

REVIEW PAPER

Linkage of the Manín and Klope units with the Pieniny Klippen Belt and Central Western Carpathians: balancing the ambiguity

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Abstract: The paper deals with the structure and evolution of the Pieniny Klippen Belt in its classic area in western Slovakia. The so-called Peri-Klippen Zone provides a transition from the Pieniny Klippen Belt s.s. built up by Jurassic to Eocene Oravic units (Šariš, Subpieniny and Pieniny from bottom to top) to the outer margin of the Central Western Carpathians composed of Triassic to mid-Cretaceous successions of the Fatric and Hronic cover nappe systems. The Peri-Klippen Zone attains a considerable width of 15 km in the Middle Váh River Valley, where it is composed of the supposedly Fatric Manín, Klope and Drietoma units, as well as their post-emplacement, Gosau-type sedimentary cover. All these units are tightly folded and imbricated. The complex sedimentary and structural rock records indicate the late Turonian emplacement of the frontal Fatric nappes in a position adjacent to or above the inner Oravic elements, whereby they became constituents of an accretionary wedge developing in response of subduction of the South Penninic–Vahic oceanic realm separating the Central Western Carpathians and the Oravic domain. Evolution of the wedge-top Gosau depressions and the trench-foredeep basins of the foreland Oravic area exhibit close mutual relationships controlled by the wedge dynamics. The kinematic and palaeostress analyses of fold and fault structures revealed only one dominating stress system coeval with development of the accretionary wedge, which is characterized by the generally NW–SE oriented main compression axis operating in a pure compressional to dextral transpressional regime, interrupted by short-term extensional events related to the wedge collapse stages. Younger, Miocene to Quaternary palaeostress fields correspond to those widely recorded in the entire Western Carpathians. Relying on the regional tectonostratigraphic and structural data, the problematic issues of the palaeogeographic settings of the Manín and Klope units, presumably affiliated with the Fatric cover nappe system, and of the provenance of numerous olistoliths occurring at different stratigraphic levels are then discussed in a broader context.

Keywords: Western Carpathians, Peri-Klippen Zone, Fatric nappe system, sedimentary and structural rock record.

Introduction

The Middle Váh River Valley (Stredné Považie) is the traditional area, where the Manín Unit (Andrusov 1931) and later also the Klope Unit (Scheibner 1968a; Marschalko & Kysela 1980) were defined. Although generally assigned to the Pieniny Klippen Belt (PKB), due to some specific features these units have been usually treated separately as the so-called Peri-Klippen Zone. This was defined by Mahel' (1980) as a structural zone adjacent from SE to the “proper” PKB formed by the Oravic units, such as the Czorsztyń and Kysuca–Pieniny. In contrast, the Peri-Klippen Zone is built by units of an ambiguous tectonic affiliation: the Manín, Klope, Drietoma and Haligovce units, and possibly also some other problematic elements in other PKB parts.

Palaeogeographic and tectonic settings of the Manín Unit and related elements (such as the Klope Unit, which was not distinguished until 1960-ties, and the Drietoma Unit occurring further to the SW) belong to the most controversial and widely discussed issues of the Western Carpathian geology. The Manín

Unit has had a key place in interpretation of the structure and evolution of the Western Carpathians starting from early 1930-ties when the first integrated concepts of tectonics of the Klippen Belt, as well as of the central Carpathian zones were formulated (Matějka & Andrusov 1931). In 50-ties and 60-ties of the previous century, two contradictory opinions were developed, which are described as the Andrusov's and Mahel's concepts below. Both views have had several relevant arguments, hence no generally accepted solution of the Manín controversy has been achieved yet.

In the ambiguous position between the PKB and the Central Western Carpathians (CWC), the tectonic and/or palaeogeographic affiliation of the Manín Unit has remained contentious until the recent times. In addition to the uncertain tectonic position, the controversy results from the “Central Carpathian” character of its Jurassic to Lower Cretaceous sedimentary succession, while the Upper Cretaceous and Palaeogene formations rather indicate the “Klippen Belt” connection. Moreover, the structural style of the Manín Unit was also mostly compared with the Klippen Belt, owing to the presence of large

rigid “klippen”, like the Manín and Butkov hills surrounded by soft sedimentary formations. However, unlike most of other similar structures in the Klippen Belt proper, these klippen are structurally and stratigraphically closely related to their “klippen mantle” and clearly represent cores of large brachyanticlines (Stur 1860; Andrusov 1938, 1968; Marschalko 1986; Michalík & Vašíček 1987; Rakús 1997; Mello ed. 2005, 2011; Plašienka & Soták 2015; Plašienka et al. 2017, 2018a). Consequently, from both the structural and lithostratigraphic points of view, the Manín Unit has been for a long time considered as a kind of an intermediary, transitional element between the PKB and CWC, but assigned either to the former or to the latter according to different authors.

In this article, for the reasons discussed below, we consider the units under question — namely the Manín, Klappe and Drietoma — as representing frontal elements of the Fatric (Křížna) nappe system, i.e. units of the CWC origin that were incorporated into the PKB structure. We also express our opinion about the main ambiguity that stems from the presence of Upper Cretaceous (Senonian) to Middle Eocene sediments within or adjacent to the Peri-Klippen Zone. This problem results from the fact that all CWC units are typically Austroalpine-type thrust sheets that lack, due to the “pre-Gosauian” tectogenesis, sediments younger than Turonian. Nevertheless, a possible exception was described from the outermost Tatric cover sequence in the Považský Inovec Mts. (Pelech et al. 2017).

There are several opinions regarding position of the Senonian and younger strata in the Peri-Klippen Zone: (1) they are generally in sequence with underlying mid-Cretaceous complexes, which is a feature characteristic for the Klippen Belt (Oravic) units, thus these units would be an integral part of the PKB (e.g., Andrusov 1972, 1974); (2) they belong to the Oravic Kysuca Unit, i.e. still belonging to the Oravic PKB, and appear from below the Manín-Klappe units in tectonic windows (Rakús & Hók 2005; Mello ed. 2005); or (3) they represent post-nappe, Gosau-type basins within the growing Carpathian accretionary wedge on top of the frontal CWC nappes (see discussion and references in the third chapter below). We present some novel arguments supporting the third interpretation (see also Plašienka & Soták 2015).

In general, the present paper aims at: (i) critical review of older and existing views and concepts regarding the lithostratigraphy and tectonics of the Manín and Klappe units; (ii) evaluation of the regional structural data; (iii) complementary interpretation of position of the Coniacian to Middle Eocene sediments as overstepping, wedge-top complexes; (iv) presentation of arguments in favour of the Fatric affiliation of the Manín, Klappe, Drietoma and analogous units.

Geological setting

The Western Carpathians form the northward-convex, W–E trending segment of the Alpine–Carpathian mountain chain, being linked to the Eastern Alps to the west and to the Eastern

Carpathians to the east. We are using the triple overall division of the Western Carpathians into the southern Internal Western Carpathians, the Central Western Carpathians and the northern arc of the External Western Carpathians (for the reviews see Plašienka et al. 1997a; Froitzheim et al. 2008 and Plašienka 2018a; Fig. 1). These three major Western Carpathian sections are separated by narrow zones with extraordinary shortening and intricate structure, partly recording also important along-strike wrench movements in various time periods.

The Internal Western Carpathians (IWC), or Pelso Megaunit in other terminology (see e.g., Kovács et al. 2011), is composed of low-grade Palaeozoic and low-grade or non-metamorphic Mesozoic complexes showing affinities to the South Alpine (Transdanubian Range) or to the Dinaridic (Bükk Mountains) facies belts. The main tectogenesis of the IWC units took place during the Late Jurassic and Early Cretaceous, partially showing the southern vergency of principal thrust structures, i.e. opposite to the other Western Carpathian zones.

The Central Western Carpathians (CWC) are separated from the IWC by a belt of crustal-scale discontinuities (Rába–Hurbanovo–Diósjenő fault zone) in the western part, which is covered by thick Cenozoic sedimentary complexes of the Danube and South Slovakian–North Hungarian basins, and by the discontinuous belt of the ophiolite- and blueschists-bearing complexes (Meliata Unit in a broader sense) in the area of the Slovak–Aggtelek Karst Mts. (Fig. 1). The CWC represent a pile of Cretaceous thick- and thin-skinned thrust sheets. From bottom to top these are the outermost Tatric basement/cover sheet, overlain by the Fatric and Hronic cover nappe systems. The central and southern CWC zones are occupied by the Veporic crustal-scale thrust wedge and the Gemeric basement/cover nappe in the SE, both overridden by the Silica cover nappe system (Fig. 1). The CWC units largely correspond to the Austroalpine tectonic system of the Eastern Alps (e.g., Schmid et al. 2008).

The Variscan high-grade metamorphic basement and granitoids of the Tatric thick-skinned sheet are overlain by the Upper Palaeozoic and Mesozoic cover deposits, mainly composed of Lower Triassic continental clastics and various Middle Triassic to Lower Cretaceous carbonates. The youngest synorogenic clastic sediments of the Tatric Superunit indicate the termination of the thrusting processes in the CWC during the Late Turonian. The overlying Fatric (Křížna) cover nappe system was detached along the Lower Triassic shales and evaporites and includes Middle Triassic shelf carbonates, Upper Triassic clastics and evaporites (Carpathian Keuper Fm.), various Jurassic and Lower Cretaceous limestones and Albian–Cenomanian synorogenic flysch deposits. Jurassic sediments used to be subdivided into the comparatively shallow-marine Vysoká–Belá succession, but the widespread Křížna Nappe is dominated by deep-water pelagic sediments (Zliechov succession). In the investigated area (Fig. 2), the frontal elements of the Křížna Nappe were detached along the Upper Triassic Keuper shales (Fig. 3). The Hronic Superunit (Choč nappe system in older terminology) is predominantly composed of Middle–Upper Triassic platform carbonates. Condensed

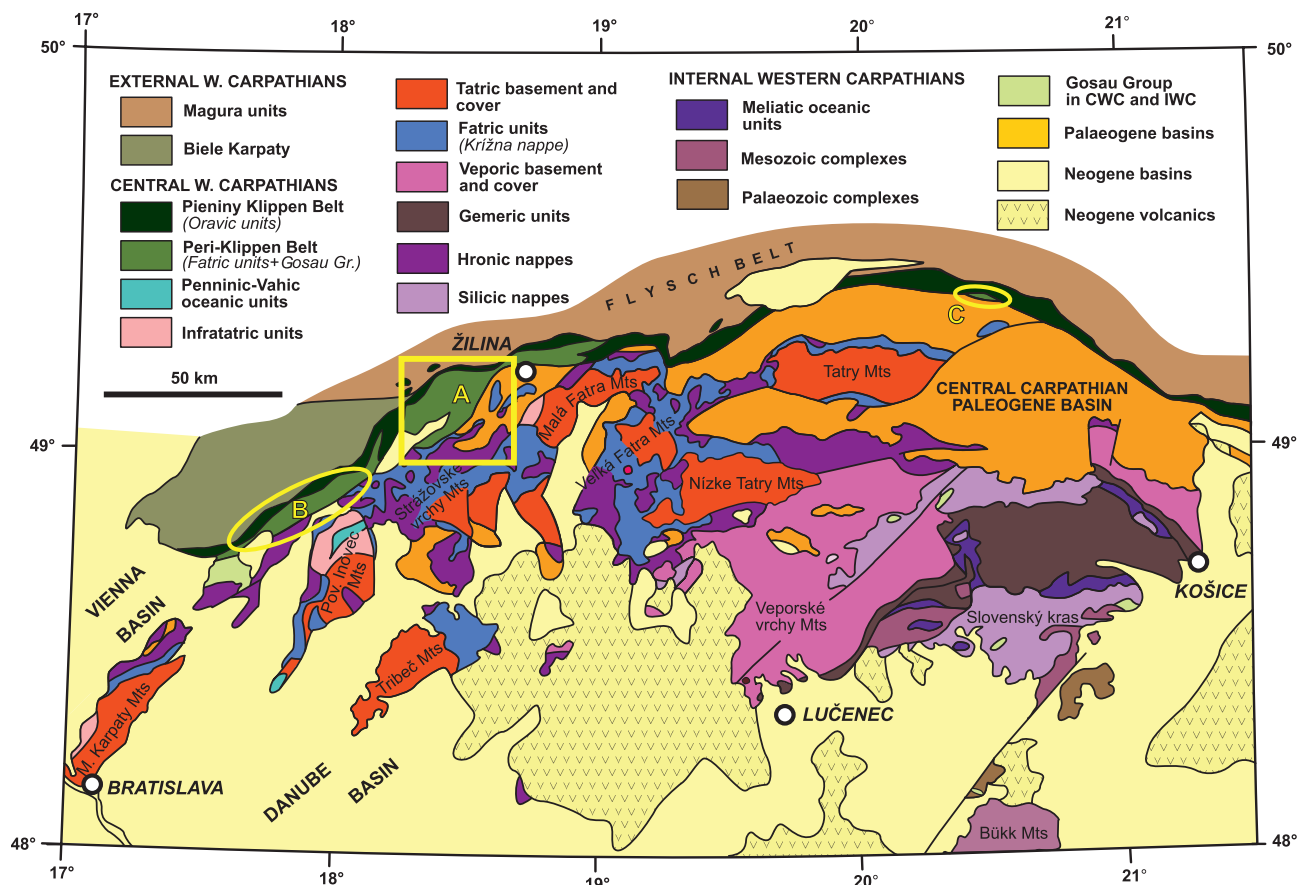


Fig. 1. Schematic map showing distribution of the principal tectonic units of the Western Carpathians. The rectangle A indicates position of the study area depicted in Fig. 2, ellipses show locations of other parts of the PKB mentioned in the text: **B** — Drietoma Unit in the Myjava–Trenčín sector; **C** — Haligovce Unit in the Pieniny Mountains.

Jurassic to Lower Cretaceous limestone strata are confined to the lowermost Homôľka partial nappe (Fig. 2), including the Hauterivian siliciclastic turbidites (Fig. 3). The outer CWC edge is followed by the PKB, a narrow zone with intricate internal structure that provides a transition from the CWC to the External Western Carpathians (EWC; Figs. 1 and 2).

The Klippen Belt forms a backbone of the Western Carpathian orogen, it spreads for more than 700 km from the Vienna area up to north-eastern Romania. However, if only the characteristic Oravic units are considered, the PKB length attains about 600 km from westernmost Slovakia to western Ukraine. It is only a few kilometres wide zone with intricate internal structure composed of several thrust units. These were derived from an independent palaeogeographic element known as the Czorsztyn Ridge, or Oravic domain in the palaeotectonic meaning. During the Middle–Late Jurassic and Cretaceous, the Oravic continental ribbon separated two branches of the Pennine oceanic zones (Alpine Atlantic) — the northern Valais–Rhenodanubian–Magura and the southern Piemont–Váh oceans. The Oravic Superunit (Oravicum) consists of three basic thrust sheets, from bottom to top these are the Šariš Unit, which is overridden by the Subpieniny Nappe that underlies the Pieniny Nappe (e.g., Plašienka 2012a,b;

2018a,b, and references therein). All these three units include strongly dismembered, but generally continuous sedimentary successions detached from their pre-Jurassic substratum. The Šariš Unit (known also as the Grajcerek or Hulina Unit in the Polish Pieniny Mts.), which overthrusts the EWC Magura elements, embraces a basinal, strongly condensed Jurassic–Cretaceous succession passing into the Palaeocene–Middle Eocene synorogenic flysch complex of calcareous turbidites and huge olistostrome bodies carrying big olistoliths (sedimentary klippen) derived from the overlying Oravic nappes. The Subpieniny Unit (Uhlík 1907) is dominantly composed of the swell-type, comparatively shallow-water Jurassic–Cretaceous Czorsztyn succession (e.g., Mišík 1994), but includes also some “transitional” (with respect to the Pieniny basinal unit), slope-derived elements like the Czertezik or Niedzica successions (cf. Birkenmajer 1977). The structurally highest Pieniny Nappe involves again basinal Jurassic–Cretaceous sediments detached from the foots of the Czorsztyn Ridge at the transition towards the Váh oceanic domain.

Beyond the PKB, the EWC are composed of the Flysch Belt and the Carpathian foredeep covering the southern margin of the North European Platform. The Flysch Belt corresponds to the Cenozoic accretionary wedge of the Carpathians orogen

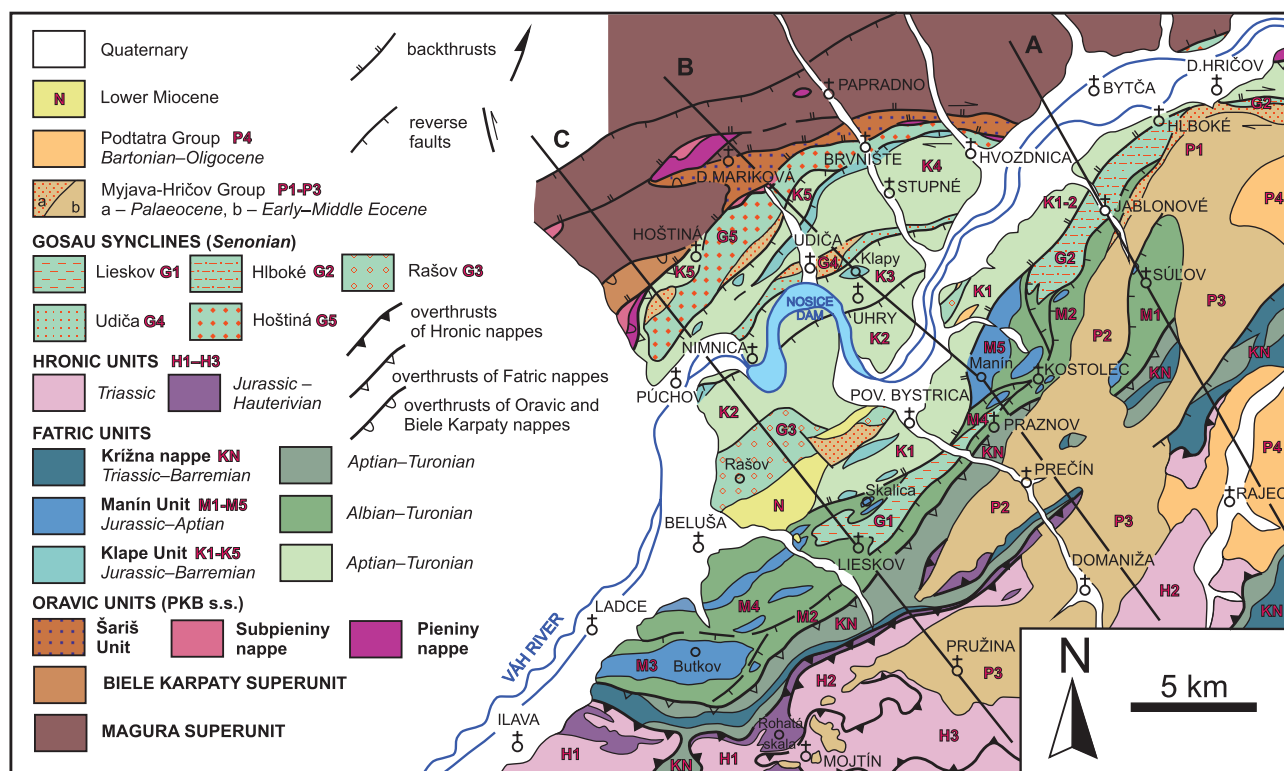


Fig. 2. Geological map of the studied area (simplified and modified after Mello ed. 2005 and Salaj 1995). Letters with numbers indicate partial units and imbricates described in the text: M1–5 subunits of the Manín Unit (M1 — Súľov domain, M2 — Praznov–Jablonové slice, M3 — Butkov domain, M4 — Skalica domain, M5 — Manín domain); K1–5 slices of the Klappe Unit (K1 — Považská Bystrica slice, K2 — Orlové slice, K3 — Nimnica–Uhry slice, K4 — Stupné–Hvozdnica slice, K5 — Hoština–Brvnište slice); H1–3 Hronic nappes (H1 — Homôľka Nappe, H2 — Ostrá Malenica Nappe, H3 — Strážov (Považie) Nappe); G1–5 Senonian (Coniacian–Maastrichtian) Gosau synclines (G1 — Lieskov–Praznov synform, G2 — Hlboké synform, G3 — Rašov synform, G4 — Udiča synform, G5 — Hoština synform); P1–4 Palaeogene (Palaeocene–Lutetian) Gosau synclines (P1 — Hričov–Žilina sliced zone, P2 — Prečín–Súľov synform, P3 — Pružina–Domaniža synform, P4 — Rajec synform). Cross-sections along the profile lines A, B and C are interpreted in Fig. 4.

consisting predominantly of the Cretaceous–Lower Miocene deep marine clastics detached from the subducted oceanic basement and intervening continental fragments of the Magura (North Pennine) and Silesian realms. It includes the inner belt of the Biele Karpaty and Magura superunits, which are connected with the Rhenodanubian Flysch Belt to the west, but are wedging out towards the Eastern Carpathians. The outer Silesian–Krosno zone is linked with the Eastern Carpathian Moldavides (see e.g., Picha et al. 2006; Oszczytko & Oszczytko-Clowes 2009 and Oszczytko et al. 2015 for the reviews).

The Alpidic tectonic evolution of the Central and External Western Carpathians exhibits a distinct northward progradation of the principal compression events and nappe stacking processes from the late Early Cretaceous to Miocene (e.g., Froitzheim et al. 2008; Kováč et al. 2016, 2017; Plašienka 2018a). In contrast, the IWC experienced the main deformation during the “Neo-Cimmerian” (Middle Jurassic up to Albian) orogenic movements related to closure of the Neotethyan (Meliata) oceanic domains, while structure of the CWC units was completed by the “Palaeo-Alpine” (Eo-Alpine), or “pre-Gosauian” tectogenesis in mid-Cretaceous times (before

the Coniacian). Development of leading structures of the PKB and adjacent zones took place during the Senonian to Eocene, “Meso-Alpine” period. This was related to subduction-collision processes of the South Penninic–Vahic oceanic zone between the Oravic domain and the northern Austroalpine (CWC) margin. The final “Neo-Alpine” stage was governed by complex movements generated by subduction of the Magura Ocean and formation of its accretionary wedge (Flysch Belt) associated with the Miocene opening of the Pannonian Basin system in a back-arc position, extensive calc-alkaline volcanism, and the counter-clockwise rotation of the eastern ALCAPA domain (cf. Kováč 2000; Kováč et al. 2016, 2017 and references therein).

The classic occurrence of the Manín Unit lies on the left side of Middle Váh (Waag) River Valley (so-called Púchov sector of the PKB; Scheibner 1968a), while the adjacent Klappe Unit occurs on both sides of the valley (Figs. 1 and 2). In a map view of the Middle Váh Valley (Salaj 1995; Mello ed. 2005; Potfaj ed. 2008), they together form a lozenge-shaped zone some 35 km long and up to 15 km wide (Fig. 2). From the geographic point of view, this area belongs to the NW part of the Strážovské vrchy Mountains and southern part of

the Javorníky Mountains. Two large and steep, mostly forested mountains dominate the area — the Mt. Butkov (765 m a.s.l.) in the southern part and the Mt. Manín (891 m) in the middle part of the Manín Unit. Both lens-shaped mountains are transversally cut by deep and narrow antecedent valleys with cliffy slopes exposing Jurassic to Lower Cretaceous limestone formations. Only these provide good outcrop conditions, along with several large quarries. On the right side of the Váh River, the cliffy Mt. Klope (actual geographic name is Klapý, 654 m a.s.l.) rises above the Nosice Dam, giving name to the surrounding Klope Unit (Fig. 2). It is considered to be a megaolistolith (almost 1 km long) of Jurassic limestones embedded in mid-Cretaceous deep marine clastic deposits (e.g., Marschalko 1986). However, most of the region is characterized by mildly hilly relief (peaks around 500 m) variably covered by woods, meadows and agricultural fields. These areas are mostly composed of soft upper Lower and Upper Cretaceous strata, where good outcrops are very rare. Units with a similar position and composition occur also in some other places along the PKB/CWC transitional zone (areas B and C in Fig. 1); these will be briefly discussed as well (see also Plašienka & Soták 2015).

Review of fundamental opinions regarding position and origin of the Manín and Klope units

The Middle Váh Valley belongs, along with the Polish–Slovak Pieniny Mountains, to the key areas where the most important ideas about the structure, evolution and position of the Carpathian Klippen Belt were invented. Initially it was studied in detail by Stur (1860), who regarded the Manín–Rohatá skala area as the third, innermost belt of klippen, in addition to the external two, which were later known as the “Outer” (Moravian–Silesian) and “Inner” (Pieniny) Klippen Belts. He distinguished, stratigraphically determined and named several type formation of the area (e.g., the Orlové sandstone, Púchov marls, Praznov beds, Súľov conglomerate). He also correctly depicted the structure of the Manín belt in two cross-sections showing its steeply south-dipping thrust and fold structure. Later on, this view was largely taken over by Uhlig (1903), who considered the Manín–Rohatá skala zone as a special transitional element between the Klippen Belt and the Central Western Carpathian zones. Rohatá skala is a hill southeast of Mt. Butkov (Fig. 2), where Jurassic to Lower Cretaceous sediments fill in a syncline within Triassic carbonates, which have been later affiliated with the Choč nappe system, i.e. with the Hronic Homôľka Nappe in the current regional tectonic terminology (Mello ed. 2005; Havrila 2011; cf. Figs. 2 and 3).

Starting from the late 1920-ties, the Middle Váh Valley and the Orava region became the favourite research areas of the distinguished Carpathian geologist and the ever-best expert in the PKB geology, Dimitrij Andrusov. From the very beginning of his investigations, Andrusov (1931; Matějka & Andrusov 1931) correlated palaeogeographically the Manín Unit with the High Tatra zone as the outermost CWC element.

This opinion was mainly based on the presence of some characteristic facies, such as the shallow-marine character of Jurassic sequences and, particularly, the Aptian–Barremian Urgon-type limestones occurring in both. On the other hand, the Manín zone includes also Upper Cretaceous sediments of the “Klippen Belt type”, which are absent in the CWC to the SE, therefore the Manín unit would be a PKB element at the same time. From the tectonic point of view, Andrusov unified the currently separated Manín and Klope units into the single Manín Nappe that overrides the Pienidic units: Subpieniny–Czorsztyn, Pieniny–Kysuca and the transitional ones, which are currently designated as the Oravic units (Maheľ 1986). During his long-termed research, Andrusov corrected several aspects of this conception, however. His modifications concerned mainly the timing of the principal thrusting events — initially he inferred the Late Aptian “Pieniny (Austrian) phase” (later renamed as the “Manín phase”) as the main nappe-forming tectonic event (with the Subpieniny, Pieniny and Manín nappes — Andrusov 1931, 1938), afterwards he stressed the role of the pre-Gosauian “Subhercynian” folding (Andrusov & Scheibner 1960), and finally the end-Cretaceous “Laramian” tectogenesis (Andrusov 1968, 1972, 1974). The latter view led Andrusov (1972) to affiliate the Manín Unit with the PKB Pienidic units, it means to the “Laramian” tectonic system of the PKB that is sharply separated from the “Subhercynian” tectonic system of the CWC.

Andrusov’s model of the Manín–High Tatra “geanticlinal” belt as the outermost palaeogeographical zone of the Central Carpathian (Tatric) domain, which at the same time shows close structural relationships to the PKB, has had a number of supporters (e.g., Scheibner 1968a; Rakús 1975; Rakús & Marschalko 1997; Rakús & Hók 2005). A remarkable corollary of this model is that most of its advocates assumed an autochthonous position of the Tatricum as a whole-crustal element and underrated the degree of shortening along its outer edge. As a result, they also doubted the prolongation of the Ligurian–Piemont (South Penninic–Vahic) Ocean into the Western Carpathian area (e.g., Rakús & Hók 2005).

In the second half of 20th century, the Andrusov’s conception has got a strong opposition from Michal Maheľ and his followers. While Andrusov looked upon the Manín Unit as a marginal and peculiar, but still integral component of the PKB, Maheľ’s opinion was based strictly on a view from the Central Carpathian side. In the western part of the Strážovské vrchy Mountains, Maheľ (1978, 1986) identified a prolongation of the Manín Unit (its Jurassic–Lower Cretaceous complexes) farther to the south, where it is closely related to the Belá Subunit of the Križna Nappe, i.e. it would be clearly an allochthonous element overriding the Tatric substratum. From the palaeogeographical point of view, he still connected the Manín Unit with the Tatric ridge area characterized by prevalence of shallow-marine Jurassic and Early Cretaceous facies, but located its sedimentary zone on the southern slopes of this ridge that were flanking the large Zliechov Basin — the main depositional area of the later Tatric Križna Nappe. In this conception, the Manín, Belá, or Vysoká subunits are all

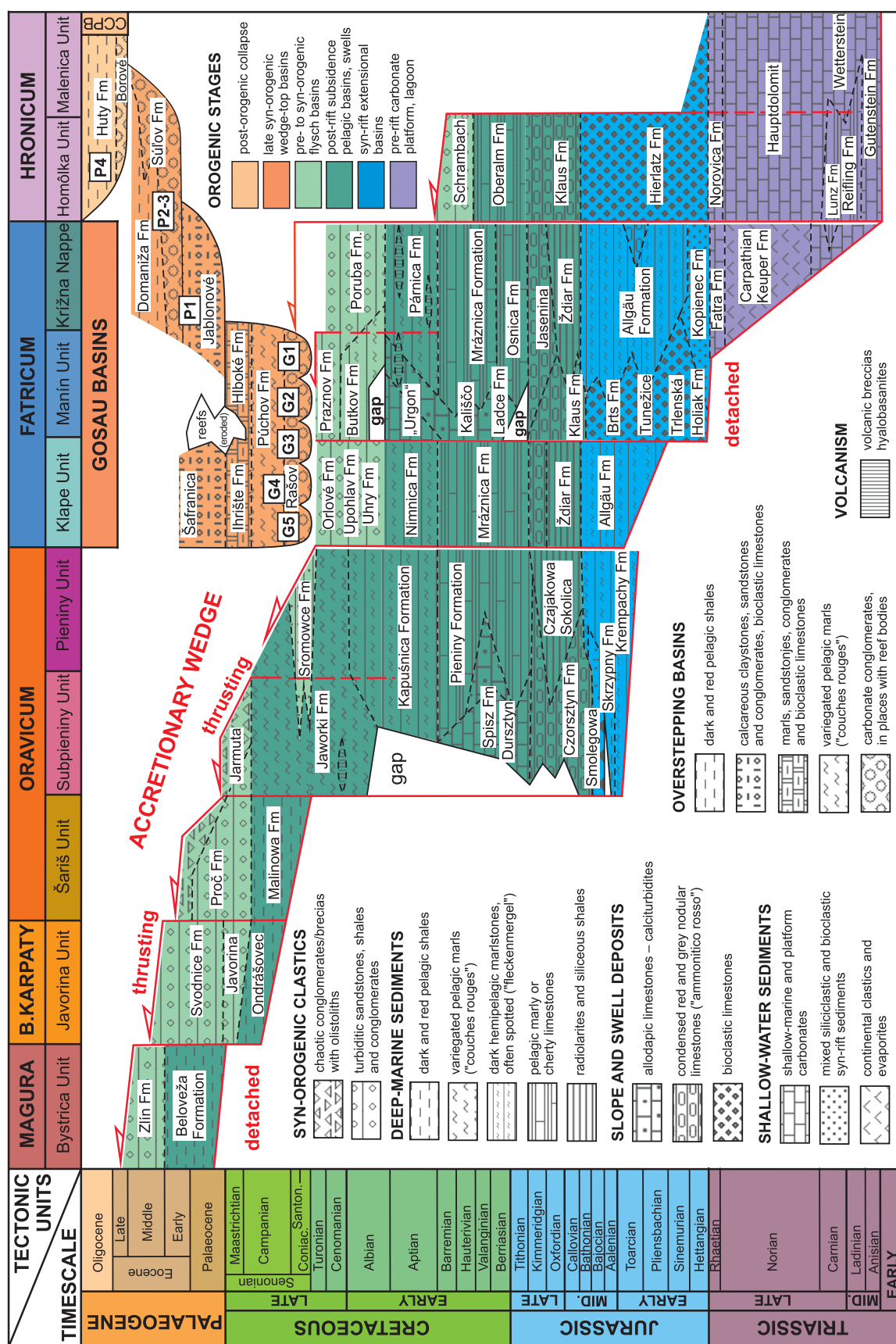


Fig. 3. Lithostratigraphic synopsis of units forming the PKB and adjacent zones in the Middle Váh Valley. Note that the Fatric units are arranged according to their present structural position and not according to their inferred palispastic settings. Note also that, due to a space problem, not all lithostratigraphic units mentioned in the text are indicated. G1–5 are Gosau synforms (Senonian–Early Eocene) located atop the Manín and Klapce units, P1–3 are Palaeocene–Lutetian basins (Myjava–Hričov Group) covering mainly the frontal CWC units, while P4 is the CCPCB filled with Bartonian–Oligocene deposits. Further details in the text.

the frontal constituents of the large Krížna nappe system that overthrust the Tatric Superunit in the outer CWC zones. This opinion has also got numerous followers from both the litho-stratigraphic–palaeogeographic (e.g., Borza et al. 1979; Borza 1980; Michalík & Vašíček 1987; Žitt & Michalík 1988; Michalík 1994; Plašienka et al. 1997b; Michalík et al. 2012; partially also Marschalko 1986), as well as from the structural–palaeotectonic viewpoints (Plašienka 1995a,b; Prokešová et al. 2012). According to Mahel' (1980, 1989) and Plašienka (1995a,b), the Manín and related units (Klape, Drietoma, Haligovce) form the so-called Peri-Klippen Zone along the inner side of the Klippen Belt s.s., while the PKB proper with its palaeogeographically independent Oravic units and with a typical klippen “block-in-matrix” tectonic style build the outer, rather narrow PKB periphery (Fig. 2). Thus the Peri-Klippen Zone is composed of the Fatic units (Krížna nappe system), which originated as thrust sheets in the Late Turonian. Subsequently, in the latest Cretaceous and Palaeogene, they were partly incorporated into the PKB structure, along with superimposed Senonian to Eocene piggyback basins. The abandoned chronostratigraphic term “Senonian” (Coniacian to Maastrichtian) is used throughout the following text for the sake of simplicity when distinguishing between the pre-Senonian sediments of the CWC units affected by pre-Gosauian tectogenesis and the superimposed Senonian through Middle Eocene deposits of the Gosau Supergroup.

Regarding the position of Senonian to Eocene deposits occurring within the Peri-Klippen Zone, three variants have been considered in general:

- Senonian sediments are an integral part of the Manín Unit and lie in a stratigraphic continuity above the Cenomanian–Turonian Praznov Fm. This view was held for a long time by numerous authors, e.g., Salaj & Began (1963), Salaj (1962, 1990, 1994a,b), and Kysela et al. (1982) who ranged all Albian through Maastrichtian sediments to their continuous Podmanín Group. However, this opinion was questioned because of lack of Senonian sediments in the uppermost structural levels of the Manín Unit, just at the contact with the overlying Krížna Nappe (Rakús & Hók 2005).
- Senonian sediments do not belong to the Manín and/or the Klape Unit at all, but they occur in tectonic windows exposing the underlying Oravic units of the PKB (Rakús 1975). They were assigned to the special Podháj succession of the Kysuca Unit (Rakús & Hók 2005; Mello ed. 2011). Originally, Salaj (1990) defined the Podháj Unit as a transitional element between the Klape and Manín units, stratigraphically ranged to the Early Cretaceous; later on Salaj (1995) redefined it as a partial Manín development (Tithonian–Santonian). Thus the third redefinition by Rakús & Hók (2005) has very little in common with the original Salaj's meanings of the Podháj Unit or succession. Moreover, the Podháj Unit is shown in totally different areas in the published maps of Salaj (1995) and Mello ed. (2005). Therefore, the term Podháj Unit seems to be superfluous and is not used in this paper — in sense of Salaj the Podháj Unit is merely the innermost partial structure of the Klape

Unit at the contact with the Manín Unit (K1 in Fig. 2), while the second concept is misleading in our view.

- Senonian sediments represent an independent sedimentary cycle deposited after the tectonic emplacement of the Manín Unit and its overthrusting by the Krížna Nappe (both events should have happened during the Late Turonian — see e.g., Prokešová et al. (2012 and references therein). Hence they would be elements of the Gosau Supergroup, i.e. fillings of post-nappe, piggy-back basins (Plašienka 1995a,b, 2012a; Plašienka & Soták 2015; Plašienka et al. 2018a). The generally transgressive character of all Senonian sediments within the PKB was originally envisaged by Andrusov & Scheibner (1960, their “second sedimentary cycle”) and Scheibner (1968a), but this concept was abandoned later, since continuous Cretaceous successions were postulated in the Oravic units of the PKB. Seemingly this applies also for the “non-Oravic” Klape and Manín units in the Peri-Klippen Zone, because of frequent contact of Turonian and Senonian strata in the map view. Nevertheless, continuous stratigraphic profiles across the Turonian/Coniacian boundary have never been thoroughly documented there. In contrast, it was declared from time to time that the Klape–Manín Senonian deposits are akin to the “proper Gosau” of the Brezová Group, distinguished from it by the clear transgressive character of the latter only (Salaj & Began 1963; Began & Salaj 1978). Others claimed that there is an Upper Turonian hiatus present (Marschalko & Kysela 1980); there is a polar change in palaeocurrent directions of the mid-Cretaceous vs. Senonian turbidites (Marschalko 1986), or that there is an abrupt boundary (unconformity?) between the Cenomanian–Turonian Praznov Fm. and Senonian deposits (Salaj 1994b). According to Mahel' (1980, 1981, 1986, 1989), the Peri-Klippen Zone with its piggy-back, Gosau-type basins (Brezová, Myjava–Hričov) represented the “upper (Meso-Alpine) structural stage” above a “false accretionary complex” (Plašienka 1995a,b) with respect to the subduction of the underlying South Penninic–Vahic oceanic lithosphere (cf. Plašienka 2012a and references therein). Finally, Salaj (2006) regarded the Coniacian to Lower Eocene sediments of the Rašov and Udiča synclines in the southern zones of the Klape Unit neighbouring the Manín Unit as transgressive Gosau developments — the view accepted here and applied also for the Senonian sediments occurring in synclines within the Manín zone itself. This concept of the wedge-top, Gosau-type basins located within the Peri-Klippen Zone has been recently elaborated in detail by Plašienka & Soták (2015).

There were also some other, occasionally somewhat strange views on the Manín Unit. Salaj (1962) and Salaj & Samuel (1963) supposed its facies transitions to the Zliechov (Krížna) Unit on one side and to the Pienidic Kysuca Unit on the other. This opinion was developed *ad absurdum* later (Salaj 1982; Salaj & Began 1983) in the fixistic concept of an autochthonous position of all units present at the Central/Outer Carpathian transitional zones, including even the Hronic (Choč) nappes. In contrast, some other authors (e.g., Rakús

1975) postulated a specific position of the Manín Unit, which occurs in a particular Manín zone independent from both the PKB and CWC. At last, we can mention Golonka et al. (2015), who consider the Manín Unit as part of a huge Cretaceous–Palaeogene olistostrome that originated in the fore-arc basin (so-called Zlatné Basin) on the inner PKB side located inside the subduction-related accretionary prism. Accordingly, the large Manín and Butkov klippen would also be megaolistoliths — however, this unsubstantiated view was not supported by any field evidence and it is in a sharp contradiction with the regional tectonic situation, therefore it has been profoundly criticised by Plašienka et al. (2017).

Until 1980-ties, all units resting in a tectonic superposition above the Kysuca–Pieniny Unit in the PKB were assigned to the large-scale Manín Nappe that was, as a supposedly frontal Tatric element, emplaced in pre-Senonian times (pre-Gosauian or older Subhercynian phase — e.g., Andrusov & Scheibner 1960), or during the Laramian phase (Andrusov 1972, 1974). Afterwards, the Klope Unit was differentiated first as a special “Klope series” of the Manín Unit (Began et al. 1965; Salaj & Samuel 1966; Scheibner 1968a; Began 1969). Later on, the Klope Unit was defined as an independent element from the point of view of lithostratigraphic content, sedimentological features and tectonic position (Marschalko & Kysela 1980). At present, the Manín and Klope units are treated as separate units with an equal order of importance. Consequently, the tectonic affiliation of some units in other PKB regions had to be redefined as well — for example the overthrust sheet overriding the Kysuca Unit in the Varín (Kysuca) sector of the PKB, which was originally described as the Manín Nappe by Haško (1978), is now assigned to the Klope Unit (cf. Polák ed. 2008).

In the modern tectonic map of Slovak Republic (Bezák ed. 2004), the Manín Unit is designated, along with the Klope and Drietoma units, as the “Neoalpine structurally modified Palaeoalpine or Mesoalpine tectonic units of Klippen Belt”. Similarly, in the legend and explanations to the Geological map of the Middle Váh Valley 1:50,000 (Mello ed. 2005, 2011), the Manín and Klope units are described as “units with Central-Carpathian affinity”, but still ranged to the Klippen Belt. In the legend to the general geological map of Slovakia 1:200,000 (sheet 25 — Bytča), the Manín and Klope units are included in the Klippen Belt *sensu lato*, too (Potfaj ed. 2008).

Lithostratigraphy of the Manín and Klope units and related Gosau deposits

The generalized lithostratigraphic content of the Manín Unit in the Middle Váh Valley includes almost complete Jurassic to Lower Cretaceous succession forming large anticlinal cores of the Manín and Butkov “klippen” and several smaller lens-shaped slices. These are composed mostly of relatively competent, but usually well stratified limestone formations prone to large-scale folding (cf. Plašienka et al. 2018a). From the Late

Albian onward, mostly incompetent marls, shales and flysch deposits accumulated and form the so-called “klippen mantle” in older concepts. A questionable occurrence of Rhaetian dark limestones and shales was mentioned by Andrusov & Scheibner (1960) from the Butkov klippe. However, this finding was not confirmed later. Despite of this, it might be inferred that in lower structural levels, not exposed on the current surface, the Manín Unit was detached from its pre-Jurassic substratum along some weak décollement horizon, presumably formed by the Norian variegated shales and evaporites of the Carpathian Keuper Fm., similarly as other frontal Fatic elements (cf. Prokešová et al. 2012).

Relying on the earlier opinion of Matějka (1932), Mahel' (1978, 1985, 1986) supposed the continuation of the Manín Unit southwards in the surroundings of Trenčianske Teplice and Soblahov in the eastern part of the Strážovské vrchy Mts. and in the northern part of the Považský Inovec Mts. (Dubodiel area). There, the inferred Manín Unit includes also the Middle Triassic carbonates, Upper Triassic Carpathian Keuper Fm. and Rhaetian fossiliferous limestones (Fatra Fm.; Fig. 3). Nowadays, these occurrences are correlated with the Belá Subunit of the Fatic Vysoká facies zone — e.g., Bezák ed. (2004) in the Strážovské vrchy Mts. and Pelech et al. (2012) in the Dubodiel area.

In the Manín and Butkov areas, the continuous Jurassic sequence (Fig. 3) begins with dark grey to black sandy-crinoidal, cherty limestones and marly shales of the early Hettangian age (Holiak Fm. defined by Rakús & Hók 2005). Starting from the Sinemurian, successions in these two areas differ to some extent. The Manín klippe has a more shallow-water character with sandy biotrital limestones passing to coarse grained, quartz-dolomitic sandstones and conglomerates, while the Butkov succession is more basinal with grey sandy-crinoidal limestones with chert nodules (Late Hettangian–Pliensbachian Trlenská Fm.) followed by pink and grey-green glauconitic, cherty crinoidal limestones containing early Toarcian ammonites (Tunežice Fm.). The overlying Toarcian–Aalenian grey sandy-crinoidal, cherty limestones of the Brts Formation are intercalated by dark shales in the upper part. The Middle–Upper Jurassic sequence is characterized by red nodular limestones (Klaus Fm.) ranging from the Toarcian (Manín area) or from the Bajocian (Butkov) up to Tithonian, inserted by a layer of the Bathonian, so-called “banana” radiolarites in the Butkov domain (Rakús & Ožvoldová 1999).

The Lower Cretaceous sequence includes several formations (Fig. 3). According to Borza et al. (1987) and Michalík et al. (2012, 2013; see also references therein), the Butkov succession consists of the maiolica-type Ladce Fm. (topmost Berriasian–Early Valanginian), dark-grey marly limestones (Mrázňica Fm., Valanginian), cherty limestones (Kališčo Fm., Hauterivian), marly cherty, partly brecciated limestones (Lúčkovská Fm., Early Barremian) and massive bioclastic, Urgon-type limestones (Podhorie Fm., uppermost Aptian–Early Albian). Much thicker (at least 100 m), massive Urgonian limestones occur in the Manín succession (Manín Fm.; Fekete et al. 2017). In smaller slices between the large Manín and

Butkov anticlines (Skalica Subunit), the Late Aptian substage is represented by mass-flow breccias composed of clasts of Urgonian limestones (Skalica Breccia — Borza et al. 1979; Michalík & Vašíček 1984) and the Early Albian substage by grey cherty limestones (Jelenia skala Fm. — Rakús & Hók 2005; Mello ed. 2011). The latter limestones are partly also brecciated and mixed with hyalobasanitic volcanoclastic material (Hovorka & Spišiak 1988 and references therein). Both the Manín and Butkov successions are terminated by the Lower Albian hardground indicating a rapid drowning of the Urgonian carbonate platform (Boorová & Salaj 1992). Originally, Andrusov (1938) considered this drowning event as the main nappe-forming “Pieniny folding phase” in the PKB and later as the “Manín emersion phase” (Andrusov 1965). An analogous drowning event following emersion affected also the Oravic Czorsztyn Ridge (Aubrecht et al. 2006), but large Tatric and Fatric palaeogeographic realm as well (Plašienka 2018a and references therein).

The new, mid-Cretaceous sedimentary cycle is represented by hemipelagic to deep-marine clastic deposits of the Podmanín Group (Kysela et al. 1982; redefined by Rakús & Hók 2005; Mello ed. 2011 and Plašienka & Soták 2015). The former authors included in their Podmanín Group the entire Albian–Maastrichtian succession of the Manín Unit, assuming an uninterrupted sedimentation across the Turonian/Coniacian boundary. On contrary, the latter authors correctly argued that the Turonian sediments of the Manín Unit are tectonically overridden by the Křížna Nappe, thus the Senonian sediments in the Manín–Butkov area cannot be in a normal stratigraphic continuity with the Turonian strata.

The Lower Albian hardground is covered by dark, bioturbated hemipelagic marlstones of the “Zementmergel” type, Middle Albian to Early Cenomanian in age (Butkov Fm., Fig. 3). Upwards, the marlstones are intercalated by distal calcareous turbidites of the Cenomanian to Middle Turonian Praznov Fm. (Stur 1860; Scheibnerovci 1958; Mello ed. 2011; Salaj 1994b). This shows a thickening-and-coarsening-upward trend (Belušské Slatiny Member dominated by thick-bedded sandstones), interfingering with more shallow-water sandstones rich in bioclastic material (including macrofauna like oysters — Kvašov Mbr). Upper parts of the Praznov Fm. are intercalated and terminated by boulder conglomerates and pebbly mudstones with partially “exotic” pebble material (Hradná Mbr.). The innermost structural zone of the Manín Unit (Praznov–Jablonové slice according to Marschalko & Kysela 1980) is composed of thick prisms of predominantly Cenomanian flysch deposits containing chaotic boulder beds and olistoliths of the Jurassic–Lower Cretaceous limestones, which is known as the Kostolec Unit. Formerly these limestone klippen, along with the Klope klippe, were interpreted as outliers of some higher Central Carpathian unit, possibly the Strážov Nappe (Andrusov 1938). However, later on Rakús (1965), Borza (1970) and Rakús & Marschalko (1997) argued that the strata succession of the Kostolec klippen are rather similar to that of the Manín Unit, especially by the presence of Urgon-type limestones and Lower Albian hardground

followed by Butkov-type marlstones. Being surrounded by the mid-Cretaceous flysch, the Kostolec klippen are presently considered to represent olistoliths, which opinion was corroborated also by some technical works (Rakús 1997; Rakús & Marschalko 1997; Rakús in Mello ed. 2011).

The most important, and at the same time the most challenging problem with the Manín Unit is the presence of Upper Cretaceous (“Senonian”, i.e. Coniacian through Maastrichtian) sediments and their relationships to the underlying mid-Cretaceous deposits (the Lieskov–Praznov G1 and Hlboké G2 synforms in Figs. 2 and 3). However, the situation is complicated due to poor outcrop conditions and tectonic overprint, therefore the contact of Turonian and Coniacian sediments has never been directly exposed and documented. In the Manín zone, the Senonian deposits of the Podmanín Group consist of alternating deep- and shallow-marine clastics — neritic sandstones and shales containing sandy slump bodies with littoral fauna (Coniacian–Santonian Žadovec Fm., see Kysela et al. 1982; Mello ed. 2011), hemipelagic variegated marls of the “couches rouges” facies (Hrabové Fm., Early Campanian), calcareous turbidites with exotic conglomerates (Hlboké Fm., Late Campanian–Maastrichtian), and *Orbitoides*-bearing bioclastic limestones, sandstones and conglomerates with local rudist reef bodies (Hradisko Fm., Late Maastrichtian to ?Danian). Following the opinion of Plašienka & Soták (2015), the Podmanín Group is assigned to the Gosau Supergroup, which was deposited in the post-nappe, late synorogenic wedge-top basins developed atop the growing accretionary wedge prograding from the CWC toward the Oravic realm of the future PKB. Propagation of this accretionary complex, which included also the frontal CWC units, was associated with and enhanced by subduction of the underlying Vahic oceanic lithosphere below the outer CWC margin (Plašienka 2012a).

In the northern part of the Klope Unit, between Upohlav, Brvnište and Hvozdnica villages, a narrow stripe of Jurassic to Lower Cretaceous limestones amidst Cretaceous clastic formations occurs (Fig. 2). This has been known as the Upohlav tectonic window, even described as “protrusion diapirs” of the underlying Kysuca Unit piercing through the overlying flysch complexes of the Manín (Klope) Unit (Andrusov & Scheibner 1960; Andrusov 1974). A similar window concept has been adopted also in the modern geological map of the area (Mello ed. 2005). On the other hand, Salaj (1994a) included a part of these Jurassic and Lower Cretaceous rocks into his Drietoma succession of the Drietoma Unit, which may be correlated with the Klope Unit to some extent. Based on our own field experience and the general structure of the area, we adopt the Salaj’s interpretation for the whole “Upohlav window” (Fig. 2) with the exception that we range it to the Klope Unit and not to the Drietoma Unit. Consequently, no windows in the tectonic sense do exist in this area.

Taking this into consideration, the Klope Unit includes a sedimentary succession from the Early Jurassic up to early Late Cretaceous. The oldest recognized rocks are dark grey spotted marlstones of the “Fleckenmergel” facies (Allgäu Fm.,

Pliensbachian–?Aalenian), followed by siliceous limestones and calcareous radiolarites (Ždiar Fm.) and then by thin-bedded dark-grey marly limestones with occasional chert nodules, strongly bioturbated in the upper part (akin to the Mráznica Fm, Tithonian to Barremian). This Jurassic–Lower Cretaceous succession is very similar to the deep-water Zliechov succession of the Krížna Nappe. It is noteworthy that these Jurassic sediments are considerably different from sediments of the Mt. Klapý klippe that gave the name to the whole unit, which is a blocky megaolistolith formed by a comparatively shallow-marine Jurassic sequence of massive or thick-bedded, variegated sandy-crinoidal, cherty and nodular limestones.

The lithostratigraphic succession of the Klapé Unit continues with the mid-Cretaceous (Aptian–Turonian) clastic formations that were included in the Šebešťanová succession of the Klapé Unit (Mello ed. 2005, 2011) and/or Hoština succession of the Drietoma Unit (Salaj 1994a). These include Aptian to Lower Albian dark hemipelagic shales of the “sphaeroiditic beds” (Nimnica Fm.) that are passing upwards into coarsening- and thickening-upwards turbiditic sequence of the Albian to Early Cenomanian age (Uhry Fm.) with huge bodies of “exotic” conglomerates (Upohlav Fm.). This so-called Klapé Flysch (Lexa ed. 2000), altogether more than thousand metres thick (Marschalko 1986), also includes several olistoliths of Jurassic sandy-crinoidal and nodular limestones, the largest of them builds up the Mt. Klapý klippe. The Early Cenomanian shallowing is registered by calcareous sandstones and sandy marls rich in orbitolinas (Považská Bystrica Fm). The Upper Cenomanian to Lower Turonian strata are represented by a terminal sequence of massive neritic to littoral sandstones with oyster banks (Orlové Fm., Fig. 3).

There are three synclines filled with the Coniacian–Lower Eocene sediments that separate individual Klapé slices (the Rašov G3, Udiča G4 and Hoština G5 synclines from SE to NW in Fig. 2). They have been assigned to the Hoština succession, originally regarded as being in a continuous series with underlying Cretaceous Šebešťanová or Drietoma successions of the Klapé or Drietoma Unit, respectively (Salaj 1994a), but later as a new transgressive sedimentary cycle of the Gosau Supergroup (Salaj 2006; Plašienka & Soták 2015). In contrast, Mello ed. (2005, 2011) connected the Hoština succession (together with the Podháj succession, see above) with internal parts of the Kysuca Unit, thus as appearing in tectonic windows from below the Klapé Unit. Consequently, they would form anticlines, not synclines. However, according to our investigations, this is not the case (see also Plašienka 2012a; Plašienka & Soták 2015).

The Hoština succession (synclines G3–5 in Fig. 3) embraces basal polymict conglomerates and rudist reef bodies of the Coniacian–Santonian Rašov Fm., overlain by a deepening- and fining-upward sequence of calcareous turbidites (Upper Santonian) and variegated marls of the couches rouges facies (Púchov Fm., Lower Campanian). The Upper Campanian to Maastrichtian Ihřište Fm. is composed of shallow-water calcareous sandstones and conglomerates, *Inoceramus* marls, *Orbitoides* limestones and blocks of rudists-bearing bioherms

(Bezdedov Limestone of Salaj 1990). The Palaeocene–Ypresian strata consist of shallow-water sandy-bioclastic limestones with Thanetian algal-coral reef bodies (Kambübel Limestone — e.g. Buček & Köhler 2017 and references therein) and carbonatic conglomerates (Šafranica Fm; Salaj 1990, 1994b; Mello ed. 2005, 2011). The latter formation was also known as the “Makovec development” in older literature (e.g., Began et al. 1970).

The inner side of the Peri-Klippen Zone in the Middle Váh Valley, at the transition to the outermost CWC, embraces also Palaeocene to Middle Eocene strata deposited in partly independent, highly mobile depressions. They were formerly known as the “Peri-Klippen Palaeogene”, later defined as the Myjava–Hričov–Haligovka zone (Scheibner 1968b), Považie–Hanušovce zone (Samuel 1972) and newly as the Myjava–Hričov Group (Mello ed. 2005, 2011). In the area concerned, the Myjava–Hričov Group occurs in a zone flanking the Manín Unit from the SE, named as the Hričov–Žilina synclinal zone here (P1 in Figs. 2 and 3). Adjacent to the Praznov–Jablonové slice and Senonian sediments of the Hlboké syncline (G2), the Palaeocene sediments are composed of variegated claystones and marlstones, sandstones and conglomerates (Hričovské Podhradie Fm.). Large redeposited blocks of Lower Thanetian bioherms and patch-reefs (Kambübel Limestone) are very common (Buček & Köhler 2017). The Jablonové Fm. (Thanetian–Ypresian) includes shallow marine biotrititic and sandy limestones overlain by carbonatic breccias and conglomerates of the Lower–Middle Eocene Súľov Fm. (Soták et al. 2017; P2–3 in Fig. 3).

Further to the SE, in the Prečín–Súľov and Pružina–Domaňža synforms (P2 and P3 in Fig. 2, respectively), the Súľov conglomerates are mostly resting directly over the CWC units. Being composed of up to 800 metres of carbonatic, mainly dolomitic breccias and conglomerates derived predominantly from Triassic carbonates of the Hronic units, the Súľov Fm. represents a new transgressive cycle related to an extensional collapse of the developing PKB–CWC orogenic wedge (Plašienka & Soták 2015; Soták et al. 2017 and references therein). Lutetian deepening of the Súľov Basin is registered by an upward fining sequence of calcareous sandstones and variegated pelagic shales of the Domaňža Formation (Fig. 3).

Following the upper Lutetian compression and sedimentary break, a new basin developed in a forearc position above the CWC units — the Central Carpathian Palaeogene Basin (CCPB; cf. Soták et al. 2001; Gross 2008; Plašienka & Soták 2015 and references therein). The basal member of the overstepping Podtatra Group of the CCPB is represented by transgressive carbonate conglomerates and nummulitic limestones of the Borové Fm. (Bartonian–Priabonian). Overlying deepening sequence is composed of grey and black shales with occasional distal turbidite beds (Lower Oligocene Hutý Fm.; P4 in Fig. 3).

In the NE part of the Rašov synform, near village Vrtižer, two small slices of steeply dipping dark-grey silty and clay shales occur. According to the personal information by Ján

Soták, they contain Oligocene microfauna. Hence the age and lithology of these shales indicate that they might represent the north-westernmost erosional remnants of the Huty Fm. in western Slovakia.

Notwithstanding the Quaternary fluvial and slope deposits and local, possibly Pliocene gravels, the youngest sediments of the studied area are the Lower Miocene (Eggenburgian) continental, brackish to shallow marine sandstones and fine-grained conglomerates (Fig. 2). These were deposited in a “wrench-fault furrow” type of basin (Kováč 2000), which developed in the rear part of the growing External Carpathian accretionary wedge. Scarce remnants of this basin are present along the southern PKB margin in western and also in eastern Slovakia.

Besides the above characterized region A (Fig. 1), the Manín Unit was described also from the right side of the Váh Valley in the Púchov sector, as well as in the more southern, Myjava–Trenčín sector of the PKB (Began 1969) — area B in Fig. 1. Being affiliated with the Kysuca or Pieniny Unit formerly (e.g., Andrusov 1931; Andrusov & Scheibner 1960), the Manín Unit in this area includes a sedimentary succession ranging from the Upper Triassic Carpathian Keuper Fm, Rhaetian fossiliferous limestones, and rather deep-water Jurassic sequence dominated by bioturbated limestones of the “Fleckenmergel” facies (Allgäu Fm) and radiolarites, then Lower Cretaceous maiolica-type and spotted marly limestones, and Albian to Turonian marls and clastic flysch deposits (Began 1969). However, presently this unit is redefined as the Drietoma Unit differing from the Manín Unit especially by the deep-water Jurassic sediments (see Hók et al. 2009 and references therein). Nevertheless, some partial slices with shallow-water Jurassic and Urgon-type limestones might be parallelized with the Manín Unit (e.g., the Bošáca Subunit of Maheľ 1978 a.k.a. Belá Subunit of Borza et al. 1980; or Urgonian limestones encountered by the deep borehole Lubina-1 in the Myjava part of the Periklippen Zone — Leško et al. 1982). Recently, the St. Veit Klippenzone north of Vienna has been tentatively correlated with the Drietoma Unit, too (Wagreich et al. 2012).

In the eastern Slovakian Pieniny Mts, the Haligovce Unit has been often connected with the Manín Unit (area C in Fig. 1). The compound Haligovce succession includes Middle Triassic limestones and dolomites, variegated Jurassic sandy-crinoidal limestones, a few metres of greenish Oxfordian radiolarites, cherty and nodular limestones, Tithonian to Hauterivian maiolica-type, bedded cherty limestones and, most typically, the Barremian–Aptian massive biogenic Urgonian limestones. In our view, the Haligovce klippen represent large tectonic blocks, possibly megaboudins, surrounded by siliciclastic turbiditic sandstones containing Albian foraminifers (Štefan Józsa, personal information). These flysch-type deposits are correlated here with the Poruba Fm. of the Križna Nappe, or with the Praznov Fm. of the Manín Unit. They are considerably different from the Palaeogene calcareous sandstones associated with the Haligovce Unit (see below).

Based mainly on presence of Urgon-type limestones, Andrusov (1968, 1974) affiliated the Haligovka klippe with

the Manín Unit, i.e. palaeogeographically with the outermost Tatic zones of the CWC. This view was then followed by a majority of Slovak researchers (e.g., Potfaj and Rakús in Janočko ed. 2000). Maheľ (1986) ranged the Haligovce Unit, as a constituent of the larger-scale Manín Unit, to the Križna nappe system (Fatricum). On contrary, Polish authors mostly considered the Haligovce Unit as an integral part of the PKB, palaeogeographically as its innermost element deposited on the northern slopes of the “exotic” ridge dividing the PKB basins from the CWC (e.g., Birkenmajer 1977, 1986). Książkiewicz (1977) even supposed that the Haligovce Unit represents a subunit of the Pieniny Nappe. Finally, Cieszkowski et al. (2009) and Golonka et al. (2015) regarded the Haligovce Unit as a group of sedimentary klippen — olistoliths resting within flysch formations. However, the source of the Haligovce sedimentary klippen was not specified and their olistolithic nature was not properly documented. The “olistolithic concept” would partly correspond to that of Nemčok (1980), who regarded all klippen of the eastern Slovakian PKB as olistoliths. On the other hand, also Nemčok et al. (1990) took off the Haligovce Unit from the PKB and supposed its post-Eocene emplacement to the PKB vicinity. This opinion was motivated by a considerably different type of Palaeogene sediments resting on the Haligovka klippe (Myjava–Hričov Group) compared to other Palaeogene deposits within the PKB itself (Jarmuta–Proč Fm.; e.g., Plašienka 2012a and references therein).

The Gosau-type succession of the Haligovce Unit includes variegated marlstones, orbitoids- and algae-bearing sandstones of the Maastrichtian age (Köhler & Buček 2000; Buček & Köhler 2017), bioturbated limestones with Thanetian large foraminifers, and Palaeocene–Lower Eocene carbonatic conglomerates (Súľov Fm.) intercalated by calcareous sandstones with nummulites and partially resedimented algal-coral patch reefs (Matějka 1961; Scheibner 1968b; Janočko ed. 2000; Köhler & Buček 2005). Banks and bedrock of the Lipník Stream south of the Haligovka klippe, at the contact with the CCPB formations, exposed a narrow slice dominated by pelagic Senonian–Middle Eocene sediments. It was described as the “southern Haligovce Palaeogene development” by Matějka (1961). It is composed of variegated marls and claystones, in places with olistostromes containing shallow-water bioclastic material (Scheibner 1968b). Nowadays, Plašienka & Soták (2015) differentiated this occurrence as an independent unit named the Lipník Unit and correlated it with the Maruszyna Unit occurring in the Polish PKB sector to the west, and with the Šambron–Kričovo Unit toward the east.

Map-scale structures of the Peri-Klippen Zone in the Middle Váh Valley

Manín Unit

The belt of the Manín Unit trends SW–NE, being truncated by subparallel, but anastomosing in the map view, faults into

several strips and lenses with partially distinct composition and internal structure. Along the NW margin, the Manín Unit adjoins the Klappe Unit, which is predominantly composed of mid-Cretaceous deep-marine clastics of the Klappe Flysch. The westernmost part of this contact is covered by Lower Miocene marine sandstones and Quaternary fluvial deposits of the Váh River (Fig. 2). The SE boundary of the Manín belt is followed by a complex imbricated zone composed of narrow slices of mainly mid-Cretaceous flysch sediments assigned by various authors either to the Manín Unit, or to the frontal elements of the adjacent Križna Nappe (Praznov–Jablonové slice according to Marschalko & Kysela 1980; Nozdovice imbricates according to Michalík & Vašíček 1979; Mahel' 1983, 1985, 1986). Further SE-ward, the Palaeogene synclines unconformably seal the Cretaceous thrust structures of the underlying CWC nappe systems.

From SE to NW, five structural domains are differentiated within the Manín Unit in the Middle Váh Valley: (1) the Súľov domain (abridged as M1 in Figs. 2 and 4) in the north-eastern part of the area; (2) the Praznov–Jablonové slice (M2) as a narrow strip rimming the Manín Unit from the SE; (3) the Butkov pericline (M3) in the south-west; (4) the Skalica folded-imbricated domain (M4) north of the Butkov pericline; and (5) the Manín fold-thrust domain (M5) further north. From the S and SE, the Manín Unit is put side by side by the frontal Nozdovice imbricated zone of the Križna Nappe and the sliced Hričov–Žilina synclinal zone filled with Palaeogene sediments in the NE (P1, Figs. 2 and 4). The M2 vs. M3 and M4 vs. M5 zones are juxtaposed and partly interchanged in a coulisse-like mode, along with intervening brachysynforms G1 and G2.

On the surface, the **Súľov domain M1** is cropping out within the Súľov “window” in the NE part of the area (Fig. 2), where it is surrounded by Palaeogene deposits of the Myjava–Hričov Group. Despite lateral relationships to other Manín subunits are obliterated by these deposits, the Súľov domain is probably the most internal element of the Manín Unit (see Fig. 4A). It is prevailingly composed of Albian–Cenomanian “flysch” deposits including numerous bodies of exotic conglomerates (Hradná Mbr.) and several large, Kostolec-type olistoliths of Jurassic–Lower Cretaceous limestones (Vrchteplá, Súľov — Borza 1970). Still within the Súľov window, the Manín Unit is overthrust from the SE by the frontal elements of the Fatic Križna Nappe.

The **Praznov–Jablonové slice M2** is laterally connected with the Butkov domain in the southwest and extends in an about 0.5 km wide strip NE-ward. It is mainly composed of mid-Cretaceous synorogenic deep-marine clastics (Praznov Fm.). The zone is tightly imbricated and steeply SE-dipping under the Križna Nappe (Fig. 4). In the Kostolec area, the Albian turbidites contain several huge blocks of Jurassic to Lower Cretaceous limestones, which are presently considered to be olistoliths (e.g., Marschalko & Kysela 1980; Rakús 1997; Rakús & Hók 2005). On the other hand, some other authors (e.g., Mahel' 1985) regarded the Praznov–Jablonové slice as a frontal element of the overriding Križna Nappe.

The **Butkov domain M3** is dominated by a large, 5 km long and 1.5 km wide brachyanticline (pericline, i.e. doubly-plunging anticline — see the detailed description by Plašienka et al. 2018a) composed of the Jurassic to Lower Albian limestone formations. The Butkov pericline is slightly asymmetric, with steeply N-dipping to vertical northern limb and moderately to steeply S-dipping southern limb, affected also by S-dipping low-angle normal faults (e.g., Michalík et al. 2012). The periclinal closures are indicated by moderately west- and east-plunging fold axes. The anticline is transversally truncated by a deep incised valley, apparently developed along a vertical transfer fault (Plašienka et al. 2018a). The southern limb of the Butkov pericline submerges to the south to south-east below the frontal Nozdovice imbricates of the Križna Nappe (Figs. 2 and 4).

North of the Butkov pericline, the complexly folded **Skalica domain M4** consists of two segments axially plunging NE-ward, separated by the nearly isometric lens-shaped Manín domain M5. The SW segment tightens NE-ward and wedges out near Kostolec village. This is also the general trend of the axial plunge of the whole domain — the SW part exposes the deeper structural levels, which are composed of tight antiforms and imbricates of Jurassic–Lower Cretaceous limestones surrounded by mid-Cretaceous clastic formations, while the tapering NE part is dominantly composed of Senonian deposits filling the complicated **Lieskov–Praznov synform G1** (Figs. 2 and 4). According to Borza et al. (1979), the Lower Cretaceous strata of this domain are akin to the Belá Subunit of the Fatic Križna Nappe. Marschalko & Kysela (1980) described this area as the “Podmanín development” with megabreccias of Urgonian limestones within the Lower Albian pelagic marlstones and considered them as frontal slices or olistoliths of the Fatic Belá Subunit. Structural pattern of this domain and development of the Lieskov–Praznov synform was presented in the paper by Plašienka et al. (2018a).

The **Manín domain M5** to the north of the Skalica domain includes two large brachyanticlines (Veľký and Malý Manín and Drieňovka and Kavčia hills incised by narrow gorges of the Manínsky potok stream). The large Manín “klippe” is an elongated (ca. 5 km long, 1.5 km wide) brachyantiform with SW–NE trending axis and with strongly asymmetric profile — its NW limb is reduced and truncated by a steep reverse fault, which provides contact with the adjacent Klappe Unit (Figs. 2 and 4B). In contrast, the satellite Drieňovka pericline to the east is a smaller (1.5×0.5 km on the surface), symmetric upright open macrofold with moderately dipping limbs (Plašienka et al. 2018a). Both antiforms are supported by a thick competent layer of massive Urgonian limestones.

After an interruption by the anticlinal Manín domain, the synclinal zone filled with Senonian sediments forms the NE segment of the Manín Unit (**Hlboké synform G2**; Figs. 2 and 4A). The synform is squeezed between the backthrust K1–2 slice of the Klappe Unit to the NW and the steeply SE-dipping Praznov–Jablonové slice M2 to the SE. It is tightened toward NE, where it merges with the P1 Hričov–Žilina sliced zone

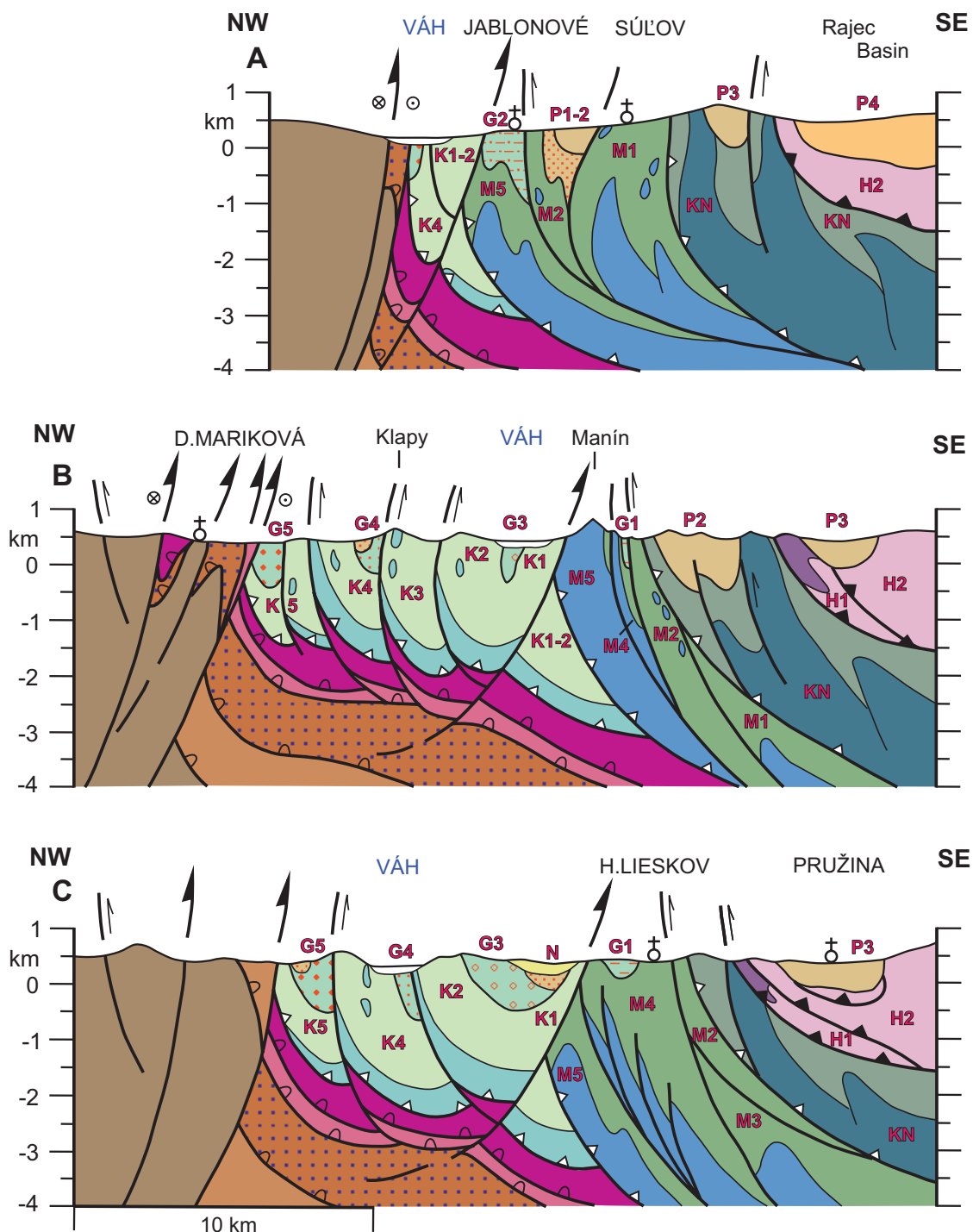


Fig. 4. Geological cross-sections of the area. For their location and legend see Fig. 2. Note that sections are vertically exaggerated.

affected by dextral strike-slipping along the W–E striking Bytča–Varín fault zone.

Klapé Unit

The Klapé Unit consists of five subparallel, lozenge-shaped imbrications that are gradually merging and wedging out toward the north-east: (1) the southernmost Považská Bystrica

slice (K1 in Figs. 2 and 4) is adjacent to the Manín Unit; (2) the Orlové slice (K2) occupies the central position within the Klapé Unit, but rapidly wedges out NE-ward; (3) the Nimnica–Uhry slice (K3) spreads across meanders of the Nosice Dam and disappears underneath fluvial deposits of the Váh Valley north-eastward; (4) the Stupné–Hvozdnica slice (K4) widens eastward, but probably wedges out below the Váh Valley as well; (5) the northernmost, rather wide and complexly

imbricated Hoštíná–Brvnište zone (K5) also narrows eastwards. These slices or imbricates may be treated as partial units (subunits) of the Klappe Unit at the same time, since they embrace more-or-less complete lithostratigraphic successions. They all join together somewhere below the Váh River deposits between Bytča and Žilina (Fig. 4A) and then continue eastward into the PKB Kysuca sector NE of Žilina as a single, undifferentiated unit.

The **Považská Bystrica slice K1**, about 15 km long and 2 km wide, neighbours the NW margin of the Manín Unit and approximates also its macrofold structural style. The southern rim of this slice is moderately up to steeply NW-dipping, i.e. opposite as a majority of strata dips in the Manín Unit. This indicates backthrusting of the Klappe Unit, which seems to postdate development of NW-verging fold-and-thrust structures that are characteristic for the Manín Unit. Tight imbricates of Lower Cretaceous marly limestones appear in the area SW of Považská Bystrica town, but the K1 domain is predominantly composed of the Klappe Flysch deposits dipping NW-ward in a normal position. The K1 Klappe subunit corresponds to the Podháj Unit in the original meaning of Salaj (1995).

The fault-bounded **Rašov synform G3** filled with Senonian–Lower Eocene sediments occurs along the contact of the Považská Bystrica slice with the Orlové slice to the NW. The syncline is up to 4 km wide in the area SW of Považská Bystrica, but rapidly wedges out towards the NE (Figs. 2 and 4). The Rašov syncline is the only of the area, to which also the Oligocene and Lower Miocene deposits are confined.

The next **Orlové slice K2** is ca 10 km long and up to 4 km wide. Its pre-Senonian strata are overturned, with a steep monoclinal dip to the NW. Considering their opposite facing (younging) directions towards the central Rašov syncline, the K1 and K2 slices are interpreted as limbs of a large-scale syncline, i.e. they would represent only one partial unit of the Klappe Unit (Figs. 2, 4B,C).

The **Nimnica–Uhry slice K3** is some 10 km long and 2.5 km wide. It contains steeply NW-dipping overturned strata of the Klappe Flysch, including megaolistolith of the Mt. Klapy. From the next Stupné–Hvozdnica slice it is separated by the narrow **Udiča synform G4** filled with Senonian to Lower Eocene sediments.

The **Stupné–Hvozdnica K4** and **Hoštíná–Brvnište K5** slices show an echelon arrangement and might be unified in one belt, being separated by a narrow antiform exposing the Jurassic to Lower Cretaceous strata of the Klappe Unit. The antiform trends obliquely to the general trend of the belt, causing a lateral coulisse-like replacement of both slices, which are together some 12 km long and 4 km wide. The western Púchov–Brvnište slice carries also the wide **Hoštíná synform G5** with Senonian–Palaeogene infill, while the eastern Stupné–Hvozdnica slice is attached to the Udiča synform G4 (Figs 2 and 4). Thus this outer Klappe belt may be characterized as a complex fold-thrust zone, unlike other Klappe subunits with typically steeply NW-dipping homoclines, though internally imbricated and overturned. Being affected by an oblique

backthrust to strike-slip fault to the NE and E, both K4 and K5 slices are probably wedging out somewhere near town Bytča.

The contact of the Manín–Klappe zone with the External Carpathian Flysch Belt is followed by a narrow discontinuous zone with slices and lenses of the Oravic units of the PKB s.s. (Fig. 2). Both the Subpieniny (Czorsztyn) and Pieniny (Kysuca) units occur there with complex mutual relationships. The contact zone appears to be nearly vertical or steeply N-dipping, probably affected by important along-strike horizontal or oblique movements (Fig. 2). Further to NW, small occurrences of Oravic units occur within the Biele Karpaty and Magura units. The most spectacular is the Dolná Mariková klippen area (Figs. 2 and 4B), which has been interpreted as a nappe outlier of the Oravic Kysuca and Czorsztyn units affected by superimposed reverse faults and strike-slips (Plašienka et al. 2010).

Between Dolná Mariková and Hvozdnica villages, rock complexes of the Šariš Unit as the outermost Oravic element of the PKB occur (Brvnište slice of Potfaj in Mello ed. 2005, 2011). It is formed by the Maastrichtian to Ypresian Jarmuta–Proč Formation — calcareous sandstones, breccias and several olistoliths of Jurassic and Lower Cretaceous limestones derived from the overriding Subpieniny Unit (cf. Plašienka 2012a). South-west of Hoštíná village, the Šariš Unit is laterally replaced by the eastward wedging out Javorina Nappe of the Biele Karpaty Superunit composed of Campanian red shales and Maastrichtian turbiditic sandstones. The underlying Bystrica Unit of the Magura Superunit mostly includes calcite-poor grey mudstones and siliciclastic turbidites of the Eocene Zlín Formation.

Palaeogene synforms

The inner SE margin of the Manín–Klappe Peri-Klippen Zone is adjoined by several subparallel synclines filled exclusively with Palaeogene sediments. In the north, the **Hričov–Žilina sliced zone P1** (Figs. 2, 3 and 4A) includes Palaeocene–Lower Eocene, steeply NW- to N-dipping, often overturned and strongly imbricated sediments of the Myjava–Hričov Group. Together with the reduced Senonian Hlboké syncline, this imbricated zone provides connection to analogous rocks in the Varín (Kysuce) PKB sector towards the east (cf. Plašienka & Soták 2015).

Southeast of the Praznov–Jablonové slice, the **Prečín–Súľov synform P2** is located (Figs. 2, 3 and 4B). It is 1 to 3 km wide, asymmetric syncline filled with mostly massive carbonatic conglomerates of the Lower Eocene Súľov Fm. and Middle Eocene pelagic shales of the Domaniža Fm. (Soták et al. 2017). These transgressively, but in general conformably overlie Lower Eocene sediments of the Hričov–Žilina imbricated zone in the northern part of the syncline, where the strata are overturned, steeply NW-dipping. Toward the SW, bedding is subvertical, or steeply to moderately SE-dipping, unconformably overlying steep structures of Cretaceous rocks of the Praznov–Jablonové slice (Marschalko & Kysela 1980). The south-eastern limb is moderately dipping to the NW, or

truncated by NW-vergent reverse faults (Fig. 4A,B). In places along this eastern limb, the coarse Súľov conglomerates unconformably cover the Manín Unit (M1 domain) in the northern part and the frontal elements of the Križna Nappe in the southern part (Fig. 2). Apparently, the SSW–NNE trend of Palaeogene synclines is slightly oblique with respect to the underlying Cretaceous SW–NE structures of the Manín and Križna units.

To the south, the Prečín synform is divided from the adjacent **Pružina–Domaníža synform P3** by the NE-ward plunging Malenica–Roháč antiform composed of the Fatric and Hronic complexes. The southern periclinal closures of both synforms display a coulisse-like arrangement (Figs. 2 and 4). The Pružina–Domaníža synform is up to 5 km wide, gentle and only slightly asymmetric, though partly fault-bounded from the SE side.

The eastward located **Rajec synform P4** is already a part of the extensive CCPB filled with Bartonian–Oligocene sediments of the Podtatra Group. Its transgressive Borové Fm. unconformably overlies Mesozoic complexes of the Fatric and Hronic nappes (Figs. 2 and 4A). In the northern part, SW of Žilina, the Podtatra Group covers discordantly younger formations of the northern parts of the P2 and P3 synforms (Fig. 2). The CCPB synforms are wide, gentle and generally symmetric, but affected by younger normal faulting.

Tectonic evolution

The PKB proper and the Peri-Klippen Zone are located at the backstop of the ancient accretionary wedge that developed during the Senonian to Eocene. The wedge was buttressed by the CWC basement/cover complexes reinforced by the granitoid plutons of the Tatric basement along its outer margin. As the wedge grew by frontal accretion, the frontal CWC units were gradually transferred from the wedge toe to its rear parts. In the final backstop position, the Klappe and Manín units were strongly compressed and attained their current complicated deformation structures.

Growth stages of the accretionary wedge as revealed by evolution of the Senonian and Palaeogene wedge-top basins

In their synthesis of Cretaceous to Palaeogene syntectonic deposits of the Manín and Klappe units in the Middle Váh Valley, Marschalko & Rakús (1997) distinguished three depositional megacycles: (1) Albian–Cenomanian progradational proximal turbidites with olistoliths (Klappe Flysch) terminated by paracyclic shallow water sandstones (Orlové Fm) indicating filling-up of the basin; (2) Coniacian–Santonian retrogradational conglomerates and olistostromes with reef bodies; and (3) Campanian–Palaeocene megacycle exhibiting progradation from hemipelagic marls (Púchov Fm) into bioclastic allodaps, tempestites and conglomerates with reef bodies. Recently, Plašienka & Soták (2015) have differentiated up to seven Senonian through Palaeogene sedimentary sequences

within the second and third megacycles of Marschalko & Rakús (1997). At the same time, these sequences represent evolutionary stages of the Gosau basins positioned above the developing accretionary wedge (Fig. 3):

Stage 1: following the Late Turonian emplacement event of the Fatric (Klappe, Manín, Križna) and later of the Hronic cover nappe systems, the Coniacian–Early Santonian fining-upward sequence includes basal polymict conglomerates with reef bodies, overlain by calcareous sandstones, olistostromes with littoral fauna and hemipelagic marls; these sediments are interpreted as deposited in the piggyback wedge-top depressions of the accretionary wedge composed of the frontal Fatric units;

Stage 2: Late Santonian to Middle Campanian variegated hemipelagic marlstones of the “couches rouges” facies (CORB-type) record sudden deepening due to an extensional collapse of the wedge;

Stage 3: sediments of the Middle Campanian to Cretaceous/Palaeogene boundary age are represented by neritic marls, shallow-water bioclastic limestones, tempestites, calcareous sandstones and conglomerates with exotic pebbles and blocks of rudists-bearing bioherms; this coarsening- and shallowing-upward sequence registers shortening of the wedge by frontal accretion of the Oravic units and internal out-of-sequence thrusting;

Stage 4: Danian to Early Ypresian period is characterized by sedimentary gaps and erosion of older deposits indicating transient emersion of the overthickened wedge; terrestrial or shallow-marine sediments rich in terrigenous material or olistoliths of Thanetian reefs were deposited in the wedge-top basins;

Stage 5: the base of the new Late Ypresian–Lutetian transgressive cycle involves coarse-grained carbonate breccias and conglomerates (Súľov Fm.), which are followed by calcareous turbiditic sandstones and bathyal variegated claystones; this fining-upward sequence records a gravitational collapse of the wedge;

Stage 6: Bartonian to Early Rupelian — after the Late Lutetian gap caused by the renewed shortening and thickening of the wedge, a new transgressive cycle is represented by a sequence of continental to shallow-water calcareous clastics and nummulitic limestones at the base of the extensive CCPB, which covered most of the CWC area; then starved sedimentation of anoxic shales prevailed during the Late Priabonian–Early Rupelian;

Stage 7: Late Rupelian to Aquitanian — the terrigenous input into the CCPB increased gradually, but considerably and the basin was probably overfilled during the earliest Miocene.

As inferred by Plašienka & Soták (2015), these depositional cycles closely correspond to those recognized in the coeval trench-foredeep basins of the Oravic units that were gradually accreted to the wedge tip, despite of partial differences in the sedimentary record (Fig. 3). Applying the critical taper theory of accretionary wedges, the supercritical, overthickened wedge states are recorded by shallow-water sedimentation in the wedge-top areas, even with emergence and erosion of

older strata, especially when simultaneous global sea-level lowstand occurred. Coeval foredeeps were filled mostly with coarse-grained gravity deposits produced by increasing erosion of the prograding wedge. This scheme concerns the stages 1, 3, 4 and 6 in particular. On the other hand, the subcritical wedge generated by the extensional collapse of overthickened wedge gave way to deposition of deep-water pelagic strata and equalization of sedimentary environments in both the trench-foredeep and wedge-top basins. The subcritical wedge states are characteristic for the stage 2 with CORB-type sediments, stage 5 with variegated pelagic shales in sediment-starved basins, and stage 7 characterized by a marked subsidence and accumulation of thick clastic deposits in the fore-arc CCPB with material derived from the elevated axial orogenic zones and from rear parts of the EWC accretionary wedge (Kováč et al. 2016). The transitional periods from the subcritical to supercritical wedge are characterized by the coarsening-upward sequences, while the fining and deepening-upward sequences are typical for the contrary transitions.

Structural development

In this chapter a tentative correlation of tectono-sedimentary cycles with development of macrostructures of the area and mesoscopic deformation stages, which were distinguished on the basis of the structural rock record (e.g., Bučová et al. 2010; Prokešová et al. 2012; Bučová 2013; Šimonová & Plašienka 2017; Plašienka et al. 2018a), is attempted. Considering the wide age span of various syn-tectonic sediments preserved in the area (Albian–Early Miocene), at least the early stages of the structural evolution of units present in the area should have overlapped in time with the depositional phases obviously controlled by tectonics to a great extent. Nevertheless, it is problematic to relate the depositional cycles and corresponding wedge states discerned above with the deformation stages and their respective structural rock record, because of no direct and unequivocal relationships can be postulated.

In general, the supercritical wedge stages would have been connected with contractional deformation within the wedge, whereas extensional structures are expected for periods with the subcritically tapered wedge conditions. However, only the uppermost structural levels of the accretionary wedge can be analysed, where deformation took place in the brittle field exclusively. Under such conditions, the overprinting criteria are not always clear and the “absolute” timing of individual deformation stages is only possible by precise dating of sediments affected, and by correlations with other neighbouring regions. This was done for the brittle structural record and its palaeostress interpretation, but merely from the Oligocene onward at the appropriate level of confidence. We can only hypothesize that the oldest discerned palaeostress states with the generally NW–SE oriented main horizontal compression axis might have corresponded to a rather long period of the wedge deformation during the Senonian up to the Early Miocene.

The Manín and Klappe units, treated here as the frontal elements of the CWC Fatic nappe system, were emplaced in the present Peri-Klippen position supposedly in the Late Turoanian times. Thus they carry also their own pre- and syn-emplacement structural record attained during their detachment, thrust stacking and final emplacement. This structural association, which can be grouped as the non-genetic D_0 deformation stage, can be correlated with the structural evolution of the Křížna Nappe in the CWC areas (cf. Prokešová et al. 2012; Plašienka et al. 2018a). In terms of deformation stages, which were discerned based on overprinting criteria and changes in the operating deformation mechanisms, Plašienka (2012b) and Plašienka & Soták (2015) discriminated five main events that affected the PKB units in post-emplacement times of the CWC units:

- Deformation stage D_1 was related to detachment of the higher Oravic units (Pieniny and Subpieniny) from the subducted substratum and their accretion to the tip of the prograding Western Carpathian orogenic wedge. On the basis of the synorogenic sedimentary record, this process lasted from the Coniacian stage (Vahic Belice Unit — cf. Plašienka 2012a) and from the Campanian (Pieniny Unit) up to the Maastrichtian (Subpieniny Unit; Fig. 5). In the accretionary wedge formed by the frontal CWC units and their piggyback Gosau basins, the D_1 stage shortening was probably accommodated by synsedimentary large-scale folding and out-of-sequence thrusting during the wedge taper states growing from critical to supercritical, interrupted by occasional extensional collapse events resulting in the subcritically tapered wedge.

Based on interpretation of the sedimentary record, extensional events occurred three times during the Senonian–Palaeogene times (Fig. 5). However, this was not really recognized in the structural record of the investigated region. Supposedly extensional structures of the first Campanian event were mostly obliterated or reactivated during the superimposed strong compressional deformation. In general, the post folding/tilting extensional faults are quite common in the investigated region, but they are interpreted as accompanying the late, Miocene–Pliocene extensional events. In spite of the absence of good stratigraphic markers, it is inferred that a part of these extensional faults might have accompanied also older post-folding distension phases. Considering data from the Middle Váh Valley, this pre-Miocene extensional event can be related to the Lutetian collapse in particular.

- The D_2 stage is represented by the so far poorly constrained event with structures like minor folds with the NW–SE to N–S trending axes and faults developed under the SW–NE to W–E operating compression — i.e. the D_2 structures trend across the older and also younger structures, therefore they are sometimes designated as the “cross-folding” event. This event should have occurred still before development of the dominant macrofold structures in the Manín zone (Plašienka et al. 2018a). Its broad-scale kinematic meaning remains unclear, however. Possible relationship with the PKB

and outer CWC arc formation seems feasible. Tentatively, it could have been associated with the incipient oblique collision of the orogenic wedge front with the Oravic continental ribbon in present western Slovakia. This took place around the Cretaceous/Palaeogene boundary, then the overall NW–SE to N–S compression and shortening renewed. Accordingly, the “cross-folding” D₂ stage might have represented a short-termed, collision-related event during the long-time uniform progression of the orogenic wedge. This interpretation is to some extent corroborated by the likely absence of these structures in the Šariš Unit accreted during the Late Palaeocene–Early Eocene and in the coeval deposits of the piggyback Myjava–Hričov Group. Vojtko et al. (2010) and Šukalová et al. (2011) indicated lack of structures generated by the W–E compression in the CCPB deposits, too.

- Deformation stage D₃ is defined as the main phase of the NW–SE to N–S compression (Sh_{max}). Although the post-emplacement contraction could have been initiated in the Senonian, the analysed structural record suggests that the main shortening and development of the general imbricated structural pattern of the area was reached during the Palaeocene and Early Eocene. It was related to the accretion of the Šariš Unit during the Palaeocene in western

Slovakia and to the subsequent enormous growth of the EWC wedge during the Eocene–Oligocene times (Fig. 5). In the Middle Váh Valley, this is recorded by pre- and syn-tilting small-scale structures (Bučová 2013), and then by development of the principal macrostructures such as the Butkov, Manín and Drieňovka periclinal and Lieskov and Hlboké brachysynforms (Plašienka et al. 2018a). The episodic growth of these synclinal basins was mirrored by presumably contemporaneous intermittent growth of adjacent periclinal elevations, as it is indicated by structural analysis of the Butkov fold. After the maximum contraction was achieved purely by folding, the subsequent horizontal shortening and vertical lengthening was accomplished by development of tight imbricates. Steeply SE-dipping reverse faults are cutting preferably the northern limbs of slightly asymmetric anticlines, like the Butkov and Manín periclinal (Fig. 4; deformation substage D_{3a}).

Probably after the Lutetian extensional episode, prolonged contraction resulted in backthrusting–backtilting, whereby most of strata were steepened up to overturned towards the south-east (deformation substage D_{3b}). At the same time, synforms P1–3 in the southerly adjacent Palaeocene–Lutetian basin formed (Figs. 2 and 4). Both the backthrusts

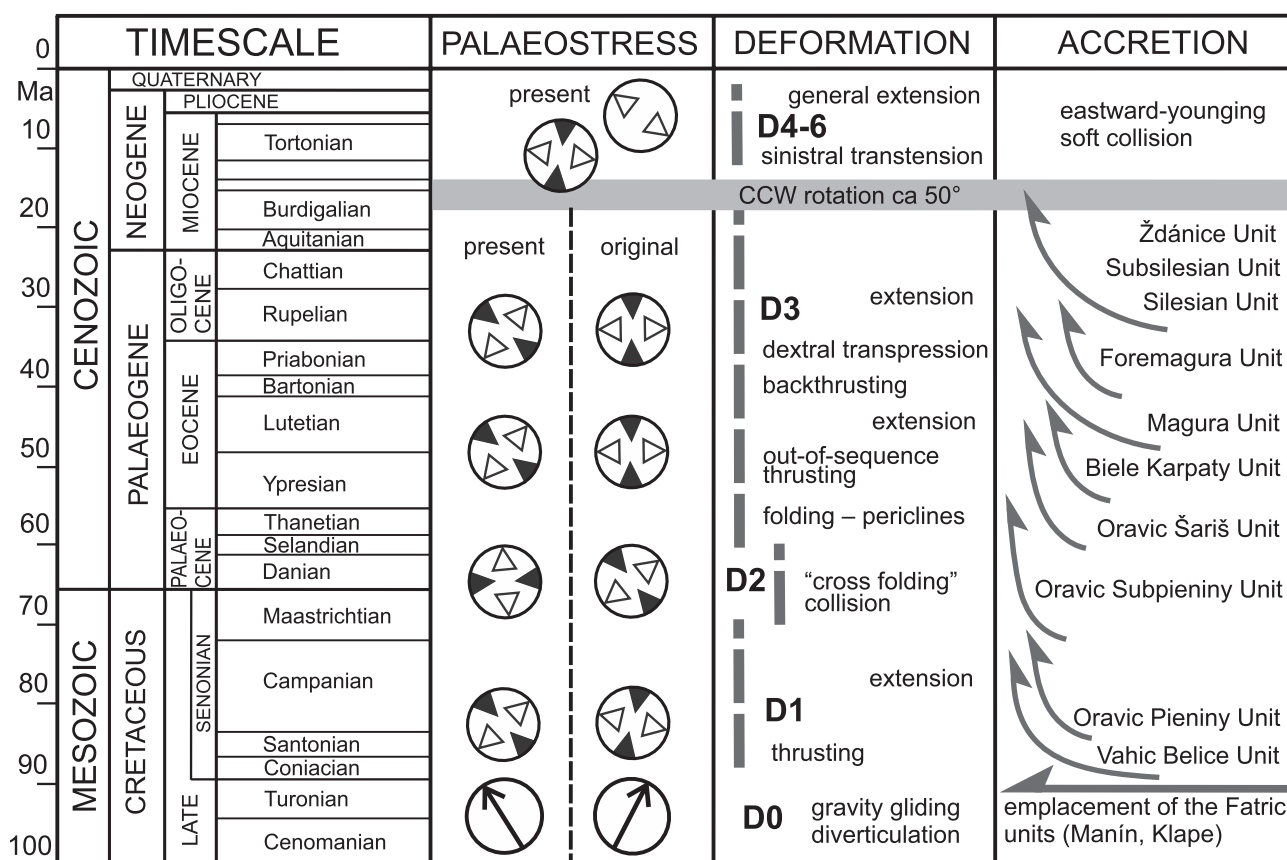


Fig. 5. Synopsis of the main deformation stages with their respective palaeostress orientation and relationships to the accretionary wedge growth. Palaeostresses are shown by circles with directions of Sh_{max} (black triangles) and Sh_{min} (empty triangles); general vergency of syn-emplacement D₀ structures is indicated by arrows. Note that the presently measured palaeostress orientations (left column) are corrected for the Middle Miocene counter-clockwise block rotation of the Western Carpathians.

and axes of these synforms are slightly oblique to older D_{3a} structural trends. The deformation stage D_{3b} culminated in the Late Eocene–Early Oligocene by dextral transpression along W–E trending wrench zones with eastward-increasing manifestations in the northern and particularly in the eastern PKB branch (cf. Ratschbacher et al. 1993; Plašienka 2012b). After the next, Late Rupelian–Chattian extensional phase with the subcritical wedge situation and marked subsidence of the CCPB, the general NW–SE orientation of the maximum horizontal compression axis still persisted. This palaeostress field controlled also the dextral transpression and development of Eggenburgian (Early Burdigalian) basins of the wrench-fault furrow type (Kováč 2000) in western Slovakia. Remnants of Eggenburgian sediments are present in the studied area, too, being confined to the underlying Rašov syncline G3 (Figs. 2 and 4C).

- During the late Early and early Middle Miocene, the principal compression direction gradually rotated into the N–S orientation. Deformation stage D_4 is characterized by sinistral transpression–transtension along the western, SW–NE trending PKB branch (Marko et al. 1995; Kováč & Hók 1996; Pešková et al. 2009; Bučová et al. 2010; Šimonová & Plašienka 2011, 2017). This stage was largely coeval with the post-Eggenburgian CCW block rotation of the Western Carpathian domain (see e.g., Kováč 2000 and references therein). It means that all the preceding palaeostress fields also rotated CCW during this stage. Consequently, assuming the 50° CCW block rotation of the entire Western Carpathian domain (e.g., Márton et al. 2013), the original position of the main compression axis was consistently oriented in the N–S direction for a long period from the Senonian up to the Lower Miocene epoch (Fig. 5).
- After the CCW block rotation of the Western Carpathian segment of ALCAPA was completed, its NW margin was firmly attached to the SE edge of the Bohemian Massif, but its NE front still progressed to fill up the space released by the retreating subduction of the EWC oceanic lithosphere. As a result, the early Middle Miocene period is characterized by the overall N–S to SSW–NNE oriented principal horizontal compression axis Sh_{max} giving way to widespread sinistral transtension in western Slovakia (Vienna Basin, Blatné and Ilava basins) — stage D_5 (Fig. 5).
- The late Middle Miocene to Pliocene–Quaternary time is characterized by rifting and general extension (e.g., the Danube Basin) with generally NW–SE oriented Sh_{min} in the Middle Váh Valley area (stage D_6 in Fig. 5).

Discussion

Present tectonic position of Fatric units in the Peri-Klippen Zone and their tentative palinspastic arrangement

Taking apart the Senonian and younger formations, which have been interpreted to represent the post-nappe, Gosau-type cover (Plašienka & Soták 2015), the Manín and Klapce units

could represent the integral, though distant frontal elements of the Fatric cover nappe system of the CWC. However, the present facies distribution of Jurassic to Lower Cretaceous formations does not correspond to the expected palinspastic arrangement in the original Fatric depositional area. In a majority of models going back to Biely & Fusán (1967) and Andrusov (1968), the Fatric Križna nappe system was derived from a basinal sedimentary area located between the present southern Tatric and northern Veporic margins. The basin developed by Early Jurassic rifting of the epi-Variscan continental crust (e.g., Plašienka 2003a,b) and included the pre-rift Permian and Lower Triassic continental clastics, Middle Triassic carbonate platform and Upper Triassic clastics and evaporites (Carpathian Keuper Formation), syn-rift Lower Jurassic shallow marine carbonates with important terrigenous input, then Middle Jurassic to Lower Cretaceous post-rift sequence of mostly deep marine pelagic and slope deposits, and finally mid-Cretaceous synorogenic “flysch” clastics (Fig. 3). Orogenic progradation from the south seized the Fatric realm in the Albian, when its southern margin against the northern Veporic domain was inverted and the attenuated Fatric crust was gradually underthrust below the Veporic basement wedge during the Late Albian–Early Turonian. Simultaneously, the basin fill was detached along the horizon of Lower Triassic shales and evaporites and then thrust forward on the foreland Tatric domain, until the whole Fatric crust was eliminated from the surface and the northern Veporic and southern Tatric margin came into collision along the so-called Čertovica Line. The structural history and tectonic model of origin of the Fatric nappes was presented in papers by Plašienka (1983, 1995c, 1997, 2003a), Plašienka & Prokešová (1996) and Prokešová et al. (2012).

The original configuration of the Fatric domain and architecture of its sedimentary infill was reconstructed by analyses of lithostratigraphic sections in various, presently allochthonous parts of Fatric units, namely the Križna Nappe, and its former Tatric and Veporic margins (e.g., Michalík & Vašíček 1979; Michalík 1993, 2007; Plašienka 2003a; Prokešová et al. 2012 and references therein). In general, the central, up to 50 km wide zone was occupied by the Zliechov Basin characterized by deep marine pelagic sedimentation during the post-rift stage, while its margins are outlined by various slope facies grading into swell elevations. The cover sediments of the latter remained solitary with their basements and currently they occur in the northern Veporic (Veľký Bok Unit) and southern Tatric zones (in the Tribeč, Tatry and Nízke Tatry Mts.). Without going into details, this situation can be illustrated by the distribution of some diagnostic formations. For example, the Barremian–Aptian shallow water, Urgon-type platform development can be followed from the autochthonous position (in both depositional and tectonic aspects) in the Tatry Mts. (Wysoka Turnia Formation of Lefeld et al. 1985) towards the prograding platform edge (Manín and Skalica fms. already detached and transported at the tip of the Fatric nappe system in the Manín Unit), typical prograding delta and slope facies of resedimented platform material (Lúčkovská and Podhorie fms.

of the Butkov succession; Muráň Fm. of the Havran partial nappe in the Belianske Tatry Mts. — Michalík et al. 1990), up to slope-toe proximal to distal calciclastic turbidites occurring in the frontal partial units of the Krížna Nappe (Vysoká Unit in the Malé Karpaty and Belá Unit in the Strážovské vrch Mts. — for the reviews see Michalík & Soták 1990, Michalík 1994 and Pečeňa & Vojtko 2011). On the other hand, the distinctive eupelagic deposits like radiolarites (Ždiar Fm. in Fig. 3) are typical for the Zliechov Basin bottom and are widespread in the Krížna Nappe (Zliechov succession), whereas they diminish in thickness and become more calcareous towards the slope Butkov succession and completely disappear in the Manín s.s. succession (Fig. 6).

As can be seen in Figs. 2 and 3, the Klope Unit does not respect this facies polarity, since it crops out in front of the Manín Unit, which should otherwise be the outermost element according to the above described rules. Despite scarce surface occurrences, the Jurassic to Lower Cretaceous sequence of the Klope Unit corresponds rather to the deep water Zliechov succession, similarly as that of the Drietoma Unit further SW-ward. A hypothetical explanation was provided by Plašienka (1995a, 2003a), Plašienka & Prokešová (1996) and Prokešová et al. (2012) by a diverticulation tectonic model — the Klope Unit was derived as the first from the top of the growing Fatric accretionary pyramid in the primary area and glided northwards over the unconstrained basinal Tatric foreland and finally beyond the northern Tatric edge. Subsequently, but still during the Late Turonian, the slope-derived Manín, Belá, Havran and Vysoká units of the Krížna nappe system were emplaced, followed by the main body of the Krížna Nappe with its typical basinal Zliechov succession. This model of the present and original palinspastic settings of the Klope and other Fatric units is schematically depicted in Fig. 6.

The thick prisms of the Albian–Cenomanian, Upohlav-type conglomerates of the Klope Flysch contain large quantities of “exotic” pebble material derived from unrecognized sources, traditionally interpreted as the (Ultra)Pieniny Cordillera a.k.a. Andrusov Ridge (e.g., Mišík & Sýkora 1981; Birkenmajer 1988; Mišík & Marschalko 1988; see also the latest review by Mišík & Reháková 2004 and references therein). However, some characteristic rocks like Permian granitoids and bimodal volcanic rocks with Early Cretaceous cooling ages (Uher & Pushkarev 1994; Kissová et al. 2005; Poprawa et al. 2013; Krobicki et al. 2018), Middle–Upper Triassic basinal carbonates (Mišík et al. 1977; Birkenmajer et al. 1990), Upper Jurassic shallow-water limestones (Mišík & Sýkora 1981), glaucophanites and other HP/LP metamorphic rocks with Late Jurassic isotopic ages (Šímová 1982; Dal Piaz et al. 1995; Faryad & Schreyer 1997; Ivan et al. 2006), Urgonian limestones with ophiolitic and blueschist detritus (Mišík & Sýkora 1981; Plašienka et al. 2018b), as well as abundance of Cr-spinels in heavy mineral fractions of sandstones (Mišík et al. 1980; Jablonský et al. 2001; Bellová et al. 2018) all indicate the provenance of this material in the southern Carpathian zones, where such rocks are only known from the present structure. An analogous pebble inventory occurs also in

the coeval conglomerates of the Fatric (Krížna Nappe) and Tatric Poruba Fm. (Mišík et al. 1981). On the other hand, no such rocks can be found in situ in zone adjacent to the PKB, moreover the structure and evolution of the northern Tatric margin, which should have neighboured the “exotic ridge”, is completely different from what is recorded in the pebble material. Therefore Plašienka (1995a,b, 2012a) proposed a model of the Fatric affiliation of the Klope Unit, whereby the exotic material was derived from the thrust stack in the southern CWC zones (including the Meliata-type, ophiolite-bearing units) and deposited in the adjacent trench basin filled with synorogenic, coarse-grained clastics. This “wildflysch” basin was most probably located in the southern part of the Zliechov Basin that was gradually shortened and deformed in time of synorogenic sedimentation (Albian–Cenomanian) due to underthrusting of its attenuated crust below the North Veporic wedge tip (see also Plašienka & Prokešová 1996; Kissová et al. 2005; Jeřábek et al. 2012; Plašienka 2018a). Another possible model by Rakús & Marschalko (1997) assumes a large-scale sinistral strike-slipping along the outer CWC margin that brought the Klope and related units to the present position from the far eastern areas where the exotic sources were closer to the present PKB. Nevertheless, since the latter model is not supported by structural or regional tectonic evidence, we are still maintaining the hypothetical concept of the southern Fatric derivation of the Klope Unit and its Klope Flysch (Fig. 6).

Provenance of olistoliths and distribution of Urgon-type carbonate platforms

Olistoliths are treated here as angular sedimentary slide blocks, often solitary “klippen”, with dimensions exceeding ca. 2–3 m, which are embedded in a much finer-grained matrix of different character. Concerning the composition, there are several different types of olistoliths existing in the investigated area, but basically they occur in four stratigraphic and tectonic settings in the Manín and Klope zones of the Middle Váh Valley (see also Plašienka 2018a,b):

- The Palaeocene–Lower Eocene deposits of the Myjava–Hričov Group contain several conspicuous, deca- to hectometric blocks and numerous smaller boulders of Thanetian Kambüchel-type algal-coral bioherms (e.g., Buček & Köhler 2017 and references therein) that were derived from temporary, later completely destroyed marginal and patch reefs (Fig. 3; see also Plašienka & Soták 2015 and references therein). Blocks of Urgonian limestones, obviously derived from the encircling Manín Unit, are also common.
- Senonian Gosau formations also include variously sized, mostly allochthonous blocks of rudist and algal-coral reefs of the same period. Clasts of Urgonian limestones are particularly frequent in the Hlboké synform G2. North of Púchov, the Coniacian–Santonian conglomerates of the Rašov Fm. filling the most external Hoštíná synform G5 contain also two decametric olistoliths and numerous smaller blocks of Middle Triassic, Wetterstein-type platform limestones. They could have originated only from

the Hronic units, although the possible sources are quite remote at present (see Fig. 2). It is inferred that they were torn off the advancing front of the overthrusting Hronic nappes (e.g., the Strážov Nappe dominated by the massive Wetterstein carbonates; cf. Havrila 2011) and transported towards the foreground depressions.

- The Kostolec Unit (Súl'ov and Praznov–Jablonové slices of the Manín Unit) is mainly composed of Cenomanian Praznov Fm. that carries ten large olistoliths and a number of smaller blocks of Jurassic to Lower Cretaceous limestones (Rakús & Marschalko 1997; Rakús in Mello ed. 2011). Their lithology is similar to that of the Manín succession, therefore their local provenance from the Manín Unit is very probable. However, unlike the above in situ Gosau complexes, derivation and emplacement of the Kostolec olistoliths must have occurred in the original sedimentary area of the Manín Unit, i.e. far from its actual place, since they are surrounded by early Late Cretaceous synorogenic flysch deposits. Most probably they represent blocks released from the edge of the Urgonian platform that slid downslope into bathyal depths of the slope toe, or a mélange-like complex developed in front of the Krížna Nappe (Belá–Vysoká Subunit; Fig. 6).
- The Klape Unit contains only few, but big olistoliths of variegated, mainly Jurassic limestones. The Mt. Klapy klippe is the largest one with its long axis measuring almost 1000 metres. These olistoliths are typical solitary slide blocks embedded in hemipelagic or distal turbiditic deposits (lower Albian Nimnica and Uhry fms.). Their provenance is unknown, a possible solution is proposed in Fig. 6B, based

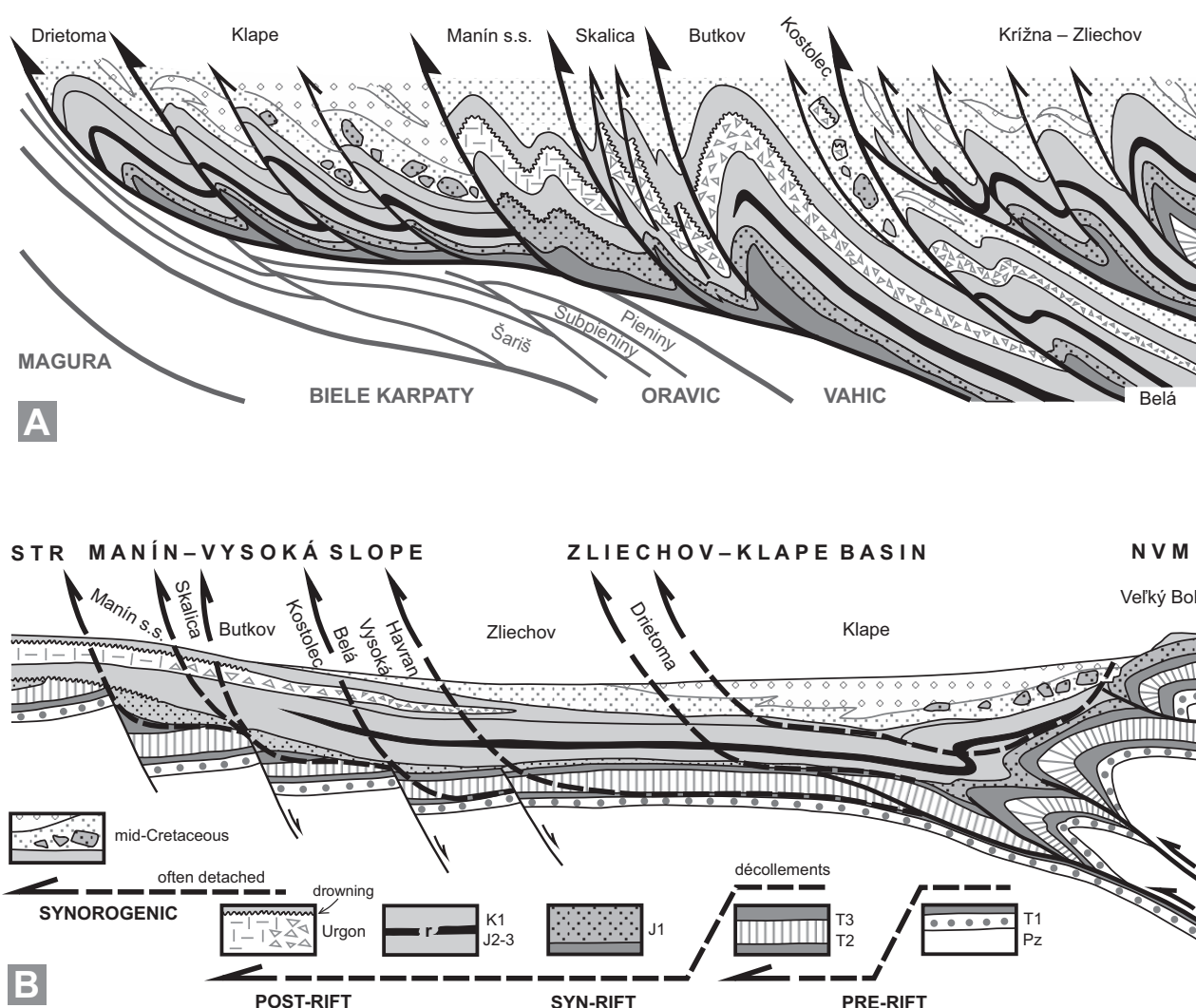


Fig. 6. The latest Cretaceous (post-D₁) arrangement of individual Fatric units in the Peri-Klippen Zone (A) and their inferred palinspastic position in the former Fatric sedimentary area (B) shown in approximately NW–SE trending, schematic sections. Not to scale (vertically exaggerated). Notice the different types of olistoliths in the Klape and Kostolec units (A). Section (B) depicts a time slice at around 100 Ma (Albian/Cenomanian boundary) with onset of shortening at the southern, Veporic margin of the Zliechov Basin. STR — South Tatric Ridge; NVM — North Veporic margin; r — radiolarites (Ždiar Fm.). Note that the main part of the Zliechov Basin was much broader, approximately 50 km wide. Note also that considerable lateral variations occurred along strike the margins of the Zliechov Basin, which cannot be shown in one section (cf. Michalík 2007).

on the inferred southern position of the Klope succession in the original Zliechov Basin and similarity of the Jurassic olistoliths with the coeval deposits of the Lučatín succession of the Veľký Bok cover unit of the northern Veporicum as the potential source area (see Plašienka 1995c; Soták & Plašienka 1996).

Assuming the proposed palinspastic arrangement of units described above, we infer existence of three different domains with Upper Barremian–Aptian to Lower Albian platform limestones (Urgon-type) in the CWC: (1) the southern, totally eroded platform that provided “exotic” pebbles of limestones with ophiolitic and blueschist detritus occurring in the Upohlav conglomerates of the Klope Flysch (cf. Méres et al. 2015; Plašienka et al. 2018b); (2) the central platform was confined to the South Tatric Ridge, which separated the Zliechov and the northern Tatric Šiprúň basins, is largely preserved in an autochthonous position in the Tatry (High Tatra) Mts. (e.g., Masse & Uchman 1997) and its slope to slope-toe detritus in the northern Fatric units (Manín–Belá–Havran–Vysoká, see Fig. 6B); (3) existence of the independent, probably rather small northern platform was related to the North Tatric Ridge, as indicated by allodapic limestones and olistostromes with northern sources occurring in the Tatric Šiprúň-type successions in the Malé Karpaty Mts. (Solárov Formation — Jablonský et al. 1993).

Still more northern Urgonian platform was indicated in the Orava sector of the PKB, where the Nižná Unit was distinguished mainly based on the presence of Urgon-like allodapic limestones in otherwise deep-water, Kysuca-type succession (Scheibner 1967; Mišík 1990; Józsa & Aubrecht 2008). However, there are no signs of Barremian–Aptian allodaps with shallow-water bioclastic detritus present in all other Pieniny or Kysuca–Branisko successions of the PKB, even more there is a general absence of Urgonian platforms on flanks of the elevated Czorsztyn Ridge (see e.g., Birkenmajer 1977). The only exception might be the Beňatina klippe in easternmost Slovakia (Schlögl et al. 2004), where Aptian allodapic limestones with shallow-water detritus accompany a Czorsztyn-like succession. However, it is only a small, tectonically separated exposure with problematic relationship to the surrounding formations. In light of this, there seems to be no place for an independent Urgonian platform in the Oravic domain. In our opinion, the Nižná succession is to a certain extent comparable to some Fatric, more distal slope successions deposited at the foot of the Manín–Vysoká slope facing the Zliechov Basin, like for example the Havran succession of the Krížna Nappe (Fig. 6B).

Summing up, overview of the results presented in this article basically confirms the conception of Michal Mahel' and his supporters about the Fatric (Krížna) affiliation of the Manín and analogous units and their interpretation as far-travelled gliding nappes that were afterwards incorporated into structures along the northern Tatric edge. There, welded with the subsequently accreted Oravic elements, these units attained the present complex structural pattern within the Carpathian Klippen Belt. Nevertheless, the distant palaeogeographic

provenance and pre-emplacement history of the Manín and other Fatric units with respect to the “classic” PKB Oravic units (or PKB s.s.) validate their affiliation to a special PKB zone defined as the Peri-Klippen Zone by Mahel' (1980). The author is aware that this terminology becomes a bit tricky, therefore it was proposed to use only one unifying term for both the Pieniny Klippen Belt s.s. and the Peri-Klippen Zone — the Považie–Pieniny Belt (Plašienka in Froitzheim et al. 2008). This name combines two areas where the main ideas about the lithostratigraphy, structure and evolution of the PKB were developed — the Považie region in western Slovakia (Váh River Valley) with dominating Peri-Klippen Zone, and the Polish–Slovak Pieniny Mts. built up of widely and almost completely preserved Oravic units.

Conclusions

Referring to the aims of this paper formulated in the introduction, it is concluded that results of the field research, interpretation of kinematics and evolution of observed deformation structures, and analyses of sedimentary successions together with an inevitable portion of generalization and hypothesizing collectively indicate that:

- The Lower Jurassic to Cenomanian lithostratigraphic successions of the Manín and Klope units largely correspond to those of other Fatric units, being generally characterized by (Fig. 3): (1) early Lower Jurassic syn-rift, mostly shallow-water sedimentation influenced by terrigenous input; (2) late Early Jurassic up to Early Cretaceous (Hauterivian) post-rift pelagic sedimentation controlled by the thermal subsidence of a thinned continental lithosphere; (3) growth of the Barremian–Aptian, Urgon-type carbonate platform in the northern Manín domain and hemipelagic dysoxic sedimentation in the southern Zliechov Basin (including the Klope Unit); (4) deposition of syn-orogenic, coarsening-upward deep marine clastics in mid-Cretaceous times (Albian–Cenomanian) and common cessation of sedimentation in the Turonian due to commencing orogenic shortening and nappe thrusting. This evolution and timing of the principal tectonostratigraphic events is very much different from those of the PKB Oravic units. Accordingly, the palaeogeographic positions of the Fatric and Oravic domains were different and remote throughout the Jurassic and Early Cretaceous up to the Turonian stage.
- The Senonian to Lower Eocene formations within the Peri-Klippen Zone are interpreted as having been deposited in wedge-top basins developing in a piggyback position atop the developing accretionary wedge composed of the frontal Fatric units (Manín, Klope, Drietoma) as a response to subduction of the underlying oceanic lithosphere of the Vahic (South Penninic) Ocean. Hence they represent a post-nappe, new sedimentary cycle of the Carpathian Gosau-type basins, notwithstanding that the time lag between the youngest sediments of the Manín and Klope units and the oldest overstepping sediments is very short, probably representing only

the latest Turonian time period (probably less than 1 Myr). Coeval synorogenic sediments in the Oravic units form continuous successions with their underlying Jurassic and Cretaceous strata and the late Turonian thrusting event is not recorded at all (Fig. 3). Nevertheless, the Senonian to Eocene evolution of the trench/foredeep Oravic and wedge-top Gosau basins exhibit close mutual relationships controlled by the accretionary wedge dynamics, subduction–accretion–collision processes and the global sea-level changes (cf. Plašienka & Soták 2015).

- Analyses of macro- and mesostructural rock records reveal the polystage structural evolution with the overall NW–SE to N–S shortening (deformation stages D_1 and D_3) during the long Meso-Alpidic tectonic period lasting from the Senonian until the Lower Miocene. This period was preceded by the D_0 stage related to the nappe emplacement of the Manín and Klappe units, and interrupted by the kinematically different D_2 stage. After the Lower-Middle Miocene CCW block rotation, the western PKB branch and adjacent zones were further affected by sinistral transtension and extension (deformation stages D_4 , D_5 and D_6 , respectively) controlled by the gradually clockwise rotation of the palaeostress field.
- The newly proposed evolutionary tectonic model of the investigated area assumes that the Manín, Klappe and other analogous units of the PKB represent frontal elements of the Fatric nappe system. During the latest Turonian, these nappes glided beyond the northern Tatric edge in a divortication manner and reached position of a “false” accretionary wedge above the Vahic oceanic crust that began to subduct during the Early Senonian. In this position, the Manín and Klappe units suffered strong post-emplacement deformation, both compressional and extensional triggered by the supercritical vs. subcritical wedge taper dynamics. Frontally accreted Oravic units (latest Cretaceous–Early Eocene) and subsequently also units of the current Flysch Belt (Biele Karpaty Superunit during the Middle Eocene; the Magura units during the Late Eocene to Early Miocene) brought about transfer of the Oravic and Manín–Klappe units from the wedge front to its rear accompanied by steepening up to overturning of pre-existing structures, backthrusting and wrench faulting. The PKB remained in this backstop position also later, during the complex Miocene orogenic movements, including the large-scale CCW rotation of the whole Western Carpathian orogenic system with respect to the North European Platform.

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