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THE SLOVAK PART OF THE PIENINY KLIPPEN BELT AFTER THE PIONEERING WORKS OF D. ANDRUSOV

MILAN MIŠÍK

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

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Abstract: The progress of investigations concerning the Pieniny Klippen Belt in the last twenty years is discussed and the actual state of opinions about its evolution presented. This most complicated zone of the Western Carpathians is remarkable for the complete separation of the unknown Paleozoic-Triassic basement from the Jurassic-Cretaceous strata. A nappe pile from shallow-water as well as deep-water successions resulted from the first compression. More rigid Jurassic-Lower Cretaceous limestones were during the following transpression torn of in the lenses (klippen) amidst the plastic sediments of the Upper Cretaceous strata („envelope"). A critical analysis of 15 successions (and their varieties) discerned up till now in the Slovak segment is given and their mutual position within the ancient sedimentary area is discussed. The following problems remain open: the origin of the exotic material in the Cretaceous and Paleogene conglomerates, the existence of a transform possessing oceanic crust, the place of Haligovce, Nižná and Michalová Hora Successions in the sedimentary area, the presence of the Magura Succession (Grajcarek Unit) on the Slovak territory, the possible provenance and transport of the Manín, Drietoma and Kostolec Successions from the Central-Carpathian nappes.

Key words: Western Carpathians, Pieniny Klippen Belt, Jurassic, Cretaceous, tectonic evolution, paleogeography.

Introduction

The Pieniny Klippen Belt was the favourite theme of Dimitrij Andrusov and the main object of his study which resulted in a monograph of five volumes (Andrusov 1931, 1938, 1945) completed in latest years by numerous publications till his death in 1976. The bibliography of D. Andrusov was published by Fusán & Samuel (1978). Our task is to sketch the new substantial contributions to the Slovak part of the Pieniny Klippen Belt, which have changed its interpretation after these twenty years. The Pieniny Klippen Belt (PKB in the further text) is a speciality of the Western Carpathians, D. Andrusov called it a „marvel of the nature". The PKB is remarkable for its extremely complicated geological evolution conditioned partly by its position at the boundary of the externides and internides.

Length of PKB

PKB is a narrow (maximum 15 km wide including the Peri-Klippen Belt) but extremely long zone, according to Scheibner (1967b) extending more than 600 km, from the outskirts of Vienna to Poiana Botizei in Rumania. There are now doubts about the appurtenance of both mentioned extreme segments to the PKB. They are mostly considered as belonging to the more external — Magura Unit. Birkenmajer (1985, p. 105) assigned the occurrence near Poiana Botizei to his Grajcarek Zone (Magura Succession). Bombita & Pop (1991), Bombita et al. (l992) attributed this sequence of strata to a new tectono-facial unit called the Poiana Botizei Subunit, possessing a still more external position than the Grajcarek Zone. Their conclusion is based on the hiatus covering the Upper Aptian and Albian. Such a hiatus with the absent Albian sediments does not exist in the PKB. The main difference is, however, an intensive basic volcanism during the Callovian–Oxfordian entirely unknown in the PKB.

The occurrence near the Vienna Zoo thoroughly described by Prey (1975) as the lowest part of the Kahlenberg Nappe is now considered by the Austrian geologists as a part of the „Kiesel-kalk Zone", the continuation of the Ybbsitz Klippen Belt (Faupl, personal communication). Some phenomena like the abundant picrite dykes in the Vienna area, or blocks of serpentines in the Ybbsitz Zone are foreign to the PKB. It should be stressed that the continuation of PKB from its last outcrop near Podbranč into the basement of the Vienna Basin was ascertained by boreholes only up to Bištava–Šaštín–Smolinské. It was not intercepted by the geophysical methods which could hardly be expected due to its almost vertical position. The last time Frasl & Uher (1996) found pebbles of exotic granites with stilpnomelane, characteristic for the PKB „Upohlav" conglomerates, in the wider area of Vienna (Wienerwald, Mödling). Such pebbles are absent in the conglomerates occurring farther to the West. Thus, the question of the termination of the PKB remains open.

Main tectonic events in the PKB

The following events may be discerned in the scenario, (some of them took place simultaneously):

1. Differentation of the sea bottom into troughs and swells during the Jurassic.

2. Synsedimentary tectonics in the elevated areas, mainly in the Czorsztyn Zone, their vaulting caused the formation of filled extension clefts (neptunic dykes) and submarine scarp breccias — Middle–Upper Jurassic and Lower Cretaceous.

3. The origin of a transform containing oceanic crust in the Peri-Klippen area close to the inner margin of the PKB (probably in the Callovian-Oxfordian), its subduction culminated in collision. Raising of the subduction mélange above sea level, origin of the exotic source area (Pieniny Cordillera = Andrusov Ridge). The first input of ophiolitic detritus in the Barremian, first abundant conglomerates with the exotic rocks since the Albian (in the East-Slovak segment of the PKB since the Paleocene due to the oblique collision). The pre-Albian transform is not generally accepted.

4. Perfect décollement of the Paleozoic+Triassic strata now deeply buried from the Jurassic nad Cretaceous strata now forming the PKB.

5. Imbrication, nappe overthrust in the Pieninic area during the Late Campanian. This could not have happened before the above mentioned décollement, if it had, the existence of numerous klippes containing Triassic strata would be expected.

6. Overthrust of a part of the Krížna Nappe onto the PKB area (Drietoma Succesion) in the Podbranč–Trenčín segment (perhaps also the Silica or Choč Nappe in the Púchov segment) in the time span Albian–Early Senonian. It is not unanimously accepted.

7. Tearing up of the rigid Mesozoic strata into tectonic lenses — klippes, mostly before the Paleogene (the lack of Paleogene strata between the scales of Mesozoic rocks in the western part of the PKB) but also after the Paleogene (scales together with the Paleogene strata near the external margin of the PKB: Púchov and Orava segments, Grajcarek in the Pieniny Mts. and East-Slovak segment). Vaulting of the Peri -Klippen area (inner margin of the PKB) in the Paleocene connected with the biohermal sedimentation on that elevation, gravitational destruction of the reefs and their gliding to the south, down the slope. Subduction of the internal part of the Magura Zone including the root area of their nappes under the PKB since the Oligocene.

8. Backthrusting in the Lower Miocene. Overthrust of the Magura Unit onto the PKB and the PKB onto the Central-Carpathian Paleogene. Mega-anticlinal uplift of the PKB followed by erosion, mainly in the western segment.

9. Sigmoidal bending in the PKB connected with younger transversal faults in the Lower Miocene.

10. Continuation of the transform movement — horizontal shifts in the PKB during the Badenian.

11. Gravitational disturbances during the Quaternary.

Dating of the mentioned tectonic events

The strong multiphase tectonic effects in the PKB have been explained by its position over the contact of the Bohemian Massif (East-European Platform) and Carpathian crystalline block; their contact surface was designated the Peri-Pieninic Lineament (Máška 1961, p. 18–20; Biely 1975). The situation of the Peri-Pieninic Lineament ascertained by the geophysical methods is not concordant with that of the PKB; in its eastern part the lineament is situated in a more external position, in the western part on the inner side far south of the PKB (Mahel' 1980) and it is now considered as a young phenomenon. The width of the original sedimentation area of the PKB was reduced by later tectonic processes to one tenth at least. Several tectonic events persisted for a long time and were repeated in numerous pulses; only a small part of them can be identified by our observation. Our description is based on the following phenomena: angular disconformities, extensional faults containing datable filling (neptunic dykes), scarp breccias accompaying listric faults, beginning of the mass input of clastic material, especially of exotic origin proceeding from the subduction mélange, volcanic activity (in the PKB minimal), measurements of structural data reflecting the tectonic history in the Cenozoic. The following course of events resulted from such a study:

Middle Liassic — neptunic dykes in limestones filled by red, mostly unfossiliferous micrite (synsedimentary fractures) — Nižná Succession (Mišík et al. 1995), Kostelec Succession (author´s own).

Aalenian. The so-called Bolešov phase (Salaj 1987, p. 140; 1990a, p. 152) is an error. Salaj supposed a pre-Aalenian erosion. He mentioned the presence of lagoonal, laminated red and white jaspilites in the klippe Bolešov (in fact, they are neptunic dykes of laminated micrites within crinoidal limestones) and a hypersaline enviroment interpretated from the anhydrite intercalations (none occur there). He derives the so-called jaspilites and Mn-hardground from volcanic activity (non-existing at that time; abundant Mn-Fe hardgrounds in the Jurassic limestones in the Western Carpathians are exclusively of sedimentary origin). A single specimen of „coarse-grained sandstone of Upper Liassic age rich in clasts of ultrabasic rocks“ was evidently mistaken for Cretaceous sandstones where such a phenomenon was frequently observed.

Bajocian. Synsedimentary fractures accompaying the vaulting of the Czorsztyn submarine swell — neptunic dykes filled by micrite: Vršatec (Mišík 1979a), Kyjov (Mišík & Sýkora 1993), Krasin (Mišík et al. 1994a), Babina near Bohunice (Mišík et al. 1994b).

Bathonian–Callovian–Oxfordian. Listric faults in the Czorsztyn Succession producing submarine scarp breccias: Krasin (Mišík, Sýkora & Aubrecht 1994), Kyjov (Mišík & Sýkora 1993). Extensional faults with synsedimentary filling in the following klippes: Krasin, Babina, Mestečko (Aubrecht 1992), Bolešov (not published). Neptunian dykes with filling of that age also penetrated into the older limestone strata: Kyjov, Vršatec, Drieňová (Mišík 1994a). It is surprising that Kimmeridgean and Lower Tithonian represented a period of relative calm — the neptunian dykes filled by the *Saccocoma* microfacies were not found up to now.

Upper Tithonian. A submarine scarp and neptunian dykes with the *Crassicollaria* microfacies in the Jurassic limestones — Kyjov and Upper Tithonian neptunian dykes in the Bathonian limestones — Vršatec.

Valanginian–Hauterivian. Neptunian dykes of that age in the Jurassic limestones — Vršatec and Krasin; at the last mentioned locality also a huge scarp breccia.

Pre-Barremian event. Abundant ophiolite detritus in the Barremian *Orbitolina*-bearing limestone pebbles signalizes the initial emersion of the components of a subduction mélange, the final stage of the transform possessing the oceanic crust and its closure during an oblique collision.

Albian. First thick strata of the „Upohlav" conglomerates with the polymictic exotic material and the beginning of the flysch sedimentation demonstrate the emersion of a large source area built of the subduction mélange (Mišík 1979b), the raising of an "Exotic" ridge (Austrian phase — Mišík 1980a). Plašienka (1996) criticized the idea about the "Exotic" ridge with the correct objection that no traces of the Albian tectonic compression exist in the surrounding zone of the PKB. However, the immediately neighbouring zone with such phenomena could also have succumbed to subduction. It is true that the pre-Albian tectonic event in the Peri-Klippen Zone would disturb the polarity of the folding from the innermost zone to the external zones of the Western Carpathians. It should, however, be remembered that the polarity at the beginning of the flysch sedimentation (the oldest flysch in the innermost and the youngest in the outermost zone) was substantially disturbed by the earliest Tithonian flysch in the Outer Carpathians, even in their external zone — the Silesian Unit. A strong Pieniny tectonic phase supposed in the older papers of Andrusov (1938, p. 49 and elswhere) was later found to be a disharmonic folding of klippes and their more plastic cover (Birkenmajer 1953). Andrusov (1959, p. 277) designated later the short interruption of sedimentation — emersion between Urgonian and Albian as the Manín phase (Manín Klippe). Borza found a submarine hiatus covering the Middle Albian in the Butkov Klippe. The hiatus with the following „transgression" of red pelagic Albian marls on the Valanginian-Hauterivian limestones in the Czorsztyn Unit was explained as a submarine one (Birkenmajer 1958). It is a very wide spread phenomenon, e.g. localities Dolný Mlyn near Lubina (Andrusov et al. 1959), Krivoklát, Vršatec, Lednica, Kamenica (Mišík 1993), Litmanová (Scheibner 1969), Podhorie (Salaj 1990a, p. 136). There are dykes with Albian filling penetrating the Bathonian limestones in Vršatec; a considerable pre-Albian erosion took place there (Mišík 1979b).

Cenomanian–Turonian–Lower Senonian. The continuing emersion of the exotic source supplied its material during the Turonian and Coniacian to the Kysuca Zone (Snežnica Formation). The supposed transport of the Subtatric (Central Carpathian) nappes onto the PKB (Drietoma, Manín and Kostelec Succesions, olistholiths of the Wetterstein limestones near Púchov) cannot be reliably proved for the present.

Upper Campanian. The imbrication of units, the stacking of nappes (Pieniny Unit thrust on the Czorsztyn Unit etc.) took place according to Birkenmajer & Jednorowska (1987) in this time span which should be documented by the absence of two foraminifer zones: Globotruncana ventricosa and Globotruncanita calcarata.

Maastrichtian. The Jarmuta Formation with the olistostromes and Zaskale Breccia testify to the tectonic activity connected with the folding. They contain already clasts from the klippes and overlie independently various successions of the PKB and thus date the nappe stacking in the PKB. A very slight volcanic activity was enregistered in the Maastrichtian sediments — localities Zázrivá (Aubrecht 1997) and Sromowce Nižne in the Polish segment (Wieser 1985).

The pre-Eocene Laramian phase was observed first in the PKB as the well-known angular unconformity near Kňažia (Andrusov 1938 and others). Priabonian sediments deposited with angular unconformity on the PKB were found between Krivá and Sedliacka Dubová by Gross & Köhler (1987). An uninterrupted sedimentation from the Maastrichtian to the Paleocene was described by Salaj et al. (1978) in the locality Hradisko near Žilina. However Hansen et al. (l990) stated a short interruption responsible for the fact that the iridium anomaly caused by the planetary catastrophic event 66 million years ago could not be detected there. The Laramian phase is considered as the most important in the tectonic evolution of the PKB. In consequence of the oblique collision several events in the East-Slovak segment were shifted towards younger epochs. The exotic source started to deliver its material there in the Paleocene (Proč conglomerates). Even the whole klippes slid in the form of olistholiths in the Paleogene sea (Gregorianka Breccia — J. Nemčok 1978, J. Nemčok et al. 1988). The uplift of the PKB in the Paleocene followed by biohermal sedimentation near its inner margin is documented by a continuous row of localities with blocks of the Kambühel Limestone (Mišík 1996; Fig. 1).

The pre-Miocene Savian phase is connected with the further compression, boudinage and tearing of the rigid strata into tectonic lenses — klippes. Birkenmajer (1986) supposes transpression along a strike-slip fault. Near the contact of the PKB with the Flysch Belt the scales of the Paleogene flysch (Magura Unit) were incorporated in the PKB (Middle Váh Valley, Orava, East-Slovak segment). The Eggenburgian strata overlie various members of the PKB with angular disconformity for example near Podbranč (Mišík et al. 1985, Fig. 1). Salaj & Began (1983, Fig. 4, 5) erroneously described that locality as a tectonic disconformity, an overthrust of the Eggenburgian sequence on the klippe during the pre-Carpatian so-called Bukovec phase. Backthrusting of the Magura Unit on the PKB also took place.

Miocene. The formation of the Párnica sigmoide (mentioned already by Andrusov 1926) was evidently connected with the Central Slovak fault system. The anticlinorial vaulting especially of the western segment of the PKB connected with the erosion of almost all Paleogene cover took place. The transform movements during the Badenian were documented in the Pieniny Mts. by Birkenmajer et al. (1987) by radiometric dating of the transversal andesite dykes disturbing longitudinal ones. We want to add that during the Youngest Miocene, Pliocene and Quatenary no large transform movement (longitudinal strike-slip) took place. In the opposite case a tearing of the Neogene sedimentary filling of the shallow Orava–Nový Targ basin would be visible on the satellite photos. Some inferior volcanic activity also took place in the western segment of the PKB: a Sarmatian andesite dyke found in the borehole near Horné Sŕnie and perhaps a further three localities (Mišík 1992). A strong volcanism affected the East-Slovak segment (Vihorlat Mts.).

The first structural measurements in the PKB were carried out by Plašienka & Marko (in Maheľ 1989). A detailed analysis was made in the Vlára Valley by M. Nemčok (1991). He distinguished five movement phases there. M. Nemčok & J. Nemčok (1994) have studied the supposed Upper Cretaceous deformations. Ratschbacher et al. (1993) documented the dextral transpression. They repeat the observations of

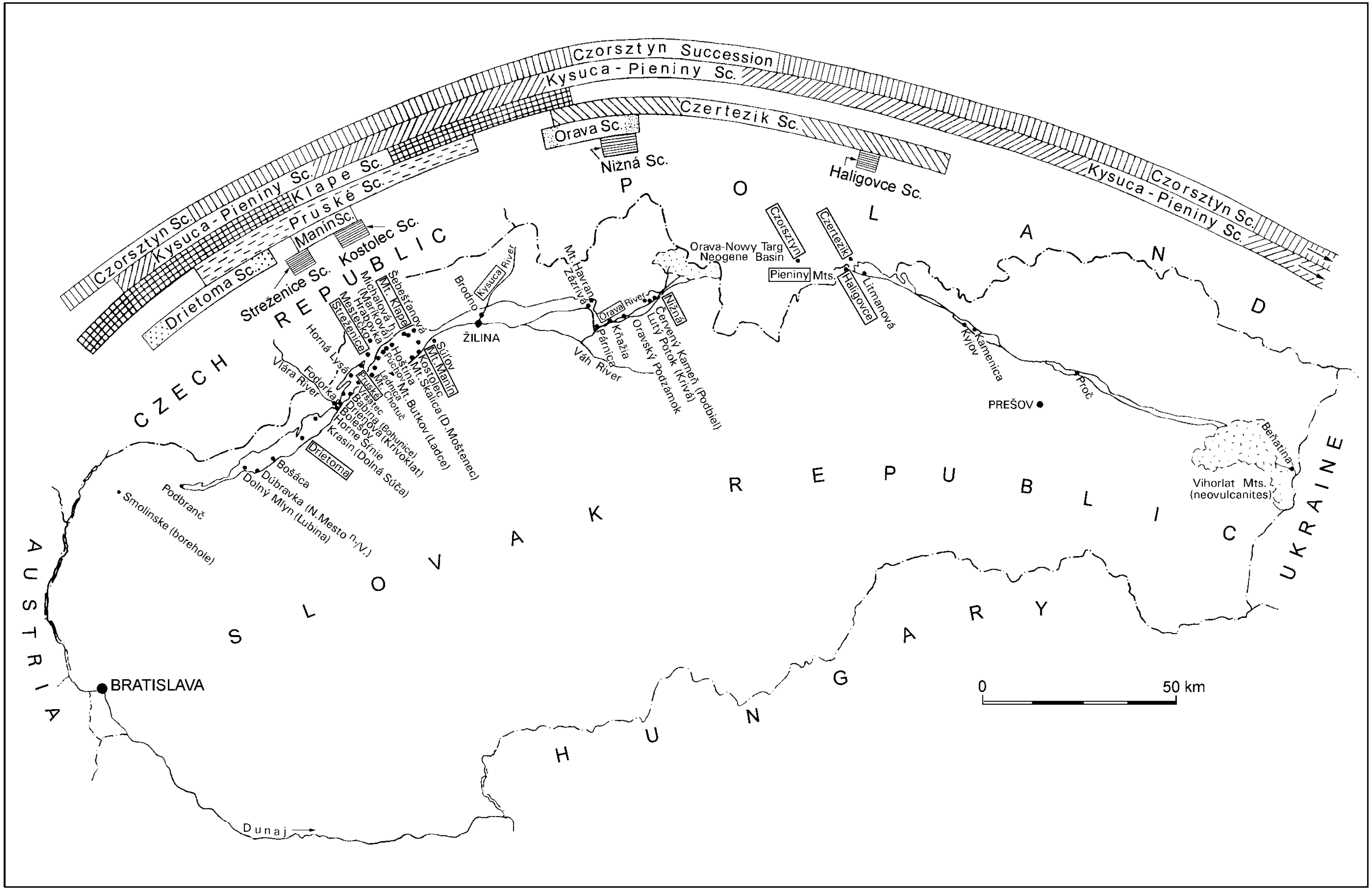

Fig. 1. Extent of successions differentiated in the Pieniny Klippen Belt — their type localities are framed. Other localities mentioned in the text are without a frame.

previous authors that the fold axes display an acute angle to the margins of the PKB. They situated internal thrusting and strike-slip faulting of the PKB in Oligocene. According to the structural analysis of the PKB by Kováč & Hók (1996) in the first phase a compression caused the development of slip-fault and fold structures (Oligocene?–Lower Miocene). In the Lower Miocene a sinistral shear zone was formed. The transpressional regime in the Middle Miocene was replaced in the Upper Miocene by an extensional regime with randomly oriented downslip faults.

Quaternary. Sliding of the klippes on the slope scree and their gravitational disruption led to the formation of cracks 1–2 m wide, open or filled by Quaternary sediments (e.g. klippes of the Lednica and Kamenica castles).

Successions and their varieties in the PKB and Peri-Klippen Zone

The strong compressional narrowing led to the perfect décollement of the Jurassic-Cretaceous strata from the unknown Paleozoic-Triassic basement. The surface of their separation was evidently represented by some Upper Triassic and/or Hettangian clayey-marly strata and, eventually, by Upper Triassic evaporites. In the case of the evaporites their diapiric penetration into the younger strata could be expected. They were not found and therefore that possibility is less possible. The PKB consists of klippes — tectonic lenses of rigid rocks (almost exclusively Jurassic and Lower Cretaceous limestones) and their „cover" in the morphological sense (more plastic marls and flysch strata). The mature tectonic stade — the klippe style was achieved by almost perfect separation of those plastic members of the middle and Late Cretaceous age from the klippes. There is frequently an uncertainty in the continuation of a succession from the klippe into the „cover" mantle strata. In spite of this, it is now certain that sedimentation continued through the Jurassic and Cretaceous periods almost everywhere uninterrupted till the Lower Campanian; according to Birkenmajer & Jednorowska (1987, p. 26) two Globotruncana zones representing the Middle and Upper Campanian are missing as a result of folding. Maastrichtian sediments already formed a stratigraphic cover deposited independently on the imbricated successions of Jurassic–Lower Campanian; thus, they represent a further sedimentary cycle. It consists mostly of the Jarmuta Formation, the first layers already containing clasts from the klippe successions. The presence of successions with the shallow-water as well as deep-water sediments of the Jurassic and Lower Cretaceous is a peculiar feature of the PKB. The axial part of the sedimentation area was represented by a deep trough with the deposits of the Pieniny (or Kysuca-Pieniny) Sc. containing radiolarites. The marginal shallow-water successions were characterized by crinoidal limestones — namely the Czorsztyn Sc. bordering the external margin, Klape Sc., Kostelec Sc. and Manín Sc. („southern geanticline" — Scheibner 1967b, p.13) along the internal margin. In addition to these a set of successions and varieties of a transitional character were distinguished. The successions 2–9 (see below) form the Pieninic; Maheľ (1984) called them Oravic. The successions 10–15 incorporated in the PKB used to be joined together as the Peri-Klippen Zone (the term was introduced by Maheľ 1980). The term Vahic or Vahicum (Maheľ 1981) originally used for a hypothetical unit with the oceanic crust in the Peri-Klippen Zone is now applied to the area affected by Laramian folding, with the Upper Cretaceous sediments under the thrust planes in the Inovec Mts. (Plašienka et al. 1994) and Strážov Mts. — borehole Soblahov (Maheľ 1986). All the successions distinguished in the Slovak part of the PKB will now be mentioned with short comments. It is necessary to add that instead of the term succession other terms such as sequence, series, group, type, variety and evolution were also frequently used. The successions and varieties defined during the last twenty years (after 1976) will be mentioned with their authors; the equivalent Polish term, if different, is situated in parentheses (the term succession is shortened to Sc., variety to Var.):

1. Magura Sc. of the Grajcarek Unit (Birkenmajer 1985), equivalent Fodorka Sc. (Salaj 1987, p.126), 2. Czorsztyn Sc. + Hrabkov Var. + Vršatec Castle Var. (Mišík 1979a), Mestečko Var. (Aubrecht 1992), Krasin Klippe Var. (Mišík, Sýkora & Aubrecht 1994), 3. Czertezik Sc., 4. Pruské Sc.(equivalent Niedzica Sc.), 5. Orava Sc. (Haško 1978) + Podbiel Var., 6. Kysuca Sc. (equivalent Branisko Sc.) Horná Lysá Var. (Mišík et al. 1994), 7. Pieniny Sc., 8. Streženice Sc., 9. Nižná Sc., 10. Klape Sc., 11. Kostelec Sc. + Súľov Var., 12. Haligovce Sc., 13. Manín Sc. + Butkov Var. + Manín Var.+ Trenčianske Teplice Var. (all by Maheľ 1986), 14. Drietoma Sc. (Rakús 1977), synonym Bošáca Sc. (Maheľ 1978), partly Vrzávka Zone (Andrusov 1972) + Drietoma Klippe Sc. + Stupné Sc. + Chotúč Sc. + Hoština Sc. (all by Salaj 1994a) + Dúbravka Sc. (Andrusov 1972), 15. Michalova Hora Sc. (new term, attribution incertain). The Jurassic–Lower Cretaceous strata of these successions will be shortly commented on. The Albian to Campanian members need further discriminating studies.

The Magura Sc. Birkenmajer (1985, p. 105 and elsewhere) defined on Polish territory the Grajcarek Unit with the Magura Sc. as the most external unit incorporated in the PKB during the late Laramian folding. This succession was not identified on Slovak territory except by the essay of Salaj (1993). We have some doubts about the existence of the Magura Sc. in the PKB. It is almost identical with the Kysuca-Pieniny Sc. except for the supposed Albian radiolarites (Gron Radiolarite) the Albian age of which was never proved. There is the suspicion they belong to the Oxfordian as in other localities. Another special member should be the Ubocz Shale Member, dark, sometimes laminated clayey shales with a poor Upper Albian–Cenomanian microfauna, only 1.5–5 m thick. The Szlachtowa Formation, formerly described as the Aalenian Flysch of the Branisko Sc. with clastic material proceeding from an intra-Pieniny source (Birkenmajer 1957), and later from an external source (e.g. Krawczyk et al. 1987) was also not found on our territory. The lack of facies transitional from such extremely shallow-water ones as the Czorsztyn Sc. to the typical trough facies of the Magura Sc. is an argument against this conception (Birkenmajer 1986, explained it by their subduction). It is more probable that near the external margin of the PKB klippes with trough facies belonging to the Kysuca-Pieniny Sc. also occur in some places. The chess-board like disposition of shallow-water and deep-water klippes is only the result of the penetration of fragments from the imbricated units in various levels during the compression. From the Slovak geologists only Salaj (1990a, p. 110) supposed his Fodorka Sc. to be equivalent to the Grajcarek Unit, however he situated it in the „Czorsztyn Basin“ (Salaj 1990a, p. 114). In a more recent paper (Salaj 1995, p. 4–7) he affirms the Fodorka Sc. was deposited at the external side from the Czorsztyn Sc. and the Grajcarek Unit still more external to it. He suppossed the black Albian shales to be the criterion of the Fodorka Sc.

The Czorsztyn Sc. (Horwitz 1922, p. 18, originally as the Czorsztyn facies) was earlier called the Subpieniny facies (Uhlig 1890). The Czorsztyn Sc. was deposited during the Jurassic and Lower Cretaceous on a submarine elevation ("pelagic swell", Mišík 1993) with dominant pelagic and condensed facies, and frequent hardgrounds. It is remarkable for the lack of terrigenous clastics, ooids, benthic algae and those foraminifers which characterize the co-eval carbonate platforms. It was repeatedly affected by synsedimentary tectonics (neptunic dykes, submarine scarp breccias). There is no evidence of emersion in the Czorsztyn Sc., the more in the trough successions, so that the opinion of Maheľ (1981, p. 296 and elsewhere) about the insular character of the Pieninic is entirely unsubstantial. The Czorsztyn Sc. is known from the whole length of the PKB and represents its most typical element.

The Hrabovka Var. (Andrusov & Scheibner 1960) should be remarkable by a large hiatus from the Upper Triassic to the Lower Senonian (the transgression of red Turonian marls on a klippe of the Wetterstein facies near Púchov). This single occurrence was illustrated by Andrusov (1968, Fig. 28) as the Hrabovka Klippe — an example of „klippe coiffée“. The red Coniacian marls are depicted on the top in the transgressive position and the Triassic lens is enveloped by the Albian-Cenomanian strata of the Klape Sc. It penetrated the marls due to the compression. The Triassic klippes occur only in the surrounding of the town of Púchov and now they are interpreted mostly as the sedimentary blocks — olistholiths.

The Vršatec Castle Var. is remarkable for the biohermal Oxfordian limestones (Vršatec Limestone, Mišík 1979a; Kochanová 1979). Perhaps it would also be useful to separate as an individual variety the **Mestečko Var.** (Aubrecht 1992) distinguished by the lack of red nodular Czorsztyn Limestone and, eventually, also the **Krasin Klippe Var.** (Mišík, Sýkora & Aubrecht 1994), peculiar for the huge submarine scarp breccia of Middle Jurassic age and by the erosional lack of the Upper Jurassic limestones (except for clasts of Oxfordian biohermal limestones in the cleft filling). Neocomian crinoidal limestones are there in the stratigraphic contact with the Middle Jurassic crinoidal limestones. The Czorsztyn Sc. is very variable. Birkenmajer (1963) differentiated 11 varieties (types) in the Polish part of the PKB.

The Czertezik Sc. (Birkenmajer 1959) is a transitional succession. It was also discerned in the Slovak part of the PKB (Scheibner 1967b; Haško 1975a).

The Pruské Sc. (Andrusov 1938, p. 15, equivalent Niedzica Sc.) like most transitional successions, is remarkable for the simultaneous occurrence of the Middle Jurassic crinoidal limestones and Callovian-Oxfordian radiolarites.

Orava Sc. (Haško 1978). The most characteristic members are the Kozinec Beds (Haško 1975b), layered pseudonodular Carixian limestones with *Uptonia jamesoni*, Domerian „Fleckenmergel“ with *Amaltheus margaritatus* and lower red nodular limestones with Toarcian ammonites. The author has assigned the Orava Castle Klippe and Červený Kameň Klippe near Podbiel (formerly quoted as the Podbiel Variety (Andrusov 1938)) to the Orava Sc. as well as the type locality Havranský vrch near Zázrivá (formerly designated by Andrusov 1974, as the Zázrivá facies).

Kysuca Sc. (Andrusov 1926). Its new variety is the **Horná Lysá Var.** (Mišík, Sýkora, Ožvoldová & Aubrecht 1994) in the Vršatec area. The main criterion is the Horná Lysá Limestone, totally different from the standard Kysuca Sc. It is a layered limestone with brown cherts containing horizons with crinoidal detritus and redeposited Upper Tithonian clasts with *Crassicollaria*. The Berriasian-Hauterivian age of the Horná Lysá Limestone was proved by the Radiolaria.

Pieniny Sc. (Uhlig 1907) is another deep-water succession with Callovian to Lower Kimmeridgean radiolarites. There exist only small differences from the Kysuca Sc., e.g. the lack of Upper Jurassic nodular limestone and therefore it sometimes used to be united in the Kysuca-Pieniny Sc.; so it may be followed through the whole length of the PKB.

Streženice Sc. (Began & Borza 1963) was rarely mentioned. It differs from the Pruské Sc. only by the presence of the spotty marls (Fleckenmergel). The Streženice Sc. was deposited according to the authors between the Kysuca Sc. and Pruské Sc. According to Salaj (1994a, p. 198) its sedimentation area was situated between the Drietoma Sc. and Kysuca Sc.

Nižná Sc. (Scheibner 1967a). Its individuality was supported by the identification of a new member — the Liassic (Sinemurian-Pliensbachian) crinoidal limestones — Lutý Potok Limestone (Mišík et al. 1995). The extent of the Nižná Sc. occurring only in the Orava area was enlarged to 10 km. There are contradictory indications as to its position within the sedimentation area. The Nižná Sc. should be the most internal zone of the Pieninic basin, the only one with the Urgonian facies (Mišík 1990, Fig. p. 26). A connection with the Klape Sc. could be considered with regard to the Liassic crinoidal limestones also outcropping there. It is a pity that the Lower Cretaceous strata, necessary for the comparison, were not preserved in the Klape Klippe. Also Birkenmajer (1985 and elsewhere) supposed mainly on the basis of the common presence of Urgonian limestones that the Nižná Sc. was deposited nearer to the inner border of the Pieniny trough, north of the "Exotic" ridge. On the other hand, the terrigenous admixture in the crinoidal limestones of the Nižná Sc. is very similar to the inventory of clastics in the crinoidal limestones of the Czorsztyn Sc. (Mišík & Aubrecht 1994; Mišík et al. 1995), as if the Nižná Sc. sedimented nearer to the outer margin of the Pieniny trough and the so-called Czorsztyn External Terrestric Ridge served as a source for both.

The Klape Sc. is already considered as belonging to the southern Peri-Klippen Zone. The term Klape „Series“ was introduced by Andrusov (1931, p. 18, 41) in connection with the Liassic strata of the Klape Klippe. The contents of the Klape Sc. was later enlarged by the attribution of the Cretaceous Flysch strata by Marschalko & Kysela (1979) formerly assigned to the Manín „Series“. Maheľ (1986, p. 32) regarded the Klape Sc. as a part of his Vahic Unit (Maheľ 1981).

The determination of paleogeographical position of the Klape Sc. is handicapped by the fact that it contains only one larger klippe (Mt. Klape) with merely Liassic to Bathonian strata. The definition of the Klape Sc. is now based on difference with respect to other successions on the middle and Upper Cretaceous strata represented by a characteristic deep-water flysch sequence more than 600 m thick with shallow-water Orlové Sandstone intercalated by oyster layers (more details in Marschalko 1986). The Klape Unit was distinguished in the Middle Váh Valley area and its continuation to the Orava area was found later (Began & Samuel 1975). The Klape Klippe formed of Jurassic limestones is now regarded by several authors as a large olistholith. Plašienka (1995) supposes that the Cretaceous strata of the Klape Sc. were deposited near the inner southern margin of the Krížna sedimentation area. The reasons against it were quoted in a discussion (Mišík 1996, in the same place also the reply by Plašienka 1996). His explanation concerning the source of intraformational conglomerates with exotics does not solve the problem because they are not limited only to the section with the Klape Sc.; they can be followed along the whole length of Eastern Alps, as well as in the East-Slovak and Ukrainian segments of the PKB. Salaj (1990b) discerned in the Klape Sc. the so-called Šebešťanová Sc. with the Klape Klippe and Udiča Sc. His hypothesis (Salaj 1990a, Fig. 5) about the common sedimentation area of the Klape Sc. and Nedzov Sc. (Nedzov Nappe of the Silicic Unit by other authors), mainly on the basis of the occurrence of olistholiths of Triassic Wetterstein limestones near Púchov, did not find any follower.

Exotic Sc. (Birkenmajer 1958a). The Albian to Senonian conglomerates in the Klape Sc. and with a lesser thickness also in the neighbouring zones (Upper Turonian–Coniacian conglomerates of the Snežnica Formation of Kysuca Sc., Cenomanian conglomerates of the Manín Sc., Albian conglomerates of the Tatric Unit and Krížna Nappe and Paleocene conglomerates of the East-Slovak segment of PKB) contain clearly exotic rocks. Ophiolite detritus occurs already in pebbles of the Barremian shallow-water limestones, then glaucophane-lawsonite rocks, special type of granites, Upper Jurrasic shallow-water limestones etc. (Mišík & Sýkora 1981), limestone pebbles with Anisian, Ladinian, Carnian and Norian conodonts (Mišík et al. 1977). The material proceeds from the emerged parts of a subduction mélange (Mišík 1979b; Mišík & Marschalko 1988). The source area was named the Pieniny Cordillera (Andrusov 1938), Klape Cordillera (Maheľ 1980; Salaj 1987), Pieniny Exotic Ridge (Mišík & Marschalko 1988), Andrusov Ridge (Birkenmajer 1988). According to the measurements of transport direction, diminution of clasts and conglomerates thickness the source was situated near the inner margin of the Klape sedimentation area in the neighbourhood of the Manín area (Marschalko 1986). Birkenmajer (l985, 1988, p. 16, 17 and elsewhere) supposed that the source was represented by the so-called Exotic Sc. deposited in the area of the future Andrusov Ridge and he placed it between the Haligovce Sc. and Klape Sc. area. We do not consider the term Exotic Sc. to be correct, as among the exotics many coeval shallow-water as well as deep-water facies occur together (Mišík & Marschalko 1988, p. 100, 101) and they certainly cannot be attributed to one single succession. The inventory of rocks represented in pebbles was submitted by Mišík & Marschalko (1988). It can now be completed by other exotics: dolomite pebbles containing authigenic feldspars with frequent Roc Tourné twinning (Mišík 1994b, p. 104), redeposited authigenic quartz grains with zonally oriented mica inclusions (Mišík 1995), further conodont zones found in pebbles of Triassic limestones (Birkenmajer et al. 1990), Dasycladaceans from the Upper Jurassic and Lower Cretaceous limestones up till now unknown from the Western Carpathians (Soták & Mišík 1993), ophicalcite pebbles (Sikora & Wieser 1979), other exotics of volcanites and plutonites (Birkenmajer & Skupinski 1990). Further exotics from the Senonian conglomerates were described by Birkenmajer & Wieser (1990); geochemical characteristics of granites submitted by Uher et al. (1994), Uher & Broska (1996), Uher & Marschalko (1993) studied the typology of zircons proceedings from acid eruptives; Uher & Pushkarev (1994) described other pebbles of granites and rhyolites and documented by radiometric methods their Early Permian age. The last paper about the granitoid exotics is from Frasl & Uher (l996). Trace elements from the magmatic rocks were studied by Šimová (1987), who also described a pebble of eclogitoid rock (Šimová 1982). The age of glaucophanes from the pebbles of glaucophanized metabasalts was dated by $^{40}Ar/^{39}Ar$ method on 155.4±0.6 million years, then Callovian-Oxfordian (Dal Piaz et al. 1995). The chemical composition of glaucophanes was studied by Martin (1991) and detrital glaucophane grains from the Albian in the westernmost locality — in the basement of the Vienna Basin, borehole Smolinské-27 by Sýkora et al. (l997). The discussion about alternative explanations of the origin of exotic material than from the above mentioned intrabasinal source is in the paper by Mišík & Marschalko (1988): transport of pebbles by currents from the Dinaric or Transylvanic, large left-lateral movements from the last mentioned area, river transport from the innermost units of the Western Carpathians.

Kostelec Sc. (Andrusov 1938, p. 16, description Rakús 1965). The situation of its sedimentary area still remains uncertain. Andrusov (1938, p. 10) considered that it belonged to a higher Subtatric nappe; Andrusov & Scheibner (1960) assigned the Kostelec Sc. to the Subtatric successions folded in the PKB. The similarity of the Liassic limestones in the klippes Kostelec and Klape indicates their spatial connection in the sedimentary area. Maheľ (1986, p. 259) considered both as huge olistholiths in the Klape Sc., later he supposed that these olistholiths came from the Tatric Unit (Maheľ 1989, p. 103). **Súľov Var.** was established by Borza (1970) as a supposed transition between Manín Sc. and Kostelec Sc.

Haligovce Sc. The sedimentation of the Haligovce Sc. was placed by Birkenmajer (1985, p. 97 and Fig. 3; 1988, p. 14) between the Exotic Sc. and Pieniny Sc. areas, i.e. he situated it on the northern slope of the Andrusov Ridge. He supported the opinion by the presence of the Upper Cretaceous Globotruncana marls (Jaworki Marls), Senonian flysch-like Sromowce Formation and Urgonian Limestone recalling the Nižná Sc. Andrusov (1974, p. 15) considered that the Haligovce Unit belonged to the Manín Nappe. All Slovak geologists hold this opinion. Maheľ (1986, p. 250) also wrote that

Haligovce Klippe is a part of the Manín Nappe. The Haligovce Sc. contains comparable members to the following strata in the Manín Sc.: Campanian red Globotrucana marls (Hrabové Formation), Turonian-Senonian flysch (Žadov Formation — Kysela et al. 1982) and also Urgonian limestones. Further common feature are blocks of Paleocene Kambühel biohermal limestones (locality Aksamítka) bordering the whole inner margin of the PKB (Mišík 1996, Fig. 1). The further serious argument is the presence of the Albian phospho-glauconitic limestones with *Calcisphaerula innominata* in the Haligovce Klippe (Mišík 1990, p. 47), deposited on the Urgonian limestones after a hiatus, thus in the same manner as in the Manín Sc. (Mt. Butkov) and High-Tatric Unit (e.g. underneath Mt. Giewont). There is also a hiatus in the shallow-water successions of the Pieninic (Czorsztyn Sc., Niedzica Sc.) but after it the Albian red marls follow on the Neocomian limestone surface. No such hiatus is known in the Branisko Sc. (Kysuca Sc.) considered by Birkenmajer (1.c.) as the neighbour to the Haligovce Sc. The position of the sedimentary area of the Haligovce Sc. south of the Pieninic is supported by the occurrence of abdundant authigenic feldspars (thermal affection) absent in the Pieninic, but frequent in the Central-Carpathian successions. They even occur in the Paleocene slightly sandy limestones in the Haligovce Klippe which is the locality with the youngest horizon with authigenic feldspars in Slovakia (Mišík 1994b). At the end Birkenmajer (1985, p. 97) also admitted that „the presence of Myjava-type Paleocene might suggest a close relation with the Klape–Myjava Basin“. It is remarkable that the separation of the Jurassic-Cretaceous members from the Triassic ones, which is typical for the Pieninic, did not take place in the Haligovce Sc. and so the Haligovce Klippe also contains Triassic strata.

Manín Sc. (Andrusov 1938). The opinions about its position in the sedimentation area are contradictory. Andrusov (1972 and elsewhere) considered it as the innermost nappe of the PKB and situated its sedimentation area externally from the Tatric. In his older papers (e.g. Andrusov 1945) he pointed to the similarity of High-Tatric Sc. and Manín Sc. and used the term Manín–High-Tatric zone. Salaj & Samuel (1966) quoted the Manín Unit as an independent tectonic unit of the first order and situated its sedimentation area between the PKB and Central Western Carpathians, i.e. between the Pieninic and Tatric. The position of the Manín area externally from the Tatric was also accepted by Rakús (1975, 1977) and Mišík (1980b). According to Salaj (1994b, p. 29) both the Manín and Kostelec units belong to the Manín Zone. He distinguished in the Manín Unit, the Manín Sc. and Podháj Sc. The Podháj Sc. includes the Cretaceous members (its Jurassic is unknown); it should be transitional between the Manín Sc. and Klape Sc. (Šebešťanová Sc.). Maheľ (1948) at first joined the Manín Unit with the Tatric one in the so-called Manín-Inovec Unit. Later he began to stress the close relations between the Manín and Krížna units (Maheľ 1978 and all more recent papers). The situation of the sedimentation zones roughly from the North to the South was according to him as follows: Tatric Sc., Manín Sc., Belá-Krížna Sc. The evidence of the common Manín and Krížna sedimentation area based on: the presence of an exceptional facies — Albian cherty limestones with *Colomiella recta* in the Krížna-Belá Sc., Manín Sc. (klippes Butkov and Skalica) and near Bošáca (Drietoma Sc. folded in the PKB); the comparable hiatuses and hardgrounds in the Albian strata of the above mentioned localities (Borza et al. 1979, 1980); the frequent occurrences of basic volcanic rocks in the Lower Cretaceous of the Krížna Nappe in the Strážov Mts. and in the neighbouring Manín Unit (cf. Mišík 1992, Fig. 2); the difficulty of separating the Albian-Cenomanian flysch of the Krížna Unit from that of the Manín Unit in the territory where both are in mutual contact as in the Bukovinka syncline (Maheľ 1986). Michalík & Vašíček (1980) also consider their Nozdrovica development to be a transition between the Krížna Sc. and Manín Sc. with the same calciturbiditic horizons. Maheľ (1978) supposed that the thrust of the Manín Sc. over the Tatric Unit even beyond its frontal part had already occurred during the Albian and, after the deposition of the Upper Cretaceous strata on the pre-Albian sequence of the Manín Sc., it was backthrust in the opposite direction. The main reasons for the independence of the Manín Sc. from the Krížna Sc. are the following: the sedimentation in the Manín Sc. continued up to the Senonian which is not the case in any varieties of the Krížna Sc. In the classical area Manín–Butkov (Manín Unit s.s.) a complete décollement of the Jurassic-Cretaceous strata from the Triassic took place as is typical for the PKB. If the Manín Unit s.s. was transported over the Tatric (Mesozoic of the „Envelope unit“) there would be no reason for the absence of the Triassic members in it (the Krížna Nappe in the neighbouring area does not display the „troncature basale“ as the Choč Nappe does which, in its most distal position, is represented only by its highest, Jurassic–Lower Cretaceous members, as on the Polish side of the Tatra Mts.). The conglomerate intercalations with exotics in the Manín Sc. are of the Cenomanian age, but in the Krížna Sc. they belong to the Albian; for the Cenomanian of the Manín Sc. the contourites are characteristic, they are absent in the Cenomanian of the Krížna Sc. (Marschalko & Kysela 1980, p. 37, 60). The Vlkolínec Breccia occurring in the Krížna Nappe of the Strážov Mts. (Jablonský & Marschalko l992, Fig. 3) is absent in the Manín Sc. The facies of the red nodular limestones in the Manín Gorge which started from the Bathonian in the Butkov Klippe lasted till the Middle Tithonian; it never represents such a time span in the Krížna Unit. The Cenomanian of the Manín Sc. (Praznov Beds) contains horizons with *Exogyra* shell beds, Orbitolines and redeposited corals, that were never found in the Krížna Sc. The last mentioned difficulty would be eliminated if we accept that nappe transport already occurred during the Albian. But the accompanying signs of such a submarine overthrusting (breccias formed by blocks broken from the nappe fronts) are missing in the Albian-Cenomanian of the Tatric Unit. Besides, the pre-Paleogene backthrust of the Manín Unit is hardly comprehensible from the point of view of geodynamics.

Drietoma Sc. The name was introduced by Rakús (1977, p. 32). It spreads out in the PKB between Myjava and Pruské. Drietoma Sc. is a single succession in PKB containing the Upper Triassic (Keuper and Rhaetian). It is remarkable for thick strata of dark shales, partly spotted („Fleckenmergel“). Maheľ (1986, p. 251) did not regard it as an individual succession and designated it as the **Bošáca Var.** Began et al. (l966) classified these occurrences as the Manín Sc. s.l. Borza et al. (1980) considered the Bošáca or Drietoma Sc. as identical with the Krížna-Belá Sc. for their surprisingly similar Lower Cretaceous strata. Andrusov (1974 and elsewhere) regarded the klippes with Keuper and Rhaetian as part of the Kysuca Sc., but he admitted that some elements of the Manín Nappe could continue as far as Bošáca and Moravské Lieskové. These middle Cretaceous strata of the Manín Nappe were designated by him as the **Vrzávka Zone** (Andrusov 1972, p. 232, Salaj 1990b, p. 159). Salaj (1994a) discerned within the Drietoma Unit the **Drietoma Klippe Sc.** (Drietoma Sc. s.s. till the Lower Albian); the higher members, Middle Albian–Cenomanian, are called by him the **Stupné Sc.** Further, he distinguished the **Chotúč Sc.** and for the higher members (Lower Albian–Maastrichtian) the so-called **Hoština Sc.** (l.c. p. 215–217). He supposed a common sedimentation area for the Kysuca Sc. and Drietoma Sc. till the Lower Albian (Salaj 1994a, p. 199). The establishement of the **„Dúbravka Unit“** near Nové Mesto nad Váhom (V. Andrusov 1968, 1972, p. 232) was based on the discovery of exotic pebbles (quartz porphyries) in a conglomerate intercalation within the Albian strata attributed to the Krížna Unit. Since such exotic pebbles were later also found in the Albian of the Tatric Unit and Krížna Nappe (Mišík et al. 1981), the Dúbravka Unit lost its reason to exist. The above mentioned continuous occurrences of the Jurassic dark marly limestones and shales are evidently identical with the Drietoma Sc. It is necessary to stress that the Drietoma (Bošáca) Sc. is really very similar to the Krížna Sc. and the simplest explanation would be that it represents a part of the Krížna Nappe thrust over and folded within the PKB. The difficulties are with the timing of the tectonic transport, as the Krížna Nappe in the Core Mountains overthrust the Cenomanian and in the Western Tatra Mts. even the Lower Turonian of the Tatric Unit. Perhaps, the Central-Carpathian (Subtatric) nappes did not advance in a continuous front, but in several segments, separated by transversal faults, they might move more rapidly. Perhaps, the Triassic olistholiths near Púchov might be explained in that way, too. However it was already stressed that no sedimentological features supporting the transport of the nappes in that time were observed in the Albian sediments. It would be useful to check once more the ages of the strata surrounding the problematic klippes and olistholiths (they might, penetrate in them as „pseudodiapirs“ injected from the lower horizons) and through a detailed comparison of lithology and microfacies demonstrate the supposed identity of the Drietoma Sc. with the nearest occurrences of the Krížna Nappe in the Core Mountains.

Michalová Hora Sc. (new name). The Michalová Hora Klippe near the village of Maríková is represented by a special succession. It contains the northernmost occurrence of Keuper in the PKB — reddish quartzites and a small outcrop of dolomites already mentioned by Andrusov (1959, p. 16 and elsewhere); perhaps the dolomites also belong to the Keuper. The following member are crinoidal limestones (Liassic or Middle Jurassic) and then a new member identified by us — white microoncoidal limestones with *Globuligerina*. This lithofacies from the time span Middle Jurassic– Oxfordian was unknown in the PKB until now. It also occurs in several smaller klippes in the surrounding of Maríková. These white limestones were erroneously regarded as Triassic (Illyrian-Ladinian) by Salaj (1991, p. 296). In a more recent paper (Salaj 1995, p. 3) he supposed that the so-called Triassic olistholiths near Dolná Maríková had been transported from the NW where in the basement of Biele Karpaty Unit (Flysch Belt), near the southern margin of the North-European Platform a Mesozoic of Central-Carpathian type should exist. The occurrence of the Keuper is the single common feature of the Michalová Hora Sc. and Drietoma Sc. If the Liassic age of the crinoidal limestones will be proved, the relationship to the Kostelec Sc. or Klape Sc. should be suggested. Andrusov (1959) regarded the locality as part of the Czorsztyn Sc., but this was rejected by Salaj (1995), because the Upper Cretaceous red Pustelniak (“Púchov“) Marls are missing there. The problem can be solved only by further study.

Epilogue

Our first intention was to quote and comment on all contributions to the sedimentology, microfacies, paleontology and published geological maps of the PKB in the last twenty years but this turned out later to be beyond the spatial possibilities of a paper in Geologica Carpathica. We hope it will be added in another place and testify that we fulfill the message of Academician Andrusov with honour.

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