# Geology and Tectonics of the Vršatec Klippen Area (Pieniny Klippen Belt, Western Slovakia)

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The Pieniny Klippen Belt (PKB) represents a tectonic zone separating the External (Outer) Western Carpathians from the Central (Inner) Western Carpathians. It is a narrow, independent structural belt with extraordinarily complicated structure, which stretches from the vicinity of Vienna, through the Považie (Váh River valley) to the Orava region and extends via the Polish Pieniny Mts. to eastern Slovakia, Ukraine and Romania. Primary absence of pre-Mesosoic rocks, scanty representation of Triassic rocks, variable developments of Jurassic and Cretaceous successions and klippen-type (block-in-matrix) tectonic style are the principal characteristics of the Klippen Belt. Most of the klippen are tectonic by origin, though olistolites are present in places. According to the present views, the main phase of tectonisation and separation of the klippen took place after the Eocene–Oligocene and before the Sarmatian (Hók and Kováč 1996, Potfaj 1998). Our study concentrates on the structure and tectonic evolution of one of the most conspicuous parts of the PKB – the so-called Vršatské bradlá group of klippen in the Middle Považie region of western Slovakia. Taking as a whole, the Vršatec area represents the largest Czorsztyn-type klippe or a group of klippen in the Slovak part of the PKB.

The studied terrain is formed by two partially independent segments – the Vršatec-Javorník and Chmeľová regions. The southern, SW-NE trending, Vršatec-Javorník row of picturesque blocky klippen is composed of massive Jurassic – Lower Cretaceous limestones forming a steeply NW-dipping monoclinal slab with overturned stratigraphic sequence belonging to the Czorsztyn Unit. The sequence starts with the Upper Liassic – Aalenian dark hemipelagic marlstones (Krempachy Fm) followed by massive, light bioherm limestones (Vršatec Fm.). The latter were considered to be of Oxfordian age before (Mišík 1979). However, the recent study by Schlögl and Tomašových (in press) indicates their significantly older, most probably Lower Bajocian age. This age would make the structure of the Vršatec-Javorník klippen much simpler – only one overturned sequence is present, on contrary to two slices (one with normal, the other with overturned sequence) as proposed by Mišík (1979). Bioherm limestones are followed by crinoidal limestones (Smolegowa and Krupianka Fms), red nodular limestones (Czorsztyn Fm) and whitish to pink biodetrital limestones (Dursztyn Fm). From the SE side, this about 50–150 m thick slab of competent limestones is in contact with Upper Cretaceous red pelagic marlstones of the couches-rouges type (Púchov Fm). Both Lower Jurassic and Upper Cretaceous marlstones form the so-called "klippen mantle", i.e. a soft matrix in which the stiff klippen are embedded. The lithological contacts, though generally in stratigraphic sequence, are tectonically reactivated in most cases. To the SE, the Púchov marlstones are juxtaposed to various sediments of distinct units participating on the PKB structure (Orava and Drietoma Units – Schlögl et al. 2000).

The slab of competent Middle Jurassic – Lower Cretaceous limestones of the Vršatec-Javorník zone is truncated by numerous fractures and slickensides. The field study revealed the presence of oblique reverse faults and oblique dextral strike-slips, which are concentrated on the lithological boundary between the rigid klippen and the klippen mantle. These steeply dipping faults cut obliquely bedding and obviously control the lozenge shape of individual, variably large (metres to hectometres) blocks (klippen) into which the Vršatec-Javorník slab is divided. Unfortunately, due to weathering of fault surfaces in natural outcrops, only a limited number of faults suitable for kinematic and paleostress analyses were found and measured. Another group of spaced subvertical faults oriented at high angles to bedding may represent the transfer (tear) faults. In addition, marlstones of the Púchov Fm bear traces of an older deformation event recorded by planparallel solution cleavage that is slightly oblique to the bedding surfaces. Part of stylolites found in massive limestones might have recorded this event as well.

In the Chmeľová area, the Czorsztyn and/or a sort of "transitional" (akin to Niedzica-Pruské) succession crops out. It slightly differs from the above-described Czorsztyn succession by beds of allodapic crinoidal calciturbidites in the upper part of the Krempachy marl Fm, lack of the reef Vršatec limestones, much thinner Middle Jurassic sandy-crinoidal limestones, presence of radiolarite lenses (Czajakowa Fm) within the nodular limestones (Niedzica and Czorsztyn Fms) and by a newly discovered body of volcanic rocks. These occur in a core of a macroscopic syncline above the Dursztyn limestones and probably below the Púchov marls. The volcanic body is about 50 m wide and over 300 m long and consists of hyaloclastites of basanitic composition, which are partly mixed with surrounding sediments. Consequently, the volcanics are most probably of Early Cretaceous age and are a normal component of the stratigraphic succession as a submarine lava flow. It is one of the very scarce occurrences of Mesozoic volcanics within the PKB successions in Slovakia, but surely the largest one, for the first time discovered in this area (cf. Hovorka and Spišiak 1990, Mišík 1992).

This unit is internally tectonically more complicated, with alternating sectors of normal and reversed stratigraphic sequences. Unlike in the Vršatec-Javorník area, this region is dominated by macroscopic fold structures. Folding was enabled by a much thinner competent limestone layer (some 20–30 m only) sandwiched between incompetent strata. Folds are upright, slightly asymmetric, with SW-NE trending axes and with locally penetrative subvertical axial plane cleavage. The map view and presence of numerous slickensides reveal that folding was

followed by reverse and strike-slip faulting that finally shaped the klippen tectonic style of the area.

In the most external position in the Chmeľová region, a narrow strip of the Kysuca Unit was discerned. It involves deep-water pelagic Jurassic strata (predominantly marlstones and radiolarites), but the Lower Cretaceous sediments are of special type with allodapic biodetrital limestones (Horná Lysá Fm – Mišík et al. 1994). The position of the Kysuca Unit is not clear; it is likely in an original tectonic superposition above the Czorsztyn-related units. To the NW, the Kysuca Unit is juxtaposed to the Maastrichtian – Paleocene flysch sediments of the Biele Karpaty Unit of the Carpathian Flysch Belt. This contact is most probably followed by a large wrench fault that forms the northern boundary of the PKB.

The PKB was formed during multistage ductile-brittle and brittle tectonic evolution that occurred in several deformation stages producing variable fold and fault structures. Probably the oldest event was thrusting of the presently most external Kysuca Unit over the Czorsztyn and Niedzica-Pruské Units. Then macroscopic folding due to orthogonal layer-parallel shortening affected especially the Chmeľová region with well-bedded Niedzica-Pruské succession, while the thick competent Vršatec-Javorník slab was steepened and partly overturned to the SE. Folding occurred at comparatively greater depths (but still beyond intracrystalline ductile deformation mechanisms) with development of cleavage formed by pressure solution. This strong compressional stage was followed by transpression, which is recorded by several generations of striated, mostly steeply dipping faults. Numerous reverse and strike-slip faults truncated the stiff limestones sandwiched between incompetent strata and produced klippen of two distinct morphostructural types: 1. the Vršatec type formed by vertical strata obliquely cut by faults into variously large, lozenge-shaped blocks arranged in one straight row; 2. the Chmeľová type with a more random arrangement of variously shaped klippen, dependent on which parts of pre-existing macrofolds (cores, limbs) were separated into klippen that slightly moved with respect to each other afterwards. Finally, the klippen style was affected also by slope movements and some independent blocky klippen are obviously loose blocks transported downslope by landslides.

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# Tectonic Deformations in the Orava Basin Margins in the Western Carpathians, Based on the DEM Analysis and Geological Research

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The tectonic structure is the main issue of the Orava Basin geology but the Quaternary deposits make difficult presentation of the depression architecture. For the recognition of the linear morphological features which could depict the basement dislocations of the Orava Basin the digital elevation model (DEM) was made. Morpholineaments were drawn along straight segments of rivers and morphological edges. It allows distinguishing two groups of morpholineament – directions: the morpholineaments which form the margins of the Orava Basin and the morpholineaments which are perpendicular to the first group of lineaments and disturb them. Morpholineaments in the contour map, shaded relief map, and the DEM refer to fault lines buried beneath deposit