THE PIENINY KLIPPEN BELT – STRUCTURE, EVOLUTION AND POSITION IN THE CARPATHIAN TECTONIC FRAMEWORK

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Abstract
The current tectonic research in the western and eastern Slovakian parts of the Pieniny Klippen Belt (PKB) has revealed some important differences between these two segments. The western PKB segment is characterized, in addition to the presence of ubiquitous Oravic units, by a broad incorporation of frontal elements of the Central Carpathian Fatric cover nappe system (Manín, Klape, Drietoma nappes). These are overstepped by still synorogenic, Gosau-type Senonian–Palaeogene basins. On the contrary, the northern and eastern PKB parts are dominated by the Oravic complexes representing an independent, originally intra-Penninic palaeogeographic element. Though strongly affected by Miocene along-strike wrench movements, several PKB sectors still preserve original fold-and-thrust structures that developed sequentially in a piggy-back manner during the Late Cretaceous to Early Eocene times. Timing of these thrust events is facilitated by the presence of syntectonic sediments in the footwalls of thrust sheets, as well as by overstep complexes sealing older structures. The syntectonic sediments typically include olistostromes and huge olistolites derived from the overriding nappe fronts. In such a way, three principal Oravic units have been recently defined in the eastern Slovakian PKB – the Šariš, Subpieniny and Pieniny nappes.

Introduction

Owing to the picturesque landscape and tectonic peculiarities, the Pieniny Klippen Belt (PKB) is considered as the most conspicuous regional zone of the Western Carpathians. It forms a narrow (merely several km), but lengthy (up to 600 km) stripe that separates the External Western Carpathians (EWC – Flysch Belt, Tertiary accretionary wedge) from the Central Western Carpathians (CWC – Cretaceous basement/cover nappe stack). The PKB involves predominantly Jurassic, Cretaceous and Palaeogene sediments with variable lithology and intricate internal structure. During almost two centuries of intense research, these have been differentiated into numerous lithostratigraphic and tectonic units of originally distant palaeogeographic provenances, hence witnessing excessive shortening and dispersal within this restricted zone. The purpose of this paper is to present briefly some new results and ideas developed during the recent investigations focussed on structural evolution of zones along the EWC/CWC boundary, i. e. the PKB and adjacent units. Our results partially, or even completely in some cases, contradict the previous views. In particular, new opinions concern the relations of the klippen to surrounding rocks, as well as the number and hierarchy of tectonic units incorporated into the PKB edifice (e. g. Plašienka – Jurewicz 2006, Froitzheim et al. 2008, Schlögl et al. 2008, Plašienka – Mikuš 2010). The inferred internal structure and relationships of the PKB to the neighbouring zones is illustrated by a series of cross-sections (fig. 1).

Structure of the Pieniny Klippen Belt

Several large-scale tectonic systems are partly or fully incorporated and/or closely juxtaposed to the PKB (fig. 1). From bottom to top (and generally from N to S), these are the Magura Nappe, Biele Karpaty Superunit, Oravic Superunit (PKB sensu stricto), elements of the CWC Fatric nappe system and overstepping complexes.

The large Magura Nappe of the EWC Flysch Belt (Senonian–Oligocene, predominantly flysch lithologies) is in a contact with PKB in north-western and eastern Slovakia. In the Middle Váh Valley, the PKB directly contacts the Bystrica Subunit, which otherwise occupies a central position in the Magura Belt. This contact is purely tectonic and relatively young, and has a character of oblique slip dextral/reverse fault zone. It indicates backthrusting, since the PKB units are overturned towards the S (fig. 1C). In the Orava region and further east in eastern Slovakia, the PKB neighbours the Oravská Magura-Krynica Unit, which is dominated by the Eocene Magura-type sandstones (fig. 1A, B). In eastern Slovakia, the outermost PKB Šariš Unit overrides the innermost elements of the Krynica Unit terminated by the Oligocene to Lower Miocene deposits (Oszczypko et al. 2010, Plašienka – Mikuš 2010).

The Biele Karpaty Superunit is the innermost element of the SW part of the EWC Flysch Belt where it is put next to and partly underlies the outer elements of the PKB. It is characterized by a special composition (rich carbonate material in clastic formations), restricted stratigraphic extent (Cretaceous–Lower Eocene; Švábenická et al. 1997, Potfaj 1993) and very low thermal and deformational reworking (Hrouda et al. 2009). It consists of several thrust sheets, the two higher being in a direct contact with the PKB (fig. 1E, F).

Oravic Superunit

The Oravic Superunit (known also as the "Pieninic" units or "Pienides" in older literature – e. g. Andrusov (1974) or PKB s. s. – Maheľ 1980) embraces the typical PKB units of their own, which are characterized by the peculiar "klippen tectonic style" (block-in-matrix struc-

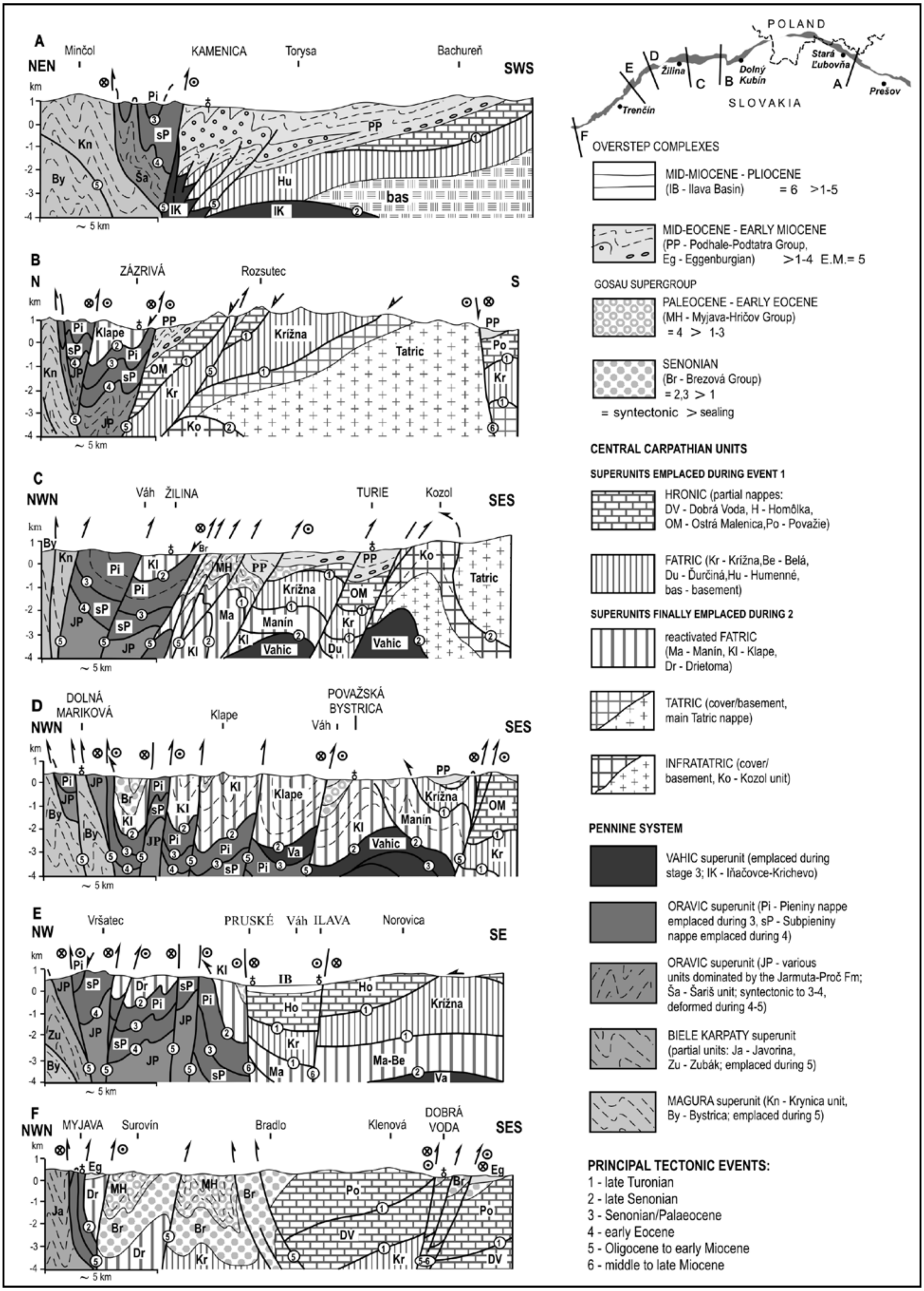

Fig. 1: Cross-sections across the PKB showing relationships of its principal units.

ture). The lowermost element of the eastern PKB s. s. is represented by the recently defined Šariš Unit (Plašienka – Mikuš 2010; fig. 1A), which was formerly considered to be a part of the "klippen mantle" (e. g. Stráník 1965). It consists of varied Upper Jurassic to Upper Cretaceous pelagic sediments followed by Maastrichtian–Lower Eocene, deep marine, pelagic (variegated shales) and clastic (turbidites, mass-flows) deposits. The latter are known as the Jarmuta and/or Proč Fm. and involve also chaotic olistostrome bodies (Milpoš Breccia) with olistolites dominantly derived from the overlying Subpieniny Nappe. These have been mostly considered as klippen, i. e. tectonic inliers until now. However, already Nemčok recognized their sedimentary character (Nemčok 1980, Nemčok et al. 1989). The overriding Czorsztyn-type units form a system of imbricated thrust sheets. Their disintegrated fronts pass into mass-flows inserted within and above the Jarmuta–Proč flysch, thus indicate close sedimentary and tectonic relationships between the Šariš and overlying units.

For the higher nappe sheet of the PKB, we come back to the old Uhlig's term Subpieniny Nappe (Uhlig 1907). This includes the most widespread Czorsztyn Succession, as well as the Pruské, Niedzica, Czertezik and similar "transitional" successions derived from the Czorsztyn Ridge and its slopes. Lithology and stratigraphy of these successions were described in detail in numerous papers (e. g. Birkenmajer 1977, 1986). On the other hand, we do not ascribe a tectonic independence to these local successions as Birkenmajer did (see also Książkiewicz 1977). The Subpieniny Nappe has a stable structural position, but it is strongly imbricated, or even disintegrated internally. The youngest sediments of the Czorsztyn-type successions are the Upper Senonian Jarmuta-type calcareous sandstones overlain by olistostrome breccias (Gregorianka Breccia – Nemčok et al. 1989). These breccias only contain material derived from the still higher Pieniny Nappe. The Subpieniny Unit is characterized either by imbricated thrust stacks and duplexes, or by a "mature" klippen style with small blocky klippen composed of massive Middle–Upper Jurassic limestones embedded within a soft matrix of Upper Cretaceous marls.

The highermost Oravic tectonic unit of the PKB – the Pieniny Nappe – includes several differing lithostratigraphic successions as well (Pieniny s. s., Kysuca-Branisko, Podbiel-Orava, Nižná). The Pieniny Nappe is strongly folded and imbricated, but generally continuous. It overlies the Subpieniny Unit, but in places directly the Šariš Unit. Usually it forms the southernmost zone of the eastern PKB. In the western PKB part, it is dominated by the basinal Kysuca Succession. The eastern part is ranged to a still more deep-basinal Pieniny Succession, which is usually detached at the base of Middle/Upper Jurassic radiolarites.

All the Oravic units are characterized by an independent palaeogeographic position around the Middle Penninic swell known as the Czorsztyn Ridge, which was a continental ribbon separated by oceanic domains from the Central Carpathian (Austroalpine) plate to the south and from the North European Platform to the north (South Penninic-Vahic and North Penninic-Rhenodanubian-Magura Oceans, respectively – e. g. Plašienka 2003). Unlike the pre-Senonian Austroalpine units, the Oravic Superunit involves more-or-less continuous Jurassic–Cretaceous stratigraphic successions reaching as late as the Early Eocene in the most external zones.

Fatric Superunit

The "non-Oravic" units of the CWC-Austroalpine provenance incorporated into the PKB are generally ranged to the Fatric Superunit (Krížna and related nappes – cf. fig. 1). These are widespread in the western PKB part, especially in its broadest Púchov sector, where they occur in a superposition over the Oravic units within the southeastern zone of the PKB designated as the "Periklippen Belt" by Maheľ (1980). Three large units compose the "non-Oravic" Periklippen zone. The Drietoma Unit, which comprises the Upper Triassic (Carpathian Keuper Fm.) – Cenomanian, chiefly basinal succession, predominates in the SW part of the PKB (Hók et al. 2009). It shows close structural links to the overlying CWC nappe systems – the Fatric Krížna Nappe and Hronic Nedzov Nappe, as well as to the Albian–Cenomanian synorogenic flysch with "exotic" conglomerates. The latter provide a link to the huge Klape Unit, which prevails in the Middle Váh Valley. This is composed of about a thousand metres thick mid-Cretaceous wildflysch complex (the Klape Flysch) with big olistolites of Jurassic carbonates (e. g. the spectacular Klape Klippe – Marschalko 1986). In the Považská Bystrica area, the belt of the Klape Unit is up to 15 km wide, composed of four to five juxtaposed subunits divided by antiformal strips of the underlying Kysuca Unit and/or synforms of the overstepping Gosau sediments (fig. 1D). These Klape subunits are considered to represent strike-slip duplexes, accumulation of which caused exceptional broadening of the PKB in the Púchov sector (Schlögl et al. 2008).

The SE-most component of the Periklippen Belt is the Manín Unit. Its Lower Jurassic–Cenomanian sequence (including the characteristic Urgon-type platform limestones) closely relates to the ridge-type successions of the Fatric Superunit (e. g. the Belá Unit in the Strážovské vrchy Mts – Maheľ 1978). However, many authors prefer the Tatric affiliation of the Manín Unit (e. g. Rakús – Hók 2005). The Manín Unit is dominated by the mid-Cretaceous hemipelagic and flysch formations, older stiff limestones build several large "klippen", which are in fact brachyanticlines (Manín and Butkov Hills). Contrary to earlier views, the Senonian sediments in the Klape and Manín Zone are supposed to represent a post-nappe, Gosau-type cover (fig. 1D; cf. Salaj 2006). The mid-Cretaceous flysch of the Manín Unit is from the SE overridden by the frontal elements of the typical Fatric Krížna Nappe.

The "non-Oravic" units participate to a lesser extent in the eastern PKB structure compared to the western one. The large, composite Haligovce Klippe in the Slovak Pieniny Mts is usually correlated with the Manín Unit. This is mainly based on distinct facies similarities (e. g. the Urgon-type limestones), the high structural position above the Oravic units, as well as on overstepping Palaeogene rocks analogous to the "Periklippen" Myjava-Hričov Group. The Haligovce Unit also contains Middle Triassic carbonates –

otherwise unusual feature for the PKB. Further east, a few km SW of the PKB proper, a structural elevation of the Humenné Mts occurs, which is composed of typical Fatric elements (Krížna Nappe). The Humenné Unit is strongly imbricated with SW-verging system of backthrusts, i. e. it occupies a position in the SW limb of the PKB transpressional structural fan (fig. 1A).

Overstep complexes

In western Slovakia, the southern boundary of the PKB against the CWC is followed by deformed Palaeocene–Lower Eocene sediments known as the "Periklippen Palaeogene" (Myjava-Hričov Group – fig. 1). In the westernmost part of the PKB and CWC (Malé Karpaty Mts), these build the upper part of the Gosau Supergroup (including the Senonian Brezová Group) in a situation analogous to the position of Gosau sediments in the Northern Calcareous Alps (NCA, e. g. Wagreich – Marschalko 1995). Gosau sediments in the NCA and Malé Karpaty Mts are interconnected through the "Giesshübl Syncline" drilled in the substratum of the Neogene Vienna Basin (e. g. Wessely 1992).

In general, the Gosau-type Brezová and Myjava-Hričov Groups are characterized by pelagic marls and calcareous flysch formations with a frequent shallow-water biogenic detritus and Maastrichtian–Palaeocene reef-derived olistolites. In the eastern PKB part, the Magura vs. PKB tectonic contact is sealed by the Middle Eocene–Oligocene sediments of the Údol (Ujak) Succession, which is composed of Middle–Upper Eocene variegated shales, Globigerina marls, menilite shales and Oligocene 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 Central Carpathian Palaeogene Basin (CCPB). However, the PKB and the CCPB are separated by a younger, steep oblique dextral backthrusts there (fig. 1A).

Tectonic evolution

Superposition of the PKB nappe units was strongly modified by post-Oligocene deformation, but it is still well recognizable in several places. The structural position, age range of included sedimentary successions and the inferred age and composition of coarse-grained synorogenic clastic deposits reveal that the stacking of the PKB units progressed from the mid-Cretaceous emplacement of the Fatric nappes followed by sequentional overthrusting of the Oravic units. The Pieniny Unit overrode the Subpieniny around the Cretaceous/Palaeogene boundary. Then the thrusting propagated northwards throughout the Palaeocene–Lower Eocene (Subpieniny + Pieniny over Šariš) and terminated by the local Lower Miocene thrusting of the Šariš Unit and the overlying nappe and overstepping complexes above the inner Magura elements (fig. 1). This compressional tectonic scenario was interrupted by the Middle/Late Eocene extension followed by Oligocene subsidence. Renewed compression/transpression and wrench faulting then occurred during the Lower Miocene. In spite of this complicated tectonic history, the data about the post-depositional thermal history indicate that the PKB sediments were never buried to considerable depths, and all the deformation occurred in the brittle field. For this reason it is assumed that shallow thrusting did not generate a significant burial and the PKB units must have always occupied a high structural position. This would indicate a prevailingly footwall-propagating, "piggy-back" mode of thin-skinned thrusting.

The Lower Miocene transpressional event generated the final form of the PKB that is restricted to a large-scale bivergent, positive "flower" structure indicated by the surface structural data, as well as by the seismic reflection profiles and deep drillings (Plašienka et al. 2008). The flower is usually centred by a generally vertical zone of the PKB, in which strike-slipping prevailed (fig. 1). The along-strike wrench movements led to the formation of the typical "klippen" tectonic style caused by pervasive brittle faulting that destructed earlier fold-and-thrust structures (Ratschbacher et al. 1993, Kováč – Hók 1996).

Summing up, the overall tectonic scenario for the PKB 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 processes during the Late Cretaceous and earliest Palaeogene, followed by Eocene extension and Oligocene–Lower Miocene dextral transpression responsible for the steepening and narrowing of the PKB that acquired its final structural style.

Conclusions

The new facts and ideas about the structure and evolution of the PKB can be delineated in the following points:

1. The Subpieniny (Czorsztyn) Unit is neither autochthonous, nor the lowermost element of the PKB structure – it is underlain by the newly defined Šariš Unit in eastern and by the Biele Karpaty Unit in western Slovakia.
2. The Šariš Unit includes pelagic Cretaceous sediments followed by coarsening-upward Maastrichtian–Lower Eocene synorogenic deep-marine clastics (Jarmuta/Proč Fm.), consequently the "Klippen Belt Palaeogene" does not represent the "klippen mantle", but constitutes a structurally independent unit.
3. The overthrust processes in the PKB Oravic units are registered by synorogenic tectono-sedimentary breccias in several units and stratigraphic levels, thus they enable stratigraphic dating of tectonic events.
4. The breccias often carry blocks of particularly the Czorsztyn-type Jurassic limestones – a significant fraction of "klippen" is in fact represented by olistolites.
5. In several sectors of the PKB, relics of early fold-thrust structures may be identified – the PKB originally corresponded to a broad, but thin imbricated fold-thrust sheet covering a considerable southern portion of the EWC accretionary wedge that developed during the Palaeogene.
6. The long-termed tectonic deformation processes were repeatedly accompanied by deposition of synorogenic and followed by overstepping formations that partly

seal older structures, but which were deformed later together with their substratum.

7. An important extensional event affected the PKB and adjacent zones during the Eocene, which was likely related to an extensional collapse of overthickened rear parts of the developing EWC accretionary wedge and followed by Oligocene subsidence.
8. The "klippen tectonic style" (block-in-matrix) resulted from the Lower Miocene transpressional deformation and disintegration of the original fold-thrust structures.

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