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A contribution to the tectonics of the Periklippen zone near Zázrivá (Western Carpathians)

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Abstract. Field structural evidences of southvergent reverse faulting (i.e. backthrusting in relation to the polarity of the orogen) were observed and analysed within the Periklippen zone of the Orava segment of the Pieniny Klippen Belt near Zázrivá village. The studied area is situated at the northern rim of the Central Western Carpathians affected by transpressional tectonic regime operating in the Pieniny Klippen Belt zone dividing the Central and Outer Western Carpathians. The sediments of the Central Carpathian Paleogene Basin rimming the Pieniny Klippen Belt from the south are tectonically deformed. Miocene (post-Oligocene) folding and backthrusting is recorded in meso-scale structures observed in the outcrops, as well as it results from the analysis of bedding attitudes of the Paleogene sediments. The backthrust tectonic style of the area is evident from the map-scale structures and deep reflection seismic profile, too. A tectonic slice of the Paleogene sediments, tectonically incorporated along south-vergent large-scale thrusts to the Mesoszoic nappe units is interpreted in the geological map. Structural interpretation of 2T seismic profile shows distinctive south-vergent (north dipping) reflectors as well. The reflectors have been interpreted as crustal-scale backthrusts.

Key words: Pieniny Klippen Belt, backthrusting, transpression, folds, paleostress, Neoalpine tectonics

Introduction

Alpine-type fold and thrust belts usually show distinctive polarity of tectonic transport within the orogen. Plate convergence results in shortening, usually realized by orogenic front vergent folding and/or thrusting. The evident vergence of tectonic movement towards the orogenic front can be explained by an active propagation of hinterland towards the stable foreland. Meso-Neoalpine tectonic evolution of the Western Carpathians was controlled by long lasting (Upper Cretaceous – recent) squeezing between the North European Platform and promoted the Apulia-Adria microcontinent pushed by the Africa lithospheric plate to the north. It led to the strong dominance of the north-verging tectonic structures within the Central, as well as Outer Western Carpathians (Flysch Belt) where asymmetric accretionary orogenic wedge was created due to consumption of a quasi-oceanic Peninic (Vahic) crustal slab. Nevertheless, south-verging, high-angle thrusts have been already described in the eastern part of the Pieniny Klippen Belt (Nemčok & Rudinec, 1990; Plašienka et al., 1998). The south vergent reverse faulting in studied area has been first described by Matějka (1931) in the Medzirozsutce saddle and later accepted in tectonic interpretation of the area (Haško & Polák, 1978).

During the last years, we have had an opportunity to study systematically the zone of tectonic junction of the Central and Outer Western Carpathians in the eastern part of the Malá Fatra Mts. and the Kysucké vrchy Mts (Fig. 1). From detailed geological mapping and structural analysis resulted that the geological structure in tight contact with the Pieniny Klippen Belt zone is also strongly affected by backthrusting. The studied area is extended south of the Pieniny Klippen Belt around Zázrivá village. The wider area is occupied by four tectonic units listed from the north to the south (Fig. 2): a) Pieniny Klippen Belt; b) Central Carpathian Paleogene Basin, c) Fatric and Hronic units, d) Tatric unit. The background knowledge concerning the geology and tectonics of the area has come from the geological maps and investigations of Andrusov & Kuthan (1943), Haško & Polák (1978), Potfaj (1974, 1979, 1998), Samuel & Haško (1978), Rakús (1984), Aubrecht et al. (2004), Marko et al. (2004).

The presence of backthrusting within the studied area has been already suggested by Haško & Polák (1978) according the map scale structures arrangement. We submit herein structural-tectonic evidences and geodynamical interpretation of south vergent reverse faulting in the Periklippen zone near Zázrivá village.

Geological settings

Studied area occupies the junction zone of Central and Outer Western Carpathians. The geological structure of the Central Western Carpathians is created by several superposed Meso-Alpine Tectonic Units (e.g. Tatric, Fatric and Hronic Units). Neo-Alpine structure of the Outer Western Carpathians is represented by the Magura nappe, the northernmost unit within the tectonic profile (Fig. 2). Overall tectonic style of the studied area is con-

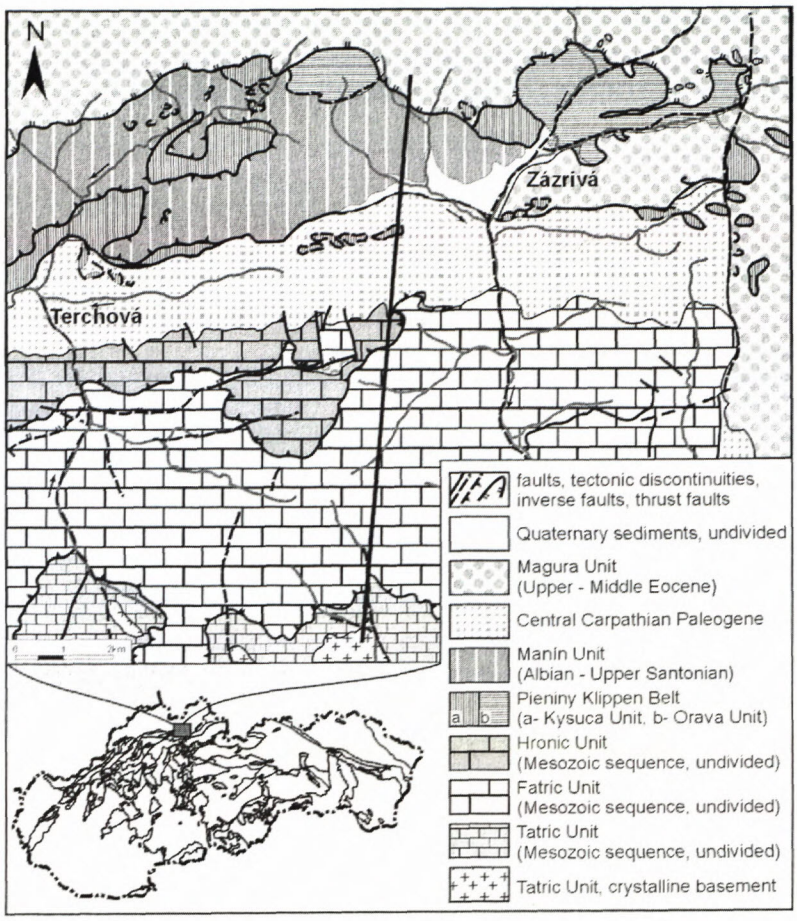

Fig. 1: Tectonic sketch of the Zázrivka River valley according to Haško & Polák (1978) with the line of the tectonic cross-section, slightly modified.

trolled by paleodynamics of the Pieniny Klippen Belt, zone of extreme shortening and shearing, accommodating convergence and translation of two stacking principal Neo-Alpine systems of the Western Carpathians – the Outer Carpathian accretionary wedge and the Central Western Carpathian orogenic backstop.

The Tatric superunit

The Variscan basement of the Tatric superunit is formed by biotitic and mica granites with authometamorphosed granodiorites, and biotitic and quartzitic diorites to granodiorites (Haško & Polák, 1978). The Tatric basement is covered by the sedimentary sequence that starts with the Scythian detrital sediments, the Middle Triassic carbonates and the Upper Triassic shales and quartzites of the Carpathian Keuper Formation. The Jurassic sequence is represented mostly by the Lias facies and "Fleckenmergel" facies. The Dogger and Malm sediments are formed predominantly by radiolarian limestones. The marly cherty limestones with intercalations of shales are typical formation of the Tithonian-Neocomian age, overlain by Aptian marly limestones, Albian synorogenic flysch sediments and Cenomanian silicic clastic sediments.

The Fatric superunit

The Fatric superunit (Krížna nappe) represents the lowest nappe system, which overthrusts the Tatric superunit. Stratigraphic ranging is from the Anisian to the Albian. The lowermost member of the Krížna nappe are the Anisian Gutenstein limestones. The Triassic sequence is predominantly carbonatic (limestones and dolomite). This is disconnected by the Lunz sandstones and claystones during the Lower Carnian and by quartzitic sandstones, claystones and dolomites of the Carpathian Keuper Formation. The Jurassic to Lower Cretaceous sequence of the Krížna nappe is represented by the deep-water Zliechov succession dominated by hemipelagic marly limestones and radiolarites, terminated by the Mid-Cretaceous flysch.

The Hronic superunit

The Hronic superunit (Choč nappe) represents the highest nappe system, which overthrusts the Krížna nappe. It forms of two separate tectonic duplexes: a) the Veľký Rozsutec duplex and b) the Malý Rozsutec duplex. The Choč nappe mostly consists of carbonate platform sediments ranging from the Anisian to Norian. The dominant sediments are dolomites that form the main mass of the Choč nappe. The rock sequence starts with the Gutenstein limestones and finish with the Hauptdolomite in the Norian. The carbonatic sequence is intercalated by the Lunz event, represented by clastic sedimentation of sandstones and sandy claystones.

The Central Carpathian Paleogene Basin

The sediments of the Central Carpathian Paleogene Basin are extended on the northern slopes of Malá Fatra Mts. They are dissected by the Pieniny Klippen Belt from north and by Párnica sigmoid structure from east. Its stratigraphic range is from the Upper Paleocene to the Upper Eocene. The sedimentary succession was also considered to the Žilina-Hričovské Podhradie Paleogene Basin (Haško & Polák, 1978; Samuel & Haško, 1978). The Eocene shallow to deep-marine sediments transgressive overlying the Mesozoic rocks of the Malá Fatra Mts. are preserved in surroundings of Zázrivá village. The sedimentary succession is represented by sediments of the Borové, Huty, Zuberec Formations and the Pucov Member (sensu Gross et al., 1984). The Borové Formation consists of the carbonate conglomerates, breccias, sandstones and organodetrical limestones. It represents shallow marine transgressive finning and deepening upward sedimentary succession. The overlying Huty Formation consists of the massive mudstones alternating with sandstone and siltstone intercalations deposited in mud-rich submarine fan. Sandstones are predominantly thin-bedded with the Bouma's Tc-d intervals (Bouma, 1962), coarse-grained and thick-bedded sandstones with basal Bouma's interval are uncommon. In the lowermost part of

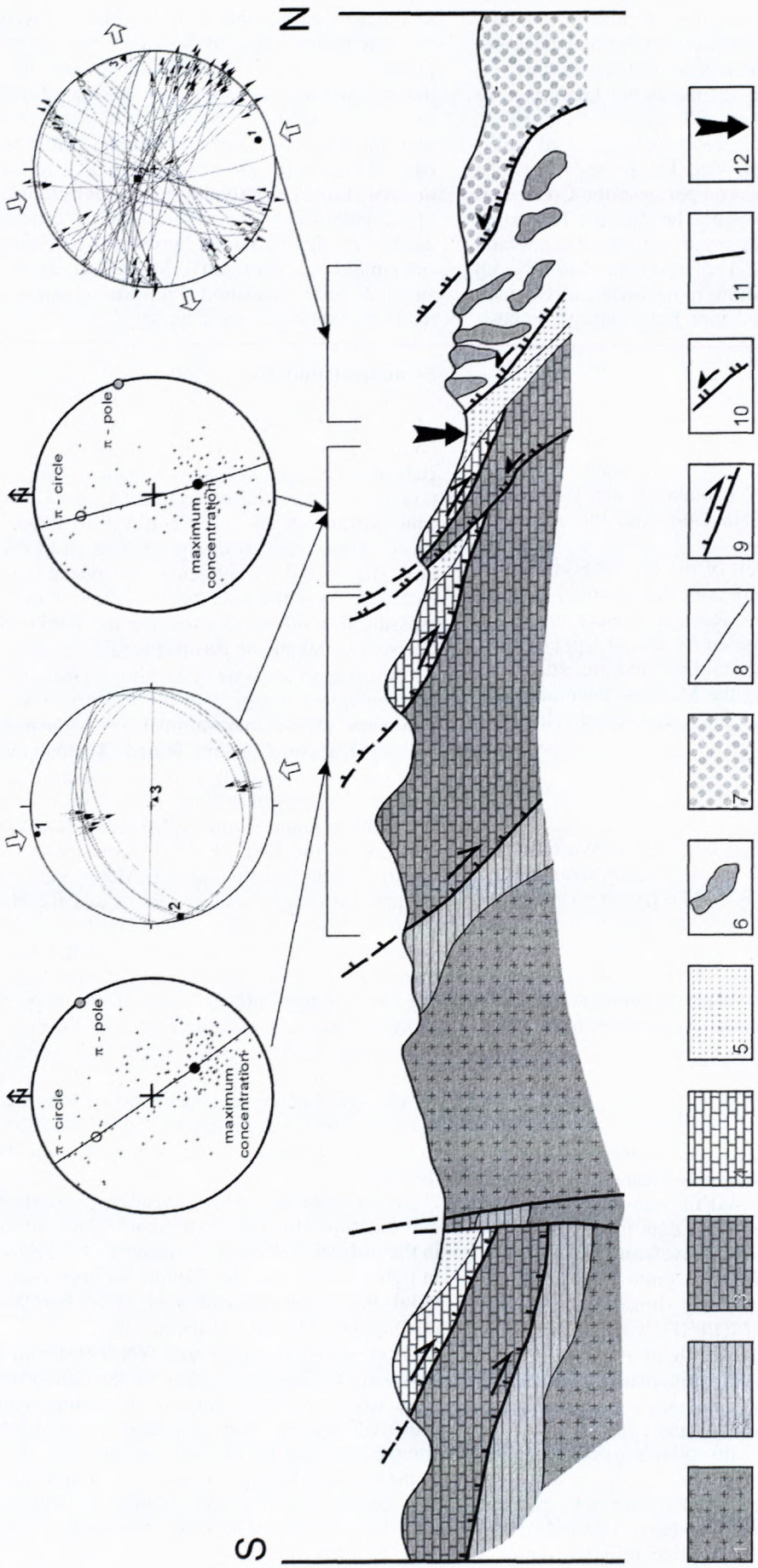

Fig. 2: Idealised tectonic cross-section of the Central and Outer Western Carpathian junction area along Zázrivka River valley (according to Haško & Polák 1978, addapted). 1) The crystalline of the Tatric supernit; 2) the Mesozoic cover of the Tatric supernit; 3) The Fatric supernit (Krížna nappe); 4) The Hronic supernit (Choč nappe); 5) The Central Carpathian Paleogene Basin sediments; 6) The Pieniny Klippen Belt; 7) The Magura supernit; 8) Lithological boundaries; 9) Meso-Alpine thrust, 10) Neo-Alpine thrust, 11) fault; 12) Localization of the outcrop Zázrivá/Terchová road crossing.

the Huty Formation, deposits of the Pucov Member are preserved. The Member composes of unsorted boulder conglomerates, sometimes with sandstone intercalations. The red colour of conglomerates is changing to grey one in upward direction. These sediments are interpreted as submarine canyon or channel fill (Gross et al., 1982), however, they have probably deposited in incised valley and fan-delta environments. The Pucov body cuts the Borové Formation and in central part also the Cretaceous Formation of the Krížna nappe. The Zuberec Formation consists of mudstones alternating with sandstones and locally with conglomerates. The sandstones are thin- up to thick-bedded and they show more complete Bouma's intervals. The sandstone/mudstone ratios depend on position in a submarine fan.

The Pieniny Klippen Belt

The Pieniny Klippen Belt within the studied area is formed by the Hettangian to Lower Maastrichtian Kysuca Unit, the Lotharingian to Neocomian Orava Unit, Aalenian to Neocomian Czertezik Unit, and the Albian to Lower Santonian Manín Unit.

The Pieniny Klippen Belt of the Kysucké vrchy displays a complex tectonic structure that resulted from its special geotectonic position. Rock sequences of the Pieniny Klippen Belt are affected by strong Upper Cretaceous to Lower Paleocene folding and thrusting and Miocene wrenching. During the Miocene tectonic activity, mostly brittle fault structures developed (Haško & Polák, 1978).

The Magura nappe

The Magura nappe belongs to the Outer Western Carpathians and is represented by the Eocene sediments of the Bystrica and Krynica Units. The Krynica Unit is extended in surroundings of Zázrivá village, both, north from Pieniny Klippen Belt and in narrrow belt tectonically incorporated between two branches of the Pieniny Klippen Belt. This unit is formed by alternated glauconitic sandstones a grey claystones, occasionally are developed red claystones.

Methods

The methodology applied during the research included detailed geological mapping (scale 1:10 000) and structural investigation focused on mesoscale fault and fold analysis. The measured fault data have been processed by analytical paleostress inversion method (Angelier 1989, 1994), using software application Tectonics FP (by F. Reiter & P. Acs, Univ. Innsbruck, Austria) and software package TENSOR (Delvaux, 1993, Delvaux and Sperner, 2003). The crucial step in the field structural research of faults was kinematical analysis of fault slips, based upon the evaluation of asymmetric structures of slickenside surfaces and evaluation of outcrop-scale structures genetically related to the fault dynamics.

Analysis of folds orientation in the Central Carpathian Paleogene Basin sediments has been realized using mesoscale fold data as well as bedding attitudes of measured during geological mapping. The paleostress field and backthrust tectonic style have been determined using the orientation data of bedding, fold axes and axial planes. The principal deformational axes have relation to the fold geometry. A strain axis is parallel with the direction of the maximum elongation, C strain axis is parallel with the direction of the shortening, and B strain axis is parallel with direction of fold axis (axis of rotation). Geometry of folds exactly defines relations to the orientation of the paleostress axes. Fold axes are generally perpendicular to the maximum principal paleostress axis σ_1 (maximum compression). Macrofold axes were constructed from measured fold limbs using the π pole method (construction of β axes).

Structural analysis

The field investigation was focused on structural records of deformation events south of the Pieniny Klippen Belt along the Zázrivka river valley. Meso-scale structural records were observed in the Upper Eocene – Oligocene sediments of the Central Carpathian Paleogene Basin. Attitudes of bedding, orientation of fold axes and fault slip data were collected. All available outcrops are localised along the trace of the structural/tectonic profile crossing in north-south direction the Periklippen Central Carpathian Paleogene Basin (Fig. 2).

Orientation analysis of bedding planes measured during geological mapping in the Paleogene and Mesozoic sediments shows that sedimentary sequences near the Pieniny Klippen Belt are folded. Tectonograms display arrangement of bedding poles, typical for tautozonal set of planes – limbs of tectonic folds. Constructed fold axes are subhorizontal with WSW-ENE azimuths, gently plunging to the ENE (Fig. 2). Axial planes of folds are mostly steeply north dipping. Many axial planes have steeper and shorter southern limbs and flatter and longer northern limbs. Except constructed macrofolds, there were observed and measured meso-scale folds in the sediments of the Central Carpathian Paleogene Basin (Fig. 3). We studied the Paleogene sediments exposed along a short N-S defilé across the Huty and Zuberec formation. According to the presence of the well developped Bouma´s intervals (Bouma, 1962), the north dipping flysch sedimentary sequences are in a normal position. Sandstone beds are folded, fold axes have ENE-WSW up to E-W direction and axial planes are dominantly north dipping.

Meso-scale slickenside lineations were studied in several outcrops along the structural/tectonic profile (Fig. 2) in the bedrock Paleogene sequences of the Zázrivka River in tight contact with the Pieniny Klippen Belt, and in the basal Paleogene sequences (Borové Formation) transgreding over Mesoalpine nappe units.

A conjugate population of WNW-ESE and NNE-SSW strike-slip faults was described in the outcrops of the Zázrivka River, in the vicinity of the Pieniny Klippen Belt. This fault system was activated under the NNW-SSE compression and ENE-WSW tension (Fig. 2). Southerly, in the basal Paleogene sequences (Čremoš hill), a dominant population of NNW dipping reverse slickensides, activated under NNW-SSE compression was observed (Fig. 2).

Fig. 3: Defilé across the Zuberec flysch formation of the Central Carpathian Paleogene Basin sediments (Locality Zázrivá/Terchová road crossing). 1) graded sandstone beds, occasionally with fine-graded conglomerates on their bases; 2) claystones, 3) recent debris; 4) interpreted reverse faults, 5) dip direction and dip of bedding , 6) azimuth and plunge of fold axis.

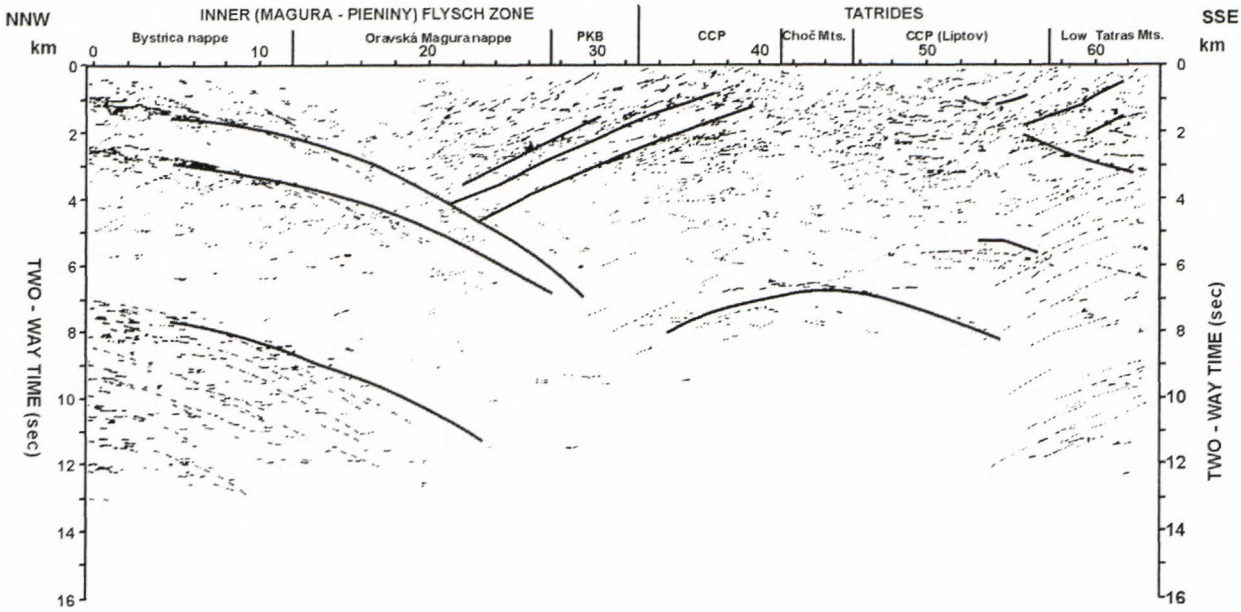

Fig. 4: Deep reflection seismic profile 2T (Tomek et al., 1987) with highlighted dominant reflectors interpreted as crustal-scale backthrusts.

Tectonic interpretation

Structural research realized along the structural/tectonic profile south of Pieniny Klippen Belt in the Zázrivá valley shows that the sediments of the Central Carpathian Paleogene Basin geodynamically representing a post-nappe unit are fairly strongly affected by tectonic faulting and folding. Both, faults and folds could have been generated during the same tectonic event, under NNW-SSE oriented maximum principal stress axis σ_1.

Processing of data by methods of structural analysis allowed to determine character and tectonic regimes operating during the deformational events. It follows, from analysis of fault-slip data; the change of the tectonic regime from the north to the south has occurred. The dominant strike-slip transpressional tectonic regime operated near the Pieniny Klippen Belt. Towards the south, the transpressional tectonic regime gradually changed up to the pure compressional tectonic regime producing reverse faulting (Fig. 2). The most distinctive and numerous population of meso-scale faults represents south vergent reverse faults. The most spectacular locality which has rendered the evident proof of southern vergency (top to the south) of these faults is the road cut just at the road crossing (Zázrivá/Terchová) at the southern periphery of Zázrivá village (Fig. 3). The outcrop-scale faults alone and their kinematics are interpreted there according to the presence and the geometry of fault-related folds. These folds even a drag fold in the right side of the outcrop as well as constructed folds from bedding attitudes display asymmetry generally indicating southern vergency (especially in the case of macrofolds (Fig. 2). We interpret these folds as related to the south vergent faulting. Tight genetical relation of faults and folds come also from the fact, that they both could be generated under the same maximum principal stress axis orientation, that means during the same tectonic event. We suppose, that faulting and folding observed south of the Pieniny Klippen Belt are genetically related to large-scale backthrusting (south vergent thrusting). It resulted from transpressional tectonic regime operating between the Outer and Central Western Carpathians.

Except the meso-scale structures, there are map-scale, even crustal-scale evidences of backthrusting within the wider area. An interpretation of Central Carpathian Paleogene Basin sediments occurence as the narrow belt tectonically incorporated as tectonic slice between the Mesozoic nappe units (see structural/tectonic profile) fits well with above suggested backthrust tectonic style.

Large-scale picture of the backthrust tectonic style south of the Pieniny Klippen Belt emerges from the deep reflection 2T seismic profile (Tomek et al., 1987; Tomek, 1993). There are recorded very distinctive crustal-scale north-dipping reflectors (Fig. 4), which as we believe represents southern branch of the post-Paleogene positive flower structure developed due to the shearing in between the Outer and the Central Western Carpathians.

Discussion and conclusions

Poles to bedding of both the Paleogene and Mesozoic sediments have a very similar array, so the style of folding and orientation of folds seems to be the analogous. However, the question is whether all folds observed in the Mesozoic sequences are genetically related to the above-described Miocene backthrusting. Another important question is the distance to which the backthrusting (generated by transpressional shearing along the Pieniny Klippen Belt) affects the tectonic structure of Central Western Carpathians. The answer to this question would need further research focussed to detailed study of deformation events along the structural/tectonic profile south of Zázrivá village.

The observed folds and folds constructed from attitudes of bedding planes are regarded to be a product of compressional tectonics. The outcrop Zázrivá/Terchová

road cross renders also crucial evidences of south vergent reverse faulting in the Central Carpathian Paleogene rocks. Nevertheless, folds in sandstone beds observed in the left part of exposure are most probably product of a submarine slump event that should have preceded the tectonic backthrusting.

In summary of our investigation we conclude that distinctive map and the outcrop-scale structural record of compressional tectonics have been observed south of the Pieniny Klippen Belt zone in a broader vicinity of Zázrivá village. This deformation structures are genetically related to the large-scale backthrusting (i.e. south vergent thrusting) represented by reverse faults and asymmetric south vergent folds.

The backthrusting was connected with the strike-slip tectonic activity along the Pieniny Klippen Belt due to the sinistral transpressional regime operating in between the Central and Outer Western Carpathians from the Karpatian up to the Middle Badenian (Marko et al., 1995, Kováč & Hók, 1996). This process led to the development of a positive flower structure, which is visible in the deep reflection seismic profiles (Tomek et al., 1987; Tomek, 1993).

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