Structural position of the Upper Cretaceous sediments in the Považský Inovec Mts. (Western Carpathians)

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AGEOS

Štruktúrna pozícia vrchnokriedových sedimentov v Považskom Inovci (Západné Karpaty)

Abstract: This contribution focuses on the analysis of the structures and tectonic attribution of the Upper Cretaceous rocks in the Selec and Hlohovec blocks of the Považský Inovec Mts. One of the principal questions arising from conflicting views is whether the Upper Cretaceous sequences represent exhumed Vahicum – a tectonic unit of possibly oceanic character cropping out from beneath the Tatricum basement, or sediments which originally overlaid the Tatricum, but were later involved in the imbricated thrust belt. All known localities with Upper Cretaceous complexes were investigated. The proposed interpretation takes into account stratigraphic, structural, geochronological, and geophysical evidence that have accumulated in recent years. New results document superposition of the Upper Cretaceous sediments above the Tatricum and suggest their evolution in a wedge top basin covering the Tatricum external zones.
Key words: Western Carpathians, Považský Inovec Mts., Late Cretaceous, Tatricum, Penninicum, Vahicum, Horné Belice Group

1. INTRODUCTION

Upper Cretaceous sediments (Coniacian–Maastrichtian) occur only rarely in the Western Carpathians south of the Pieniny Klippen Belt, or the so called Peri-Klippen Zone (Mišík, 1978; Bezák et al., 2008). Various facies of these sediments lying above the Silicicum nappes are known predominantly from the internal zones of the Western Carpathians (e.g., Mello & Salaj, 1982) or from the region of Brezovské Karpaty Mts., where they overlie the Hronicum (Brezová Group, Samuel et al., 1980). The last mentioned occurrence was correlated with the Gosau Group of the Eastern Alps (Wagreich & Marschalko, 1995). In addition, other reported occurrences are known from the Pre-Cenozoic basement of the Vienna Basin (e.g., boreholes Studienka: St-5, St-37, St- 83; Závod: Z-57, Z-68, Gajary: Ga- 125; Lakšárska Nová Ves: LNV-4, LNV-6, LNV-7; Biela, 1978; Kysela, 1988; Bujnovský et al., 1992; Mišík, 1994; Stern & Wagreich, 2013), where they represent synform structures continuing from the Northern Calcareous Alps. These sedimentary sequences were considered to be post-tectonic, post-nappe or only slightly deformed (Andrusov et al., 1973; Plašienka et al., 1997; Bezák et al., 2011).

Not all occurrences of the Gosau sediments may be regarded as undeformed or post-nappe in the Internal Western Carpathians (IWC). It is possible to interpret position of the Brezová Group sediments in the syncline structure bellow the Hronicum in the Čachtické Karpaty Mts. (Vranová, 2010). The Upper Cretaceous sediments occur below the Fatricum nappe in the borehole SBM-1 Soblahov located north of the Považský Inovec Mts. (Maheľ & Kullmanová, 1975; Kullmanová, 1978; Gašpariková, 1980). Therefore, considerations regarding Palaeo-Alpine post-Late Cretaceous nappe movement in the IWC emerged (Kysela, 1988; Havrila, 2011).

The Gosau Group sequences in frame of the IWC overlie or they are tectonically incorporated into the uppermost nappe structures. The Upper Cretaceous sediments are overlying the Silicicum in the Upper Group of nappes or the uppermost nappe structure (Hronicum) in the Middle Group of nappes (*sensu* Hók et al., 2014). The exception is the occurrence of Upper Cretaceous sediments in the Považský Inovec Mts. (PI). These sediments are positioned above or within the Tatricum which is considered to be the lowermost tectonic unit (Fig. 1). They are represented by syn-orogenic flysch sediments with olistoliths between the thrust slices of the Tatricum crystalline basement in the Northern (Selec) Block (Ivanička et al., 2007). Similar facies, however, with more distal character and absence of coarser clastic input overlying the granitic basement, were observed in the Southern (Hlohovec) Block (Havrila in Havrila & Vaškovský; 1983; Havrila et al., 1998). Recently analogous Upper Cretaceous sediments were found in the Central (Bojná) Block, overlying the Tatricum sedimentary cover of the Fatra type (Pelech et al., 2014).

Sediments of Late Cretaceous age were recognized in the PI for a first time during the detailed biostratigraphic research of the Tatricum sedimentary cover (Kullmanová & Gašparíková, 1982). Maheľ (1986) correlated these sediments with the Klape Unit as a part of the Vahicum unit i.e. hypothetical continuation of the South Penninicum into the Western Carpathians (Maheľ, 1981). The rock complexes of the whole Selec Block including the micaschist crystalline basement were correlated with the South Penninicum by Leško et al. (1988) but without further reliable geological arguments.

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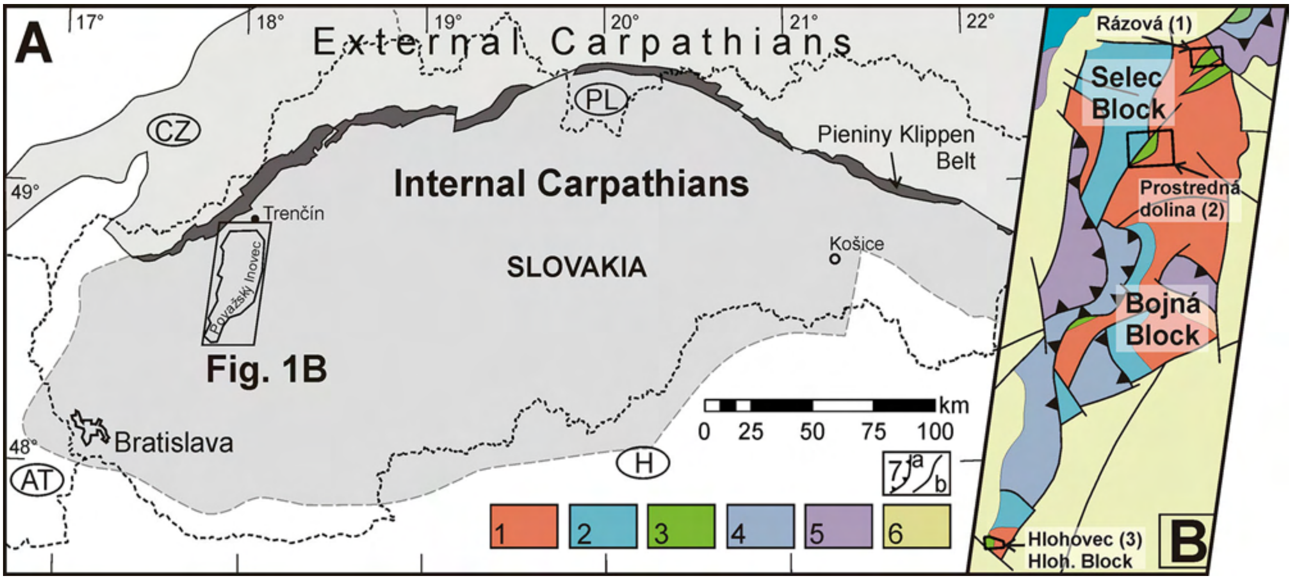

Fig. 1. A: Location map of the Považský Inovec Mts. (PI) in the Western Carpathians. B: Tectonic scheme of the PI. with marked investigated localities modified after Bezák et al. (2011). 1: Tatricum crystalline basement; 2: Tatricum Upper Palaeozoic and Mesozoic sedimentary cover; 3: Horné Belice Group (Upper Cretaceous); 4: Fatricum; 5: Hronicum; 6: Cenozoic sediments; 7: Faults: thrust faults, strike-slip, and normal faults.

The Upper Cretaceous sediments together with the Middle to Upper Jurassic and Lower Cretaceous sequence were later defined as the Belice Succession (Plašienka et al., 1994; Plašienka & Ožvoldová, 1996). According to their interpretation the Belice Succession forms a composite stratigraphic section from the Jurassic to Upper Cretaceous (Fig. 2) present in separate thrust slices in the footwall of the Tatricum. Only complexes of the Belice Succession were considered to be a part of the Vahicum (Soták et al., 1993; Plašienka et al., 1994; Plašienka, 1995, 1999, 2012). The hypothesis of the Penninic/Vahic affiliation of the Belice Succession (*sensu* Plašienka et al., 1994) is based on following assumptions (Plašienka, 1999):

1) Structural position of the Belice Succession below the Tatricum crystalline basement.

2) Presence of steep "out-of-sequence thrusts" which emplace thrust slices of the Belice Succession above the Tatricum crystalline basement.

3) Presence of the Middle Jurassic to Lower Cretaceous deep-water sediments (the Lazy Formation *sensu* Plašienka et al., 1994) in association with basalts of presumed Jurassic age suggesting oceanic crust affinity (Soták et al., 1993).

4) Continuity of sedimentary succession of the Jurassic to the Upper Cretaceous members of the Belice Succession documenting the record of rifting, collision, and destruction of sedimentary basin.

The presence of the Vahicum rocks on the surface of the Western Carpathians gives arguments for a geodynamic model based on subduction of two oceanic domains – Meliatic in the Jurassic to Early Cretaceous and Vahic in the Late Cretaceous to Early Miocene (e.g., Plašienka et al., 1997; Plašienka, 1999; Kováč et al., 2003).

Other interpretations emerged in the following period. The first is based on the position of the Upper Cretaceous rocks above the Tatricum granitoids in the southern PI, near Hlohovec town

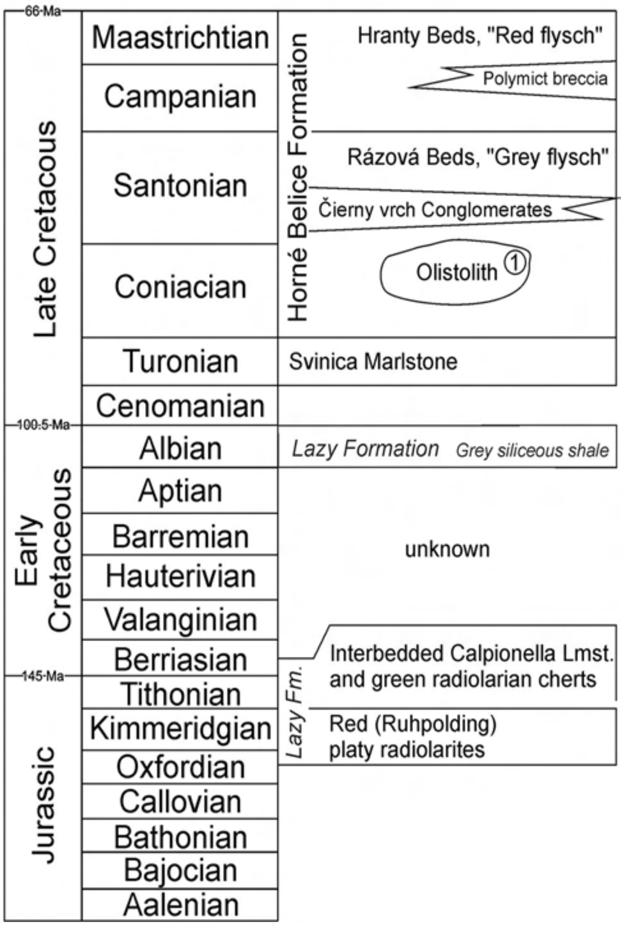

Fig. 2. Composite stratigraphic column of the Belice Succession *sensu* Plašienka et al. (1994) and Plašienka (2012). Members older than the Coniacian are considered as a separate thrust slices. (1) Olistoliths of older rocks, including mica schists, Permian sandstones, Lower Triassic quartzites, Middle Triassic carbonates, basalts etc.

(Havrila et al., 1998; Havrila in Pristaš et al., 2000[a], 2000[b]). This fact was later confirmed by the structural borehole HPJ-1 Jašter (Pelech, 2015; Pelech et al., 2016 in this issue).

Some authors question the oceanic character of the Belice Succession at all due to absence of ophiolites or HP/LT metamorphism in the PI (Rakús & Hók, 2005). Rakús (in Ivanička et al., 2011) redefined the Belice Succession and replaced it with a formal lithostratigraphic unit called the Horné Belice Group, which consists of the Rázová and Hranty Formations. Both formations include olistoliths of different rocks of Palaeozoic, Triassic, Jurassic, and Early as well as Late Cretaceous age (Rakús et al., 2006). A structural position above the Tatricum crystalline basement in accordance with original interpretations of Maheľ (1986) was proposed (Rakús & Hók in Ivanička et al., 2011). On the base of the structural position of the Upper Cretaceous sediments in the southern part (Havrila in Pristaš et al., 2000[a], 2000[b]; Havrila in Maglay et al., 2011) as well as in the northern part of PI (Rakús in Ivanička et al., 2011) it was proposed that the Upper Cretaceous sediments represent a new sedimentary cycle incorporating olistoliths of older rocks (newly defined Humienec Unit). These sequences are preserved as synclines between the thrust slices of the Tatricum crystalline basement (Hók in Ivanička et al., 2011). Therefore, it is quite logical that a model considering their Tatric origin was proposed as well (Bezák et al., 2008). Putiš et al. (2006) consider the Humienec Unit and the Belice Group as tectonic windows of the lower Tatricum, so called Infratatricum. According to paleotectonic interpretation the sediments are part of the fore-arc basin over the subducting oceanic crust of the Vahicum. Putiš et al. (2006, 2008) pointed out that geochemical character of the basalt olistoliths is identical with the Permian continental basalts of the Tatricum Kálnica Group (cf. Štimmel et al., 1984; Olšavský, 2008).

2. AIMS AND METHODS

This contribution aims on the investigation of the structural position of the Upper Cretaceous rock complexes (the Horné Belice Group *sensu* Rakús in Ivanička et al., 2011) exposed in the region of the Považský Inovec Mts. (Fig. 1). The research was based primarily on mapping of geological structures. Two localities were examined in the Selec Block. The first one is Rázová (between the Jastrabie Fault and the area of Staré salaše) SW of Mníchova Lehota (Fig. 2). The second is the area at the end of the Prostredná dolina Valley (between the localities Horné vápenice and Pod Jakubovou) SE of Kálnica (Fig. 3). The observations from the Hlohovec Block originate mostly in the Soroš quarry N of Hlohovec (Fig. 4).

3. RESULTS AND DISCUSSION

3.1. Question of continuity of Belice Succession

The so called Belice Succession represents composite and deformed sequences of Jurassic to Late Cretaceous age exhumed

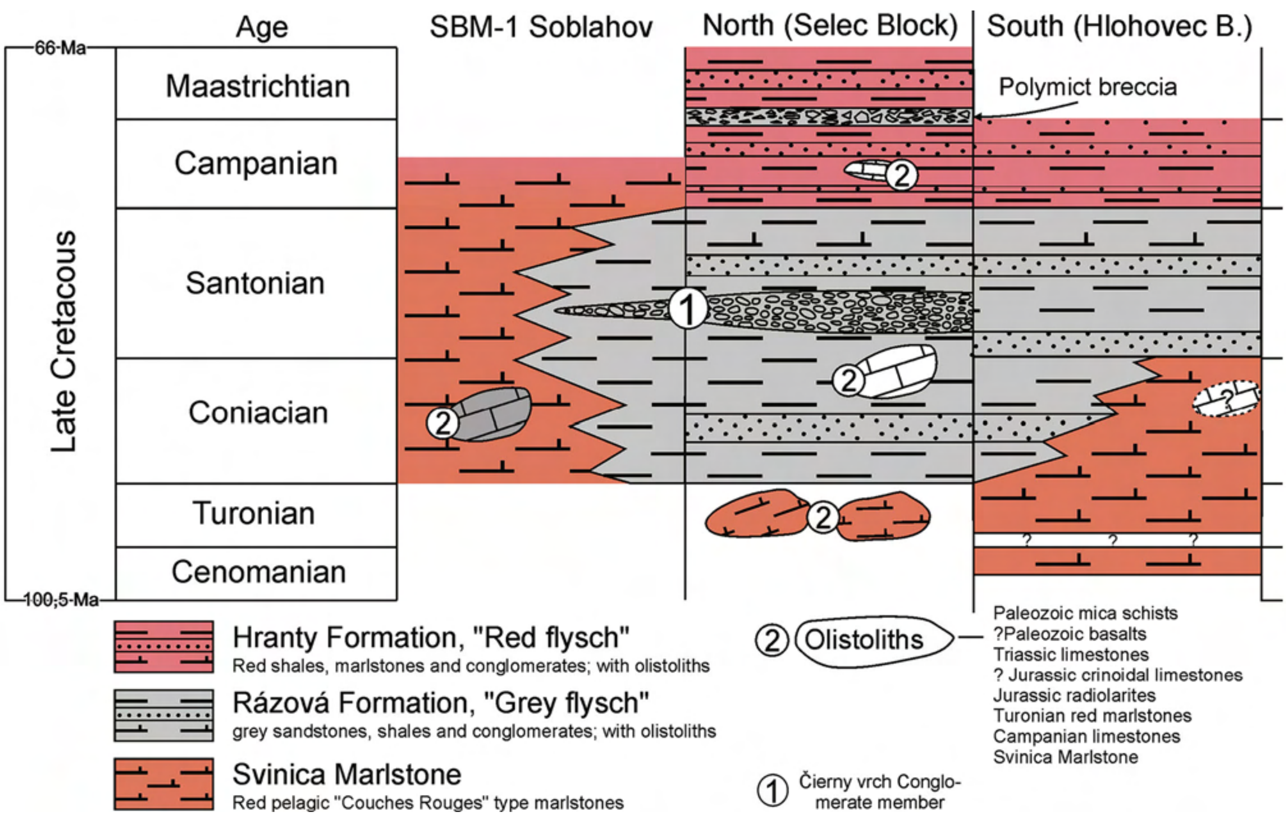

Fig. 3. Litostratigraphy of the Upper Cretaceous sequences in the PI and the SBM-1 borehole (according to Kullmanová, 1978; Maheľ, 1985; Plašienka et al., 1994; Rakús in Ivanička et al., 2011; Havrila in Maglay et al., 2011; Pelech et al., 2016 in this issue).

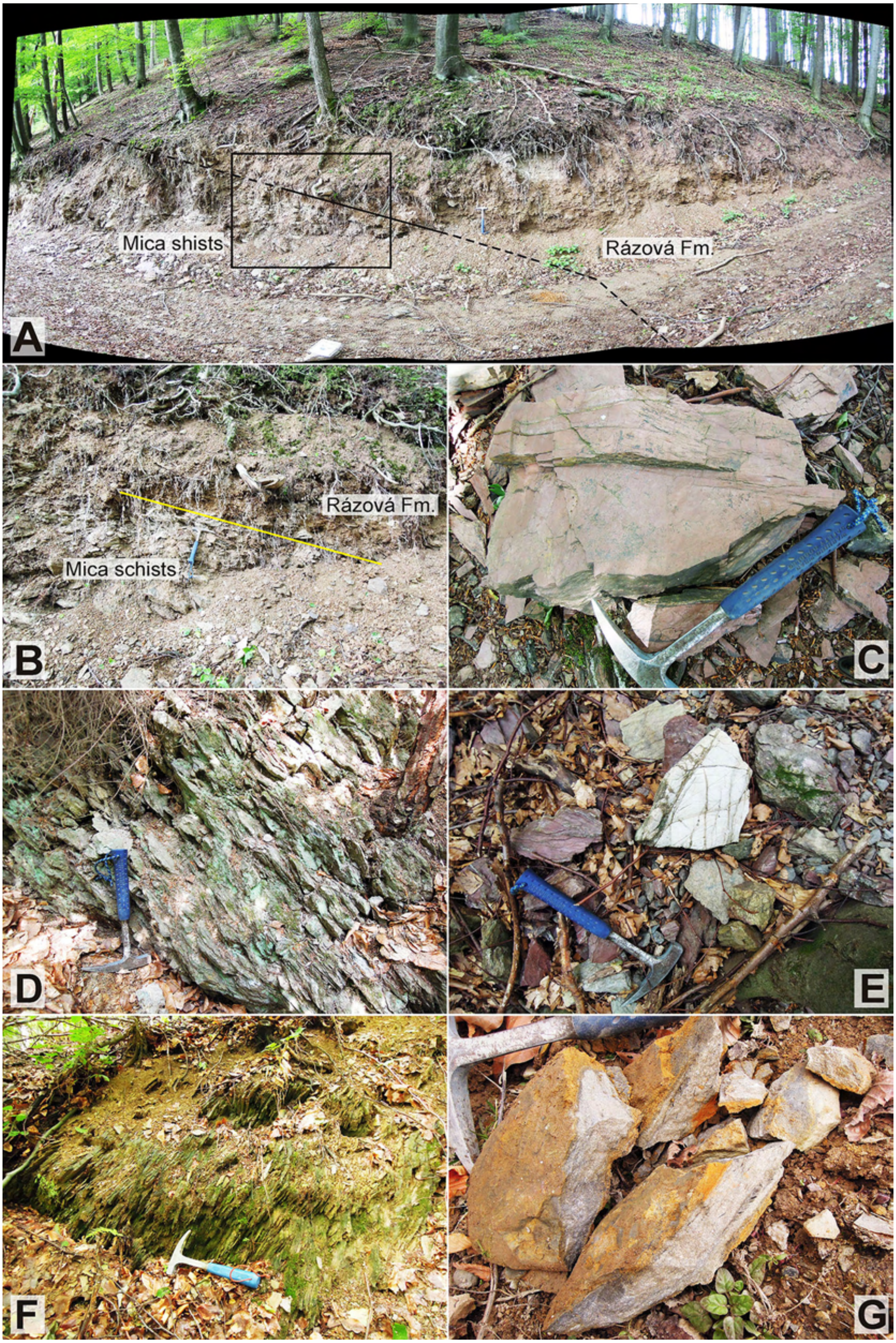

Fig. 4. A – Contact of the Rázová Fm. with the underlying micaschists, Krásna dolina Valley; B – Detail from the Fig. 4A; C – Red (Rupholding) Radiolarites, Humienec; D – Grey siliceous shales of the Lazy Fm., locality Lazy; E – The grey Calpionella Limestones in between the radiolarite debris, Lazy; F – Grey shales of the Rázová Fm., locality Humienec; G – Sandstones of the Rázová Fm., NW of the Humienec Hill.

from below the allochtonous Tatricum crystalline basement due to steep out-of-sequence thrusts according to Plašienka et al. (1994). The Belice Succession (*sensu* Plašienka et al., 1994) starts with red Ruhpolding radiolarites (Late Oxfordian, possibly Kimmeridgian; Plašienka & Ožvoldová, 1996) known from Lazy locality (Fig. 4C). However, the radiolarites at this locality are present in overturned position (if the sedimentary sequence *sensu* Plašienka et al. 1994 is accepted) and are overlain by grey siliceous shales. Thin beds of the Calpionella limestones with silicitic beds or cherts of the Early Berriasian age are described from the debris on the contact of both lithologies (Fig. 4E). The overlying grey siliceous shales (Fig. 4D) contain sporadic sections of hedbergelid foraminifera indicating Albian age (Kullmanová & Gašpariková, 1982; Soták in Plašienka et al., 1994). Poorly preserved *Hedbergella* sp. and *Thalmanninella* sp. were identified in the shales already by Kullmanová & Gašpariková (1982). However, they are usually present in the association with the genus *Globotruncana* which indicates redeposition of older taxa into the younger Upper Cretaceous formations. The red platy radiolarites and especially the grey siliceous shales interbedded by the grey Calpionella limestones constitute together a separate lithostratigraphic unit – the Lazy Formation. The continuous succession the Oxfordian–Lower Berriasian radiolarites and Calpionella limestones to Albian siliceous shales was never documented. The upper part of the Belice Succession which gradually passes from the grey siliceous shale is represented by Coniacian–Maastrichtian flysch (Rázová and Hranty Beds) of the Horné Belice Formation (Fig. 2).

Other geological investigations suggest that the original interpretation of a continuous sequence of the Belice Succession *sensu* Plašienka et al. (1994) must be reconsidered (e.g., Havrila et al., 1998; Rakús in Ivanička et al., 2011). In fact, the position of the "basal" red (Ruhpolding) radiolarites cannot be sufficiently documented. The problem whether they represent an individual tectonically separated thrust slices or olistoliths in the Upper Cretaceous flysch is a matter of debate. While the presence of olistoliths in the Coniacian–Santonian flysch at the locality Humienec is generally accepted, the occurrence at the locality Lazy is more problematic due to larger extent (1–1.5 km wide, tens of meters thick) of the body as well as its complicated position. The radiolarites here are overlain by the Coniacian–Santonian flysch but the sequence continues down the (overturned) section to grey siliceous shales with interbeds of the Calpionella limestone. The age of siliceous shales with sections of foraminifera *Hedbergella* sp. and *Thalmanninella* sp. believed to be Albian according to Plašienka et al. (1994) is disputed, however. Lithologically similar rocks are also known from other occurrences of the Upper Cretaceous complex (e.g., locality Rázová and Krásna dolina Valley) where they are considered as a part of "grey flysch" of Rázová Formation (Ivanička et al., 2007). The silicified shale bodies occur in the Rázová Formation on several places (e.g., at the type locality in the erosion gully on the Rázová). We believe that a such silicified body of the Rázová Fm. is in fact present as well at the locality Lazy. The presence of the Albian microfauna may be explained by redeposition which is very typical at numerous profiles of the Horné Belice Group (and was documented by Kullmanová & Gašpariková, 1982; Mahel' & Kullmanová, 1975; Mahel', 1985). According to facts mentioned above we propose that the existence of the Lazy Formation as a separate lithostratigraphic unit (*sensu* Plašienka et al., 1994) is very unlikely and instead represent olistoliths in Upper Cretaceous rocks.

Field observation in the Selec and Hlohovec Block of the PI (cf. Ivanička et al., 2007, 2011; Havrila et al., 1998); geophysical ERT survey on the locality Hranty (Bošanský et al., 2013) as well as results of the borehole HPJ-1 Jašter (Pelech, 2015; Pelech et al., 2016 in this issue) suggest that the old lithostratigraphic term Belice succession *sensu* Plašienka et al. (1994) should not be used any longer. We propose to continue the use of the term Horné Belice Group (*sensu* Rakús in Ivanička et al., 2011) which represents the Upper Cretaceous syn-orogenic flysch with olistoliths initially overlying the Tatricum crystalline basement.

3.2. Lithostratigraphy of Horné Belice Group

The **Horné Belice Group** (*sensu* Rakús in Ivanička et al., 2011; or Humienec Unit *sensu* Leško et al., 1988; partly corresponding to term Horné Belice Formation *sensu* Plašienka et al., 1994; Fig. 3) represents a lithostratigraphic unit of Late Cretaceous age, exposed in the PI and correlated with the lower part of the section penetrated by the borehole SBM-1 Soblahov in the western Strážovské vrchy Mts. It is mainly composed of two formations – the Rázová and Hranty formations and the Svinica Marlstone which position in the sedimentary sequence and relation to other lithostratigraphic units is discussed below. Overall thickness of the group is variable; however, it does not exceed 550 m. The direct sedimentary contact with underlying rocks is preserved only locally (e.g., locality Krásna dolina Valley; Fig. 11A and B; or occurrences NE of Hlohovec). The initial sedimentary contact with the basement is usually modified by the younger Alpine thrusts or Neogene normal faults at most sites.

The **Rázová Formation** ("Grey Flysch" *sensu* Marschalko in Plašienka et al., 1994) represents the most widespread lithostratigraphic unit of the Horné Belice Group. It is composed of dark grey to grey-green shaly, slightly calcareous claystone, marlstone to shale (Fig. 4F) with laminae of siltstone; sericite on the bedding planes; locally with medium beds of fine-grained calcareous sandstone of turbiditic character (Fig. 4G) and lenses of polymictic Čierny vrch Conglomerate Member and olistoliths of different rocks (Fig. 5C). The direction of palaeotransport of the Čierny vrch Conglomerate Member was generally from S to N (NNE to SSW, Marschalko in Plašienka et al., 1994). Grey claystones correlateable with the Rázová Fm. appear in the borehole SBM-1 in the depth intervals of 516–762 m, 850–1317 m, and 1347–1801 m (Mahel' & Kullmanová, 1975; Mahel', 1985). The Čierny vrch Conglomerate occur in the borehole as well. The Rázová Fm. is less developed in the area of the Hlohovec Block. It consists mainly of greyish brown shaly calcareous sandstone and shale with very low grade metamorphic overprint and silky lustre (sericite) on the bedding planes. The Rázová Fm. does not contain conglomerates, olistoliths and appears more distal in nature in this region (Havrila in Maglay et al., 2011). The age was determined based on foraminifera as Coniacian–Santonian (Kullmanová & Gašpariková, 1982; Soták in Plašienka et al., 1994). The thickness is varying between a few meters and 410 m. However, it is believed that locally observed thickness exceeding 200 m is a result of tectonic repetition of several thrust slices.

The upper portion of the Horné Belice Group is represented by the **Hranty Formation** ("Red Flysch" *sensu* Marschalko in Plašienka et al. l.c.). It is composed of red calcareous claystones and shales with bodies of grey-green calcareous sandstones, calcarenites of monomictic (mica schist) and polymictic sedimentary breccias (Fig. 5B). The bodies of polymictic chaotic breccias probably represent chaotic unsorted debris which

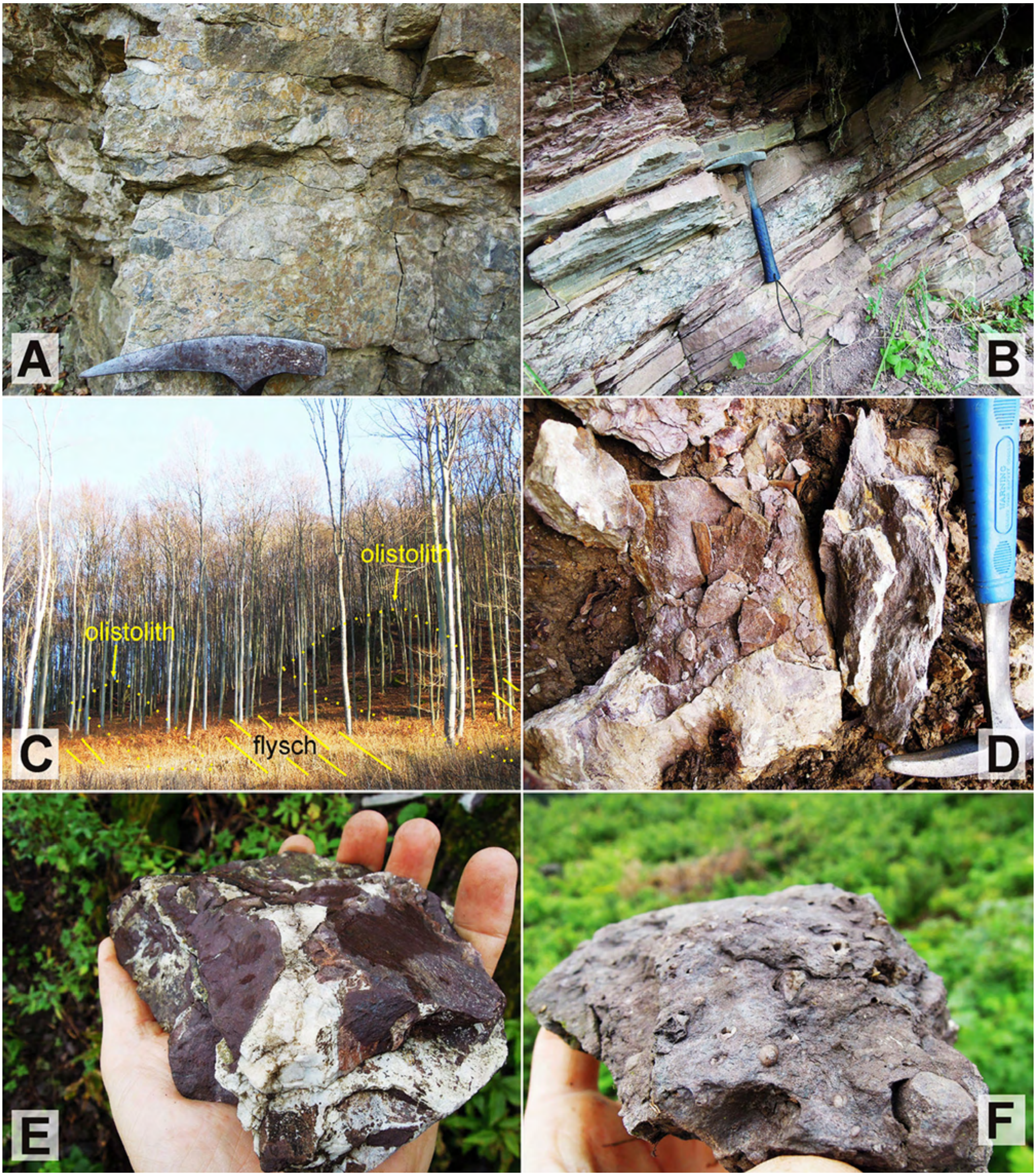

Fig. 5. A – The Čierny vrch Conglomerates at the Čierny vrch; B – Red claystones with beds of sandstones and mica schist breccias, Hranty Fm., locality Hranty; C – View from the valley of Turniansky potok to the locality Rázová. Olistoliths of limestones and dolomites occurring in the flysch of the Rázová Fm. which forms flat topography. D – Red and purple shales of the Svinica Marlstone, NE slope of the Humienec. E – Purple basalts with neptunic dykes of micritic limestone in the olistolith at locality Humienec; F – Amygdaloidal basalts from the olistolith on the locality Humienec.

experienced only short transport. The turbidites of the Hranty Fm. are characterized by the palaeotransport direction from the NW to SE, S and SW, thus in opposite direction than the underlying Čierny vrch Conglomerate (Marschalko in Plašienka et al., l. c.). The Hranty Fm. is represented by the red marlsones, shales to variegated pelagic limestones in the Hlohovec Block and is more distal than in the north as well (Havrila in Pristaš et al., 2000[b]; Havrila in Maglay et al., 2011). The analogous lithology known in the borehole SBM-1 was found at depth 1317–1345 m (Kullmanová, 1978). Based on occurrence of foraminifera, the age of Hranty Fm. is Campanian–Maastrichtian in the Selec Block (Soták in Plašienka et al., 1994); Coniacian–Early Campanian (Kullmanová, 1978; Gašpariková, 1980) in the borehole SBM-1 and Campanian in the Hlohovec Block (Salaj in Havrila & Vaškovský, 1983; Boorová in Havrila et al., 1998). The thickness varies between a few meters and 100 m.

3.2.1. The olistoliths

The Horné Belice Group could be classified as a collision related mélange or a sub-nappe mélange (*sensu* Festa et al., 2012) containing numerous olistoliths. Some of them are rather unique (radiolarites, basalts with neptunic dykes, Calpionella limestones with mica schist detritus; Upper Cretaceous pelagic limestones). The numerous olistoliths are large enough to be cartographically represented in the geological map at a scale of 1:50,000 (Ivanička et al., 2007; Geologická mapa Slovenska M 1:50 000, 2013).

Much controversy is related to the basalt olistolith found at the Humienec Hill. The basalts are purple-red to grey, massive or amygdaloidal and partially altered. It has alkali character and within plate basalt affinity. Several cm thick neptunic dykes composed of pale micritic limestone which are believed to be Jurassic in age are found at the Humienec (Soták et al., 1993). Several authors consider the occurrence of basalts as one of signs of the oceanic affinity of the Belice Succession (e.g., Soták et al., 1993; Plašienka et al., 1994). However, Their lithological, petrological, and geochemical character allows also unsophisticated correlation with the continental Permian volcanites of the Tatricum Kálnica Group (Putiš et al., 2006, 2008; forming relatively extensive bodies, e.g., in the Hôrčanská dolina Valley; Štimmel et al., 1984; Putiš, 1986; Olšavský, 2008).

Occurrence of olistoliths in association with basalts (of supposed oceanic character), radiolarites and siliceous shales lead several authors to correlate the Belice Succession with the Vahicum, the Carpathian analogue of the South Penninicum (Plašienka et al., 1994; Méres & Plašienka, 2009; Plašienka & Soták, 2015). However, the presence of radiolarites is known as well as in areas built by the continental or transitional crust (Mišík, 1999; Bill et al., 2001). The absence of other features tied to the oceanic crust (serpentinites, mid-ocean-ridge basalts) or subduction processes (HP-LT meramorphism) may cause serious doubts about the accuracy of the correlation of the Belice Succession with the oceanic Vahicum (Havrila in Pristaš et al., 2000[b]; Rakús & Hók, 2005; Hók et al., 2006; Bezák et al., 2008).

The Horné Belice Group contains several olistoliths of Upper Cretaceous rocks which probably represent the sediments transported from internal regions of the Late Cretaceous basin (from south or east in present day co-ordinates).

The olistolith of the **Svinica Marlstone** (*sensu* Plašienka et al., 1994; or reddish calcareous shale and shaly carbonate *sensu* Putiš et al., 2006) represents variegated marlstones of the Couches Rouges or CORB facies, known as the Púchov marls in the Carpathians. These facies do not usually occur south of the Pieniny Klippen Belt. However, it is known in the Gosau Group (Košariská and Nierental formations). The Svinica Marlstone is represented by the variegated, mostly purple-red, pink and grey-green, metamorphosed, slaty and deformed marlstones with cm-thick veins of creamy white calcite in the Selec Block (Fig. 5D). Similar rocks, mostly pinkish marlstones to pelagic limestones, locally with silt laminae and sericite on the bedding planes, overlying the granites were penetrated by the borehole HPJ-1 in the Hlohovec Block. Pink and variegated marlstones with calcite veins are described as well in the borehole SBM-1 in the interval 1317–1345 m (Kullmanová, 1978). The age was determined based on planktonic foraminifera as the Turonian in the Selec Block (Soták in Plašienka et al., 1994). The same lithofacies may range up to the Santonian (Mišík in Putiš et al., 2006). The age of variegated marlstone interval in the borehole SBM-1 was determined as Coniacian to Santonian (Kullmanová, 1978; Gašpariková, 1980) and Late Cenomanian–Coniacian in the borehole HPJ-1 (Józsa in Pelech et al., 2016 in this issue). Based on these findings it can be proposed, that the Svinica Marlstone is not stratigraphically limited to the Turonian, but this lithofacies may be also lateral equivalent of the Rázová Fm. The marlstones represent deep-water sedimentation with weaker siliciclastic input and different oxygenation conditions. The wider stratigraphic range documented in the borehole SBM-1 (Kullmanová, 1978); in the Selec Block (Mišík in Putiš et al., 2006) as well as in Hlohovec Block (Józsa in Pelech et al., 2016 in this issue), also indicates a gradual transition between the Svinica Marlstone and "Red Flysch" of the Hranty Fm. which differs mainly by higher amount and coarser siliciclastic admixture and thicker sandstone beds.

Weakly metamorphosed **pale grey micritic limestones** without cherts but with mica schist lithoclasts represent the second type of the Upper Cretaceous sediments occurring in the mélange as olistolith. This type is known only from one olistolith at the locality Svinica on the NE slopes of the Humienec in the Selec Block. It contains foraminifera indicating middle to late Campanian age (Boorová in Rakús et al., 2006).

3.3. Structural cross-sections

3.3.1. Rázová

One of the classic localities of the Horné Belice Group occurrence is the area between the Jastrabie Fault and the Paľová, SW of Mníchova Lehota. The investigated locality represents structurally the lowermost thrust slices of the Upper Cretaceous rocks known from the surface, where the character of the Rázová Fm. and occurrence of olistoliths could be well studied (Fig. 6A and B).

Unlike the previous investigation (cf. Ivanička et al., 2007) the geological mapping and field research in this area did not confirm the presence of Upper Cretaceous sequences west of the Rigeľ creek and north of elevation 538 m a.s.l. More to the W, in the investigated section (Fig. 6B) on the northern slopes of the locality Rázová, olistoliths of rocks of Early and Middle Triassic age were observed in the Rázová Fm. (Fig. 5C). The studied section is monoclinal dipping to SE and is overlaid by the rudimentary preserved overturned fold limb (Fig. 6A) of the Tatricum sedimentary cover composed of Lower Triassic quartzites and Permian sandstones of the Kálnica Group

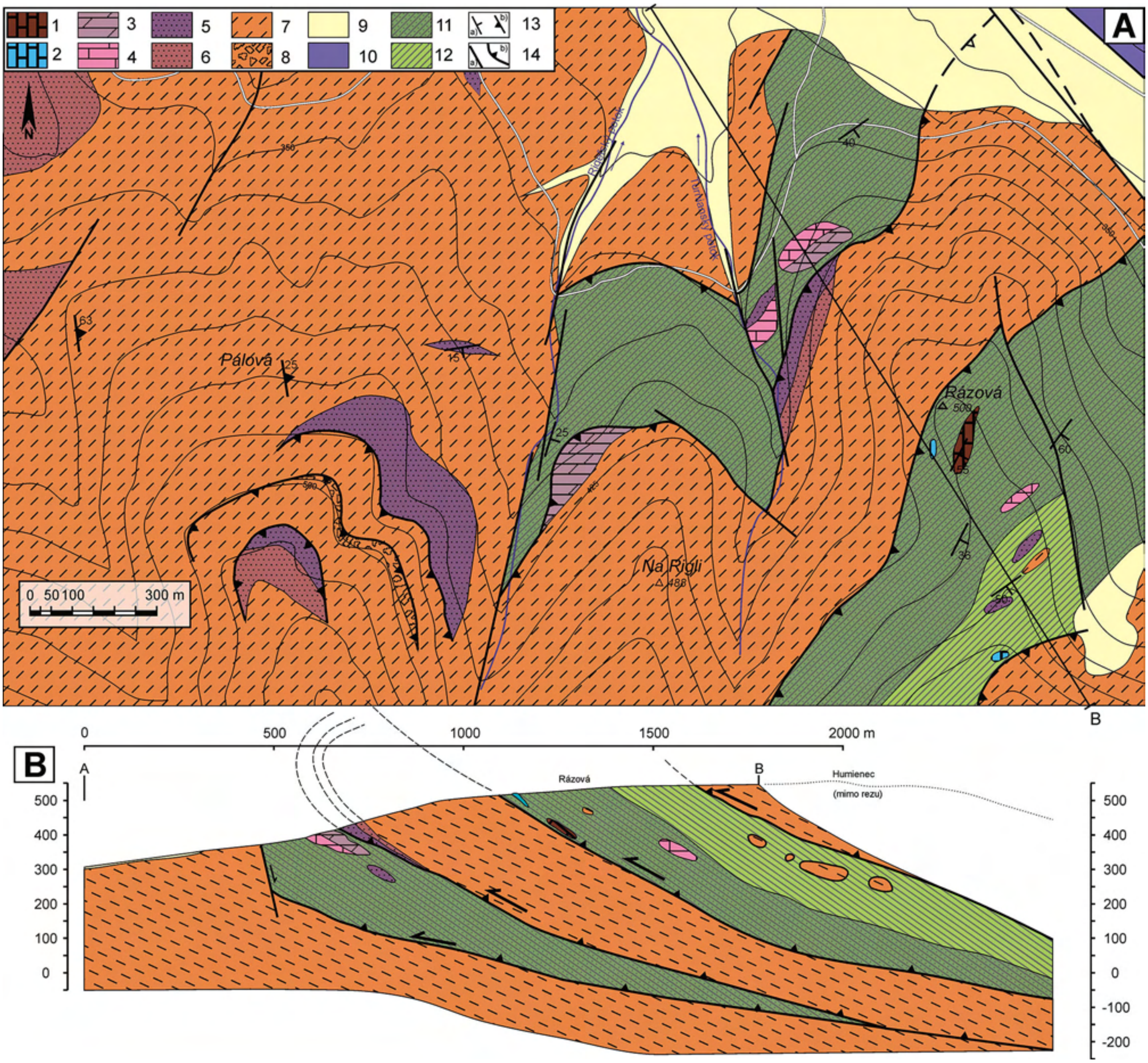

Fig. 6. A – Geological map of the Rázová (see location in Fig. 1). B – Geological cross section A-B through the locality Humienec and Rázová (without vertical exaggeration). 1: Ruhpolding Radiolarite (Upper Jurassic); 2: Trlenská Formation (Lower Jurassic); 3: Ramsau Dolomite (Middle Triassic); 4: Gutenstein Limestone (Middle Triassic); 5: Lúžna Formation (Lower Triassic); 6: Krivosúd Formation (Upper Permian); 7: Mica schist (Carboniferous); 8: Mica schist breccia; 9: Undivided Quaternary sediments; 10: Hronicum undivided; 11: Rázová Fm. (Coniacian – Santonian); 12: Hranty Fm. (Campanian – Maastrichtian); 13: a) Bedding; b) Metamorphic schistosity; 14: a) Normal and strike-slip fault; b) Thrust and reverse fault.

occurring below the mica schist basement rocks. Similar sequence is found in the area of the elevation 538 m a.s.l. and overlies the body of tectonic breccia with mica schist clasts (found only in debris). The breccia is apparently linked with the thrust fault; however, there are no signs about the presence of the Upper Cretaceous rocks below.

3.3.2. Prostredná dolina Valley

Relicts of the Upper Cretaceous structure can be observed at the end of the Prostredná dolina Valley in the region of the Horné vápenice and Pod Jakubovou. Structural cross-section is oriented in NW–SE direction (Fig. 7B) perpendicular to the so called Selec thrust (Štimmel et al., 1984). The existence of the Selec thrust is confirmed for example in the borehole no. 808 (Štimmel et al., 1984). The lowermost structure belongs to the Mesozoic carbonates of the Hradisko Hill which are overlaid by the Upper Cretaceous rocks and overridden by the Tatricum crystalline basement. The NW region of investigated area is dominated by the flat lying body of the Selec thrust composed of the Permian rocks that wedge out to the E (Štimmel et al., 1984). The Selec thrust represents SE-vergent imbricated zone, where the Permian sedimentary and volcanoclastic rocks are (?back-)thrusted over the weakly metamorphosed Triassic carbonates of the Hradisko Hill (mega-olistolith *sensu* Plašienka et al., 1994).

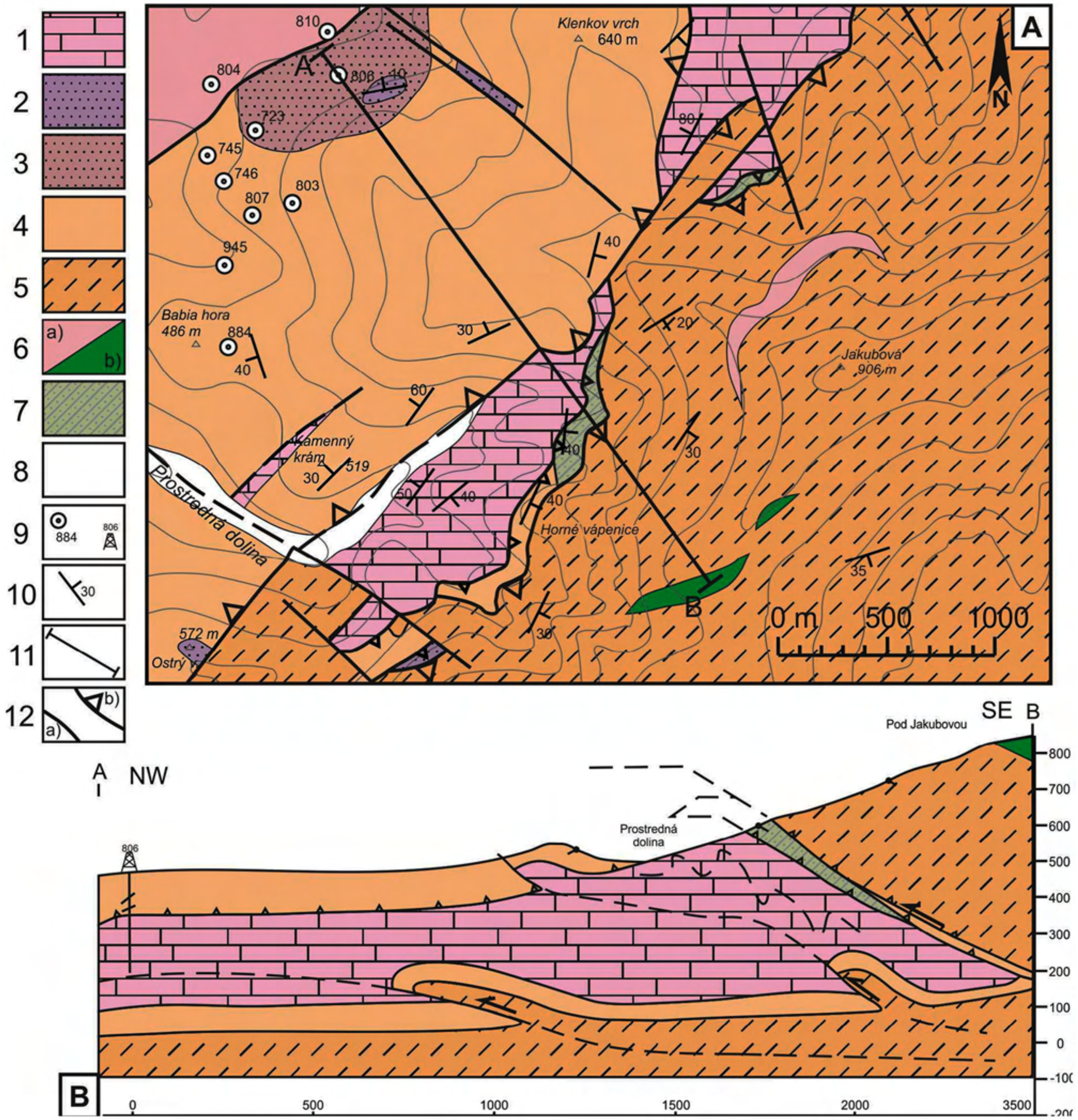

Fig. 7. Position of the Upper Cretaceous sediments at the end of the Prostredná dolina Valley (Horné vápenice). Map (A) (based on Ivanička et al., 2007, slightly modified) and cross-section (B). Legend: 1: Gutenstein Lmst. (Anisian); 2: Lúžna Fm. (Lower Triassic); 3: Krivosúd Fm. (Upper Permian); 4: Selec and Kálnica Fm. (Lower Permian); 5: Chlorite-muscovite mica schist (Carboniferous); 6: a) Quartz paragneiss, b) Amphibolite; 7: Rázová Fm. (Coniacian – Santonian); 8: Quaternary sediments undivided; 9: Borehole; 10: Bedding or metamorphic schistosity; 11: Geological cross-section; 12: Faults: a) normal and strike-slip fault, b) Thrust and reverse fault.

The limestones of the Hradisko Hill are folded and inclined to the SE below the thrust slices of the Upper Paleozoic and the Upper Cretaceous rocks. The Horné Belice Group here is mainly composed of the Razová Fm., grey calcareous shales and sandstones (Fig. 11A) with olistoliths. The uppermost part of the Rázová Fm. is characterized for presence of the olistoliths of crinoidal limestones (Fig. 11B) with intraclasts of mica schists and the Upper Paleozoic rocks. The clasts of Triassic limestones and dolomites occur sporadically in the middle and lower part of the section. The basal part is composed of the mica schist breccia of tectonic or sedimentary origin. The Upper Cretaceous rocks form approx. 100 m thick thrust slice wedging out to the SE.

The eastern part of the area is built mostly by the thrust sheet of mica schist crystalline basement, overlying rocks of the Horné Belice and Kálnica Groups and the Mesozoic carbonates.

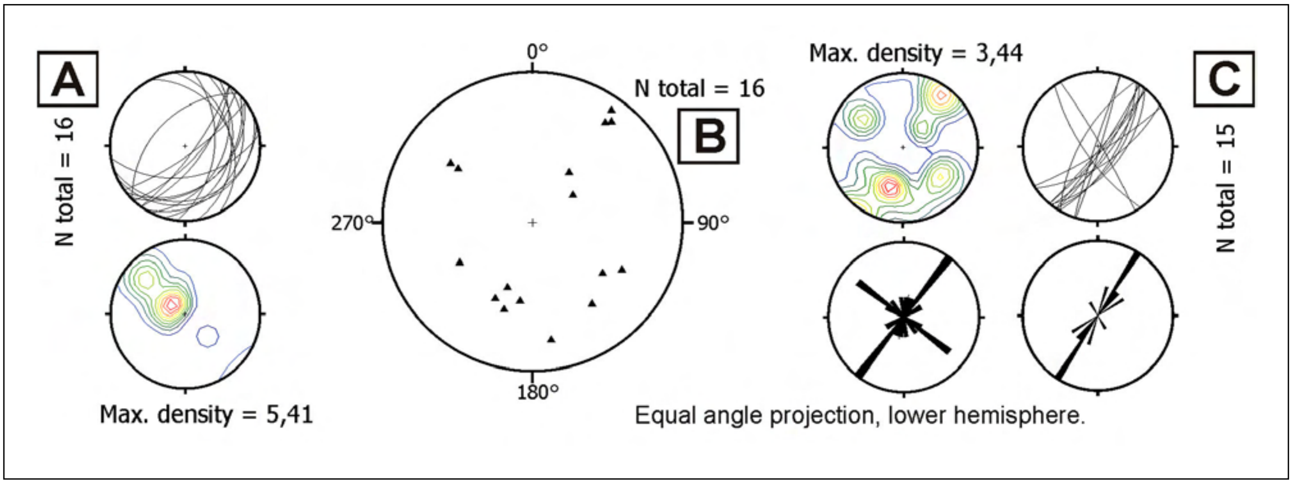

Fig. 8. Structural characteristics of the Upper Cretaceous sediments in the Selec Block: A: Bedding planes; B: strike of fold axis; C: orientation of cleavage planes.

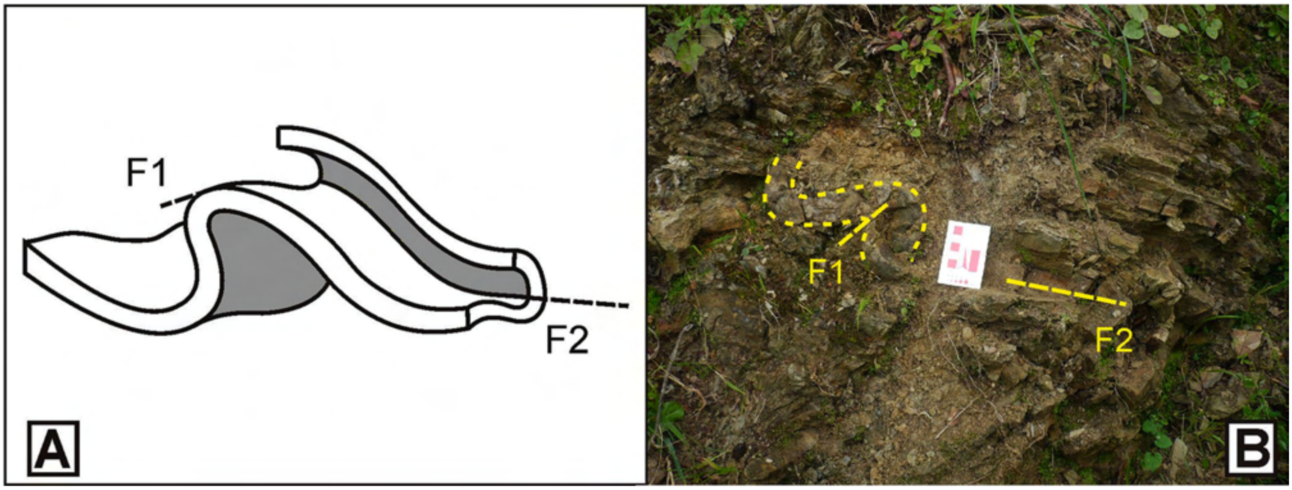

Fig. 9. A: Scheme of complex folds with two axis in rocks of the Rázová Fm. B: Complex fold with two axis on the site Hradisko. F_1 fold with NW-vergence and F_2 with SW vergence.

3.3.3. Deformation of the Selec Block

According to the current structural observations, geological mapping (Hók et al., 2006) and geophysical data (Bošanský et al., 2013) the Upper Cretaceous sequences represent strongly deformed hundreds meters thick thrust slices overlying the Tatricum crystalline basement or a rudimentary preserved sedimentary cover. The thrust slices are usually dipping to the SE (Fig. 8A) and are located below the thrust of the crystalline basement, locally below the overturned fold limbs of the Tatricum sedimentary cover. Two generally perpendicular fold axis are present. The NE–SW trending folds (F_1) are prevailing, while the NW–SE folds (F_2) are less common (Fig. 8B). The F_1 folds are associated with the SE-dipping fold axis cleavage planes (Fig. 8C). Non-cylindrical macrofolds of decimetre dimensions with two superimposed fold axis are well preserved; particularly in the Rázová Fm. below the Hradisko Hill (Fig. 9A and B). These folds may represent two deformation events but they can also be the result of the inclined transpression (Jones et al., 2004; Plašienka, 1995). More pronounced fold axis F_1 formed during NW- or W-vergent thrusting, whereas the F_2 are consequence of strike-slip component of the movement.

3.3.4. Hlohovec, the Soroš Quarry

Structural observations in the region of Hlohovec could really only on observation of few exposures (Plašienka, 1999; Pelech, 2015) and the results of the borehole HPJ-1 (Pelech et al., 2016 in this issue). The best exposed sequences of Late Cretaceous age were observed in the Soroš quarry and its vicinity (Fig. 10). They are dipping generally to the S and SE (outside the quarry also to the W, Fig. 12). Penetrative foliation of the Mesozoic complexes is result of flattening due to the lithostatic overburden pressure as well as rotation of cleavage planes to the plane parallel to the metamorphic schistosity (S_0 parallel to the S_1 and C; Fig. 11C–F). The SE–NW orientation of tectonic transport is inferred from the orientation of mineral stretching lineation expressed by the growth of calcite aggregate in the

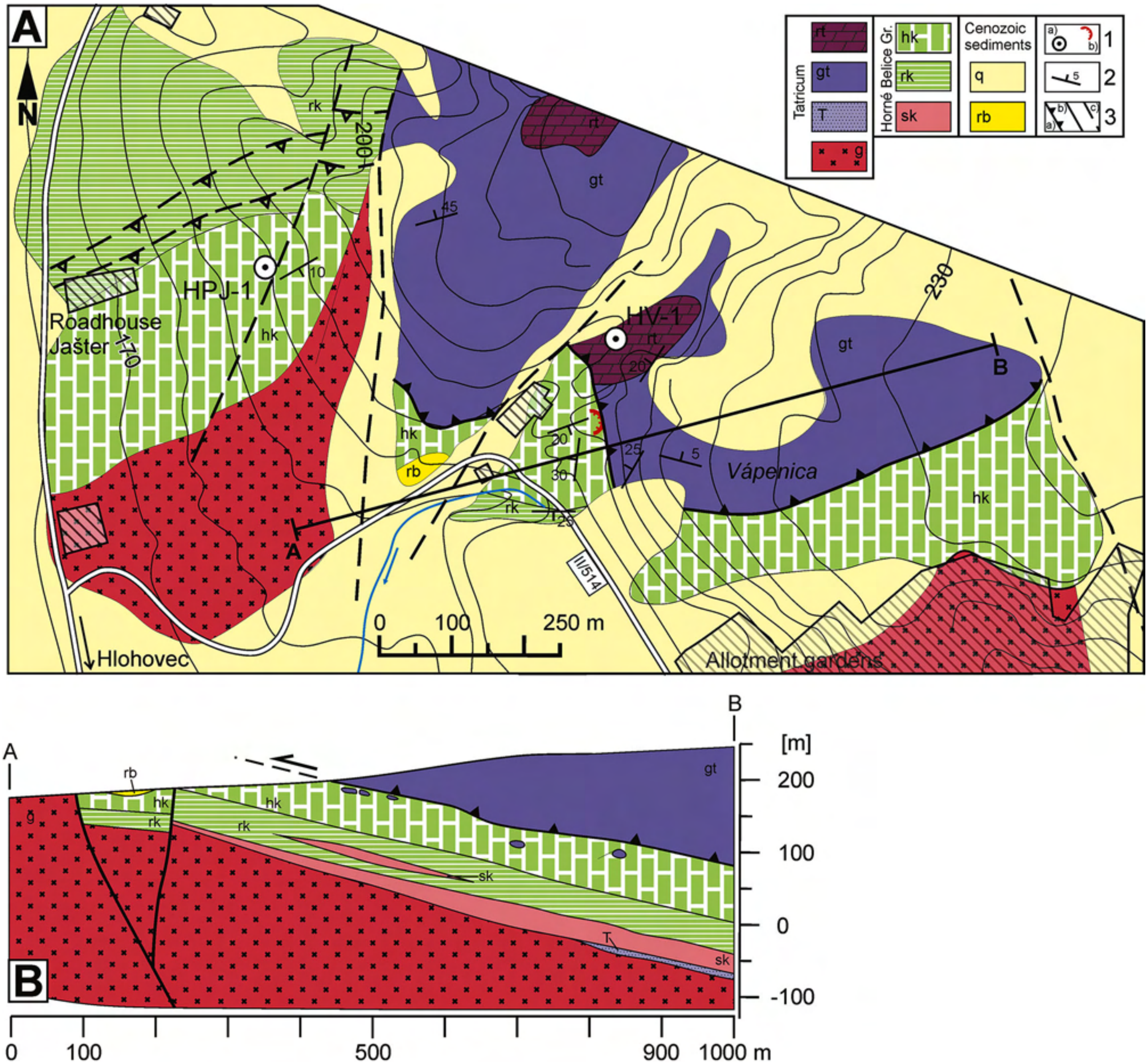

Fig. 10. A – Geological map of the area north of Hlohovec, including Soroš quarry (modified after Ivanička et al., 2007 and own data). Legend: rk: Rázová Fm. (Coniacian – Santonian); hk: Hranty Fm. (Campanian); sk: Svinica Marlstone (Late Cenomanian – Campanian), only in cross-section. Tatricum: g: Granodiorite (Carboniferous); T: Triassic sediments undivided, only in cross-section; gt: Gutenstein Limestone (Middle Triassic); rt: Ramsau Dolomite (Middle–Upper Triassic). Cenozoic sediments: rb: Ratkovce Beds (Badenian); q: Undivided Quaternary sediments. 1: a) borehole; b) Soroš quarry. 2: strike and dip of beds. 3: a) Thrust fault, b) Normal fault or strike-slip fault; c) inferred fault. B – Geological cross-section.

limestones (Fig. 11D) or fine-grained phyllosilicates in the calcareous shales of the Late Cretaceous age (Fig. 11F). No reliable kinematic indicators were observed in situ. According to the structural position, stretching lineation and broader regional relationships but the top to the W or NW direction of tectonic transport could be predicted. This is consistent with earlier observation by Plašienka (1999).

The overall structural position of the Upper Cretaceous sediments in the hanging wall of the Tatricum sequences is evident from the map view, especially north of allotment gardens (Fig. 10A), as well as from results of borehole HPJ-1 (Pelech et al., 2016 in this issue).

3.4. Structural position in broader context of the Tatricum

Alpine shear zones in the Tatricum domain are known from the Malé Karpaty Mts. (Plašienka, 1990; Plašienka et al., 1991), the Považský Inovec Mts. (Putiš, 1991; Putiš et al., 2008; Pelech, 2015) as well from the Tribeč Mts. (Lenárt & Hók, 2013). Geochronological data (Putiš, 1991; Putiš et al., 2008, 2009) suggest that shear zones were active mostly in the Albian–Santonian (the youngest up to Early Eocene time). If the gradual Palaeo-Alpine (Eo-Alpine) Late Cretaceous convergence of the IWC units with their foreland is taken into account and

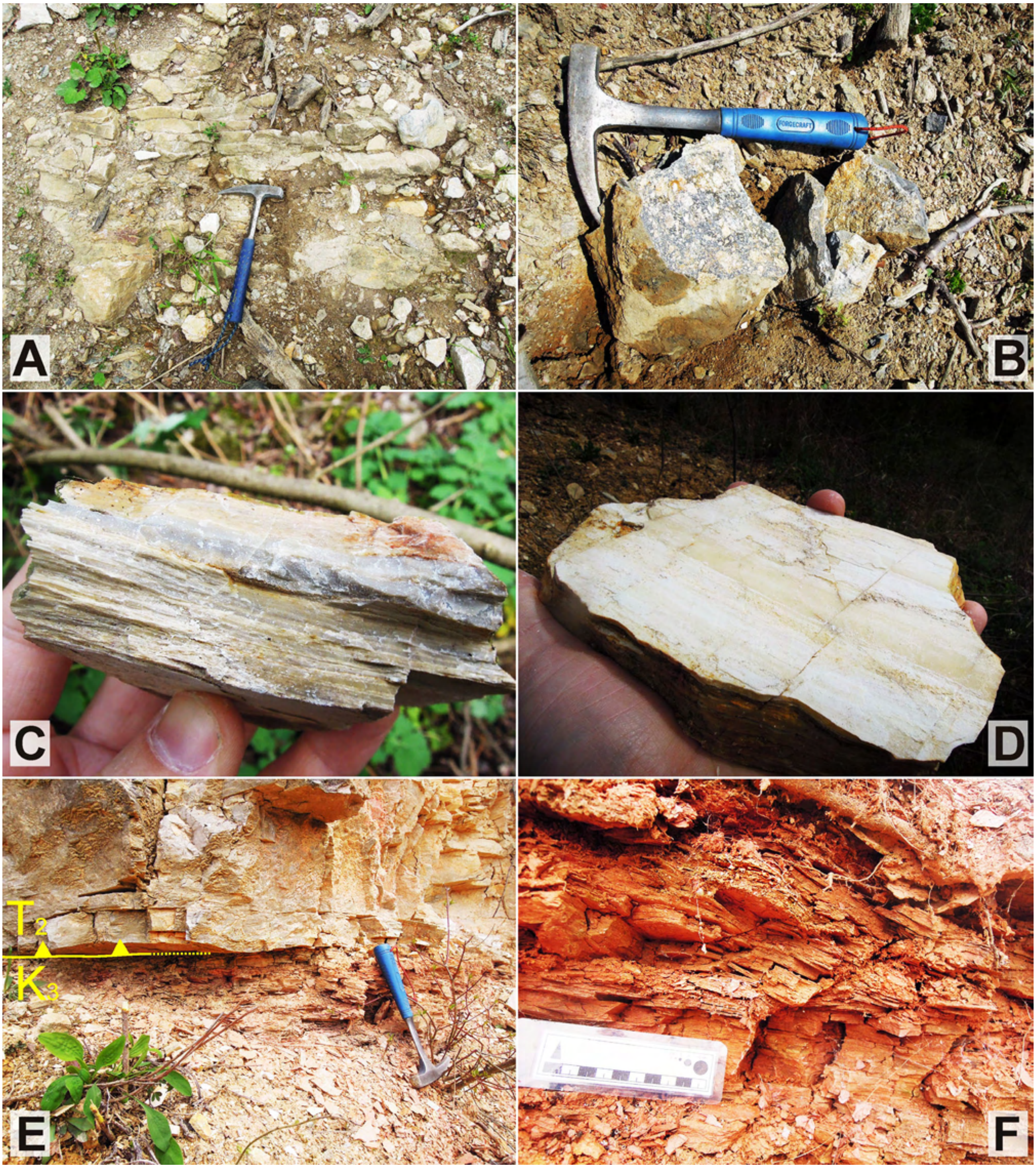

Fig. 11. A – Grey-green thinly bedded sandstones of the Rázová Fm., Prostredná dolina - Horné vápenice; B – Grey crinoidal limestone with mica-schist clasts, Horné vápenice. C – Foliation and metamorphic overprint of metacarbonates to marbles of the Middle Triassic age in the Soroš quarry. D – Foliation planes and stretching lineation in the metamorphosed limestones/carbonatic phyllonites of Middle Triassic age. E – Thrust contact of the Triassic limestones over the Upper Cretaceous rocks in the Soroš quarry. F – Metamorphosed red marly shales of Late Cretaceous age situated a few meters below the tectonic contact.

presumed nappe emplacement of the Fatricum and Hronicum in the Cenomanian–Turonian (Andrusov et al., 1973; Plašienka 1999; Prokešová et al., 2012) is accepted. The documented ages of thrusting before the Coniacian could be considered as out-of-sequence thrusts.

The existence of thrust slices is most evident in the east part of the Selec Block in the footwall of the Hrádok-Zlatníky shear zone. The region is build dominantly by the Tatricum mica schist crystalline basement with number of predisposed discontinuities. The area is bounded from the south by the roof thrust of the

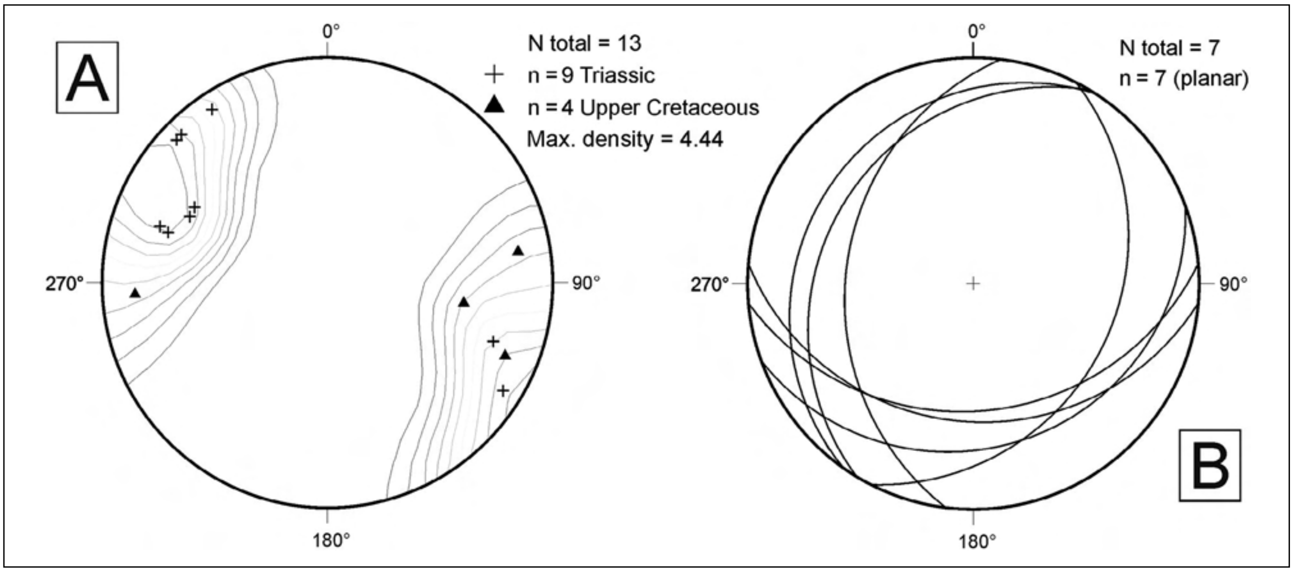

Fig. 12. Structural diagrams from the area of Soroš quarry and its surroundings. A – Orientation of the stretching lineation measured in the Triassic carbonates (+) and Upper Cretaceous sequences (Δ). B – Bedding planes and metamorphic foliation in the Triassic carbonates and the Upper Cretaceous complexes.

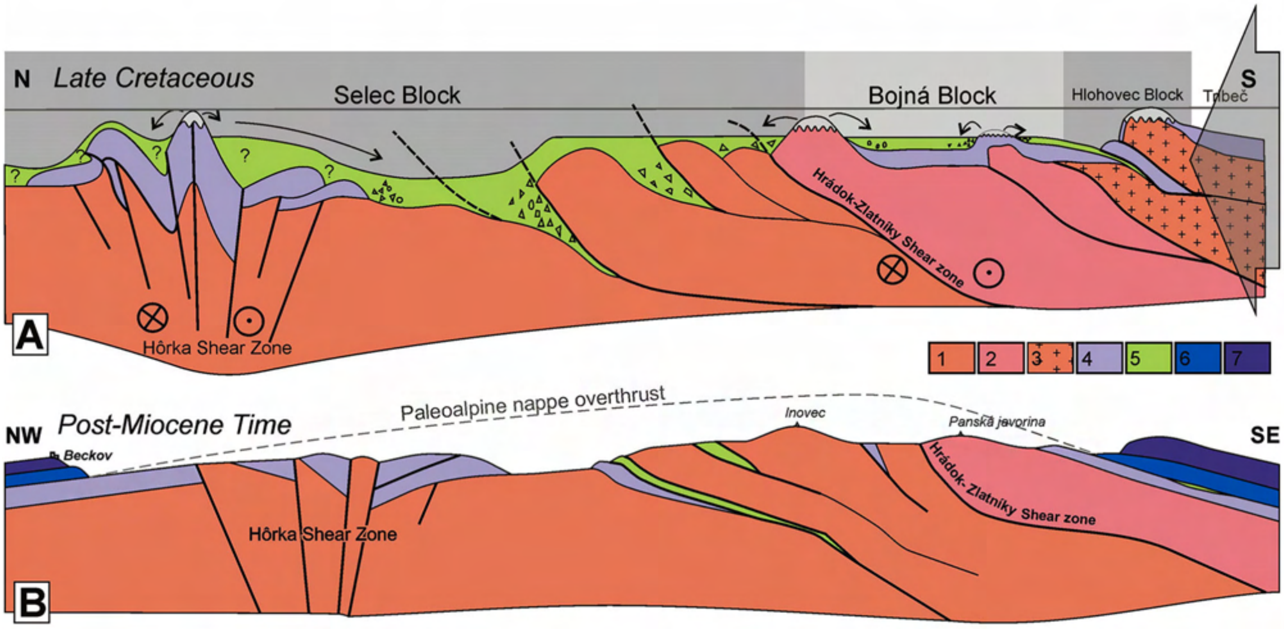

Fig. 13. Schematic profile of the Late Cretaceous sedimentary basins in the area of Považský Inovec Mts. (A) and the structural position of the Selec Block in the Post-Miocene period (B). 1: Crystalline basement of the Tatricum Selec Block; 2: Crystalline basement of the Tatricum Bojná Block; 3: Crystalline basement of the Tatricum Hlohovec Block; 4: The Upper Paleozoic and Mesozoic sediments of Tatricum; 5: The Upper Cretaceous sediments (the Horné Belice Group); 6: Fatricum; 7: Hronicum.

Hrádok-Zlatníky shear zone and from the west by the (?dextral) strike-slip of the Hôrka shear zone (*sensu* Pelech, 2015). At least two thrust slices of basement rocks are separated by a thin strip of the Upper Cretaceous Horné Belice Group in the eastern Selec Block (e.g., Rázová, Fig. 6). The Upper Paleozoic Kálnica Group sediments and the less common Mesozoic sediments occur in the same structural position on several places (e.g., Krásny buček, Jablunkov vrch; Stanova dolina; Ivanička et al., 2007).

The Hlohovec Block represents more internal zone of the Tatricum which is usually correlated with the Tribeč Mts. (Broska & Uher, 1988; Ivanička et al., 2011). The Upper Cretaceous sediments here overlie the Tatricum Hercynian granitoids as is documented by the borehole HPJ-1 (Pelech et al., 2016 in this issue). The geological structure in the quarry Soroš (Fig. 11E) well documents the position below the metamorphosed Triassic carbonates considered as Tatricum (Havrila in Maglay et al., 2011).

Occurrence of rocks correlated with the Horné Belice Group is known from below the Belá or Manín Unit (Fatricum) in the borehole SBM-1 Soblahov (Mahel' & Kullmanová, 1975). The age of the sediments was determined Coniacian–Early Campanian (Kullmanová, 1978; Gašpariková, 1980) and with some uncertainty could possibly continue up to the Eocene (Maheľ, 1985).

Wagreich & Marschalko (1995) introduced an idea that the Campanian–Maastrichtian subsidence in the Gosau and Brezová groups was driven by the subduction erosion along the external margin of Adriatic/Austroalpine plate in fore-arc position. A similar model for the younger Palaeogene deposits was proposed by Kázmér et al. (2003).

Recently a model of the Late Cretaceous and Palaeogene foreland basin controlled by the change of critical taper of the IWC orogenic wedge was proposed by Plašienka & Soták (2015). The Upper Cretaceous sequences (the Belice Succession *sensu* Plašienka et al., 1994) are considered to be the relicts of accretionary complex of Vahicum – the South Penninicum in the PI. However, the interpretation of the Upper Cretaceous succession as the exhumed relicts of the oceanic crust or ocean-continent transition zone in the Považský Inovec Mts. is highly questionable and is not followed in this paper.

This interpretation contradicts the series of observations: 1) serious doubts regarding continual sedimentary sequence from the Jurassic to Upper Cretaceous members (the Lazy Fm.); 2) occurrence of the Upper Cretaceous rocks between the thrust slices (or synclines) of the Tatricum basement; 3) the absence of material of undoubtedly oceanic origin. Presence of the Jurassic radiolarites (despite geochemical affinity, Méres & Plašienka, 2009) is not sufficient argument for correlation with oceanic crust (cf. Mišík, 1999; Bill et al., 2001). Lithological and stratigraphic difference in comparision with classical occurrences of the Penninicum is yet very significant (cf. de Graciansky et al., 2011). The presence of important structural discontinuities, heavy masses or strongly magnetic bodies of oceanic or transitional crust bellow or in vicinity of the PI was not confirmed by means of seismic (Vozár et al., 1999), magnetic (Kubeš et al., 2010), magnetotelluric (Bezák et al., 2014), gravimetric (Szalaiová & Šantavý, 1996) nor other geophysical methods (Kucharič et al., 2013).

Putiš et al. (2008) proposed a passive margin model for the Upper Cretaceous sediments in the PI. This interpretation; however, does not take into account discontinuous sedimentary sequence and presence of the Upper Cretaceous rocks in the northern, central and southern block of the PI (both external and internal Tatricum zones), or timing of emplacement and erosion of the Fatricum and Hronicum in the region. If the structural position of the Upper Cretaceous rocks between thrust slices of the Tatricum and below the Fatricum and Hronicum nappe pile is considered, the piggyback or wedge top basin model may explain the occurrence of the Upper Cretaceous sequences in the PI. It is analogous to model of Wagreich (2001) but not limited only to the Fatricum (Tannheim-Losenstein nappe in Alps) but also to the Tatricum.

4. CONCLUSION

The subduction of the Vahicum bellow the Internal Western Carpathian (IWC) orogenic wedge is today considered as one of the main mechanisms that triggered the foreland vergent motion of the IWC units and led to compression in the region of the Pieniny Klippen Belt and Carpathian Flysch Belt. The Belice Succession (*sensu* Plašienka et al., 1994) present in the Považský Inovec Mts. (PI) is considered the main representative of the Vahicum (Penninicum) in the present surface structure of the Western Carpathians. Based on the evaluation of previous studies and own observations, it is necessary critically review the possibility of a continuous sedimentary sequence of the Belice Succession from the Jurassic to Upper Cretaceous. The Upper Cretaceous rocks, here referred as the Horné Belice Group (*sensu* Rakús in Ivanička et al., 2011), known from the Selec and Hlohovec blocks form syn-orogenic gravity driven deposits locally with olistoliths originating from overriding tectonic units or eroded internal parts of the sedimentary basin (Svinica Marlstone; Campanian grey limestones).

Based on the occurrence of the variegated marls similar to the Púchov Marls (Cretaceous Oceanic Red Bed facies) which represent deposits of periods of pelagic sedimentation between the episodes of input of clastic, gravity derived sediments, it could be assumed that the Late Cretaceous sedimentary basin in the region of the PI was hydrodynamically connected to the region of Peri-Klippen zone or directly to the Oravicum.

Formation of the sedimentary basin was influenced by the higher sea level (Haq, 2014). The Late Cretaceous piggyback basin sediments overlaid disintegrated Tatricum basement. The major accumulation of the sediments was deposited in the wedge-top and piggyback basins not only on and between the Tatricum thrust slices of the Selec Block but as well as top the Hronicum (Fig. 13A and B). Subsequent deformation of the Tatricum crust led to formation of several partial thrust slices. Similar structural position of syn-orogenic sediments below the overthrust, is proposed for the occurrence of the Upper Cretaceous sediments in the Hlohovec Block. However, the Horné Belice Group sediments there are situated bellow the metamorphosed Triassic carbonates probably of the Tatricum origin.

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