In: PLAŠIENKA, D., HÓK, J., VOZÁR, J. & ELEČKO, M. (Eds.): Alpine evolution of the Western Carpathians and related areas. Internat. conf., Sept. 1997, Introduct. articles to the excursion, Geol. Survey Slov. Rep., D. Štúr Publ., Bratislava, Slovakia.

♦ Jurassic synrift sedimentation on the Czorsztyn Swell of the Pieniny Klippen Belt in Western Slovakia

R. AUBRECHT, M. MIŠÍK & M. SÝKORA

Department of Geology and Paleontology, Faculty of Natural Sciences, Comenius University, Mlynská dolina - G, 842 15 Bratislava, Slovak Republic

Abstract. Several sections of the Czorsztyn Unit have been found, mainly in the western part of the Pieniny Klippen Belt, with lithostratigraphical contents not corresponding to the classical scheme introduced by Andrusov (1945) and Birkenmajer (1963, 1977). All of these localities reflect shallower sedimentation environment than the profiles known so far. These newly discovered parts of the Czorsztyn sedimentation area appear to be originally situated much closer to the emerged Czorsztyn Ridge. Possibility of an original dissection of the Czorsztyn Ridge into eastern (deeper) and western (shallower) part is also discussed in the paper. The differences characteristic for the shallower parts of the Czorsztyn sedimentary area are as follows:

1. Presence of the Krasín Scarp Breccia associated with concentration of the neptunian dykes reflecting an extensive Middle Jurassic synsedimentary tectonics.
2. Shallower facies of the Vršatec and Bohunice limestones instead of the nodular Czorsztyn Limestone.
3. The differences of smaller importance are: indistinct differentiation between red and white crinoidal limestones, absence of silicification in the crinoidal limestones, dominance of massive crinoidal limestones, relatively larger size of clastics and a rare presence of the oolitic limestones.

Key words: Jurassic, Western Carpathians, Pieniny Klippen Belt, Czorsztyn Unit, paleogeography, sedimentology

Introduction

Jurassic evolution of the units recently forming the Pieniny Klippen Belt (PKB) was influenced by the rifting of the Ligurian - Penninic - Vahic ocean. This rifting represented a passive extension connected with tilting of individual crustal segments. It resulted in facial variability of former relatively undisected Triassic carbonate shelf. This evolution is analogical to that in the Central Western Carpathians. However, due to later extensive multiple tectonic deformation, reconstruction of the paleotectonic and paleogeographic evolution of the Czorsztyn Unit and of all the Oravic units (sensu Mahel', 1986) is difficult. The main tools of the reconstruction are: 1. paleobiogeography, 2. facial relationship, 3. analysis of clastic admixture.

1. Paleobiogeographical data are not the topic of this paper. They provided only little information on the original position and movement of the Oravic crustal segment and the provenance of other units of the PKB (Manín, Klape and Drietoma units). Generally, these units were under the influence of both - the Mediterranean and Boreal faunistic provinces during their evolution. For some details, the reader is referred to the papers of Rakús (1989), Michalík (1989), Kutek & Wierzbowski (1986) and Krobicki (1993).

2. Facial relationship of the Jurassic sediments are for long time the most used criterion in paleogeographical reconstructions of the Western Carpathians, particularly of the PKB. All the Oravic units were defined on the basis of facial contents and their mutual position was reconstructed by their facial relationship. Since the time when Uhlig (1907) divided the Oravic successions to northern Subpieninic Unit (later Czorsztyn Unit) and southern Pieninic Unit, the detail investigation and catalogization of the lithostratigraphic units has started. Though their relationship was not fully clear, and the progress of knowledge has been often hindered by concepts which later appeared as incorrect, thanks to the activity of outstanding geologists as Andrusov, Birkenmajer, Scheibner, Began, Salaj etc., the evolution of knowledge reached its recent stage. Very important, from the point of view of the Jurassic evolution, was distinguishing of the "transitional unit" with various partial developments (Pruské, Kysuca and Podbiel developments) by Andrusov (1927, 1938), who proved the connection between apparently different Czorsztyn and Pieniny units. Later the mentioned developments became the separate units. Birkenmajer (1953) distinguished individual equivalents of these units in Poland, under

the names as Niedzica and Branisko units. Later the new, Czertezik Unit, was also distinguished (Birkenmajer, 1959). Distinguishing of the Streženice Unit (Began & Borza, 1963), .Nižná Unit (Scheibner, 1967) and Orava Unit (Haško, 1978) completed the inventory of the principal Oravic units. The position of some units is problematic and is still a subject of discussions. Among them are, for example, Haligovce Unit (being attributed rather to Manín Unit), Grajcarek Unit (according to Birkenmajer, 1977 being a part of the Magura Unit) and the Fodorka Unit (according to Salaj, 1990 its sedimentary area was also north of the Czorsztyn Unit). The most detailed description of lithostratigraphic units of Oravicum was made by Birkenmajer, 1977; some new Jurassic lithostratigraphic units were also summarized by Mišík et al.(1996). However, the principal view of Birkenmajer (l.c.) on the mutual arrangement of the individual units persisted up to the Recent time. This view resulted from the supposed position of the units in the Middle Jurassic. However, during the Lower Jurassic, the paleotopography was different.

3. Analysis of clastic admixture provides information on an unknown basement and foreland of the Oravic units, as well as on the interrelationship between the Oravic units and other units of the Western Carpathians. This method brought many new and interesting data which, however, deserve a special paper. In this paper the problem of clastic admixture is treated only marginally.

Lower Jurassic of the Oravic Units – contrast to the Middle Jurassic

Lower Jurassic deposits of the Oravic units are relatively rare due to their consumption during the subduction and later collision in the latest Cretaceous. The up-to-date investigations show that the Lower Jurassic facial distribution in the PKB does not correspond to the Middle Jurassic one. Oravic paleogeography in the Middle Jurassic was most probably principally different, even almost inverted with respect to the Lower Jurassic one. It might be related to the gradual opening of the sedimentary area in an extensional regime, accompanied by block tilting. The examples are as follows:

- spotty marlstones with Echioceras raricostatum (Lotaringian - relatively deep marine facies) were found at Vršatec (Began & Kantorov , 1961), whereas black spongiolitic, sandy and organodetrital limestones and spotty limestones were described at Dolný Mlyn locality - Sinemurian s.s. (Hlôška, 1992), as well as at Beľatina quarry in the Eastern Slovakia (Rakús - pers. com.). All localities belong to the Czorsztyn Unit with relatively shallow marine Middle Jurassic deposits.
- relatively shallow marine arcosic sandstones and crinoidal limestones of Lower Jurassic are known to form the base of the Nižná Unit (localities Krásna Hôrka - Sinemurian s.s., Sedliacka Dubová- Skalka and Lúty Potok - Pliensbachian) in the Orava section of the PKB (Mišík et al., 1995). Middle Jurassic development of this unit is identical with that in the Kysuca Unit (deep marine).

The change started probably during Aalenian with relatively levelled deposition of marls and clays which took place all over the Oravic units, free of any larger facial differences. It was disrupted only by local turbiditic sedimentation (Szlachtowa Formation) which persisted probably from Toarcian time (Birkenmajer & Tyszka, 1996). The main paleogeographical event, which gave rise to the Czorsztyn Swell, had to take place after Aalenian. Similar situation was, however, in the Manín Unit and many central Western Carpathian units where originally shallow marine facies of the Trlenská, Kopienec and Hierlatz Formations gave way to spotty limestones and later to radiolarites.

Middle Jurassic of the Czorsztyn Unit – the hitherto stage of research

Middle Jurassic, namely Bajocian and Bathonian, was the time of dissection of the Aalenian Oravic basin. Extension, connected with block-tilting, led to creation of the Czorsztyn Swell and, on the other hand, the Kysuca-Pieniny Trough. This synsedimentary tectonics was recorded also in the synrift deposits, namely in the shallowest - Czorsztyn Unit. In the deeper part of the basin (Kysuca and Pieniny Unit) the record was not so distinct.

Czorsztyn Unit usually comprises the shallowest occurrences of the Oravic units, being simply defined by their absence of radiolarites. However, already Birkenmajer (1963) distinguished 11 types of the Czorsztyn Unit which reflected its dissection and differential subsidence mostly during the uppermost Jurassic and Lower Cretaceous. At the same time, the Middle to Upper Jurassic sequence was considered to be relatively uniform. This view resulted from the investigations carried out mainly in the relatively restricted Polish part of the PKB, e.g. its eastern part. Nevertheless, later research revealed still high variability in deposits of the Czorsztyn Unit, namely in the western section of the PKB. It resulted from different subsidence of the blocks of the Czorsztyn crustal segment, when blocks representing now the western part of the PKB remained in somewhat shallower depths than those in the eastern part. The classical lithostratigraphic scheme, introduced in detail by Birkenmajer (1963, 1977), was derived mainly from the eastern part. From that time, many new data have been collected, completing the view on the Czorsztyn sedimentary area.

Synrift deposition at the Czorsztyn swell in the light of modern investigations

The main progress in the investigations has been done by distinguishing of several new lithostratigraphic units (summarized in Mišík et al., 1996) and new facial interrelationships (Fig.1), sheding a new light on the synsedimentary tectonics responsible for formation of the Czorsztyn Swell.

Mišík (1979) distinguished a special shallow marine development of the Czorsztyn Unit, characterized by presence of the Oxfordian reefal facies (Vršatec Limestone, Fig.2).

Mestečko development, distinguished by Aubrecht (1992) is characterized by muddy, massive (unnodular) Bohunice Limestone (Mišík et al., 1994), instead of nodular Czorsztyn Limestone. This limestone was hitherto found in several localities i.e. Mestečská skala, Babiná, Štepnická skala, Podhorie (all sites in the western part of the PKB) and Stankowa Skala (eastern part of the PKB - see Kutek & Wierzbowski, 1986, fig.3).

The Bohunice Lst. might be either a shallower facies which was not influenced by submarine dissolution or it might represent some isolated mud-mounds or mud-banks surrounded by an area of condensed sedimentation. The latter theory is based mainly on the presence of stromatactis cavities within the limestone (Fig.3), being typical for mud-mounds. However, little is known about the transition between supposed mound and off-mound facies. Only one perspective locality has been hitherto found - Lorencowe Klippes (Wierzbowski, 1994, fig.3) - where nodular and massive beds alternate within the Czorsztyn Limestone Formation.

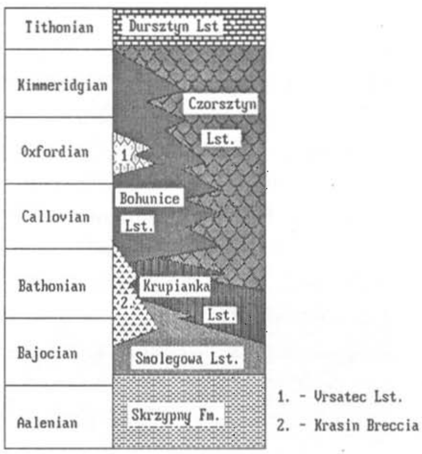

Fig. 1 Schematic lithostratigraphic column of thje Czorstyn Unit based on the latest data

Another instance of the differential subsidence of the Czorsztyn crustal blocks are the Bajocian and Bathonian crinoidal limestones. The first division of these limestones, which was done by Mojsisovics (1867), has been later accepted also by Birkenmajer (1977). The division was based on the colour of the limestones. The Bajocian one (Smolegowa Lst.) possess white to grey colour whereas the Bathonian one (Krupianka Lst.) is red coloured. The main colour-bearing component of the limestones is red micrite. Its absence resulted in the white or grey colour of the limestone. The presence of micrite depends on the hydrodynamic conditions during deposition (some instances of later implacement of micrite into intergranular pores are known also), hence it indirectly indicates also the bathymetry. In this way, the superposition of the red limestones over the white ones reflects general trend of continual deepening of the sedimentary area. Such superposition has been enregistered at the majority of the occurrences of the Czorsztyn Unit. However, some sites found at the western part of the PKB do not correspond to this division. For instance, in the Mestečská skala Klippe, a multiple alternation of the limestones of both colours has been enregistered (Aubrecht, 1992). Also inverted sequence has been found. At the Babiná Klippe (the type locality of the Bohunice Lst.), already Halajov (1981)

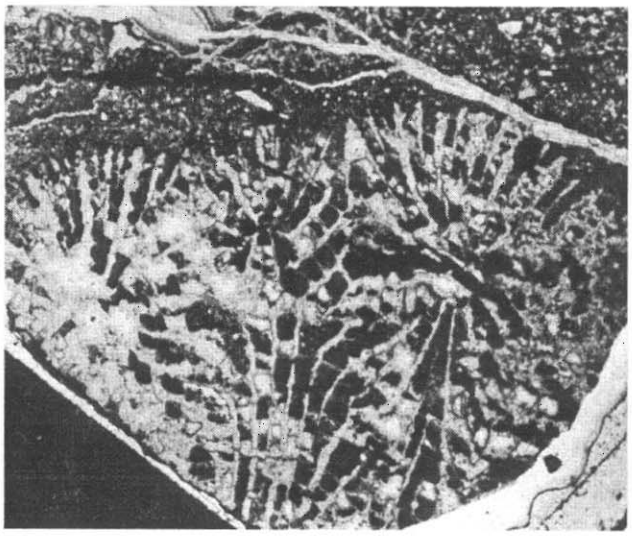

Fig.2 - Coral Complexastrea carpathica MORYCOWA, *thin-section of Vršatec biohermal limestone. Magn. 5x.*

described white crinoidal limestones overlying the red ones. According to the prevailing stratigraphical scheme of the Czorsztyn Unit, she marked the contact of the limestones as tectonic. Nevertheless, later research ascertained their normal stratigraphical superposition (Mišík et al., 1994). After a hardground representing an omission surface (non-deposition during the uppermost Bathonian to Lower Callovian), the white crinoidal limestone is directly overlain by the Callovian part of the Bohunice Limestone. Both instances indicate a differential subsidence with respect to the sites with "normal" superposition.

Besides the Oxfordian Vršatec Limestone, another very shallow marine facies has been discovered in the Czorsztyn Unit. So far unknown oolitic limestone has been found at a locality in Bolešovsk dolina Valley, W of Ilava. The locality has been described already by Salaj (1990) and attributed to the Fodorka Succession. According to our opinion, this occurrence does not differ from other occurrences of the Czorsztyn Unit. Occurrence of the oolitic limestone places this locality to the shallowest parts of the Czorsztyn sedimentary area. The limestone fills synsedimentary clefts and neptunian dykes in which the sediment was trapped. It has not been found in its natural environment from which it was most probably replaced. There is a relatively thick layer of Mn-hardground above the crinoidal limestone, indicating the nondeposition (or leaching and winowing of the sediment) during the Callovian rapid sea-level rise. In this context, the exclusive preservation of the oolitic limestones in the fissure traps seems logical. The limestone contains no other components except ooids and microoncoids (Fig.4). Since the fissures occur in the Bajocian-Bathonian crinoidal limestones, they are younger, probably of Callovian-Oxfordian age.

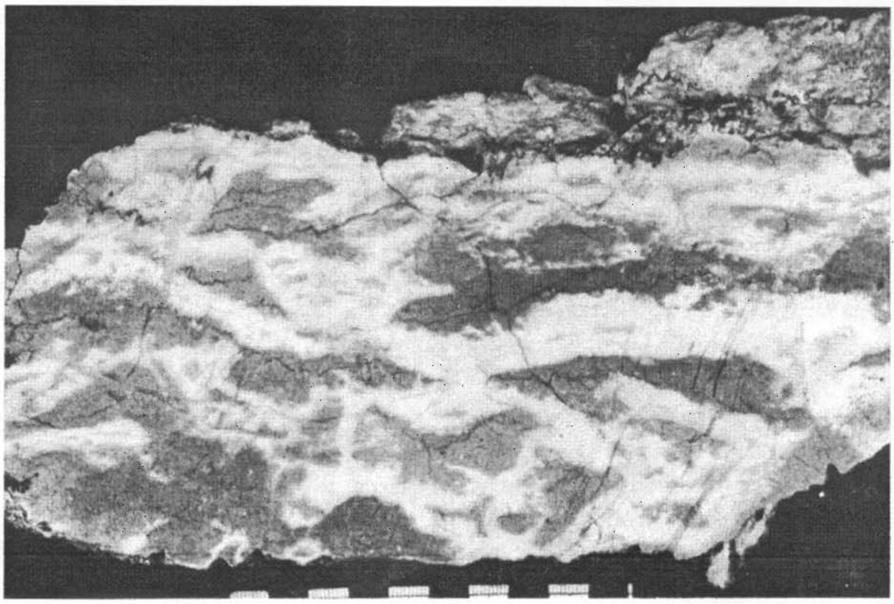

Fig. 3 - Stromatactoid cavities in the Bohunice Limestone (Callovian). Locality: Podhorie. Centimeter scale at bottom.

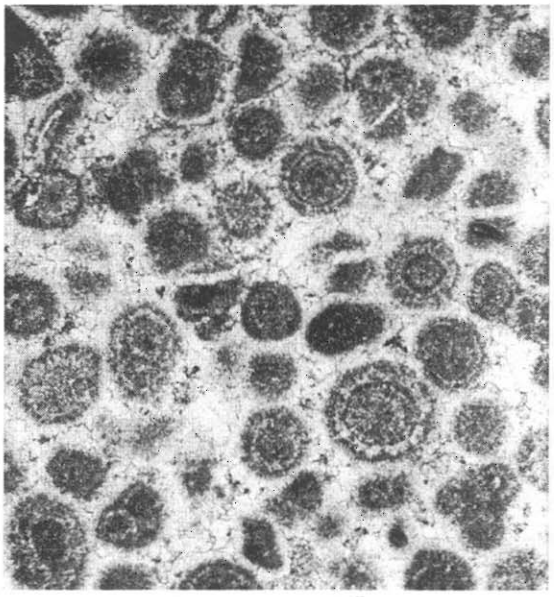

Fig.4 - Oolitic to microoncolitic limestone (oosparite) representing a cleft filling. Klippe at the NW end of the Bolešov Valley. Magn. 30x.

The phenomenon directly reflecting synsedimentary tectonics are neptunian dykes (Fig.5). Neptunian dykes in the Czorsztyn Unit were firstly noted by Birkenmajer (1958) who assumed that the fractures probably formed by earthquakes. Mišík (1979) described at least four generations of neptunian dykes from Vršatec Klippes. According to our observations, the neptunian dykes are concentrated mainly to those klippes which are characterized by the above mentioned shallower facies. It determines also the maximum activity of the extensional faults in this part of the sedimentary area. Some structural measurements were carried out (for example Mišík et al., 1994, fig.2). However, the results were not yet completed by paleomagnetic studies which would provide the basic data for orientation of the individual klippes during Middle Jurassic.

Other difference from the "classical" scheme of the Czorsztyn Unit is the Krasín Breccia (Fig.6) of Bajocian to Bathonian age, which is directly related to the synsedimentary tectonics. It reflect an unquiet deposition, multiple destruction and reworking of the sediment, as well as the facial changes which took place in the Middle Jurassic time. This scarp breccia represents an unique phenomenon found hitherto only at 4 localities in the western part of the PKB. The individual occurrences will be mentioned in the order they were found:

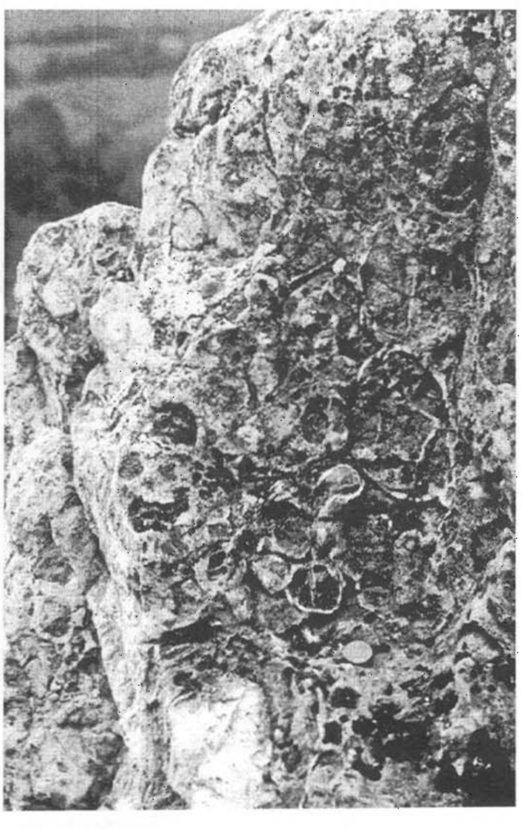

Fig. 5 Tithonian-Berriassian neptunian dykes in the Callovian-Oxfordian limestone breccia. Locality:Kyjov-Pusté Pole.
Fig.6 Clast of the Middle Jurassic breccia in the Lower Cretaceous younger breccia. Locality: Krasín - quarry. Coin for scale.

1. First time, the breccia has been discovered at the large quarry in the Krasín Klippe, W of Dolná Súča village (Mišík, Sýkora & Aubrecht, 1994). The clasts, as well as the matrix of the breccia consists mainly of crinoidal limestones, hence the time of its origin falls still to the Bajocian/Bathonian. The scarp-forming process was most likely induced by a fault tectonic movements related to tilting of the Czorsztyn crustal block (Fig.7). It is documented also by numerous neptunian dykes (Fig.8) occurring not only at this locality, but being very frequent in the Czorsztyn Unit occurring in the western segment of the PKB. Krasín Klippe is also characterized by sedimentary gaps connected with emergence and erosion of some members as for instance Oxfordian Vršatec Limestone, clasts of which are preserved only in the neptunian dykes (Fig.9). Remnants of the Czorsztyn nodular limestone which occurred in the quarry were removed by mining, hence they are not available for our study. The Lower Cretaceous crinoidal Spisz Limestones directly overlap the Middle Jurassic crinoidal limestones, filling large clefts. All this facts situate the Krasín Klippe to the zone with maximum synsedimentary tectonic movements within the Czorsztyn sedimentary area.

2. Next locality has been revealed near Horné Sŕnie village, at local part Samášky (Aubrecht (1997). It represents an outcrop of "evinosponge" breccia with clasts of the Middle Jurassic crinoidal limestones and complex cement and intergranular sediment filling (Fig.10).

The clasts frequently bear signs of rounding. They are enveloped by several generations of cyanolithic and microbialitic crusts (stromatolites) originated in various sedimentary conditions.

The second phase of filling is radiaxial fibrous calcite full of inclusions. This cement provides the "evinosponge" appearance of the rock (this type of breccia occurs only rarely at the Krasín type locality). The radiaxial fibrous calcite represents typical marine cement (Tucker & Wright, 1990). Formerly it was considered as paramorphosis after primary aragonite cement (Kendall & Tucker, 1973); the opinions about its primary origin predominate recently (Kendall, 1985, Saller, 1986).

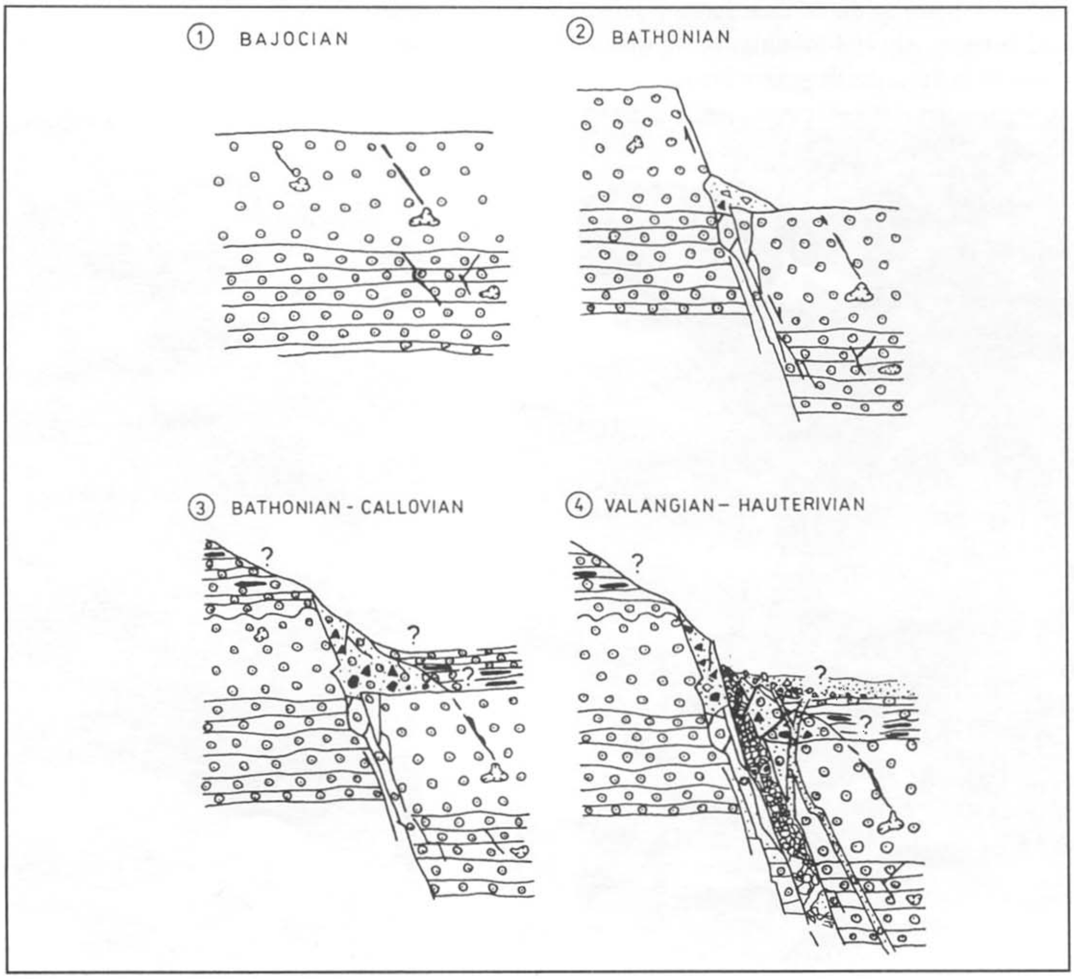

Fig.7 - Suggested geological evolution at the Krasín locality.

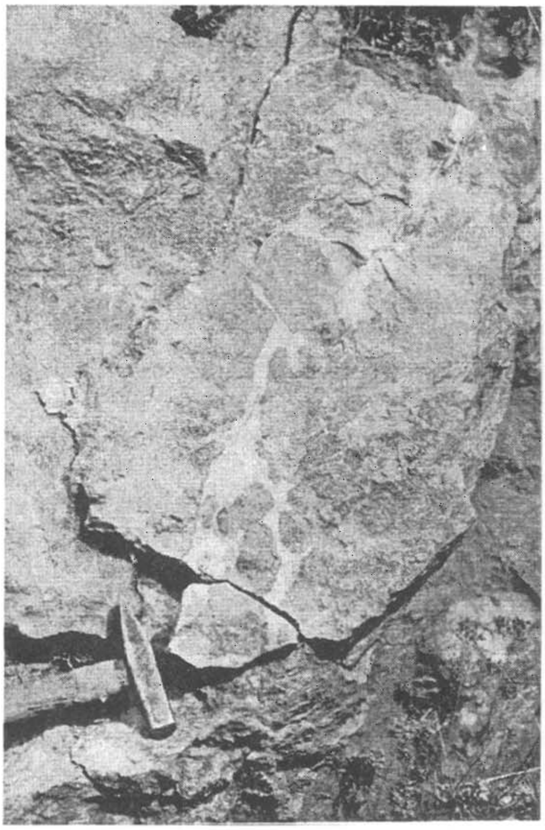

Fig.8 - Neptunian dyke with clasts in the Middle Jurassic breccia. Locality: Krasín - quarry.
Fig.9 - Bioherm breccia probably of Oxfordian age with Triassic dolomite lithoclasts - filling of a cleft in the Middle Jurassic limestones; western margin of the Krasín quarry. Coin for scale.

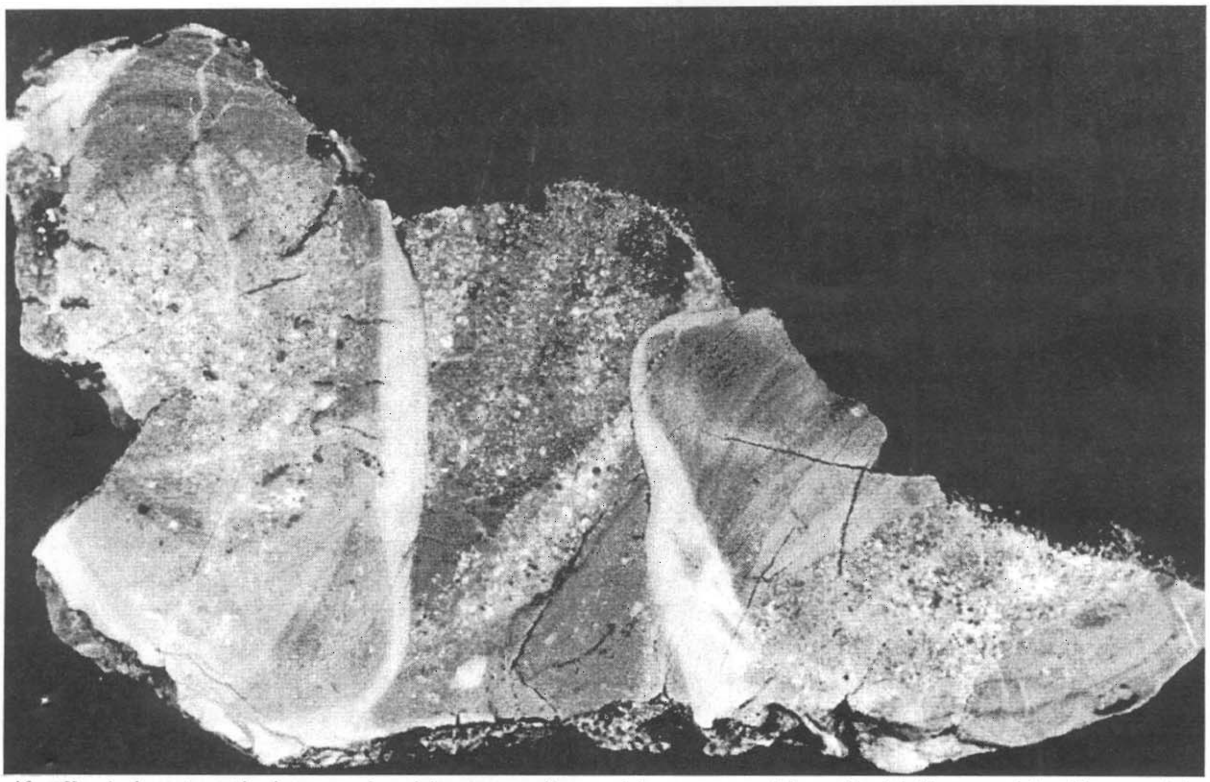

Fig.10 - Krasín breccia with clasts enveloped by stromatolites and later cemented by radiaxial fibrous calcite. The remaining interstitial space is filled by laminated crinoidal detritus. Locality: Horné Sŕnie - Samášky II. Centimeter scale below.

Remaining voids, if they are small are filled by clear blocky calcite; larger voids are filled by sediment. The first phase of the sedimentary void filling consists mainly of crinoidal detritus, indicating synchronous origin of the breccia and deposition of the Middle Jurassic crinoidal limestones. Later this filling was replaced by wackestone to packstone with "filament" microfacies (containing thin shells of bivalves Bositra) which indicates Upper Bathonian to Callovian age in the Czorsztyn sedimentary area.

The third phase of filling (when the voids were sufficiently closed, with restricted communication with open sea), was the micrite full of sculptured ostracods sedimented. These ostracods have been enregistered at many sites of the Czorsztyn Unit, always in the voids and fissure fillings. Firstly they were described by Mišík (1979). They represented the original dwellers of voids, fissures and cavities in sea bottom. Based on the negative and positive outprints of their shells they were successfully determined as Pokornyopsis feifeli (Triebel) described hitherto only from the German Jurassic sediments. The mentioned species has its Recent descendants (genus *Danielopolina*) dwelling in the same environment - in the submarine caves in the Carribean sea (Kornicker & Sohn, 1976). This way, the Recent ostracod fauna dwelling in the submarine caves involves relics of Mesozoic fauna (Aubrecht & Kozur, 1995).

Isotope data ($\delta^{18}O$ and $\delta^{13}C$) from majority of the cements and sedimentary fillings, as well as from the wall-rock show marine values ($\delta^{13}C$ between 1.8 and 3.3‰ PDB, $\delta^{18}O$ between -5.8 and 0.4‰ PDB). Only the first generation of the stromatolites display freshwater origin ($\delta^{13}C$ between -4.1 and -4.5, $\delta^{18}O$ between -4.5 and -5.8). It is the first direct proof of the emergence connected with freshwater cementation found in the Jurassic of the Pieniny Klippen Belt (Aubrecht, 1997). It indicates that diagenetically rapidly lithified crinoidal limestones were emerged still during Bathonian and subsequently eroded. Their debris were covered by freshwater stromatolites, most probably in the stream. Later the clasts were transported and deposited in the marine environment, where they were cemented firstly by marine stromatolites and then by radiaxial fibrous calcite. The remaining voids were filled by crinoidal detritus, later by micrite with Bositra shells and other subsequent fillings mentioned above. From this results that the breccia originated still during deposition of the crinoidal limestones, most likely in Bathonian.

3. The third occurrence represented only small remnant in the Babiná quarry (not mentioned in Mišík et al., 1995). Like at the previous locality, the rounded clasts of crinoidal limestones were cemented by radiaxial fibrous calcite, with remaining voids filled by sterile red micrite.

4. The latest occurrence has been found at klippe on the top of Babiná hill, relatively closely to the previous site. It is also similar to the occurrence near Horné Sŕnie, but with less developed stromatolites and microbialites. The empty spaces between clasts are also filled by crinoidal limestone, indicating the Bajocian-Bathonian age of the breccia.

Somewhat younger - Callovian cliff breccia has been mentioned also from Kyjov - Pusté Pole locality (Mišík & Sýkora, 1993). Similar voids filled by radiaxial fibrous calcite and later by micrite with mentioned ostracods has been found also at this locality.

Paleotopography of the Czorsztyn swell

The mentioned new sedimentary phenomena in the Czorsztyn Unit led us to reconsideration of the paleobathymetry and paleotopography of the Czorsztyn sedimentary area. These phenomena appear to be generally related to each other, e.g. sections with Vršatec and Bohunice limestones contain more neptunian dykes than those with Czorsztyn Limestone; neptunian dykes are also closely connected with Krasín Breccia. These "shallower" occurrences apparently contain also much coarser clastic admixture (pebbles up to 10 cm in size) in the crinoidal limestones. As a rule, the crinoidal limestones are massive and less affected by silicification. The "deeper" occurrences contain finer clastics, the crinoidal limestones are frequently bedded and silicified. The criteria differing these two basic types of the Czorsztyn Unit are summarized in Tab.1.

Hitherto known lithostratigraphic scheme of the Czorsztyn Unit, described in detail by Andrusov (1945) and Birkenmajer (1963, 1977), appears to be derived from its somewhat deeper developments.

There are some notes to the position of these two basic developments. According to the classical paleogeographical scheme of Birkenmajer (1977, fig.5), the deeper-water development had to be situated more to the south, while the shallower one more to the north, closer to emerged Czorsztyn

Swell. However, besides the transverse facial relationship, also a longitudinal dissection of the Oravic sedimentary area must be taken into account. There are several examples, resulting from the recent arrangement of the Pieniny Klippen Belt:

Tab.1 Criteria for distinguishing of the deeper-water and shallow-water parts of the Czorsztyn Unit

	deep-water developments	shallow-water developments
Kimmeridgian + Oxfordian + Callovian	Czorsztyn Nodular Limestone	Bohunice Limestone (mudstone to wackestone). Vršatec Limestone (biohermal)
	-	oolitic limestone
	rare neptunian dykes	frequent neptunian dykes
Bathonian + Bajocian	smaller size and content of clastics	larger size and content of clastics
	dominance of bedded crinoidal limestones	dominance of massive crinoidal limestones
	frequent silicification(cherts in the crinoidal limestones)	rare silicification
	–	Krasín Scarp Breccia
	Krupianka Limestone (red biomicrite)	non-differentiated crinoidal limestones (white biosparite)
	Smolegowa Limestone	

1. Nižná Unit, together with Orava Unit, range only within relatively short restricted belts in the Orava part of the PKB.
2. Czorsztyn Unit occurs mainly at the Váh Valley, in the Pieniny Mts. and in the eastern part of the PKB. It is commonly absent in the Kysuca and Orava sections of the PKB.
3. Majority of the occurrences of the mentioned shallower developments of the Czorsztyn Unit is situated at the Váh Valley.

According to our opinion, this recent longitudinal distribution of the Oravic units and their developments partially reflects their original paleogeographical position and topography. Later disturbance of the Oravic units by multiple folding phases of different orientation made this original dissection more distinct. In this manner, the Czorsztyn Swell was more articulated then it was supposed so far. If we took only the longitudinal dissection into consideration, the Czorsztyn Swell would appear to consist of two large segments of different subsidence rate, partially separated by depressions. The western segment, the remnants of which occur now at the Váh Valley, displays some signs of shallower sedimentary environment with respect to the eastern one (Pieniny and East Slovakia). Nevertheless, relative facial uniformity of the Oravic units, which is still remarkable all along the PKB, as well as the identical clastic admixture show that this division cannot be taken as an absolute one. The original dissection has been most probably strongly modified and became more distinct during the latest (Miocene) phases of folding (lateral displacement along peri-Pieninic Lineament).

Provenance of the Oravic crustal segment deduced from heavy minerals contents in the Lower and Middle Jurassic deposits

Clastic admixture analysis in the Oravic units has been used several times, dealing particularly with small pebble fraction (Birkenmajer et al. (1960), Krawczyk & Slomka, 1987, Krawczyk & al., 1987, Mišík & Aubrecht, 1994).

Heavy mineral analysis, as a tool of paleogeographic reconstruction, was omitted for a long time, since works of Lozinski (1956, 1959). The main reason was probably the narrower spectra of heavy mineral assemblages in the Jurassic, resulting from intrastratal dissolution. However, utilization of new methods enabling determination of the wall rocks from chemical composition (garnet, tourmaline, chromium-spinels) or morphological typology (zircon), provided new important data (variation analysis - see Morton, 1985). The percentages of heavy minerals, though influenced by numerous factors, can itself provide a very usefull information. Assuming the stability of various heavy minerals can help in determination of similarities and dissimilarities in the heavy mineral assemblages.

The recent heavy mineral studies of the Jurassic sediments of the PKB (Aubrecht, 1993 and unpublished manuscripts) and of the Central and Inner Western Carpathians (Aubrecht, 1994 and unpublished reports) show a conspicuous difference. It partially results from somewhat wider heavy mineral spectra in the PKB, resulting from less extensive tectonometamorphic affection of its units (having effect on the intrastratal dissolution in the sediment). The narrow spectra in the units south of the PKB cannot be explained, however, only by intrastratal dissolution, since they occur also in the less affected Hronic and Silicic nappe units. Hence the origin of these depleted assemblages is partially primary.

In the PKB, the association containing garnet, zircon, rutile, tourmaline and apatite is dominant (with general decrease of contents in the mentioned order), whereas in the Central and Inner Western Carpathians only the most stable assemblage of tourmaline, zircon and rutile dominates. The difference is visible also in the ratio of the most stable minerals. While the Oravic Units are dominated by zircon, the units south of the PKB are dominated by tourmaline. This indicates at least two main provinces of heavy mineral distribution. The province of Oravicum is most probably connected with Gresten Klippen Belt and the autochthonous Jurassic cover of margins of the Bohemian Massiff, beneath the West Carpathian overthrust (Aubrecht, 1994a and the sources cited therein). Hence it connects the Oravic units with the North European platform, not with the Central Western Carpathians.

Position of the Klape, Manín and Drietoma units is problematic. It is reflected also by heavy minerals. They contain the wider heavy mineral spectra like the Oravic units, but the most resistant part is dominated by tourmaline, like the Central and Inner Western Carpathian units.

Very interesting data (still in process) have been provided by the variation analysis of some minerals. The most significant was the chemical analysis of garnet grains from the Lower Jurassic of the PKB (Nižná Unit, Manín Unit and Klape Klippe). Majority of the garnet grains is characterized by increased contents of the pyrope molecule (Mg) in the amounts typical for granulites and/or eclogites. Such garnets do not occur in the Central and Inner Western Carpathian crystalline complexes. It indicates that the sedimentary areas of the Manín Unit and Klape Klippe (its relationship to the Klape Unit is uncertain) may be also situated to the mentioned Oravic distributional province.

The peculiar chemical contents of garnets even more restrict the presumed original domain, from which the Oravic crustal segment was derived. The closest occurrences of granulites are in the Moldanubicum of the Bohemian Massif, about 130-140 km W of the westernmost recent outcrops of the PKB. The northeastward movement of the Oravic segment would be consistent with the presumed general movement of Central West Carpathian segment (Michalík, 1994).

However, placing the Oravic segment at the Moldanubic margin contradicts to the data obtained from pebble analysis (Birkenmajer et al., 1960, Krawczyk & Slomka, 1987,Mišík & Aubrecht, 1994). Neither granulitic, nor eclogitic detritus has been reported. On the other hand, many of the reported rocks (e.g. acid volcanics - porphyries etc.) do not occur in the Moldanubicum, hence the question of the Oravic provenance still remains open.

Conclusion

The Oravic crustal segment was separated from the North European Platform by an oblique rifting and subsequently migrated east- to northeastward. The rifting started during the Lower Jurassic period, but the new ocean fully developed in Middle to Upper Jurassic. After Aalenian, the segment consisted of continental crust of various thickness which was caused by block tilting and partial extensional thinning of the crust. From this resulted also the facial variability among the Oravic units. The thicker crustal part formed basement of the Czorsztyn Swell. It was surrounded by thinned continental crust (passing gradually to oceanic one) underlying the basinal facies of the Kysuca-Pieniny Unit.

In Bajocian and Bathonian, the Czorsztyn swell was partially emerged, eroded (influx of clastic admixture), with local temporary freshwater cementation. Synsedimentary tectonics was responsible for formation of neptunian dykes and scarp breccias, as well as for the differential block subsidence, reflected in the various sedimentary record in the individual sections. The Czorsztyn Swell consisted at least of two segments partially separated by axial depression, which is still conspicuous in the recent distribution of the occurrences of the Czorsztyn Unit. The western segment was somewhat shallower submerged than the eastern one. The shallow neritic to subtidal areas of the swell were sites where the crinoidal limestones sedimented. In shallower parts with dynamic water environment (probably still above the wave base), the crinoidal grainstones (biosparites - Smolegowa Lst.) originated, whereas below the wave base originated the biomicrites (Krupianka Lst.). Subsequently, the biomicrites became dominant with gradual deepening of the sedimentary area.

Callovian was characterized by the global sea-level rise combined with Tethyan tectonic sinking caused due to the extension. In this time, the whole Czorsztyn Swell became submerged. In spite of the submergence, sedimentary record displays previous dissection of the relief. The restricted coral bioherms formed in the shallowest parts, in somewhat deeper parts, the pink mudstones sedimented. Toward the basin they passed to the condensed nodular limestone; the deepest parts of the basin bellow the CCD were characterized by sedimentation of the radiolarian muds (future radiolarites). Such facial distribution persisted generally up to the Upper Jurassic-Lower Cretaceous time with relatively uniform basinal sedimentation (biancone and maiolica facies) and relatively variable sedimentation at the swell (Dursztyn Limestone Fm.).

The continuing synsedimentary extensional tectonic activity is reflected by neptunian dykes with Oxfordian, Tithonian up to Albian filling (Mišík, 1979). Kimmeridgian dykes were not found so far (absence of the Saccocoma microfacies in the dykes).

Acknowledgements

The data used in this summarizing paper are the results of the following projects at which the authors participated: Grants No. 1/1812/94 and 1/3052/96 of GAV and VEGA agencies, project "Geodynamic evolution of the Western Carpathians" managed by the Geological Survey of Slovak Republic and G06 project of the Comenius University.

References

Andrusov, D., 1927: Předběžná zpráva o geologických výzkumech ve vnitřním pásmu bradlovém na Slovensku (1925-1926). Věst. St. geol. Úst. ČSR (Praha), 3, 2-3, 126-152.

Andrusov, D., 1938: Geologický výzkum vnitřního bradlového pásma v Západních Karpatech Část III. (Tektonika). Rozpr. St. geol. Úst. ČSR (Praha), 9, 1-135.

Andrusov, D., 1945: Geologický výskum vnútorného bradlového pásma v Západných Karpatoch. časť IV (Stratigrafia doggeru a malmu) a časť V (Stratigrafia kriedy). Práce Št. GÚ (Bratislava), 13, 1-176.

Aubrecht, R., 1992: Mestečská skala klippe and its importance for stratigraphy of Czorsztyn Unit (Biele Karpaty Mts., Western Slovakia). Acta geol. et geogr., Geologica (Bratislava), 48/I, 55-64.

Aubrecht, R., 1993: Clastic admixture in Dogger crinoidal limestones of Czorsztyn Unit. Geologica Carpathica (Bratislava) 44, 2, 105-111.

Aubrecht, R., 1994: Heavy mineral analyses from "Tatric" units of the Mal, Karpaty Mts.(Slovakia) and their consequence for the mesozoic paleogeography and tectonics. Mitt. Österr. Geol. Ges. (Wien), 86, 121-132.

Aubrecht, R., 1994a: Sedimentológia a faciálne pomery jurských sedimentov pienidných jednotiek bradlového pásmaa ich vzťah k jednotkám centrálnych Západných Karpát na základe štúdia ťažkých minerálov. Manuscript - PhD thesis. Dept.of Geol.and Paleont., Com. Univ. Bratislava.

Aubrecht, R., 1997: Indications of the Middle Jurassic emergence in the Czorsztyn Unit (Pieniny Klippen Belt, Western Carpathians). Geologica Carpathica (Bratislava), 48, 2,71-84.

Aubrecht, R. & Kozur, H., 1995: Pokornyopsis (Ostracoda) from submarine fissure fillings and cavities in the Late Jurassic of Czorsztyn Unit and the possible origin of the Recent anchialine faunas. Neues Jb. Geol. Paläont. Abh. (Stuttgart), 196, 1, 1-17.

Began, A. & Borza, K., 1963: Nová séria - streženická - vo vnútornom bradlovom pásme Západných Karpát. Geol. sbor. (Bratislava), 14, 2, 217-220.

Began, A. & Kantorov , V., 1961: Krieda bradlového pásma Považia v úseku Púchov - Bošácka dolina. Geol. Práce., Správy (Bratislava), 22, 69-81.

Birkenmajer, K., 1953: Preliminary revision of the Stratigraphy of the Pieniny Klippen-belt series in Poland. Bull. Acad. Pol. Sci., III, 1, 6, Warszawa, 271-274.

Birkenmajer, K., 1958: Submarine Erosional Breaks and Late Jurassic Synorogenic Movements in the Pieniny Klippen-belt Geosyncline. Bull. Acad. Pol. Sci. (Warszawa), 6, 8, 551-558.

Birkenmajer, K., 1959: Seria czertezicka - nowa seria skalkowa Pienin. Acta geol. Pol. (Warszawa), 9, 4, 499-517.

Birkenmajer, K., 1963: Stratigrafia i paleogeografia serii Czorsztynskiej pieninskiego pasa skalkowego Polski. Stud. geol. Pol. (Warszawa), 9, 1-380.

Birkenmajer, K., 1977: Jurassic and Cretaceous lithostratigraphic units of the Pieniny Klippen Belt, Carpathians, Poland. Stud. Geol. Pol. (Warszawa), 45, 1-158.

Birkenmajer, K., Gasiorowski S.M. & Wieser T., 1960: Fragments of exotic rocks in the pelagic deposits of the Bathonian of the Niedzica Series (Pieniny Klippen Belt, Carpathians). Roczn. Pol. Tow. Geol. (Kaków), 30, 1, 29-57.

Birkenmajer, K. & Tyszka, J., 1996: Palaeoenvironment and age of the Krzonowe Formation (marine Toarcian - Aalenian), Pieniny Klippen Belt, Carpathians. Stud. Geol. Pol. (Kraków), 109, 7-42.

Halajová L., 1981: Terigénna prímes vo vápencoch jury bradlového pásma a stavba bradla Babiná pri Krivokláte'-Bohuniciach. Manuscript - MSc. thesis - Dept. of Geol. and Paleont., Com. Univ., Bratislava, 1-73.

Haško, J., 1978: Oravská séria - nová séria bradlového pásma Kysuckej vrchoviny. Geol. Práce, Správy (Bratislava), 70, 115-121.

Hlôška, M., 1992: Geologická stavba pieninského bradlového pásma severne od Starej Turej. - Manuscript - MSc. thesis Dep. of Geol. and Pleont., Com. Univ., Bratislava, 1-41.

Kendall, A.C., 1985: Radiaxial fibrous calcite: a reapraisal. In: Schneidermann N & Harris P.M. (eds.): Carbonate Cements SEPM Spec.Publ. 36, 59-77.

Kendall, A.C. & Tucker, M.E., 1973: Radiaxial fibrous calcite:a replacement after acicular carbonate. Sedimentology, 20, 365-389.

Kornicker, L. F. & Sohn, I. G., 1976: Phylogeny, ontogeny, and morphology of living and fossil Thaumatocypridacea (Myodocopa: Ostracoda). Smithson. Contrib. Zool., 219, 1-124.

Krawczyk A.J. & Slomka T., 1987: Exotic rocks from the Szlachtowa Formation (Jurassic flysch) of the Pieniny Klippen Belt, Carpathians. Stud. Geol. Pol. (Warszawa), 92, 7, 69-74.

Krawczyk A.J., Muszynski M. & Slomka T., 1987: Okruchy skal w psamitach formacji szlachtowskiej pieninskiego pasa skalkowego. Stud. Geol. Pol. (Warszawa), 92, 7, 75-87.

Krobicki, M., 1993: Tithonian-Berriassian brachiopods in the Niedzica Succession of the Pieniny Klippen Belt (Polish Carpathians): Paleoecological and paleobiogeographical implications. In: Pálfy, J. & Vörös, A.(eds.): Mesozoic Brachiopods of Alpine Europe. Hung. Geol. Soc.- Budapest, 69-77.

Kutek, J. & Wierzbowski, A., 1986: A new account on the Upper Jurassic stratigraphy and ammonites of the Czorsztyn succession, Pieniny Klippen Belt, Poland. Acta Geol. Pol. (Warszawa), 36, 4, 289-316.

Lozinski, J., 1956: Mineraly ciezkie piaskowców aalenu fliszowiego w pieninskim pasie skalkowym. Acta Geol. Pol. (Warszawa), 6, 17- 23.

Lozinski, J., 1959: Mineraly ciezkie piaskowców dolnej i srodkowej kredy w pieninskim pasie skalkowym. Rocz. Pol. Towar. Geol. (Kraków), 29, 1, 119-125.

Maheľ, M., 1986: Geologická stavba československých Karpát. Paleoalpínske jednotky 1. Veda - vyd.SAV, 1-503.

Michalík, J., 1989: Vývoj, zmeny a štruktúry asociácií jurských brachiopodov. In: Zbor. Z paleont. konf. - Súčasné probl. a trendy ČS paleontológie, 85-107.

Michalík, J., 1994: Notes on the Paleogeography and Paleotectonics of the Western Carpathian Area During the Mesozoic. Mitt. Österr. Geol. Ges. (Wien), 86, 101-110.

Mišík, M., 1979: Sedimentologické a mikrofaciálne štúdium jury bradla Vršateckého hradu (neptunické dajky, biohermný vývoj oxfordu). Západné Karpaty, Sér. geológia (Bratislava), 5, 7-56

Mišík, M. & Aubrecht, R., 1994: Source of rock fragments in the Jurassic crinoidal limestones of the Pieninicum (Klippen Belt, Western Carpathians). Geologica Carpathica (Bratislava), 45, 3, 159-170.

Mišík, M. & Sýkora, M. (1993): Jurassic submarine scarp breccia and neptunian dykes from the Kyjov - Pust, Pole klippen. Mineralia Slovaca (Bratislava), 25, 6, 411-427.

Mišík, M., Siblík, M., Sýkora, M. & Aubrecht, R., 1994: Jurassic brachiopods and sedimentological study of the Babiná klippe near Bohunice (Czorsztyn Unit, Pieniny Klippen Belt). Mineralia slovaca (Košice), 26, 4, 255-266.

Mišík M., Sýkora, M. & Aubrecht, R., 1994: Middle Jurassic scarp breccias with clefts filled by Oxfordian and Valanginian-Hauterivian sediments, Krasín near Dolná Súča (Pieniny Klippen Belt). Geologica Carpathica (Bratislava), 45, 6, 343-356.

Mišík, M., Sýkora, M., Siblík, M. & Aubrecht, R., 1995: Sedimentology and brachiopods of the Lower Jurassic Lúty Potok Limestone (Slovakia, West-Carpathian Klippen Belt). Geologica Carpathica (Bratislava), 46, 1, 41-51.

Mišík, M., Aubrecht, R., Sýkora, M. & Ožvoldová, L., 1996: New lithostratigraphic units in the Klippen Belt. Slovak Geological Magazine (Bratislava), 1/1996, 17-19.

Mojsisovics, E., 1867: Umgebung von Rogoznik und Czorsztyn. Nordliche Tatra Thäler. Verh. geol. Reichsanst. (Wien), 10, 25-29

Morton, A.C., 1985: Heavy minerals in provenance studies. In: Zuffa, G.G. (ed.): Provenance of arenites, 249-277.

Rakús, M., 1989: Paleobiografia amonitov pliensbachu Západných Karpát. In: Zbor. z paleont. konf. - Súčas probl. a trendy ČS paleontológie, 111-116.

Salaj, J., 1990: Nové poznatky o geológii a paleogeograficko-tektonickom vývoji bradlovej a pribradlovej zóny stredného Považia a jeho problematika. Knih. Zem. plynu a nafty, sv. 9a, str.93-168, Hodonín.

Saller, A.H., 1986: Radiaxial calcitein Lower Miocene strata, subsurface Enewetak Atoll. Journal of Sedim. Petrol. (Tulsa), 56, 743-762.

Scheibner, E., 1967: Karpatské pásmo bradlové. In: Regionální geologie ČSSR, díl II - Západní Karpaty (ed. Buday, T. et al.), 7-105, Praha.

Tucker, M.E. & WRIGHT, V.P., 1990: Carbonate sedimentology. Blackwell Scientific Publications (Oxford), 1-482.

Uhlig, V., 1907: Über die Tektonik der Karpathen. Sitzungsber. Akad. Wiss. Wien (math.-naturw. Kl.) (Wien), 116, 1, 871-982.

Wierzbowski, A., 1994: Late Middle Jurassic to earliest Cretaceous stratigraphy and microfacies of the Czorsztyn Succession in the Spisz area, Pieniny Klippen Belt, Poland. Acta Geol. Pol. (Warszawa), 44, 3 - 4, 223-249.