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ORIGINAL PAPER

Geological significance of Upper Cretaceous sediments in deciphering of the Alpine tectonic evolution at the contact of the Western Carpathians, Eastern Alps and Bohemian Massif

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Abstract
The kinematic evolution of the Western Carpathian and Eastern Alpine orogenic belts shows similarities but also differences. In both orogens Eo-Alpine (Cretaceous) deformation is prevalent in the internal southeastern part, whereas nappe stacking in the northern frontal part occurred during the Neo-Alpine (Cenozoic) phase, which caused also back thrusting within the Cretaceous nappe stack. Upper Cretaceous to Paleogene sediments are present in several positions: flysch sediments occur in the Rhenodanubian and Magura nappe systems derived from the Valais domain of the Penninic oceanic basin. The Jarmuta Formation seals nappe contacts within the Pieniny Klippen Belt. The Gosau Group developed in piggyback basins on top of the Hronicum and the Bajuvaric, Tirolic-Noric and Juvavic nappe systems. Finally, sediments previously interpreted as remnants of the Penninic (Váhic) Ocean, are reinterpreted as remnants of wedge-top basins on the Tatric nappes. The analysis of the published geological record allows the following conclusions: (1) The Borinka Unit situated below the Tatricum in the Malé Karpaty Mts. is attributed to the Lower Austroalpine Unit. (2) The Western Carpathian units are marginally thrust northwest directed onto the adjacent Austroalpine Unit. (3) The Pieniny Klippen Belt represents the frontal part of the Eo-Alpine orogenic wedge displaced over the Magura nappe system during the Oligocene period. (4) The St. Veit Klippen Belt is the termination of the Drietoma Unit of the Peri-Klippen Zone. (5) We argue against the existence of the proposed Váhicum as the Carpathian equivalent of the Upper Penninic nappes derived from the Piemont-Ligurian oceanic domain.

Keywords Geodynamics · Tectonics · Penninicum · Tatricum · Austroalpine

Introduction

The geological structure in the junction of the Western Carpathians (WECA), Eastern Alps (EA) and Bohemian Massif (BM) is a result of the Mesozoic to Cenozoic Alpine orogeny (Fig. 1). While the units from the southern European margin exposed in the BM stayed in the foreland of the Alpine orogenic wedge and preserved their Variscan structural and metamorphic imprint, both other mountain belts are built up by Alpine nappe stacks including some remnants with earlier Variscan structures (Andrusov 1968; Rakús et al. 1988; Raumer et al. 2013).

In general, the WECA and EA share a relatively similar tectonostratigraphy (e.g. Häusler et al. 1993; Dallmeyer et al. 1996; Lexa et al. 2000; Froitzheim et al. 2008). The northern part of both orogenic wedges is formed by the Paleogene to Miocene fold and thrust belts composed of Jurassic to Miocene sediments (Jurassic sediments in the Ultrahelvetic Unit) derived from the southern European margin and the Penninic (Alpine Tethys) Ocean. Further south complex nappe piles mainly stacked during the Cretaceous occur. They include polymetamorphic basement as well as the Paleozoic and Mesozoic (meta)sediments originated from the Adriatic continental crust (Plašienka 1999, 2018; Schmid et al. 2008). In the following text the Cretaceous phase, which is related to deformation within the northern continental Adriatic lithosphere is referred as the Eo-Alpine. In contrast, the term

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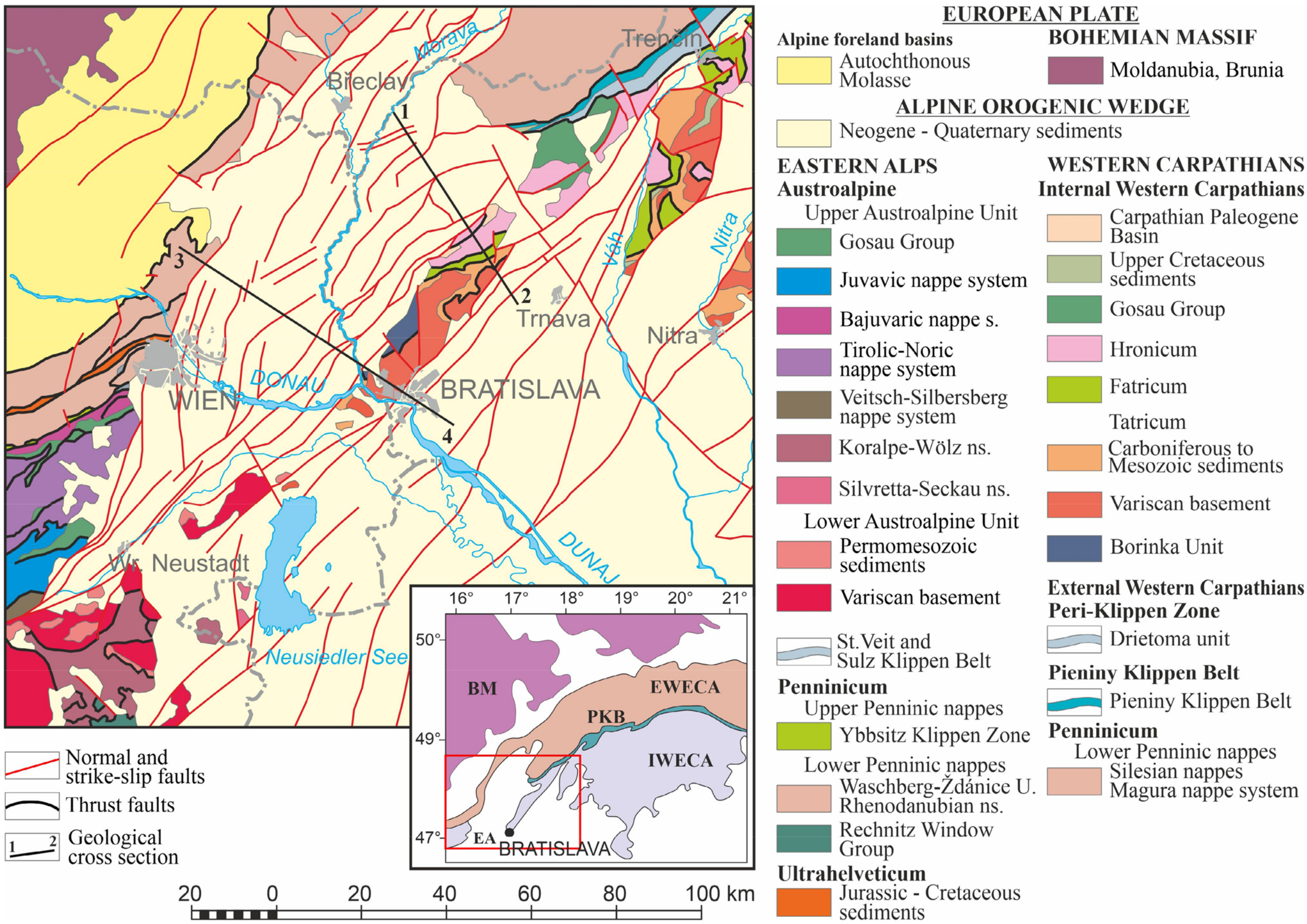

Fig. 1 Simplified tectonic map of the Western Carpathians and Eastern Alps junction area (modified after Lexa et al. 2000). BM, Bohemian Massif; EA, Eastern Alps; EWECA, External Western Carpathians; IWECA, Internal Western Carpathians

Neo-Alpine is used for the Paleogene to Miocene phase, which is mainly due to the collision of the Cretaceous nappe stack and the Adriatic microplate behind it with the southern continental margin of the European plate.

Despite the rather similar tectonostratigraphy, several important differences argue against a simple correlation of the individual tectonic units of the WECA and EA. The correlation is hindered by an intense Neogene tectonic overprint of the transition zone, which is largely covered by the Neogene and Quaternary sediments of the Vienna and Danube basins (Němec and Kocák 1976; Kysela et al. 1988; Kröll et al. 1993; Šamajová et al. 2019; Tari et al. 2021). In the WECA the External Western Carpathians (EWECA) in the north and Internal Western Carpathians (IWECA) in the south represent the Neo-Alpine and Eo-Alpine structural domains respectively (Hók et al. 2019). The situation in the EA is a little bit more complicated, because the Neo-Alpine nappe stack includes slices of Jurassic and Cretaceous ophiolites, as well as nappes stripped off from underthrusting European foreland. Further south the Neo-Alpine nappe stack appears within tectonic windows surrounded by the Austroalpine Unit, representing the Eo-Alpine domain (Neubauer et al. 2000; Schmid et al. 2004; Froitzheim et al. 2008).

The Upper Cretaceous (Turonian and younger) and Cenozoic successions are mostly pre- or syntectonic in the Neo-Alpine domain, but were traditionally considered as "post-nappe stacking" formations in the Eo-Alpine domains of the IWECA (Biely 1988; Mišík 1997a) and EA (Faupl and Wagreich 1996), although they are often tectonically affected together with their substratum (Hók et al. 2016; Ortner et al. 2016; Pelech et al. 2017b).

The southwestern part of Slovakia (Fig. 1) and its vicinity are characterized by Upper Cretaceous sediment successions of various lithostratigraphy, lithofacies, and tectonic setting. These sediments have a particular importance for deciphering the spatiotemporal context of the Alpine orogeny of the region, as the Late Cretaceous was an epoch of large-scale convergence and plate tectonic rearrangement in the orogenic wedges of WECA and EA and their contact to the BM forming the northern foreland (e.g. Handy et al. 2010).

The aim of this paper is to outline a model of the Alpine tectonic evolution of the region based on analyses of literature data on the Upper Cretaceous sedimentary record and geochronological data from the metamorphic basement.

Geological setting

In the area of interest, the Alpine orogenic wedge is thrust onto the European foreland including sediments of the foreland basin (Carpathian foredeep and Authochthonous Molasse). The northernmost and youngest tectonic slices of the EWECA as well as the EA (Silesian nappes, Waschberg-Ždánice Unit, Allochthonous Molasse) consist of deformed sediments of the foreland basin and some slices of its basement (Wessely et al. 2006; Granado et al. 2016; Stráník et al. 2021).

Above, an accretionary wedge derived from the Penninic (Alpine Tethys) paleogeographic domain is present. Its main part is formed by the Magura and Rhenodanubian nappe systems, which are composed of a few remnants of the Cretaceous oceanic crust (Tulbingerkogel nappe of the Rhenodanubian nappe system; Prey 1977; Ritzinger 2011) overlain by the Cretaceous to Paleogene flysch sediments (Wessely et al. 2006). They were derived from the basins referred to as the Valais, Rhenodanubian and Magura basin along strike of the orogen (Oszczypko et al. 2015; Teťák et al. 2019). Tectonic units from this paleogeographic domain are attributed as the Lower Penninic nappes according to Schmid et al. (2008, 2020). In the Eastern Alps sediments from the underlying distal European margin appear as the Ultrahelvetic slices within the Rhenodanubian nappe system. The remnants of the Jurassic oceanic sea floor overlain by the Jurassic to Cretaceous sediments occur above. The latter originate from the Piemont-Ligurian oceanic basin and builts up the Ybbsitz Klippen Belt of the Upper Penninic nappes (Schmid et al. 2004, 2008).

The southerly adjacent Pieniny Klippen Belt (PKB) consists of more than 15 sub-units (Mišík 1997b; Plašienka and Mikuš 2010), which underwent several phases of folding and faulting during the Cretaceous to Miocene (Mišík 1997b). Remarkably, they consist exclusively of Jurassic–Cretaceous strata, and their former substratum is a matter of discussion. The most typical elements are the Czorsztyn and Kysuca units, known from the entire length of PKB. The internal (southerly) situated deep-water Kysuca Unit was thrust over the external shallow-water Czorsztyn Unit (Mišík 1997b). The PKB is interpreted as a relatively shallow structure, thrust together with the Mesozoic cover nappes (Hronicum, Fatricum), over the Magura nappe system (Šamajová et al. 2019).

The Drietoma Unit is located on the inner margin of the PKB in the area of interest. It belongs to the Peri-Klippen Zone together with some other units (Mišík 1997b). The Peri-Klippen Zone represents elements with the Mesozoic sequences similar to those of the Fatricum or Tatricum (Froitzheim et al. 2008; Hók et al. 2009) but appear in the same structural position as the PKB. The Drietoma Unit includes Upper Triassic to Turonian strata, with the "Carpathian Keuper" (Norian), Fatra Fm. (Rhaetian equivalent to Kössen Fm.) and Allgäu Fm. (Lower Jurassic) being of particular importance for correlation with the EA units. These lithostratigraphic units are typical in some exotic klippen belts and tectonic slices appearing in the transition zone between the Austroalpine and Penninic units at the eastern margin of the EA. For this reason, the Drietoma Unit is correlated with the St. Veit Klippen Belt (Wagreich et al. 2012; Ślączka et al. 2018), but there are also similarities to the Sulz Klippen Belt and the Groisbach-Nöstacher slices at the base of the Tirolic-Noric nappe system (Prey 1987; Wessely et al. 2006).

Further on, IWECA include from bottom to top the Infratatricum, Tatricum, Fatricum and Hronicum. According to Plašienka (1997, 2018) an additional Váhicum, representing an equivalent to the Upper Penninic nappes of the Alps (sensu Schmidt et al. 2008) is present in the lowermost position. It consists of Cretaceous sediments, which are described in more detail later on. In a recently published article (Tari et al. 2021), the Váhicum is interpreted as an equivalent of the Lower Penninic nappes.

A phenomenon of particular importance in the study area is the occurrence of the Borinka Unit (Plašienka 1987), which is attributed to the Infratatricum (Plašienka 1999) or Lower Austroalpine (Häusler et al. 1993). Its lithostratigraphic record has no analogue in the geological structure of the WECA (e.g. Plašienka 1987). The Borinka Unit contains synrift scarp breccias, turbiditic and hemipelagic Lower to Upper Jurassic sediments. Scarce occurrences of Lower to Middle Triassic sediments are considered as components within olistoliths, even if this interpretation is disputable. Remarkably, no remnants of a crystalline basement are known. The Borinka Unit is underthrust below the Tatric crystalline basement and its sedimentation area is supposed to be at the southern margin of the Penninic oceanic trough (Plašienka 1995a). The overlying Tatric thick-skinned unit contains a Variscan basement and Mesozoic cover also including Jurassic breccia (Mišík 1986; Wessely et al. 2006), whereas the overlying Fatricum and Hronicum represent cover nappes composed only of Carboniferous to Cretaceous sediments (Hók et al. 2019).

With respect to the discussed part of the EA, the lowermost Austroalpine Unit is represented by the Lower Austroalpine Semmering-Wechsel nappe system consisting of a Variscan basement and a Permo-Triassic cover with a lower greenschist facies Eo-Alpine overprint (Tollmann 1977; Häusler et al. 2019). The overlying Upper Austroalpine includes from bottom to top the Veitsch-Silbersberg (Schuster 2016), Bajuvaric, Tirolic-Noric and Juvavic nappe systems, whereby the former and the latter re only present in the subsurface of the Vienna Basin in the study area (Schuster 2015). For the Veitsch-Silbersberg and minor parts of the Tirolic-Noric nappe systems, which are built up by the Paleozoic metasediments and a few slices of Variscan basement, they are composed of Permo-Mesozoic sedimentary successions.

The relation of the southern European margin in the continuation of the BM with respect to the Alpine nappe stack is known from boreholes and geophysical investigations (e.g. Wessely et al. 2006; Granado et al. 2016). In the eastern part of the Eastern Alps, it is documented, e.g. by the Berndorf-1 borehole (Wachtel and Wessely 1981). The latter penetrated the Tirolic-Noric nappe system (Göller and Unterberg nappes), Rhenodanubian nappe system (Laab nappe), Alpine foreland basin sediments and terminated in the Variscan crystalline basement of the BM. The basement of the BM was reached at a depth of c. 5500 m in a distance of 35 km to the southeast of the Alpine frontal thrust. Towards the Slovak part of the Vienna Basin the BM Variscan crystalline basement and probably its Mesozoic cover are situated beneath the EWECA, which is in turn overlain by Eo-Alpine nappe piles of Carpathian and Alpine provenance (Šamajová et al. 2018) (Fig. 2). The Hronicum is locally thrust onto the Bajuvaric and Tirolic-Noric (?Juvavic) nappe systems below the Neogene sediments of the Vienna Basin (Šamajová et al. 2019). Further east, the subsurface continuation of the BM can be traced until the southern margin of the PKB and its contact to the thick-skinned Tatric nappes. The boundary of the EWECA and underlying BM towards the IWECA nappe pile is mostly subvertical (Šamajová et al. 2018).

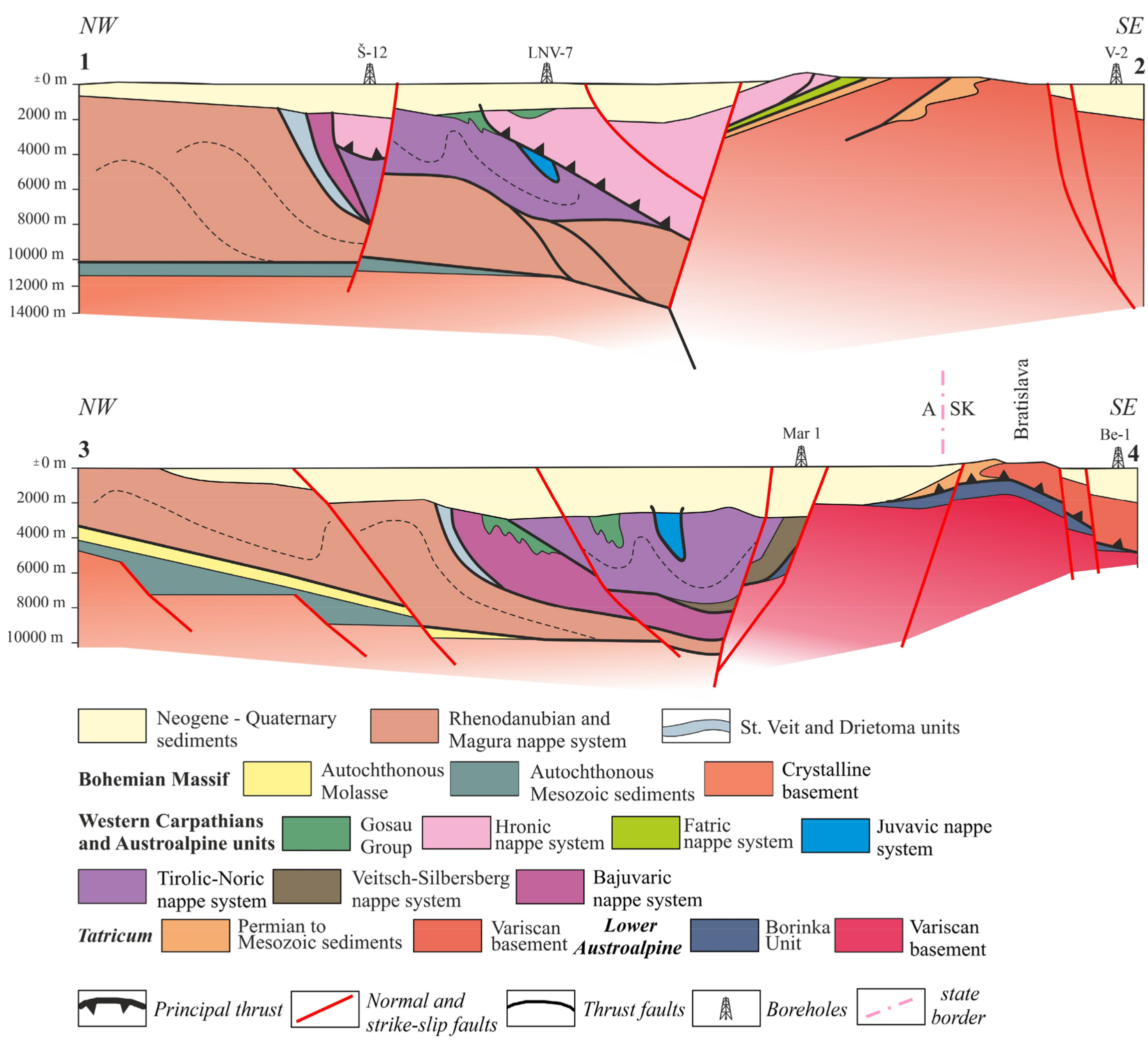

Fig. 2 Simplified geological cross sections (based on: Bielik et al. 1992; Wessely et al. 2006; Šamajová et al. 2019). Boreholes: Š-12 Šaštín, LNV-7 Lakšárska Nová Ves, V-2 Vištuk, Mar-1 Marcheg, Be-1 Bernolákovo (cf. Biela 1978; Kysela et al. 1988; Kröl et al. 1993)

Position and characteristics of the Upper Cretaceous sediments

A substantial volume of the Upper Cretaceous sediments is present in the Magura nappe system of the EWECA (Fig. 3; occurrence 1) and the Rhenodanubian nappe system in the Eastern Alps. For example, Cenomanian to Eocene successions build up the Bošáca and Javorina nappes of the Biele Karpaty Unit (Teťák 2016) (Fig. 4) or the Laab and Kahlenberg nappes (Wessely et al. 2006).

The Upper Cretaceous (Campanian−Maastrichtian) sediments of the adjacent portion of the PKB are represented by the Jarmuta Formation (Potfaj et al. 2014; Teťák et al. 2015). From the geological map (Potfaj et al. 2014) it is possible to infer their transgressive position onto several units of the PKB and the Drietoma Unit as well as their subsequent Cenozoic deformation (Fig. 3; Potfaj et al. 2014; Teťák et al. 2015).

The Gosau Group sediments (Upper Cretaceous−Paleogene) are overlying the Bajuvaric, Tirolic-Noric and Juvavic nappe systems in the Northern Calcareous Alps (NCA) and their continuation beneath the Neogene sediments of the Vienna Basin (Wessely 1992; Kröll et al. 1993; Stern and Wagreich 2013; Fig. 3, occurrence 3). At the surface, they appear in west–east oriented outcrop belts, arranged in structurally complex synforms (Gießhübl, Glinzendorf and Grünbach synforms) mainly post-Eocene in age (e.g. Wagreich and Faupl 1994). In the subsurface the continuation of these synforms can be traced with southwest–northeast strike. The Upper Cretaceous and Paleogene (Paleocene−Eocene) sediments correlated with the Gosau Group rest transgressively on the Hronic nappe in the Myjavská pahorkatina Mts. (Ostriež, Brezová and Myjava groups; Salaj et al. 1987; Wagreich and Marschalko 1995; Stern and Wagreich 2013; Teťák et al. 2015; Fig. 3, occurrence 4). A specific lithostratigraphic and lithofacial type of Upper Cretaceous sediments is represented by Turonian freshwater limestones (Fig. 3, occurrence 5) occurring as erosive remnants on top of the Hronic Mesozoic sedimentary successions (Chtelnica Formation sensu Hók and Littva 2018) in the Brezovské Karpaty Mts. These sediments represent a pre-Gosau lithofacial sequence that has no equivalent in the

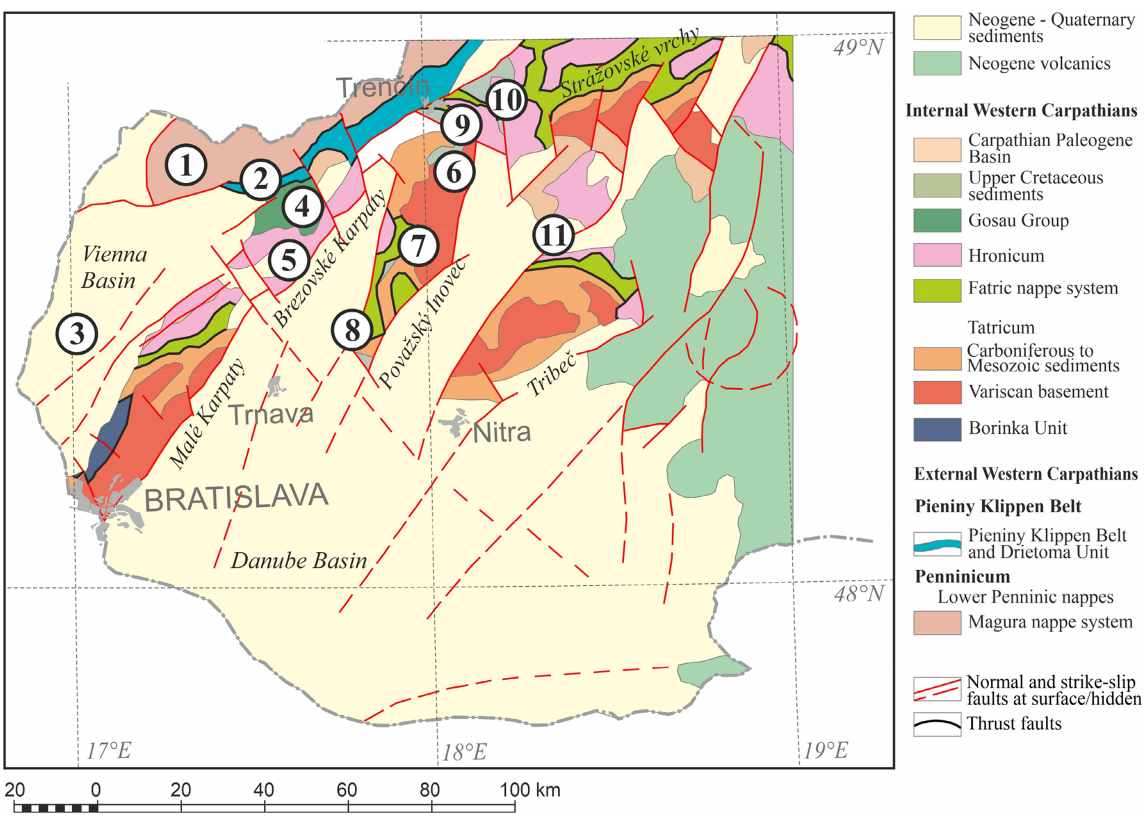

Fig. 3 Occurrences of the Upper Cretaceous sediments in southwestern Slovakia. The numbers refer to the description in the text. (1) Magura nappe system, (2) Jarmuta Fm., Pieniny Klippen Belt, (3) Vienna Basin, (4) Upper Cretaceous atop of Hronic nappe, (5) Chtelnica Fm., Turonian freshwater limestones, (6) Horné Belice Group, (7) Hubina Fm., (8), Horné Belice Group (9) Upper Cretaceous sediments in borehole SBM-1 Soblahov, (10) Upper Cretaceous sediments in borehole P-1 Peťovka, (11) Upper Cretaceous sediments in borehole KRS-3 Kršteňany

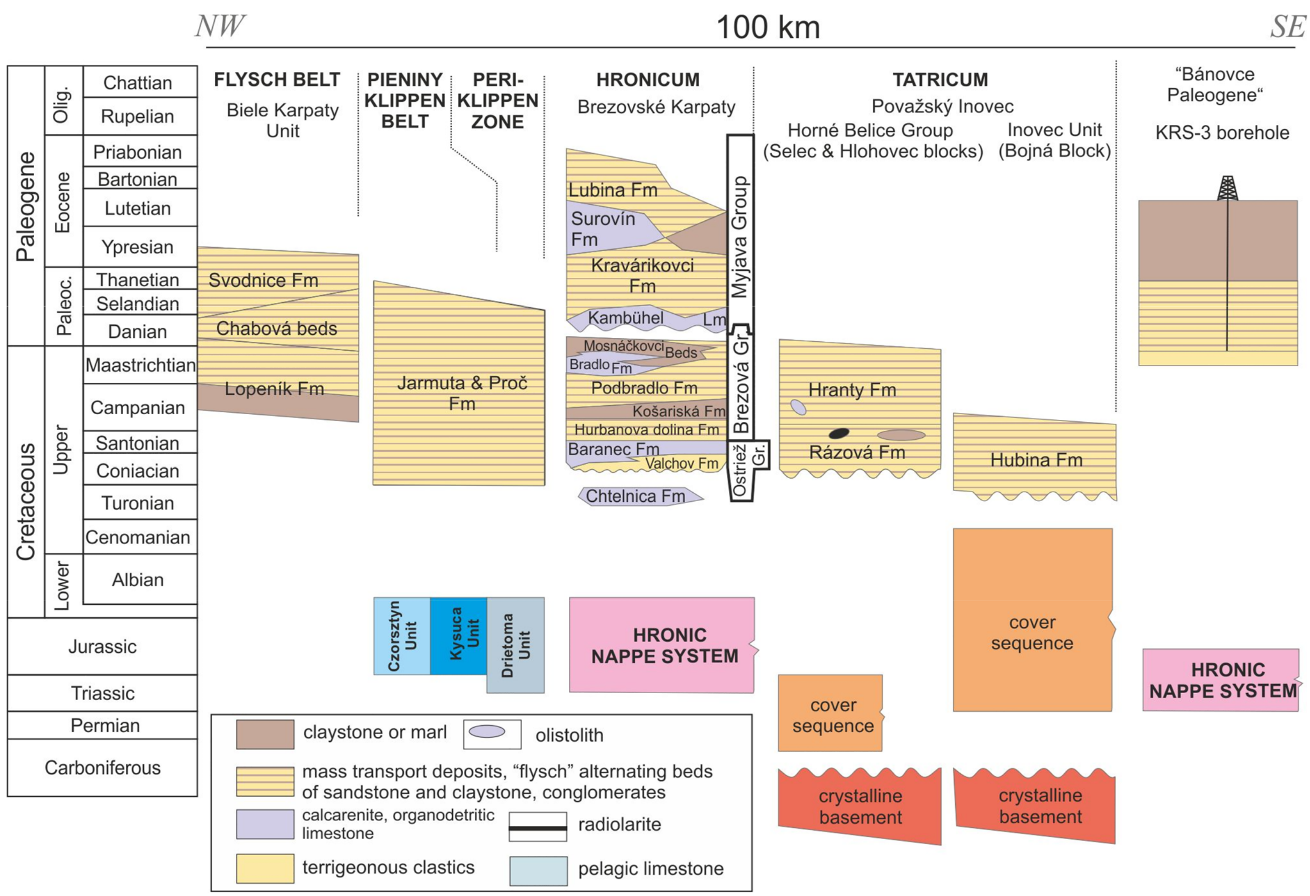

Fig. 4 Stratigraphic chart showing the position and chronostratigraphic range of the Upper Cretaceous–Paleogene rock formations in the southwestern portion of the Western Carpathians (compiled after Mello et al. 2011; Teťák et al. 2015; Ivanička et al. 2011; Pelech et al. 2016a, 2017b, 2021; Soták et al. 2021)

Western Carpathians. In the EA the Branderfleck Formation (Cenomanian–Turonian) is partly contemporaneous. It also formed in a piggy back basin on the Bajuvaric nappes, but it does not contain freshwater limestone (Ortner and Gaupp 2007).

Other occurrences of the Upper Cretaceous sediments are cropping out in the Považský Inovec Mts. The Považský Inovec Mts. are traditionally divided into three blocks (Mahel' 1986; Ivanička et al. 2011) characterised by different rock composition of crystalline basement and cover units as well as different overlying cover nappes (Fatricum and Hronicum). From north to south, these are the Selec, Bojná and Hlohovec blocks. Significant occurrences of the Upper Cretaceous sediments (Coniacian–?Maastrichtian) are found in the Selec block (Fig. 3, occurrence 6). They were originally defined as the Belice Unit, and interpreted as sediments detached from the South Penninic (Váhic) oceanic crust, underthrust southwards beneath the Tatricum (Plašienka et al. 1994). However, the Belice Unit was later redefined (Horné Belice Group sensu Rakús in Ivanička et al. 2011) and considered as transgressive lithofacial element overlying the crystalline basement (Pelech et al. 2016b). The Horné Belice Group contains two different formations: the Rázová Formation (Coniacian–Santonian) and the Hranty Formation (Campanian–?Maastrichtian), both containing conglomerate bodies and various olistoliths (Fig. 4).

The Hubina Formation (Pelech et al. 2017b) consists of Turonian – Santonian mass transport and hemipelagic sediments overlying the Albian – lower Cenomanian Tatric sedimentary cover of the Bojná block. The Hubina Formation is overthrust in turn by Middle Triassic successions of the Fatricum (Fig. 3, occurrence 7).

In the Hlohovec block of the Považský Inovec Mts. (Fig. 3, occurrence 8) the sediments of the Hranty and Rázová formations occur as well. However, they do not contain olistoliths and exhibit more distal facies. The Upper Cretaceous sequence of the Hlohovec block was drilled by the borehole HPJ-1 (Jašter), which documents its position above the Tatric crystalline basement (Pelech et al. 2016a).

The principal question whether the Upper Cretaceous sequences represent Váhicum—a tectonic unit of oceanic origin, or Tatric autochthonous sediments has been widely discussed (Pelech et al. 2016b, 2017a; Plašienka et al. 2017). With regard to the results of geophysical investigations (Pelech et al. 2017c) and due to the position of the Upper Cretaceous sediments between the Tatric Mesozoic cover and the Fatric thrust sheet (Pelech et al. 2017b), it is no longer possible to attribute these sediments to the Upper Penninic nappes, derived from the Piemont-Ligurian oceanic domain. According to Pelech et al. (2016b) the position of the Horné Belice Group above the Tatricum suggest their deposition in piggyback basins on top of the Tatric nappes, during their overthrusting onto the Magura oceanic domain and the wedge formed by the developing Lower Penninic nappes (sensu Schmid et al. 2004, 2008) of the Magura nappe system respectively.

Similar Upper Cretaceous and Eocene lithostratigraphic sequences were drilled below the Fatric sediments in boreholes SBM-1 (Soblahov) (Maheľ and Kullmanová 1975; Kullmanová 1978; Maheľ 1985) and P-1 (Peťovka) (Maheľ 1969) southeast and west of Trenčín respectively (Fig. 3, occurrences 9 and 10). Both borehole logs as well as the surface outcrops of the Horné Belice Group exhibit a “blocks in matrix” structure (cf. Festa et al. 2012, 2019; Ogata et al. 2012; Geologická mapa Slovenska 1:50 000 2013).

The Cretaceous–lower Paleogene sediments are also known from the Horná Nitra depression (Fig. 3, occurrence 11). The most complete sequence of these sediments overlying Hronicum was drilled in borehole KRS-3 (Fig. 4), where they reach a thickness of about 250 m. Paleocene formations are underlain by red-bed sediments, which are constrained to be already the Late Cretaceous in age (Soták et al. 2013, 2021).

Dating of tectonic events in the WECA

Thrusting of the EWECA onto the Bohemian Massif was completed during the Early Miocene (Jiříček 1979) according to the age of the youngest deformed strata along the Alpine frontal thrust (Fig. 5). This is in line with surface observations and data from the Berndorf-1 borehole (Wachtel and Wessely 1981).

The tectonic units of PKB, Hronicum and Upper Austroalpine were thrust over the Magura nappe system flysch sediments during the late Eocene−Oligocene (Teťák 2016; Šamajová et al. 2019; Teťák et al. 2019). This is dated by the youngest preserved sediments (Svodnica Formation) of

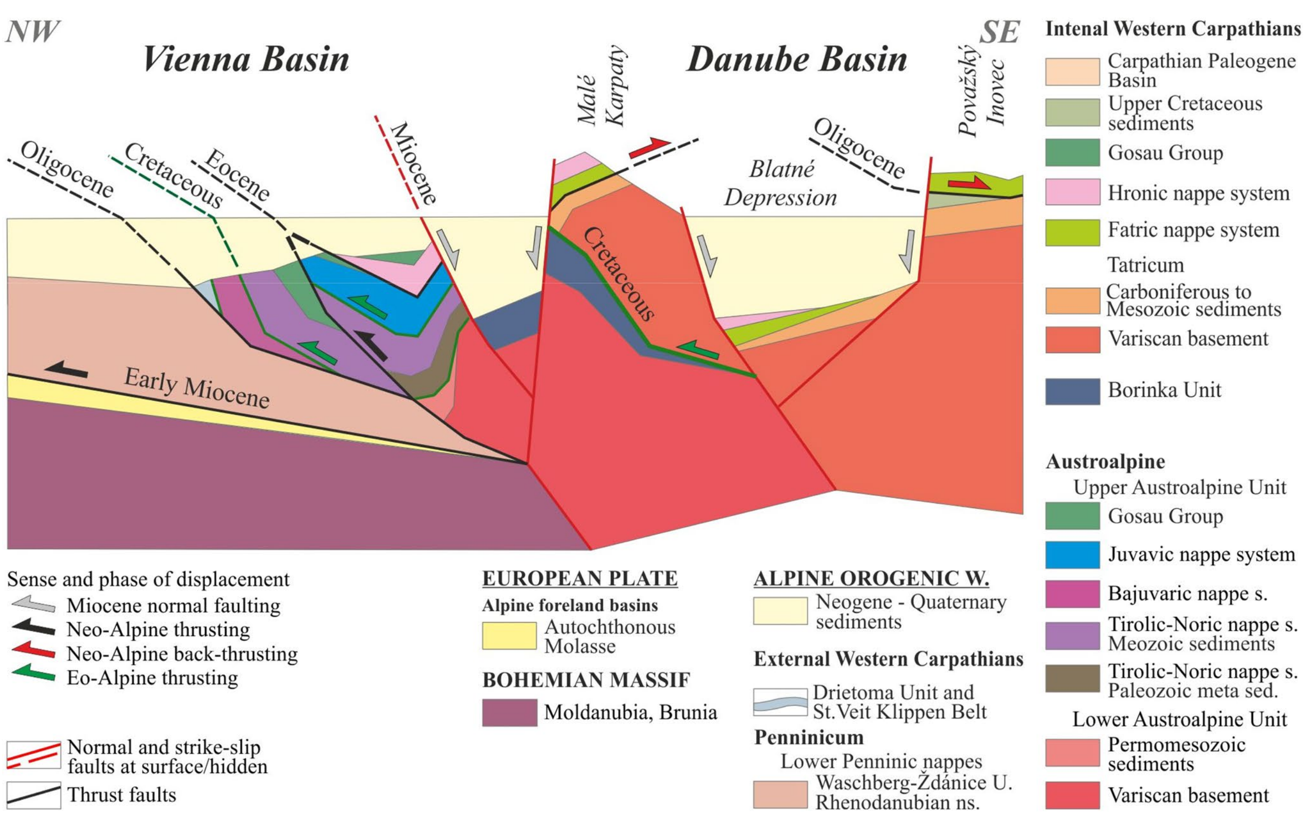

Fig. 5 Synoptic profile across the primary tectonic units in the western part of Slovakia. Presumed ages of thrusting are indicated on the thrust planes by coloured arrows

the Magura nappe system underneath the frontal parts of the PKB.

The age of internal thrusting of the principal PKB units (Czorsztyn, Kysuca) and Drietoma Unit can be estimated from the youngest preserved sediments of the Drietoma Unit and dates back to the Cenomanian−?Turonian. The thrust contacts between the main units of the PKB and the Drietoma Unit are sealed by the Jarmuta Formation (Campanian−Maastrichtian). The Jarmuta Formation was deformed later on (during Miocene) together with the PKB and Drietoma units (Teťák et al. 2015).

Based on the biostratigraphic data from the Gosau sediments, the age of the Hronicum overthrust onto the Bajuvaric and Tirolic-Noric nappe systems in the pre-Neogene basement of the Vienna Basin is Eocene (Bujnovský et al. 1992; Stern and Wagreich 2013; Šamajová et al. 2019).

Eo-Alpine nappes of IWECA were formed in a continuous process of northwest-oriented stacking (in present-day coordinates), which began during the Early Cretaceous (Plašienka 2018). The stratigraphy of terminal lithological members allows to date thrusting of the Hronicum over Fatricum back to the Aptian−Albian stages in the Malé Karpaty, Považský Inovec and Strážovské vrchy Mts. (Maheľ 1985; Polák et al. 2011; Ivanička et al. 2011; Geologická mapa Slovenska 1: 50 000 2013). The displacement of Fatricum over Tatricum started during the Early Cretaceous. In the Malé Karpaty and most of the Strážovské vrchy Mts. overthrusting occurred during Cenomanian−Turonian (Polák et al. 2012; Hraško et al. 2021).

Beside top-to-northwest directed thrusting, southeast vergent backthrusts are a significant phenomenon in the peripheral areas of the IWECA (cf. Kováč and Hók 1996; Pečeňa and Vojtko 2011; Pešková 2011; Pelech 2015; Pelech and Hók 2017; Soták et al. 2017; Pelech et al. 2017b, 2018; Pelech and Olšavský 2018). The extent of backthrusting varies in different segments of the IWECA, but it contributed to the preservation of otherwise rare Upper Cretaceous strata. In several places, the tectonic emplacement of the Fatricum onto Upper Cretaceous − Eocene sediments occurred during generally southeast directed backthrusting in the late Oligocene−Early Miocene in the Strážovské vrchy Mts. (Maheľ 1969; Maheľ and Kullmanová, 1975) and the Bojná block (Pelech et al. 2017b) of the Považský Inovec Mts. (Fig. 5). Similar data were obtained for the Hronicum in the Malé Karpaty and Považský Inovec Mts., where Eocene and Lower Miocene sediments are sandwiched between Mesozoic sediments (Marko et al. 1990; Marko 2012; Pelech and Hók 2017).

Various radiometric data make it possible to constrain the timing of tectonic events in the basement units. They include formation ages of synkinematic minerals as well as cooling ages. The Tatricum in the Malé Karpaty Mts. consists of allochthonous thrust sheets overlying the Borinka Unit (Koutek and Zoubek 1936; Plašienka et al. 1991; Polák et al. 2012). Ar–Ar ages determined on synkinematically recrystallised white mica from the shear zone at the base of the Tatric nappe are in the range of 81−72 Ma, indicating emplacement in the Campanian (Putiš et al. 2009).

Zircon and apatite fission track ages (ZFT, AFT) of 68.3 ± 5.4 and 36.3 ± 3.4 − 39.9 Ma respectively (Danišík et al. 2004; Králiková et al. 2016) constrain subsequent cooling during exhumation. These data are in agreement with the biostratigraphic record. On the one hand the Jurassic sediments of the Borinka Unit in the footwall act as lower time limit for the overthrusting event and on the other hand Albian−Cenomanian cover sediments in the northern portion of the Tatric nappes restrict their detachment and internal deformation to post 90 Ma (cf. Polák et al. 2011; Geologická mapa Slovenska 1:50,000 2013).

The Tatric crystalline basement of the Selec block (Inovec nappe sensu Putiš et al. 2009) in the northern part of the Považský Inovec Mts. (Selec block) is characterised by amphibolite facies assemblages with a retrograde overprint (Ivanička et al. 2007; Geologická mapa Slovenska 1:50,000 2013). Ar–Ar muscovite ages of 307−310 Ma (Kráľ et al. 2013) and ZFT ages in the range of 256.3 ± 20.6 to 255.4 ± 20.3 Ma (Králiková et al. 2016) indicate a Variscan metamorphic imprint and a neglectable Alpine thermal influence. The Alpine low temperature metamorphic overprint was restricted to local shear zones (e.g. Korikovsky et al. 1997; Putiš et al. 2009). Thus, the aforementioned ZFT data are considered to be post-orogenic cooling ages after collapse of the Variscan orogen. The clasts of Variscan metamorphic rocks are present in Carboniferous, Permian, Lower Jurassic, Lower and Upper Cretaceous sediments indicating repeating exposure and erosion (Kamenický 1956; Plašienka et al. 1994; Ivanička et al. 2011). Geochronological data from a uranium mineralisation situated in the post-Variscan cover sequence yielded scattering U/Pb ages in the range of 110–60 Ma (Archangelsky and Daniel 1981; Štimmel et al. 1984), proving at least intense hydrothermal activity during the Eo-Alpine event. Folding of the Tatric crystalline basement together with Upper Cretaceous sediments can be dated to post-Campanian time (Rakús et al. 2006; Pelech et al. 2021).

In the south the Selec block is overthrust by the Bojná block (Panská Javorina nappe sensu Putiš et al. 2009) along the south dipping Hrádok-Zlatníky shear zone. The Tatric crystalline basement of the Bojná block mostly consists of Variscan granities and gneiss, lacking a Variscan retrograde overprint. According to K–Ar dating of sericite-muscovite and K-feldspars; Ar–Ar ages of white micas the Hrádok-Zlatníky shear zone was active from 100 to 50 Ma (Albian–Cenomanian to early Eocene; Putiš 1991; Putiš et al. 2008, 2009). However, the age of the youngest tectonic activity (early Eocene) is not consistent with the occurrence of Eocene sediments (Lutetian−Bartonian) overlying the crystalline basement of the Selec block (Ivanička et al. 2007; Pelech et al. 2017a; Geologická mapa Slovenska 1:50,000 2013). The Hrádok-Zlatníky shear zone was later reactivated as dextral transtensional fault, causing unroofing of the Selec block from below the Bojná block, probably during the Miocene (Pelech and Hók 2017).

AFT data determined on samples from borehole HPJ-1 (Jašter) located in the southernmost part of the Hlohovec block (see above and Pelech et al. 2016a) yielded an age of 51.6 ± 5.3 Ma (Králiková et al. 2016). According to this AFT age, the exhumation of the granitic rocks of the Považský Inovec Mts. started in the south during the Eocene and terminated in the north during the Miocene (Danišík et al. 2004; Králiková et al. 2016).

In the Tatric cover sequence of the Tribeč Mts. Eo-Alpine tectonic activity is dated by K–Ar method on white micas to 95 Ma (Biely in Kuthan et al. 1963), whereas in the crystalline basement of the overlying Fatric thrust sheet Ar–Ar muscovite ages yield 80 Ma (Putiš et al. 2009). The published ZFT and AFT data are in the range of 56.2 ± 3.4 to 57.8 ± 3.7 Ma and 31.2 ± 3.3 to 33.7 ± 3.5 Ma respectively (Králiková et al. 2016).

Discussion

This chapter starts with a summary on the tectonic evolution of the EWECA and Eastern Alps, respectively. After that, the paleogeographic positions of the Borinka Unit and PKB are discussed. Finally, the question whether the IWECA or Austroalpine Unit hold the structurally higher tectonic position is in the focus.

Tectonic evolution of the WECA

Using the available geochronological and biostratigraphic data the evolution of the Alpine nappe pile in the investigated part of the Western Carpathian can be reconstructed. In general, a growth of the orogenic wedge from the internal part of the IWECA towards the northern front of the orogen is obvious, whereby an Eo-Alpine and Neo-Alpine phase of thrusting can be separated. Unsurprisingly, the geological structure is complicated by later out of sequence and backthrusting as well as transpressive and transtensive tectonics.

After Middle Jurassic to Early Cretaceous accretion of the Meliatic, Silicic, Gemeric and Veporic units forming the southeastern part of the IWECA (e.g. Lexa et al. 2003; Schmid et al. 2008; Dallmeyer et al. 2008; Potočný et al. 2020) deformation migrated into the area of interest. The tectonic contact of the Hronicum and Fatricum dates back to the Aptian−Albian stages (c. 125−100 Ma) followed by the emplacement of the Fatricum onto the Tatricum in the Cenomanian−Turonian (c. 100−90 Ma). The Cenomanian (100−95 Ma) internal thrusting of the Tatric nappes is documented from the Považský Inovec and Tribeč Mts. but it continued until the Campanian to ?Maastrichtian (c. 85−70 Ma) in the Malé Karpaty Mts. and Považský Inovec Mts. Moreover, some of the tectonic contacts date back to Cenomanian−?Turonian (c. 100−90 Ma), the recent structure is result of various later overprints until the Miocene time, however (Mišík 1997b).

The Eo-Alpine nappe stack was overprinted during the Neo-Alpine deformation phase in the Cenozoic era. The stack of Mesozoic cover nappes of the Fatricum and Hronicum was overthrust north onto flysch sediments of the Magura nappe system, but also south directed backthrusting over the Tatric Mesozoic sediments occurred in the Oligocene − Early Miocene (c. 30−15 Ma) in the Malé Karpaty, Považský Inovec and Strážovské vrchy Mts.

The onset of Neo-Alpine internal thrusting within the Magura nappe system can be inferred only indirectly. A minimum age is indicated by the end of sedimentation in the Biele Karpaty Unit, which is near the Paleocene-Eocene boundary at about 56 Ma. The final emplacement of the Magura nappe system together with the Waschberg–Ždánice Unit and Silesian nappes onto the Bohemian Massif can be dated to the early Miocene (c. 23−15 Ma) (Fig. 5).

In summary, a first phase of thrusting affected the Hronicum, Fatricum, Tatricum and PKB of the EWECA in Cretaceous time. These Eo-Alpine tectonic processes are related to collisional processes immediately after the closure of the Meliata Ocean and persisting contraction with a backstop to the southeast of the IWECA (Lexa et al. 2003; Schmid et al. 2004). The second Neo-Alpine phase during the Cenozoic is responsible for nappe stacking in the EWECA units, but is now also documented as overprinting event in the IWECA. In the past, thrusting related to this phase in the units south (internally) of the PKB was often believed to be pre-Cenozoic (Biely 1988; Mišík 1997a; Plašienka et al. 1997). The Cenozoic Neo-Alpine tectonic processes reflect the closure of the Penninic oceanic domain and the overthrusting of the Eo-Alpine nappe stack onto the European southern continental margin represented by the BM.

Tectonic evolution of the Eastern Alps

In the Eastern Alps the tectonic evolution shows many similarities but also some differences with respect to the WECA. Alpine tectonics initiated in the Middle Jurassic (c. 155 Ma) by intraoceanic subduction and continued by obduction of nappes derived from the Neotethys (Meliata) oceanic realm onto the Adriatic continental margin (Schmid et al. 2008; Gawlick et al. 2002). It caused the emplacement of the

Meliaticum onto the future Juvavic and Tirolic-Noric nappe systems. For the latest Jurassic and earliest Cretaceous (c. 145 Ma) sinistral transpressive strike slip tectonics cutting through the northern part of the Adriatic microplate is proposed based on Triassic facies distributions and large-scale considerations (e.g. Bechstädt 1978; Handy et al. 2010). Subsequently, in the Early Cretaceous (c. 135−125 Ma) northwest directed Eo-Alpine tectonism started along the former strike slip zone, which was reactivated as southeast dipping, intracontinental subduction zone (Stüwe and Schuster 2010). From the southerly positioned upper plate the Drauzug-Gurktal and Ötztal-Bundschuh nappe systems formed, whereas from the lower plate a complex nappe stack including the Meliatic, Juvavic, Tirolic-Noric and Veitsch-Silbersberg nappe systems developed, while the basement of the lower plate units was subducted. Thrusting of the Tirolic-Noric onto the future Bajuvaric nappes initiated in the Aptian – early Cenomanian stages (125−95 Ma). During this time, the Losenstein Basin formed as a foreland basin in front of the Tirolic nappes but was later on transformed into a piggyback basin on top of the Bajuvaric nappes (Wagreich 2001). In the northernmost part of the Bajuvaric nappe system ("Cenoman-Randschuppe") sedimentation continued until the Cenomanian (c. 95 Ma). With respect to eclogite formation ages of 105–90 Ma (Thöni 2006; Miladinova et al. 2022) rapid extrusion of the subducted lower plate continental crust initiated in Late Cretaceous times. The rapid exhumation is indicated by widespread Coniacian–early Campanian (90−75 Ma) Ar–Ar muscovite cooling ages (e.g. Thöni 1999; Dallmeyer et al. 1998). The exhumation process caused drastic changes in the geometry of the orogenic wedge. The Koralpe-Wölz nappe system representing a metamorphic extrusion wedge formed and the Jurassic to Early Cretaceous nappe pile on top of it was shifted northwestwards onto the Bajuvaric nappe system, which was stripped of from its basement during that time (Froitzheim et al. 2008). In the following, also the former substratum of the Bajuvaric nappes was incorporated into the orogenic wedge representing the Silvretta-Seckau nappe system and Lower Austroalpine unit. Radiometric ages indicate thrusting in Santonian–early Campanian times (85−75 Ma) (e.g. Dallmeyer et al. 1998). The Late Cretaceous processes in the frontal part of the orogenic wedge are archived in the sediments of the Gosau Group (Faupl and Wagreich 1996). The terrestrial to shallow-marine sediments of the Lower Gosau Subgroup were deposited mainly within small, fault-bound basins in a dextral transpressive regime from the late Turonian onwards (Wagreich and Faupl 1994; Ortner et al. 2016). The change to deep marine "flyschoid" deposits in the Upper Gosau Group occurred diachronously, starting in the west in the latest Turonian and ending in the east in the Maastrichtian (Wagreich 1995). The basins show northwestward prograding deepening trends and the transition is due to the entrance of Penninic oceanic lithosphere into the subduction zone.

The Penninic Ocean to the north of the Austroalpine Units was closed in the Eocene (~45–50 Ma, Liu et al. 2001; Schmid et al. 2004). After that the Peninnic nappes, which partly initiated as oceanic accretionary wedge, where thrust onto the European southern continental margin represented by the BM and its continuation (Wessely et al. 2006). Thereby cover nappes stripped off from the European margin were incorporated as Helvetic and Ultrahelvetic slices, now intercalated within the Rhenodanubian nappe system. Paleogene and Neogene shortening also caused conjugate strike-slip faults and south directed backthrusting especially along the southern margin of the Northern Calcareous Alps (e.g. Peresson and Decker 1997). Finally, the Allochthonous Molasse and Waschberg–Ždánice Unit were formed until Ottnangian time (~18 Ma, Wessely et al. 2006; Stráník et al. 2021).

Paleogeographic relations of the PKB

The units of the PKB are thought to originate from a continental crust between the Magura oceanic basin in the north and the IWECA in the south (Mišík 1997b; Rakús et al. 1988). Unfortunately, in the section of the WECA all units derived from this paleogeorgaphic realms consist exclusively of sedimentary sequences, detached from their basement. During Neo-Alpine nappe stacking in latest Eocene−Oligocene the sediments of the PKB were thrust onto the flysch sediments of the Magura nappe system together with elements of the Peri-Klippen Zone as well as Hronic and Fatric nappes (Hók et al. 2016; Šamajová et al. 2018, 2019). To get some information on the former basement one can have a look at the nappe piles of the adjacent Eastern Alps.

In the Eastern Alps several klippen belts are intercalated among the major tectonic units in the frontal part of the orogenic wedge (Wessely et al. 2006). They allow the following paleogeographic reconstruction: The Gresten Klippen Belt (Hauptklippenzone) originated from the extended southern European continental margin. The Tulbingerkogel nappe representing the northernmost element of the Rhenodanubian nappe system contains serpentinite breccias at its base (Prey 1977; Wessely et al. 2006; Ritzinger 2011). These breccias indicate oceanic lithosphere (exhumed lithospheric mantle) for some parts of the Valais Basin, whereas other part may have been floored by hyperextended continental lithosphere. Since, the Magura nappe system was derived from the same basin as the Rhenodanubian nappe system a basement with similar characteristics is likely. In this area sedimentation persisted into the Cenozoic era (cf. Oberhauser 1995; Schmid et al. 2004, 2008; Oszczypko et al. 2015; Teťák et al. 2019).

In the overlying Ybbsitz Klippen Belt Jurassic ophiolites of the Piemont-Ligurian domain are typical, but there are no hints on a continental swell between the two oceanic branches, and there are no units comparable to those of the PKB in the EA. The St. Veit Klippen Belt, Sulz Klippen Belt and Groisbach-Nöstacher slices include Upper Triassic quartzites similar to the Carpathian Keuper and they show other similarities to the Peri-Klippen Zone (Prey 1987; Wessely et al. 2006). For this reason, the St. Veit Klippen Belt was correlated with the Drietoma Unit of the PKB (Wagreich et al. 2012, 2013; Pfersmann 2013). The paleogeographic position of the St. Veit Klippen Belt was most probably on the outer (northern) margin of the Adriatic shelf facing towards the Penninic Ocean (Ślączka et al. 2018). A similar paleogeographic origin is generally accepted for the Bajuvaric and Tirolic nappe systems located to the south (e.g. Tollmann 1977).

Based on the reinterpretation of the Horné Belice Group as remnants of a piggyback basins on top of the Tatric nappes (Pelech et al. 2016b), it is highly improbable that a Jurassic branch of the Penninic Ocean (Piemont-Liguria basin) extended eastward between the paleogeographic domains from which the PKB units on the one side and the Drietoma Unit, Fatricum and Tatricum on the other side were derived. This is neither supported by geological mapping (Ivanička et al. 2011; Potfaj et al. 2014; Pešková et al. 2021) nor by geophysical data (Vozár et al. 1999; Kubeš et al. 2010; Šamajová et al. 2018, 2019). For this reason, we expect the paleogeographic position of the PKB units in a Jurassic rift basin floored by continental crust. In the Cretaceous, a branch of the Penninic Ocean opened north of the depositional area of the PKB units.

Tectonic and paleogeographic position of the Borinka Unit

The Borinka Unit is the lowermost tectonic element of the IWECA at least in the investigated area. Its lithofacial character with scarp breccias, turbiditic and hemipelagic Lower to Upper Jurassic sediments is unique among successions of the entire Western Carpathians and considered to be the vestige of Jurassic rifting of the Váhic oceanic realm (Plašienka et al. 1991, 1993; Plašienka 1995b). However, according to the interpretation of the PKB presented above the existence of a Váhic oceanic branch (Plašienka et al. 1991, 1993; Plašienka 1995b) is questionable.

Although the Borinka Unit has no equivalents in the WECA, it shows similarities to the Lower Austroalpine unit of the EA, especially with respect to the occurrence of Jurassic synrift breccias (Häusler et al. 1993). Such breccias are not present in the immediately adjacent Lower Austroalpine nappes of the Leitha Mts., because the stratigraphic sequences there are already tectonically truncated in the Middle Triassic, but they are frequent in the central and western part of the Eastern Alps (Häusler 1988). Based on the similarities Häusler et al. (1993) argued for a Lower Austroalpine position of the Borinka Unit, whereas Plašienka (1999) attributed it as the only element of the Infratatricum. Even if the different attributions seem insignificant at first, the second interpretation suggests an autonomy that may not exist.

Regarding the paleogeographical position of the Lower Austroalpine and Borinka Unit respectively, there is widespread agreement that they originate from the northern Adriatic continental margin towards the Jurassic part of the Penninic (Piemont-Liguria) oceanic basin (Häusler et al. 1993; Plašienka 1995b; Froitzheim et al. 2008). For the sector of the EA Penninic oceanic crust is indicated by the Ybbsitz Klippen Belt, whereas no remnants of oceanic crust are present in the WECA sector. Instead, the Jurassic to Lower Cretaceous sediments of the PKB may have formed in a basin still floored by continental crust and attached to the area from which the Fatric and Tatric units were derived. This indicates that the Borinka unit may have been located near the eastern end of the Penninic Ocean in the Jurassic. Further extension in the Cretaceous caused eastward propagation of the Penninic Ocean. Thereby the Valais and Magura oceanic domains formed. While in the west the Valais basin spread within the Jurassic basin (Handy et al. 2010), the Magura basin extended eastward to the north of the IWECA paleogeographic realm from which e.g. the PKB, Drietoma Unit, Fatricum and Tatricum were derived.

The Tatric crystalline basement and its Permo-Mesozoic cover were thrust onto the Borinka Unit in a dextral transpressional tectonic regime (Plašienka 1990, 1995b) during the Late Cretaceous (Putiš et al. 2009). Plašienka (1997) proposes underthrusting of the Tatric and Borinka units by the Váhicum since about 80 Ma. However, the presence of remnants of oceanic material in the footwall of the Tatricum is not confirmed by geophysical data (Vozár et al. 1999; Kubeš et al. 2010; Šamajová et al. 2018, 2019). More likely, the Borinka Unit is underlain by a piece of continental crystalline basement. With respect to the available data, the proposed crystalline basement might be a (para)authochthonous substratum of the Jurassic sediments, or a continuation of the Lower Austroalpine Unit visible in the Leitha Mts.

Position of the IWECA units with respect to the Austroalpine units

While the units of the EWECA show a more or less continuous transition or at least an interlocking with the nappe pile in the northeastern part of the EA (Fig. 6), there are no surface outcrops showing a direct contact of the IWECA

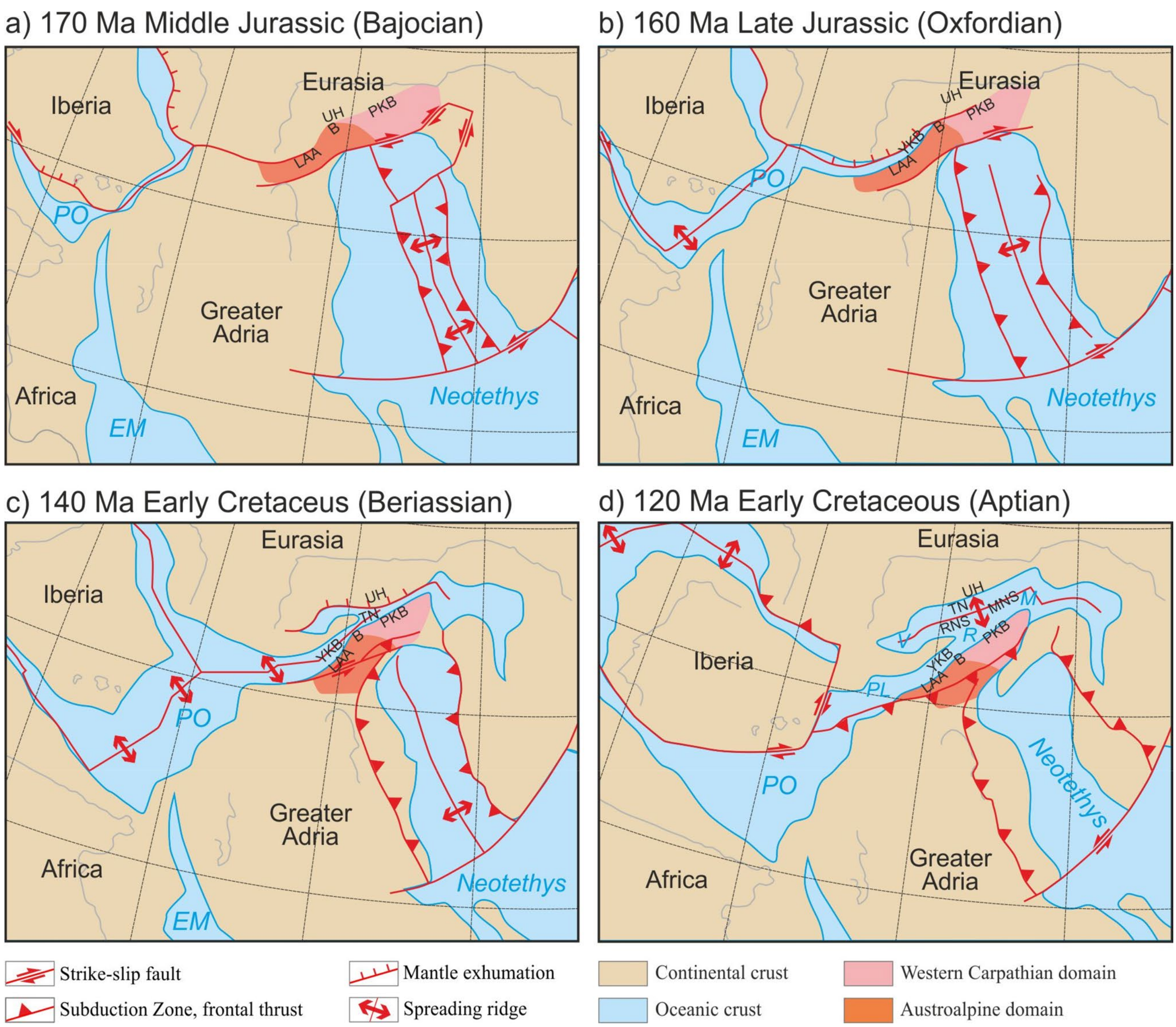

Fig. 6 Paleogeographic maps of the Alpine area based on van Hinsbergen et al. (2020). **a** In the Middle Jurassic the WECA and Austroalpine domains were located at the northern margin of the Neotethys Ocean. **b** In the Late Jurassic the Penninic (Alpine Tethys) Ocean propagated eastwards to the north of the Austroalpine domain. The PKB domain was situated in a rift graben in the eastern extension. **c**, **d** The Valais domain of the Penninic Ocean formed since the earliest Cretaceous. Explanation see in the text. Abbreviations: positions of recent tectonic units, B, Borinka Unit; LAA, Lower Austroalpine; MNS, Magura nappe system; RNS, Rhenodanubian nappe system; PKB, Pienniny Klippen Belt; TN, Tublingerkogel nappe; UH, Ultrahelveticum; YKB, Ybbsitz Klippen Belt. Oceanic subbasins; M, Magura Basin; R, Rhenodanubian Basin; V, Valais Basin

units to typical Austroalpine units. As mentioned above, the Neogene sediments of the Vienna and Danube basins hide the contact and the course of the borderline is badly known. In addition, the Neogene tectonics obscured the former relationship, which must have been formed as early as the Late Cretaceous. In the following the available information from outcrops of the inselberg and borehole data are summarised.

In the Malé Karpaty Mts. the exotic Borinka Unit and the inferred crystalline basement below may represent an equivalent to the Lower Austroalpine Unit and they are overthrust by Tatric nappes of the IWECA.

The Lower Austroalpine rocks sequences in the northeastern portion of the Leitha Mts. comprise crystalline basement and Lower to Middle Triassic metasediments. These rocks are affected by Eo-Alpine greenschist facies metamorphism (Schuster et al. 2004) and ductile deformation expressed by folds, continuous cleavage and stretching lineation with a north-westward displacement. This type of deformation is missing or at least less intense in the southwestern Leitha

Mts, where Variscan textures are locally preserved even if extensive sericitisation of feldspar and chloritisation of biotite are typical (Häusler et al. 2010). Towards the east this succession is truncated by the NE-SW trending Leithagebirge Fault, representing a steeply dipping normal fault with an east-side down offset (Häusler et al. 2010) of more than 150 m and maybe a sinistral component. On the eastern side strongly chloritised biotite-sericite schist is present. According to an Ar–Ar muscovite age of 202 Ma (Häusler et al. 2010) the latter experienced only a weak Alpine overprint. These schists have no counterpart in the nearby Lower Austroalpine Unit of the Leitha Mts., but share many similarities to biotite-sericite schists of the Tatric basement in the Hainburg Mts. (Paleozoic schists in Wessely et al. 2006) and Malé Karpaty Mts. In general, the Tatric basement in the latter localities shows well preserved Variscan assemblages and Eo-Alpine ductile deformation is limited to discrete shear zones.

With respect to observed internal deformation of the Lower Austroalpine Unit and the kinematic character of the Leithagebirge Fault, a superposition of the Tatricum above the Lower Austroalpine Unit is possible. However, no remnants of Tatricum on top of the Lower Austroalpine Unit are present and a former existence is speculative.

In the subsurface of the northernmost part of the Vienna Basin the Mesozoic sediments of the Hronicum (IWECA) are overlying nappes of the Bajuvaric and Tirolic-Noric nappe systems (Šamajová et al. 2019). The Upper Cretaceous – Paleocene sediments below the Triassic sequence of the Hronicum in borehole Studienka-83 can be correlated with the Gießhübel Gosau Basin (Bujnovský et al. 1992; Stern and Wagreich 2013). In general, the involved tectonic units were stacked during latest Paleocene/earliest Eocene (Fig. 5) north-vergent dextral transpression (Wagreich and Faupl 1994; Wagreich 1995). Further south, the interpreted spatial distribution of the "Grauwacke zone" (Paleozoic

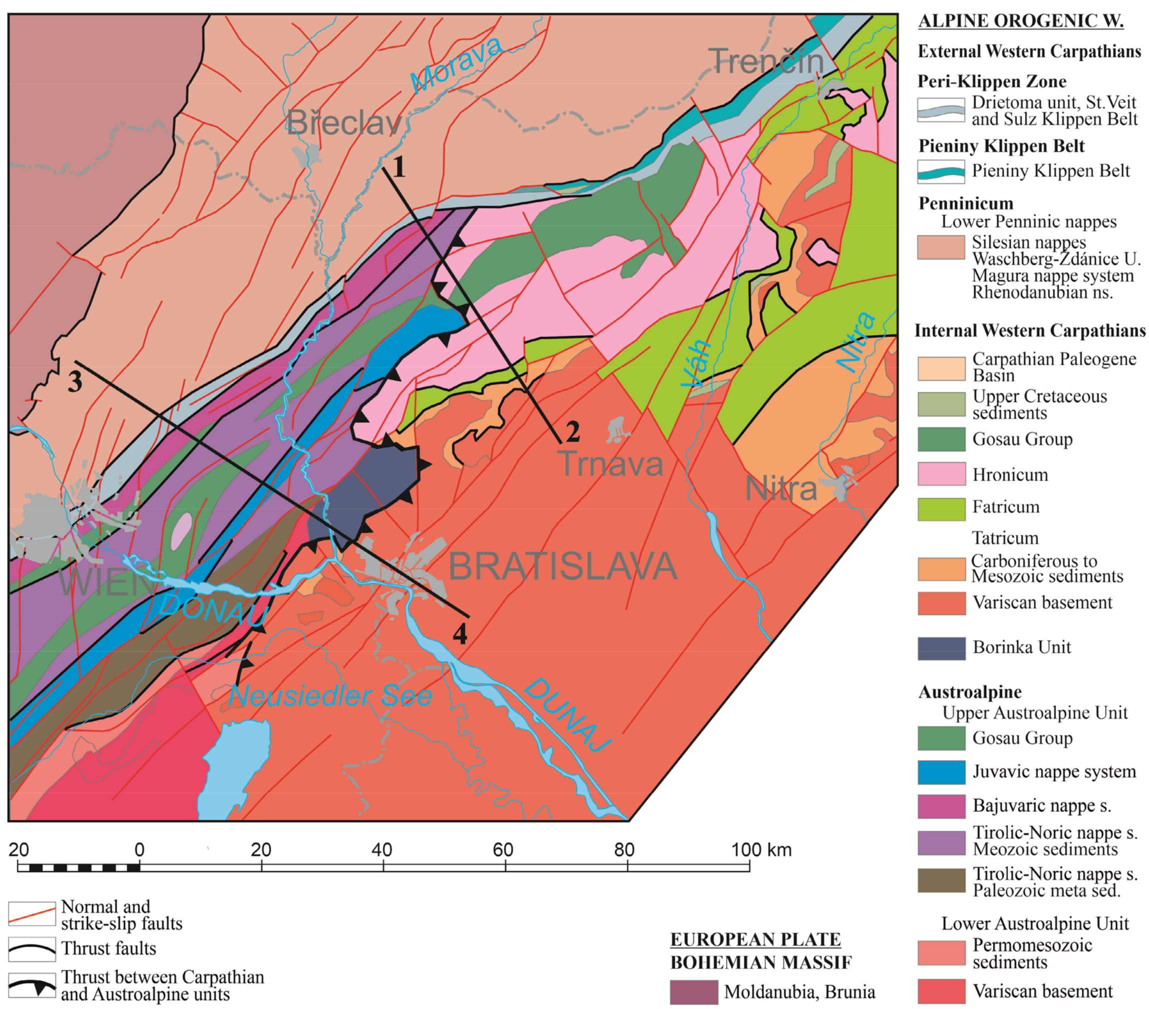

Fig. 7 Simplified tectonic map of the pre-Cenozoic basement with the principal overthrust of the Carpathian provenance tectonic units (compiled according Němec and Kocák 1976; Fusán et al. 1987; Kröll et al. 1993; Šamajová et al. 2018, 2019)

successions of the Tirolic-Noric nappe system) (Fig. 7) in the Pre-Cenozoic basement of the Vienna Basin (e.g. Marcheg-1 borehole, Fusán et al. 1987; Kröll et al. 1993) also suggests a superposition of the IWECA onto the Austroalpine Unit (see Fig. 6).

In our model, a marginal superposition of the Western Carpathian units over the adjacent Austroalpine units is much more likely (cf. Šamajová et al. 2019) than the opposite. This is in contrast to the interpretation by Wessely (1992), Kroll et al. (1993) or Tari et al. (2021).

Conclusions

The discussed Upper Cretaceous sediments in the junction area of the Western Carpathians and Eastern Alps comprise various lithofacial units derived from different geodynamic settings: (1) Upper Cretaceous flysch sediments form major parts of the Magura and Rhenodanubian nappe systems derived from the Penninic (Valais, Magura) oceanic domain. (2) The Upper Cretaceous sediments of the Jarmuta Formation seal internal nappe contacts within the Pieniny Klippen Belt, which had amalgamated during mid-Cretaceous time. (3) Upper Cretaceous to Paleogene sediments were deposited in piggyback basins on top of the Hronicum. They belong to the Gosau Group, which also occurs in the Bajuvaric, Tirolic-Noric and Juvavic nappe systems forming the Northern Calcareous Alps. (4) Upper Cretaceous to Paleogene sediments in the Považský Inovec and Strážovské vrchy Mts. were deposited in piggyback basins overlying different lithostratigraphic and lithotectonic units belonging to the Tatricum. Destruction of these basins is linked with the final emplacement of the Tatric and Fatric nappes during the Upper Cretaceous and with backthrusting of the Fatricum and Hronicum during the Oligocene−Early Miocene epochs. In terms of depositional timing and environment, these sediments show some similarities with the Gosau Group, but a strict correlation with these remains to be discussed.

The Pieniny Klippen Belt of the Western Carpathians has no equivalents in the Eastern Alps. In contrast, the Drietoma Unit of the Peri-Klippen Zone continues into the St. Veit Klippen Belt of the EA based on the Upper Triassic and Lower Jurassic sedimentary record including the Carpathian Keuper. Similar sediments also appear in the Sulz Klippen Belt and Groisbach-Nöstacher slices. The sedimentary record of the Drietoma Unit indicates deposition on the external margin of the Adria.

There are no indications for remnants of the Upper Penninic nappes between the main Pieniny Klippen Belt and Drietoma Unit. For this reason, the concept of a hypothetical Váhicum can be considered redundant. The Pieniny Klippen Belt together with the Drietoma Unit was thrust over the flysch sediments of the Magura nappe system sediments during the Oligocene.

The Borinka Unit is unique in the Western Carpathians and interpreted as part of the Lower Austroalpine unit. Like the latter, it contains Jurassic synrift sediments which were deposited at the extended Adriatic continental margin during the opening of the Jurassic branch of the Penninic Ocean. The Borinka Unit was overthrust by the Tatricum in a dextral transpressional regime in the Late Cretaceous.

Marginal overthrusting of IWECA units on top of Austroalpine units is indicated by the superposition of the Tatric on top of the Borinka Unit in the Malé Karpaty Mts. and by overthrusting of the Hronicum upon the Bajuvaric and Tirolic-Noric nappe systems in the pre-Neogene basement of the Vienna Basin.

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