Tectonic Evolution of the Pieniny Klippen Belt and its Structural Relationships to the External and Central Western Carpathians

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The Pieniny Klippen Belt (PKB) is a narrow zone dominated by wrench tectonics (Nemčok and Nemčok 1994, Ratschbacher et al. 1993, Kováč and Hók 1996) that separates the External Western Carpathians (ECW – Flysch Belt, Tertiary accretionary wedge) from the Central Western Carpathians (CWC – Cretaceous nappe stack). The PKB involves predominantly Jurassic, Cretaceous and Paleogene sediments with enormously variable lithology and intricate internal structure (e.g. Andrusov 1931, 1938, 1953, Birkenmajer 1977, 1986, Mišík 1997). During more than a century of intense research these have been subdivided into numerous lithostratigraphic and tectonic units. However, the mutual structural relationships of various PKB units and the neighbouring tectonic zones remains a matter of controversy and no general agreement has been achieved even in some fundamental questions.

We present a series of generalized cross-sections through various segments of the PKB in Slovakia and Poland aimed at illustration of the internal structure of the PKB and its tectonic interactions with adjacent ECW and CWC zones (see Fig. 1 as an example). Sections are constructed based on regional geology using published maps and profiles, lithostratigraphic contents of tectonic units and our own structural data (e.g. Jurewicz 1994, 1997, Plašienka 1995a, Plašienka et al. 1998). In general, we distinguish units of the Pennine tectonic system structuralized during the Tertiary and those of the Slovakocarpathian (Austroalpine) tectonic system structuralized and emplaced predominantly during the Late Cretaceous, but partially reactivated during the Tertiary (Plašienka 1995b).

Four superposed superunits compose the Pennine system: 1) the Magura superunit (North Penninic) consisting of the Upper Cretaceous – Oligocene sedimentary formations composed mostly of flysch formations; 2) the Biele Karpaty superunit (North Penninic) as the innermost element of the ECW involving Cretaceous – Eocene strata (incl. synorogenic flysch of Jarmuta and Proč Fms); 3) the Oravic (Middle Penninic) superunit comprising Lower Jurassic – Upper Cretaceous sediments that is subdivided into several well-known PKB units of their own (e.g. Czorsztyn, Niedzica-Pruské, Kysuca-Branisko, Pieniny s.s., Orava etc); 4) the Vahic (South Penninic) superunit composed of Upper Jurassic – Upper Cretaceous oceanic sediments (Belice and Iňačovce-Krichevo unit).

However, the PKB and zones adjacent to its inner side involve also units derived from the CWC Cretaceous nappe systems, namely (from bottom to top): 5) the Tatric superunit consisting of the pre-Alpine crystalline basement and its Scythian–Turonian sedimentary cover; the structurally lowest and most external Infratatric units (Inovec, Kozol) include also Pennsylvanian–Permian rocks; 6) the Fatric superunit of detached Middle Triassic – Cenomanian sedimentary formations (Krížna nappe s.l.) that was emplaced in the Late Turonian; 7) some external partial Fatric and/or Tatric units that were strongly reactivated during the Early Tertiary and were largely incorporated into the PKB structure (Drietoma, Manín, Klape, Haligovce, Humenné subunits); 8) the Hronic superunit of detached Pennsylvanian – Hauterivian complexes (Choč nappe s.l.).

Except of the nappe superunits, four sets of overstep sedimentary complexes have been discerned. Still partially synorogenic Gosau Supergroup consists of: a) the Senonian Brezová Group; b) Paleocene – Lower Eocene Myjava-Hričov Group; c) Eocene – Egerian Podhale-Podtatra Group (incl. Eggenburgian sediments in places); c) Neogene sediments and volcanics.

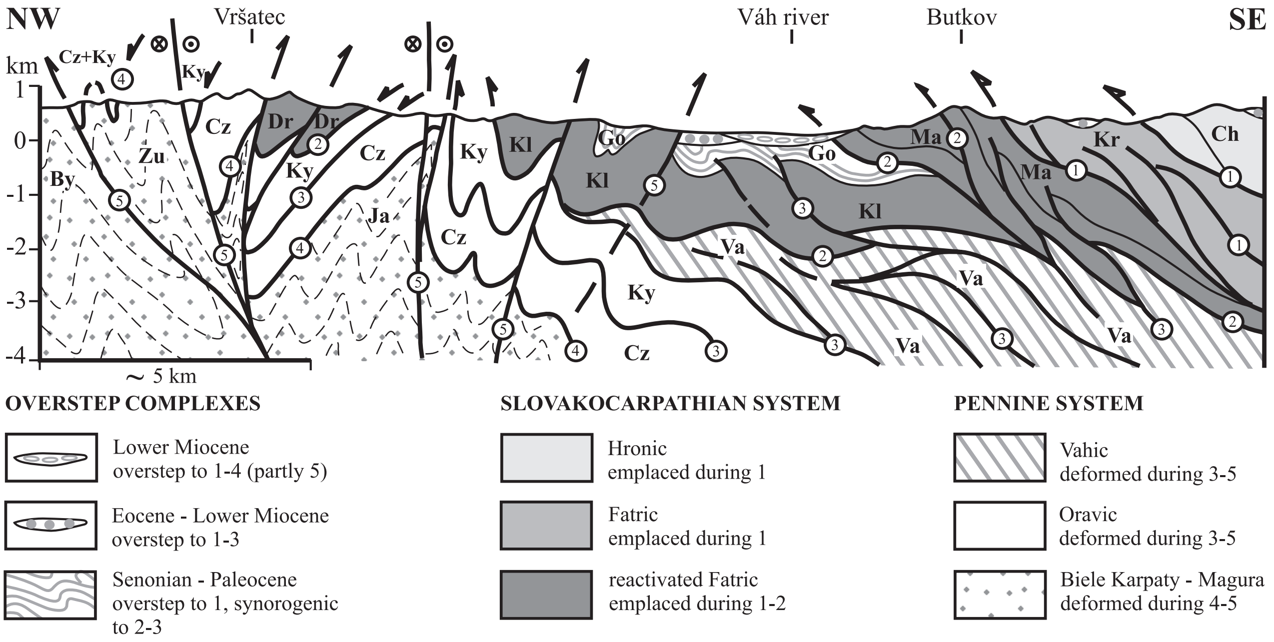
Tectonic evolution of listed units was very complex and proceeded in the following principal steps:

1. Late Turonian or slightly younger emplacement of the Fatric and Hronic cover nappe systems that overrode the Tatric substratum; transgressive Coniacian sediments of the piggyback Gosau Brezová Group are syn- to posttectonic with respect to this event;
2. Senonian subduction of the South Penninic oceanic substratum and subcretion of the Vahic Belice unit beneath the frontal Infratatric units of the Tatric basement sheet, with piggy-back Fatric-Hronic nappes; Late Senonian (post-Campanian) partial reactivation of the most external Fatric units (Drietoma, Manín, Klape), somewhere with piggy-back Hronic, which overrode the Vahic and southern Oravic elements; Senonian sediments are inversion-related in the Magura, preorogenic (pelagic swell) in the Czorsztyn, synorogenic (lower plate) in the Kysuca and synorogenic piggy-back (upper plate) atop the Fatric-Hronic stack; thrust-related structures (ductile/brittle shear zones, low-grade metamorphism) in the Vahic and Infratatric units;
3. Latest Cretaceous – earliest Paleogene closure of the Vahic ocean, collision-related detachment of the Jurassic – Cretaceous successions of the Kysuca and allied “transitional” Oravic units (partly with piggy-back reactivated Fatric and synorogenic Gosau) to overthrust the ridge-related Oravic Czorsztyn succession; incipient fold-and-thrust belt of detached and piggy-back units and synorogenic Gosau sediments;
4. Paleocene to Early Eocene detachment of the Czorsztyn unit from its basement that was underthrust beneath the CWC and its thrusting (along with piggy-back higher Oravic, reactivated Fatric and synorogenic Gosau Myjava-Hričov Group) over the most internal Biele Karpaty elements with synoro-

genic Jarmuta and Proč Formations; duplexing and recumbent folding accompanied by shearing-related cleavage within the Czorsztyn unit;

5. After the Eocene – Oligocene extensional event associated with deposition of the Podhale-Podtatra Group overstepping the CWC and partly also the inner PKB zones, the PKB experienced strong dextral transpression during the Late Oligocene and Early Miocene, with development of a positive flower structure – the outer forward-thrust limb is located within the rear parts of the frontally accreted Biele Karpaty – Magura units, back-thrusts of the inner limb intensely affected the especially boundary PKB/CWC zones; the flower is usually centred by a narrow, generally vertical zone of the PKB s.s., in which strike-slipping prevailed that lead to the formation of the typical "klippen" (block-in-matrix) tectonic style caused by pervasive brittle faulting; Early Miocene dextral transpression is presumably related to counter-clockwise rotation of the CWC block with respect to the EWC, which was most probably accompanied also by narrowing and oroclinal bending of the PKB; sets of post-folding cleavages and shear zones record transpression on a mesoscopic scale;
6. Neogene evolution is complex as well and its kinematics strongly varies in individual PKB sectors – mid-Miocene to Pliocene sinistral transtension occurred along the inner side of the SW-NE trending PKB in western and northern Slovakia (Mur–Mürz–Leitha–Dobrá Voda–Považie–Žilina wrench corridor related to the tectonic escape of the ALCAPA block from the Alpine collision); mid-Miocene orthogonal shortening followed by the Late Miocene–Pliocene sinistral transtension (Orava Basin) affected the northernmost W-E striking PKB sector in Poland; the NW-SE trending eastern Slovakian sector underwent only dextral wrenching – first transpression during the Early–Middle Miocene, then transtension pursued by general extension during the Late Miocene and Pliocene (opening of the Transcarpathian depression).

Summing up, the overall tectonic scenario includes piggy-back mode of forward thrusting, formation of a fold-and-thrust belt capped by synorogenic sedimentary basins and some out-of-sequence thrusting as the principal tectonic regime during the Late Cretaceous and earliest Paleogene, followed by Oligocene–Lower Miocene dextral transpression responsible for the steepening and narrowing of the PKB that acquired its final tectonic style. The overall N-S convergence during the Middle–Late Miocene affected the already bended PKB, consequently its western SW-NE part underwent inversion to sinistral wrenching, whilst the eastern NW-SE trending part remained in a dextral regime. The klippen style resulted form the rheological contrast between a relatively thin, later disintegrated, stiff layer of Middle Jurassic to Lower Cretaceous limestones sandwiched within Lower Jurassic (décollement horizon) and much thicker Upper Cretaceous incompetent



■ **Fig. 1.** Schematic cross-section through the PKB and adjacent zones in western Slovakia (middle Váh Valley). Note that the Vršatec area represents the "PKB s.s." with tight imbricated flower structure, whereas the Váh Valley represents the "Periklippen Belt" as a mixture of Penninic and Slovakocarpathian units and several overstepping formations. Abbreviations: Go – Gosau Supergroup (Senonian – Paleocene); Ch – Choč nappe system (Middle Triassic – Hauterivian); Kr – Krížna nappe system (Middle Triassic – Cenomanian); Ma – Manín Unit (Lower Jurassic – lower Turonian); Kl – Klape Unit (Aptian – lower Turonian); Dr – Drietoma unit (Upper Triassic – Cenomanian); Va – Vahic units (Upper Jurassic – Senonian); Ky – Kysuca-Pieniny unit (Lower Jurassic – Campanian); Cz – Czorsztyn unit (Lower Jurassic – Maastrichtian); Ja – Javorina and Zu – Zubák nappe (Campanian – Lower Eocene); By – Bystrica unit (Senonian – Oligocene). Numbers refer to the age of principal fault and fold structures: 1 – late Turonian; 2 – late Senonian; 3 – Senonian/Paleocene; 4 – early Eocene; 5 – Oligocene to early Miocene.

marly and flysch sediments, as well as due to long-termed deformation progressing in several stages, including nappe-thrusting, extension and transpression.

The constructed cross-sections show that various PKB sectors record all these complex tectonic movements very irregularly, especially as far as the presence and distribution of tectonic units and overstep complexes are concerned. On the other hand, all sectors are dominated by the stage 5 dextral wrenching that finally shaped the PKB units. In many cases the stage 5 wrench faults juxtapose segments with fairly different collections of units, their thickness, pre-5 structure and erosional level. The fan-wise transpressional belt attains its maximum breadth of about 20 km in the middle Váh Valley near Považská Bystrica due to accumulation of at least 5 subvertical strike-slip duplexes developed within the Klape and underlying units. Relics of older thrusting stages are variably recorded, sometimes totally obliterated by wrenching. Nevertheless, if present, the superposition and lithostratigraphic content of units with different affiliation helps much in deciphering complicated tectonic history of this worldwide unique tectonic phenomenon.

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References

ANDRUSOV D., 1931. Étude géologique de la zone des Klippes internes des Carpathes Occidentales. Partie I: Introduction, Partie II: Stratigraphie (Trias et Lias). Rozpr. St. geol. ústavu ČSR, 6, 167 p.

ANDRUSOV D., 1938. Étude géologique de la zone des Klippes internes des Carpathes Occidentales. Partie III: Tectonique. *Rozpr. St. geol. ústavu ČSR*, 9: 135.

ANDRUSOV D., 1953. Étude géologique de la zone des Klippes internes des Carpathes Occidentales. Partie IV: Stratigraphie du Dogger et du Malm, Partie V: Stratigraphie du Crétacé. *Geologické práce, Sošit*, 34: 147.

BIRKENMAJER K., 1977. Jurassic and Cretaceous lithostratigraphic units of the Pieniny Klippen Belt, Carpathians, Poland. *Studia Geol. Pol.*, 45: 1–158.

BIRKENMAJER K., 1986. Stages of structural evolution of the Pieniny Klippen Belt, Carpathians. *Studia Geol. Pol.*, 88: 7–32.

JUREWICZ E., 1994. Structural analysis of the Pieniny Klippen Belt at Jaworki, Carpathians, Poland. *Studia Geol. Pol.*, 106: 7–87.

JUREWICZ E., 1997. The contact between the Pieniny Klippen Belt and Magura Unit (the Małe Pieniny Mts.). *Geol. Quart.*, 41: 315–326.

KOVÁČ P. and HÓK J., 1996. Tertiary development of the western part of Klippen Belt. Slovak Geol. Mag., 2/96: 137–149.

MIŠÍK M., 1997. The Slovak part of the Pieniny Klippen Belt after the pioneering works of D. Andrusov. *Geol. Carpath.*, 48: 209–220.

NEMČOK M. and NEMČOK J., 1994. Late Cretaceous deformation of the Pieniny Klippen Belt, West Carpathians. *Tectonophysics*, 239: 81–109.

PLAŠIENKA D., 1995a. Origin and structural position of the Upper Cretaceous sediments in the northern part of the Považský Inovec Mts. Part 2: Structural geology and paleotectonic reconstruction. *Mineralia Slov.*, 27: 179–192.

PLAŠIENKA D., 1995b. Mesozoic evolution of Tatric units in the Malé Karpaty and Považský Inovec Mts.: Implications for the position of the Klape and related units in western Slovakia. *Geol. Carpath.*, 46: 101–112.

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 Slov.*, 29: 173–184.

RATSCHBACHER L., FRISCH W., LINZER H.-G., SPERNER B., MESCHEDE M., DECKER K., NEMČOK M., NEMČOK J. and GRYGAR R., 1993. The Pieniny Klippen Belt in the Western Carpathians of northeastern Slovakia: structural evidence for transpression. *Tectonophysics*, 226: 471–483.

Late Jurassic to Early Miocene Tectonic Evolution and Palaeogeography of the Western Outer Carpathians

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The recent contribution aims to discuss tectonic processes, controlling the late Jurassic to early Miocene evolution of the Western Outer Carpathian (WOC) sedimentary basins and their source areas. In particular it attempts to compile in a coherent model constraints obtained from analysis of tectonic subsidence history of sedimentary basins (Poprawa et al. 2002), uplift history of source area based on analysis of deposition rate (Poprawa et al. 2006), as well as geochronology of basement of the sediment source area based on isotopic and chemical dating of crystalline pebbles (Ślączka 1998, Poprawa et al. 2004, 2005, Kusiak et al. 2004, Michalik et al. 2004, Malata et al. 2005). The model was confronted also with other data, like general facies evolution of the WOC basins (e.g. Książkiewicz 1963, Koszarski 1985), structural data (e.g. Świerczewska and Tokarski 1998,