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Paleogeography of the Jizera Formation (Late Cretaceous sandstones), Kokořín area, central Bohemia

Paleogeografie jizerského souvrství (svrchnokřídové pískovce) na Kokořínsku

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Abstract : Upper part of the Jizera Formation (Late Cretaceous, Middle to Upper Turonian) in the Kokořín area, central Bohemia, is described in terms of a detailed lithofacies analysis. Two basic lithological units are described and subdivided according to the sandstone lithologies, structures and types of cyclic development. The study of sedimentological criteria helps to reconstruct the sedimentary environment which is believed to be shallow inner shelf with migrating linear sand ridges. A model of hydraulic regime is proposed with prevailing southeasterly currents.

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Quartzose sandstones of the "quadersandstein" type of Skoček - Valečka (1983) are relatively well exposed in the vicinity of Kokořín (N of Mělník) and provide a good chance to characterize the tri-dimensional lithofacies architecture of the Jizera Formation (Middle to Upper Turonian).

From regional aspect, the sandstone sequence of the Jizera Formation (in text referred to as Kokořín sandstones) belongs to the Lusatian facies region of the Bohemian Cretaceous Basin being located close to the basin axis (Fig. 11).

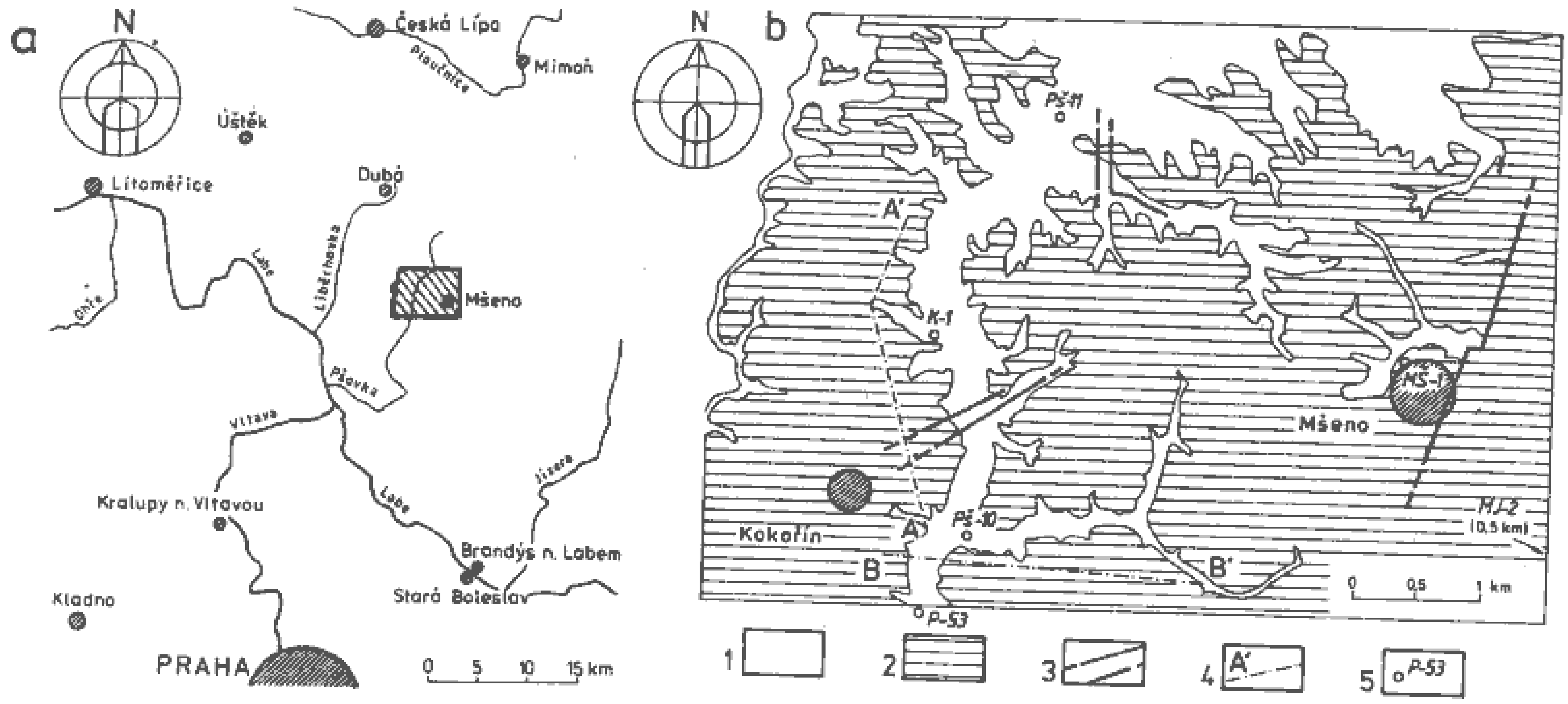
However, Middle to Upper Turonian sandstones of the quadersandstein type are also well exposed over large areas of northern Bohemia, Saxony and Silesia. Besides Kokořín, sedimentological analyses were done and are being done also in other parts of these areas : Milewicz (1965), Jerzykiewicz (1968), Klein (1962), Klein et al. (1967), Valečka (1974, 1979, 1989), Wojewoda (1986), Klein and Tajovský (1986).

The Kokořínský důl Valley and the adjacent gorges and canyons are very popular for their remarkable geomorphological phenomena. Landscape morphology is strongly influenced by volcanic bodies of Tertiary age which rise above the flat sandstone table forming such elevations as Šibenec, Čepička, Víno etc. Bottoms of the valleys lie almost 150 m below the surface of the highest structural plains.

Unique rock forms originated at the mouth of the Močidla Gorge and east of Jestřebice: up to 6 m thick layer of resistant limonitic sandstones and conglomerates protects the underlying sandstones from erosion thus forming columns known as "Pokličky" (caprocks, Pl. I). Many various pseudokarst forms of micro- and mesoscopic scale including rock arches and windows, rock shelters, ledges, cavities and potholes and several types of honeycombs occur in the vicinity of Kokořín. The only true rock city in the area -"Bludiště" (Labyrint) - is located 2 km NW of Mšeno.

The study area, where sedimentological research combined with geological mapping was carried out, lies between Kokořín, Jestřebice, Mšeno and Kanina covering 30 sq.km (Fig. 1).

Results of four boreholes deeper than 100 m and of many shallower ones were taken into account. The locations of all boreholes used in this study are shown in Fig. 1b. The most important borehole MJ-2 Stránka (depth 1,157.5 m) was situated 1.5 km SE of Mšeno. The drill cores were clearly documented by Klein (1965a,b,c) and the finds of fossil fauna reported by Klein and Pražák (1965) enabled correlations between lithostratigraphical and biostratigraphical units.



1. a - Index map showing the location of the study area in central Bohemia. b - Geological sketch map of the study area. 1 - Lower Sandstone Sequence, 2 - Upper Sandstone Sequence, 3 - faults, 4 - sections A-A' and B-B' (illustrated in Figs. 6 and 7), 5 - location of the boreholes.

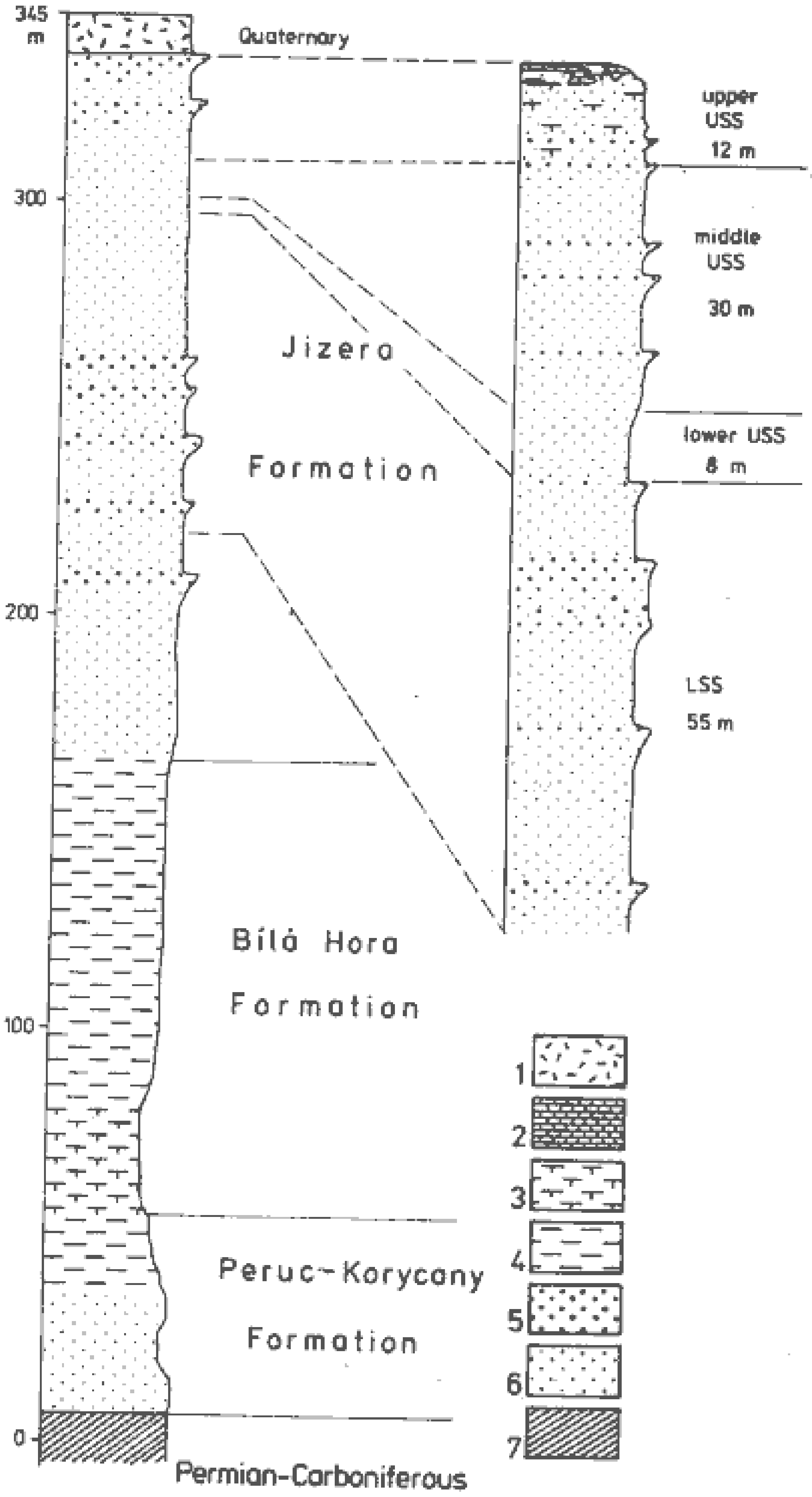
Stratigraphy and lithology of the sandstones in the Kokořín area

One hundred vertical lithologic sections were measured in the study area and another seven in its close neighbourhood (Fig. 3). In cases the course of lithohorizons could not be deduced easily, horizontal correlation sections were made.

The main stress was put on lithological aspects : medium and maximum grain size, matrix type, coarser fraction accumulations, sequence and cyclicity analyses. Besides, there were described also the fossil content and bioturbation structures. Sedimentary structures of cross-bedding type were documented for paleocurrent analysis. A limited number of measurements of elongate pebble orientation were taken.

In thin sections, the relation between polycrystalline quartz grains and grain size was studied as well as internal structures and shape of quartz grains.

In the vicinity of the studied area, the Cretaceous sediments overlie a sequence of the Carboniferous and ?Permian deposits up to 800 m thick. The Cretaceous stratigraphy is illustrated in Fig. 2 (MJ-2 Stránka borehole).



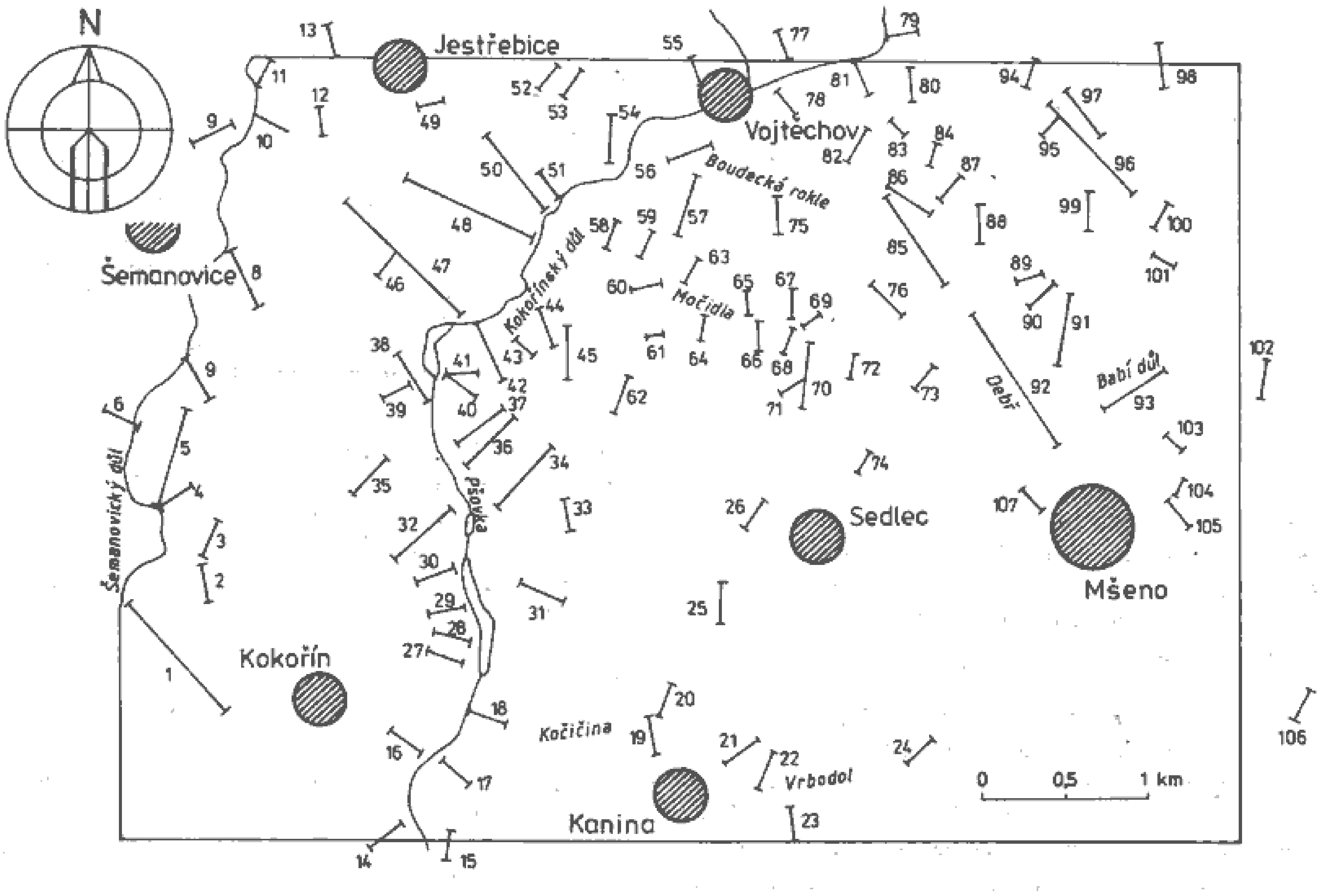
2. MJ-2 Stránka borehole (left; lithology after Klein, 1965a) and a typical section through the Upper Cretaceous sediments exposed in the study area. Average thicknesses observed in the field are given. 1 - Quaternary sediments, 2 - biomicritic limestones, 3 - marlstones, 4 - siltstones and calcareous siltstones, 5 - quartz pebbles, 6 - fine- to medium-grained sandstones, 7 - footwall of the Upper Cretaceous sediments.

Table 1
Correlations between the herein used and formerly used stratigraphical units

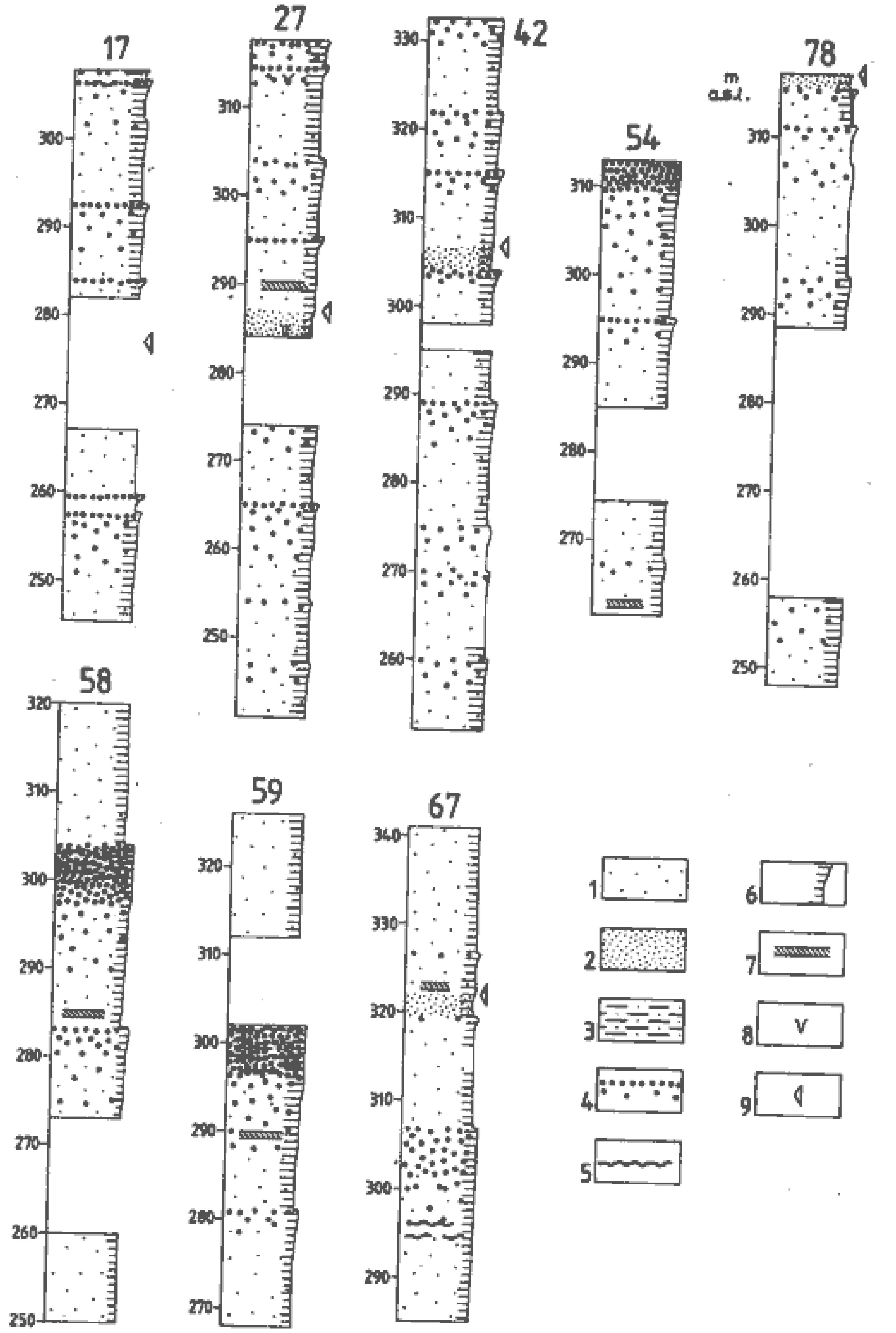
A.Frič, 1885	Č. Zahálka 1895	V. Klein 1966	this paper	
Kanina Bryozoic Member bryozoické vrstvy u Kaniny	IXd	3rd cycle	Jizera Formation	Upper Sandstone Sequence, upper part
Choroušky Trigonia Member chorouŝecké vrstvy trigoniové	IXc			
Second Kokořín Quader druhý kokořínský kvádr	IXb			Upper Sandstone Sequence middle part
Hleďsebe Marlstone Intercalations hleďsebské opukové vložky	IXa			Upper Sandstone Sequence lower part
First Kokořín Quader první kokořínský kvádr	VIII	2nd cycle (part)		Lower Sandstone Sequence

The thickness of the Upper Cretaceous deposits increases from SW to NE, i.e. from Mělník (118.5 m in the MJ-10 Vavřineč borehole) towards Mšeno (327.8 m in the MJ-2 Stránka borehole). In the same direction also the thickness of the Jizera Formation increases : from less than 150 m at Mělník to 250 m at Mšeno, thus substantially exceeding the thickness of the Bílá hora Formation (26 to 65 m) as well as the thickness of the Peruc-Korycany Formation (40 to 50 m). Upper portion of the Jizera Formation has been eroded from a major part of the area and the overlying Teplice Formation marlstones persisted only in several small relics behind the limits of the area studied.

The sandstones cropping out in the Kokořín area belong to the upper part of the Jizera Formation as defined by Čech et al. (1980). Previously they were stratigraphi-



3. A map showing the locations of the lithologic sections measured in the Kokořín area.



4. Stratigraphic sections from the Kokořínský důl Valley (17, 27, 42, 54, 78) and from the Močidla Gorge (58, 59, 67). 1 - medium-grained sandstones, 2 - fine-grained sandstones, 3 - calcareous sandstones passing into sandy limestones, 4 - quartz pebbles, conglomerate beds, 5 - limonitic cement, 6 - lamination, 7 - cross-bedding, 8 - bioturbation structures, 9 - lower/middle USS boundary.

cally subdivided by Krejčí (1869), Frič (1885) and by Č. Zahálka (1895). These stratigraphical divisions did not, however, respect the diachronous character of the unit boundaries. As Čech et al. (1980) point out, stratigraphical units of the above mentioned authors are of a very limited local importance and lead to various misunderstandings in regional correlations.

In studies based on the results of the Mělník-Ještěd borehole series, Klein (1965d, 1966) described cyclic sedimentation from the eastern margin of the Lusatian facies region with three upwards coarsening cycles (see Table 1 and Fig. 2). The first cycle includes the Bílá Hora Formation and lower part of the Jizera Formation, i.e. the Lower Turonian to the lower part of the Middle Turonian. The second and the third cycles constitute the middle and the upper part of the Jizera Formation, i.e. the upper part of the Middle Turonian and the lower part of the Upper Turonian respectively.

However, Klein concentrated on broader aspects of sandstone lithology within the Jizera Formation and his cycles have rather a regional character. The well-exposed surface localities in the studied area allow the present author to define a great number of more or less distinct cycles of smaller scale (thicknesses 4 to 22 m) usually starting with fine-grained sandstones and ending with conglomerate beds. Lithological units of the sandstone facies in the Kokořín area proposed in this paper are based on grading cyclicity, grain size parameters and carbonate content.

Upper and Lower Sandstone Sequences are distinguished with the Upper Sequence differentiated into lower, middle and upper parts. Relations to the formerly defined units are illustrated in Table 1. In this sense, the Upper Sandstone Sequence applies to the third cycle of Klein (1966) and the Lower Sandstone Sequence represents the upper part of the second cycle of Klein. Upwards coarsening cycles of smaller scale are developed in the typical "quadersandstein" sandstones of the Lower Sandstone Sequence and of the middle part of the Upper Sandstone Sequence.

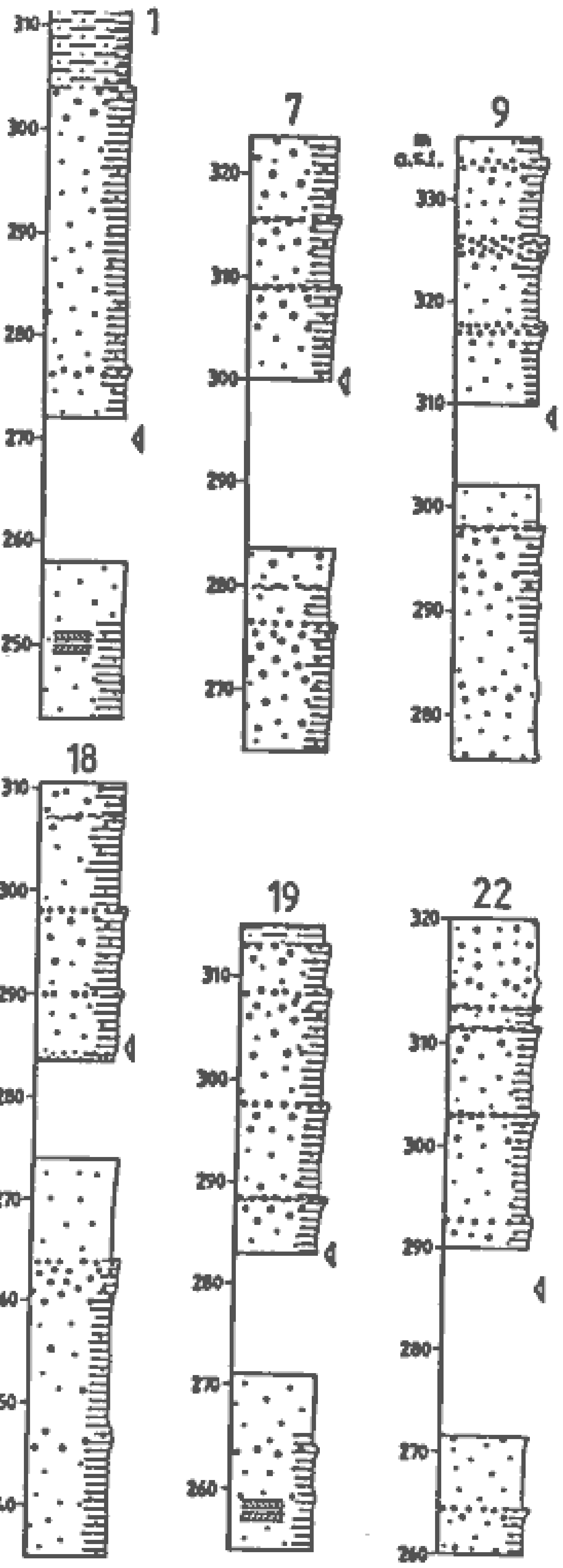
Lower Sandstone Sequence (LSS)

The character of the LSS base or its respective equivalent (see Table 1) has been specified neither by Frič (1885) and Č.Zahálka (1895), nor by B.Zahálka (1941). It can be described as a gradual change from marly sandy siltstones to silty sandstones within the second cycle of Klein (1966). Its upper boundary is characterized by the sharp contact with fine-grained sandstones with poor clay matrix of the USS.

The Lower Sandstone Sequence as determined above ranges from the altitude of 165 m to 244.3 m above sea level (or, possibly, 296.8 m - see USS, lower part) in the MJ-2 Stránka borehole with a thickness of 78 m or more. The LSS is incomplete in other boreholes with one of the boundaries missing : MŠ-1 Mšeno (thickness 90.5 m), PŠ-10 (59 m), PŠ-13 (34 m) and P-53 (38 m). The PŠ-10 data supplied by field observations (Sections 17, 18) indicate that the total thickness of the LSS is 108 m at the mouth of the Kočičina Gorge. Middle Turonian age of the LSS is documented by the finds of *Inoceramus lamarcki* Park. at the depths of 110.6 and 112.65 m in the MJ-2 Stránka borehole (Klein and Pražák, 1965).

The exposed part of the LSS, usually steep rock walls, increases in thickness from SW to NE as far as to the Močidla Gorge. At the Kočičina Gorge mouth, the observed thicknesses vary between 18.5 and 21.5 m (Sect. 16, 17) but reach 69 to 71 m in Sections 48, 51 and 58 (mouth of the Močidla Gorge). This fact is explained by the upper boundary of the LSS lying some 50 m higher at Močidla (dipping at 1.5° to SSW) while the altitude difference of the erosional base - the Pšovka Creek - is less than half as big. NE of Močidla, the rock walls are not so high and the erosional base rises more quickly. The largest exposures of the LSS in the northern part of the study area are situated E of Jestřebice (Sect. 52 and 53, thickness 45 m), SE of Vojtěchov (Sect. 78, 46 m) and NE of Čepička Hill (Sect. 94 to 96, 25 m). In the vicinity of Mšeno, the USS prevails in outcrops and the LSS is well exposed only in the valley of Babí důl.

The Lower Sandstone Sequence is composed of quartzose sandstones with poor clay or carbonate matrix in places. Porosity comprises about 30 % of the sandstone volume. As revealed by microscopic studies, sandstones are poorly sorted, with grain size varying between 0.15 and 0.6 mm, occasionally reaching 2 mm. Variable



5. Stratigraphic sections from the Šemanovický důl Valley (1, 7, 9), from the Kočičina Gorge (18, 19) and Vrbodol Gorge (22). For explanations see Fig. 4.

amount of coarser particles including pebbles is present according to the position in a cycle. Contacts between the grains are tangential or long, some coarser grains are corroded. Average grains size is given in Table 2 and mineral composition in Table 3.

Internal structure of quartz grains was studied in thin sections. Coarser polycrystalline quartz grains (over 0.5 mm in diameter) are composed either of 2 to 3 crystals (type I) or of 5 and more crystals (type II). Abundance of a particular type varies rather laterally than vertically with type II slightly prevailing in general. In grains of type II, crystals are isometric or morphologically elongated

Table 2

Grain parameters and sedimentological characteristics of the Jizera Formation sandstones in the Kokořín area. Data in columns 1 through 7 based on thin section studies

qs - quartzose sandstones, cs - calcareous sandstones, l - biomicritic limestones, a - average value, b - value for the coarse fraction (coarser than 0.5 mm), d_S/d_L - short axis over long axis lengths, LSS - Lower Sandstone Sequence, USS - Upper Sandstone Sequence

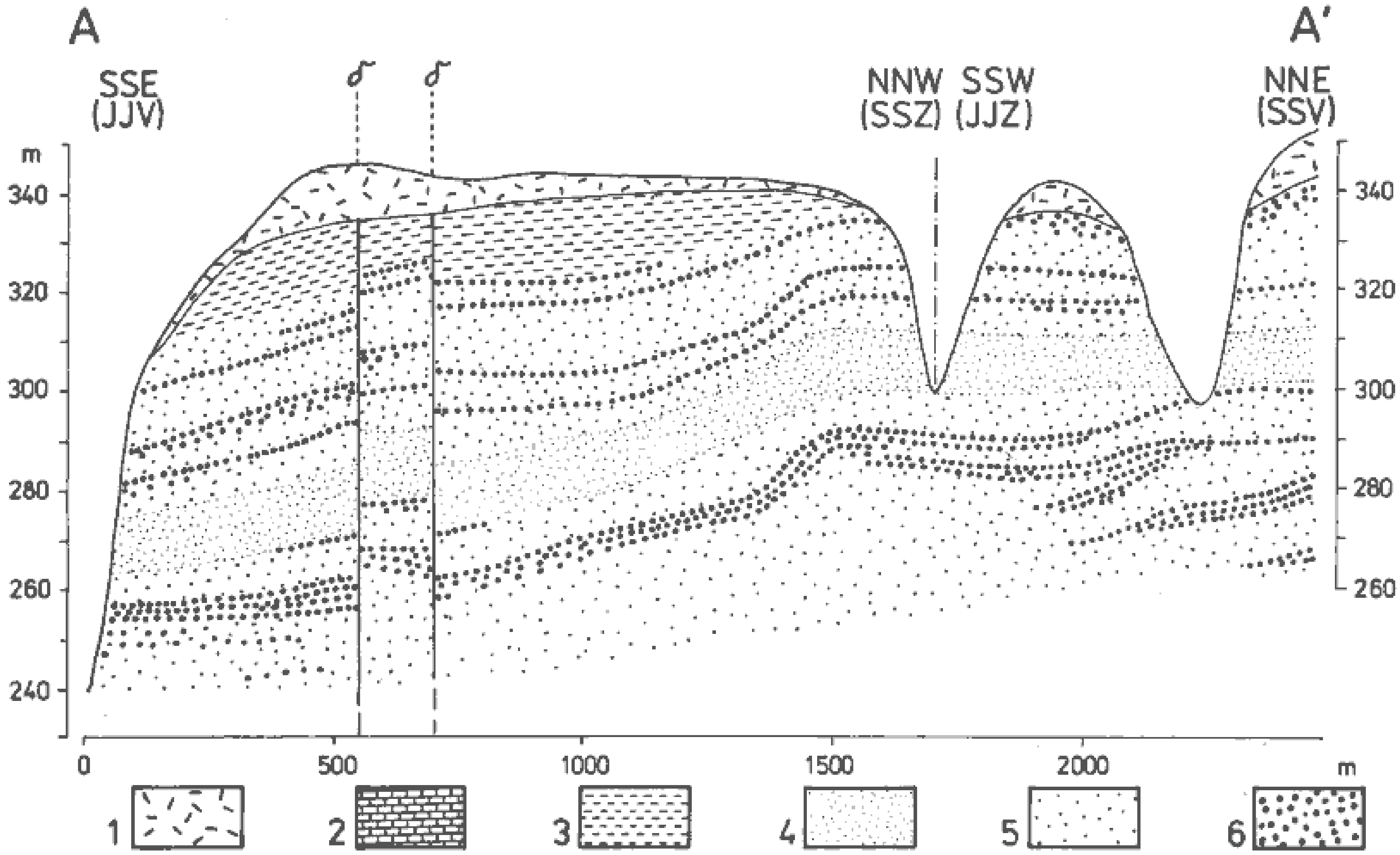
Unit		[1]Average grain size (mm)	[2]Prevailing roundness of grains	[3]Polycrystalline grains (%)		[4]Quartz grains and pebbles of metamorphic origin	[5]Elongation of polycrystalline grains d_S/d_L b	[6]Sorting	[7]Fossil fauna content (%)	[8]Bioturbation	[9]Smaller-scale cycle thicknesses (m)
				a	b						
USS, upper part	l	0.3	angular	10		absent	-	poor	40 - 50	-	-
	c_s	0.15 to 0.8	angular to suboval	4 - 7	40 - 50	present	0.5 - 1	poor	0 - 5	-	-
	q_s	0.15 to 0.6	angular to suboval	5	15 - 20	present	0.5 - 0.8	poor	0 - 3	-	-
USS, middle part	q_s	0.5	angular to subangular	7	50	present	0.75 - 1	medium to poor	0 - 2	present	3 - 15
USS, lower part	q_{cs}	0.15	angular	3 - 7		present	0.3 - 0.8	good	0 - 5	common	-
LSS	q_s	0.35	angular to subangular	5 - 15	50	present	0.5 - 1	medium to poor	0 - 2	rare	5 - 22

Table 3

Mineralogical characteristics of the Jizera Formation sandstones in the Kokořín area

qs - quartzose sandstones, cs - calcareous sandstones, l - biomicritic limestones, LSS - Lower Sandstone Sequence, USS - Upper Sandstone Sequence

Unit		Feldspar (%)	Glauconite (%)	Rock fragments	Heavy minerals recorded in thin sections	Heavy minerals in the MJ-2 borehole (after Klein, 1965c)
USS, upper part	l	-	-	none	none	-
	c_s	0 - 5	0 - 3	chert, intraclasts of carbonate rocks	tourmaline, zircon, rutile, garnet	anatase staurolite
	q_s	0 - 2	-	chert	zircon	
USS, middle part	q_s	0 - 2	present	chert	tourmaline	
USS, lower part	q_s c_s	1 - 5	0 - 1	chert	tourmaline, rutile, zircon	
LSS	q_s	0 - 3	present	chert	tourmaline, zircon	tourmaline, zircon, rutile, anatase, garnet



6. A section along the Kokořínský důl Valley. For location see Fig. 1. 1 - Quaternary sediments, 2 - biomicritic limestones, 3 - calcareous sandstones to sandy limestones, 4 - fine-grained sandstones, 5 - medium-grained sandstones, 6 - conglomerate beds, quartz pebbles.

having shingle structure. In Mlčeň and Kočičina gorges, the abundance of shingle structure polycrystalline quartz grains decreases upwards within the LSS. Intercrystalline boundaries are slightly curved or sutured, lobate in type I grains and sutured in type II grains.

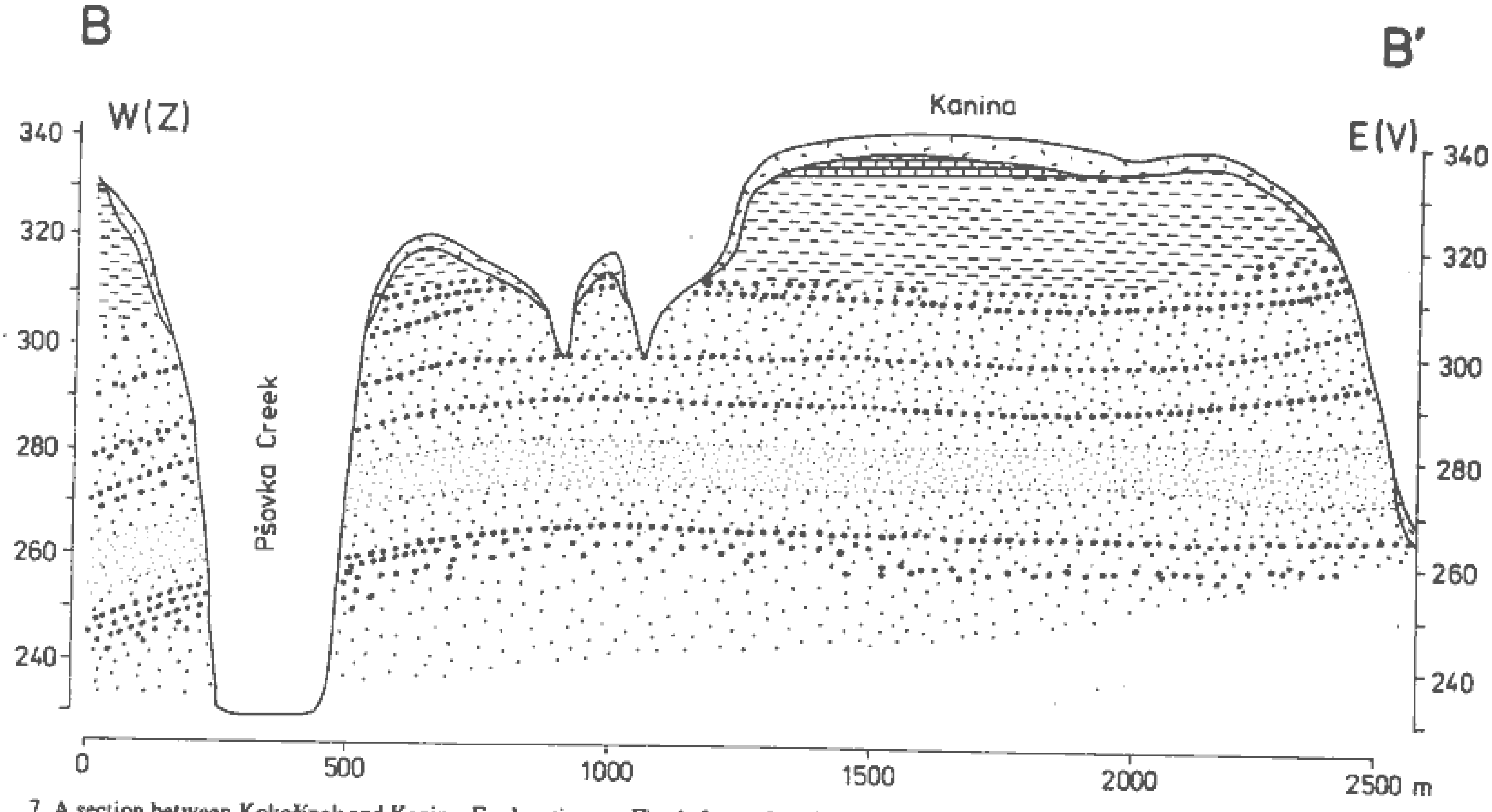
Lower parts of the smaller-scale cycles within the LSS have medium grain sizes between 0.25 and 0.4 mm. Mixing of laminae of different grain size is typical. In the direction upwards, quartz pebbles 2 to 3 mm in diameter occur and, in the course of a few metres, they cluster into small isometric accumulations. Pebbles 7 to 12 mm in diameter appear in the upper parts of the cycles and gradually increase in number and join the accumulations of finer particles. Cycles are ended with conglomerate beds (single, doubled or trippled) usually several tens of centimetres thick. This scheme generally applies also to the cycles of the middle part of the USS, although the latter are of smaller thicknesses (see Table 2 and Figs. 6, 7).

The uppermost part of the LSS is formed by medium-grained sandstones resembling the sandstones in the lower parts of the underlying cycles in grain size. Thickness of this sandstone body varies from 6 to 13 m in the valleys of Kokořínský důl and Šemanovický důl, from 5 to 13 m in the Močidla Gorge and remains stable at 7 m in the gorges of Kočičina and Vrbodol. In the western quarter of the study area, a poorly developed upwards coarsening cycle is formed in this body whereas in major part of the area no grading is developed. South of the line connecting Sections 3, 46, 41, 20, 92 and 93, this part of the LSS is represented by sandstones having massive structure and no lamination. In other parts of the LSS, subhorizontal lamination is the most frequent structure.

The lowermost cycle of the LSS is not exposed in the area and therefore not discussed here. Its top lies 21 to 38 m below the bottom of the Kokořínský důl Valley (see Hercog, 1965, 1966).

Cyclic sedimentation of the LSS is represented by a single upwards coarsening cycle at the Kokořín Castle (Sect. 32, see also Frič, 1885 and B. Zahálka, 1940). In other parts of the area, another one to three cycles ended with conglomerate beds may be developed within the LSS. South of the Kokořín Castle, a single cycle is developed with a variable number of conglomerate beds at its top : second bed (Sect. 15, 17, 34) lying 2 m above the first, or two more beds (Sect. 16, 31, 33) about 1.5 m from each other. Minor inhomogeneities in cyclicity occur in Sections 27 and 18.

North of the Kokořín Castle (Sect. 36 to 45), the LSS becomes generally coarser. Pebbles up to 10 mm in diameter are present either in the whole uppermost 30 m of the LSS (Sect. 37), or concentrated into two intervals thus forming two upwards coarsening cycles 6 to 10 m and



7. A section between Kokořínek and Kanina. For location see Fig. 1, for explanations see Fig. 6.

20 m thick. The upper cycle is differentiated into two smaller cycles in Sections 42 to 44. At the top of the upper cycle, conglomerate bed may be doubled with the second bed lying 2.5 m (Sect. 43) to 6 m (Sect. 40) above the first, or even trippled with the beds 0.3 and 1 m apart (Sect. 45). Thickness of the lower conglomerate bed reaches as much as 1.5 m in Section 48.

In the gorges of Kočičina and Vrbodol, the LSS is imperfectly exposed. 5 m below the upper boundary of the LSS, 3 to 13 cm thick conglomerate bed is developed. Coarsening upwards trends were, however, recorded only in the lower part of Vrbodol (Sect. 21, 22).

In the gorges of Močidla and Boudecká rokle, two upwards grading cycles are formed. The lower cycle has a thickness of 10 m (Sect. 58) to 13 m (Sect. 57) but less than 1 km to the east the signs of grading almost disappear and the cycle is represented only by sandstones with a 30 cm thick conglomerate bed at their top (Sect. 66). In the Boudecká rokle Gorge, the lower cycle is even more distinct than the upper cycle. The upper cycle in the Močidla Gorge has a constant thickness of 21 to 22 m with the exception of the Apatyka Gorge - 16 m (Sect. 64, 66). It is ended by a conglomerate bed, sometimes doubled (Sect. 57) which has a thickness of up to 7 m (Sect. 58, 59) but grows less distinct to the east passing into a sandstone with high content of 5 to 10 mm pebbles. Limonitic cement occurs in a band running along the Močidla Gorge to Jestřebice and is bound primarily to the upper cycle conglomerates.

Coarse-grained sandstones with accumulations of small pebbles (up to 5 mm) alternating with medium-grained sandstones build up the LSS between Vojtěchov and Brusné (Sect. 77 to 79). In Section 81 W of Ráj, upwards grading cycle is developed with 17 m of sandstones containing quartz pebbles (up to 7 mm in diameter) and 50 cm thick conglomerate bed at its top. In other sections closer to Mšeno, coarser admixture is almost absent.

The top of the upwards coarsening cycle of the LSS can be observed also in the Šemanovický důl Valley, on the western edge of the study area. It is represented by 9 to 11 metres of coarse-grained sandstones with pebbles up to 10 mm in diameter, ended by a conglomerate bed. In Section 2, three beds are developed with the second and third lying 0.7 and 4 m above the first. More than one cycle can be observed in the Šemanovický důl Valley closer to Jestřebice : two cycles 12 and 18.5 m thick are formed in Sections 9 to 11, the upper cycle being divided into two parts in Section 11.

East of Jestřebice (Sect. 52, 53), cycles of smaller scale are developed and the LSS (45 m thick in outcrops) is terminated with 8 m of sandstones with quartz pebbles followed by 3 m of conglomerates. In the uppermost two metres of the LSS, matrix was replaced by limonite. Limonitic sandstones and conglomerates E of Jestřebice and in the Močidla Gorge were once connected, they lie at the same altitude and follow the same lithostratigraphical horizon, i.e. the top of the upper cycle of the LSS.

Upper Sandstone Sequence, Lower Part

The boundary between the Lower Sandstone Sequence and the Upper Sandstone Sequence (USS) is exposed only rarely, more often it is covered by deluvial sediments. The onset of the fine-grained sandstones of the USS is sharp, five centimetre thick bed of quartz pebbles lies at the top of the LSS in the Babí důl Valley (Sect. 93) whereas in the Močidla Gorge (Sect. 67) the boundary between the two sequences is represented only by an admixture of pebbles up to 7 mm in diameter.

Lower part of the USS corresponds to the Member IXa of Č. Zahálka (1895) - see Table 1. In the MJ-2 Stránka borehole (Fig. 2), it occupies an interval 296.8 to 301.3 m above sea level and its thickness is 4.5 m. The observed thickness in the MŠ-1 Mšeno borehole is 2 m (351 to 353 m a.s.l.) with the upper part eroded.

Thickness of the lower part of the USS is approx. 10 m in the valleys of Kokořínský důl and Šemanovický důl south of the line Březinka-Hlučov. The best outcrops were documented in Sections 3, 30 and 35. Farther to the north and to the east, the thickness drops to 1 to 3 m at Vojtěchov, Jestřebice and in the Močidla Gorge (Sect. 67 - 2.5 m). In the gorges of Kočičina and Vrbodol, the thickness decreases to the east with only 4 m in Section 24.

In the vicinity of Mšeno, lower part of the USS is well exposed but usually small in thickness : 4 m in the rock city of Bludiště, 1-2 m north of Romanov, 1-2.5 m in the Debř Valley, 6 m in the upper part of the Babí důl Valley and 5 m in western Mšeno.

Sandstones of the lower part of the USS are clearly recognizable by their lithology. They are finer than any other sandstones in the area and they are better sorted. Their unique lithology and wide distribution make them an important horizon suitable for regional litho-stratigraphical correlations. Various parameters including grain size and mineral composition are given in Tables 2 and 3. The sandstones are yellow in colour, quartz grains comprise 70 to 90 % of the rock volume, poor clay matrix is present in the interstices.

The study of thin sections showed that all fine and medium size quartz grains (besides chert grains which occur rarely) are monocrystalline, undulosity is 35 to 65 %. At the top of the lower part of the USS, coarser quartz grains (0.5-1.5 mm) often occur as admixture. 10 % of these are polycrystalline, often composed of many mosaic-arranged crystals. About 10 % of the poly-crystalline grains (especially those very coarse) have shingle structure and may be strongly elongated.

Interbeds of calcareous sandstones occur especially in the upper portion of the lower part of the USS, 10 to 15 cm thick, much harder than the surrounding sandstones, with their margins imperfectly bounded. In Sections 21 and 30, these calcified sandstones lie at three levels one above another. Quartz and feldspar grains comprise 60 to 70 % of the rock volume. The grains are cemented and often corroded by poikilitic crystals of calcite up to 5 mm in length. Fragments of molluscs are also present in the calcified interbeds.

The fine-grained sandstones gradually pass into marlstones to the SW of the study area. Also in the study area these sandstones are slightly coarser towards NE and decrease in thickness in the same direction. In the northeastern part of the study area, the lower part of the USS is therefore less distinct and can be confused with a basal part of a smaller-scale cycle. Upper boundary of the lower part of the USS is defined as a more or less gradual onset of medium-grained sandstones of the middle part of the USS. No conglomerate beds are developed at the boundary.

Upper Sandstone Sequence, Middle Part

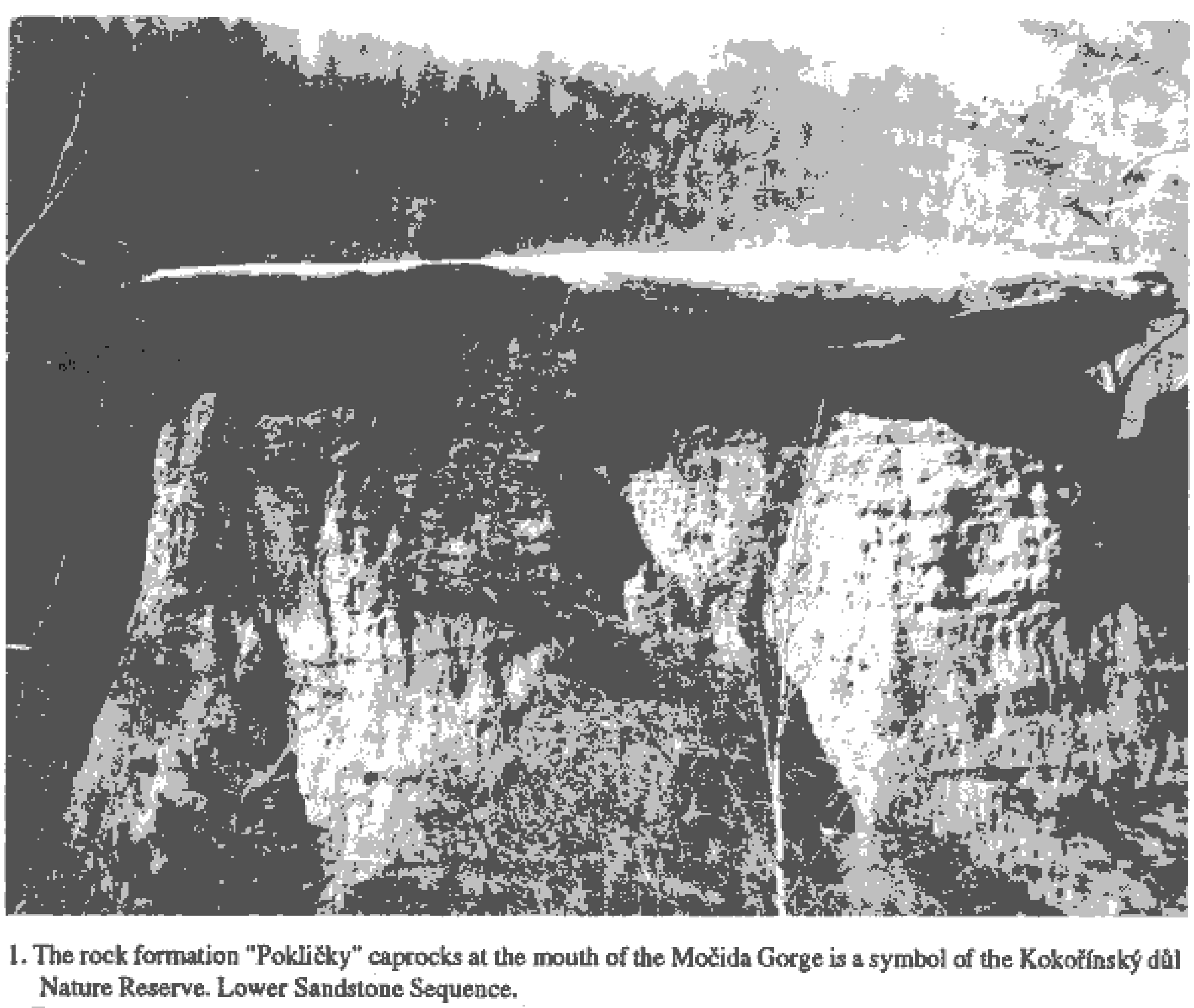
With the exception of the northeastern part of the study area cyclic sedimentation is a characteristic feature of the middle part of the USS. It corresponds to the LSS in many respects the most typical of which is the grading cyclicity. Medium- and coarse-grained sandstones form the main part of the cycles. Some grain parameters and mineral content are given in Tables 2 and 3. Porosity is 30 to 35 % of the rock volume. Clay matrix fills only a minor part of the interstices.

Most of the polycrystalline quartz grains observed in thin sections are composed of less than 5 crystals. Intercrystalline boundaries are usually sutured, crystals are lobate, isometric. Elongated crystals uniformly oriented within the grain are rare.

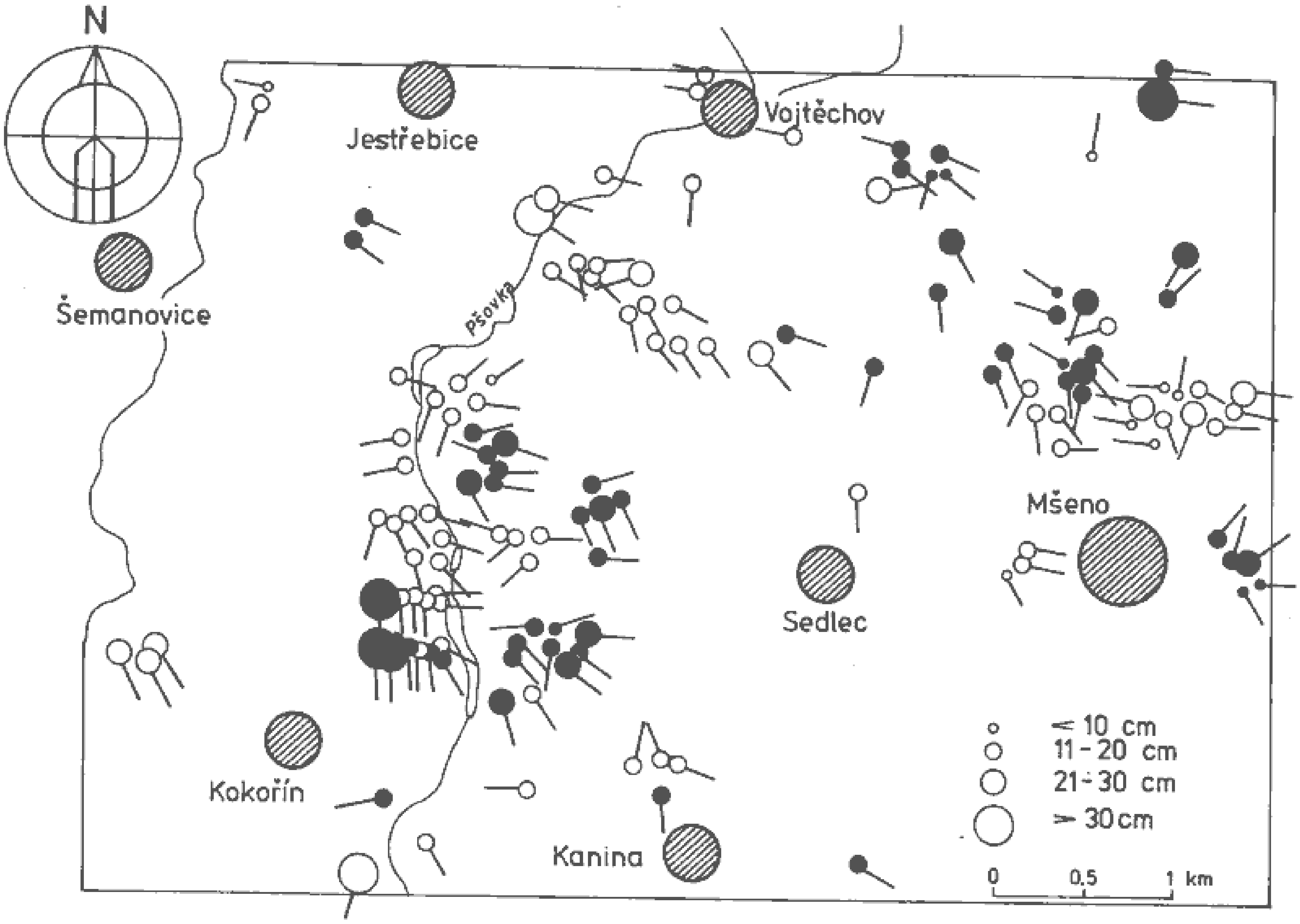
Thicknesses of the middle part of the USS are decreasing eastwards and attain only 10 m SE of Mšeno (8.7 m in the MJ-2 Stránka borehole). In Section 74 N of Sedlec the thickness is still small - 22 m. Thicknesses in the valley of Šemanovický důl (W margin of the area) vary between 29 m and 40 m, in the central part of Kokořínský důl between the Kokořín Castle and Hlučov 24 to 35 m, usually with the upper boundary inaccessible. The maximum thickness was recorded in the lower part of the Kokořínský důl Valley (Sect. 14) - 50 m. The lowermost 1-4 m of the middle part of the USS often have a bimodal grain size distribution with modes 0.15-0.4 mm and 2-3 mm.

In the valley of Kokořínský důl, grading within the cycles is not very significant but conglomerate beds at tops of the cycles are well developed and up to 50 cm thick. Three cycles are usually present, first two cycles are 5 to 9 m thick with the second cycle having a relatively good grading. The third (uppermost) cycle is 9 to 15 m thick and may be divided into two cycles (Sect. 17, 27).

Also in the gorges of Kočičina and Vrbodol 3-4 cycles are developed, second cycle best graded. Thicknesses of the cycles are 3.5 to 5 m, approx. 10 m and 12 m respectively. The amount of quartz pebbles decreases to the north and the tops of the cycles are represented only by coarse-grained sandstones (instead of conglomerates) in Sections 25 and 26 in northern Kočičina. Conglomerate beds at cycles' tops in other parts of Kočičina and Vrbodol have average thicknesses of 30 cms, beds in upper cycles



1. The rock formation "Pokličky" caprocks at the mouth of the Močida Gorge is a symbol of the Kokořínský důl Nature Reserve. Lower Sandstone Sequence.
2. Ferruginous sandstones and conglomerates at the top of the uppermost cycle of the Lower Sandstone Sequence are more resistant to weathering than the underlying quartzose sandstones. Thickness of the iron-rich layer is 0.7 to 0.9 m.

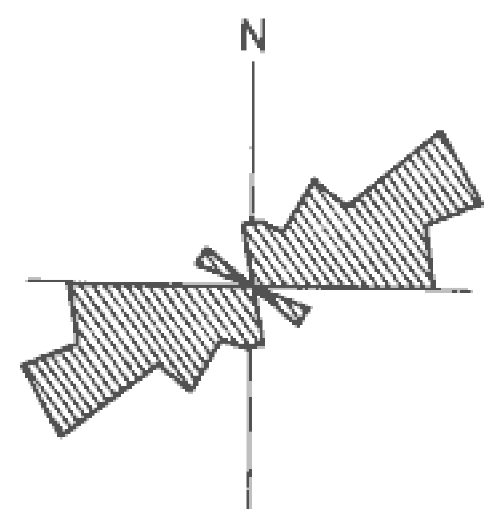


9. Pin diagram showing the foreset dip directions of the cross-bedded sets and their thicknesses in the study area. Empty circles - LSS, full circles - USS.

Formation, Middle Turonian) and the Teplice and Březno Formations (Upper Turonian to Coniacian) where southerly to south-southwesterly directions are dominant in most of the localities in the Bohemian Cretaceous Basin as documented by Skoček and Valečka (1983).

Paleocurrent measurements in the Jizera Formation from the northwestern part of the B.C.B. (Valečka, 1979; Skoček and Valečka, 1983) are in good accordance with the results from the Kokořín area. In contrast, the Jizera Formation sandstones from the vicinity of Česká Lípa (Skoček and Valečka, 1983) display south-southwesterly directions and the Middle Turonian Radków Bluff sandstones in the Intrasudetic Basin display southwesterly paleocurrent directions (Wojewoda, 1986).

Besides the southeasterly currents which operated throughout the study area, Figure 9 shows the smaller areas of unstable flow regime in the LSS (the valley of Babí důl, left bank of the Pšovka Creek NE of the Kokořín Castle). In the case of Babí důl, E - W bipolar paleocurrent pattern is present. Stratigraphically highest measured cross-bedded sets (USS, upper part) lie on the eastern margin of Mšeno and have a unique northeasterly orientation of foreset laminae. Paleocurrent measurements affirm the observations of Klein (1965b) who reported - on the basis of the MJ-2 borehole data



10. Rose diagram of the orientation of the elongate quartz pebbles' a-axes. 12 measurements, Močidla Gorge, LSS.

(cross-bedding, fauna accumulations) - a relatively strong south-southeasterly flow in the Middle to Upper Turonian.

Paleocurrent directions given by measurements of cross-bedding orientations can be compared with the orientation of quartz pebbles' a-axes. Preferred orientation of elongate, spindle-shaped quartz pebbles 1 to 3 cm long was measured at twelve places in the Močidla Gorge conglomerates (LSS). A rose diagram (20° intervals) is shown in Figure 10. Prevailing a-axis orientation is west-southwesterly/east-northeasterly which is parallel to the minor current direction and perpendicular to slightly oblique to the major current direction.

Considering all the facts above, the following paleocurrent model can be proposed for the Kokořín area. Bimodal paleocurrent pattern shows the presence of two different flow systems. The dominant system (directions to the SE to SSE) is parallel to the basin axis (probably to the shoreline, too) and operated over a major part of the Lusatian region of the Bohemian Cretaceous Basin (see references above). In the Kokořín area, the dominant flow directions shifted from SE (LSS, Fig. 8b) to SSE (USS, Fig. 8c).

In the Česká Lípa and Doksy region, north of the study area, paleoflow directions in the LSS agree with those at Kokořín (Klein et al., 1967) but in the USS, southwesterly to south-southwesterly dipping, giant scale cross-bedding is predominant. This was documented by Skoček and Valečka (1983) from Zahrádky and Velenice and by Klein (1962) and Klein and Tajovský (1986) from Zahrádky, Podolí and Holany.

The dominant system probably transported most of the sand material and it comes from the direction of the herein proposed source area (the Lusatian Pluton). According to the diagram of Reineck and Singh (1980), current velocity can be estimated on the basis of the migrating bedform size and the grain size. The value for the Kokořín sandstones (megaripples tens of centimetres high, average grain size 0.3 mm) is approximately 60 to 100 cm/s.

The USS conglomerate beds with no grading signs below or above, cross-bedded at places, can be considered as storm lags - tempestite layers. Prevailing south-southeasterly dip directions of foreset laminae show their affinity with the dominant flow system.

The average cross-bedding set thicknesses of this flow system are higher than the thicknesses of the sets dipping to other directions (see Table 4), being seldom lesser than 10 cm. Giant scale cross-bedding is absent.

The above described characteristics of the dominant flow system are consistent with the idea of regional, wind driven along-shelf currents. During major storm events, patches of gravel pavement were formed. The non-dominant but distinct flow system (directions to the W to WSW) is typical especially for the LSS (Fig. 8b) and is based primarily but not exclusively on paleocurrent measurements from the valley of Babí důl, from the left bank of the Pšovka Creek NE of the Kokořín Castle and from Vojtěchov. In all these cases, the cross-bedded sets lie 16 to 28m below the USS base. It should be noted that in the USS exactly the opposite directions (i.e. easterly) are relatively frequent (Fig. 8c). However, there is no clear evidence that this means current reversal of a single flow system at the LSS/USS boundary. Westerly and west-southwesterly paleocurrent directions have not been recorded so far in the Middle to Upper Turonian of the Czech part of the Bohemian Cretaceous Basin and must be of a limited areal extent.

Great variability in set thicknesses shows an inconstant flow velocity and/or erosion of upper parts of the cross-bedded sets. The lesser average set thickness probably speaks for generally higher flow velocities in comparison with the dominant southeasterly currents but may be also explained by a more profound erosion of dune crests during successive flow events.

Two different models can be proposed for the westerly flow: 1) tidal currents prevail, or 2) storm-induced currents prevail. Sedimentary environment influenced by tidal and non-tidal (regional), possibly wind-induced currents was proposed by Skoček and Valečka (1983) for the Upper Turonian to Coniacian in certain parts of the Bohemian Cretaceous Basin. Tidal currents were also reported from the Cenomanian in the southeastern part of the B.C.B. (Adamovič, 1990). In both of the above mentioned cases, sandstones display many signs typical for tide-dominated environment: giant scale cross-bedding is common and cross-bedding of trough type is present, though rare.

These features are absent in the Kokořín area but are present in the Česká Lípa vicinity, approx. 20 km N of the study area (see above) where they can be interpreted as a result of a tide-dominated environment. The locally developed bipolar chracter of the non-dominant flow system in the Kokořín area would also suggest an influence of tidal currents, however, easterly and westerly directions of the alternating flows can be hardly explained within the assumed paleogeographical configuration.

Herringbone bedding, as observed in the valley of Babí důl, can be also formed in the zones of bedload-parting which are known from both tidal current areas (Kenyon and Stride, 1970) and non-tidal areas (Flemming, 1980).

Orientation of a-axes of quartz pebbles (Močidla Gorge, LSS) is shown in Fig. 10. Elongate pebbles are usually deposited with their long axes parallel to the current direction (e.g. Gradzinski et al., 1986) which, in this case, corresponds with the W- to WSW-trending flow. This would demonstrate the relative strength of the westerly currents.

Westerly flows operating during the deposition of the LSS sandstones as well as easterly flows of the USS sandstones probably originated as a result of hydraulic conditions in a transitional zone between the tide-dominated region in the N-NE and the region dominated by wind-driven currents in the S-SW. They bear some but lack many of the tidal current features.

Cyclic arrangement of the sandstone units

A very important feature of the Kokořín sandstones is their cyclic development. Cycles of two different sizes can be distinguished : upwards coarsening cycles usually many tens of metres thick were characterized by Klein (1962, 1965d) from the Lusatian region of the B.C.B. and similar cycles were described from the vicinity of Děčín (Valečka, 1989). Besides these cycles, cycles only several metres to first tens of metres thick are developed in the Kokořín area (see Stratigraphy and lithology) with more of less distinct coarsening upwards. Unlike the large-scale cycles, these are laterally unstable (See Figs. 6 and 7).

Genesis of the large-scale cycles is discussed by Klein (1962, 1965b), Klein and Tajovský (1986) and by Valečka (1989). Klein (1962) points out the coincidence between the tops of the cycles and the periods of local regression in eastern Bohemia and Moravia. Klein (1965b) and Klein and Tajovský (1986) state that the Jizera Formation cycles originated as a reaction for changing tectonic activity at the faults on the northen margin of the B.C.B. and perhaps also inside the basin. Valečka (1989) considers the disequilibrium between the sedimentation rate and the rate of subsidence as the main factor for cyclic development. He points out that the Jizera Formation has a transgressive character and there are no proofs of regressional phases in the B.C.B. during the Jizera Formation deposition.

However, the above mentioned authors do not make any difference between the cycles of various thicknesses. The origin of small-scale upwards coarsening cycles can not be explained by climatic changes or tectonic activity because of their relatively low stability and great lateral variability. More probably, their formation is linked with the sedimentary environment including such factors as paleoflow and paleotransport directions, flow velocity distribution and bedform migration.

One of the possible explanations is the presence of linear sand ridges (offshore bars) migrating perpendicular to the shoreline. Linear sand ridges are known from both ancient and modern seas and may be formed either by tidal currents or storm currents (Johnson and Baldwin, 1986). Their long axes are aligned parallel to the shoreline and parallel to or slightly oblique to the dominanat current direction. The up-current bar flank experiences erosion during storm events and/or high tides. Finer particles are winnowed from the up-current flank and deposited on the down-current flank. Pebble horizons may form on the surface of the up-current flank during high-energy events. As the ridge migrates down-current, negatively graded sequences are formed approaching ridge height in their thickness. Upper Cretaceous Shannon and Sussex Sandstones, Wyoming, USA (Tillman and Martinsen, 1984 ; Gaynor and Swift, 1988), Upper Cretaceous Duffy Mountain Sandstone, Colorado, USA (Boyles and Scott, 1982) and Late Precambrian deposits from northern Norway (Johnson and Baldwin, 1986) are the examples of offshore bar sedimentation.

In the Kokořín area, sandstone cycles - unlike most ancient bar deposits - are not separated by shale sequences which can be explained by an intense influx of detrial material during the Middle to Upper Turonian. Bar migration was probably controlled by westerly to west-southwesterly flows whereas the wind-driven southeasterly flow caused dune migration over the bar crest. Landward dipping, low-angle accretion surfaces were not recognized in the Kokořín sandstones but they are also absent in many ancient bar deposits.

The increasing amount of carbonate content (upper part of the USS) can be explained either by increasing depth due to sea level rise or by separating of smaller area from the currents transporting terrigenous detritus. The latter seems much more probable because the calcareous sandstones contain more fauna known from shallow marine environment and finally pass into biomicritic limestones which probably originated in a very shallow part of the sea. These limestones (the "Kanina Bryozoic Member" of Frič, 1885) contain shallow-water organisms (see Faunal content), undulating subhorizontal bedding and a very low amount of sand and silt particles. Prevailing micrite and a poor sorting of allochems indicate a low-energy environment.

Source of detrital material

Character of quartz grains was observed as the main feature in provenance determination. Most of the grains are monocrystalline, however, 15-50 % of the coarse fraction (above 0.5 mm) are polycrystalline. In all units, two different types of polycrystalline grains can be distinguished : those composed of less than 5 crystals but usually only 2 or 3 (type I) and those composed of more than 5 crystals (type II). The abundance of both types in the sandstones is about equal, although in many samples some of the two types clearly prevails (See Stratigraphy and lithology). Among type II grains, those with elongated crystals and shingle structure indicate a metamorphic source (usually 2-10 in every thin section). Part of the fine monocrystalline grains may also originate from larger polycrystalline grains through fracturing during sediment transport (Blatt - Middleton - Murray, 1972).

Nevertheless, most of the quartz grains probably come from a plutonic source as evidenced by absolute prevalence of nonundulatory monocrystalline quartz grains and by presence of monocrystalline quartz pebbles. Quartz grains derived from acidic volcanic rocks, which might represent a part of the monocrystalline quartz grains without undulatory extinction, are not supposed to be very frequent because the potassium feldspars are of low-temperature character with prevailing microcline. Milky quartz with water-filled vacuoles indicating a hydro-thermal source is rare. Generally low feldspar content may be caused by rock weathering in the source area.

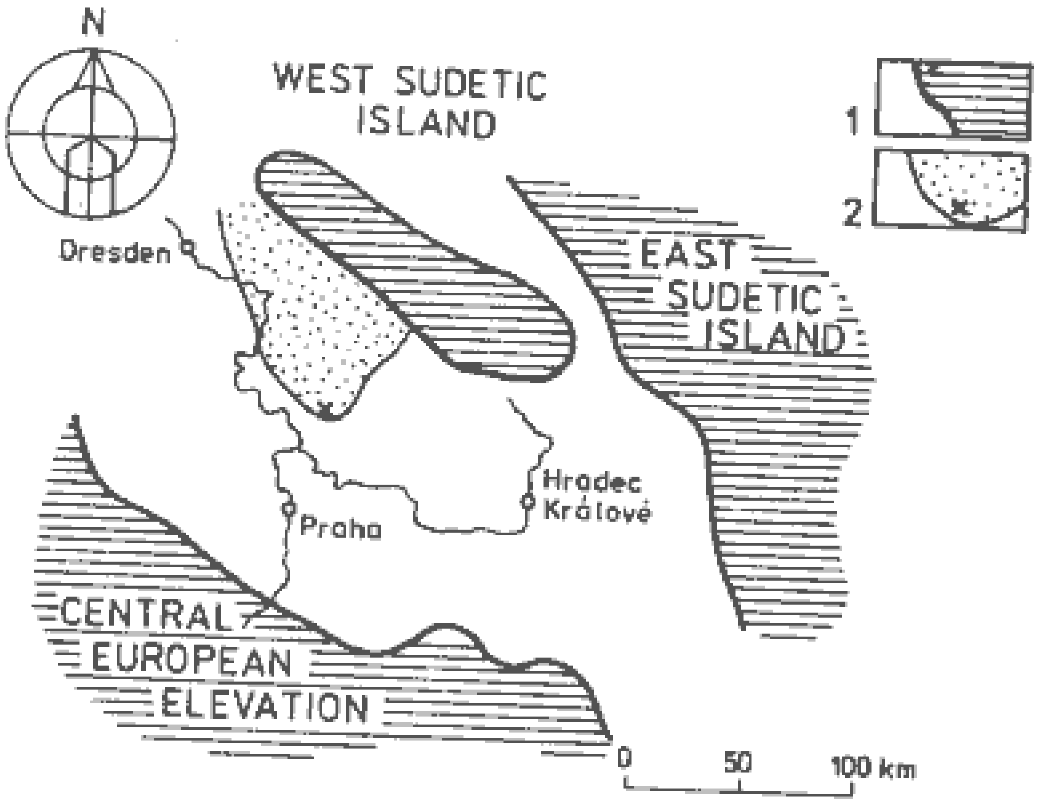
In the typical fine-grained sandstones of the lower part of the USS, about 95 % of quartz grains are monocrystalline; polycrystalline grains with shingle structure are very rare. Several characteristics argue for a relatively rapid deposition of these sandstones : angular shape of most of the grains, high content (50 %) of thermodynamically unstable undulatory quartz, slightly higher feldspar content (up to 5 %) and presence of macroscopical muscovite. Their good sorting contrasts with the facts above.

Grains and pebbles of metamorphic origin are often suprisingly well rounded, especially in the upper part of the USS and may represent a second-cycle material. In the upper part of the USS their amount increases. This, combined with the higher amount of staurolite (Klein, 1965c), indicates that more metamorphic rocks functioned as source material during the deposition of the upper part of the USS.

In the Middle to Upper Turonian, the area of Kokořín was lying halfway between the West Sudetic Island (the Lusatian Pluton and the Krkonoše-Jizera Crystalline Complex) and the Central European Elevation (see Fig. 11). The Central European Elevation can be hardly considered the source area for the Kokořín sandstones because it is separated from the sandstone lithofacies by vast areas of marlstone and limestone lithofacies probably originated at greater depths in the central part of the basin. The West Sudetic Island was located approxinately N and NW of the study area. It was composed prevailingly of granites and granodiorites of Variscan age and by orthogneisses.

The above mentioned facts as well as the paleocurrent directions discussed in the next chapter indicate that the West Sudetic Island was probably the main source of the detrital material for the Middle to Upper Turonian Kokořín sandstones (see also Skoček and Valečka, 1983).

The location of the source of quartz grains for the Kokořín sandstones in the area of the Maršovice Hill elevation (its centre lying 13 km N of the study area) is improbable. This idea was proposed by Malkovský (1952), but Malkovský (1957) and later Klein (1962) bring an evidence that the top of the elevation was lying below the water surface in the Middle Turonian and that the Cenomanian and Lower Turonian sediments on the elevation were nor destructed in the Middle Turonian period.



11. Paleogeographical map of the Middle to Upper Turonian in the Bohemian Cretaceous Basin region (after Klein et al., 1979). 1 - source areas, 2 - areas of psammitic deposition, study area marked with a cross.

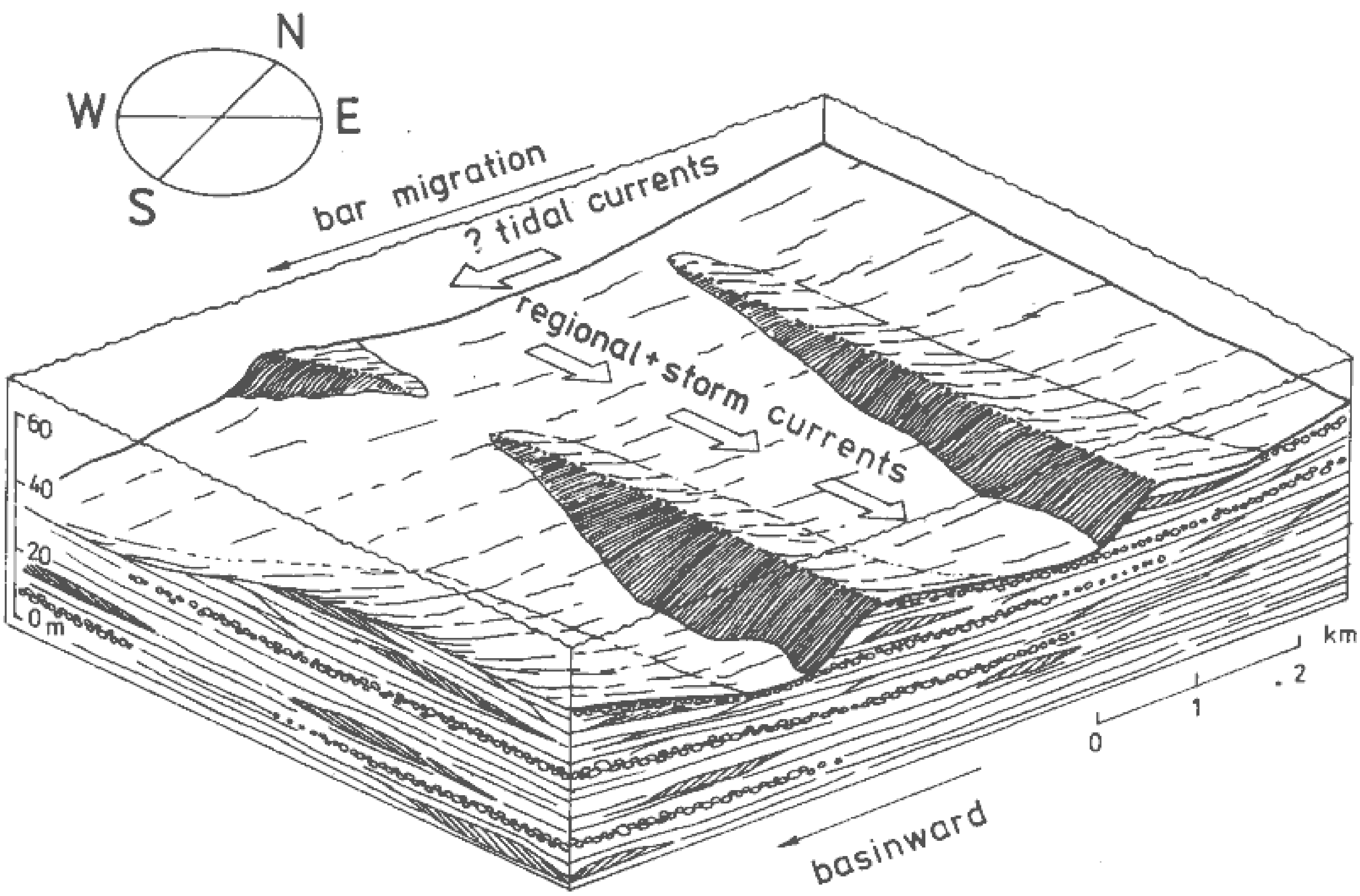
Paleogeography

Paleogeography of the late Cretaceous quadersandstein of the Bohemian Cretaceous Basin is well illustrated in the study of Klein et al. (1979). In the Turonian, the B.C.B. functioned as a passage connecting the boreal sea in the North Sea Basin in the NW and the Tethys Sea in the SE. Crystalline elevations in the north were important for the formation of quartzose sandstones : the West Sudetic Island (i.e. Lausitz Block of Ziegler, 1982) and the East Sudetic Island. The West Sudetic Island is considered the main clastic source for the Lusatian region sandstones (Skoček and Valečka, 1983) including the Kokořín sandstones (see also Source of detrital material and Fig. 11). Hereby the following factors were the most decisive: 1) prevailingly granitic composition of the West Sudetic Island, 2) deep kaolinic weathering of the granites and 3) tectonic uplift of the island pronounced by a relatively rapid subsidence of the adjacent part of the basin.

The elevation of Maršovice Hill (N of Dubá) has been submerged since the Upper Cenomanian (Malkovský, 1957; Klein, 1962) and could supply no material for the Kokořín sandstones. However, the Maršovice Hill elevation may have influenced the sedimentation of the Kokořín sandstones. According to Klein (1962), thicknesses of the upper part of the Jizera Formation and of the Teplice Formation on the elevation are reduced. This indicates relative uplift of the Maršovice Hill area but says nothing about the possible impacts on sea bottom morphology. Some phenomena observed in the middle and upper parts of the USS at Kokořín may result from sea bottom uplift in the Maršovice Hill area: changes in paleocurrent directions also reported from Hradčany (N of Kokořín - Klein, 1962 and Klein et al., 1967) and decreasing water depth documented by the biomicritic "bryozoic" limestone facies (uppermost USS).

Paleocurrent diagrams (Fig. 8) are bimodal and show the presence of two different flow systems. Southeasterly to south-southeasterly unidirectional, atmospheric shelf currents (i.e. fair weather and storm-induced currents sensu Johnson and Baldwin, 1986) transported detrital material to the Kokořín area. Westerly to west-southwesterly currents (LSS) and easterly currents (USS) operated only periodically. The presence of linear sand ridges seems to be probable : migration of sand ridges with axes parallel to the shoreline in directions normal to the shoreline can explain the cyclic arrangement of the LSS and the middle part of the USS.

Water depth cannot be deduced from cross-bedding thicknesses because there is no relation between dune height and water depth in the modern seas (Swift et al., 1979; Reineck and Singh, 1980; Terwindt and Brouwer,



12. Inner shelf sedimentation model, Jizera Formation in the Kokořín area. A series of bars approximately parallel to the shoreline is affected by southeasterly fair weather currents and storm-induced currents of the same direction. A lesser influence of tidal currents is possible. Upwards coarsening cycles are formed through basinward bar migration. Cross-bedding is caused by dune migration on bar slopes and between the bars. Scales are approximate.

1986). Water depth can be, however, estimated on the basis of paleoflow and bioturbation structures and fauna assemblage. These criteria indicate depths of several tens of metres for "quadersandstein" deposition (LSS plus middle part of USS) and the inner shelf environment sensu Swift et al. (1979).

Fine-grained sandstones of the lower part of the USS with their locally developed ripple lamination, intense bioturbation, and the absence of cross-bedding, laterally passing into marlstones suggest an environment with stagnant sediment transport and deposition rates in deeper parts of inner shelf. Direct supply of material from the littoral zone is documented by a relatively good sorting caused by grain fragmentation and a relatively decreased mineral maturity (see Tables 2 and 3).

Decreasing water depth in the period applying to the upper part of the USS can be explained : 1) by changes of sea bottom morphology connected with the uplift of the Maršovice Hill elevation area or 2) by filling of the space between the sand ridges and the shoreline with clastic material and a consequent formation of shallower embayments and lagoons. The uppermost part of the USS at Kokořín was dominated by carbonate sedimentation in low-energy marine environment. Bryozoans from these limestones belong to shallow marine genera (L. Hradecká, pers. comm.).

Conclusions

Sedimentology and stratigraphy of the Jizera Formation sandstones (Middle to Upper Turonian) from the area of Kokořín were characterized on the basis of field mapping, field lithologic section and borehole section correlations.

1. Two basic lithological units were recognized and described: the Lower Sandstone Sequence (LSS) and the Upper Sandstone Sequence (USS), having a character of a large-scale upwards coarsening cycles. Within these units, many smaller-scale upwards coarsening cycles several metres to several tens of metres thick were recognized. Four lithofacies types are present : 1) cross-bedded medium-grained quartzose sandstones to conglomerates (LSS, middle part of the USS), 2) thin-bedded and bioturbated fine-grained sandstones (lower part of the USS), 3) calcareous and quartzose medium- to coarse-grained sandstones passing into sandy limestones and 4) biomicritic limestones (both in the upper part of the USS).

2. Sandstone body architecture including smaller-scale cyclicity and various sedimentary structures are explained in terms of sea bottom dynamics. Migrating linear sand ridges (bars) are supposed to be responsible for the smaller-scale cycle formation.

3. Paleocurrent analysis was carried out and, on the basis of the cross-bedding measurements, two flow systems of different origin can be deduced. The southeasterly to south-southeasterly flow system was probably controlled by atmospheric conditions (basinal current) whereas the westerly to west-southwesterly/easterly flow system has some signs of tidal influence.

4. Sediment lithologies and structures in the upper part of the USS as well as shallow marine fauna assemblage indicate a decrease in water depth and low-energy environment. Possible causes of this trend are discussed.

K tisku doporučil J. Valečka
Přeložil autor

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Paleogeografie jizerského souvrství (svrchnokřídové pískovce) na Kokořínsku

(Resumé anglického textu)

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V kvádrových pískovcích jizerského souvrství na Kokořínsku (střední až svrchní turon) byly převážně na základě terénního mapování vyčleněny dvě hlavní litologické jednotky: spodní a svrchní pískovcová sekvence. Spodní sekvence odpovídá vyšší (pískovcové) části druhého nahoru hrubnoucího (inverzního) cyklu Kleina (1966), svrchní odpovídá třetímu cyklu Kleina.

Podrobné litologické studium kokořínských pískovců prováděné na 107 vertikálních profilech ukázalo, že vedle nahoru hrubnoucích cyklů velkého měřítka jsou zde vyvinuty cykly o mocnosti metrů až prvních desítek metrů. Začínají jemnozrnnými až středně zrnitými pískovci a jsou většinou zakončeny slepencovými polohami. Na rozdíl od cyklů velkého měřítka mají poměrně malý plošný rozsah a profily vzdálené 500 m mohou vykazovat zcela odlišnou litologickou stavbu. Cykly jsou nejstálejší ve směru ZSZ - VJV.

Spodní pískovcová sekvence odpovídá prvnímu kokořínskému kvádru Friče (1885) a pásmu VIII Č. Zahálky (1895). Za její bázi je možno považovat nástup prachovitých pískovců ve druhém inverzním cyklu Kleina (1966). Její horní hranice je dána nástupem jemnozrnných pískovců svrchní sekvence s chudou jílovitou základní hmotou. Spodní sekvence je budována středně zrnitými křemennými pískovci až slepenci s chudou jílovitou nebo vápnitou základní hmotou. Křemenná zrna jsou špatně vytříděná, prům. 0,35 mm velká, v závislosti na poloze v cyklu jsou přítomny křemenné valouny. 5 až 15 % křemenných zrn je polykrystalických. Spodní sekvence je při j. okraji mapovaného území odkryta v mocnosti kolem 20 m, nejvyšší pozorovatelné mocnosti (kolem 70 m) nabývá v rokli Močidla. V Kokořínském dole j. od hradu Kokořína a u Jestřebic je vyvinut pouze jediný cyklus s nezřetelnou gradací, zakončený pískovci s příměsí křemenných valounů nebo slepenci. V ostatních částech území jsou vyvinuty 2-3 cykly, každý zakončen 1-3 slepencovými polohami. Slepence nejvyššího cyklu dosahují v rokli Močidla mocnosti až 7 m, jejich horní polovina je prostoupena železitým (limonitickým) tmelem. Nejvyšších 5-13 m spodní sekvence je tvořeno středně zrnitými pískovci, většinou bez známek zrnitostní gradace. V jižní části území se tyto pískovce vyznačují masivní texturou.

Spodní část svrchní pískovcové sekvence odpovídá bázi 3. inverzního cyklu Kleina (1966), hleďsebským opukovým vložkám Friče (1885) a pásmu IXa Č. Zahálky (1895). Je budována sytě žlutými jemnozrnnými křemennými pískovci s chudou jílovitou základní hmotou. Tyto pískovce jsou dobře vytříděné, tence vrstevnaté, s poměrně častými bioturbacemi. Jejich přechod do kvádrových pískovců v nadloží je pozvolný. Ve spodní části Kokořínského dolu dosahují mocnosti kolem 10 m, ve Mšeně 5 m, směrem na S se jejich mocnost zmenšuje a jejich zrnitost se již příliš neliší od zrnitosti typických kvádrových pískovců.Střední část svrchní pískovcové sekvence je tvořena středně zrnitými křemennými pískovci až slepenci a velmi se podobá spodní pískovcové sekvenci. Odpovídá druhému kokořínskému kvádru Friče (1885) a pásmu IXb Č. Zahálky (1895). Pískovce jsou špatně vytříděné, průměrná velikost zrn 0,5 mm, asi 7 % zrn je polykrystalických. Mocnost střední části svrchní sekvence celkově klesá od Z k V ve prospěch svrchní části svrchní sekvence, největší mocnosti byly zaznamenány ve spodní části Kokořínského dolu (50 m). Tři až čtyři nahoru hrubnoucí cykly (mocnosti 3-15 m) bývají zakončeny slepencovými polohami, někdy zdvojenými. V oblasti Kokořínského dolu, v Pastuší rokli a v rokli Močidla je zrnitostní gradace v rámci cyklů nevýrazná, ve skalním městě Bludiště sz. od Mšena nejsou vyvinuty slepencové polohy a většinou ani zrnitostní gradace.

Svrchní část svrchní pískovcové sekvence je charakteristická přibýváním vápnité složky směrem do nadloží. Část tvořená vápnitými pískovci až písčitými vápenci byla Fričem (1885) označována jako chorouŠecké vrstvy trigoniové (pásmo IXc Č. Zahálky, 1895) a vápence v jejich nadloží jako bryozoické vrstvy u Kaniny (pásmo IXd). Je možno zde rozlišit tři základní litofaciální typy : křemenné pískovce s vápnitou základní hmotou, pískovce s kalcitovým tmelem až písčité vápence a biomikritové bryozoové vápence. Hranice mezi jednotlivými typy většinou nejsou pozorovatelné ve výchozech, lze je charakterizovat jako pozvolné, s přibýváním vápnitých vložek směrem do nadloží. Hranice s kvádrovými pískovci střední části svrchní sekvence je také dána pozvolným přechodem. Zrnitostní gradace ve vápnitých pískovcích není tak zřetelná jako v kvádrových pískovcích, vytřídění je špatné (zrna 0,15-0,8 mm), podíl polykrystalických křemenných zrn může dosahovat až 15 %. Na většině studovaného území není svrchní část svrchní sekvence zachována, mocnost pískovců až písčitých vápenců dosahuje ve spodní části Kokořínského dolu asi 20 m. Biomikritové vápence jsou odkryty v mocnosti 4 m pouze u Kokořínku, nacházejí se také v úlomcích na poli u Kaniny.

Typické kvádrové pískovce neobsahují téměř žádnou faunu. Ve střední části svrchní sekvence byly ve vrtu MJ-2 Stránka nalezeny úlomky mlžů (Klein - Pražák 1965). Bioturbace typu *Thalassinoides* a *Planolites* se vyskytují v kvádrových pískovcích, mnohem častější jsou však v jemnozrnných pískovcích spodní části svrchní sekvence. Zbytky fauny jsou časté v pískovcích až písčitých vápencích svrchní části svrchní sekvence, zaznamenány byly ústřičné slapy (*Exogyra*, *Pycnodonte*, *Lima* a další). Biomikritové vápence na vrcholu svrchní sekvence jsou tvořeny skelety mechovek, schránkami foraminifer a tenkostěnnými mlži.

Kvádrové pískovce na Kokořínsku vykazují znaky dynamického prostředí - subhorizontální vrstevnatost s případy šikmého zvrstvení. Šikmo zvrstvené polohy (sety) mají mocnost 4-40 cm (průměrně 17 cm), úklony lamin 10-36° (průměrně 24,5°) a vyskytují se převážně ve středně zrnitých pískovcích. Zaznamenán byl jeden případ protisměrného zvrstvení (Babí důl), případy tzv. křížového zvrstvení jsou častější. Masivní textury jsou vázány zejména na vrchol spodní pískovcové sekvence v j. části území. Jemnozrnné pískovce spodní části svrchní sekvence jsou tence vrstevnaté, tato textura může být ale setřena intenzivní bioturbací sedimentu. Ve sledovaném území bylo proměřeno 140 setů šikmého zvrstvení. Z naměřených hodnot orientace spádnic je možno soudit na převládající směr proudění k JV až JJV. Ten je zhruba rovnoběžný s osou pánve a byl naměřen i jinde v jizerském souvrství. Je připisován stálému pánevnímu proudění ovlivněnému atmosférickou cirkulací. Stejný směr měly i bouřkové proudy, jak dokládá zvrstvení ve štěrčíkových polohách vyvinutých nezávisle na cyklické stavbě - tempestitech. Další časté směry proudění - západní, příp. východní, mohou souviset s dmutím. Tidální ovlivnění ve větším měřítku je nepravděpodobné. Dlouhé osy křemenných valounů v rokli Močidla jsou většinou orientovány ve směru VSV-ZJZ.

Vznik nahoru hrubnoucích cyklů menšího měřítka je spojován s migrací lineárních písečných valů - barů. Prostředí sedimentace typických kvádrových pískovců je možno charakterizovat jako spíše dynamické, mělkovodní, vázané na vnitřní šelf. Jemnozrnné pískovce spodní části svrchní sekvence ukazují svými texturami a zrnitostí na méně dynamické, poněkud hlubší prostředí, jsou však mineralogicky poněkud méně zralé. Sedimenty svrchní části svrchní sekvence vznikaly v postupně změlčujícím se prostředí, zřejmě stále více odškrcovaném od zdroje klastického materiálu. Biomikritové mechovkové vápence vznikly nejspíše v hloubce do 30 m, skupiny mechovek zjištěné L. Hradeckou (úst. sděl.) indikují mělkovodní prostředí.

Vysvětlivky k tabulkám

1. Vzájemné vztahy mezi dříve používanými stratigrafickými jednotkami a jednotkami používanými v této práci.
2. Zrnitostní a sedimentologické charakteristiky pískovců jizerského souvrství z okolí Kokořína. Údaje ve sloupcích 1 - 7 jsou založeny na studiu výbrusů; qs - křemenné pískovce, cs - vápnité pískovce, l - biomikritové vápence, a - průměrná hodnota, b - hodnota pro hrubou frakci (hrubší než 0,5 mm), d_S/d_L - poměr délek krátké a dlouhé osy, LSS - spodní pískovcová sekvence, USS - svrchní pískovcová sekvence.
3. Mineralogické charakteristiky pískovců jizerského souvrství z okolí Kokořína. qs - křemenné pískovce, cs - vápnité pískovce, l - biomikritové vápence, LSS - spodní pískovcová sekvence, USS - svrchní pískovcová sekvence.
4. Směry spádnic šikmého zvrstvení a mocnosti zvrstvených poloh. Sestaveno na základě 140 měření.

Vysvětlivky k obrázkům

1. a - Přehledná mapa znázorňující polohu sledovaného území v rámci středních Čech. b - Zjednodušená geologická mapa sledovaného území. 1 - spodní pískovcová sekvence, 2 - svrchní pískovcová sekvence, 3 - dislokace, 4 - linie geologických řezů (viz obr. 6-7), 5 - lokalizace vrtů.
2. Profil křídy ve vrtu MJ-2 Stránka (litologie podle Kleina 1965a) a typický profil části odkryté ve studovaném území. Udány průměrné mocnosti pozorovatelné v terénu. 1 - kvartérní sedimenty, 2 - biomikritové vápence, 3 - slínovce, 4 - prachovce a vápnité prachovce, 5 - křemenové vylouny, 6 - jemnozrnné až středně zrnité pískovce, 7 - podloží křídy.
3. Mapa Kokořínska s vyznačením mapovacích profilů.
4. Geologické profily z Kokořínského dolu (17, 27, 42, 54, 78) a z rokle Močidla (58, 59, 67). 1 - středně zrnité pískovce, 2 - jemnozrnné pískovce, 3 - vápnité pískovce až písčité vápence, 4 - křemenné

valouny, 5 - limonitický tmel, 6 - vrstevnatost, 7 - šikmé zvrstvení, 8 - bioturbace, 9 - hranice spodní a střední části svrchní pískovcové sekvence.

5. Geologické profily z Šemanovického dolu (1, 7, 9), z rokle Kočičina (18, 19) a z rokle Vrbodol (22). Vysvětlivky viz obr. 4.
6. Geologický řez v ose Kokořínského dolu. Umístění řezu je znázorněno na obr. 1. 1 - kvartérní sedimenty, 2 - biomikritové vápence, 3 - vápnité pískovce až písčité vápence, 4 - jemnozrnné pískovce, 5 - středně zrnité pískovce, 6 - slepencové polohy, křemenné valouny.
7. Geologický řez mezi Kokořínkem a Kaninou. Umístění řezu je znázorněno na obr. 1. Vysvětlivky viz obr. 6.
8. Růžicový diagram směrů spádnic šikmého zvrstvení, členění po 20°. a - celkový diagram, b - spodní pískovcová sekvence (81 měření), c - svrchní pískovcová sekvence (59 měření).
9. Špendlíkový diagram znázorňující směry spádnic šikmého zvrstvení a mocnosti zvrstvených poloh ve sledovaném území. Prázdné kroužky - spodní pískovcová sekvence, plné kroužky - svrchní pískovcová sekvence.
10. Růžicový diagram orientace dlouhých os protažených křemenných valounů. Dvanáct měření, spodní pískovcová sekvence v rokli Močidla.
11. Paleogeografická mapa středního až svrchního turonu oblasti české křídové pánve (Klein et al. 1979). 1 - zdrojové oblasti, 2 - oblasti psamitické sedimentace, křížkem je označeno studované území.
12. Model sedimentace na vnitřním šelfu, jizerské souvrství v okolí Kokořína. Série písečných hřbetů (barů) zhruba rovnoběžných s pobřežím je ovlivňována jv. prouděním klidných období a občasným bouřkovým prouděním stejného směru. V menší míře snad působily výčasové proudy. Migrací barů směrem do pánve se vytvářejí nahoru hrubnoucí cykly. Šikmé zvrstvení je způsobeno migrací dun na úbočích barů a v prostoru mezi bary. Vyznačeno přibližné měřítko.

Vysvětlivky k přílohám

Příl. I

1. Skalní útvar Pokličky u ústí rokle Močidla je symbolem SPR Kokořínský důl. Spodní pískovcová sekvence.
2. Železité pískovce a slepence ve vrcholu nejvyššího cyklu spodní pískovcové sekvence jsou odolnější vůči zvětrávání než křemenné pískovce v jejich podloží. Mocnost proželeznělé polohy 0,7-0,9 m.

Příl. II

3. Diagonální zvrstvení ve střední části svrchní pískovcové sekvence na profilu 31. Orientace lamin je 130/29°.
4. Diagonální zvrstvení ve střední části svrchní pískovcové sekvence na profilu 31. Zvlněná erozní plocha odděluje zvrstvené sety, jejichž laminy zapadají zhruba opačným směrem. Vlevo západ.

Příl. III

5. Slepencová poloha ze střední části svrchní pískovcové sekvence, profil 31 v Kokořínském dole; netvoří vrchol dílčího cyklu, ale má ostrou spodní hranici. Zřejmě vznikla při výrazné bouřkové události vymytím jemné frakce. Poloha je porušena bioturbacemi.
6. Jemnozrnné pískovce spodní části svrchní pískovcové sekvence. Patrná je dobrá vrstevnatost s náznaky čeřinového zvrstvení. Severní okraj Mšena.

Příl. IV

7. Diagonálně zvrstvené polohy v pískovcích spodní pískovcové sekvence v Babím dole (s. od Mšena). Diagram spádnic diagonálního zvrstvení zde má bipolární charakter V-Z. V horní části snímku leží sety s opačnou orientací lamin přímo nad sebou (protisměrné zvrstvení).
8. Výchozy biomikritových vápenců u Kokořínku. Svrchní část svrchní pískovcové sekvence.

Všechny fotografie autor