Scientific Annals, School of Geology, Aristotle University of Thessaloniki Proceedings of the XIX CBGA Congress, Thessaloniki, Greece	Special volume 100	221-229	Thessaloniki 2010

TECTONICS OF THE KLIPPEN BELT AND MAGURA NAPPE IN THE EASTERN PART OF THE PIENINY MTS. (WESTERN CARPATHIANS, POLAND AND SLOVAKIA) – NEW APPROACHES AND RESULTS

Oszczypko N.[1], Jurewicz E.[2] and Plašienka D.[3]

[1]*Institute of Geological Sciences, Jagiellonian University, Oleandry 2a, PL-30-063, Kraków, Poland, nestor.oszczypko@uj.edu.pl*
[2]*Faculty of Geology, University of Warsaw, Żwirki i Wigury 93, PL-02-089 Warszawa, Poland, edyta.jurewicz@uw.edu.pl*
[3]*Department of Geology and Palaeontology, Faculty of Natural Sciences, Comenius University, Mlynská dolina, SK-842 15 Bratislava, Slovakia, plasienka@fns.uniba.sk*

Abstract: The Pieniny Klippen Belt (PKB) is a suture zone, which separates the Central Carpathians from the Outer Carpathians. The PKB successions are built up of the Lower/Middle Jurassic to Upper Cretaceous, dominantly pelagic and flysch deposits. The traditional multi-stage tectonic model of the PKB assumes that during the Palaeocene, retro-thrusting followed by subsidence and deposition of the "Magura Autochthonous Palaeogene" took place. Recently, we have studied the structural relationship of these deposits in the PKB, and we came to the conclusion that they belong to two formations with different tectonic positions. The Kremná Formation (?Oligocene – Lower Burdigalian) belongs to the Magura succession and appears in a tectonic window, beneath the Grajcarek thrust-sheet and the Czorsztyn (Sub-Pieniny) Nappe, while position of the Złatne Beds, which occur inside the Pieniny Nappe, is not clear. In the Slovak part the calcareous flysch sediments of the Jarmuta-Proč Formation described earlier as a "klippen mantle" form the youngest sedimentary member of the lowermost tectonic unit of the PKB, named here as the Fakľovka Unit. These youngest deposits are involved in tectonics of the PKB and document that final folding and thrusting of the PKB took place in the late Early Miocene (after Eggenburgian), corresponding to folding and thrusting of the Magura Nappe.

Key words: tectonic evolution, Pieniny Klippen Belt, Magura Nappe, Western Carpathians, Poland and Slovakia

1. Introduction

The Pieniny Klippen Belt (PKB) is up to 600 km long, but only a few km wide zone that follows the boundary between the External (Outer) Western Carpathian Flysch Belt (Tertiary accretionary wedge) and the Central (Inner) Western Carpathians composed of Cretaceous basement/cover nappe units (Austroalpine system) and its overstepping Cenozoic sedimentary and volcanic cover (Fig. 1A; for the general overview see e.g. Froitzheim et al., 2008). The PKB is a zone with intricate tectonic structure, known as the "klippen style" – block-in-matrix arrangement of stiff Jurassic to Lower Cretaceous limestones, traditionally called "klippen", embedded in soft Upper Cretaceous and Palaeogene marlstones, shales and sandstones, known as the "klippen mantle". Mixture of units with originally distant palaeogeographic provenances (partly "exotic") reveals an extraordinary internal shortening within this narrow zone. Predominantly brittle deformation of PKB rocks occurred in several phases from the latest Cretaceous up to Middle Miocene times. The PKB is therefore often considered as a suture, in spite of the lack of ophiolites in the surface structure of the PKB and adjacent zones.

Lithology and stratigraphy of the klippen successions, i.e. Jurassic and Early Cretaceous sediments, is generally well known (e.g. Birkenmajer, 1977 and references therein) and will not be concerned in this paper. On contrary, the soft rocks of the "klippen mantle", i.e. Late Cretaceous to Palaeogene pelagic and flysch deposits are comparatively less known due to poor outcropping and intense deformation, which obliterated to a high degree their original mutual relations. The same applies for the interrelationships of the PKB to the Magura Nappe (Carpathian Flysch Belt) adjoining from the north and to the Central Carpathian (Podhale)

Palaeogene Basin (CCPB) bounding the southern PKB margin. Thus although having been studied in a great detail over 150 years, many important aspects of the PKB structure and its relationships to neighbouring units remain poorly constrained. This paper is focussed on the so-called Pieniny sector of the PKB and adjacent innermost part of the Magura Nappe, in the eastern part of the Pieniny Mts nearby the Polish-Slovakian state boundary. Based on some new results of detailed sedimentological, biostratigraphical and structural studies, the presented paper aims mainly at the description of local tectonic structure and correlation of some problematic rock units between Poland and Slovakia.

ążkiewicz, 1977 and references therein), the general structure and evolution of the PKB and adjacent zones was established. The generalized view recognizes two main nappe units differing in their Jurassic–Cretaceous lithostratigraphic successions: the ridge-type Czorsztyn and the basinal Pieniny ones, which are interrelated by several "transitional" successions (e.g. Czertezik, Niedzica-Pruské, Kysuca-Branisko). Views on time of the nappe formation were changing during time, but the most widely accepted opinion considers the Late Cretaceous age of the PKB nappe structure (e.g. Birkenmajer, 1986).

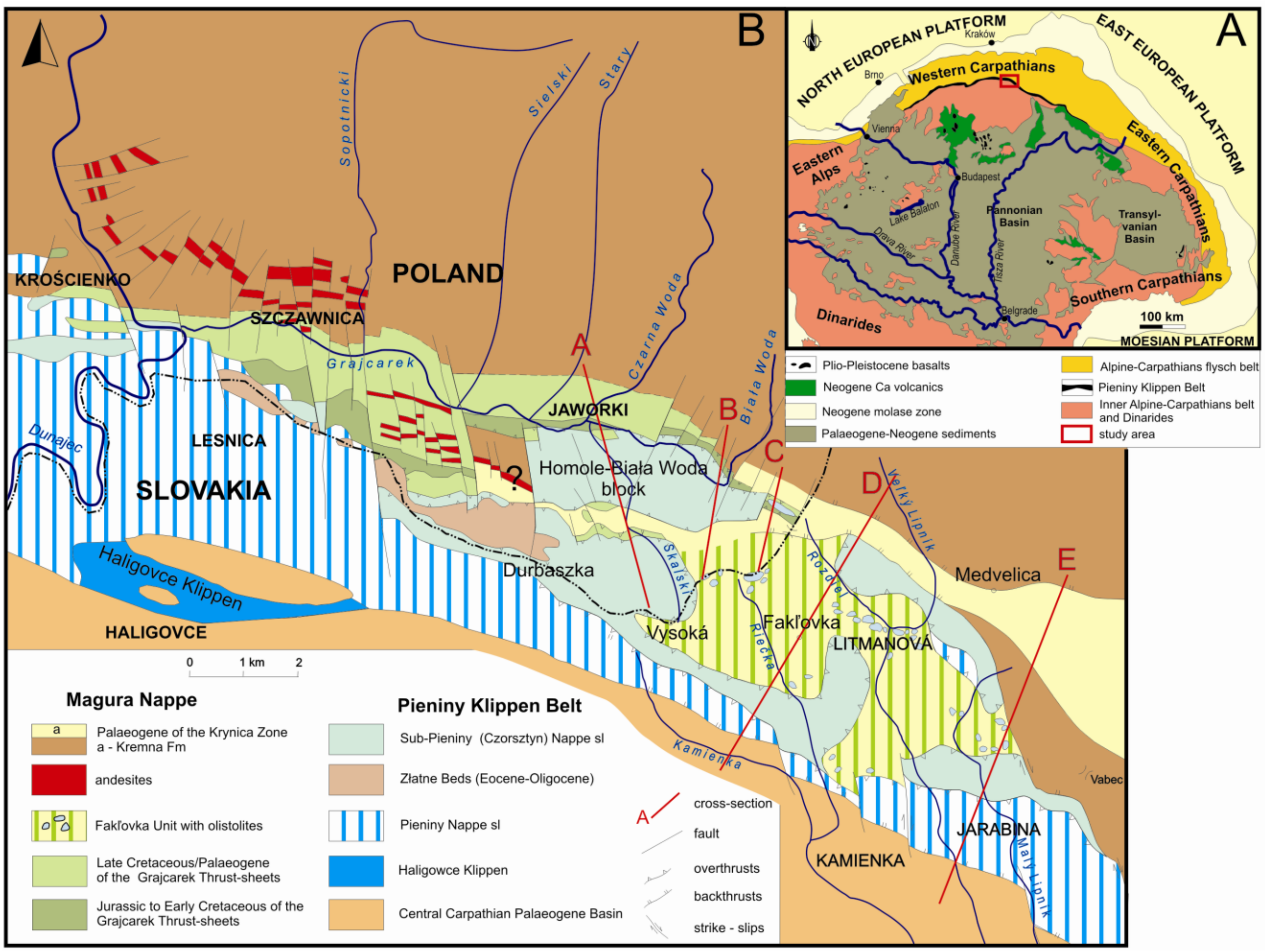

Fig. 1. A – Position of the studied area in the Alpine-Carpathian and Pannonian realm; B – Geological sketch-map of the eastern part of the Pieniny Mts. The Polish Małe Pieniny Mts based on Birkenmajer 1979 (simplified and changed).

2. Previous research

The Polish and adjacent Slovak part of the Pieniny Mts represent the classical area of the PKB geology and tectonics. After the milestone works by Neumayr, Uhlig, Limanowski, Horwitz, Andrusov, Książkiewicz, Birkenmajer and Matějka (see Ksi-

In the Małe Pieniny Mts, the Magura Nappe and PKB are separated by the narrow, strongly deformed Peri-PKB Zone *(s.l)*, known in Poland as the Grajcarek Unit (Birkenmajer, 1977; 1979; 1986) or Hulina Zone (Sikora, 1974). This unit is composed of the Jurassic, Cretaceous and Palaeocene, pelagic and flysch deposits belonging to the Magura succession. According to this concept, the Laramian Grajcarek Unit was thrust back over the PKB, and finally overstepped by the Late Palaeocene to Early Eocene "Autochtonous Magura Palaeogene" (AMP) deposits as a lateral extension of the Magura Basin (see also Birkenmajer and Oszczypko, 1989).

The idea of retro-arc thrusting of the Grajcarek Unit over PKB was questioned by Golonka and Rączkowski (1981) and Jurewicz (1997). According to these authors, the Grajcarek Unit appears in tectonic windows within the PKB. According to Jurewicz (1997, 2005), the terminal phase of nappe thrust-folding was followed by gravitational sliding of the Czorsztyn (Subpieniny) Nappe. This nappe was detached from the basement, defragmented into slices and thrust onto on the southern slope of the Magura Basin, forming numerous olistoliths and olistrostomes (e.g. the Homole-Biała Woda block).

This concept has been recently supported by Cieszkowski et al. (2009).

It was Ján Nemčok late in the last century (e.g. Nemčok et al., 1990), who performed new detailed geological mapping and investigations in the Slovak part of the area and brought many new ideas that partially contradicted the views of older authors. In particular, he characterized the Jarmuta-Proč Formation (Maastrichtian – Early Eocene) as a dominating complex of the "klippen mantle", uniting the various "series", "facies" and "developments" of the Peri-klippen Palaeogene, which were distinguished by older authors (e.g. the Kremná, Ujak, Kyjov, Lackovce, Inovce series etc.). He also stressed the role of "Illyrian" folding before the Late Eocene, which was responsible for creating of the main structures of the PKB. The post-Illyrian sediments (Ombron Group – Nemčok et al., 1990, see also Leško and Samuel, 1968 an references therein) partly seal the deformed substratum and reveal unified sedimentary conditions within the CCPB, PKB and Magura Basin, in spite they were deformed again during the Miocene. Certain aspects of these Nemčok's concepts are accepted also in the present work. On the other hand, we do not follow some other Nemčok's opinions, especially his hypothesis about the megaolistostromatic nature of the whole PKB (Nemčok, 1980). He did not differentiate between various PKB klippen successions and partial nappe units, considered all klippen and even parts of the "klippen mantle" (Late Cretaceous marlstones) as olistoliths and, consequently, questioned the existence of partial PKB nappes differing in lithostratigraphy and position. However, we fully agree that a large part of the klippen (but not all!) are sedimentary slide blocks in the Jarmuta-Proč Formation and not tectonic lenses or boudins, as considered by all other authors.

The last important work dealing with the Palaeogene sediments of the "klippen mantle" in relation to the neighbouring sediments of the Magura Unit was recently published by Oszczypko et al. (2005). These authors established the lowermost Miocene age of the newly-defined Kremná Formation and assign it to the Magura Nappe (Krynica Zone), together with the underlying Eocene – Oligocene Magura Formation. The Kremná-type sediments (Kremná facies or development) were previously considered to be Eocene in age and regarded as constituents of the "Klippen Palaeogene", i.e. part of the transgressive klippen mantle (e.g. Matějka et al., 1963).

3. Methods

During the last few years, new geological mapping of the contact zone between the Magura Nappe and PKB in the Szczawnica and Jaworki area (Małe Pieniny Mts) has been performed by the first author. More or less simultaneously, the authors equally studied relationships between the Magura Nappe, Grajcarek thrust-sheet and the Mesozoic nappes of the PKB (see Oszczypko and Jurewicz 2009). At the same time, we sampled "Autochtonous Magura Palaeogene" flysch (AMP) inside PKB for the petrographic and biostratigraphic purposes (see Oszczypko and Oszczypko-Clowes submitted).

At the same time, new geological mapping in the scale 1:10,000, along with the structural research, has been performed in the eastern Slovakian part of the Pieniny Klippen Belt by the third author. Geographically, the research treated here covers the eastern part of the Pieniny Mts, which are built by units of the PKB and adjacent parts of the Magura Nappe and CCPB. Along with mapping, field-based structural investigations were focused on relationships of minor and major structures, structural relations of klippen to klippen mantle, and spatial/temporal distribution of deformation phenomena. Studied minor structures include bedding-parallel foliation, occasional cleavage and minute folds, and especially shear zones – ductile-brittle in incompetent shales and marls and brittle (faults, slickensides) in competent limestones and sandstones. Results of the structural investigation will not be treated in detail here, since they are prepared to be published in a special paper.

4. Results

The geological structure of the Małe Pieniny Mts significantly differs from the Pieniny Mts to the west. This is manifested by dissimilarities between the two areas shown in the geological map (Fig. 1B). To the east of the Dunajec River the PKB clearly narrows, while the Peri-Klippen Zone expands. At the same time, the structure of the PKB is changed from the fold-and-thrust belt into block structure. Next to the east, the big blocks of the Mesozoic rocks disappear and their place is occupied by single small klippen (e.g. the Fakľovka Unit between Litmanová and Jarabina villages). Concurrently, the area of AMP significantly extends east of Szczawnica town.

4.1. Lithology, age and tectonic position of "AMP" in the Małe Pieniny Mts

In the Małe Pieniny Mts, the AMP occurs in three, more or less separated belts (Fig. 1B). The first one, 4 km long and up to 1 km wide appears cartographically inside the Czorsztyn (Subpieniny) Nappe, and runs from Slovak-Polish boundary, narrowing towards the west (Fig. 1B), and disappears south of the Homole Block. This area is occupied by thick-bedded, fine to coarse grained sandstones, with sporadic intercalations of fine conglomerates. The sandstones are similar to the Magura type, muscovitic sandstones, while infrequent fine conglomerates, rich in carbonate clasts, show similarity to the Jarmuta type sandstones. The shale intercalations are very rare. Recently these deposits were sampled, south of the Homole block, as well as in the upper flow of the Sztolnia Stream. These samples contain calcareous nannoplankton belonging to Early Miocene NN2 Zone (Oszczypko and Oszczypko-Clowes, submitted). For these very recent age determinations, the Kremná sediments have not yet been cartographically distinguished from the Palaeogene sediments of the Fakľovka Unit – the latter most probably overly them tectonically. This is the reason why the map in figure 1 and sections A – C in figure 2 do not show a contact between these two units.

The second belt of the AMP is located west of the Homole-Biała Woda block, surrounded by the Grajcarek thrust sheet. This area is dominated by thick-to very thick-bedded sandstones of the Magura type without any intercalations of shales, which prevented micropaleontological tests. Taking into account the lithological development of these beds, we can regard them as an equivalent of the Piwniczna or Poprad Members of the Magura Formation, but Kremná Formation also cannot be excluded (Fig. 1B).

The third belt of AMP is located along the Polish-Slovakian state boundary, west of the Durbaszka Mt. From the north this area is bounded by a narrow belt (100–200 m) of Mesozoic limestones and marls similar to the Branisko (Kysuce) succession of the Pieniny Nappe. On the Slovak side this type of AMF passes into the calcareous sandstones of the Jarmuta-Proč Formation (Palaeocene – Middle Eocene; see Nemčok 1992). For unclear reasons, in the map of Janočko ed. (2000) these rocks are shown as the Upper Cretaceous flysch sediments of the Klape Unit. The small exposures of medium to thick-bedded calcareous sandstones, with infrequent claystone intercalations are visible in the upper flows of the Krupianka and Sztolnia streams (Fig. 1B). Taking into account lithology and tectonic position of the AMP in this area, we decided to establish these strata as the Złatne Beds (Golonka and Rączkowski, 1981).

The possible relationship between the AMP (Kremná Formation) and PKB nappes, Grajcarek thrust-sheet and the Magura Nappe is presented in the cross-sections (Fig. 2). The cross-sections A, B and C suggest that major part of the AMP, belonging to the Lower Miocene Kremná Formation, appears in tectonic windows beneath the Grajcarek thrust sheets and PKB nappes.

In the eastern part of the Małe Pieniny Mts, the Kremná Formation has been recognized both at the front of the PKB, as well as in tectonic window inside the PKB. The Kremná Formation is overlapped by two tectonic outliers of the Czorsztyn (Sub-Pieniny) Nappe and Grajcarek thrust-sheet. Towards the south the Kremná Fm. is overthrust by the Mesozoic rocks of Czertezik succession of the Czorsztyn (Sub-Pieniny) Nappe. Towards the west (Fig. 2B, C) position of the Brysztan outlier is occupied by the Homole-Biała Woda Block, composed of both the Czorsztyn and Niedzica successions of the Czorsztyn (Subpieniny) Nappe. This nappe is underlain by the south Grajcarek thrust-sheet up to 100 m thick, composed of the Szlachtowa and Malinowa formations. Both tectonic units of the Homole-Biała Woda Block are thrust over the northern Grajcarek thrust sheet.

The tectonic position of the Złatne Beds (Fig. 1B) of the Durbaszka Mt. and along the Polish/ Slovakian boundary is not clear. On the Slovakian side of PKB, an equivalent of the Złatne Beds is represented by the Jarmuta-Proč Formation.

4.2. Structure of the Slovak part of the Pieniny Mts

Based on the recent geological mapping and structural investigation, the following major tectonic units have been distinguished (in a zonal arrangement from bottom and north to top and south): 1. the Magura Unit (Krynica subunit) of the Outer Carpathian Flysch Belt; 2. Oravic units of the

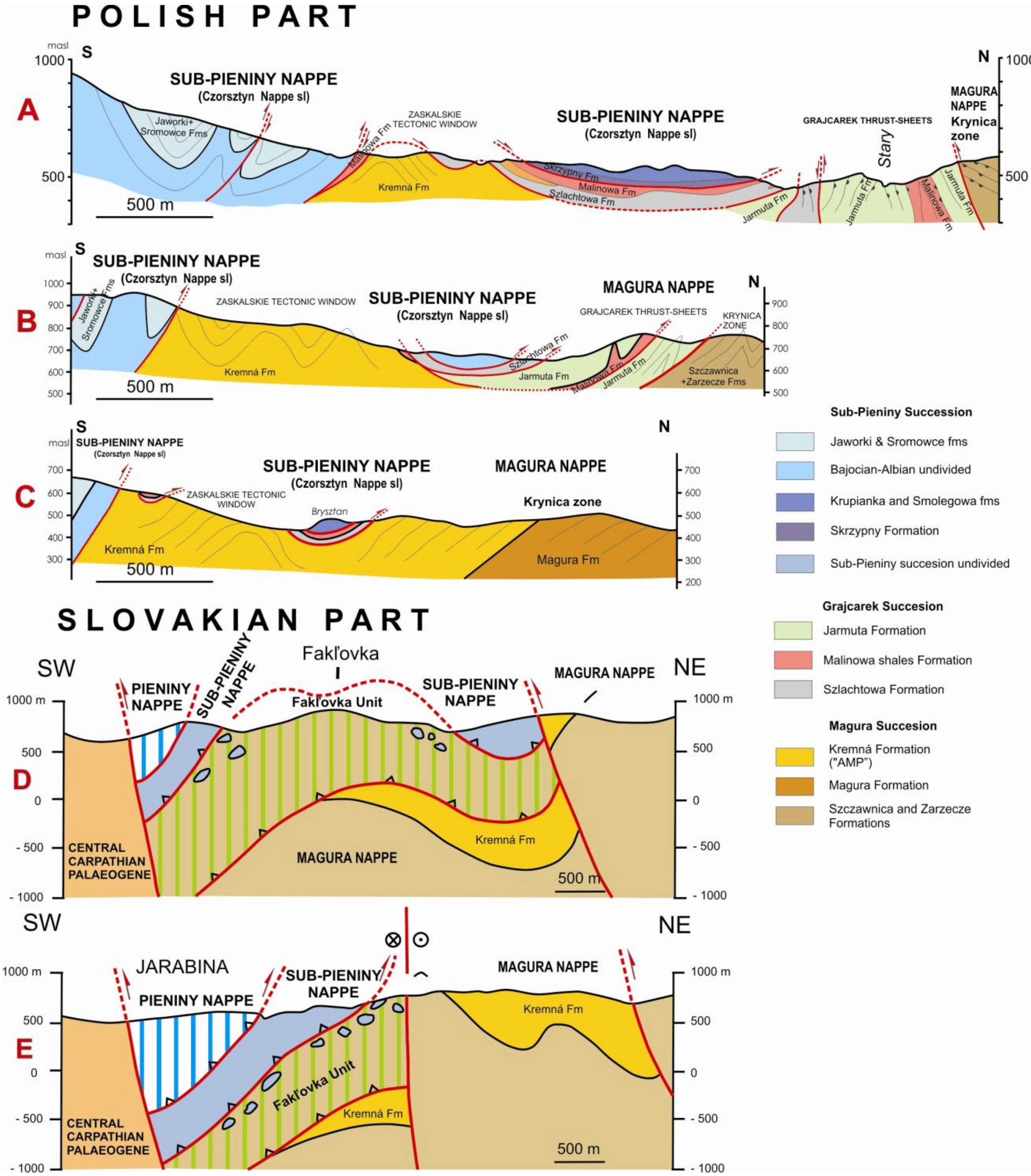

Fig. 2. Geological cross-sections of the area. For their position and key of sections D and E see Fig. 1.

PKB; 3. CCPB (Podhale-Podtatra Group). Further east, out of the area described here, the Magura vs. PKB tectonic contact is partly sealed by the Upper Eocene – Oligocene sediments of the Údol Succession (Ujak facies of older authors, Ombron Group of Nemčok et al., 1990), which is composed of variegated shales, Globigerina marls, menilite shales and calcareous flysch of the Malcov Formation (see Oszczypko et al., 2005 for details). These formations exhibit close facies relationships to the southward adjacent, coeval sediments of the Podhale-Podtatra Group.

The Magura Unit, adjacent to the PKB (Krynica Zone or subunit, Čergov Unit of older Slovak authors), is dominated by the Magura-type sandstones. These are usually thick-bedded, medium- to coarse-grained, siliciclastic, which seemingly do not contain material typical for the PKB formations. From bottom to top, the Magura Formation is subdivided into three members (Oszczypko et al., 2005): Piwniczna Sandstone (Lower – Middle Eocene), Mniszek Shale (Middle Eocene) and Poprad Sandstone (Upper Eocene – Oligocene), which is conformably overlain by the Early Miocene Kremná Formation (NN1-NN2) in a synform close to the northern boundary of the PKB (Fig. 1B). The Poprad sandstones contain conglomerate bodies bearing exotic material dominated by crystalline basement rocks, which considerably differ from exotics found in the Upper Cretaceous – Palaeogene conglomerates of the PKB (Mišík et al., 1991; Oszczypko et al., 2006). Therefore different sources have been reconstructed for the coeval clastic sediments of the Magura and Klippen Belt basins. On the other hand, some authors indicated a gradual transition from carbonate-bearing Palaeogene sandstones of the PKB to siliciclastic deposits of the Magura Unit across their boundary (e.g. Stráník, 1965).

The contact of the Magura Unit with the PKB is always tectonic, formed by steeply NE dipping reverse fault (backthrust) segmented by N-S trending strike-slips with dextral offset (Figs 1B, 2D, E)). Bedding of the Magura sediments is steeply to moderately N-dipping at this contact. This situation indicates oblique dextral backthrusting of the Magura Unit, which occurred late in the tectonic evolution of the area, most probably during the Early – Middle Miocene. This event affected also the PKB units and their overstepping cover (Údol Succession), as well as the southern boundary fault of the PKB and adjacent sediments of the CCPB (Šambron-Kamenica antiform; Plašienka et al., 1998).

The lowermost structural unit of the PKB mostly occurs along the northern boundary of the PKB, in places also more southerly in windows or half-windows. This unit includes Upper Jurassic radiolarites and Lower Cretaceous spotted cherty limestones, variegated, but mostly grey to black, often calcite-free shales and silicites overlain by “black flysch” (mid-Cretaceous?), Upper Cretaceous variegated, mostly red shales and marls with thin turbiditic beds of fine-grained, siliciclastic sandstones, and then hundreds of metres thick calcareous sandstones and conglomerates/breccias (Jarmuta-Proč Formation). Huge slide blocks and mass flows (olistostromes) occur as stratiform bodies or incised channel fillings in the uppermost parts of this succession (e.g. Litmanová, Miľpoš – part of the Gregorianka Breccia in the sense of Nemčok et al., 1989). Sandstones and conglomerates obviously contain material derived mainly from the Czorsztyn and/or Niedzica and Czertezik successions (Pieniny-Kysuca/Branisko might be also present). Their inferred age is Palaeocene – Early Eocene. The lithostratigraphic content of this unit roughly corresponds to the Birkenmajer’s Grajcarek Unit (see above), our view on its tectonic position is considerably different, however. Paleogeographically, the unit under question should be placed at the southern margin of the Magura Basin, but structurally it forms the lowermost, not the uppermost thrust unit of the PKB, as reconstructed by Birkenmajer (e.g. 1986). Therefore the term Grajcarek Unit is not used in Slovakia. Instead, a provisional term Fakľovka Unit is proposed here. Moreover, according to the newest results presented here from the Polish Małe Pieniny Mts (see above), the Grajcarek Unit appears to override the Kremná Formation of the Magura Nappe and, vice-versa, is overridden by the typical PKB Czorsztyn and/or Niedzica nappes (see also Jurewicz, 1997).

In addition to clastic material in sandstones and olistostromes, huge olistoliths of typical PKB rocks occur within the Jarmuta-Proč Formation (Figs 1B, 2D, E). These were considered as klippen, i.e. tectonic lenses until now. The overriding Czorsztyn-type units form imbricated thrust sheets, their fronts passing gradually into mass-flows inserted within and above the Jarmuta-Proč flysch, hence indicating close sedimentary and tectonic relationships of the Fakľovka Unit and the overlying

Subpieniny nappe.

For the higher nappe unit of the PKB, we return to the old Uhlig's term Subpieniny Unit (Uhlig 1907). This view corresponds also to the division of Książkiewicz (1977), i.e. the Subpieniny Nappe includes the dominating Czorsztyn Succession, as well as Niedzica, Czertezik and similar "transitional" successions derived from the Czorsztyn ridge and its slopes. Lithology and stratigraphy of these successions were described in numerous papers, readers are recommended e.g. to Birkenmajer (1977, 1986 and others). However, in no case these successions represent independent large-scale units in the tectonic sense as some other authors proposed. The Subpieniny Nappe is a more-or-less continuous overthrust sheet with stable structural position, but strongly imbricated or even disintegrated internally, which at least partly resulted also from the morphological dissection of the original sedimentary area and consequent wavy or upstepping nature of the detachment plane. Especially the frontal parts are very complicated with numerous slices or lenses (klippen) embedded in Upper Cretaceous marlstones ("diapirs" of Birkenmajer, 1979). Nappe fronts were even probably gravitationally detached and form disintegrated bodies above the Jarmuta-Proč flysch (Figs 1B, 2D, E). These slide bodies are closely related to olistoliths and olistostromes within the underlying Jarmuta-Proč Formation of the Fakľovka Unit (sometimes not distinguishable), which originated from gravitationally liberated frontal parts of the Subpieniny Nappe. Only the most internal (but structurally lower) parts of the Subpieniny Nappe, formed by the Czorsztyn Succession with thick rigid crinoidal limestones, are more coherent, but still imbricated. The youngest sediments of the Czorsztyn Succession are Upper Senonian Jarmuta-type calcareous sandstones overlain by olistostrome breccias (Gregorianka Breccia at the type locality near Jarabina–Nemčok et al., 1989). These breccias only contain material from the overriding Pieniny Nappe (Upper Jurassic radiolarites, Lower Cretaceous biancone-type limestones).

The highermost tectonic unit of the PKB – the Pieniny Nappe is clearly independent from the Subpieniny Nappe, but includes several lithostratigraphic successions as well (Pieniny s.s., Kysuca-Branisko, see e.g. Birkenmajer, 1977). The Pieniny Unit is strongly folded and imbricated again, but generally continuous and coherent. It overlies the Subpieniny Unit, but in places directly the Fakľovka Unit (Figs 1B, 2D, E). Except a few places, it forms the southernmost zone of the PKB.

5. Discussion and conclusions

New data on the age and position of the "AMP" allows for the development of a new scenario of tectonic evolution of the PKB (Fig. 3).

1) Late Cretaceous/Palaeocene: detachment of the Pieniny Unit and its thrusting over the Czorsztyn slope and ridge (Gregorianka Breccia).

2) Palaeocene – Early Eocene: detachment of the Subpieniny Unit, its internal imbrication (partially also with the overlying Pieniny Unit) and thrusting over the foreland Jarmuta-Proč Basin facing the Magura Ocean, its frontal parts were disintegrated into slide sheets, olistoliths (the largest one could be just observed in the Małe Pieniny, famed as Homole-Biała Woda block) and debris flows (Milpoš-type breccias of the Proč Formation). This gravitational sliding influenced also the background sediments and caused their folding and forming the Grajcarek thrust-sheets.

3) Eocene: detachment of the Fakľovka Unit, out-of-sequence thrusting in the Subpieniny and Pieniny Nappes, possibly also thrusting of the Fakľovka Unit along with the overlying Subpieniny and Pieniny Units over the innermost Magura elements. Probably during the same time the Grajcarek thrust-sheets could be activated ones more. These gravitational movements at the boundary of PKB and Magura Basin prolonged to the Eocene/?Oligocene (Fig. 4 B,C). Further shortening and first manifestations of dextral transpression took a place (steep shear zones affecting all PKB units).

4) Eocene – Oligocene: Collapse of the thrust stack, flat extensional shear zones in PKB units, subsidence and subsequent deposition of the Údol Succession.

5) Early Miocene (Burdigalian): The youngest thrust of the PKB units onto the Magura Nappe (after deposition of the Kremná Formation) connected with folding and thrusting within the Outer Carpathians (Intra-Burdigalian or Early Styrian movements). Renewed thrusting along the PKB/Magura boundary in the rear part of the developing accretionary wedge of the Carpathian Flysch Belt, affecting also the Lower Miocene Kremná Formation according to present study.

6) Late Burdigalian/ Middle Miocene: dextral tran-

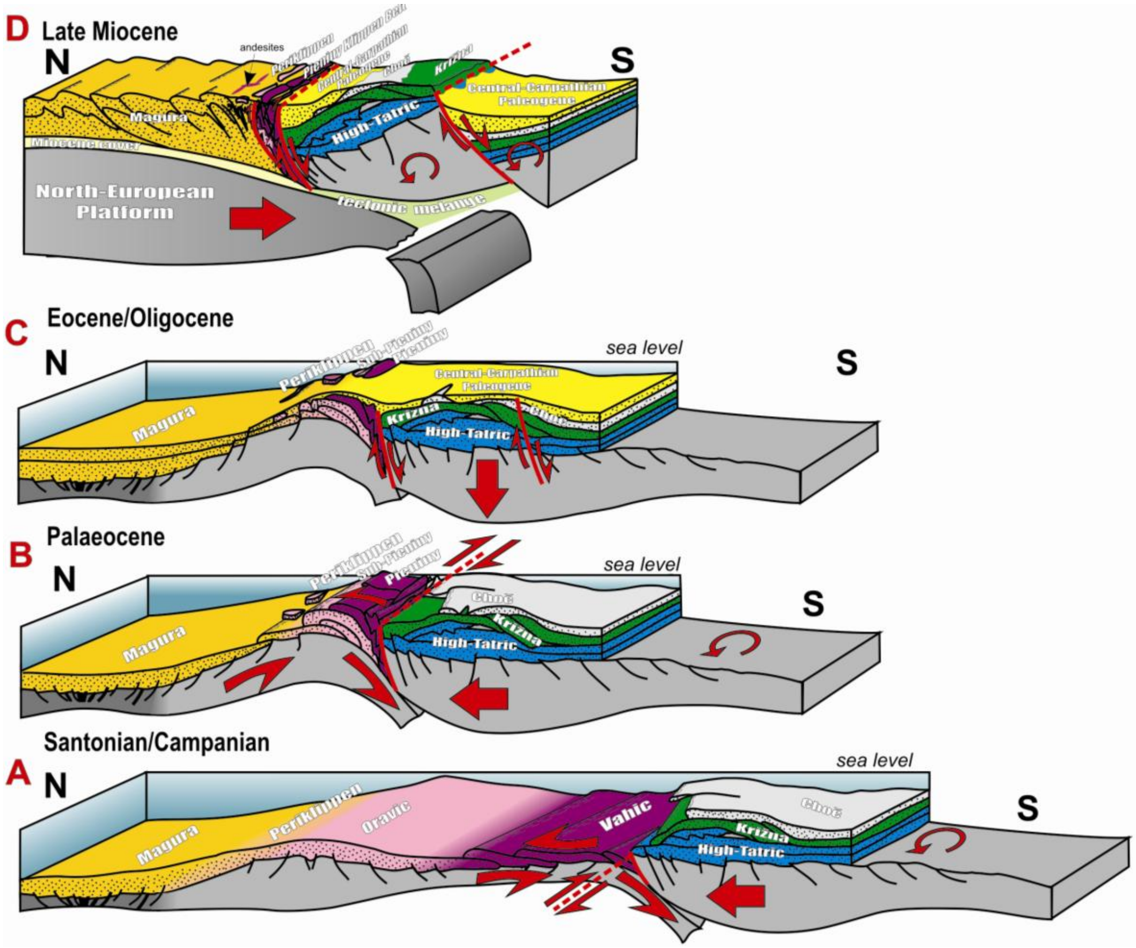

Fig. 3. Late Cretaceous – Late Miocene evolution of the Pieniny Klippen Belt and adjacent areas (based on Jurewicz 2005, supplemented).

spression and shaping of the final “flower” structure of the PKB. The eastwards escape and counterclockwise rotation of the ALCAPA caused involvement of the PKB into strike-slip movements and development of a flower structure, consequently some parts of klippen units were retrothrust onto the CCPB (Fig. 4D; compare to Fig 3D). This event was apparently accompanied by narrowing and development of the orogen-scale curvature of the PKB.

Acknowledgements

The research was supported by the Polish Ministry of Sciences and Higher Education grant N307 025 31/1997 (to N.O.). Research in the Slovak Republic was performed in frame of the project APVV-0465-06 “Tectogen”. D.P. wishes to thank the Slovak Research and Development Agency for the financial support. Authors thank cordially to Prof. Jan Golonka and Dr. Michal Potfaj for reviewing this paper.

References

Birkenmajer K., 1977. Jurassic and Cretaceous lithostratigraphic units of the Pieniny Klippen Belt, Carpathians. Studia Geologica Polonica, 45, 158p.

Birkenmajer K., 1979. Pieniny Klippen Belt of Poland – geological guide. Wydawnictwa Geologiczne, Warszawa, 237p (in Polish).

Birkenmajer K., 1986. Stages of structural evolution of the Pieniny Klippen Belt, Carpathians. Studia Geologica Polonica, 88, 7-32.

Birkenmajer K. and Oszczypko N., 1989. Cretaceous and Palaeogene lithostratigraphic units of the Magura Nappe, Krynica Subunit, Carpathians. Annales Societatis Geologorum Poloniae, 59, 145-181.

Cieszkowski M., Golonka J., Krobicki M., Ślączka A., Oszczypko N., Waśkowska A. and Wendorff M., 2009. The Northern Carpathians plate tectonic evolutionary stages and origin of olistoliths and olistostromes. Geodinamica Acta, 22/1-3, 101-126.

Froitzheim N., Plašienka D. and Schuster R., 2008. Alpine tectonics of the Alps and Western Carpathians. In: The Geology of Central Europe, vol. 2: Mesozoic and Cenozoic (T. Mc Cann, ed.), Published by the Geological Society, London, 1141-1232.

Golonka J. and Rączkowski W., 1981. Detail Geological Map of Poland, Piwniczna sheet. Wydawnictwa Geologiczne, Warszawa (in Polish).
Janočko J. (ed.), 2000. Geological map of the Spišská Magura Mts 1 : 50 000. Geol. Služba SR, Vyd. D. Štúra, Bratislava, 174 p.
Jurewicz E., 1997. The contact between the Pieniny Klippen Belt and Magura Unit (the Małe Pieniny Mts). Geological Quarterly, 41, 315-326.
Jurewicz E., 2005. Geodynamic evolution of the Tatra Mts. and the Pieniny Klippen Belt (Western Carpathians): problems and comments. Acta Geologica Polonica, 55, 295-338.
Książkiewicz M., 1977. The tectonics of the Carpathians. In: Geology of Poland Volume 4. Tectonics (Pożaryski W., ed.), Wydawnictwa Geologiczne, Warszawa, 476-699.
Leško B. and Samuel O., 1968. The geology of the East Slovakian Flysch. Vydav. Slov. Akad. Vied, Bratislava, 245 p. (in Slovak with English summary).
Matějka A. (ed.), 1963: Explanations to the general geological map of ČSSR 1 : 200 000, sheet M-34-XXI Spišská Stará Ves. Geofond, Bratislava, 60-132. (in Slovak)
Mišík M., Sýkora M. & Jablonský J., 1991: Strihovce conglomerates and the south Magura cordillera. Západné Karpaty, Geológia, 14, 7–72.
Nemčok J., 1980. Non-traditional view of east-Slovakian Klippen Belt. Geologický Zborník – Geologica Carpathica, 31, 563–568.
Nemčok J., 1990. Geological map of the Pieniny, Ľubovnianska vrchovina Highland and Čergov Mts in the scale 1:50,000. Geologický Ústav D. Štúra, Bratislava.
Nemčok J., Kullmanová A. and Ďurkovič T., 1989. Development and stratigraphic position of the Gregorianka breccias of the Klippen Belt in eastern Slovakia. Geologické Práce, Správy, 89, 11–37 (in Slovak with English summary).
Nemčok J., Zakovič M., Gašpariková V., Ďurkovič T., Snopková P., Vrana K. and Hanzel V., 1990. Explanation to the geological map of the Pieniny, Čergov, Ľubovnianska and Ondavská vrchovina Mts. Geologický Ústav Dionýza Štúra, Bratislava, 132p (in Slovak with English summary).
Oszczypko N. and Jurewicz E., 2009. The position of the so called autochtonous Magura Paleogene in the Małe Pieniny Mts. (Magura Nappe and Pieniny Klippen Belt, Poland). In: Conference of Environmental, Structural and Stratigraphical Evolution of the Western Carpathians, 2-5.12.2008 (Reháková D. and Józsa Š., eds). Mineralia Slovaca, 40, 3-4, Geovestník, 245-246.
Oszczypko N. and Oszczypko-Clowes M., 2009. Stages in the Magura Basin evolution: a case study of the Polish Sector (Western Carpathians). Geodinamica Acta, 22, 83-100.
Oszczypko N. and Oszczypko-Clowes M., submitted. New Data on the stratigraphy of the Paleogene and Early Miocene of the Beskid Sądecki Range and Ľubovnianska Vrchovina (Magura Nappe, Outer Carpathians, Poland and Slovakia**).** Acta Geologica Polonica.
Oszczypko N., Oszczypko-Clowes M., Golonka J. and Marko F., 2005. Oligocene – Lower Miocene sequences of the Pieniny Klippen Belt and adjacent Magura Nappe between Jarabina and the Poprad River (East Slovakia and South Poland) – their tectonic position and paleogeographic implications. Geological Quarterly, 49, 379-402.
Oszczypko N., Oszczypko-Clowes M. and Salata D., 2006. Exotic rocks of the Krynica Zone (Magura nappe) and their palaeogeographic significance. Geologia, 32, 21-45.
Plašienka D., Soták J. and Prokešová R., 1998. Structural profiles across the Šambron-Kamenica Periklippen Zone of the Central Carpathian Paleogene Basin in NE Slovakia. Mineralia Slovaca, 29, 173–184.
Sikora W., 1974. Outline of the tectogenesis of the Pieniny Klippen zone in Poland in the light of the new geological data. Annales Societatis Geologorum Poloniae, 41, 1, 223-239. (In Russian with English abstract).
Stráník Z., 1965: Geology of the Magura Flysch in the Čerchov Mts and western part of the Ondavská vrchovina Mts. Sborník Geologických Vied, Západné Karpaty, 3, 125–178 (in Czech, German summary).
Uhlig V., 1907: About tectonics of the Carpathians. Sitzungsberichte der kaiserischen Akademie der Wissenschaften, matematisch-naturwissenschaftliche Klasse, 116, Abt. 1, Wien, 871-982 (in German).