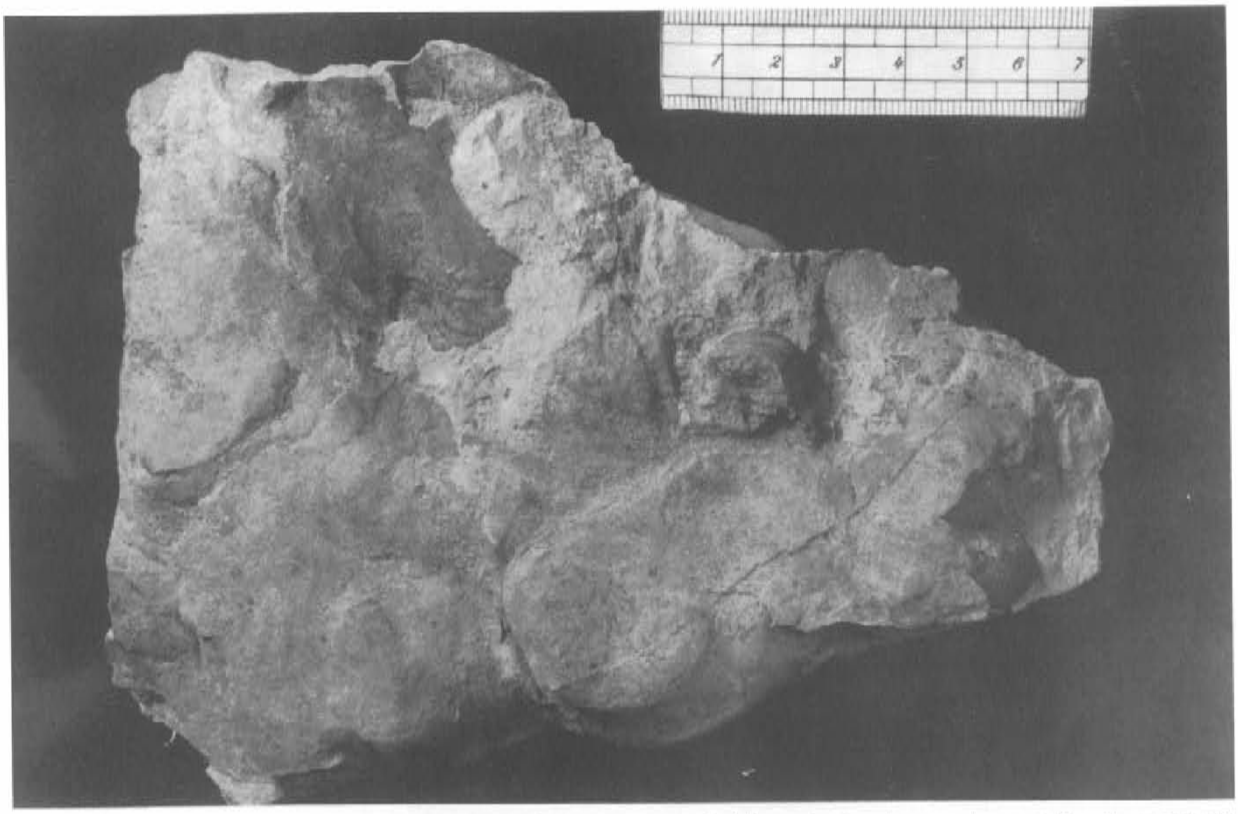
1. Two parallel oblique systems of thin tool marks on the siltstone bedding plane. Also minute skip marks are present. Pičín
Photo by N. Hrdličková



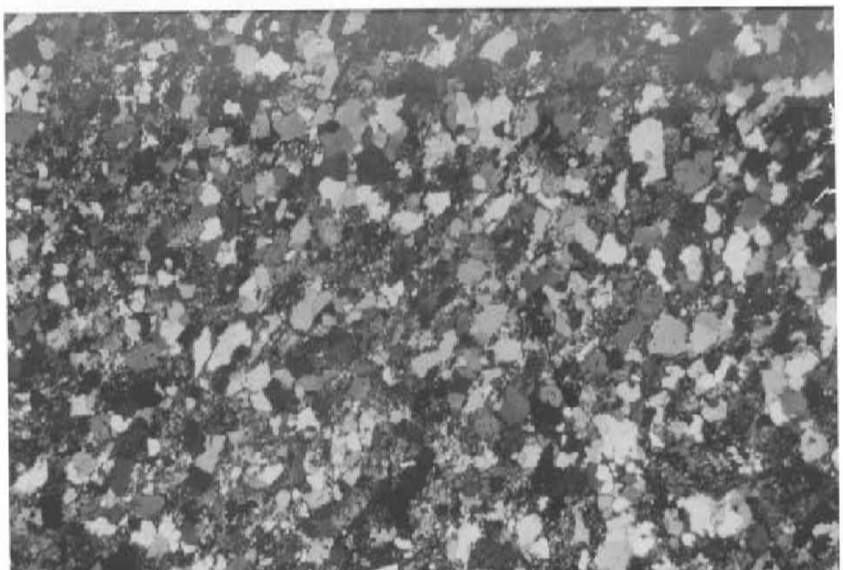
2. "Paper" silty lamination in the claystones. Sharply bounded laminae consist of quartzose silt. They are of variable thickness and irregularly spaced. Medalův mlýn section, x18.5 *Photo by D.Hejdová*



3. Boundary between the "pure" greenish claystone (top) and pale greenish silty claystone (bottom). Medalův mlýn section, x45
Photo by D. Hejdová



1. Sole marks on the deformed sandstone bed. Bowl-shaped casts are composed of fine grained sandstone and separated by clayey and silty streaks. Medalův mlýn section *Photo by N. Hrdličková*



2. Quartzose sandstone from the upper parts of the Paseky Shale section (Medalův mlýn, about one metre beneath the top). Quartzose sandstone is passing into a subgreywacke. Magnif. x21.7, polarized light *Photo by S. Bártlová*