Mineralia Slovaca, Web ISSN 1338-3523, ISSN 0369-2086
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Post-early Eocene backthrusting in the northeastern Strážovské vrchy Mts. (Western Carpathians)

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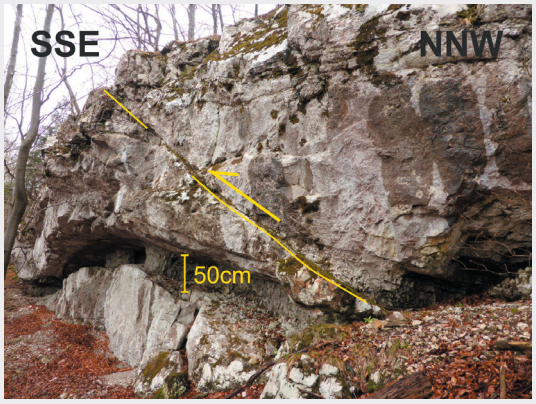
Abstract: The Strážovské vrchy Mts. represent a complicated elevated horst in the northwestern part of the Western Carpathians. Backthrusts were found in the Fatric and Hronic Mesozoic cover nappes and overlying (post-nappe) Paleogene Myjava-Hričov Group in the north-eastern portion of the Strážovské vrchy Mts. Observed brittle structures are represented mostly by the north to north-west dipping slickensides with signs of tectonic transport of the hangingwall blocks to the south or south-east, thus opposite to the regional tectonic transport direction known in the Western Carpathian thrust belt. Presence of the early Eocene rocks sandwiched between the Mesozoic formations in the backthrusts allows to consider them to be post-early Eocene. Such structural position precludes that aforementioned retro-vergent thrusts are related to the Cretaceous emplacement of the Paleo-Alpine cover nappes. Observed south- or southeast-vergent structures are related to younger Neo-Alpine, probably Oligocene-early Miocene backthrusting.

Key words: thin-skinned tectonics, backthrust, Hronicum, Fatricum, Myjava-Hričov Group

Graphical abstract



Highlights

- Geological mapping and structural investigation confirm Fatricum, Hronicum and Myjava-Hričov Group deformation by south- to southeast-vergent backthrusts in the northeastern part of the Strážovské vrchy Mts.;
- Age of the backthrusts is post-early Eocene, since the Ypresian – early Lutetian Súľov Conglomerates are sandwiched between Hronic duplexes.

Introduction

Thrust belts apart of thrust faults with tectonic transport to the foreland (forethrusts) contain also thrusts and reverse faults on which the tectonic transport direction is opposite to the regional transport direction (Butler, 1987; Xu et al., 2015). Backthrusts may occur in various tectonic settings within the thrust belts and accretionary wedges.

The Western Carpathians are generally considered as north- (or northwest-)vergent thrust belt (Andrusov, 1958; Andrusov et al., 1973; Plašienka et al., 1997; Hók et al., 2014; Plašienka, 2018). However, backthrusting was already observed in various regions of Western Carpathians south of the Pieniny Klippen Belt between the Malé Karpaty Mts. and Malá Fatra Mts. (Fig. 1 and references therein). While the backthrusts in the Malé Karpaty Mts., Považský Inovec Mts. and Malá Fatra Mts. are considered as clearly proven, the occurrence of backthrusting in the Strážovské vrchy Mts. was briefly mentioned only by Maheľ (1985a, p. 157; and 1985b, 1986, p. 366) and Salaj (2001), however without further structural evidence. Earlier research considered these structures as anticlines of the Fatric nappe cropping from below the Hronicum (Hanáček, 1976). This was followed in all later maps (Maheľ et al., 1982; Bezák et al., 2004; Elečko et al., 2008). Since the "anticlines" were never properly re-investigated the correct interpretation of these structures remained unclear.

The studied area in the north-eastern part of the Strážovské vrchy Mts. (Figs. 1 and 2a) near the Fačkov village is built of the Fatric and Hronic sequences, which are transgressively overlain by the Paleogene rocks of the Myjava-Hričov Group (sensu Buček in Mello et al., 2011) formerly also known as the Súľov Paleogene (e.g. Salaj, 2001).

During the geological mapping in the area of Fačkov and Čičmany villages, the attention was paid to the occurrences of the Early Cretaceous marly limestones of

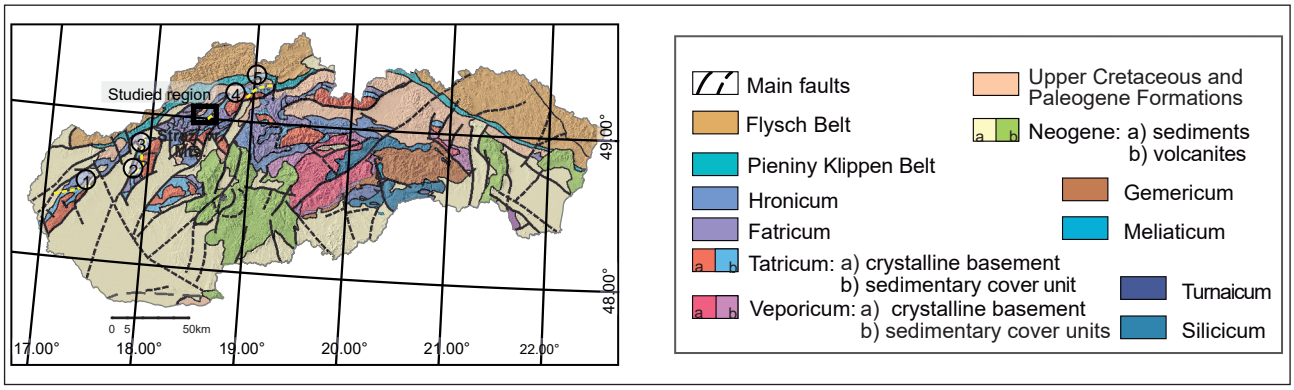


Fig. 1. Tectonic map (according to Biely et al., 1996) with marked backthrusting and location of studied region visualized in Fig. 2a. StV – Strážovské vrchy Mts. 1 – Northern Malé Karpaty Mts. (Maheľ, 1987; Marko et al., 1990, 1991); 2 – Central part of the Považský Inovec Mts. (Pešková, 2011; Pelech et al., 2018), 3 – Northern part of the Považský Inovec Mts. (Ivanička et al., 2007; Pelech, 2015); 4: Krivánska Malá Fatra Mts. (Matějka, 1932; Polák, 1975; Sentpetery, 2011).

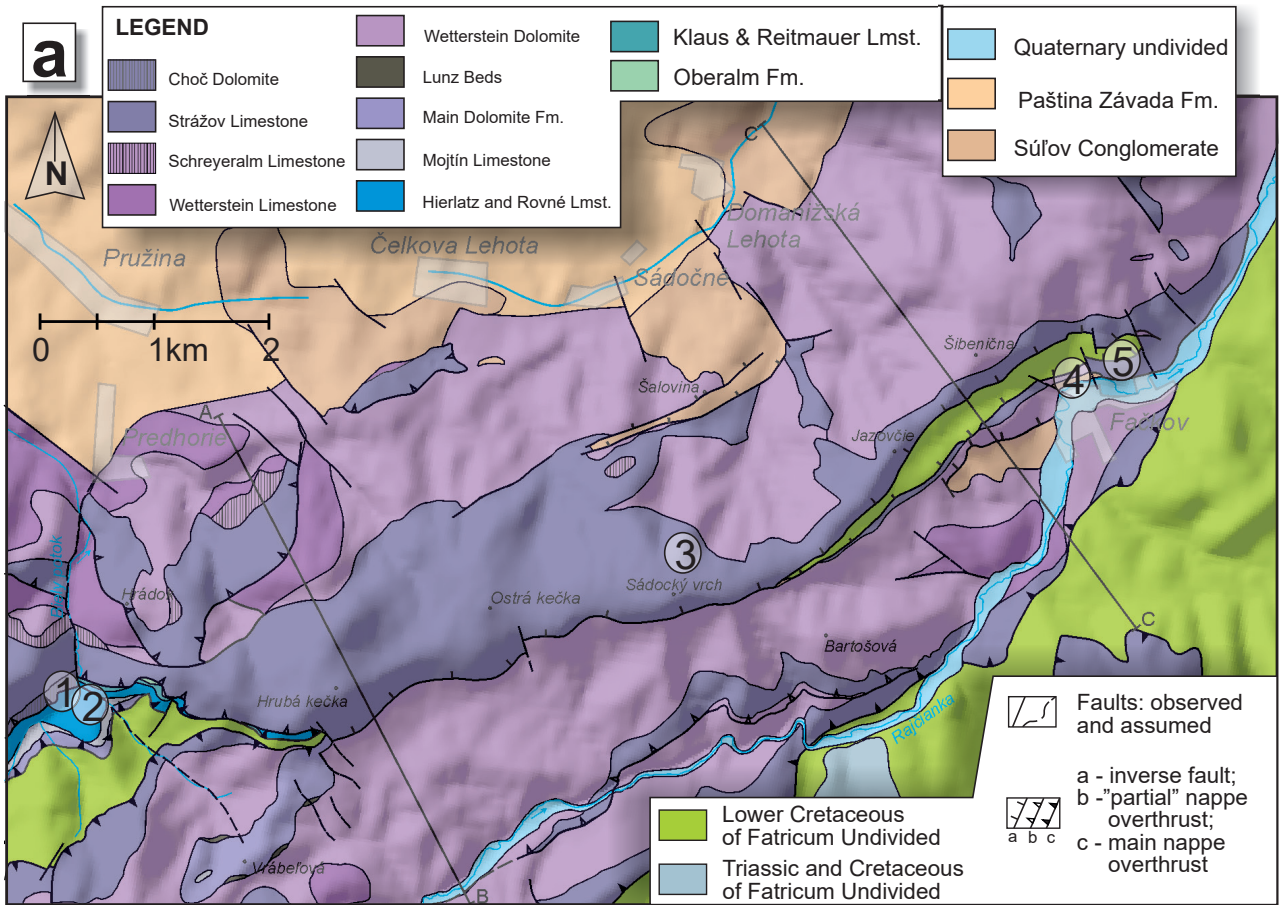


Fig. 2a. Geological map of investigated area of the Strážovské vrchy Mts. between Fačkov and Pružina localities (according to own original data and map of Mello et al., 2005). Circles with numbers represent studied sites. For location details see Tab. 1.

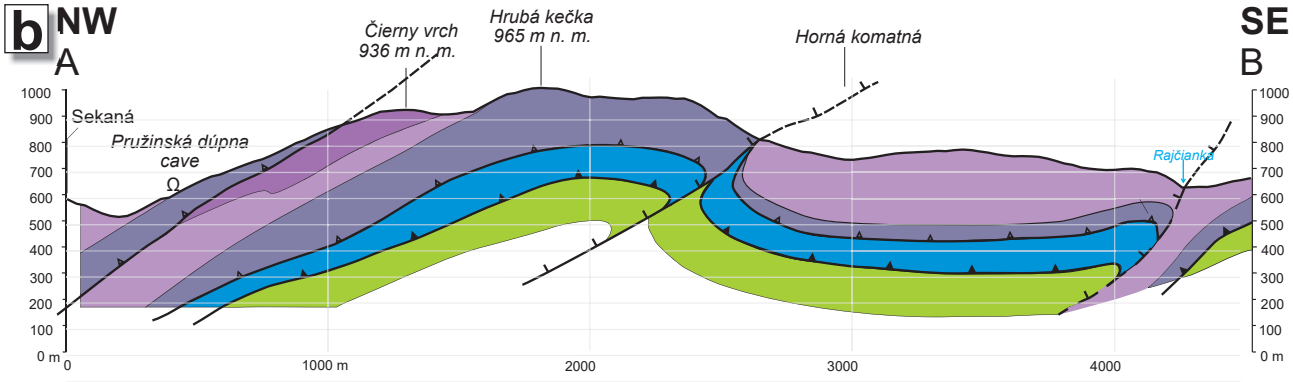


Fig. 2b. Geological cross-section A-B passing east of the Predhorie village.

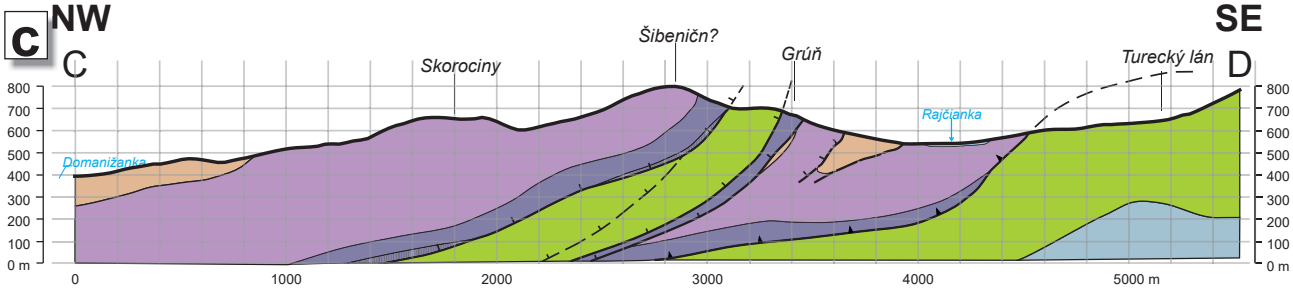


Fig. 2c. Geological cross-section C-D located west of the Fačkov village.

the Mraznica Formation located between the Triassic rocks, mostly the Strážov Limestone and Wetterstein Dolomite. The aforementioned rocks represent parts of two contrasting sequences of different origin and composition. While the prevailing Triassic complexes are clearly part of the Hronic nappe system, the Early Cretaceous rocks are usually assigned to the underlying (tectonically lower) Fatric nappe. Described structure have been formerly interpreted as tectonic windows or anticlines of the Fatricum cropping out from below the Hronicum (Hanáček, 1976; Maheľ et al., 1982).

The Hronicum is Paleo-Alpine (Eo-Alpine) cover nappe system composed of several thrust sheets with different lithological content (Kováč & Havrila, 1998; Havrila, 2011). The basal part of the Hronic sequence in the investigated territory (Fig. 3) is formed by Middle Anisian grey medium to thick bedded Strážov Limestone, with lenses of dolomite. The term Strážov Limestone was introduced by Havrila (in Mello et al., 2011) and can be correlated with the Annaberg Limestone in the Northern Calcareous Alps (e.g. Lein et al., 2012). Limestone sometime contains grey chert nodules and can be usually identified due to characteristic bituminous smell in the fresh surface. Parts with more abundant echinoderm detritus are analogous to the Gader Limestone Member. The Strážov Limestone locally gradually passes into pink or red, often nodular Schreyeralm Limestone. Thick overlying dolomitic sequence is composed of the Upper Anisian – Lower Carnian pale grey to white, mostly very thick bedded, brecciated Wetterstein Dolomite with lenses of white Wetterstein Limestone. Locally occurrences of the Middle Carnian grey-green sandstones and claystones designated as the Lunz Beds enable easy identification of the overlying grey Main Dolomite. The Carnian-Norian grey thick bedded Main Dolomite often with laminated stromatolites is overlain by grey organodetritic Mojtín Limestone of Rhaetian age. The overlying Jurassic to Early Cretaceous sequence is classically referred to as the Rohatá skala Group. The basal part is composed of locally preserved grey organodetritic, mostly crinoidal limestones of the Rovné Formation (defined by Havrila in Mello et al., 2011), which gradually passes into the Hierlatz Limestone. Grey Hierlatz crinoidal limestones represent thickest and most competent post-Triassic member, often well exposed and forming steep cliffs. Younger Middle and Late Jurassic formations are mostly represented by red nodular limestones of Klaus Formation and grey and pink crinoidal and cherty Reitmauer and Steinmühl limestones. Overlying Early Cretaceous clayey limestones of the Oberalm Formation represents the youngest lithostratigraphic unit of the Hronicum in the investigated region (Fig. 3).

The Hronicum is usually overlying the youngest Fatric formations, mostly represented by the widespread Early Cretaceous grey thin bedded marly limestones of the Mraznica Formation and locally preserved Albian “flysch” of the Poruba Formation (Fig. 3).

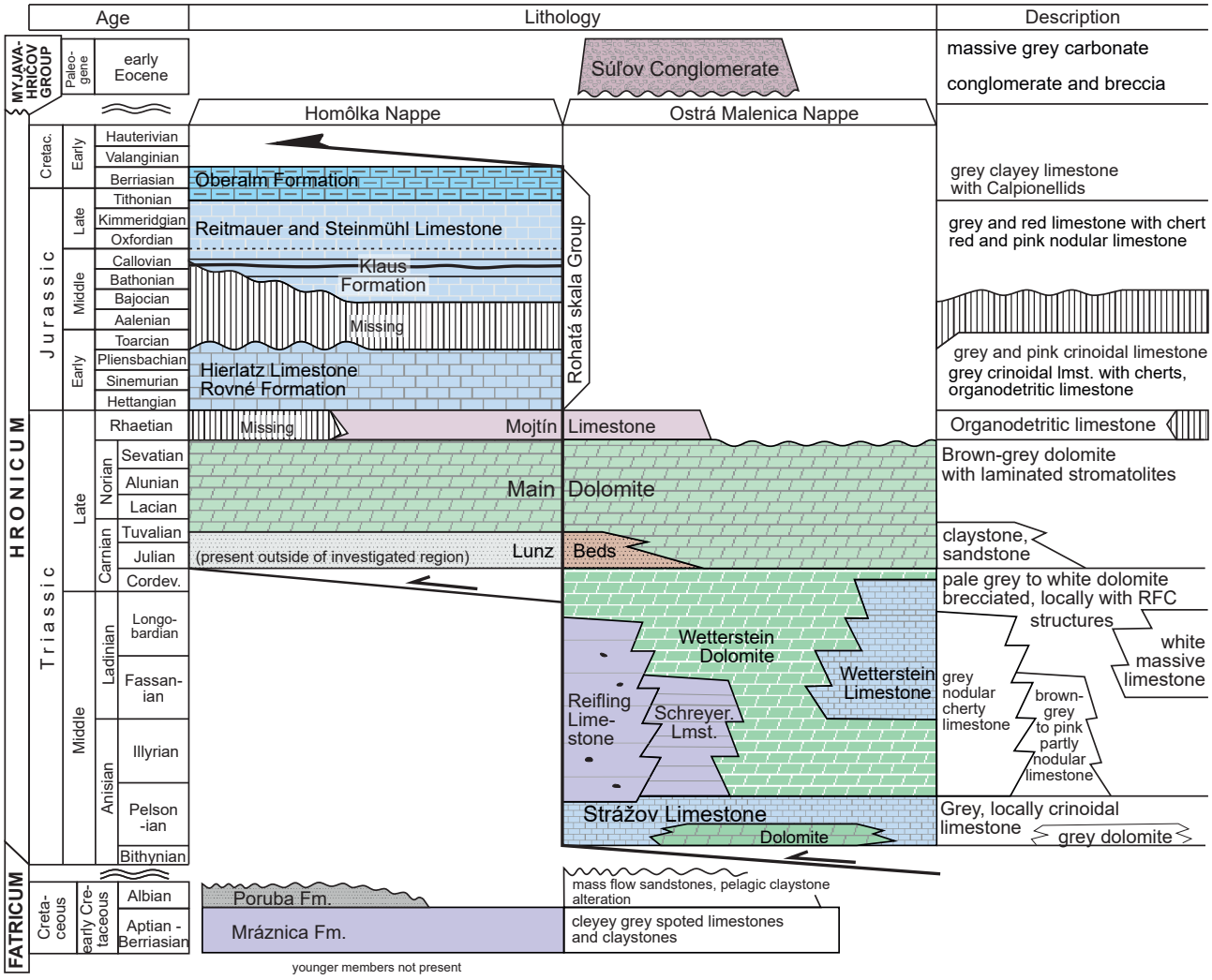


Fig. 3. Lithostratigraphy of the investigated Fatric, Hronic and Myjava-Hričov Group sedimentary sequences.

The Hronic sequence is unconformably overlain by the Súľov Conglomerate, massive grey to grey-brown carbonate conglomerate and breccia, representing probably the basal part of Paleocene-Eocene Myjava-Hričov Group (Marschalko & Samuel, 1993; Buček & Nagy in Mello et al., 2005; Soták et al., 2017). Signs of clast imbrication are rare. Basically, they represent structurally immature and variable rounded conglomerate and sandy conglomerate. The size of the largest clasts varies between pebbles 10 – 15 cm and blocks of 40 – 60 cm in diameter. Matrix is usually sandy. Clasts are composed entirely of the Hronic Triassic members, mainly the Strážov limestone and dolomites, Wetterstein and Main dolomite. The clastogenic pebbles (probably Lunz Beds) occur only rarely. Sandstone layers were recorded only in few places, their position suggests that they overlie the conglomerate lithofacies. Age of the Súľov Conglomerate is Ypresian – early Lutetian (Soták et al., 2017; Pulišová, 2018).

Main aim of this paper is the structural investigation of the Fatricum, Hronicum and overlying Myjava-Hričov Group, with special focus on re-examination of the presence of backthrusts or supposed "anticlines" in the investigated region of the Strážovské vrchy Mts. (Fig. 1) approx. between the Fačkov and Pružina villages.

Methods

The paleostress analysis in this paper is based on the interpretation of slickensides i.e. mesoscopic faults and shear fractures (e.g. Marko, 2000). According to the principle of the scale invariance they reflect activity of large megascopic faults which are hidden due to cover of vegetation and superficial deposits.

The actual stress values that generated faults, or slickensides cannot be directly detected, but the shape of the deformation ellipsoid for a given fault population can be

calculated. This is determined by the parameter Φ, which can be calculated as $\Phi = (\sigma_2 - \sigma_3)\,(\sigma_1 - \sigma_3)$, where $0 \leq \Phi \leq 1$ and $\sigma_1 > \sigma_2 > \sigma_3$. Equivalent to the parameter Φ is R, which can be calculated as $1 - \Phi$. Different stress modes can be defined based on size Φ (0 = uniaxial compression, 1 = uniaxial tension).

The Win-Tensor® and InnStereo software were used for the data processing. Win-Tensor® was developed by Dr. Damien Devaulx, Royal Museum for Central Africa, Tervuren, Belgium. It uses Right Dihedron (RD, Angelier & Mechler, 1977; Marko, 2000; Delvaux & Sperner, 2003) and PBT axis method (Sperner et al., 1993).

Tab. 1
Location of studied sites with WGS84 coordinates. Numbers in circles represent location points in Fig. 2a.

Fig. 2	locality	site	x(E)	y (N)	σ1
①	Predhorie	OP265	18.48419°	48.98176°	
②		OP216	18.47726°	48.97980°	
③	Sádocký vrch	MO587	18.55858°	48.99611°	
④	Fačkov	OP192	18.60320°	49.01414°	
⑤		OP153	18.59728°	49.01294°	

Results

The prevailing part of the investigated region is built by the Hronic rock complexes. They represent nappe outliers above Fatricum and are locally overlain by the Paleogene rocks of the Myjava-Hričov Group. Hronic sequences are generally monoclinally dipping to the north with local undulations (ranging from northwest to northeast; Fig. 4).

Predhorie (OP216 and OP265)

Observed outcrops are located at two sites south of Predhorie Village (Pružina Municipality, Považská Bystrica District; formerly Predhorie in older maps). The first one is situated on the northern slopes of the Strážovský potok Valley, approx. 650 m a.s.l. (Tab. 1). The second documented outcrop is situated on the eastern slope of the hill in altitude of 745 m a.s.l. in the Biely potok Valley (Fig. 7a). Site is located at the base of Hronic nappe system in the so-called Homôľka nappe (see Havrila, 2011) which represents basal thrust sheet of the Hronicum with deep-water Middle Triassic rocks and better-preserved younger Jurassic and Lower Cretaceous members. Geological setting is expressed in the cross-section A-B (Figs. 2a and 2b). The slickensides were measured in the Jurassic grey and pink

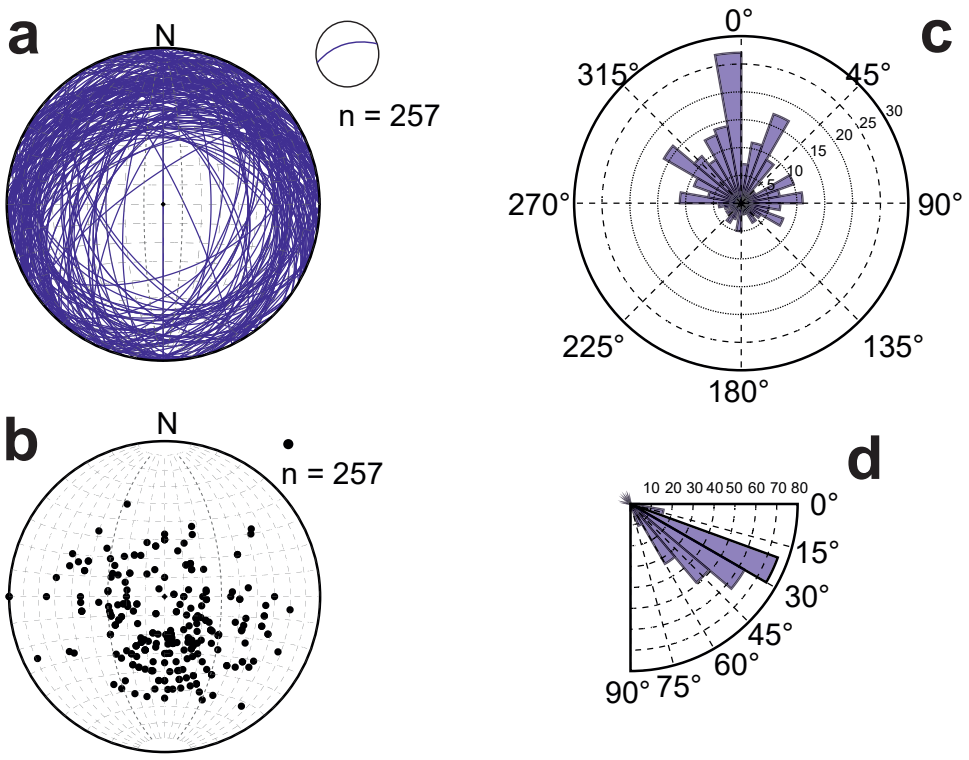


Fig. 4. Orientation of bedding planes (257 measurements) of Hronicum in the investigated region. **a** – Equal area stereonet (lower hemisphere) showing great circles of bedding planes. **b** – Equal area stereonet with poles to bedding planes. **c** – Rose diagram showing dip direction of bedding planes. **d** – Diagram showing dip of bedding.

crinoidal Hierlatz Limestone. Observed slickensides (Fig. 5a and 5b) are represented by NNW- to N-dipping reverse faults with calcite accretionary steps indicating generally "top to SSE" tectonic transport.

Fačkov (OP153 and OP192)

The wider area northeast and north of Fačkov Village from the map view (Fig. 2a) exhibits peculiar geometry of the Fatricum and Hronicum. Body of the Hronicum, which is higher nappe unit in this region, is interrupted by wedge like strip of clayey limestones of the Mraznica Formation of the Fatric affiliation. However, Fatricum is located in the middle part of the slope between Jazovčie and Šibeničná Hills, sandwiched between the Hronic Strážov Limestones or other Triassic carbonates (Fig. 2a and 2c). East of the Sádocký vrch Hill, in the westernmost tip of this Fatric body, remnants of the early Eocene breccias and conglomerates (Súľov Conglomerate) are incorporated into the southeast-vergent structure (Fig. 2c).

Outcrops with analysed slickensides are located at the bend of Rajčianka river north of Fačkov Village (Žilina District), approx. 555 m a.s.l. (Tab. 1). Site is located in the outcrops of the early Eocene Súľov Conglomerate (Fig. 7b) close to contact with the Wetterstein Dolomite of the Hronic Ostrá Malenica Nappe and in the Strážov Limestone. Approximately 250 m to the north generally NE-SW trending reverse fault causes that Hronic rocks are overlain

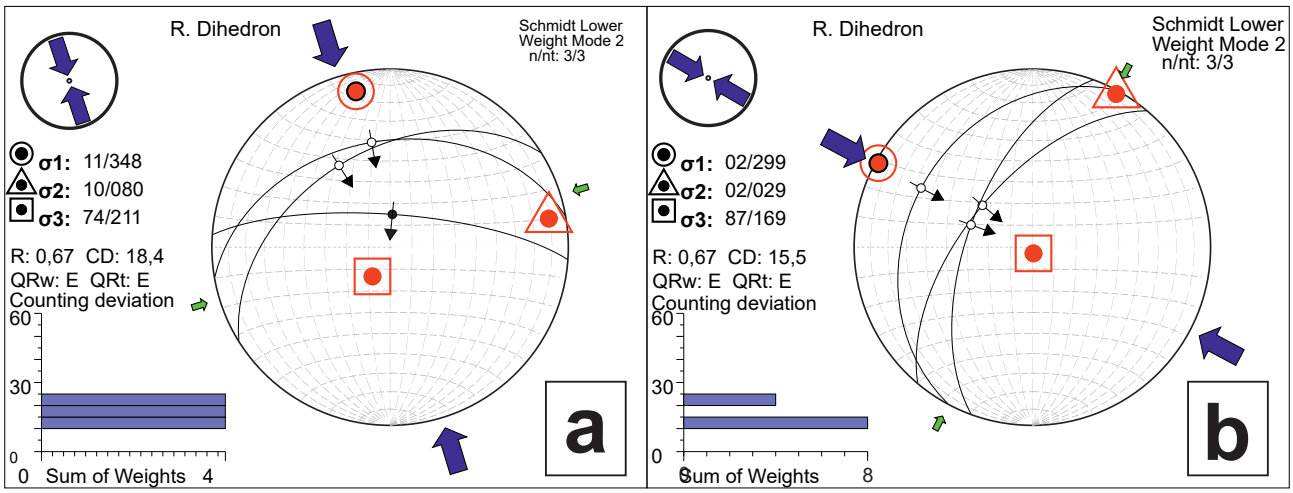


Fig. 5. Stereograms of fault slip data from the area of Predhorie. Interpretation of paleostress data using RD method. **a** – Site OP216. Bedding $S_0$326/60°. **b** – Site OP265. Bedding $S_0$295/45°.

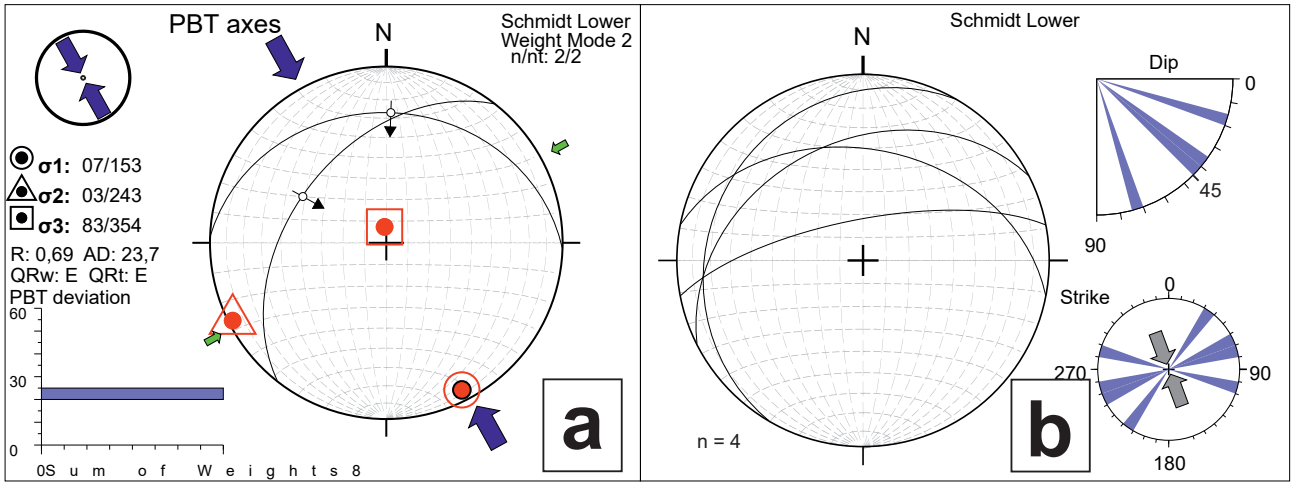


Fig. 6. a – Stereograms of fault slip data from the Fačkov area (OP153 and OP192). Interpretation of paleostress data using PBT method. Bedding S_0 = 332/30°. **b** – Shear fractures with Riedel shears at loc. Fačkov (OP153). Equal area stereonet (lower hemisphere) shows the great circles of shear planes, rose diagrams are showing the strike and dip of shear planes. Arrows indicate the proposed strike of maximum compressional stress σ_1.

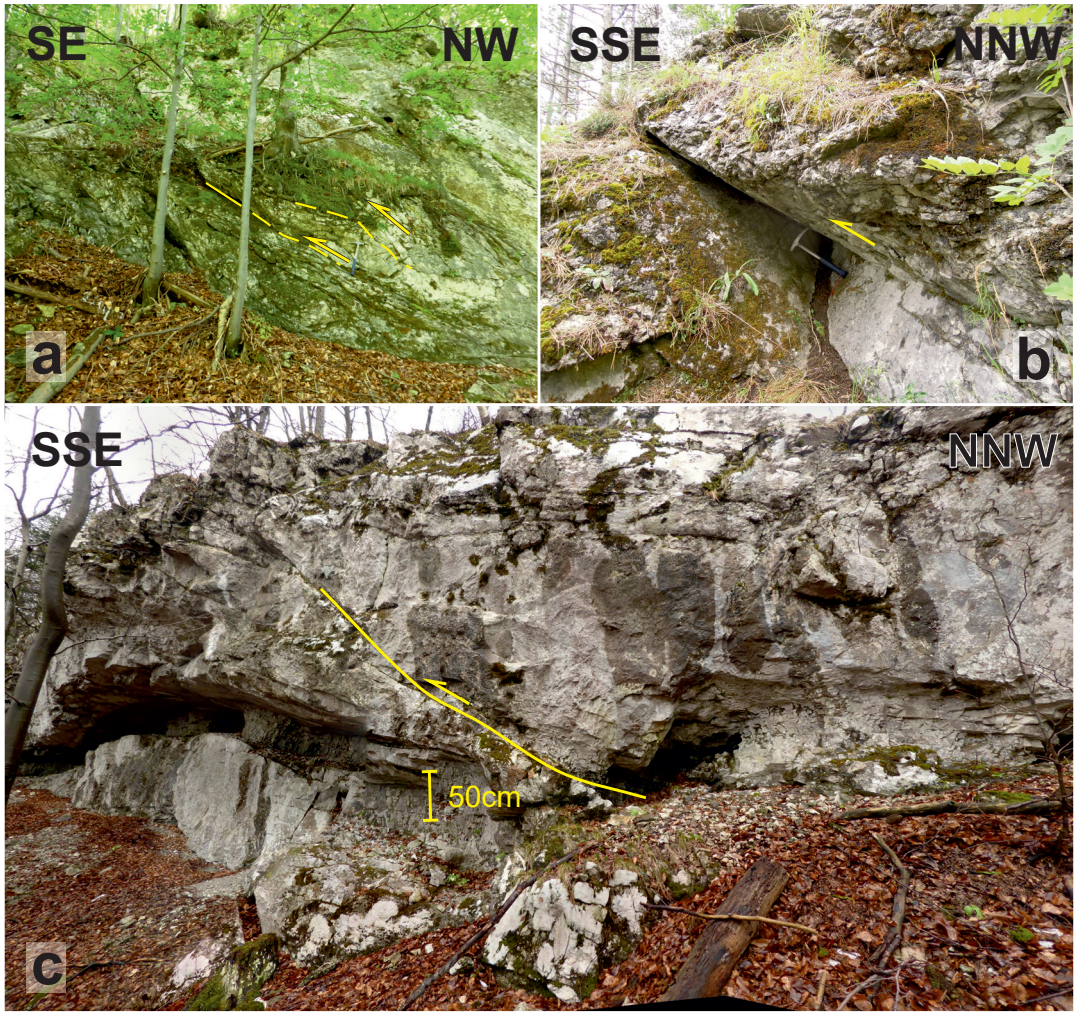


Fig. 7. a – Backthrust with the top to SE tectonic transport in the Hierlatz Limestone, south of the Prehorie village (OP256); **b** – Backthrust with top to SSE tectonic transport in the Súľov Conglomerate, north of Fačkov village (OP153); **c** – Backthrust with apparent top to SSE tectonic transport in the Strážov Limestones, north of Sádocký vrch Hill (MO587). Bedding $S_0 = 330/20°$.

by the Fatricum. This very unique situation in the whole Western Carpathians is a result of backthrusting and has only a local dimension.

The Súľov conglomerates and breccias are massive, thus clear identification of bedding was not possible. Two types of fractures were observed in the Súľov Conglomerate and Strážov Limestone. However, only two rare slickensides with preserved calcite accretionary steps were observed. Dipping to the north or northwest they show general tectonic transport to the south or southeast (Fig. 6a). More often NNW-dipping fractures with Riedel shears were observed, indicating "top to SE" tectonic transport (Fig. 6b).

Discussion

The pioneering paleostress studies resolving Cenozoic tectonic evolution in the western part of the Western Carpathians were performed by numerous authors (e.g. Marko & Kováč, 1996; Nemčok et al., 1998; Fodor et al., 1999; Sperner et al., 2002). Tectonic evolution of this area was marked by the interplay between subduction in the area of the Flysch Belt and extension in the back-arc region (Jiříček, 1979; Kováč, 2000; Sperner et al., 2002). The area is as well marked by locally pronounced block rotation (see Márton et al., 2015, for a review), associated with transpression and transtension tectonics which caused apparent rotation of the paleostress axes.

Observed backthrusts correspond to slickensides described by various authors (Šimonová & Plašienka, 2011; Soták et al., 2017 and Pulišová, 2018) in the Middle Váh Valley, Domaniža and Rajec basins. These were recorded mostly in Mesozoic and Paleogene rocks and are assigned to Oligocene – middle Miocene deformation phases. Analogous backthrusts in the rocks of the Central Carpathian Paleogene from the Orava region (east of investigated region) are considered early Miocene in age (Marko

et al., 2005; Pešková et al., 2009; Sentpetery, 2011). The backthrusting in the Western Carpathians south of the Pieniny Klippen Belt is generally considered as related to final phases of Alpine thrusting and nappe stacking. This phenomenon is traditionally explained as a result of wrenching along the contact of the External and Internal Western Carpathians during early Miocene oblique subduction (Kováč et al., 1989; Vass, 1998; Kováč, 2000; Pešková et al., 2012).

Occurrence of Early Cretaceous rocks of the Mraznica Formation in between the Hronic carbonates north of the Fačkov village was previously interpreted as the anticlines of Fatricum cropping from below the Hronicum (Hanáček, 1976; Maheľ et al., 1982; Bezák et al., 2004). Geological mapping and structural observations that included collection of fault slip data performed during this research indicate that the former assumptions were incorrect. The body of the Mraznica Formation north of Fačkov represents slice of the Fatricum displaced to the hangingwall of the Hronicum and the Eocene Súľov Conglomerate by the younger backthrust. The backthrusts were also documented on the other localities south of Predhorie in the Biely potok Valley and south of Sádočné in the area of Šalovina Hill or north of the Sádocký vrch Hill (Fig. 7c). This interpretation is close to some older views (Maheľ, 1985a, 1985b and Salaj, 2001).

It is also necessary to point out that studied backthrusts often occur together with regular top to north and north-west thrusts, reverse faults and asymmetric folds that mostly represent original Paleo-Alpine deformations related to compression and emplacement of the Fatricum and Hronicum. The presence of early Eocene rocks sandwiched between the Mesozoic formations in the backthrusts allows to consider these structures to be clearly post-early Eocene, thus definitely not related to emplacement of Paleo-Alpine cover nappes. Due to the absence of younger rocks, however, direct dating of slickensides is not possible. Based on the correlation with previous paleostress studies and own knowledge from other Western Carpathian areas, the observed backthrusts can be considered Oligocene to Karpatian (Late Burdigalian) in age.

Conclusions

This study was performed during geological mapping of Hronic, Fatric and partly also Myjava-Hričov Group sequences in the north-eastern Strážovské vrchy Mts. The analysis of brittle deformations structures – mostly north- and northwest-dipping slickensides and shear fractures suggests the existence of the phase of top to south or south-east tectonic transport of the Fatric, Hronic and Paleogene sequences.

From the point of view of these new findings, it can be stated that the observed Fatricum occurrences do not represent "anticlines", as was previously assumed (e.g. by Hanáček, 1976), but are rather younger post-early Eocene, probably Oligocene to Karpatian (Late Burdigalian), backthrusts disrupting the original Paleo-Alpine structure. Sandwiching of the Fatricum between the Hronic thrust sheets is very peculiar and represents unique, however, very local situation within the whole Western Carpathians.

Acknowledgement

The contribution was carried out during project supported by Ministry of the Environment of Slovak Republic no. 12 15-01 *Geological map of Strážovské vrchy Mts. – eastern part at a scale 1 : 50,000*. Authors are thankful to M. Havrila for fruitful discussions regarding geology of the Hronic nappe and reviewers Z. Pulišová and Z. Németh for constructive comments which improved the quality of this paper.

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Postranoeocénne spätné násuny v severovýchodnej časti Strážovských vrchov (Západné Karpaty)

Pozorovania spätných násunov v Západných Karpatoch sa evidujú už dlhší čas (obr. 1). Počas geologického mapovania a štruktúrneho výskumu v severovýchodnej časti Strážovských vrchov, približne medzi Pružinou a Fačkovom (obr. 1 a 2), sa analyzovali horninové sekvencie fatrika, hronika a myjavsko-hričovskej skupiny (sensu Buček in Mello et al., 2011; obr. 3). Na viacerých lokalitách sumarizovaných v tab. 1 boli identifikované tektonické zrkadlá a strižné fraktúry sklonené na sever a severozápad (obr. 5 – 7), ktoré dokumentujú juho- alebo juhovýchodnovergentné spätné násuny. Medzi spätné násuny možno zaradiť aj z mapového pohľadu šošovkovité teleso mraznického súvrstvia fatrika vystupujúce vo svahoch severne od Fačkova uprostred horninových súborov hronika. Pozorovaná pozícia fatrika na hroniku severne od Fačkova predstavuje v rámci Západných Karpát veľmi osobitý a unikátny jav, ktorý je však iba lokálnou poruchou. V minulosti boli tieto štruktúry interpretované ako tektonické okná („antiklinály“) fatrika vystupujúce spod hronika (Hanáček, 1976; Maheľ et al., 1982; Bezák et al., 2004). Pozorované spätné prešmyky inkorporujú v oblasti východne od Sádockého vrchu horniny myjavsko-hričovskej skupiny, čo umožňuje datovať tieto štruktúry ako postpaleoalpínske. Ich vek je teda postranoeocénny, pravdepodobne oligocénny až karpatský (spodný burdigal), ako je to aj v iných regiónoch. Pozorovania sú čiastočne v súlade s niektorými staršími názormi (Maheľ, 1985a, 1985b; Salaj, 2001) a potvrdzujú aj iné paleonapäťové štúdie z oblasti Stredného Považia, Domanižskej kotliny a Rajeckej kotliny (Šimonová a Plašienka, 2011; Soták et al., 2017; Pulišová, 2018).

Doručené / Received: 5. 9. 2018
Prijaté na publikovanie / Accepted: 3. 12. 2018