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Lithology and position of the Biele Karpaty Unit SE of Lednica (Biele Karpaty Mts., Western Carpathians)

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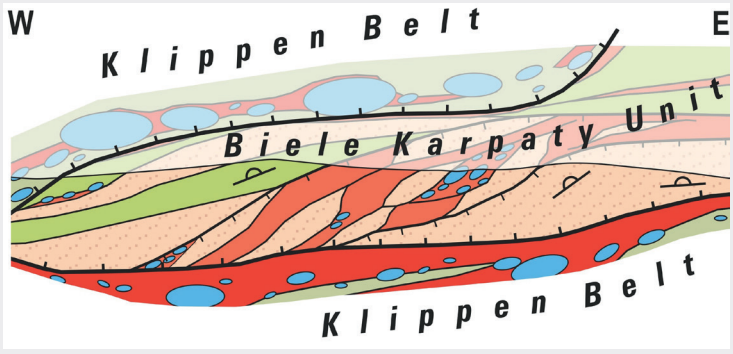
Abstract: Recent geological research and mapping SE of Lednica village brought several new findings important not only for the studied area, but also for understanding the relationship between the Klippen Belt and Flysch Belt at all: (1) The flysch sequence from the base to top is the Ondrášovec, Javorina, Chabová and Bzová mbs. of the Biele Karpaty Unit of Magura Nappe (Campanian to early Eocene). (2) The sequence of the Biele Karpaty Unit is situated in an overturned position with the prevailing strike of the beds 250–360° and dip of the beds 20–50°. (3) The structure is significantly sliced, especially in the zone with the Ondrášovec Mb. The slices of the Biele Karpaty Unit were turned back and then they were back thrust to the SE over Klippen Belt together with the Vršatec slice. (4) So far undescribed group of the Bukovina hill klippen NW from the Dolná Breznica village and a group of klippen NW from Kvašov village have been identified. (5) Six paleocurrent measurements were measured from the Ondrášovec Mb. – 210°, Javorina Mb. – 315° and Chabová Mb. – 2 x 330° and 2 x 10°.

Key words: stratigraphy, back thrust, Klippen Belt, Flysch Belt, Magura Nappe

Graphical abstract



Highlights

- The flysch sequence SE of Lednica village belongs to the Biele Karpaty Unit of Magura Nappe. From the base to top the Ondrášovec, Javorina, Chabová and Bzová mbs. are present.
- The external position of the klippen integrated into the Magura Nappe can be explained by back thrusting.

Introduction

The studied area of the Biele Karpaty Mts. forms a nappe complex of "flysch" formations belonging to the Biele Karpaty Unit of the Magura Nappe and to the complex structure of Klippen Belt of the Western Carpathians (Fig. 1). In the past, the area SE of Lednica village has been processed several times and displayed in geological maps (Maheľ et al., 1962; Salaj et al., 1983; Began et al., 1992, 1993; Mello et al., 2005, 2011). The authors focused more on the study of Jurassic-Lower Cretaceous klippen of Klippen Belt than on the flysch sequences. Salaj et al. (1983) defined the flysch formations in this area as the Kvašov development of the Klape Unit. Within the geological map of the Žilina sheet at a scale of 1 : 200,000 (Maheľ et al., 1962) authors divided the flysch complex of the studied area into the Biele Karpaty Unit (middle to late Eocene) and Klippen Belt (flysch development of Pupov Mb. – Santonian–Campanian) without structural data, between which they distinguished the variegated marls of late Santonian in two places.

The geological map of the Pruské sheet at a scale of 1 : 25,000 (Salaj et al., 1983) is a relatively detailed map. The authors documented position of 8 outcrops, but they did not specify the position of the sequence (top and bottom). Therefore, the authors could not find that the sequence was overturned. The map also omits a group of klippen NW from Dolná Breznica village and NW from Kvašov village, which led to the opinion that the sequence is continuous in a normal position. The authors classified the flysch sequences as the Kvašov development of the Drietoma succession of Klape Unit. In some places of the map, the belt of "variegated marls" is missing or it is incorrectly displayed. The mentioned work represented a base for the compilation of the later maps. Former limitations were later included in the works of Began et al. (1992, 1993) and Mello et al. (2005, 2011).

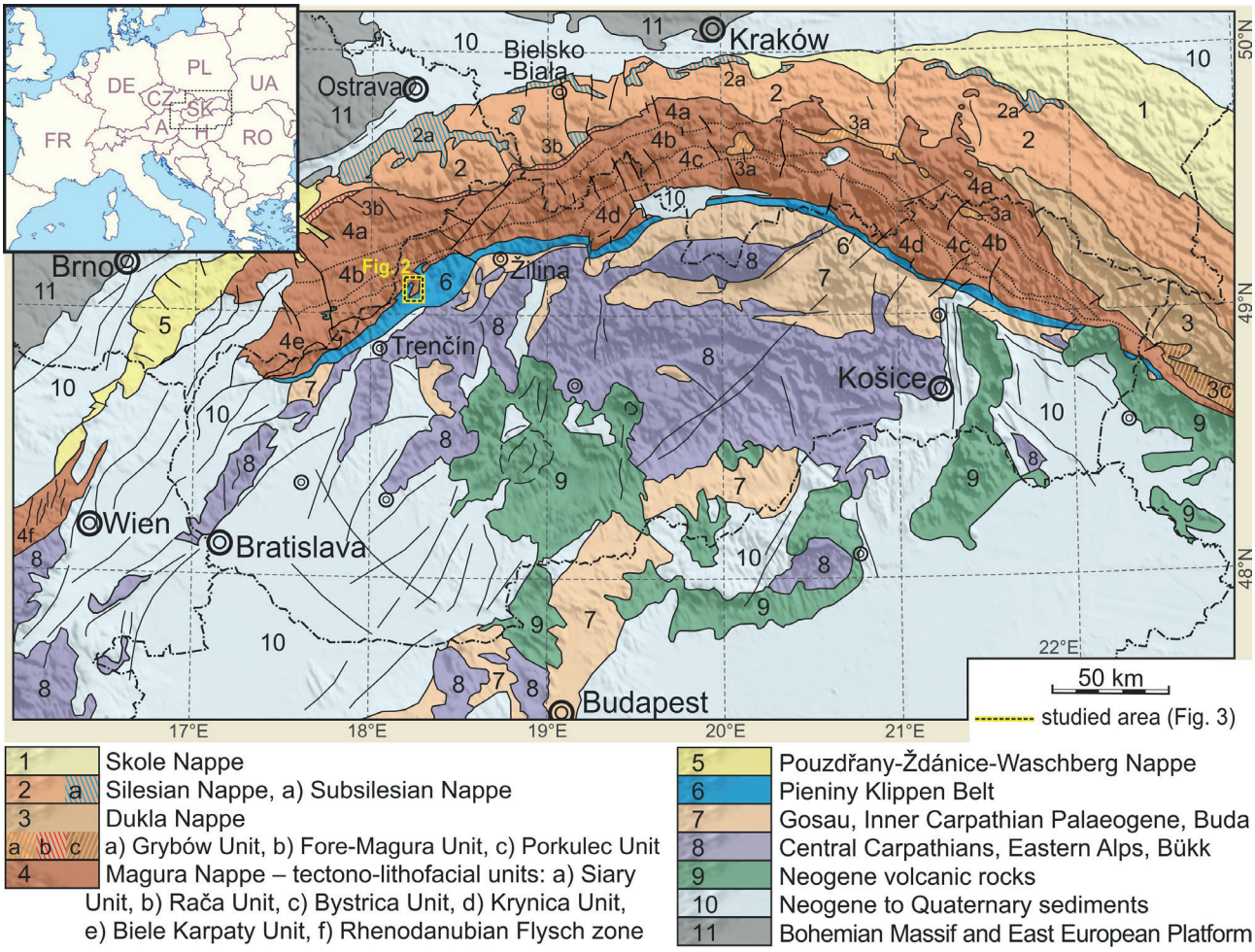


Fig. 1. Schematic geological map of the Western Carpathians with the location of studied area (designated as Fig. 2).

Methodology

The intensive geological research and mapping at a scale of 1 : 25,000 that carried out in the Biele Karpaty Mts. since 2016, intended to compile a new geological map and to solve the geological setting of the area between towns of Nové Mesto nad Váhom and Nemšová (Pešková et al., 2021a). Since 2019, the engineering geological monitoring of slope deformations was tied on previous regional geological research in the area of the Biele Karpaty and Javorníky Mts. The problematic areas of the geological map underwent the reambulation. Also, the area built by the Biele Karpaty Unit and Klippen Belt SE of Lednica was reambulated at a scale of 1 : 10,000. Geological mapping and its evaluation took place without the availability of LIDAR maps (high-resolution relief maps). Rock samples were not petrographically and paleontologically analysed, because the research was focused on the identification, inventory and engineering geological mapping of slope deformations. The advantage of done geological research was its connection to previous detailed research of the Biele Karpaty Mts. and the possibility to mutually compare the areas.

The research results

The geological research in the area SE of Lednica has distinguished four lithostratigraphic units. Although they originally formed a continuous sequence of the Biele Karpaty Unit, the enormously complex geological development of the area caused the tectonic contacts probably of all lithostratigraphic units. The more plastic horizon of the Ondrášovec Mb. rocks was squeezed into the main tectonic zones. The rock sequence can be reconstructed from bottom to top as follows: the Ondrášovec and Javorina mbs. of the Lopeník Fm. and the Chabová and Bzová mbs. of the Svodnice Fm. (Figs. 2 and 3), reaching the age from Campanian to early Eocene (Potfaj, 1993; Pešková et al., 2021b).

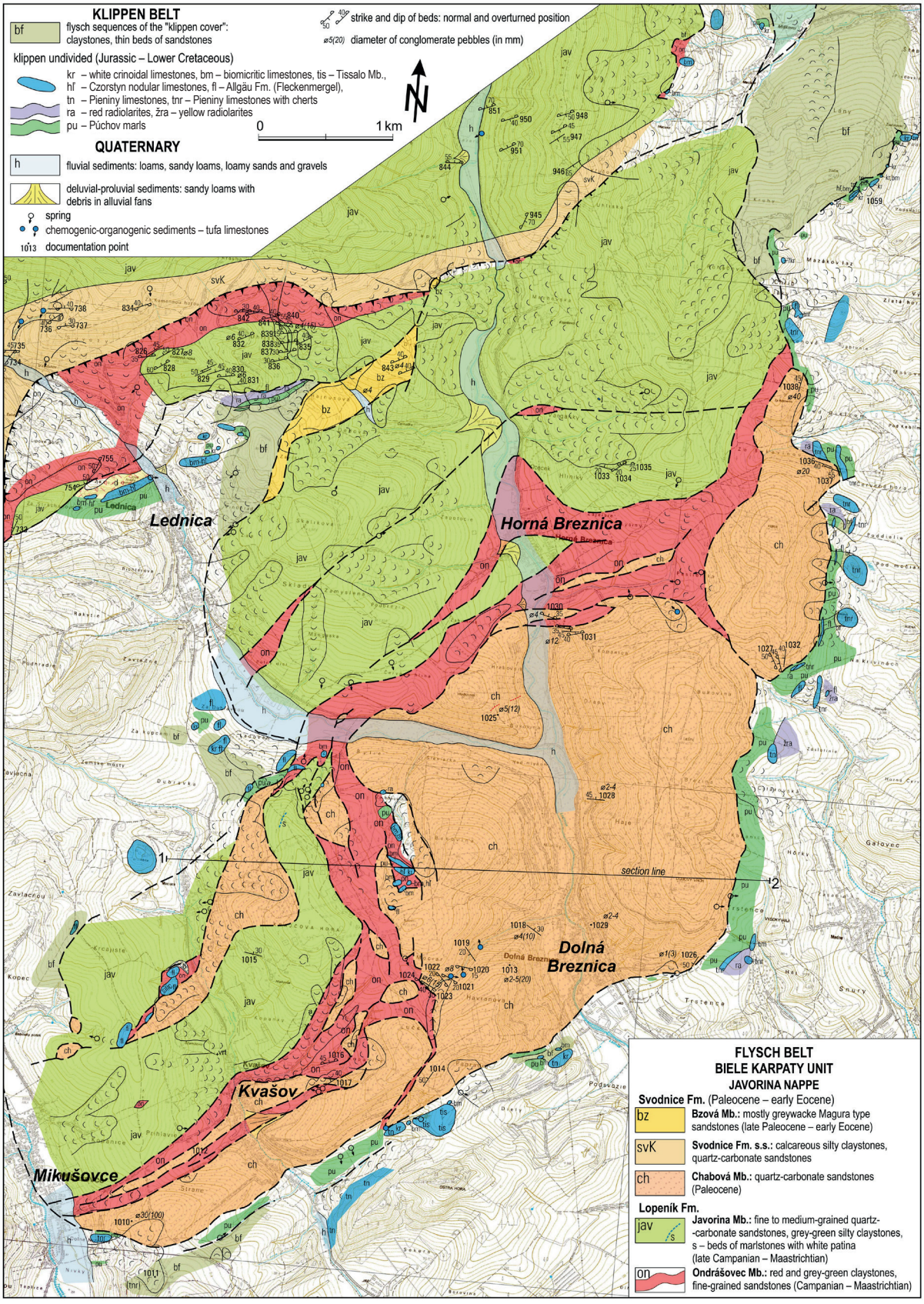


Fig. 2. Geological map of the Biele Karpaty Unit SE of Lednica.

Biele Karpaty Unit

Ondrášovec Mb.

The Ondrášovec Mb. was defined by Potfaj (1993) on the outcrops near the Ondrášovec settlement on the southern slope of the Veľký Lopeník Mt., describing a variegated formation at the base of Javorina Nappe. The member can be characterized as thin-bedded flysch deposits, formed by red and grey-green claystones alternating with thin beds of greenish laminated sandstones with muscovite.

Just one outcrop of Ondrášovec Mb. was observed in the studied area (Fig. 4A). Claystones predominate over sandstones. Light green-grey, grey and red non-calcareous claystones to silty claystones alternate with thin but also thicker beds (4–20 cm) of laminated very fine-grained quartz-carbonate sandstones. All other outcrops were significantly weathered.

The Ondrášovec Mb. is located at the basal plane of the Javorina, Zubák and Vrbovce nappes, it is rheologically plastic and it tends to be significantly deformed and tectonically reduced. The thickness of the member is only a few tens of meters. Tectonic duplexes are assumed to form over a 100 m thick complex in some places. They are a significant and important marker in geological mapping. Based on nannoplankton, Potfaj (1993) indicates a middle Campanian to early Maastrichtian age of the member.

Javorina Mb.

The development of the Javorina Mb. (Potfaj, 1993; Pešková et al., 2021b) is facially diverse. It can vary within areas, tectonic slices or the bed sequence of the Biele Karpaty Unit. In the studied area, the Javorina Mb. can be characterized as a flysch-type formation with a variable proportion of sandstones and claystones known only from several outcrops and character of the deluvium in studied area. Sandstones slightly predominate over claystones. They form 20 to 60 cm thick beds of well-sorted fine-grained, rarely medium-grained, massive or laminated quartz-carbonate sandstones with a higher content of muscovite and coalified plant detritus (Fig. 4B). Green-grey non-calcareous claystones form only thinner layers.

The debris of a solid grey marlstone bed with a white patina was observed in a deluvium on the ridge north of the Kvašov village. Beds of such marlstones to limestones are typical for the higher part of the Javorina Mb. (Potfaj et al., 2014; Pešková et al., 2021b).

The thickness of the Javorina Mb. is significantly tectonically reduced. It does not exceed 400 m in the studied area. Based on nannoplankton, Potfaj (1993) indicates the age of Javorina Mb. as a late Campanian to Maastrichtian.

Chabová Mb.

The member can be characterized as thick-bedded flysch sequence with massive quartz-carbonate sandstones almost without claystones (Potfaj, 1993; Pešková et al., 2021b). In the studied area, Salaj et al. (1983) interpreted it as Jarmuta Mb. in a continuous sequence passing from the Púchov marls. Due to the relatively abundant outcrops, it was possible to verify reliably the overturned position

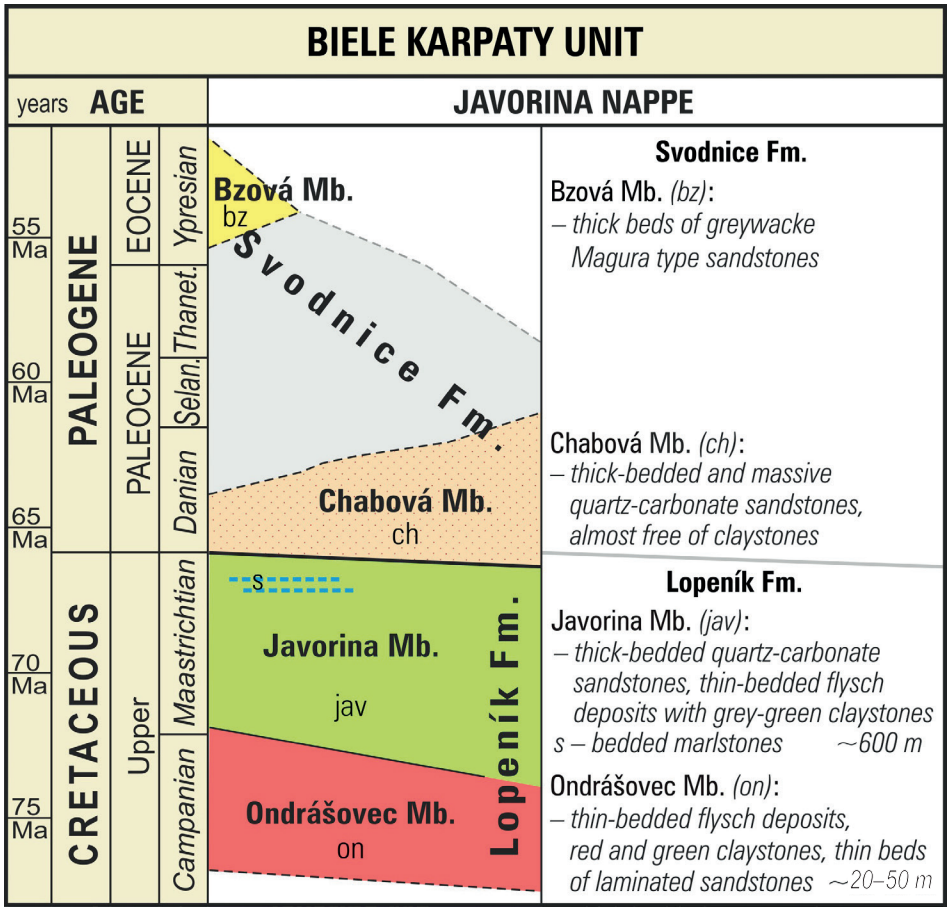


Fig. 3. Lithostratigraphy of the Biele Karpaty Unit SE of Lednica (modified after Pešková et al., 2021b).

of the Chabová Mb., having tectonic contact with the Púchov marls.

There is an absolute predominance of sandstones over claystones in the studied area. The character of the member changes continuously towards the top. The ratio of sandstones to claystones, the thickness of layers and grain size of sandstones are increasing and the lithification of sandstones is weakening towards the top. Fine- to coarse-grained quartz-carbonate sandstones form 40 to 300 cm thick, generally amalgamated, massive structureless beds. The fine-grained parts of the beds show an indistinctive plane lamination. Rapid weathering or disintegration with poorer lithification, rusty coatings to liesegang bands, rusty cracks, absence of clay interlayers, abundant muscovite and coalified plant detritus are the common features of sandstones (Fig. 4C, D). Deluvium is formed by thick yellowish-white sandy loams (Fig. 4E).

Green-grey and grey silty claystones are only up to 5 cm thick. Intraclasts of green claystones are rare in sandstones.

Lenses or layers of fine-grained conglomerates were observed in several places. The pebbles reach a diameter of 2–10 (max. 100) mm. In addition to standard quartz and quartzites, the conglomerates contain metamorphic rocks, granites, porphyries, phyllites, melaphyre pebbles, but carbonate material is predominating over quartz – dolosparite (?Triassic), fossil-free micritic and sparite limestones, calpionella-radiolarian biomicritic limestones of Tithonian and Berriasian and sandstones with Cenomanian orbitolina (*Orbitolina concava* Lamarck, *O. plana* d'Archiac, a.o.; Salaj et al., 1983).

Salaj et al. (1983) determined the age of the member in the studied area based on agglutinated microfauna and orbitoid foraminifers as the late Campanian and Maastrichtian. It can be considered a redeposition based on an analogy with the Chabová Mb. of Biele Karpaty Unit and the age of member classify as Paleocene (Potfaj, 1993; Pešková et al., 2021b).

The thickness of the member does not exceed 500 m in the studied area, or 300 m according to Salaj et al. (1983).

Bzová Mb.

About 1.5 km long tectonic slice, formed by Magura type sandstones, should be included into the Biele Karpaty Unit within the studied area east of the Lednica village. These sandstones represent the youngest sequence of the Svodnice Fm. and in the case of larger accumulation they form the Bzová Mb. within the Biele Karpaty Unit sequence. Magura type sandstones were clearly identified from the debris in the studied area, and especially on the several outcrops with over 1.5 m thick graded beds of coarse- to medium-grained greywacke sandstones. Weathered sandstones are brown, usually with scattered larger grains with a diameter of 1–(4) mm (paraconglomerate) and with water-escape structures. Their age is middle to late Paleocene based on nannoplankton from Bzová area (Potfaj, 1993) and thickness reaches up to 300 m in the studied area.

Klippen Belt

The aim of geological research and mapping was not a detailed research of the Klippen Belt, but especially the flysch sequence of the Biele Karpaty Unit. Nevertheless, the research revealed several unpublished data. Red and pinkish marls with globotruncana to red claystones of the Púchov Fm. form an almost continuous belt around the Biele Karpaty Unit sequence in the studied area (Fig. 4F). Púchov marls are accompanied with the flysch sequence of the klippen cover in particular between Lednica and Mikušovce villages (Fig. 2). Spotted marls of the Tissalo Mb. occur between Kvašov and Dolná Breznica villages. Mentioned Cretaceous members form the cover of smaller irregularly distributed klippen, built by various Jurassic-Lower Cretaceous lithofacies. Klippen build by spotted limestones of Allgäu Fm. (Fleckenmergel), white crinoidal limestones, red and yellow radiolarites, biomicritic and nodular Czorsztyn limestones and Pieniny limestones with or without cherts were observed (Fig. 2).

Two groups of klippen tectonically incorporated between the slices of the Biele Karpaty Unit were found NW from Kvašov and NW from Dolná Breznica. Klippen are built by most of the above mentioned lithofacies, including the Púchov marls. The southeastern edge at the junction of Biele Karpaty Unit with the Klippen Belt is bordered by the Púchov marls (Fig. 4F). This boundary line is sharp and the Púchov marls or klippen were not found folded into the Chabová Mb. along this border.

Paleocurrent analyses

Six paleocurrent measurements were done during geological research (Fig. 5). They do not represent a statistically sufficient set, but with the support of the knowledge of the neighbouring Biele Karpaty Unit paleogeography, it is possible to draw certain conclusions (Fig. 5). The SW (210°) paleotransport direction of the Ondrášovec Mb. corresponds to the predominant paleotransport direction of the thin-bedded facies during the latest Cretaceous in the direction parallel to the Magura Basin elongation (Teťák et al., 2019).

The paleotransport direction of the Javorina Mb. to the NW (315°) is in accordance with the knowledge of

Fig. 4. A: Ondrášovec Mb. – weathered variegated claystones and thin beds of sandstones (road cut east from Kvašov, documentary point 1016); **B:** Javorina Mb. – bedding plane with flute casts (d. p. 1035); **C, D:** Weathered and disintegrating sandstone of Chabová Mb. (d. p. 1018, 1037); **E:** Excavation of at least 4 m thick deluvium of weathered sandstones of Chabová Mb. (Dolná Breznica, d. p. 1029); **F:** Red Púchov marls in the road cut (d. p. 1032).

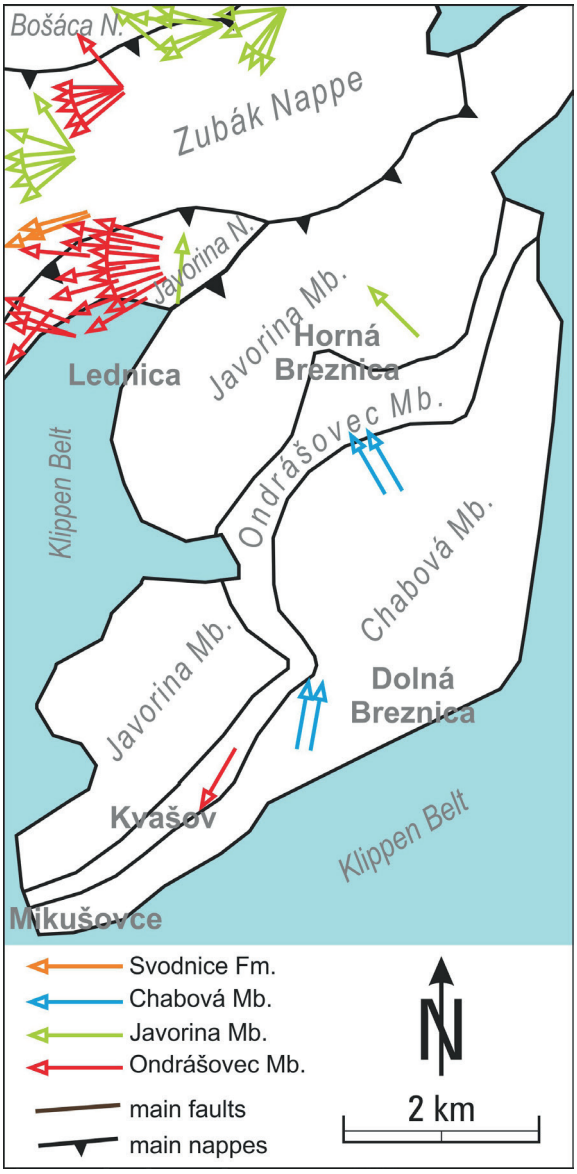


Fig. 5. Schematized map of the studied area shows the measured paleocurrent directions. Their lithostratigraphic and lithofacial classification is distinguished by colour. Unpublished paleocurrent measurements are supplemented in the neighbouring Javorina and Zubák nappes.

the paleotransport directions of Javorina Mb. of the Biele Karpaty Unit (Stráník et al., 1989; Marschalko, 1985 and unpublished data).

The Chabová Mb. deposits are the result of the sedimentation of a relatively smaller submarine fan. The paleotransport measurements direct to the north (2 x 330° and 2 x 10°). Together with the facial development, the paleotransport directions of Chabová Mb. in the studied area can be interpreted as the place of lateral supply of clastic material into the Magura Basin.

In this interpretation it is necessary to take into account the statistically insufficient number of measurements and possible tectonic rotation of the measured rock blocks, as the investigated area is significantly tectonically deformed.

Tectonics

The more detailed knowledge of the geological structure of the Biele Karpaty Unit flysch sequence SE of Lednica as well as its relation to the Klippen Belt were brought by geological mapping. It has been found that it is not a single continuous sequence as suggested by earlier works of Salaj et al. (1983) and Began et al. (1992, 1993). The area is formed by several tectonic blocks or slices. The slices and blocks are formed by flysch sequences of the Javorina and Chabová mbs. They are surrounded by tectonically strongly deformed Ondrášovec Mb. This had the function of a plastic tectonic gliding horizon at the base of displaced nappes and slices. During the movement of the nappes, blocks of the underlying formations were incorporated into the Ondrášovec Mb. Also, the nappe duplexes were observed (Fig. 6). The base of the Javorina Nappe in the Nová Bošáca and Horná Súča areas represents an example of duplexes (Pešková et al., 2021a). The structure of the narrow zone formed by Ondrášovec Mb. is so complicated that it is still not obvious whether the slice with Chabová Mb. was moved first as a nappe to the NW over the Javorina Mb. before thrusting/tilting over on the Klippen Belt, or it was the opposite process – back thrusting after tilting over the Klippen Belt. Based on the occurrence of the Chabová sandstones blocks in zone/belt with the Ondrášovec Mb., as well as the analogy

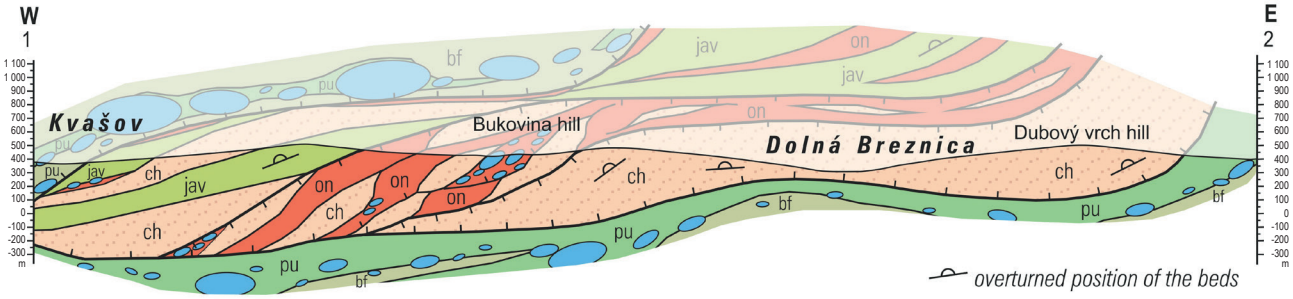


Fig. 6. Schematic section with the interpretation of the geological structure. Section line courses between Kvašov and Dolná Breznica villages.

with the Javorina Nappe and knowledge of the deposition conditions, the following development is more probable:

(1) In the first folding phase after the middle Eocene, the slice formed by Chabová Mb. shift to the NW over the slice formed by Javorina Mb. Small slices formed by the Chabová and Javorina mbs. were incorporated into the Ondrášovec Mb. at the contact of both slices.
(2) The slices were together turned back to the Klippen Belt to the SE. At the same time, a Vršatec slice was back-thrust over them to the SE.

By this mechanism, part of the Biele Karpaty Unit could be involved in the structure of Klippen Belt. The external position of the klippen integrated into the Magura Nappe can be explained in a similar way. A similar position of the klippen and overturned Krynica Unit is in the Oravská Magura Mts. (Potfaj et al., 1991).

Discussion

Flysch sequence SE of Lednica village, so-called the Kvašov development of the Klape Unit (Salaj et al., 1983) was interpreted as a set of various lithostratigraphic units of several tectonic units of the Inner and Outer Western Carpathians. This interpretation could be explained by a lack of outcrops and information and by the unique tectonic position of these deposits, which has no equivalent in the Western Carpathians. More detailed information on the position of the beds and the succession of the flysch sequence has not yet been published. For this reason, the previous authors determined that the sedimentation continuously passed from the Púchov marls, surrounding the klippen of the Klippen Belt, to the top into the Jarmuta Mb., upwards into variegated clays, and finally into the fine-grained flysch deposits (Salaj et al., 1983; Began et al., 1992, 1993). This interpretation of the sequence was also supported by the findings of microfauna, though probably redeposited. The authors did not find significant group of klippen at Bukovina hill NW from Dolná Breznica village. This group of klippen is situated directly in the zone with the variegated claystones. This fact may disprove the opinion of a contiguous sequence.

The fact that rock samples were not petrographically and paleontologically analysed in this work is a disadvantage of the processing of this article. However, the conditions and a number of outcrops in the field, suitable for sampling, is very limited and the field research do not provide enough suitable outcrops and samples for the analyses even at maximum effort, especially for the paleontological determination of rock age. It is therefore necessary to rely on field observations of debris lithology, which is fortunately clearly assignable to the lithostratigraphic units known from the Biele Karpaty Unit.

The Jarmuta and Proč mbs. are the alternative classification of the studied sequence instead of the Javorina and Chabová mbs. on the basis of similar lithology, age and tectonic position. The occurrence of Jarmuta and Proč mbs. in the western part of the Klippen Belt is many times rather fragmentary and uncertain (Mello et al., 2005, 2011; Potfaj and Teťák et al., 2014; Teťák and Potfaj et al., 2015). The above mentioned alternatives are based rather on their occurrence in Eastern Slovakia (Žec et al., 2006, 2011). It is possible to assume that the mentioned alternative lithostratigraphic units of the Jarmuta and Proč mbs. are close to the Biele Karpaty Unit in paleogeographic interpretations, but to speak about the complete conformity would not be correct. It is more appropriate to classify the studied sequence within the Biele Karpaty Unit.

Conclusions

During the rich history of the Klippen Belt research in the Považie region, the flysch sequence in the area SE of Lednica village has been assigned to different lithostratigraphic units of Inner and Outer Western Carpathians (Maheľ et al., 1962; Salaj et al., 1983; Began et al., 1992, 1993; Mello et al., 2005, 2011). The Kvašov development of the Klape Unit was defined in this area by Salaj et al. (1983). The authors presumed that it was a continuous sequence in the top of the Púchov marls of the Klippen Belt.

Geological research and mapping in the area SE of Lednica village brought several new findings important not only for the studied area, but also for understanding the relationship between the Klippen Belt and the Flysch Belt at all:

(1) Lithostratigraphically the flysch sequences belong alternatively to Ondrášovec, Javorina, Chabová and Bzová mbs. of the Biele Karpaty Unit of Magura Nappe, having an age range from the Campanian to the early Eocene.
(2) The sequence of the Biele Karpaty Unit is situated in an overturned position with the prevailing strike of the beds 250–360° and dip of the beds 20–50°.
(3) Six paleocurrent measurements were measured from Ondrášovec Mb. – 210°, Javorina Mb. – 315° and Chabová Mb. – 2 x 330° a 2 x 10°.
(4) The structure is significantly sliced, especially in the zone with the Ondrášovec Mb.
(5) So far undescribed group of the Bukovina hill klippen NW from the Dolná Breznica village and a group of klippen NW from Kvašov village have been identified. It was precised the contact of the Biele Karpaty Unit with the Klippen Belt accompanied by the Púchov marls, flysch sequences of the "klippen cover" and the Jurassic-Lower Cretaceous klippen.

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Litológia a pozícia bielokarpatskej jednotky juhovýchodne od Lednice (Biele Karpaty, Západné Karpaty)

V priebehu bohatej histórie výskumu bradlového pásma na Považí bola flyšová sekvencia v oblasti juhovýchodne od Lednice priraďovaná k rôznym litostratigrafickým jednotkám viacerých tektonických jednotiek Vnútorných Západných Karpát i Vonkajších Západných Karpát (obr. 1) (Maheľ et al., 1962; Salaj et al., 1983; Began et al., 1992, 1993; Mello et al., 2005, 2011). Salaj et al. (1983) tu vyčlenili tzv. kvašovský vývoj klapskej jednotky. Autori sa však zameriavali viac na štúdium jursko-spodnokriedových bradiel než na ich flyšový obal. Napriek neznalosti úložných pomerov sekvencie sa autori domnievali, že ide o súvislý sled v nadloží púchovských slieňovcov bradlového pásma. Doteraz neboli publikované informácie o pozícii vrstiev a tým ani dôkaz o postupe sekvencie. Preto sa autori domnievali, že sedimentácia plynulo prechádza z púchovských slieňov obklopujúcich bradlá bradlového pásma do nadložia do jarmutských vrstiev, ďalej do pestrých ílov a na záver do jemnozrnného flyšu (Salaj et al., 1983; Began et al., 1992, 1993).

Nedávny geologický výskum a mapovanie v tejto oblasti priniesli viacero nových poznatkov, významných nielen pre skúmanú oblasť, ale aj z hľadiska pochopenia vzťahu bradlového a flyšového pásma vôbec (obr. 2 a 3):

1. Flyšová sekvencia litostratigraficky patrí k ondrášoveckým, javorinským, chabovským a bzovským vrstvám bielokarpatskej jednotky magurského príkrovu (kampán – starší eocén).
2. Sekvencia bielokarpatskej jednotky je v prevrátenom slede, so sklonom 20 – 50° prevažne na SZ (250 – 360°).
3. Stavba je výrazne tektonicky porušená a zošupinatená, najmä v pruhu s ondrášoveckými vrstvami.
4. Podarilo sa zistiť zatiaľ neznámu skupinu bradiel Bukovina sz. od Dolnej Breznice a bradlá sz. od Kvašova. Spresnilo sa poznanie kontaktu bielokarpatskej jednotky s bradlovým pásmom s výskytom púchovských slieňovcov, flyšových sekvencií obalu bradlového pásma a jursko-spodnokriedových bradiel.
5. Meraním bolo získaných šesť výsledkov paleoprúdových meraní – ondrášovecké vrstvy 210°, javorinské vrstvy 315° a chabovské vrstvy 2x 330° a 2x 10° (obr. 5).

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