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Geodynamics of polyorogenic zones: Case study from the Western Carpathians

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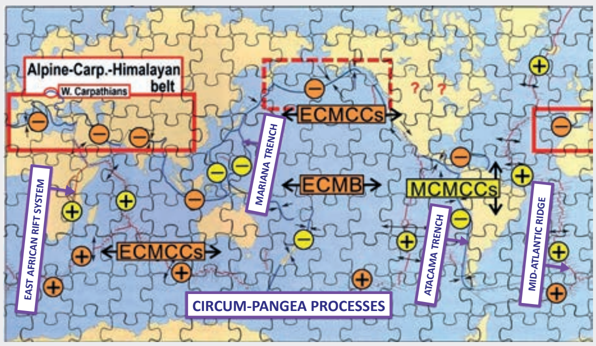
Abstract: Within the Alpine-Carpathian-Himalayan belt, the remnants of polyorogenic evolution are usually documented with a series of parallel suture zones of subequatorial course. In several cases some suture zones are interpreted as remnants of back-arc basins. In the Western Carpathians, the products of three principal Phanerozoic orogenic (Wilson) cycles were exemplarily documented – Variscan (Paleozoic), Paleo-Alpine (Mesozoic) and Neo-Alpine (Cenozoic) ones. The processes and products of the post-Cadomian Cenerian orogenesis are not treated in this article due to their ongoing research in the Western Carpathians, which is not yet completed. Based on presented geological and tectonic observations, as a driving force for polyorogenesis and multiple continental breakup a long time mantle convection (during a whole Phanerozoic eon) is interpreted, acting along a global subequatorial-course mantle bulge (ECMB) and parallel subequatorial-course mantle convection currents (ECMCCs). The submeridian zones with different kinematics are driven by submeridian-course mantle convection currents (MCMCCs), producing submeridian trending global rifts, but also subduction zones. Both systems of mantle convection currents – subequatorial (ECMB, ECMCCs), submeridian (MCMCCS) and their eventual interconnections, all briefly descriptively named as hot lines, are interpreted as principal drivers of global geodynamics. They are acting simultaneously with columnar mantle plumes (mantle diapirs). According to cited studies of different authors the heat for mantle convection currents and plumes is supplied by the thermonuclear fusion in innermost zones of the Earth. Combining the interpretation of global importance of mantle convection currents and their effect on processes within the lithosphere with the principles of plate tectonics, gives a basis for establishing a hypothesis of New Global Tectonics 2.0. For the simple and understandable description of a succession of orogenic cycles and their phases within polyorogenic evolution, including overprinting relations within tectonic and deformation phenomena, the methodology of XD labelling is applied in this contribution.

Key words: polyorogenic processes, extended orogenic cycle, subequatorial-course mantle bulge (ECMB), subequatorial-course mantle convection current (ECMCC), submeridian-course mantle convection current (MCMCC), hot line, XD and MX labelling, Western Carpathians

Graphical abstract



Highlights

- The Western Carpathians segment of Alpine-Carpathian-Himalayan belt is characteristic with polyorogenesis – geodynamics of the sequence of multiple orogenic cycles.
- Synthesis of research results, documenting evolution of the Western Carpathians, indicates a role of linear subequatorial-course mantle convection current (ECMMC) as a driver of Phanerozoic geodynamics of all three orogenic cycles – Variscan, Paleo-Alpine and Neo-Alpine.

1 Introduction

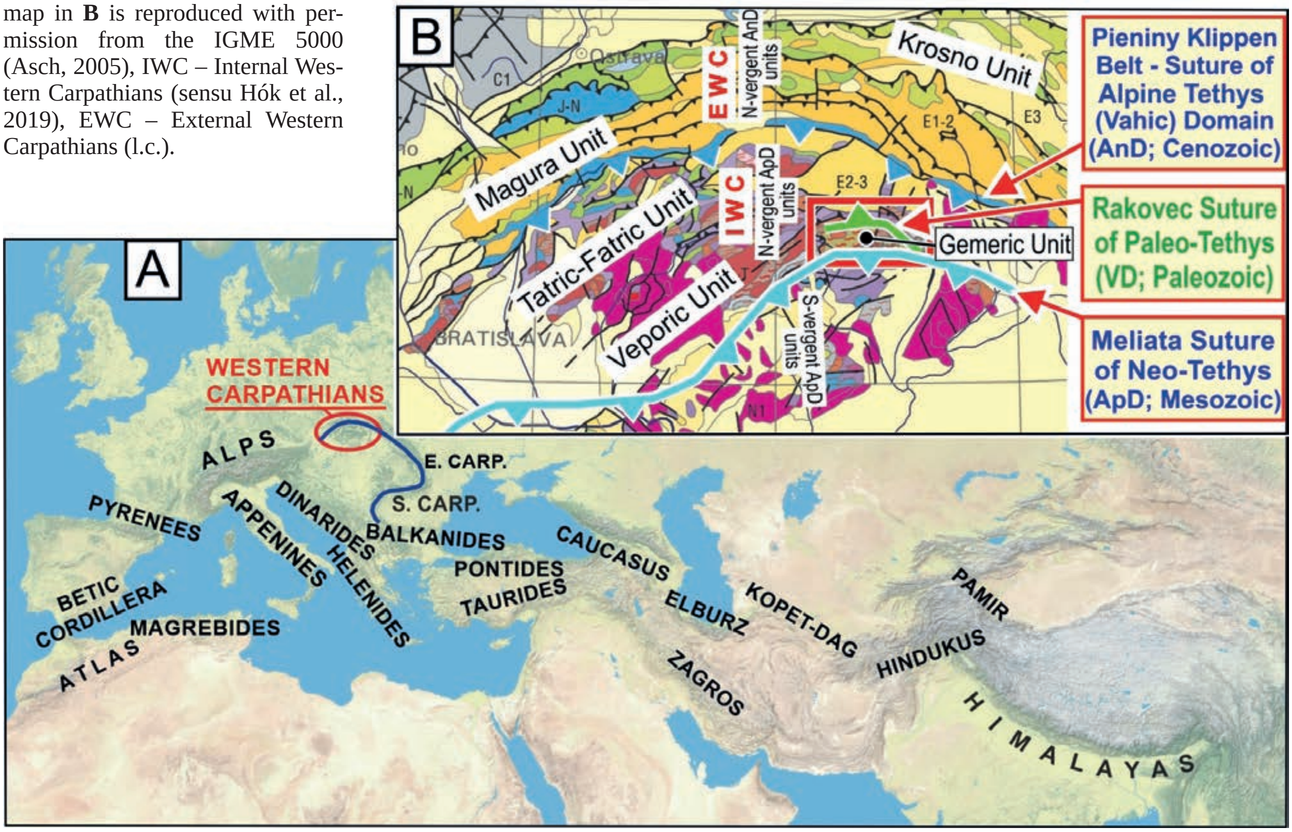
This contribution aims to introduce several new terms, not used (or used only marginally) in geological practice. The term **polyorogenesis** means action of a sequence of several orogenic cycles in a distinct zone, e.g. Alpine-Carpathian-Himalayan zone and producing a sequence of divergences with multiple parallel continental breakups, as well as convergences producing suture zones and orogenic belts. The continent-continent type collision at polyorogenic processes in zones of Intra-Pangea-type of subequatorial direction differs them from the Cordilleran-type mountain building at standard subduction / accretion prism forming processes in submeridian course zones of the Circum-Pacific-type. For the easy use and understandability of this sequence of orogenic cycles and their phases – they are described by the simple symbols of **XD labelling** methodology (Németh, 2021), being described further in the text.

Article provides a comprehensive review focused on polyorogenic evolution in the Western Carpathians, as a representative segment of generally subequatorial trending Alpine-Carpathian-Himalayan belt (Figs. 1 and 2). This contribution is based on detail knowledge on kinematics and products of three orogenic cycles in the Western Carpathians: Variscan (abbreviation **V**; Paleozoic), Paleo-Alpine (**Ap**; Mesozoic; western extension of Cimmerian cycle) and Neo-Alpine (**An;** Cenozoic; eastern extension of Penninic cycle). The processes and products of the post-Cadomian Cenerian orogenesis are not treated in this article due to their ongoing research in the Western Carpathians, which is not yet completed.

The present configuration of three suture zones (alternative term: geosutures) in the Western Carpathians (Fig. 1B) and polarity of subduction exclude an interpretation of backarc-type evolution of described three elongated basins: The Variscan equatorial trending geosuture (named Rakovec geosuture; Németh, 2002), located along the axis of the Western Carpathian polyorogenic belt, was produced by convergence having subduction polarity to north (l.c.). Younger Paleo-Alpine geosuture (Meliata geosuture, incl. Bôrka nappe; Mello et al.,1998; Putiš et al., 2019c; Potočný et al., 2023, 2025; Molčan Matejová et al., 2025), was located parallel, but south of Variscan geosuture, being produced by convergence with southern subduction polarity – slab dipping to south. Such geometry of these two orogenic cycles excludes the Paleo-Alpine basin position as a backarc developed during older Variscan process.

The youngest geosuture, present in the W. Carpathians – the Neo-Alpine Pieniny Klippen Belt Penninic-Váhic-Magura geosuture (cf. Plašienka et al., 2020 and references therein), is located parallel to both previous geosutures, but north of them. Related subduction slab was in this case

Fig. 1. A – Position of Western Carpathians (northernmost located red oval in part **A** within the polyorogenic Alpine-Carpathian-Himalayan belt. The Carpathian belt of triple oroclinal bend (syneclisis) is indicated by blue line drawn from Western Carpathian red oval towards SE – depicting the segment of Eastern Carpathians – and next to W, S and shortly to SE – depicting the segment of Southern Carpathians. The location and names of mountain ranges, located SW and SE of Western Carpathians were taken from van Hinsbergen et al. (2014) and Marko et al. (2020). The entire area shown in A is located north of the equator. **B** – Nearly symmetric course and northward convex oroclinal bending of Western Carpathians show very distinctly the course of three suture zones – Paleozoic Variscan (Rakovec geosuture of Paleo-Tethys sensu Németh, 2002; VD; light green), Mesozoic Paleo-Alpine (suture zone after Meliata ocean of Neo-Tethys; sensu Mello et al., 1998; ApD; light-blue) and Cenozoic Neo-Alpine suture zone (Pieniny Klippen Belt – Alpine Tethys / Vahic suture – presently summed up by Plašienka et al., 2020; AnD; dark blue). Despite clear zonality of these suture zones, the Western Carpathians contain also scattered remains of earlier Lower Paleozoic Rheic ocean Cenerian evolution (e.g. Putiš et al., 1997, 2024). Presented segment of geological map in **B** is reproduced with permission from the IGME 5000 (Asch, 2005), IWC – Internal Western Carpathians (sensu Hók et al., 2019), EWC – External Western Carpathians (l.c.).



dipping to south, which again excludes the possibility that elongated Neo-Alpine basin represented a back-arc basin during subduction of the crust of Paleo-Alpine basin. Position of suture zones, including the dips of subduction slabs are visualized in Fig. 1B.

It is important to note that the definition of Tethys Ocean varies among different authors. The Western Carpathian geologists, owing to distinct zonality of Variscan and Alpine successive events, use designation applied in this contribution: The Paleozoic Variscan elongated oceanic basin, having well developed suture zone in the W. Carpathians, is named the **Paleo-Tethys** (Grecula, 1982; Putiš et al., 2009, 2024; Plašienka et al., 1997a; Németh, 2002; Németh et al., 2016). The elongated Paleo-Tethyan Rakovec basic was closed by subduction-collision process in Upper Carboniferous (Németh, 2002; Dallmeyer et al., 2005), the Mesozoic one – **Neo-Tethys,** represented by Meliata Ocean, was closed by Lower Cretaceous collision (Plašienka et al., 1997b; Mello et al., 1998; Lexa et al., 2007). The youngest – third elongated oceanic basin in this succession consists of two zones – the southern – Piemont-Váhic Ocean as elongation of South Pennine Ocean subducted and closed at 80 Ma and northern zone – the Magura Ocean as elongation of North Pennine one subducted and closed between 35–20 Ma (cf. Plašienka et al., 2020). These two zones were primarily separated by so-called Oravic continental ribbon (Czorsztyn Ridge; l.c.). This gradual two-stadial partial subduction is interpreted as **Neo-Alpine evolution** in the W. Carpathians and the course of its suture zone is very spectacularly evidenced by the Pieniny Klippen Belt.

1.1 The XD labelling as a tool for simple and efficient classification of orogenic phases within orogenic cycles

To express understandable and readily depictable, the relations and time succession within individual orogenic

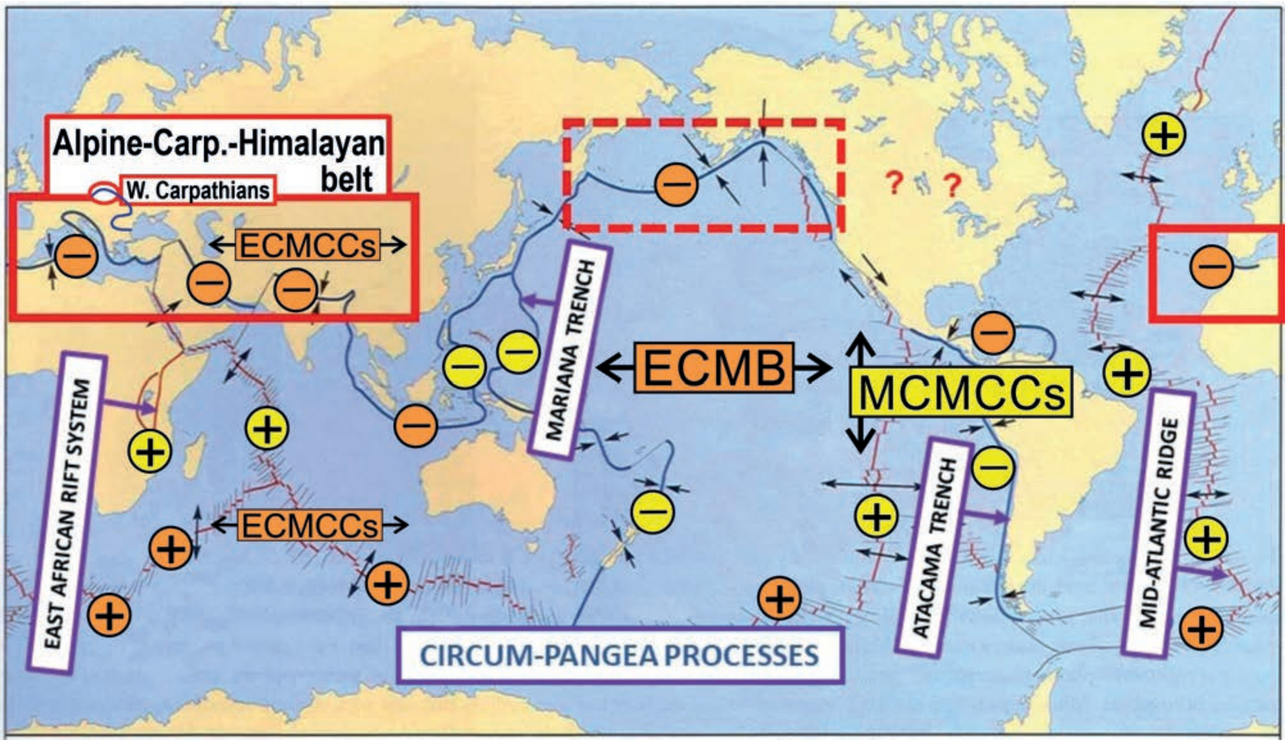


Fig. 2. Spatial orientation of subequatorial trending Intra-Pangea polyorogenic zone (red full or dashed line rectangles). The continuation of this zone within North American continent is not clear, its shift to Caribbean area is interpreted due to dextral displacement starting in San Andreas fault (located in western side of North American continent; cf. Wallace – ed., 1990). The designation of Circum-Pangea-type processes, chosen correspondingly with the situation during the existence of compact Pangea supercontinent in Permian, covers dominantly the processes of submeridian-course divergence (e.g. East African Rift System representing the embryonal stage of riftogenesis within continental crust or the Mid-Atlantic Ridge in mature stage of riftogenesis within oceanic crust), as well as convergence of submeridian course (e.g. subduction along Mariana and Atacama trenches as type localities). On the publicly available basemap the rift zones are marked with red curved lines and subduction zones with blue lines. The plus signs in circles indicate the upwelling mantle currents producing rift zones and minus signs in circles indicate downwelling mantle currents producing subduction zones. Both types of signs related to ECMB and ECMCCs are highlighted by orange circles. In the case of submeridian-course mantle convection currents (MCMCCs) the signs are placed to yellow circles.

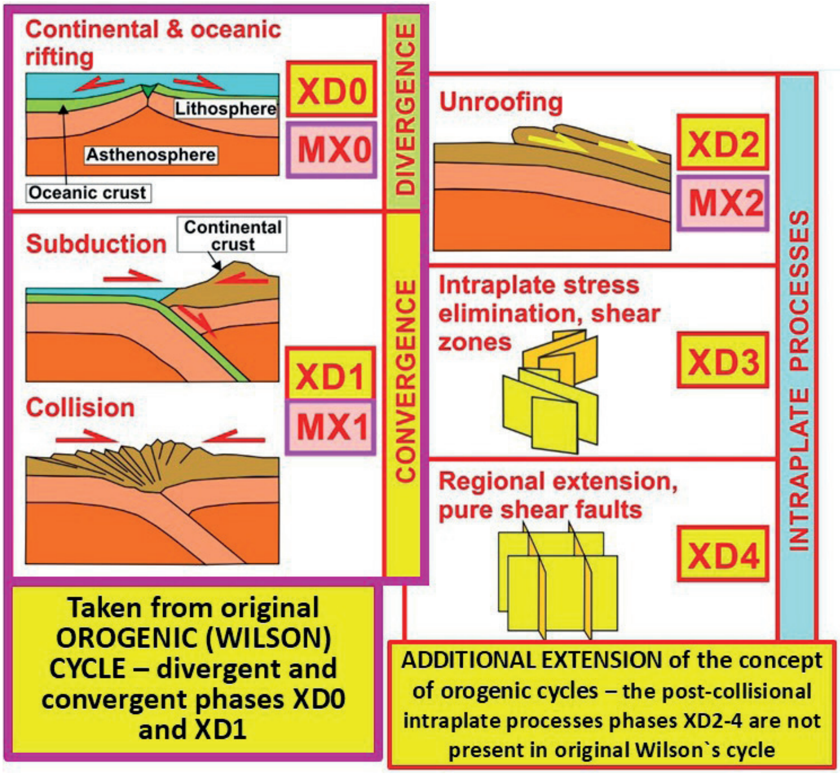


Fig. 3. The schematic visualization of a sequence of orogenic phases (XD0-4) and metamorphic overprints (MX0-2) within an orogenic cycle (Németh, 2021; reproduced with permission) highlights adding new orogenic phases (XD2-4) to primarily defined orogenic (Wilson) cycle (XD0-1), owing to extensive research in the Western Carpathians, focussed on tectonic and structural manifestations of individual phases and overprinting relations.

phases of orogenic cycles, the "XD labelling" methodology was suggested by Németh (2021; Fig. 3). Despite this methodology may be partly reminiscent of the concept of Hans Stille (1924), who postulated the idea of globally synchronous orogenic phases, the XD labelling is not targetted to global synchronization. Its aim is preferably descriptive – to mark simply and readily the orogenic cycles and their phases when discussing the geodynamic evoluton and orogenesis in the territory of interest.

At XD labelling, the name of particular orogenic cycle is expressed by the X variable – e.g. in the case of orogenic cycles in European territory: Sv – Svecofennian, Go – Gothian, Sn – Sveconorwegian, Ti – Timanide, Cd – Cadomian, Cl – Caledonian, **V – Variscan,** Ur – Uralian, **A – Alpine** (in W. Carpathians: **Ap – Paleo-Alpine – western extension of Cimmerian cycle** and **An – Neo-Alpine – eastern extension of Penninic subduction / collision events**) and He – Hellenic orogeny. Also further orogenic cycles with specific X labels (even word-wide) can be involved into this classification. A specific orogenic phase in the frame of orogenic cycle is expressed by adding relevant number after D: **XD0** – divergent process of riftogenesis – this orogenic phase is subdivided to three subphases: XD0a – stretching subphase, XD0b – thinning subphase (both relate to evolution within continental crust) and XD0c – ocean spreading subphase. The **XD1** phase designates the convergent processes of subduction (XD1s), obduction (XD1o) and closure of elongated oceanic space by collision (XD1c). In original plate tectonic (Wilson) cycle the collision represents the final phase of the cycle. Extended research in the Western Carpathians revealed the significance of post-collision evolution (revealed for both Variscan and Paleo-Alpine orogenic cycles (Németh, 2021), being classified by three additional phases within a cycle, covering the **post-collisional thermal / deformation processes, metamorphic core complex active evolution and related unroofing – XD2 phase;** intraplate stress consolidation – **XD3 phase** (strike slips, transpression, transtension, rotation of blocks, etc.) and regional extension – **XD4 phase** (pure shear-type regional faults – preferably of N-S and E-W trends, as well as the continental grabens developments and Basin & Range-type tectonics. Possible is even more detail classification applying the subphases.

Metamorphic overprints related to specific phases of orogenic cycle are labelled by similar way: MX0 – metamorphism related to mid-oceanic ridges, MX1 – subduction metamorphism (MX1s) and collision metamorphism (MX1c), MX2 – post-collision evolution of metamorphic core complexes and related metamorphism.

1.2 Interconnection of earlier geodynamic findings in the Western Carpathians with new designation of orogenic cycles and phases

In the Western Carpathians it is clearly decipherable that within orogenic cycles of **the subequatorial Intra-Pangea-type the regional extension leading to continental breakup acts dominantly in phases XD2 and XD4, being followed by X^{+1}D0 rifting of a new orogenic cycle.** Concerning the extensional phase XD4, the extended regional faults (lineaments) with pure shear kinematics, trending generally E-W (subequatorial trend) or N-S (submeridian trend) were important for continental breakups. These faults represent a common sign of Intra-Pangea as well as Circum-Pangea processes and on a global scale, they represent the embryonic phase of future rifts, being a consequence of mantle convection currents. In regional, or even local scales, the **XD4 pure shear faults can also be a product of XD3 shearing – they represent merging of synthetic as well as antithetic mega-shears of the same course within NW-SE and NE-SW trending XD3 shear zones** (cf. Németh et al., 2017; Németh in Gaál et al., 2017).

Regarding the topic of this contribution, we focus dominantly on **VD0 / ApD0 / AnD0 as well as on VD2 / ApD2 phases of Variscan and Alpine evolution**. The **VD2 / ApD2 phases** actively generated metamorphic core complexes **MV2 / MAp2** and extensional unroofing tectonics, in both cases leading to new continental (Pangea) breakups and origin of generally E-W trending basins with oceanic-type crust. For complexity, also other orogenic phases acting in evolution of the Western Carpathians will be briefly described in the XDs time succession. By this way this contribution provides reader a complete information about evolution of the Western Carpathian segment of Alpine-Carpathian-Himalayan orogenic belt, which can be useful e.g. when comparing this evolution with the evolution of other segments of polyorogenic belts in Europe or in the world.

1.3 Peculiarities of Intra-Pangea polyorogenic evolution in zones of subequatorial direction

We differ the **Intra-Pangea orogenic processes** in zones of subequatorial direction, encompassing dominantly the Alpine-Carpathian-Himalayan zone (being along the western margin of North American continent possibly shifted to Caribbean area), from the submeridian processes that acted not only in Pangea, but also in the rest of the world, being named as the **Circum-Pangea-type processes** (earlier designation was Circum-Pacific-type processes; Németh et al., 2016; Németh, 2018). In this division, the situation along the NNW-SSE trending San Andreas Fault System is much more complicated – simultaneously with regional dextral shearing this fault system represents also northern continuation of submeridian rifting zone separating the Pacific plate from Cocos and Nazca lithospheric plates (cf. Wallace – ed., 1990; Fig. 2),

At the **Circum-Pangea-type processes / zones** the rift zones and trenches have generally N-S – submeridian trend and their tectogenesis corresponds to present convergent processes along western coast of South America – e.g. the Atacama trench zone as well as east of Japanese islands – the Mariana trench zone, both as exemplary cases (Fig. 2). As an example of submeridian-course divergent zones there can serve the spreading of the Mid-Atlantic ridge, or presently developing East African Rift System. The continent-continent-type collisions are significantly less common at the submeridian Circum-Pangea zones than in the case of subequatorial Intra-Pangea-type polyorogenic zoness (cf. Fig. 2). There is necessary to emphasize that the Intra-Pangea orogenic processes in zones of subequatorial direction occur presently in evolutionary stage of finishing Neo-Alpine phases AnD1 / AnD2 and the Alpine-Carpathian-Himalayan belt is undergoing mainly the Neo-Alpine shearing (AnD3) and extensional faulting (AnD4), which is interconnecting the Intra-Pangea and Circum-Pangea processes. In the Mediterranean area the Hellenic orogenic cycle occurs now in the subduction phase HeD1s.

In the case of pre-Pangea supercontinents of Rodinia (Mesoproterozoic and Neoproterozoic in age) and Nuna (Paleoproterozoic and Mesoproterozoic in age) we suppose the corresponding kinematics of divergent processes, continental breakups, as well as convergent processes, as in younger, here described, Pangea-type processes – having similar kinematic evolution, spatial orientation and sequence of events, though acting in slightly warmer conditions.

1.4 Earth rotation and its role in positioning of principal mantle convection currents

As reviewed in monograph by Frisch et al. (2022), Alfred Wegener, professor at the University of Graz (Austria) in the 1920s, unsuccessfully attempted to add credibility to his theory of continental drift explaining its driving forces by the rotation of the Earth. Parallel with Alfred Wegener at the same university worked professor Robert Schwinner, developing far-reaching theory of convective heat transport, producing the currents in the Earth's interior. If both professors would have communicated, they could unify the drift theory with accepted theory of its driving force, thus markedly accelerating the birth of the theory of plate tectonics (l.c.).

The concept presented in our further text and its conclusion are built exclusively on the theory of mantle convection heat currents, emphasizing that on a global-scale the Earth's rotation organizes them preferably to mantle currents of subequatorial-course (ECMB and ECMCCs), as well as submeridian-course (MCMCCs), contributing to location of rift zones / subduction zones in the lithosphere. All author's interpretains are based on geological and tectonic observations, so he only reports primary reasons of mantle convection currents citing works of other authors (in chapter 5).

The variability of the Earth-rotation vector relative to the body of the planet or in inertial space is caused by the gravitational torque exerted by the Moon, Sun and planets, displacements of matter in different parts of the planet and other excitation mechanisms (IERS, 2023). Concerning geodynamics, the oscillations can be interpreted in terms of mantle elasticity, Earth flattening, structure and properties of the core-mantle boundary, rheology of the core, and the understanding of the coupling between the various layers of our planet (l.c.). The role of Earth rotation in plate tectonics was considered by numerous earlier authors:

The existence of a global westward rotation of the lithosphere independently from the location of the hot spots sources was suggested by Ricard et al. (1991). These authors emphasized that this rotation is a real one and is not an artifact of the choice of the reference frame in which plate motions are defined. As a consequence of the westward rotation of the lithosphere an anchoring effect in the case of subduction slabs at submeridian trending subduction zones acts in the mantle which is migrating east. This mechanism could explain the observed steeper dips of the west dipping subduction slabs which contrast the mantle flow. This concept was further developed by Doglioni et al. (1991, 1999, 2006).

Hide et al. (1993) review earlier models of the topography of core-mantle boundary as well as the hypothesis that the astronomically determined irregular fluctuations in the Earth's rotation vector is due to the fluctuating torque on the lower surface of the Earth's mantle produced by magnetohydrodynamic flow in the underlying liquid metallic core as well as **equatorial bulge**.

Wilson (1995) emphasized that only few local observations and satellite remote sensing observations measurements of Earth rotation changes offer genuinely global measures. The Earth's long term rotation stability was explained by Richards et al. (1997) by the slow rate of change in the large-scale pattern of plate tectonic motions during Cenozoic and late Mesozoic time, as well as relatively **slow changes in the global pattern of subduction zones**. The subducted lithosphere represents a **major component of the mantle density heterogeneity generated by convection**. This effect of three-dimensional mantle density heterogeneity on Earth rotation was confirmed by Liu et al. (2016): The difference of the observed Earth polar motion and length of day, taking into account the model only considering ocean tides, **must have added also the contributions of the lateral density heterogeneity of the mantle**. Study of the effect of mantle density heterogeneity on torque-free Earth rotation may provide useful constraints to construct the Reference Earth Model.

Sun and Xu (2012) improved prediction accuracy of Earth's rotation parameters (ERP), based on improved weighted least squares (WLS) and autoregressive (AR) model. **Earthquakes may lead to mass redistribution in the Earth interior and by this way to influence the Earth's rotation** due to the change of Earth inertia moment (Xu & Sun, 2012). Authors (l.c.) adopted the elastic dislocation to compute the co-seismic polar motion and variation in length of day (LOD) caused by the 2011 Sumatra earthquake. They **indicate the tendency of earthquakes make the Earth rounder and to pull the mass toward the centre of the Earth**.

The rotation rate of Earth determines **its uniaxial compression along the axis of rotation**. The **Earth's ellipticity variations, caused naturally by the rotation rate variations**, are manifested in **vertical components of various surface elements**, which can be determined by precise GPS measurements (Levin et al., 2017). Analysis of the observations made by the International Earth Rotation and Reference System Service (IERS) **revealed regularities in the natural variations of the Earth's angular rotation rate**. The work by Levin et al (l.c.) performs comparison of geodetic ellipsoid dynamics theoretical estimates obtained from studies of **the pulsation model of the Earth's shape due to variations of its rotation rate**. By this way this study has added a new dimension for understanding of **the variations in the Earth rotation caused by mass redistribution**.

Relation of geodynamics to the Earth rotation was extensively researched by a number of Polish institutions in the 2010s (Bogusz et al., 2015). The tectonic plate motions models and the map of the continuous velocity field were developed applying information from over 300 permanent reference stations of the EUREF Permanent Network (EPN) as well as Polish Active Geodetic Network (ASG-EUPOS) and interpolating velocities using the Kriging method with the nugget effect. The robustness of geodetically-defined kinematic model, describing recent geodynamics, was tested using numerical finite element modelling of stress and strain distribution in Central Europe (Bogusz et al., 2011). Simplified mechanical model of the lithosphere was developed using geological and geophysical data including tectonically defined discontinuities. The results of model predictions were evaluated by comparison with measured present-day stress and strain.

2 Brief description of regional geological setting of the Western Carpathians

The Western Carpathians represent arcued elongated orogenic segment of the Alpine-Carpathian-Himalayan belt (Fig. 1A, B). They are characteristic with dominant northern vergency of Alpine ApD1c tectonic imbrication and nappe stacking, despite having incorporated also southern vergency tectonic structures of earlier Variscan evolution VD01.

Despite the triple division of the Western Carpathians to Outer, Central and Inner W. Carpathians was dominantly used in the past (e.g. Mahel', 1986), we prefer simpler division to Outer (External – EWC) and Inner (Internal – IWC) W. Carpathians (cf. Hók et al., 2019), better distinguishing units with dominant Neo-Alpine (Cenozoic) vs. dominant Paleo-Alpine / Variscan (Mesozoic /

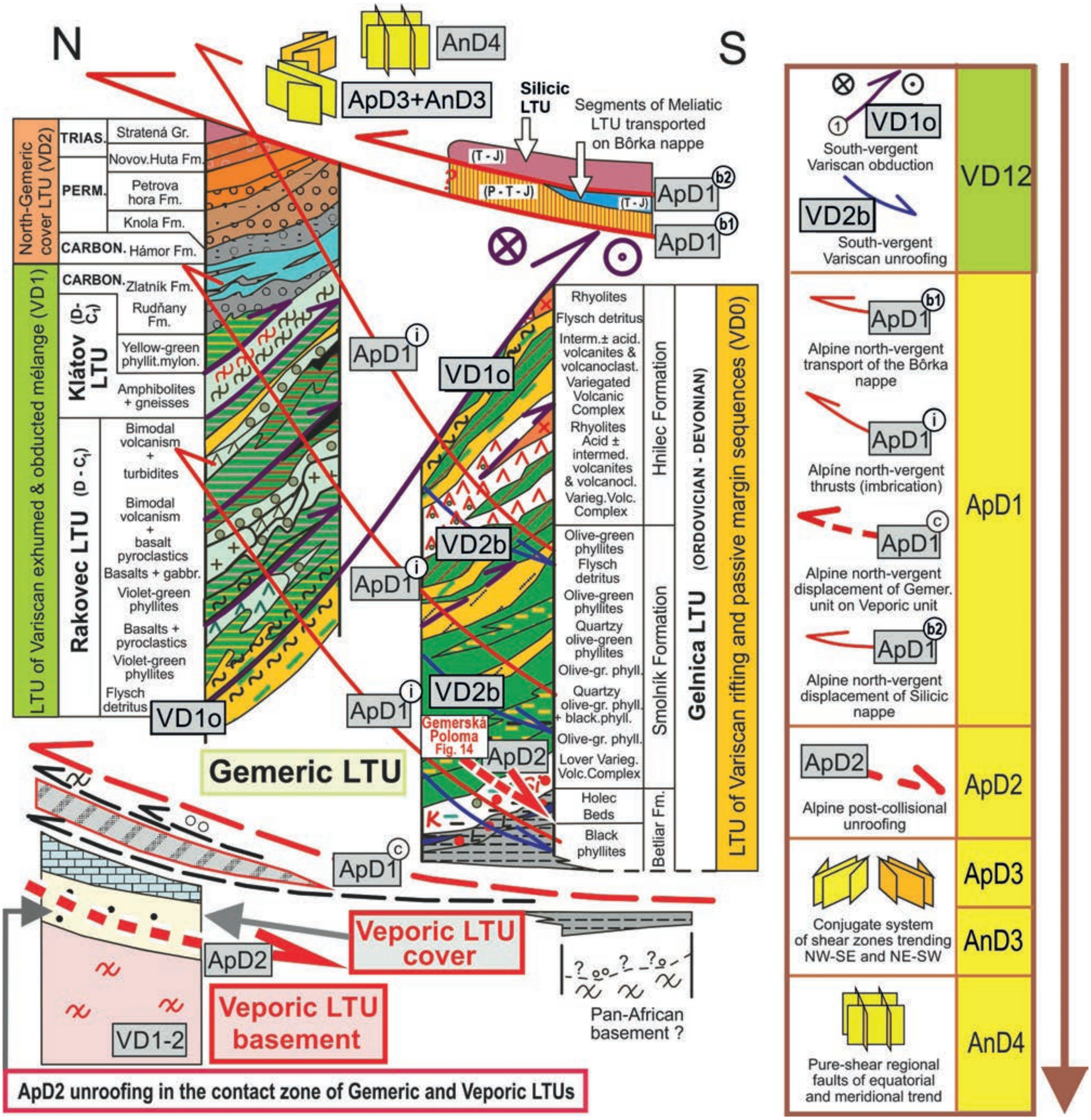


Fig. 4. Detail lithotectonic column of the innermost zone of Internal Western Carpathians (IWC), depicting succession of orogenic phases in Variscan (VD) and Paleo-Alpine (ApD) orogenic cycles, as well as their overprint by Neo-Alpine shearing (AnD3) and faulting (AnD4). Orientation of this lithotectonic column is N–S, localized it is in the middle the red rectangle in Fig. 1B. This lithotectonic column expresses the relations of supreme order lithotectonic units of Internal W. Carpathians: Gemeric, Veporic, Meliatic (incl. the Bôrka nappe) and Silicic units (cf. Németh, 2005b; Németh et al., 2012; reproduced with permission). Methodology of XD labelling of lithotectonic units (LTUs) and lithotectonic limits (LTLs) allows to express clearly the succession of tectonic structures and overprints. Red arrow lines express the Early Cretaceous north-vergent thrusts of Meliatic Bôrka nappe on Gemeric lithotectonic unit (LTU; ApD1b1), north-vergent imbrication (ApD1i), then thrust of Gemeric + Bôrka nappe pile on Veporic one (ApD1c). The whole lithotectonic sequence is then overthrust by the Silicic nappe (ApD1b2). Apparent paradox of Lower Cretaceous evolution of IWC is that simultaneous with this prominent ApD1 compressional / collisional phase taking place in the innermost (i.e. southernmost) zones of IWC, an extension was prevailing in the outermost (northernmost) zones of the Western Carpathians, forming here several longitudinal elevated and subsided domains (cf. Plašienka, 2018). The same paradox is characteristic for the Late Cretaceous evolution of IWC – the southernmost zones underwent ApD2 extension and unroofing (designated by red thick dashed arrow line), but in the northernmost zones of Western Carpathians this period is characterized with contraction and its differentiated topography was inverted and previous facial zones became constituents of regional tectonic units (cf. l.c.).

Paleozoic) evolution. Superficially, the dividing line between External and Internal W. Carpathians is represented by the Klippen Belt, geometrically parallelized with the Penninic evolution in the Eastern Alps and Briançonnais domain (Tomek, 1993) in the Western Alps. The Klippen Belt marks simultaneously boundary between Neo-Alpine nappes in External W. Carpathians and Pre-Paleogene Paleo-Alpine nappes of Internal W. Carpathians.

2.1 Internal Western Carpathian belt

In Paleo-Alpine nappe pile the following main lithotectonic units, having northern general vergency of thrusting and nappe displacement, will be described from the bottom upwards: *Tatric*, *Veporic* and *Gemeric units* (all three represent so-called basement nappes), *Meliatic (Bôrka nappe)*, *Turnaic (Tornaic in Hungary)* and *Silicic units* (representing the superficial nappes; cf. Figs. 1B and 4). Moreover, from the space between Tatric and Veporic units the *Fatric Unit (Krížna nappe) wa*s derived and from the space between *Veporic* and *Gemeric units* it was the *Hronic Unit (Choč nappe)*. The geodynamic evolution of these sequences is described in more details in relevant chapters in further text.

The Tatric Unit (*Tatricum*; probable equivalent of Lower Austroalpine Unit of the Eastern Alps) – crops out in the W. Carpathian core mountains and consists of Variscan medium to high-grade metamorphic rocks (schistose gneisses with sporadic HP metamorphics and granitoids). The primary cover of Tatricum starts with Upper Paleozic / Lower Triassic clastics, being followed by Middle Triassic carbonates. The sedimentary area became differentiated during the Jurassic period, encompassing radiolarian limestones, radiolarites, crinoid and sandy limestones. The Lower Cretaceous pelagic, cherty limestones sedimentation ended with flysch formation. The Tatricum represents the lowermost unit of Internal Carpathians. In present north-vergent tectonic setting the Tatric tectonic underlier is represented by *Váhicum* as equivalent of southern *Penninicum*, and tectonic overlier by flat-lying nappe of *Fatricum,* containing sedimentary sequences corresponding with that of Tatric cover.

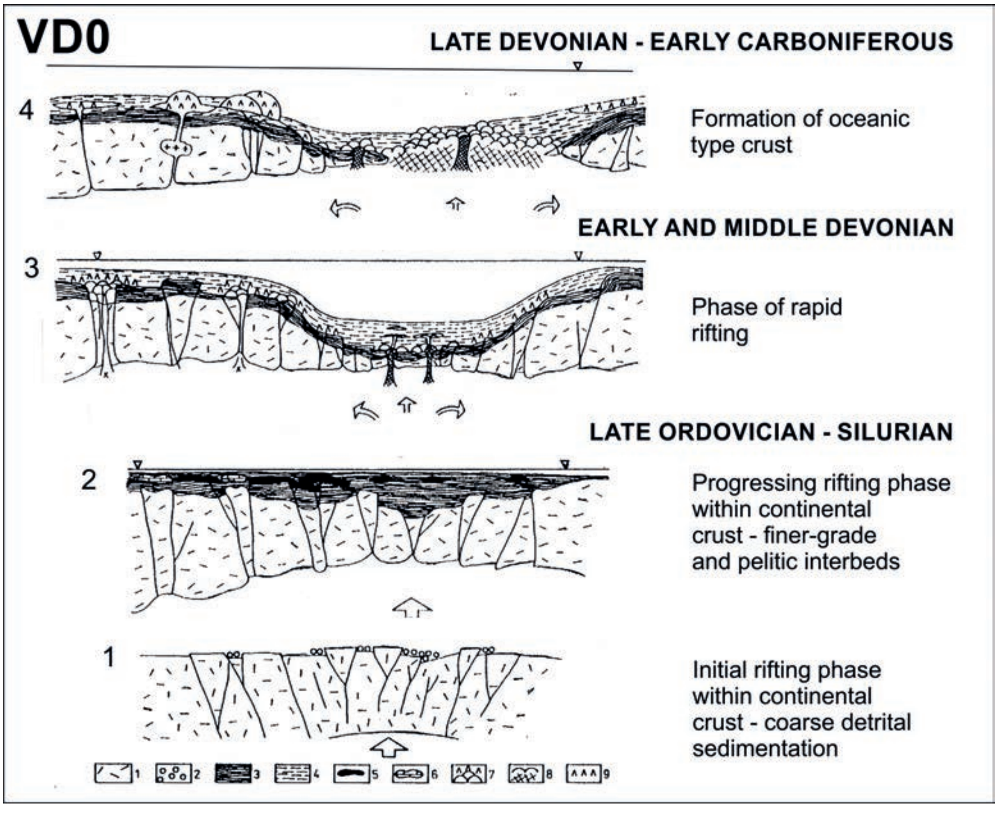


Fig. 5. The Early Paleozoic Variscan continental breakup and origin of Paleo-Gemeric riftogenous basin VD0 in the territory of future Western Carpathians (slightly modified after Grecula, 1982 – Plate 3.1 ibid., Grecula in Grecula et al., 1995 – Fig. 1.8 ibid; reproduced with permission). The source of convectional heat (EC-MCC; hot line) is indicated by arrows beneath the rift zone. Development phase **1** (VD0a) is not preserved in present Gemeric Unit due to ApD1c north-vergent amputation of coarse-grained detrital Gemeric sequences from their Pan-African homeland (cf. in Fig. 4 – middle column down), applying the soft horizon preferably of black phyllites (lithology 3 in this Fig.) in the Paleo-Alpine nappe detachment ApD1c. This rheologically soft horizon of black phyllites is presently affiliated with the Gemeric **Betliar Formation** (former Late Ordovician-Silurian sedimentation in anoxic environment; in this figure shown in evolution phase **2**), **3** – development of **Smolník Fm.** with bimodal volcanism of first rapid rifting phase VD0b; all sequences belong to **Gelnica Group** (**LTU**; cf. Fig. 4), **4** – opening of ocean and development of mid-oceanic ridge VD0c, which sequences are included into the **Hnilec Fm.** of **Rakovec Group (LTU)** and – in higher temperature metamorphosed facies – to the **Klátov Group (nappe; gneiss-amphibolite complex; LTU).** Lithology in the legend beneath sketches: 1 – rocks of continental crust, 2 – coarse-clastic sediments, 3 – formation of black phyllites – dominantly organic matter / graphite bearing pelites and psammites, 4 – formation of greenish (dominantly chlorite bearing) pelites and flysch sequences, *5* – lydite, 6 – carbonate, 7 – basalt-keratophyre bimodal volcanic complex, 8 – magmatic series of the mid-oceanic ridge, 9 – rhyolite domes.

The Veporic Unit (Veporicum), similarly like Tatric Unit, comprises of Variscan crystalline basement and Upper Paleozoic / Mesozoic cover. The Alpine evolution zone between Veporic and Gemeric units is interpreted to be the homeland of *Hronic Unit (Hronicum)* with conspicuous development of Carboniferous-Permian volcanosedimentary formations.

The *Gemeric Unit (Gemericum)* represents the uppermost Paleo-Alpine basement nappe, having well preserved Lower Paleozoic volcano-sedimentary sequences of Variscan riftogenous phase (VD0; Fig. 5), as well as – in Northern-Gemeric rim – well preserved suture zone with a wide range of rock sequences, including also HP and UHP blocks exhumed from Variscan subduction zone and VD1oc thrust southward on Variscan passive margin sequences (Radvanec & Németh, 2018; Figs. 6, 7 and 8). The Gemeric Upper Paleozoic / Mesozoic cover sequences are bearing superficial nappes of *Meliatic Unit (Meliaticum; Bôrka nappe), Turnaic and Silicic units* (cf. Fig. 4, upper part).

2.2 External Western Carpathian (Flysch) belt

This belt is a product of Upper Cretaceous-Cenozoic Neo-Alpine evolution. External Carpathian Flysch belt consists of Cenozoic rootless nappes thrust over the North-European platform. The flysch-like Mesozoic and Paleogene formations predominate. The *Magura group of nappes (Unit)* consists mainly of Paleogene flysch formations with prevailing sandstones. These are as a whole, thrust northward over the north located *Krosno Unit of Flysch Belt, built of prevailing variegated claystones.*

The Klippen Belt (Oravic Unit; cf. Hók et al., 2019, p. 39 ibid.) represents in pre-Neo-Alpine deformation phase the hypothetical continental ribbon named as Czorsztyn ridge, separated from the European Platform on the north by oceanic domain of the Northern Penninicum (Magura Ocean) and from the Internal Western Carpathians by the oceanic domain of the Southern Penninicum of the Váhicum (Plašienka, 2012; Plašienka & Soták, 2015). The most widespread here are the Czorsztyn and Kysuca (Kysuca–Pieniny) sedimentary successions starting with Lower Jurassic rocks.

The more detail characteristics of individual Western Carpathian lithotectonic units are available in further text, describing them in the frame of their polyorogenic evolution.

3 Methodology of research

Research consisted of three decades of author's field geological mapping and study of relations of rock sequences with individual phases of orogenic cycles in the Western Carpathians, and in some special cases also besides this territory. This research was accompanied with structural analysis, revealing the overprinting relations and displacement kinematics of individual rock sequences and lithotectonic units (Németh et al., 1997, 2001, 2004; Németh, 2005a, 2018, 2021; Németh et al., 2012b, 2016, 2023 and references for structural and tectonic investigations in these publications). Ductile deformation was studied also by techniques of structural petrology (microtectonics; Németh, 2002). The deformation gradient within regional ductile shear zones was calculated by paleopiezometry, applied on monocrystalline calcite marbles and quartzites (Németh, 2005b; Németh et al., 2012a). Present study benefits also from published regional geological, tectonic and petrological results of hundreds other researchers from the Western Carpathians, Alpine-Carpathian-Himalayan belt and further parts of the world (cf. following works and references herein: Plašienka, 2018, 2021; Plašienka et al., 1997a, b, 1999, 2020); Putiš, 1992, 1994; Putiš et al., 2008, 2009a, b, 2019a, b, c, 2024; Radvanec et al., 2007, 2009, 2017; Radvanec & Németh, 2018; Kováč, 2000; Kováč & Plašienka, 2002; Kováč et al., 2002; Lexa & Konečný, 1998; Konečný et al., 2002; and many others).

For simple and efficient description of a succession of orogenic cycles and their phases, including overprinting relations within tectonic structures, the methodology of XD labelling was developed, intending to make the research of lithotectonic units (LTUs) and lithotectonic limits (LTLs) much more effective (Németh, 2021). The geological units (tectonic, sedimentary, magmatic, etc.), treated in this contribution, are presented in lithotectonic meaning (i.e. having attributed geodynamic aspects). Despite the terms *Unit* / *units* are in some cases preserved, in all cases they represent lithotectonic units (LTUs).

4 Geodynamic evolution of the Western Carpathians with emphasis on extensional tectonics leading to continental breakups, formation of elongation basins with oceanic-type crust along their axis and their closure during convergence – wider geodynamic considerations

The advantage of the Western Carpathians, as an appropriate study territory within the polyorogenic Alpine-Carpathian-Himalayan belt (Fig. 1A), is their distinct zonality and nearly symmetric northward convex oroclinal bending (Fig. 1B). Owing this zonality, the products of individual orogenic phases of three orogenic cycles (Variscan – VD, Paleo-Alpine – ApD and Neo-Alpine – AnD), as well as their tectonic and metamorphic overprints are decipherable directly in the field and can be easily studied by structural, microtectonic, petrologic and geochronologic methodologies. As indicated above, Alpine evolution in the Western Carpathians manifests a special case of two "intermingling" orogenic cycles –

Paleo-Alpine (Triassic-Cretaceous; ApD) and Neo-Alpine (Jurassic-Recent; AnD), which orogenic phases are time shifted.

Further information, describing the zonality of the W. Carpathians and their geodynamic evolution, are provided in summarizing contributions by Plašienka et al. (1997a, b) as well as Hók et al. (2019), but mainly in monographic issues edited by Grecula et al. (1997), Rakús (1998), Vozár and co-eds. (2010), Kováč (2000) and Janočko and Elečko (eds., 2003). Presently there was issued an extended paper about an Early Alpine tectonic evolution (**ApD**) of the Western Carpathian by Plašienka (2018). In the frame of Alpine-Carpathian-Dinaridic belt the orogenic evolution of W. Carpathians is treated by Schmid et al. (2008, 2020), van Hinsbergen et al. (2020) and a number of Polish authors, referred in chapter about AnD processes.

The Variscan and Paleo-Alpine continental breakups can be best characterized in the innermost zones of Internal W. Carpathians. The principal basement unit in this zone (red rectangle in Fig. 1B) is the *Gemeric Unit* (ApD), representing the ApD1c nappe overlier on north-located ApD *Veporic Unit*. The *Gemeric unit* is bearing superficial nappe outliers of *Meliatic Unit* (*Bôrka nappe*; ApD1b1; cf. Fig. 4) and *Turnaic* (*Tornaic* in Hungary) *Unit*. This basement and superficial nappes sequence was as a whole thrust over north-located *Veporic Unit* (ApD1c; cf. Fig. 4 – lower left side). Moreover – over both – the *Gemeric* and *Veporic units* the *Silicic Unit* was displaced at the end of ApD1 phase (cf. Fig. 4 – upper middle side). Two generations of continental breakups (Variscan and Paleo-Alpine) as well as their later convergent – collisional phases are in described region well proved with two continuous–course suture zones (Fig. 1B), but also by obduction and nappe displacement of two generations of exhumed ultramafic rocks and further ophiolite suite fragments (Fig. 6). The third generation Neo-Alpine continental breakup, registered in the W. Carpathians, is characterized by the course of *Pieniny Klippen Belt* as suture after the Alpine Tethys (Váhic) ocean, representing the boundary between Internal and External W. Carpathians.

4.1 Geodynamics of Variscan orogenic cycle revealed in the innermost zones of W. Carpathians

VD0 divergent – continental breakup phase

The Variscan continental breakup and riftogenesis in the Western Carpathian zone was well described owing to extended (the 1970s–2010s) geological-geophysical and geochemical research of *Gemeric Unit* (Grecula, 1982; Grecula et al., 1995 – Figs. 1.5 and 1.8 ibid.; Grecula & Kobulský – eds., 2011). This breakup (Fig. 5) was

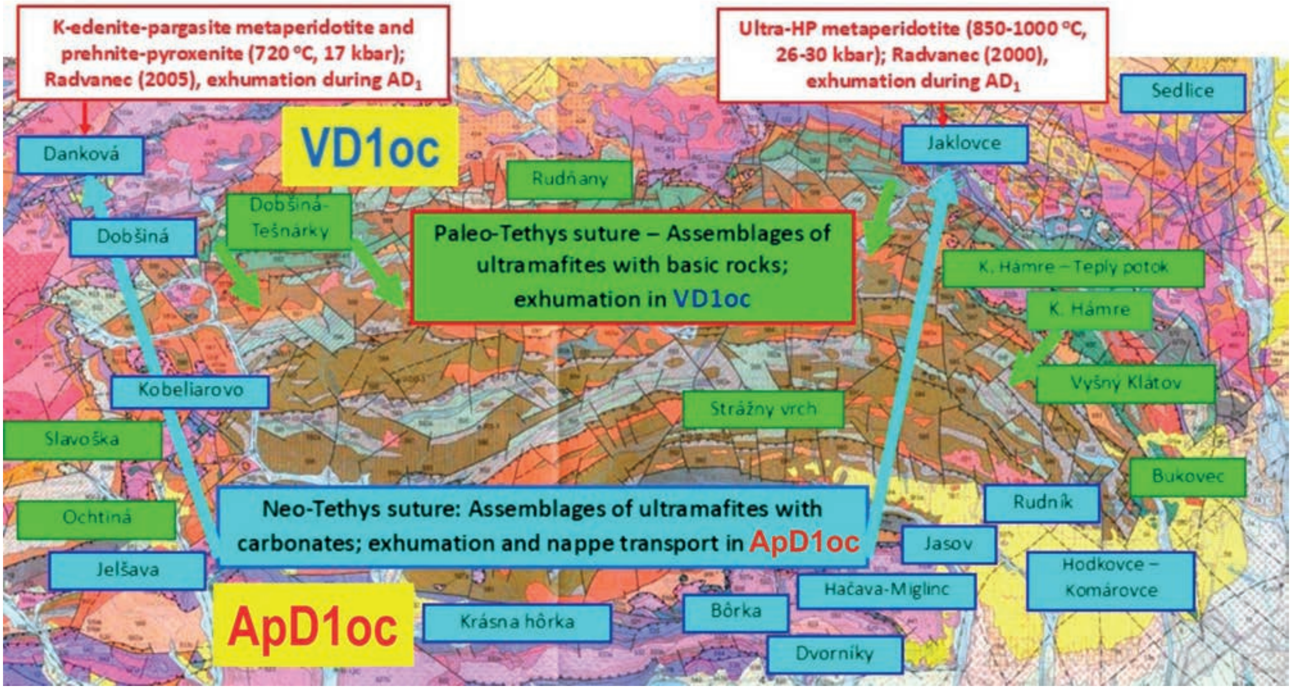


Fig. 6. Two generations of exhumed, obducted and locally distantly displaced ultramafic rocks in Gemeric region: Green colour – south-vergent VD1oc exhumation and obduction of Variscan Paleo-Tethys Rakovec basin ultramafics and other fragments of ophiolite suite, related to collisional closure of this basin. Blue colour – north-vergent ApD1co exhumation and collisional obduction of Paleo-Alpine Neo-Tethys Meliata basin ultramafics with ophiolites fragments. Compilation of data from Hovorka (ed., 1985) and Radvanec (2000, 2005). Basemap: segment of the map by Grecula in Mello and Ivanička (eds., 2008; reproduced with permission).

registered by Early Paleozoic riftogeneous **(VD0)** and later passive margin **(VD1a)** lithology of the **Gelnica LTU** (central part of the Fig. 4; originally defined as a lithostratigraphic group; Bajaník et al., 1983; Grecula et al., 2009), as well as the pre-subduction lithology of the **Rakovec** and **Klátov LTUs** (cf. left side column of Fig. 4), representing Variscan oceanic-type crust (Fig. 4 shows later – their VD1o obducted position on Gelnica LTU). Because Gemeric Unit (Gemericum) as LTU was individualized in Paleo-Alpine ApD1c phase, from the viewpoint of one generation earlier Variscan origin and evolution of Gelnica, Rakovec and Klátov LTUs, for the sake of correctness in naming – they belong to Variscan **Paleo-Gemeric Unit** (or **Paleo-Gemericum**).

The Paleo-Tethys passive margin sequences from the side of Gondwana – **Gelnica LTU** – were deposited on Pan-African basement. This situation is shown in Fig. 5, though the Pan-African coarse-detrital sediments are not present on recent surface due to their amputation during Early Alpine north-vergent **ApD1c** basement nappe displacement (Fig. 4 – this **ApD1c** amputation is shown below the column of Gelnica LTU). Progressing Variscan rifting on continental crust (cf. Figs. 4 and 5) was accompanied with changes in volcanosedimentary activity within three distinguished formations (Grecula, 1982): The lowermost Upper Ordovician-Silurian **Betliar Formation** (built of prevailing black phyllites and lydites in so-called Holec Beds; Fig. 4 – lower part of middle columg), next

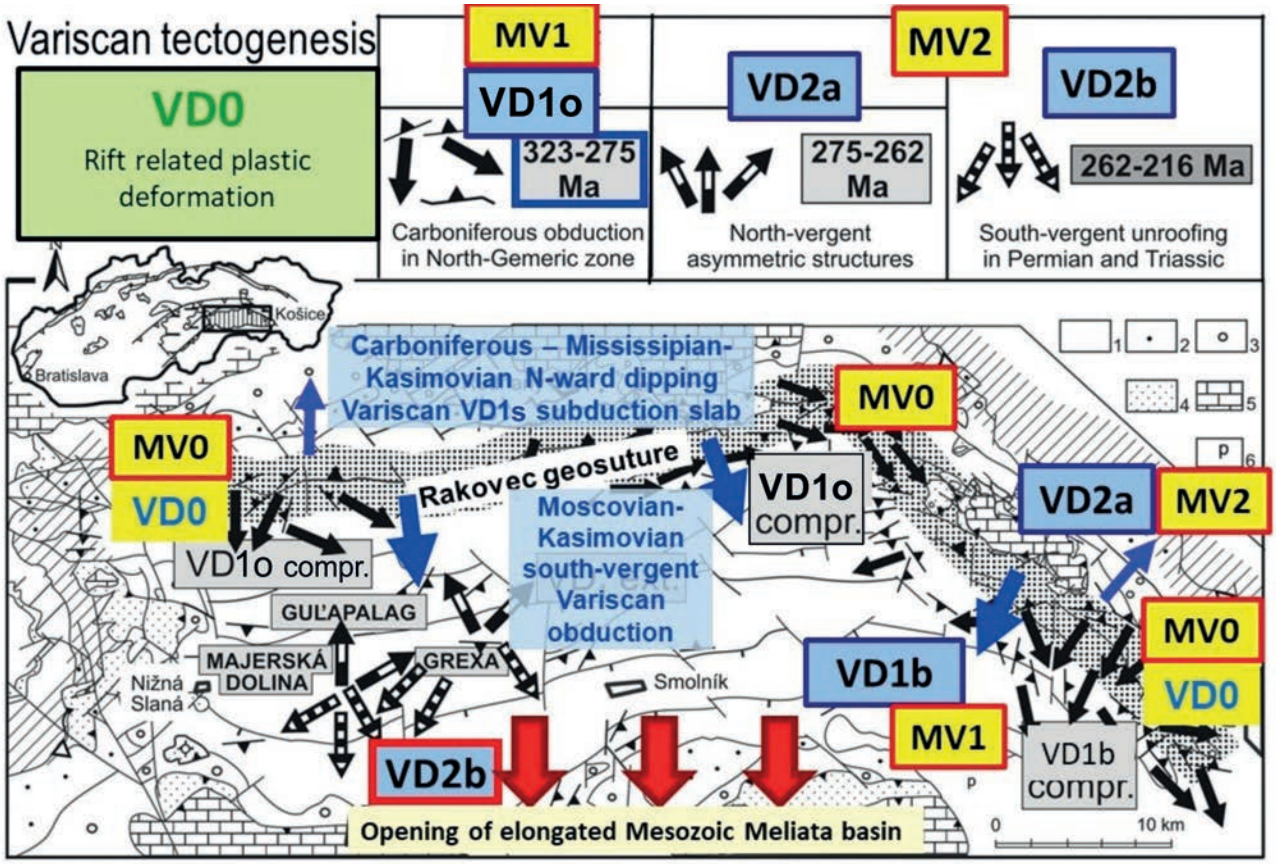


Fig. 7. Summary of field structural and microtectonic evidences of Variscan evolution in the Gemeric region of Internal Western Carpathians. Arrows indicate situation after Variscan VD1c collision with obducted sequences situated along Rakovec geosuture (suture zone) and before Paleo-Alpine ApD0 continental breakup and opening of new elongated Mesozoic Paleo-Alpine Meliata basin (Neo-Tethys; thick red arrows in the lower part of the figure indicating south vergent VD2b unroofing – indicated also in the summary Variscan geodynamic review in upper bar in Fig. 7). Red thick arrows targeted to south in lower part of Fig. 7 indicated start of the Paleo-Alpine Neo-Tethys continental breakup. The Variscan VD1c collision was preceded by VD1o Late Carboniferous south-vergent obduction partially of Rakovec, but mainly Zlatník and Klátov LTUs (terranes) on Gelnica LTU (cf. in Fig. 4). In localities of Guľapalag, Majerská dolina and Grexa, depicted in lower right side of the Fig. 7, the switch of Late Variscan unroofing from north-vergent (VD2a) to south-vergent (VD2b) was discovered by microtectonic studies (Németh in Radvanec et al., 2007). The sequence of Variscan kinematics and metamorphic overprints during Variscan obduction and later post-collisional unroofing is shown in bar in upper side of this figure. Explanation of lithology (rectangles in the right side middle): 1 – Lower Paleozoic sequences of Gemeric Unit, 2 – Carboniferous rocks of Gemeric Unit and its contact zone with Veporic Unit, 3 – Permian rocks of Gemeric Unit, 4 – Upper Paleozoic and Mesozoic rocks of Meliatic Unit, 5 – Mesozoic rocks of Silicic Unit, 6 – Paleogene cover.

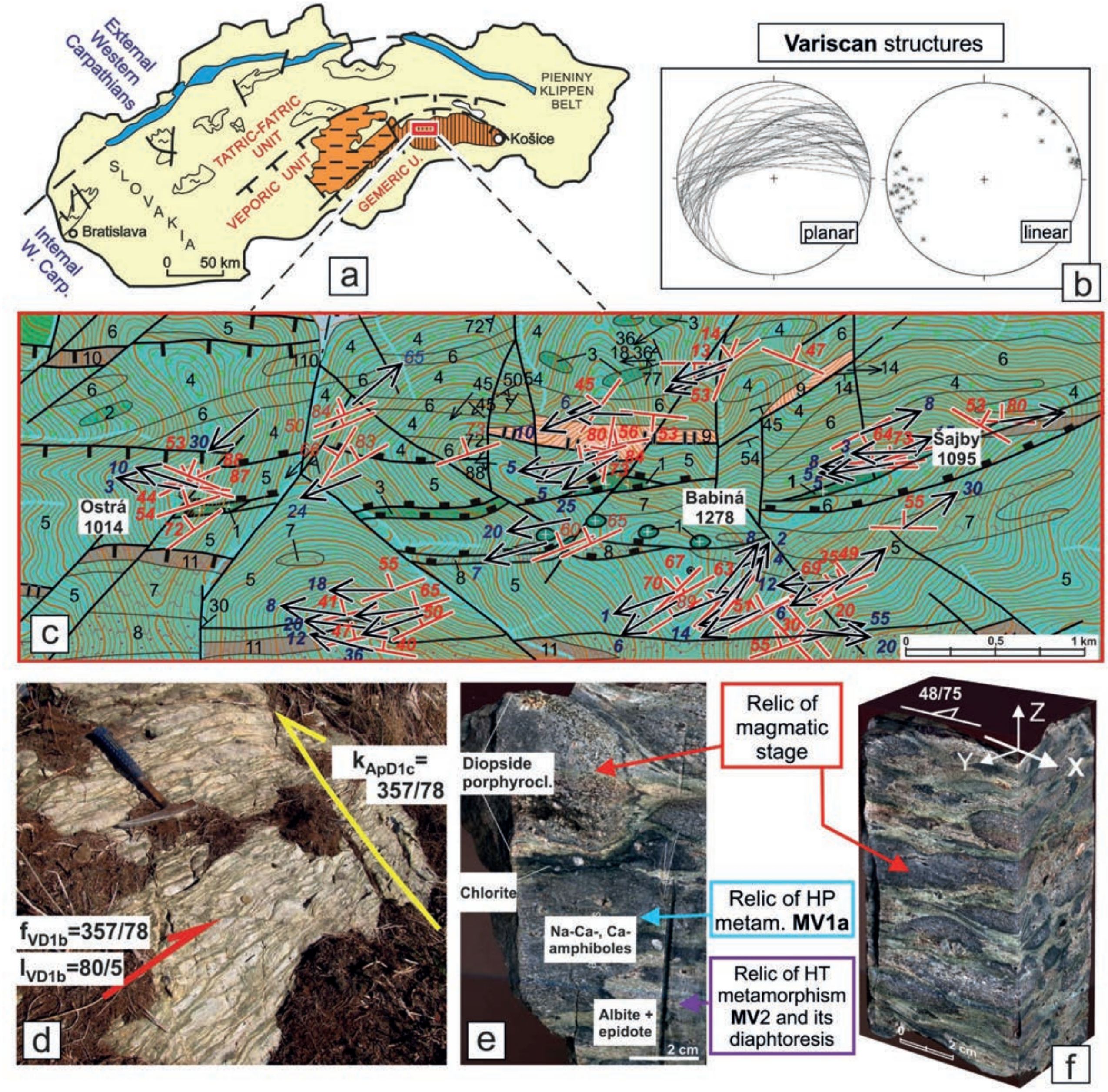
Fig. 8. Variscan VD1o exhumation and obduction of HP-UHP rocks (Radvanec & Németh, 2018; reproduced with permission), being finished by Variscan collision VD1c with origin of Rakovec suture zone. **a** – Position of described segment of Rakovec geosuture (red rectangle) within Gemeric Unit and the W. Carpathians, **b** – Projection of Variscan planar and linear mesoscopic structures into the lower hemisphere of the tectonograms (Schmidt projection). **c** – Detail map with the occurrences of exhumed Cpx/SrEp metagabbro blocks (l.c.; item No. **1**) in the zone of Ostrá – Babiná – Šajby localities. Geological map by Grecula et al. (2009) was slightly modified and supplemented with new structural data. Lithology (cf. with Fig. 4): **Early Paleozoic of the Gemeric Unit** (Ordovician to Devonian) – **Hnilec Fm: 1** – **Cpx/SrEp metagabbro**; 2 – coarse-grained basalt (dolerite); 3 – basalt locally with thin intercalations of ultrabasic rocks, basalt metapyroclastics, green and violet phyllites; 4 – basalt metapyroclastics, locally with intercalations of green and violet phyllites, greenish and pinkish silicites and carbonates; 5 – basalt metapyroclastics, locally with fine-grained amphibolites, intercalations of keratophyre metapyroclastics and phyllites. **Smolník Fm.:** 6 – dark-green, green and yellow-green chl.-ser. phyllites with intercalations of violet hematite phyllites and basic, locally keratophyre metapyroclastics; 7 – crystalline to porphyroblastic violet-green chl.-ser. phyllites; 8 – crystalline to eyed green chl.-ms. phyllites, locally violet with intercalations of silicites, basalt and keratophyre rocks locally recrystallized in amphibolite facies; 9 – metamorphosed variegated volcanic complex. **Betliar Fm.:** 10 – black and grey gr.-ser. phyllites (alternation of light and dark lamina and bodies) with intercalations of metapsammites; 11 – alternation of coarse-laminated recrystallized to eyed grey to black gr.-bt. metapelites and metapsammites. **d** – The exhumed metagabbro mylonite in the Šajby locality situated in VD1 Rakovec suture zone manifests a pervasive Variscan ductile mylonitic foliation. As manifested also by tectonograms (**b**), the combination of WSW-ENE and ESE-WNW trending lineations and secondary foliation planes generally dipping to NWN-N, locally also to NNE, indicates the transpression kinematics in this phase of exhumation. The outcrop is penetrated by Alpine cleavage directed to NNW. **e-f** – hand-samples of exhumed metagabbro mylonite, showing recrystallization fabric from the magmatic phase and overprints by succession of tectonometamorphic events **MV1a** and **MV2** (more details are available in Radvanec & Németh, 2018).

the overlying Lower Devonian **Smolník Fm.** of Lower Variegated Volcanic Complex, green phyllites and flysch psammitic-pelitic sediments, as well as the uppermost Middle-Upper Devonian **Hnilec Fm.**, built dominantly of acid volcanic products. More distantly developed sequence of **Rakovec LTU** (Grecula & Kobulský – eds., 2011) have characteristic dominance of basic volcanic products in the Hnilec Fm. These facial changes place the Rakovec LTU to zone to evolving oceanic-type crust. In recent polyorogenic setting and erosional cut the Rakovec LTU consists of lithology of Variscan passive margin situated more distantly than marginal sequences of Gelnica LTU. On Rakovec LTU there were south-vergently obducted the sequences with remnants of Variscan oceanic crust (parts of Zlatník Group sensu Ivan, 1996; Ivan & Méres, 2012), but also blocks of ultra-high-pressure rocks – Cpx/SrEp metagabbro – being exhumed from the lower crust (cf. Radvanec, 1999; Radvanec & Németh, 2018; cf. Figs. 7 and 8). The magmatic activity along the Variscan VD0 mid-oceanic ridge is documented by the sequences of **Klátov LTU** (dominantly mafic and ultramafic rocks; cf. Figs. 5 and 6), together with Rakovec LTU marking **Variscan Upper Paleozoic continental breakup of Pangea** and mature stage of Variscan Paleo-Tethys oceanic-type crust (the metaophiolite suite of the Klátov gneiss-amphibolite complex, Cpx metagabbro, plagiogranite, as well as ultramafic rocks) and its multiple metamorphic overprint (MV0, MV1, MV2; Radvanec et al., 2017). The Klátov gneiss-amphibolite complex was earlier defined as Klátov Group (Spišiak et al., 1985), as well as the Klátov nappe consisting of the oceanic-type crust lithology (Hovorka et al., 1984; Hovorka, ed., 1985).

The polyorogenic evolution of the W. Carpathians and opposite dips of Variscan VD1s vs. Paleo-Alpine ApD1s subduction slabs and related exhumation vergencies – Variscan (south-vergent), but Paleo-Alpine (north-vergent) caused exhumation of two generations of ultramafic rocks – Variscan vs. Paleo-Alpine in age (Fig. 6). Besides exhumed Variscan VD1oc ultramafics (green rectangles in Fig. 6; generally south-vergent transport) also the presence of the younger – ApD1oc generation of ultramafic rocks was revealed, being exhumed from the Neo-Alpine Meliata zone (with generally north-vergent transport; blue rectangles;) and displaced over the territory of Gemeric Unit from the South-Gemeric Zone to the North-Gemeric Zone (Dobšiná and Jaklovce areas), and even more to the north of it to Danková and Sedlice areas on neighbouring Veporic Unit (the red rectangles in Fig. 7 contain an information by Radvanec, 2000, 2005).

VD1 convergent phase – origin of Rakovec suture zone

The Rakovec suture zone after Variscan elongated basin of Paleo-Tethys (Németh, 2002) is a product of Variscan convergence and south-vergent VD1c collision (earlier subduction slab with northern polarity; Fig. 8). Nowadays a large amount of data is available about Variscan ophiolite suite (Radvanec et al., 2017), as well as subduction and exhumation / obduction kinematics (Fig. 8; Németh, 2002 – Fig. 1 ibid.; Németh et al., 2012; Németh in Radvanec et al., 2007 – Fig. 28 ibid.; Radvanec & Németh, 2018). The exhumed sequences of Klátov, Zlatník and partly Rakovec LTUs were obducted south-vergent on former passive margin sequences of transitional Rakovec and Gelnica LTUs (cf. Figs. 4, 6 and 8; Németh, 2005a).



VD2 Variscan metamorphic core complex formation and related unroofing, initiating new continental breakup = new orogenic cycle

After the VD1c collisional closure of Variscan Rakovec Paleo-Tethyan basin, the rock sequences during the **Late Variscan post-collisional evolution VD2** were heated (Fig. 9) by the same linear subequatorial-course mantle convection current (ECMCC) as that causing the Variscan VD0 riftogenesis (cf. Fig. 10). This interpretation is based not only on assumption that there was no reason for the termination of heat production in ECMCC when the VD0 spreading zone was closed by collision. **The main proof of this concept of continual action of ECMCC is represented by numerous petrological evidences of VD2 amphibolite facies Permian overprints of already exhumed and obducted VD1o HP-UHP rock sequences and even the VD1c collided orogenic belt**. Important argument is also Permian, or even Triassic A-type magmatism / volcanism in zones parallel to orogenic belt (and besides of any remnant of former subduction slab), i.e. parallel with the ECMCC. Heating of rock sequences in formed orogenic belt over this still existing hot line caused also magmatic corrosion of the root of orogenic belt, heat induced uplift along the axis of orogenic belt, metallogenesis (forming of ore veins in orogen parallel brittle fractures in the uppermost crust levels due to fluid influx), as well as unroofing to both sides of orogenic belt. The Permian metamorphism up to amphibolite facies and anatexis is commonly reported from the Gelnica Unit (earlier representing the Lower Paleozoic passive margin sequences; cf. Radvanec, 2007, 2009), as well as from the lithologies of exhumed Variscan ophiolite suite, incl. metagabbro, in Permian being already obducted and positioned on lithology of Gelnica Unit (Radvanec et al., 2017; Radvanec & Németh, 2018).

Our geodynamic considerations about Permian post-collisional evolution VD2 are based on generally accepted interpretation of Pangea, in Permian forming uniform supercontinent without active subduction processes. **This important moment in Earth's history – joining the whole continental crust into one – Pangea supercontinent – still encompasses one principal fact, may-be neglected in present geodynamic interpretations: The mantle convection in ring of subequatorial-course mantle bulge (ECMB) and related subequatorial-course mantle convection currents (ECMCCs), related to Earth's rotation had no reason to change their thermal-kinematic parameters at least during the Neo-Proterozoic-Phanerozoic time span.** So, all divergent / convergent processes in subequatorial trending polyorogenic zones are related to them. **This is the reason of their thermal contribution to Variscan (an earlier) orogenic processes in divergent phases (XD0), but also contributing with heat after subduction of the mid-oceanic ridge, and especially at the time after the collision (cf. Fig. 10). Using other expression – lithospheric plates were drifing on the Earth (some of them carrying continents), but the ECMB and ECMCCs remained in their same subequatorial circular position.** The polyorogenic processes driven with ECMB and related ECMCCs differ

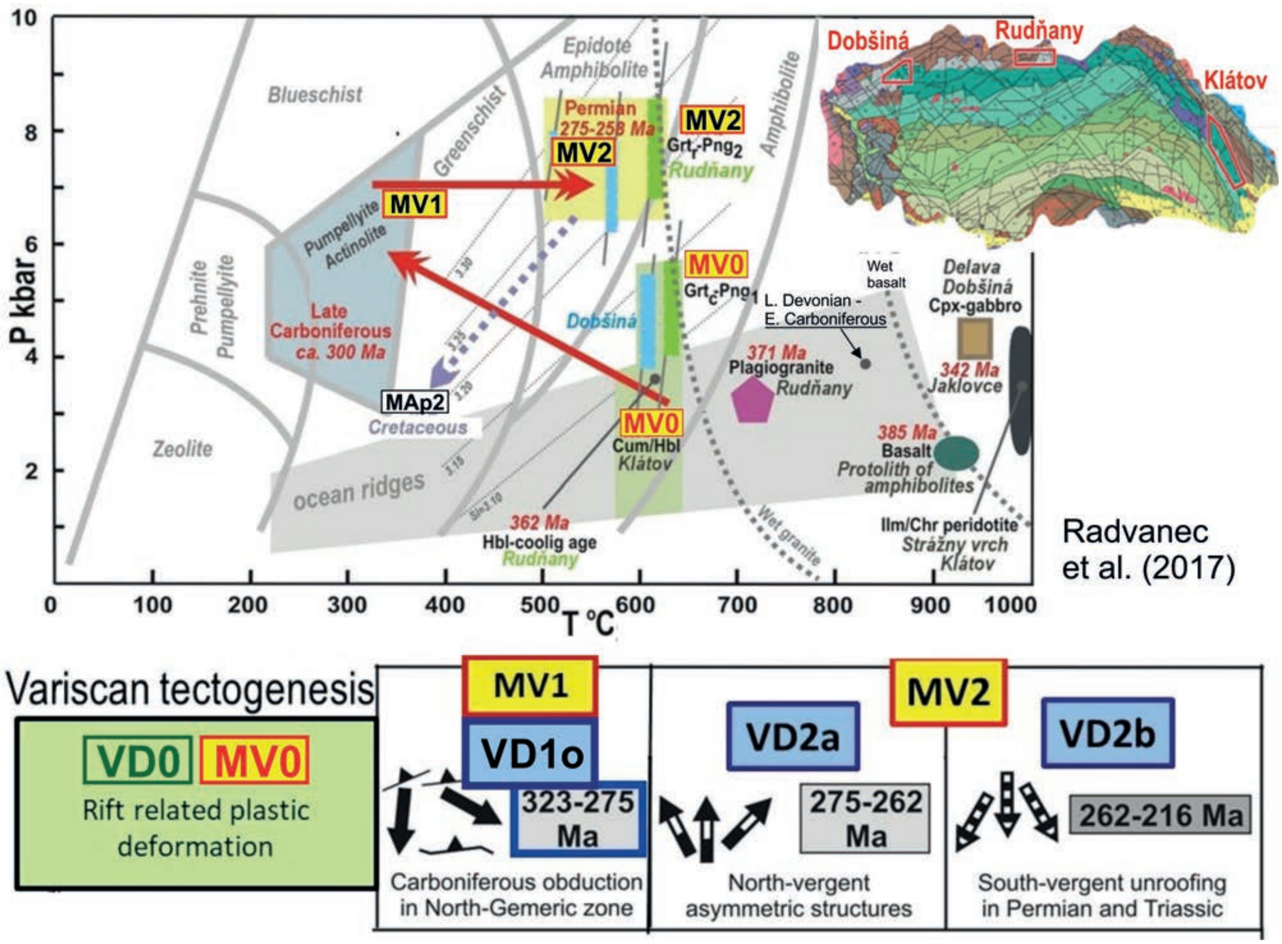


Fig. 9. Petrological proofs of the increase of MV2 temperature in Permian, postdating the MV1 Late Carboniferous metamorphic recrystallizatin at the beginning of Variscan exhumation of ophiolite suite sequences in Gemeric Unit (Radvanec et al., 2017; slightly modified, reproduced with permission). The map in right up side up of the figure shows localities of ophiolite suite along Rakovec suture zone in Gemeric Unit, where such metamorphic overprints of rocks were revealed. Bar in the lower part of the figure shows relations of individual metamorphic overprints (MVX) to orogenic phases (VDX).

from perpendicular meridian trending rifting and subduction processes driven by linear submeridian-course mantle convection currents (MCMCCs), being genetically more closely related to “classical” columnar mantle plumes with genesis interpreted by Dewey and Burke (1974) on example of N-S located series of rift-rift-rift (r-r-r) junctions in continental crust.

Magmatic evidences of VD1s and VD2 processes in the Western Carpathians

Until the moment of submerging of axis of the diverging zone (mid-oceanic ridge) under active margin of northern continent, the Upper Devonian-Lower Carboniferous I-type subduction-related granites in north-located Paleo-Tatric and Paleo-Veporic units were abundant. The additional convectional mantle heat caused switch of magmatism from I to I/S, or exclusively to S type magmatism. These later S-type granitoids differ from the I-type Veporic granitoids by increased contents of K, Rb, B, Y, U, Be, Sn, W, (F) and reduced contents of Sr, Ca and Ba and high Rb/Sr ratio. They can be distinguished also by high-iron biotite and mixed A-S-type zircon population. Most their attributes, including tourmalinization, are reminiscent of the granitoids known in the Permian post-collisional Paleo-Gemeric Unit (cf. Hraško et al., 1997). Due to the Permian orogen parallel convectional heat input the rocks underwent the thermal overprint leading to anatexis and origin of specialized S-type Gemeric granites. They belong to alkaline type with high SiO_2 content (73–78 wt. %) and distinctly peraluminous character – Shand’s index A/CNK = 1.2–1.6, having low concentration of Sr, Ba, Zr and V (Tauson et al., 1977; Petrík & Kohút, 1997; Broska & Uher, 2001). High initial ratio is I_{Sr} = 0.711 9–0.714 4 (Kovách et al., 1979, 1986). The negative value $e_{Nd}(I)$ = –4.6 and increased values $d^{18}O_{(SMOV)}$ = 10 ‰ and $d^{34}S_{(CDT)}$ = 4.48 ‰ indicate that granites originated by remelting of continental crust sources (Cambel et al., 1989; Kohút et al., 1999, 2001; Kohút & Recio, 2002).

According to Kohút (2012), the granite apophyses in innermost territory of Internal W. Carpathians are derived from a huge underlying post-orogenic granite body 50 km long and 15 km wide, revealed by geophysics. This granite was generated by melting of crustal rocks of reworked Pan-African basement remnants which experienced earlier seafloor (VD0) weathering and were permeated by volcanic (boron) emanations, as well as finally modified by ore bearing fluids (l.c.). The emplacement of volatile-enriched magmas into upper crustal conditions was followed by deeper rooted porphyric magma portion, undergoing second boiling and re-melting to form the porphyric granite or granite-porphyry during its ascent (Broska & Kubiš, 2018). Variscan orogenic prograde metamorphism (MV2) was produced by high geothermal gradient, reaching 40–60 °C, being accompanied with the main post-collisional extensional tectonic events in orogenic belt (Radvanec et al., 2007). The Upper Permian–Lower Triassic (260–240 Ma), or even Middle and rarely Upper Triassic (225–205 Ma) monazite-uraninite isochrones in granites of southern zones of Internal Western Carpathians (IWC) orogenic belt (Radvanec et al., 2007, 2009) were not revealed in the northern zone of this orogenic belt. This fact confirms northward shift of lithosphere over the subequatorially directed linear source of convectional heat (hot line; ECMCC). The new Paleo-Alpine orogenic cycle – **ApD0 continental breakup** starts in Triassic and is exclusively localized in the southern zone of IWC. The northern zone of IWC reflects these processes by disjunctive tectonics.

According interpretation presented in our contribution, the northward shift of lithosphere over the axis of convectional heat (hot line) was documented also by geochronological data, demonstrating older ages of Variscan geodynamic processes in the northern zones of Internal W. Carpathians (IWC; Tatric Unit, Veporic Unit) – including the tectogenesis of the Rheic Ocean – then in southern zones of IWC (Gemeric Unit). The classical work by Finger et al. (2002) provides following general scheme of Variscan tectonometamorphic events: Collision in **IWC northern zones** within 370–360 Ma (probable related to closure of parallel Rheic Ocean) caused crustal thickening and orogenic (regional) metamorphism. Then at 360–340 Ma the decompression crustal melting acted, producing mainly S-types granites and at 340–310 Ma the post-collisional I-type plutons were generated. This scheme is supported also by geochronological results of other authors – Kohút et al. (2009), Radvanec et al. (2009) and Vozárová et al. (2020, 2021). The process of origin of post-collisional (Rheic collision) I-type plutons can be explained with contribution of heat produced by still acting Paleo-Tethys subduction (its subduction slab was dipping just beneath that collisional zone). In the **IWC southern zones** (Gemeric Unit) the collision terminated later – inbetween Kasimovian and Gzhelian of Pennsylvanian (uppermost Carboniferous; 303 Ma).

The Mid-Permian ages of S and A-type plutons were uniformly proved by numerous researches (Finger et al., 2002; Villasenor et al., 2021; Vozárová et al., 2012, 2016). In the Infratric Inovec nappe in Považský Inovec Mts the 267–262 Ma rhyolite intercalations occur in Permian siliciclastics, as well as rhyodacite dyke in micaschists (Putiš et al., 2016). The rhyodacite dyke suggests the within plate acid volcanism, typical for the Pangea breakdown and rift-related volcanism (l.c.).

As documented by results of several generations of Western Carpathian geologists, from the uppermost

Carboniferous (Gzhelian) throughout Permian and Triassic on both sides of Paleo-Gemeric collisional belt the VD2 extension started to produce orogen parallel sedimentary basins (Fig. 10; VD2 and ApD0 phases). For the sake of more precise expression the north-vergent unroofing we mark as **VD2a** and the south-vergent one as **VD2b** (Fig. 7). The north-vergent unroofing VD2a ended in Triassic, and dominant for the further evolution of the W. Carpathians

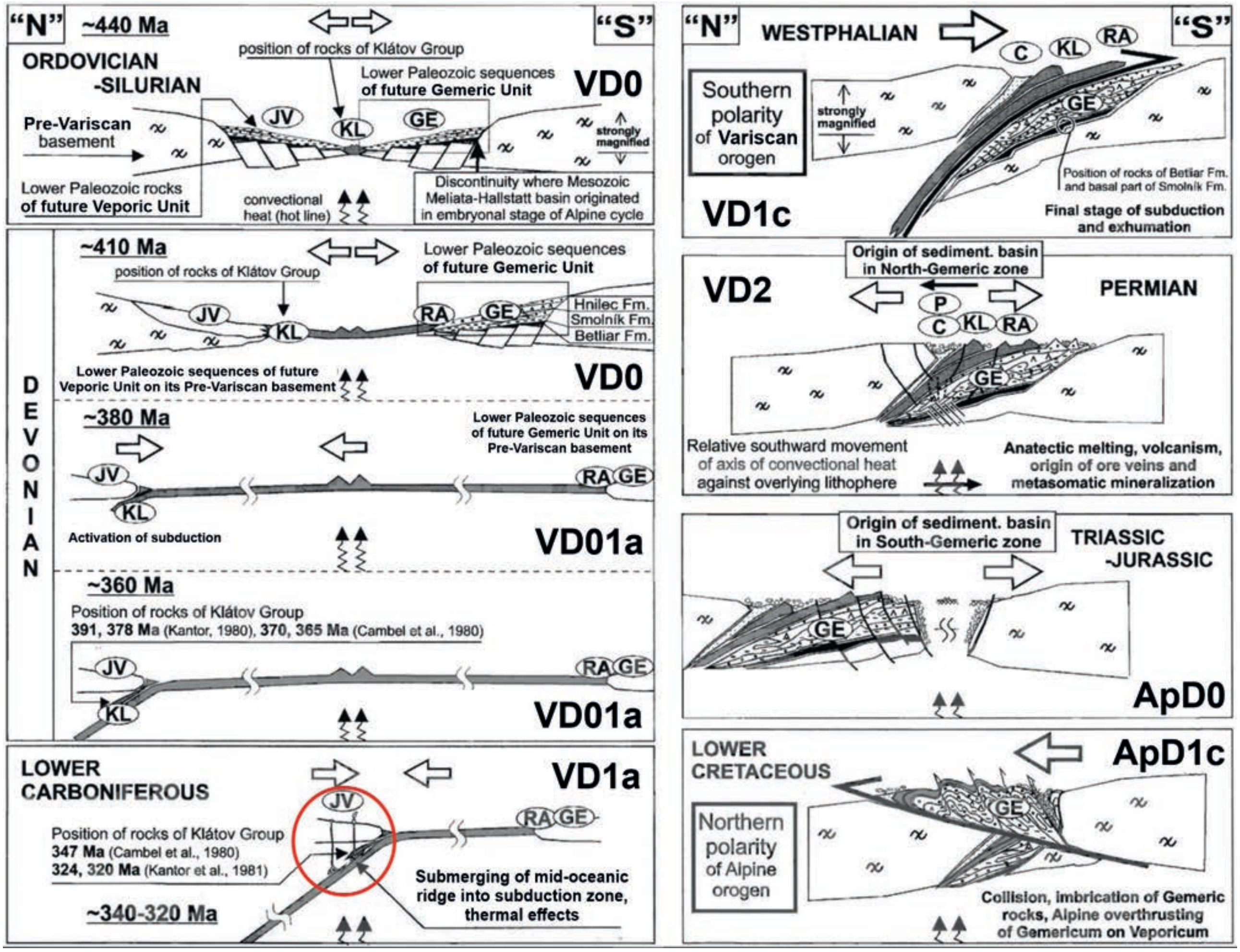


Fig. 10. Pilot concept of the role of hot lines (ECMB and ECMCCs) in polyorogenic evolution (Németh, 2005; slightly updated; reproduced with permission). Differing from traditional plate tectonic interpretations – in this model both – the Variscan spreading zone (VD0 mid-oceanic ridge), as well as the source of convectional heat (hot line) after progress of subduction (subducting ca half of the basin width = segment between the trench and the rift – will appear over the hot line (marked by red circle in the left down side of figure for lower Carboniferous evolution). The convection heat in position beneath the continental arc contributes to processes of magmatism / volcanism, including the mineral deposits formation. After subducting of the whole oceanic-type crust this convection heat contributes to metamorphic and granitization processes in collisional (orogenic) VD1c belt (including the unroofing to one or both sides of orogenic belt and opening of orogen parallel brittle fractures for fluid ingress and origin of vein mineralization; for details see Fig. 11). **Shift of lithosphere over this linear heat source (hot line; black horizontal thin arrows in VD2 part of the figure) causes the shift of lithosphere and developing of a new divergence zone away from the axial zone of former orogenic belt** (in this particular case it is the start of a new – post-Variscan Paleo-Alpine orogenic cycle; ApD0). Visualization in the left shows Variscan divergent and convergent evolution finishing with Variscan collision in Upper Carboniferous (Kasimovian; VD1c; upper right segment of the figure). Northward shift of lithosphere over this hot line caused new divergence and Paleo-Alpine ApD0 opening of Triassic-Jurassic basin of Neo-Tethys (Meliata) Basin. Lower Cretaceous ApD1c closure of this basin (right down segment of the figure) produced in the Western Carpathians a new metamorphic core complex (MAp2). Explanation of abbreviations (for further details see also lithotectonic column in Fig. 4): **JV** – South Veporic Unit, representing north Ordovician / Silurian passive margin of Paleo-Tethys and in Devonian / Carboniferous the active margin of Laurasian lithospheric plate; Gemeric Unit: **GE** – Gelnica lithotectonic unit (LTU) of Variscan passive margin, **RA** – Rakovec LTU represents generating Variscan oceanic-type crust, **KL** – *Klátov LTU – lithology of Variscan mid-oceanic rift zone;* **C** – Carboniferous syntectonic sequences, **P** – post-collisional cover sequences of Uppermost Carboniferous (Stephanian) and dominating Permian age (cf. positions of these lithologies in Fig. 4).

became the south-vergent extension and unroofing VD2b, leading in Jurassic to opening of elongated Neo-Tethys Meliata oceanic basin. (If not stated explicitly – in this article the designation VD2 indicates the south-vergent unroofing, which is principal in further evolution).

Revealing that north of the axis of orogenic belt the unroofing evolution stopped in Triassic, but south of the belt it continued to Jurassic (Fig. 11), leading to opening of Meliata Neo-Tethys basin, we interpret the northern shift of orogenic belt with respect to hot line (ECMCC heat). The translation / drift of lithospheric plates is common phenomenon (interpreted already from the Wegener's and Holmes' time; the 1920s). The opposite alternative – change of position of mantle bulge of subequatorial course to south in relation to fixed lithosphere – was not proved yet by geo-sciences and it has no meaning concerning the Phanerozoic Earth's geodynamics. Other reason of the opening the elongated Meliata Neo-Tethys basin does not exist, because the pre-collisional (pre-VD1c) dip of Paleo-Tethys subduction slab was to the north – just to the opposite side with respect to originated Meliata basin, i.e. an interpretation of eventual back-arc position of the Meliata basin with respect to Variscan one can be excluded.

The shift of lithosphere over hot lines resulting to continental breakups we interpret as the peculiarity of polyorogenic processes in zones of subequatorial direction (Figs. 10 and 11).

VD3 Variscan intraplate stress consolidation

Disjunctive structures of this Variscan phase are not unambiguously defined because of younger overprints by tectonic processes of two subsequent orogenic cycles. Their existence is very probable and they could represent weakened zones for preferred establishing of younger (ApD and AnD) disjunctive structures.

VD4 Variscan phase of regional extension

Equatorial and meridian trending faults of VD4 phase acted simultaneously with originating dominant extensional orogen parallel basins north and south of Variscan orogenic belt. The Permo-Triassic pure shear type transcrustal discontinuities can be manifested also

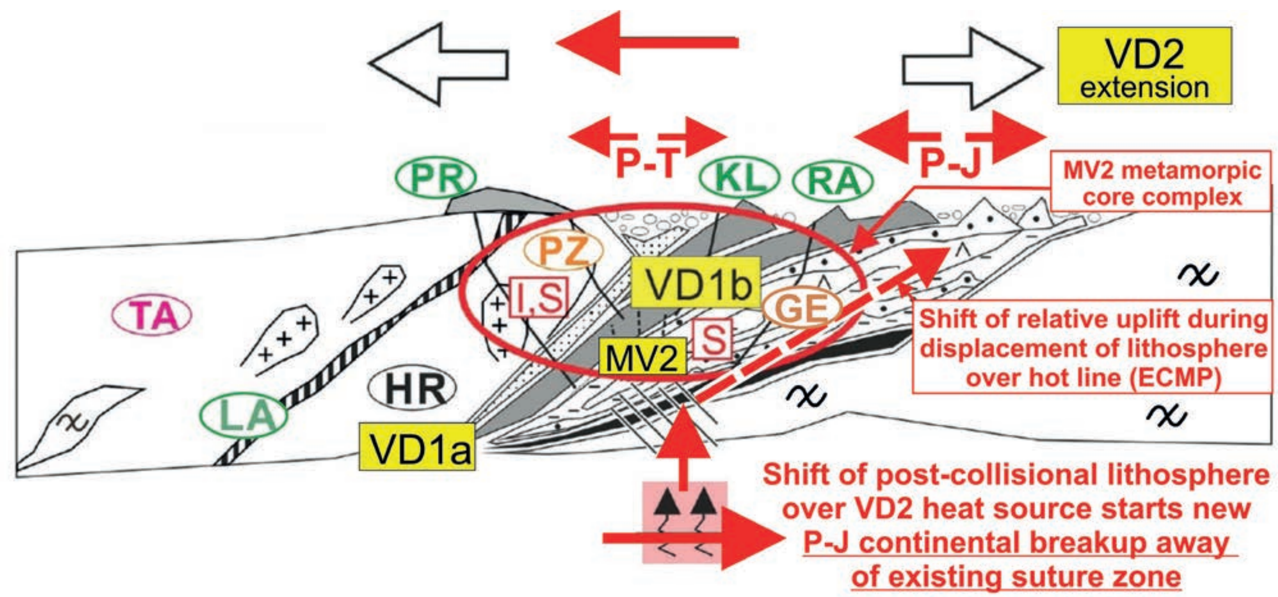


Fig. 11. Variscan post-collisional evolution in inner zone of Internal Western Carpathians leading to **Paleo-Alpine continental break-up and opening of elongated Neo-Tethys Meliata basin** (detail of general VD2 scheme in Fig. 10). In presented interpretation all geodynamic processes in polyorogenic zones are caused by a convection heat of linear course (ECMCC), parallel with the zone of equatorial-course mantle bulge (ECMB). This heat causes the orogen parallel uplift of VD1 collided zone and VD2 unroofing on both sides of bulging belt, resulting in origin of elongated basins on both sides of orogenic belt. In the case of Paleo-Gemeric bulging the evolution in north located basin stopped in Triassic, but the south located basin developed continually to Jurassic. This we interpret as a consequence of the northward shift of post-collisional lithosphere in Permian-Jurassic, being accompanied in Jurassic with ApD0 spreading with production of Neo-Tethys oceanic-type crust. Explanation of used symbols for lithotectonic units (LTUs) is from the left side: TA – Paleo-Tatricum, mainly crystalline basement, LA – Layered amphibolite complex, HR + PZ – Hron and Pezinok LTUs – both represent continental crust north of Rakovec suture zone (which is shown in this figure by dark grey colour slices), PR + KL + RA – Pernek, Klátov and Rakovec LTUs – ocean-type and transitional crust of Variscan Paleo-Tethys Rakovec zone, GE – Gelnica LTU – Paleozoic sequences of Variscan passive margin south of Rakovec zone. Convectional heat caused the MV2 metamorphic overprint of collided rock sequences in suture zone and generating metamorphic core complex. Northward shift of lithosphere over the hot line (ECMCC) caused the change of geochemical character of generating granites – from I-type to specialized anatectic S-type (marked by letters I and S in rectangles). For further details see Németh et al. (2016) and Putiš (1994); cf. Figs. 4, 7, 9 and 10.

by numerous A-type non-orogenic magmatic and volcanic bodies, known in the Western Carpathians and located in orogen-parallel position.

4.2 Geodynamics of Paleo-Alpine (Mesozoic) orogenic cycle in the W. Carpathians

The Paleo-Alpine (ApD) Mesozoic orogenic cycle in the Western Carpathians has attracted attention of geologists already from the time of pioneering works of Dionýz Štúr (1827–1893). Divergent and convergent orogenic phases ApD0 and ApD1 of Paleo-Alpine evolution, as well as post-collisional evolution ApD2 are presently comprehensively documented regarding their causes, kinematics and products. Similar as at Variscan orogenesis, a novel point of our interpretation is a principal role of Paleo-Alpine post-collisional ApD2 evolution for Upper Cretaceous Penninic (Váhic, Magura) continental breakup and a convection heat contribution of the same hot line (ECMCC) as in the Variscan evolution and Paleo-Alpine divergent processes. Moreover, similarly as at Variscan orogenic phase **VD1se** (index "**se**" means subduction exhumation, resp. exhumation during subduction), describing the exhumation peculiarities of rotated rigid blocks (megaporphyroclasts) during subduction VDs, also in Paleo-Alpine we have found relics of **ApD1se** – the syn-subduction exhumation megaporphyroclasts ("exhumation balls") – moving in ductile environment of subduction slab upwards against "the flow" of subducting rocks. The findings in the Western Carpathians can be applicable also in other segments of polyorogenic Alpine-Carpathian-Himalayan belt, and evidently also in other relevant places in the world (cf. Fig. 13G).

For general information about the Paleo-Alpine orogenesis in the Western Carpathians we recommend to reader the summarizing monographs by Grecula, Hovorka and Putiš (eds., 1997), Rakús (ed., 1998), Vozár (and co-eds., 2010) as well as review paper by Hók et al. (2020). The schematic visualization of the sequence of Paleo-Alpine events, following after the Variscan ones and preceding the Váhic-Penninic Neo-Alpine ones is in Németh et al. (2016; Fig. 1 ibid.).

ApD0 divergent phase

As documented in previous text, the asymmetric – dominantly south-vergent VD2b unroofing (VD2 in further text for simplifying the designation) led to opening of Neo-Tethys Meliata basin with formation of oceanic-type crust in Jurassic. During this basin evolution, after thin Lower Triassic detrital sequence and dominant Middle / Upper Triassic carbonatic sequence of marginal *Silicic* and *Turnaic (Tornaic)* units, the sequences of Meliatic Unit represented the basin axial zone and started to be intercalated by basic volcaniclastic material and later there originated the spreading zone with basaltic volcanism. The Paleo-Alpine AD1s subduction and MAp1s HP metamorphic recrystallization changed the basic volcanic / volcaniclastic rocks to glaucophanites. The asymmetric structures demonstrate their north-vergent exhumation (Figs. 12 and 13F) and ApD1o obduction on Gemeric Unit. The remnants of the obduction ApD1o Bôrka nappe outliers, bearing also ApD1se "exhumation balls" occur in the Dobšiná area (Fig. 13C + E) as well as in the Jaklovce area (Fig. 13B + D). The Bôrka nappe consists mainly of high-pressure recrystallized limestones, basic and ultramafic rocks. Within the Internal W. Carpathians, the pre-metamorphic lithology of ApD0 *Silicic*, *Turnaic (Tornaic)* and *Meliatic units* is presently on display dominantly in ApD1o nappe outliers positioned on older units (cf. upper side of Fig. 4). Concerning the ApD0 as well as ApD1 geodynamic evolution, the research of numerous authors was focused mainly on *Meliaticum / Bôrka nappe* sequences, providing the principal information about tectogenesis of Paleo-Alpine orogenic cycle (Kozur & Mock, 1995; Mock et al., 1998; Mello et al., 1998; Németh, 2005b; Ivan et al., 2009; Putiš et al., 2011; Németh et al., 2012).

ApD1 convergent phase – origin of Meliata suture zone

Besides geophysics and volcanic manifestations, the southern dip = southern polarity of the Neo-Tethys Meliata subduction slab was proved also by dominant north-vergent ApD1oc obduction and collision kinematics, building present north-vergent basement / cover nappes setting of the whole Internal Western Carpathians. Minor part of the collision fan was thrust to south, building e.g. the Bükk Mts in the present Hungary.

The Paleo-Alpine ApD1 north-vergent kinematics in the innermost zones of Internal W. Carpathians (Fig. 12; cf. Figs. 4, 6 and 10), encompassing *Gemeric Unit*, southern zone of *Veporic Unit* as well as superficial *Bôrka nappe* (exhumed HP sequences from the Meliata subduction slab), was proved parallel with other authors (extensively referenced above in this subchapter 4.2) also by regional structural as well as microtectonic research applying oriented rock samples (Németh, 2002; Fig. 1 ibid.). Proofs of allochthonous position of the *Meliatic Bôrka nappe* on sequences of the North-Gemeric zone in Jaklovce area (cf. Fig. 12 right side) by Németh (2005b) and Németh et al. (2012a) have excluded the existence of so-called Northern branch of the Meliata Ocean (sensu Kozur & Mock, 1995). Extremely high differential stresses in the frontal part of the Bôrka nappe in the Jaklovce area, revealed by paleopiezometry (Németh et al., 2012a), indicate fast exhumation and north-vergent nappe displacement by the superficial nappe kinematics, which has preserved the state of strong dynamic recrystallization – extreme grain-size reduction in marbles inside the subduction zone, occurring now "fro-

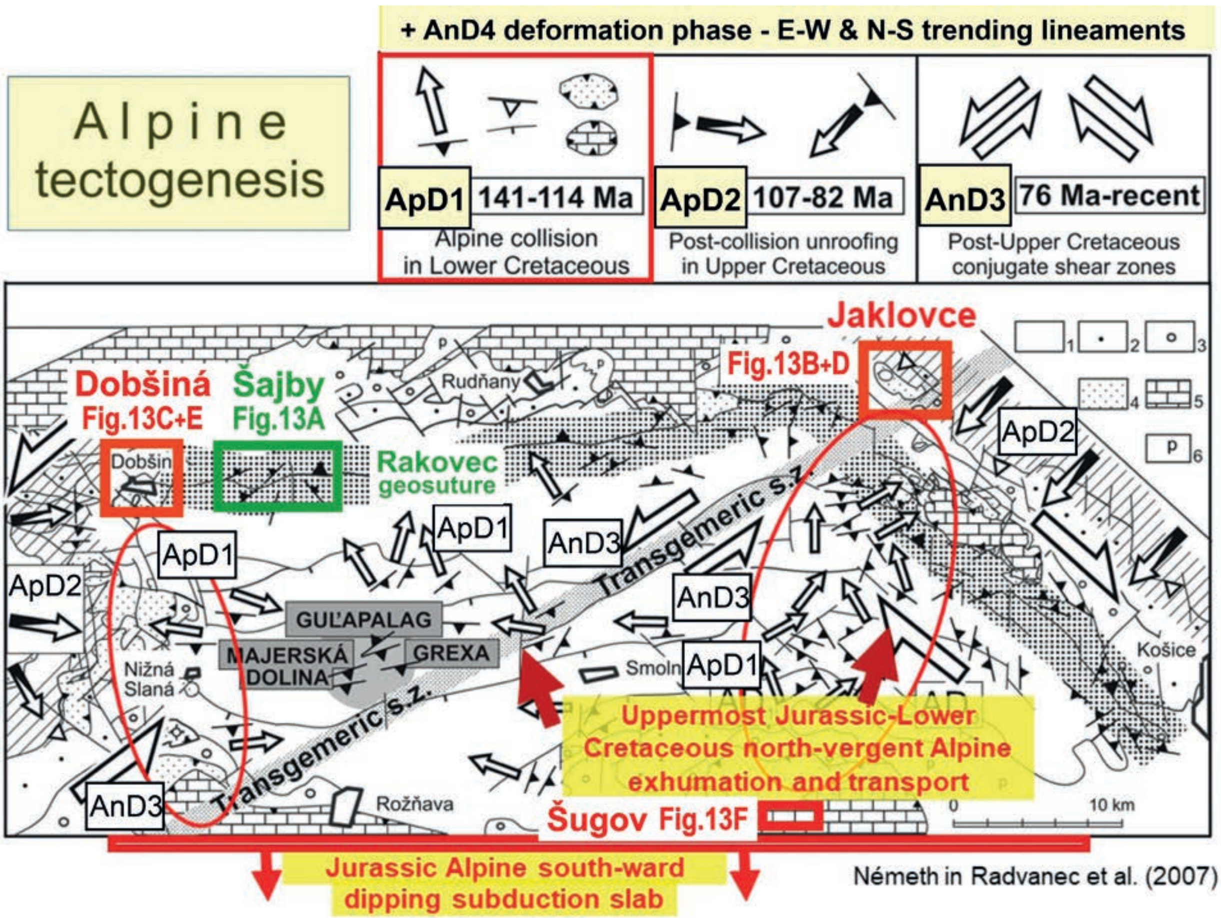


Fig. 12. Review of kinematics of Paleo-Alpine events in inner zone of Internal W. Carpathians: ApD1 – Early Cretaceous north-vergent obduction and collision thrusting – red ellipses mark transport of the Bôrka nappe Neo-Tethys Meliatic HP ophiolite suite sequences from the closing Meliatic basin over the Gemeric Unit to areas of Dobšiná and Jaklovce municipalities in the North-Gemeric zone. Similarly as in Variscan subduction-obduction process VD1so there was revealed a special type of syn-subduction exhumation (VD1se; ApD1se), being manifested by "ball-shaped" individualized megaporphyroclasts of rigid rocks in exhumed rock suite (cf. Fig. 13A–F; position of characteristic localities bearing such exhumation products – in Rakovec geosuture – Šajby – VD1se; as well as Šugov, Dobšiná and Jaklovce – ApD1se – is visualized in schematic map of Fig. 12). Further explanation of this special kind o exhumation is in explanation to Fig. 13 and the text. ApD2 – Late Cretaceous south-vergent post-collisional unroofing of Gemeric Unit from Veporic one. Present apparently opposite unroofing trend to SW in the eastern segment of the Neo-Alpine oroclinal bend (in present geological setting) and to E and SE in western segment of this bend was caused by younger bending due to conjugate system of Neo-Alpine AnD3 shear zones (dextral ones trending NW–SE and sinistral ones trending NE–SW; cf. Fig. 15C). This complicated tectonic setting of Internal W. Carpathians is further segmented by the Neo-Alpine AnD4 E–W and N–S trending pure-shear type regional faults / lineaments (not shown in this figure due to sake of simplification).

zen" in frontal parts of the nappe. This completely differs with the situation in the rear parts of this nappe, where input of convectional heat from the hot line to the rock volume, including that present in subduction slab, caused static recrystallization and growth of new large calcite grains at the expense of older small dynamically recrystallized calcite grains. The process of static recrystallization is a reason of lowered differential stresses revealed by paleopiezometry (l.c.).

The suture zone after Neo-Tethys Meliata basin is located at the southern margin of Gemeric Unit in so-called Rožňava discontinuity zone. In this zone, the extended ultramafic body large of several square kilometers and moderately inclined to south is present and was documented also by boreholes and N–S trending magnetotelluric profile in the eastern part of *Gemeric Unit* (Pavliszyn, 1980, in Grecula et al., 1995). These ultramafic rocks were partly displaced northward over *Gemeric Unit*, forming ApD1o nappe outliers at Dobšiná and Jaklovce localities in the North-Gemeric zone or even besides *Gemeric Unit* in Danková and Sedlice localities (cf. Fig. 6, blue rectangles). The northern vergency of displacement is demonstrated by numerous asymmetric structures at outcrop scale as well as in microscale.

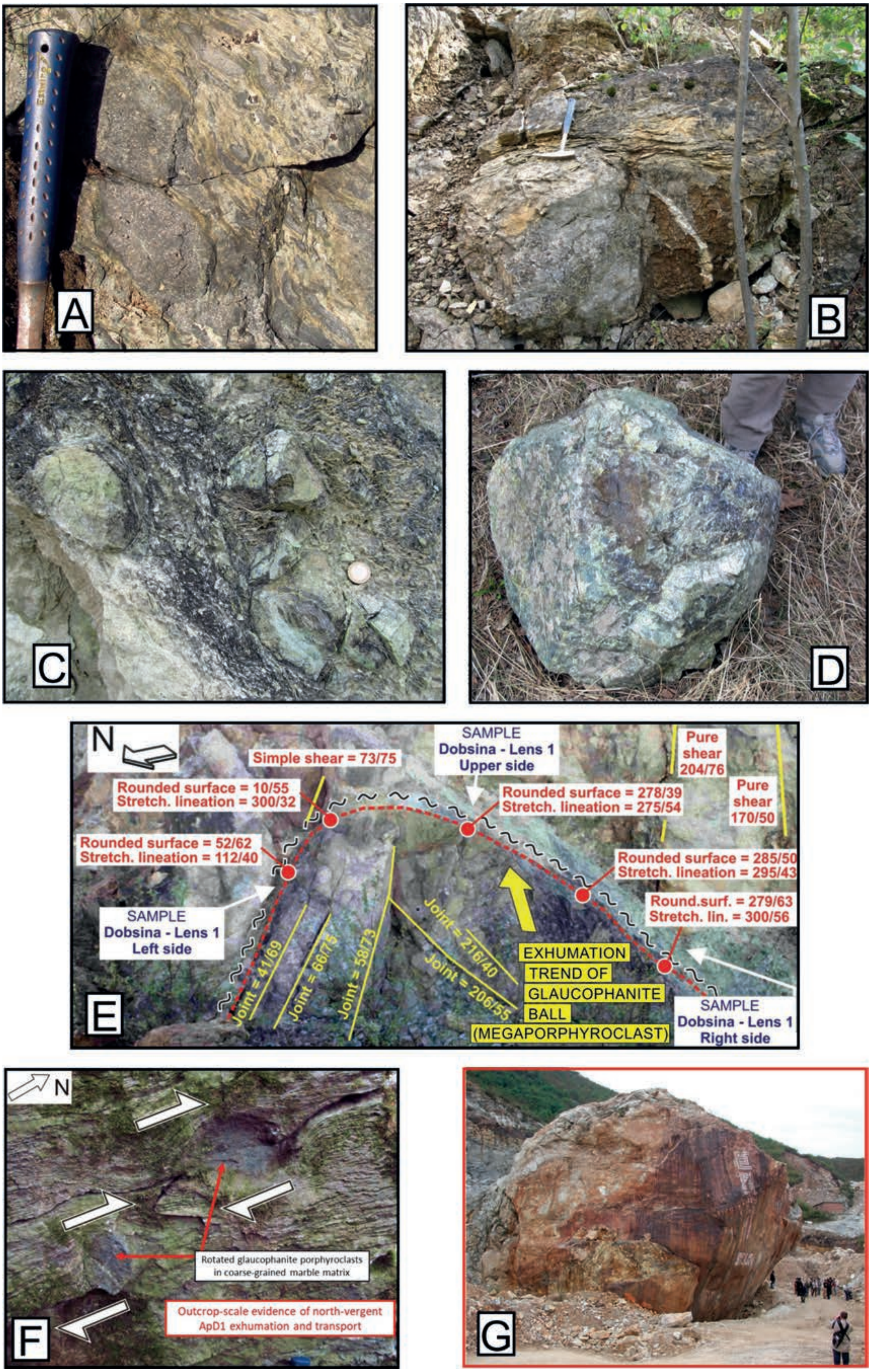

A
B
C
D
N
SAMPLE
Dobsina - Lens 1
Upper side
Pure shear 204/76
Pure shear 170/50
Simple shear = 73/75
Rounded surface = 10/55
Stretch. lineation = 300/32
Rounded surface = 278/39
Stretch. lineation = 275/54
Rounded surface = 52/62
Stretch. lineation = 112/40
Rounded surface = 285/50
Stretch. lineation = 295/43
Round.surf. = 279/63
Stretch. lin. = 300/56
SAMPLE
Dobsina - Lens 1
Left side
Joint = 41/69
Joint = 66/75
Joint = 58/73
Joint = 216/40
Joint = 206/55
EXHUMATION TREND OF GLAUCOPHANITE BALL (MEGAPORPHYROCLAST)
SAMPLE
Dobsina - Lens 1
Right side
E
N
Rotated glaucophanite porphyroclasts in coarse-grained marble matrix
Outcrop-scale evidence of north-vergent ApD1 exhumation and transport
F
G

Fig. 13. Exhumed megaporphyroclasts – products of syn-subduction exhumation. **A** – Variscan VD1se exhumation revealed in the Rakovec suture zone in the Šajby mountain range – the exhumed metagabbro megaporphyroclasts reach dimensions up to 25 cm. **B + D** – The ApD1se marble, chert and peridotite megaporphyroclasts in the Jaklovce locality of Meliatic Bôrka nappe outliers reach meter dimensions; for more information read article by Németh et al. (2012). **C + E** – The ApD1se megaporphyroclasts of Meliatic Bôrka nappe outlier at Dobšiná town (abandoned chrysotile asbestos quarry) represent mainly rounded glaucophanites in serpentinite matrix. Individual glaucophanite porphyroclasts reach here the diameter up to 3 m (Fig. 13E). **F** – Evidences of north-vergent exhumation directly in Paleo-Alpine suture zone in the Šugov valley: Glaucophanite sigma and delta porphyroclasts in pre-metamorphic (pre-MAp1s) state represented the ApD0c basic pyroclastic interbeds in limestones – products of the volcano-sedimentary evolution at the margin of widened Meliata Ocean. During ApD1s subduction the pyroclastic material as well as limestones were recrystallized to glaucophanites and calcitic marbles and during syn-subduction exhumation glaucophanite bed was disintegrated and underwent in ductile environment of calcitic marbles the reverse transport towards the surface in form of individual porphyroclasts of dimensions up to 20 cm. **G** – Presently probably the largest exhumed gigaporphyroclast in the world – jadeite in serpentinite matrix in Xiuyan Jade Mine, Anshan, Liaoning, China. For comparison of its enormous dimensions see standing persons on the right side of exhumed gigaporhyroclast. Authors of pictures: A–F – Zoltán Németh, G – Martin Radvanec.

ApD2 metamorphic overprint in South-Veporic zone and related unroofing tectonics leading to Neo-Alpine continental breakup north of Paleo-Alpine orogenic belt

The Paleo-Alpine Lower Cretaceous ApD1 collision produced dominant north-vergent setting of the Internal Western Carpathians. The strongest post-collisional thermal overprint MAp2 of post-ApD1c thickened continental crust was revealed in the South-Veporic zone, being overthrust by Gemeric basement nappe as well as superficial nappes dominantly of the *Silicic* and *Meliatic units* (the *Bôrka nappe*; cf. Fig. 4). This MAp2 thermal overprint of thickened crust we interpret (similarly as in the case of earlier Variscan MV2 thermal overprint during VD2 phase) as the consequence of mantle convection (hot-line) heat contribution (Németh et al., 2016). Thermobarometric data document in South-Veporic zone increasing PT conditions from ca 500 °C and 7–8 kbar to ca 620 °C, 9–10 kbar, reflecting a coherent metamorphic field gradient from greenschists to middle amphibolite facies (Janák et al., 2001a, b). The $^{40}Ar/^{39}Ar$ data obtained by high spatial resolution in situ ultraviolet (UV) laser ablation of white micas constrain the timing of cooling and exhumation to Late Cretaceous (77 a 73 Ma). Anatectic melt at 650 °C and 9 kbar bound to local unroofing ApD2 normal fault was revealed also by Radvanec (1994). The geochronological data of the Upper Cretaceous Rochovce granite crystallization in the western segment of unroofing zone of Gemeric Unit from Veporic Unit provide 82 ± 1 Ma U-Pb age of zircon population (Hraško et al., 1999). Mineralization related to Rochovce granite provided Re-Os ages of 81.4 ± 0.3 Ma and 81.6 ± 0.3 Ma (Kohút et al., 2013). The Rochovce granite is bearing the northernmost occurring Cretaceous calc-alkaline magmatism mineralization in the Alpine-Balkan-Carpathian-Dinaride metallogenic belt (l.c.). The ApD2 unroofing normal faults locally crosscut the ore bodies of U-Mo deposit Košice I – Kurišková, situated in the eastern Gemeric segment of the Gemeric-Veporic unroofing zone, and by this way they form the pathways for remobilization of the U mineralization to hanging wall of the main ore body (cf. Kohút et al., 2013; Szabó et al., 2014).

The MAp2 thermal overprint in South-Veporic zone and ApD2 unroofing kinematics were revealed as the key factors in Upper Cretaceous MAp2 talc genesis from the former Paleozoic limestones protolith, being in Permian replaced to magnesite (Figs. 14 and 15).

Similarly as in the case of Variscan VD2 evolution, where unroofing from the uplifting orogenic belt was double sided, but principal in following evolution there became the south-vergent unroofing – i.e. to the opposite side of orogenic belt to that side, where the VD1c thrusting took place, also within the Paleo-Alpine evolution, leading to opening of younger generation Váhic – Alpine Tethys and Magura elongated orogen parallel oceanic basins, the same principle took place, though in opposite spatial orientation: The ApD1 processes and collision were located south of VD orogenic belt, with dip of ApD1s subduction zone to south and acting north-vergent ApDoc obduction and collision – but the final Neo-Alpine AnD0 opening of elongated oceanic space was located north of uprising ApD1 orogenic belt. This principle, documented in both (VD and ApD) subsequent orogenic cycles, clearly manifests that the dip of subduction slab is a criterion for the same lithosphere shift direction over the still lasting convection heat of subequatorial-course mantle convection current. At VD1s subduction, the slab was dipping north and later collided VD1c orogenic belt was displaced also to north over the ECMCC, at ApD1 subduction the slab was dipping south and collided ApD1 orogenic belt was displaced also to south over the ECMCC. At the beginning of the plate tectonic concept postulation this phenomenon was defined as the subduction slab pull. Despite – in our concept **the subduction is not a reason of geodynamics, but it is a consequence due to the convection heat mantle flow processes. The importance of a concept of sub-**

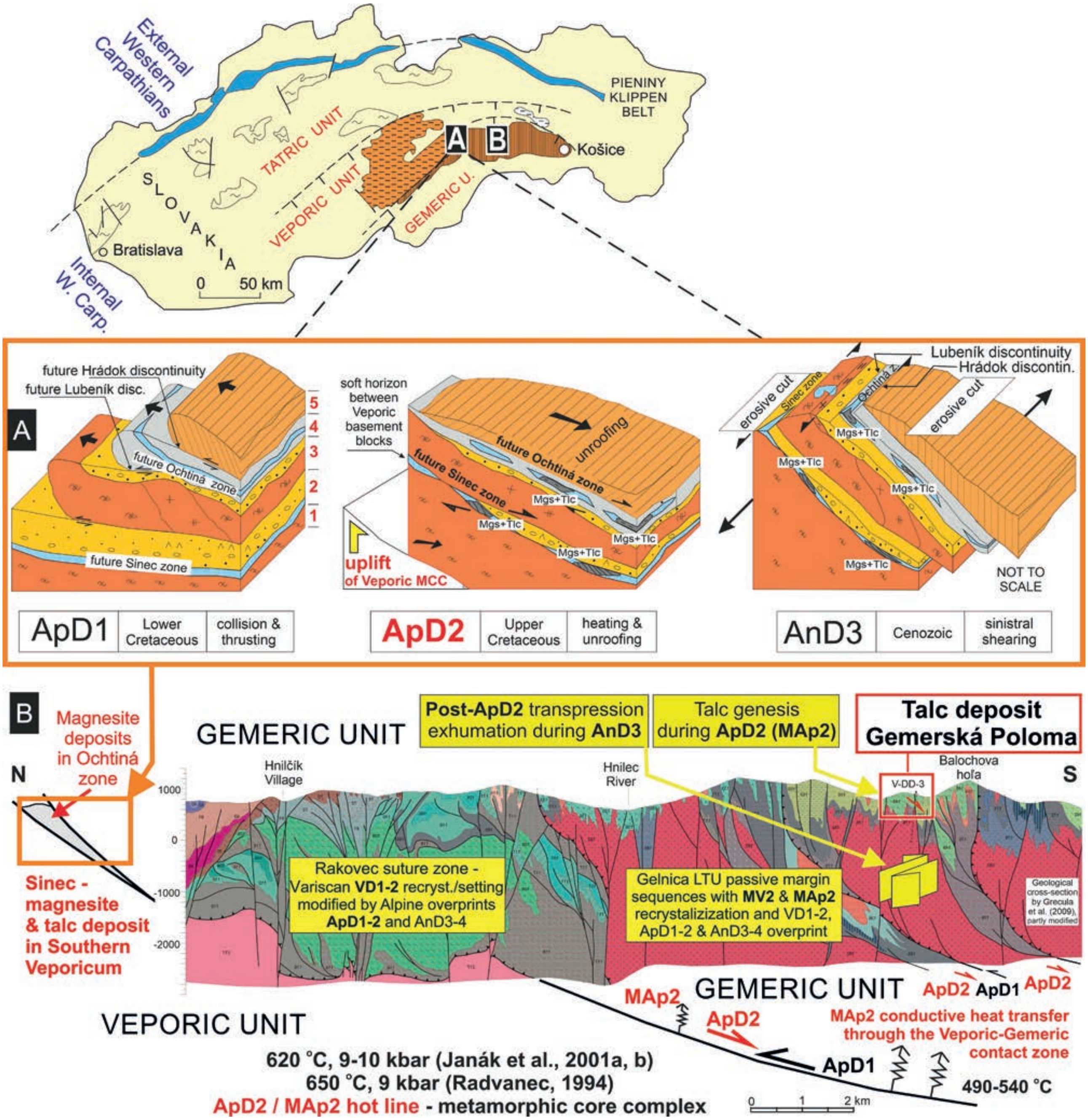


Fig. 14. The south-vergent Upper Cretaceous Paleo-Alpine ApD2 unroofing kinematics is manifested also by talc genesis in the Internal Western Carpathians as a product of MAp2 metamorphism and ingress of fluids to appropriate magnesite protolith: **A** – Situation in the western contact zone of Veporic and Gemeric units (Németh in Radvanec, Németh & Bajtoš – eds., 2010; reproduced with permission): **A** – ApD1 – Imbrication and north-vergent overthrust of the Gemeric basement nappe on Veporic basement and cover sequences during the Lower Cretaceous ApD1 phase caused "sandwiching" of magnesite bodies and accompanying lithologies inbetween crystalline blocks. ApD2 – Talc genesis is a consequence of increased thermic gradient (heat from hot line), ingress of relevant fluids, upwelling the crystalline core of Veporic Unit and post-collisional unroofing of Gemeric sequences from it. AnD3 – Present zonality in occurrence of two magnesite-talc belts along contact zone of Veporic and Gemeric units was produced by Cenozoic AnD3 sinistral shearing. **B** – Similar evolution of talc deposit as in **A** was revealed also in higher level of Alpine setting of Gemeric Unit at the presence of Lower Paleozoic magnesite host rocks, tectonothermal overprint and ingress of fluids. Cross-section of B presents in the left (northern) side the place of evolution of Ochtiná and Sinec zones (shown in A), as well as overthrust of Gemeric Unit on Veporic Unit. Within Gemeric Unit the profile shows Variscan Rakovec suture zone with Alpine overprint, as well as variegated lithology of Gelnica Unit representing former Variscan passive margin (cf. Fig. 5). The MAp2 PT conditions are stated in lower parts of B. Used geological section in B by Grecula et al. (2009) was slightly modified and horizontally overturned.

duction slab pull is further lowered by revealing the mega- and gigaporphyroclasts exhuming just opposite the flow of subducting matter. It means that principal at geodynamics is not a subduction slab pull, but mantle convection currents – in this case forcing also compressional processes in subduction channel and exhuming rigid and heavy blocks from lower crust or even mantle lithosphere by rotation movement in soft ductile environment of subducting rocks in subduction channel (cf. Fig. 13).

In the time of the most vigorous Upper Jurassic convergence within the Neo-Tethys during the Paleo-Alpine cycle, reflected in ApD1s subduction in the Paleo-Alpine southern zone of IWC, the northern zone of IWC registered the synchronous AnD0 divergence – riftogenesis of Penninic – Váhic basin. It seems that this sequence of events, being proved in the Western Carpathians by many ways (cf. Plašienka, 2003), is not fully reflected in paleogeographic maps of the Alpine areas based on van Hinsbergen et al. (2020) reconstruction (cf. Fig. 43 and 44 ibid.).

ApD3 Paleo-Alpine intraplate stress consolidation and AnD4 regional extension

The interpretation of Paleo-Alpine ApD34 evolution in the Western Carpathians faces to difficulties in unambiguous identification due to younger Neo-Alpine overprint of post-AnD12 structures. Due to divergence in AnD0 Váhic and Magura basins, being timely coeval with ApD12 evolution of Meliata basin, **the ApD34 and AnD34 intraplate stress consolidation shearing and faulting represent the same processes**.

Concerning the scale of the whole Carpathian belt (Western, Eastern and Southern Carpathians), the age of Alpine oroclinal bending deserves discussion. Published reconstructions (e.g. van Hinsbergen et al., 2020) show N-S trending Meliata ocean, in Hettangian (200 Ma), dividing the Greater Adria and Dacia continents. Principal in reconstructions of the wider Mediterranean area (l.c.) is the Moesian block, having within the Europe fixed reference frame the same position from Ladinian (240 Ma) up to present. At this architecture also the Neo-Alpine riftogenous zone (AnD1), subduction zone (AnD1s) and related volcanic arc zone should have the same bent course. Kinematics of these processes can be interpreted with difficulties. **Author of this paper prefers an interpretation of general linearity also at Neo-Alpine AnD12 processes (similar like during VD12 and ApD12 processes) and oroclinal bending (syneclisis) of the whole Carpathian zone is interpreted by him as a product of AnD3 evolution with contribution of Hellenic HeD convergent evolution.**

Kinematics of oroclinal AnD3 bending (syneclisis) in inner zones of Internal Carpathians is well documented in the case of contact zone of Gemeric and Veporic units (left side of Fig. 15C). The AnD3 shearing explains well also the apparently antagonistic ApD2 unroofing kinematics in the western and eastern parts of contact zone of these units (Fig. 15C).

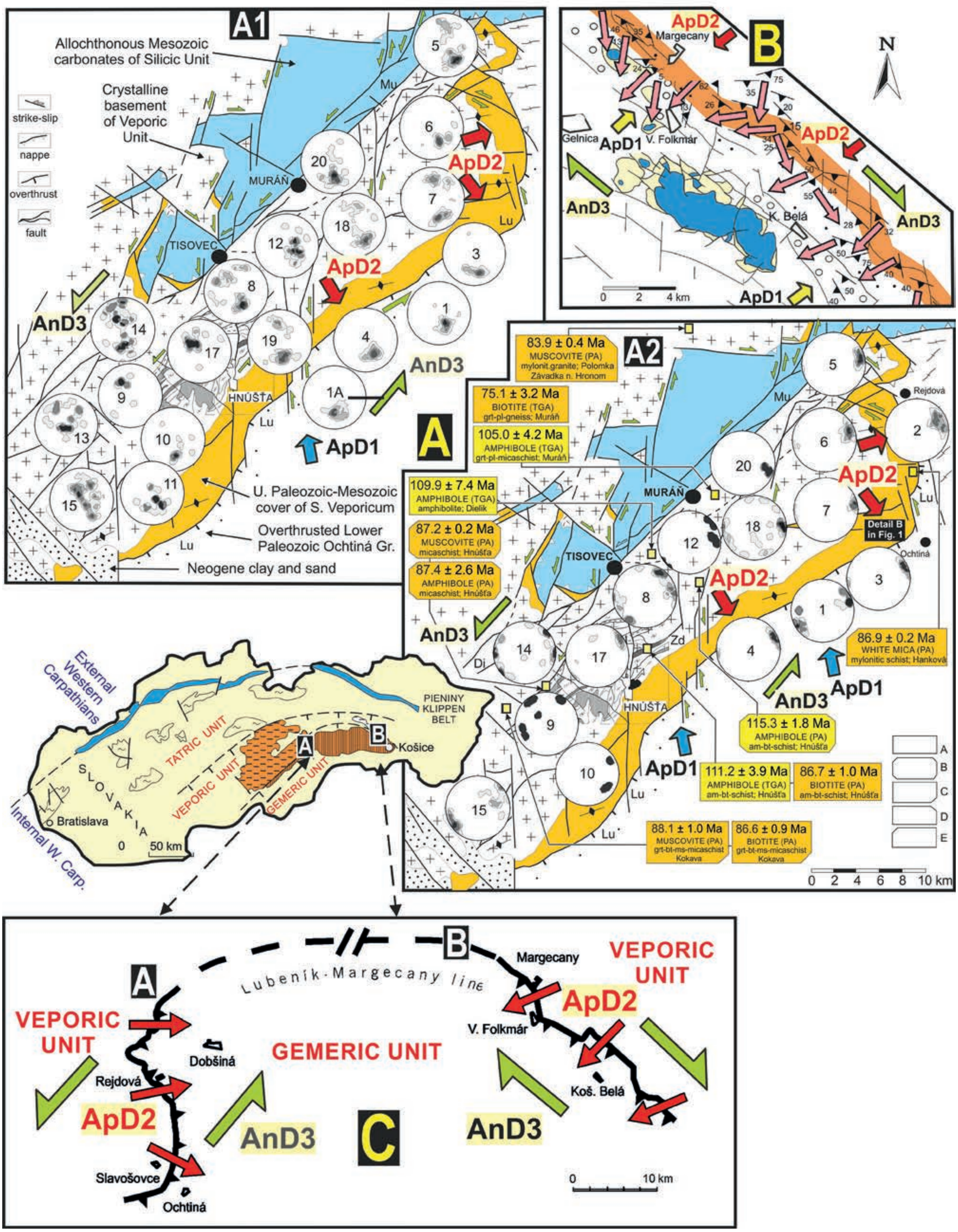
4.3 The Neo-Alpine (Cenozoic) orogenic cycle in the Western Carpathians

The subdivision of the Alpine orogenic cycle in the Western Carpathians into two orogenic sub-cycles – Paleo-Alpine (ApD) and Neo-Alpine (AnD) was caused by the time shift of divergent and convergent phases in the Alpine elongated basins with oceanic crust developed south and north of the axis of Internal Western Carpathians, represented by elevated zone of crystalline basement. Moreover – the Paleo-Alpine evolution represents the western extension of Cimmerian evolution and Neo-Alpine evolution represents eastern extension of the Penninic evolution. The late Mesozoic-Cenozoic Neo-Alpine processes of divergence (AnD0) and convergence (AnD1) of External W. Carpathians took place along the northern rim of Internal W. Carpathians, occurring that time already in the post-collisional ApD2 evolutionary phase, following after Paleo-Alpine convergent processes ApD1, which took place along southern rim of Internal W. Carpathians.

The principal tectonic unit dividing Internal and External W. Carpathians – the *Pieniny Klippen Belt* (PKB; *Oravicum*; cf. Fig. 1B) is characteristic with intensive AnD1 and AnD3 deformation. The units being described in subchapters about Variscan and Paleo-Alpine evolution occur south of this belt.

The zones of *Oravic (Pieniny Klippen Belt)* and *Magura units* represent eastern continuation of the Southern and Northern Penninic zones of Eastern Alps. The *Oravic units* of the *Pieniny Klippen Belt* (Fig. 1B) were primarily geodynamically defined by Sikora (1971, 1974; *Zlatná Unit*) and Maheľ (1981; *Váhicum*). The present knowledge about tectonic setting and lithology of *Oravic* and *Magura units* was summarized by Plašienka (2018) and Plašienka et al. (2020 and references therein). We emphasize also principal contributions of Polish authors, namely Birkenmajer (1986, 1988), Birkenmajer and Oszczypko (1989), Cieszkowski et al. (2009), Barski et al. (2012), Gawęda et al. (2021), Golonka (2011), Golonka et al. (2003, 2018), Jurewicz (2005), Krobicki et al. (2003), Ludwiniak et al. (2019) as well as Czech authors: Picha et al. (2006) and Skupien and Vašíček (2008).

The post-collisional evolution (AnD234) in Neo-Alpine orogenic zone has influenced geology and tectonics in wide areas north and south of it, encompassing also Internal Western Carpathians. Despite, reconstruction of the origin of whole Western / Eastern / Southern Carpathian sigmoidal oroclinal bend (syneclisis; cf. Fig.



A1
Allochthonous Mesozoic carbonates of Silicic Unit
Crystalline basement of Veporic Unit
strike-slip
nappe
overthrust
fault
MURÁŇ
TISOVEC
HNÚŠŤA
Mu
Lu
ApD2
AnD3
ApD1
A
U. Paleozoic-Mesozoic cover of S. Veporicum
Overthrusted Lower Paleozoic Ochtiná Gr.
Neogene clay and sand
B
Margecany
Gelnica
V. Folkmár
K. Belá
N
0 2 4 km
A2
83.9 ± 0.4 Ma
MUSCOVITE (PA)
75.1 ± 3.2 Ma
BIOTITE (TGA)
105.0 ± 4.2 Ma
AMPHIBOLE (TGA)
109.9 ± 7.4 Ma
AMPHIBOLE (TGA)
87.2 ± 0.2 Ma
MUSCOVITE (PA)
87.4 ± 2.6 Ma
AMPHIBOLE (PA)
86.9 ± 0.2 Ma
WHITE MICA (PA)
115.3 ± 1.8 Ma
AMPHIBOLE (PA)
111.2 ± 3.9 Ma
AMPHIBOLE (TGA)
86.7 ± 1.0 Ma
BIOTITE (PA)
88.1 ± 1.0 Ma
MUSCOVITE (PA)
86.6 ± 0.9 Ma
BIOTITE (PA)
Rejdová
Ochtiná
Detail B in Fig. 1
0 2 4 6 8 10 km
External Western Carpathians
PIENINY KLIPPEN BELT
TATRIC UNIT
VEPORIC UNIT
GEMERIC UNIT
Košice
SLOVAKIA
Bratislava
50 km
Internal W. Carp.
Lubeník-Margecany line
VEPORIC UNIT
GEMERIC UNIT
Dobšiná
Rejdová
Slavošovce
Ochtiná
Margecany
V. Folkmár
Koš. Belá
C
0 10 km

Fig. 15. Kinematics of oroclinal bending of the W. Carpathians demonstrated on AnD3 bend of the ApD1c / ApD2 thrust / unroofing zone between Veporic and Gemeric units, forming syneclise at the western part of this contact zone (shown in **C** down in this figure). The revealing that the ApD2 unroofing kinematics is apparently antagonistic in this Paleo-Alpine ApD12 zone – in western syneclisis segment of this zone the unroofing is generally to E and SE (cf. **A1, A2, C**), but in eastern segment of this zone is the opposite – towards the SW (**B, C**). In earlier reconstructions, this bending was interpreted to be a product of the ApD3 shearing (e.g. Németh et al., 2012), but a new reconstruction of kinematics of Alpine processes in this zone magnifies the role of younger Neo-Alpine AnD3 shearing as a reason of present oroclinal bending. This principle applies also in other bended segments of the whole Carpathian belt. General tectonic situation is shown in this figure by pale-yellow schematic map of W. Carpathians situated in center left position. Oroclinal bending of the W. Carpathians was produced by AnD3 displacements along conjugate systems of sinistral (NE–SW) and dextral (NW–SE) shear zones (Németh et al., 2001), being visualized in **C** by green half arrows. Figure in part **A** (**A1** – mesoscopic foliation, **A2** – mesoscopic linear structures, including ^{40}Ar/^{39}Ar dating of synkinematic white micas) documents also ApD2 unroofing kinematics revealed from the 1990s by structural geologists in the western contact zones (**A1;** cf. Hók et al., 1993; Madarás et al., 1996; Németh et al., 2004) and being dated by ^{40}Ar/^{39}Ar ApD2 tectonometamorphic white micas (**A2**). Authors of geochronological data are indicated by rectangles in right down bar in A2: A – Maluski in Kováčik et al. (1996), B – Kováčik and Maluski (1995), C – Maluski et al. (1993), D – Dallmeyer et al. (1993), E – Dallmeyer et al. (1996). TGA represent total gas age, PA plateau age. The role of Cenozoic conjugate shear zones kinematics in oroclinal bending of the Internal W. Carpathians became known when revealing generally opposite ApD2 unroofing kinematics in the eastern part of the Veporic-Gemeric contact zone by Németh et al. (2001); shown in segment **B** (right up in the figure).

1a) is a principal problem of the evolution of whole Alpine-Carpathian orogenic belt, including the role of Neo-Alpine subduction (AnD1a), magmatism / volcanism (AnD2? + 4?), as well as Neo-Alpine shearing (AnD3) in formation of this bend. In further text we will try to address this challenge.

AnD0 continental breakup and rifting phase

The AnD0 rifting phase of Neo-Alpine evolution encompasses two events: (1) the Middle Jurassic (AnD0_V) continental breakup, leading to origin of the Alpine Tethys related South Penninic-Váhic Ocean (Late Bajocian–Early Bathonian; Oravic evolution). This continental breakup is contemporaneous with Jurassic ApD1s subduction of the elongated Meliatic oceanic basin located on the opposite – southern side of orogenic belt, having ApD1s subduction slab dipping south (i.e. away of orogenic belt), and (2) the Early Cretaceous (AnD0_M) rifting and continental breakup, leading to opening of orogen parallel Magura Ocean as continuation of the North Penninic zone (cf. Plašienka, 2003, 2018). This Early Cretaceous process was coeval with the Paleo-Alpine ApD1c collision acting in south located zone of Internal Western Carpathians with generally north-vergent ApD1c nappe stacking including also sequences of Meliatic oceanic domain (cf. Plašienka, 1997). By this way the zone of Internal W. Carpathians became the axial zone of orogenic belt. We must emphasize that according our reconstructions (cf. l.c.), the course of elongated Neo-Tethys Meliatic ocean was nearly equatorial (E–W), correspondingly as the course of previous Variscan Paleo-Tethys Rakovec basin, as well as the youngest – Neo-Alpine Oravic and Magura basins. **Parallelism of suture zones is one of characteristic features of polyorogenic evolution.**

The contradicting synchronous convergent vs. divergent kinematics in parallel Alpine zones represents another paradox, occurring in polyorogenic zones and being traditionally interpreted as a consequence of subduction slab pull. In our particular case it would relate to the Meliatic oceanic crust subduction slab pull southward. **The slab pull concept here forces again to problem of existing hot line (ECMB) below the spreading zone at Meliata Ocean (ApD0),** occurring between Rakovec suture zone in the North and later zone of Meliata subduction slab in the South. If so, when Meliata ocean in W. Carpathians was closed by subduction, this hot line was still active beneath the Variscan + Paleo-Alpine suture zones and this is demonstrated by Late Cretaceous south-vergent ApD2 unroofing of MAp2 overheated Veporic basement nappe by the same hot line. This process is documented in previous subchapters. **The configuration looked as follows: in direction from the south northward – (1) Meliata subduction slab dipping south, (2) zone of collision stack and accretion prism nappes, being overheating by hot line and (3) more to the north acting new AnD0 Oravic and Magura spreading zones. This configuration indicates that new AnD0 spreading could not be driven by a subduction slab pull, but again by the same (Variscan / Paleo-Alpine / Neo-Alpine) hot line.**

Here presented interpretation of the role of elongated subequatorial–course convectional heat related to ECMCC (hot line), driving the polyorogenic cycles geodynamics of Intra-Pangea subequatorial type is a novel contribution to current global plate tectonic concepts.

AnD1 collision

According present interpretations by numerous authors (see references in first paragraphs of subchapter 4.3), the AnD1 convergence generally accounts the southward polarity of AnD1a subduction of the flysch zone between the southern margin of European Platform and the ALCAPA (Alpine-Carpathian-Pannonian) zone. In the territory of W. Carpathians this subduction caused individualization and strong AnD1 north-vergent deformation of the Pieniny Klippen Belt, built dominantly of carbonatic sequences of the southern margin of AnD0 flysch basin. The complex Neo-Alpine AnD1c collisional events of Late Cretaceous to Middle Eocene age were caused by northward drift of the Adriatic microplate (Plašienka, 2018). Similar to other orogenic belts, the convergent folding in the External Western Carpathians (ECW in Fig. 1B) commenced in their internal parts and progressed in time towards their foreland (Oszczypko, 2006). From the end of Paleogene the AnD1c collision, acting at the Pieniny Klippen Belt / Magura Basin boundary, has progressed more externally and completed it was in early Miocene – early Burdigalian in the northern part of the Krosno flysch basin (Fig. 1B). During Early and Middle Miocene the Polish Carpathian Foredeep developed as a peripheral foreland basin in front of advancing Carpathian orogenic wedge (l.c.). The development of this Foredeep can be related with AnD2 / MAn2 thermal processes and gradual uplift of collided zone of External Western Carpathians.

AnD2 post-collisional events

The former AnD1 subduction-related structures were overprinted by the AnD2 gravitational collapse normal faults (Zuchiewicz et al., 2002; Tokarski et al., 2006). These faults bound intramontane basins, being filled with Neogene sediments. The postcollisional MAn2 thermal processes produced Neogene magmatism and superficially very vigorous volcanism. We interpret the MAn2 magmatism and volcanism again as a consequence of the input of convectional mantle heat from the ECMCC.

The Miocene to Quaternary volcanism in the Western Carpathians (and s.l. the Circum-Pannonian region) contributes to understanding of the youngest evolutionary stage of Eastern / Southern Carpathians arc (syneclisis) evolution. The volcanic products of Miocene to Quaternary age were divided into sequence of volcanic suites linked to Neo-Alpine post-convergent (AnD2?, AnD4?) magmatogenic events (cf. Lexa & Konečný, 1998): The **areal type silicic volcanism** and later **andesite volcanism** have terminated with **alkali basalt volcanics related to post-convergence extension environment** (AnD4). Authors (l.c.) emphasize that the compositional difference between areal-type and arc-type andesite volcanics is negligible and these suites were divided on the basis of spatial distribution and temporal evolution. Arc type andesite volcanics are interpreted to be the proof of deep reaching subduction. Their position and timing indicate that subduction has reached the magma generation depth when it was nearly vertical and reached its final stage of tear-off (Konečný et al., 2002). According to our interpretation the nearly vertical position of AnD1a subduction slab and tear-off were caused by the positioning of subduction slab against to descending convection current of ECMCC flow. The Cenozoic flysch belt subduction initiation to opposite (northward) direction was not possible because of the barrier effect of European Platform crystalline basement (cf. Fig. 1B). Exceptionality of this subduction process is magnified also by the fact of "imperfection" of supposed Neo-Alpine Klippen Belt subduction process, which took place earlier in more southern parallel zone than the Magura basin subduction (cf. Lexa & Konečný, 1998, and Fig. 1 part I in Németh et al., 2016).

AnD3 origin of oroclinal bend of Western Carpathians

The conjugate NW-SE and NE-SW (AnD3) systems of Alpine shear zones in the Western Carpathians were first discovered by Grecula et al. (1990) in the region of Gemeric Unit. Later the importance of dextral NW-SE trending and sinistral NE-SW trending shear zones was emphasized also by other authors. Their structural research was focused on principal Tertiary shear zones, displaying the inconsistences / shifts in the course of individual lithological strips. Into this category of XD3 shear zones of brittle / brittle-ductile kinematics we do not account moderately inclined brittle-ductile / ductile shear zones related to XD1 thrusting and XD2 unroofing. Younger re-activation / overprint of these XD12 discontinuities by younger AnD3 shear zones is clearly decipherable by overprinting relations (cf. Fig. 14A). The research of kinematics of AnD3 shear zones has contributed to explanation of convex oroclinal bending of W. Carpathians (cf. Fig. 1B and 15C). Principal information about AnD3 shear zones is available in works dealing with following topics: AnD3 reactivation of ApD12 contact zone of Gemeric and Veporic units – Gazdačko (1994), Németh et al. (2001), Farkašovský et al. (2023), Transgemeric shear zone – Lexa et al. (2003), Pohorelá shear zone – Hók and Hraško (1990), Madarás et al. (1994), Muráň fault – Marko (1993), Pelech and Kronome (2019), Gerátová et al. (2022), Sinec shear zone – Németh et al. (2004), Mýto-Tisovec fault – Marko and Vojtko (2006), northern part of Internal W. Carpathians – Vojtko et al. (2010, 2015). Modern review of tectonic evolution of W. Carpathians, including topics of Cenozoic AnD3 conjugate system of shear zones provide works by Kováč et al. (2002), Kováč and Plašienka (2002), Marko et al. (2017), Plašienka (2018) and Bezák et al. (2023).

AnD4 regional faults of pure-shear kinematics of sub-equatorial and submeridian courses

Besides the arched course of the individual mountain ranges (Fig. 1B), the Western Carpathians provide spectacular morphological evidences of a net of subequatorial and submeridian trending faults, cross-cutting older tectonic and morphological elements. These overprinting relations demonstrate that these subequatorial and submeridian prevailingly pure-shear type faults with dominant vertical kinematics (uplifts and subsidences) of rock sequences bordered by them, represent a product of the youngest orogenic phase – AnD4 – present in the Western Carpathians. Besides regional faults and frequent morphological evidences (e.g. course of valleys), the AnD4 brittle disintegration of older structures and lithology are well observable also at the outcrop scale. Several faults of submeridian course (e.g. the Zázrivá-Budapest fault, Central Slovakian fault zone, a.o.) cross the whole Western Carpathians and represent regional reflection on E-W trending extension related to MCMCCs. The post-AnD3 N-S coursing transcrustal discontinuities can produce the pathways for Miocene volcanism. The N-S trending volcanic range of the Slanské vrchy Mts in the eastern part of W. Carpathians can serve as an exemplary case of linearly situated range of Middle / Upper Miocene andesite volcanoes, spatially contradicting to their relation with eventual continental or island arc volcanism of subduction related AnD1s process (cf. Bacsó, 2023).

5 Geodynamic considerations leading to birth of hypothesis of the New Global Tectonics 2.0

5.1 Columnar mantle plumes (mantle diapirs) vs. convection currents of subequatorial-course mantle bulge (ECMB), subequatorial-course mantle convection currents (ECMCCs), submeridian-course mantle convection currents (MCMCCs) and their interconnections

The origin of new rift zones and mid-oceanic ridges was traditionally interpreted as a consequence of the lithosphere breaks due to the pull of descending slabs in subduction zones (e.g. Jacobs, 1992).

The research by several authors from the 1970s has described within the globe the differing number of the mantle plumes (mantle diapirs). Even that time they were interpreted to be a driving force of global geodynamics. Morgan (1971, 1972) in his pioneering works defined 20 plume localities. Burke and Wilson (1976) distinguished altogether 122 hot spots (superficial indications of mantle plumes), being active during the last 10 million years. From this number, altogether 53 were located in oceanic basins, 24 on or near mid-ocean ridges and 69 on continents. Altogether 25 hot spots defined in Africa represented the greatest concentration revealed within the continent. The hot spots were revealed in relatively regular net on the globe. **The rift zone origin due to heat generated by several mantle plumes having generally linear arrangement** was presented by Dewey and Burke (1974) on example of N-S located series of rift-rift-rift (r-r-r) junctions in continental crust. They represented the initiation of rift divergence, leading to South-Atlantic-type advanced rifting stage. This important outcome emphasizes, that several hot spots with generally linear position of submeridian course can cause a special type of continental breakup and become a rift zone. New principal interpretation appeared in work by Courtillot et al. (2003), distinguishing altogether 49 hot spots with anchoring of their mantle plumes in depths of 500 km and 2 850 km. In subequatorial plane two antipodal domes of mantle upwelling are shown in this work (l.c.) – below the central Pacific Ocean and Africa (Fig. 4 ibid; used slightly modified in Fig. 16 of our interpretation). Based on results of finite frequency tomography, the deep mantle plumes catalogue by Montelli et al. (2006) states 17 mantle plumes originating at least below the upper mantle and 4 plumes reaching only to middle mantle. Only the Eifel and Seychelles plumes are unambiguously confined to cross-cut only the upper mantle. Starting plumes are visible in the lowermost mantle beneath South of Java, East of Solomon, and in the Coral Sea (l.c.). Authors (l.c.) suggest a pulsating behaviour of the Iceland plume due to the substantial disagreement between *P-wave* and *S-wave* images.

Continental breakup in the case of Rodinia and Pangea with relation to mantle convection was comprehensively explained by Pirajno (2000). The pioneering works about mantle convection currents appeared in the 1920s (Schwinner, 1920; Holmes, 1929). Regarding the mantle convection, presently there are available several concepts – interpreting two separate convecting layers above and below 670 km discontinuity, or a whole-mantle convection. Important there were results of the seismic tomography, supporting the idea of flow across the boundary layer between upper and lower mantle (van der Hilst et al., 1997). This concept joints previous ones and is known as “leaky two-layer” theory.

Owing the long-time research and based on works referred above, the author of this contribution prefers a new hypothesis of linear trending sources of convectional heat, being categorized into **(1) subequatorial-course mantle bulge (ECMB) and (2) subequatorial-course mantle convection currents (ECMCCs) / submeridian-course mantle convection currents (MCMCCs; Fig. 16) with existing crossings of subequatorial-course and submeridian-course systems, as well as diagonal interconnections of both systems.** All these categories represent hot lines owing to upwelling mantle currents – they contribute with heat to rifting (XD0), post-collision processes (XD2) and intra-plate processes (XD4). The descending currents – are principal at subduction (XD1s). All principally contribute to lithosphere geodynamics, parallel with existing “classic” **(3) columnar mantle plumes (mantle diapirs),** superficially being expressed by hot spots. **The**

subequatorial-course mantle bulge (ECMB) and parallel – situated in higher latitudes – subequatorial-course mantle convection currents (ECMCCs) are principal for polyorogenic / polymetamorphic / polymetallogenic evolution (cf. Németh, 2002, Fig. 3 ibid; Németh, 2005a, Németh et al, 2016), and in Phanerozoic Eon such evolution seems to be very distinctive in the Alpine-Carpathian-Himalayan belt.

Findings in the Western Carpathians (l.c.) indicate that **the same linear source of subequatorial convectional heat (hot line) acted throughout several orogenic cycles and produced within them the riftogenesis generating the oceanic-type crust, but also contributes to closure of generated elongated basins at convergent collisional evolution and principally contributing to post-collisional evolution and origin of orogen parallel metamorphic core complexes and uplift in the axis of orogenic belt, unroofing and gradual opening of a new generation rift(s). Shift of lithosphere over hot line causes parallel location of products of individual orogenic cycles, i.e. suture zones** (cf. Figs. 10 and 11), which cannot be explained by interpretation of linear arrangement of columnar hot spots (according to rift-rift-rift concept by Dewey and Burke, 1974). **This hot line hypothesis explains well the polyorogenic evolution, but also fits well at reconstruction of polymetamorphic and polymetallogenic events and their products throughout several orogenic cycles** (Németh et al., 2016).

Concerning the source of heat for continual flow of magma within the mantle (the most significantly but indirectly registerable in ECMB, ECMCCs and MCMCCs), presently is well proved the concept of thermonuclear reactions acting in the innermost parts of the Earth which resemble those in the Sun (Fowler, 1984; Herndon, 1996, 2011; Raghavan, 2002; Anisichkin et al., 2005; Schuiling, 2006; Rusov et al., 2007; de Meijer & van Westrenen, 2008; Terez & Terez, 2011, 2013, 2015; Fukuhara, 2016; Sobolev & Bilan 2018; Pawula, 2022; for mantle flow interpretations see also Davis, 2022). According to studies referred above, **the mantle plumes (mantle diapirs) could be parallelized with the eruptions from the Sun, but happening in totally different environment – not in vacuum and zero temperatures, but to glowing mantle environment, so the enormous thermal effect of such eruptions can last millions of years, or even throughout several orogenic cycles.**

When considering the Earth geodynamics and the counter-clockwise rotation of the globe, important aspect is the **difference in rotation of the lithosphere with respect to that in the deep mantle**. Modelling by several authors (e.g. Ricard et al., 1991, Fig. 2 ibid.; Doglioni, 1993; Doglioni, et al., 1999) has resulted into series of vectors, trending generally E–W and depicting the lithosphere movement generally westward with respect to deep mantle. If we express it by the opposite interpretation – the mantle is relatively moving east with respect of the lithosphere moving west (Fig. 3 in Ricard et al., 1991). This interpretation was used in model suggested in this article (Fig. 16) in combination with the model by Courtillot et al. (2003). The different rotation velocity of lithosphere with regard to that of Earth's mantle and core causes that the submeridian Circum-Pangea-type subduction slabs are dipping west very steeply, but dipping moderately to the east. **This kinematics is principal in the Circum-Pangea submeridian-course transcrustal discontinuities, but also inside present Europe – cf. dip of Vrancea subduction slab and its break-off in the Eastern Carpathians** (Sperner et al., 2001)**.** Interesting in Fig. 2 of Courtillot et al. (2003) is the moderate bending of vectors course from their E-W trajectory. In the territory on North America these vectors are so short and unimportant that it can indicate why the continuation of the Intra-Pangea subequatorial polyorogenic belt in North American territory is unclear.

5.2 "Continental drift" vs. drift of lithospheric plates

As generally known, the concept of continental drift by Alfred Wegener (1912 and following outcomes) was not accepted unequivocally, when he as a driving force interpreted the rotation of the Earth. The Russian-American mathematician Paul Sophus Epstein proved that kinematics suggested by Alfred Wegener is not real / possible. Really – continents are not drifting on Earth surface as they are. **Continents are drifting on Earth being passively carried by drifting lithospheric plates.** Hence – instead of continents alone – drifting on our planet are lithospheric plates. This idea was published in the series of principal geodynamic articles by John Tuso Wilson (1965, 1966 and 1967).

Drift of lithospheric plates operates with difficulties, because the whole surface of our planet is covered by lithospheric plates = lithosphere (continental but also oceanic crust). When imagined completed puzzle picture – how some segments can be changed when they appear in wrong position? In the case of lithosphere there is no possibility to uplift those in a "wrong position" and exchange them with others. No subduction and lithospheric collision with imbrication, accretion and nappes stacking are helpful, because oceanic rift zones still produce a new – oceanic – crust. So the coverage of our planet with lithosphere is all the time complete.

At drift of lithospheric plates the oceanic rift zones play relatively passive role. They are products of extension (divergent movement) caused by mantle convection currents. Zone where the mantle convection currents reach the bottom of lithosphere is named as **hot line**. In this uppermost zone the mantle convection zones divide to both sides of the zone and gradually start to descend, in some places contributing to start or progression of subduction. Smaller importance of riftogenesis at lithospheric

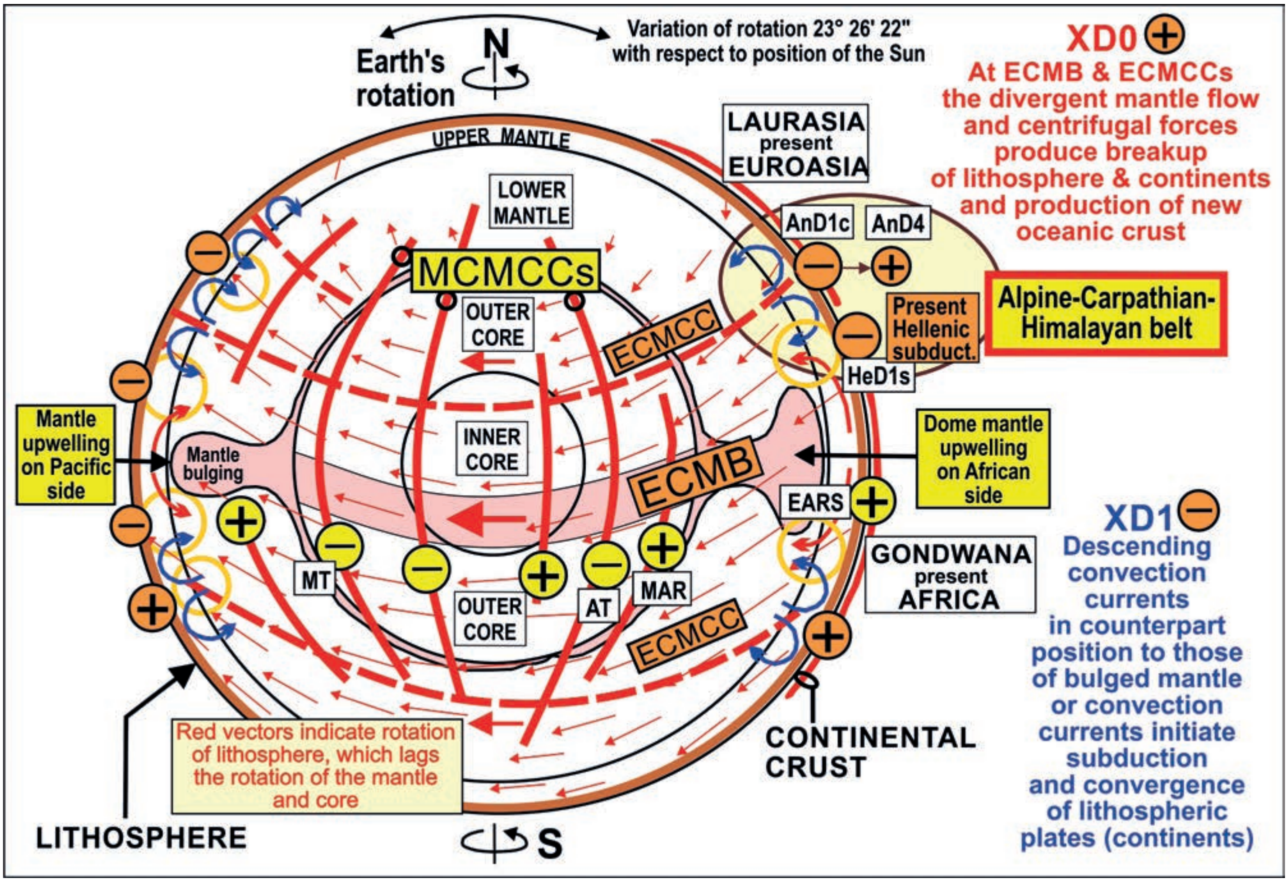


Fig. 16. Model of the global geodynamics based on the concept of polyorogenic zones trending subequatorial and characterized by the case study of the Western Carpathians (positioned on the right side up in this visualization). The concepts by Courtillot et al. (2003; equatorial mantle bulging), as well as Ricard et al. (1991; differential rotation between lithosphere and mantle – red generally E-W trending thin arrows) were used for consideration of subequatorial and submeridian zones. The Earth's geodynamics benefits from thermonuclear reactions corresponding with those in the Sun (references are in the chapter 5.1). For simplification, in this model the mantle plumes (mantle diapirs) are not visualized. The shape of ECMB (pale red) taken from Courtillot et al. (l.c.), shows two principal cases: ECMB beneath the extended continent (Africa) and beneath the globally extended oceanic crust (Pacific). In other places around the wider zone of globe equator the ECMB shapes differ between these two principal shapes. Signs in orange circles (also in Fig. 2) represent rifting (+) or subduction (–) in subequatorial zones and those in yellow circles in submeridian zones. MT – Mariana Trench, AT – Atacama Trench, MAR – Mid-Atlantic Ridge, EARS – East African Rift System.

plates displacement and orogenesis s.l. ("mountain building") is highlighted in XD labelling by number ZERO = XD0.

Convergent subduction processes lead at polyorogenic evolution to collision (XD1c) and "mountain building". As we demonstrate in present paper, this happens dominantly at zones of subequatorial direction. Zones of submeridian direction have many times smaller frequency of collision events.

The drift of lithospheric plates author of this paper explains by the shifts along transform faults / shear zones. Within individual orogenic cycles they are labelled as XD3 phase, but they may be acting throughout several orogenic cycles, especially at polyorogenic case indicated by this article (e.g. ApAnHeD3 – continual activity of some shear (transform) faults during several orogenic cycles – here Paleo-Alpine, Neo-Alpine and Hellenic ones). The importance of transform faults was firstly revealed by John Tuso Wilson (1965). These simple shear-type faults = transform faults / zones are extremely frequent in the lithosphere (up to decameter mutual distance, or decipherable by steeply dipping cleavage zones even at the outcrop scale), so the lithosphere is disintegrated by them to microplates or rock blocks. Because the transform / shear faults dominantly develop in conjugate system of two preferable directions NW–SE (dextral shear) and NE–SW (sinistral shear), the lateral shifts allow in long time perspective the drift of lithospheric plates / microplates / rock blocks. Transversal courses of transform / shear faults are caused by the different displacement length along the equator and equator parallel zones in higher latitudes at the rotation of the Earth. In this point author provides also explanation of the reason of origin of subequatorial weakened zones with located mantle convection currents

(ECMMC), which are developed also due to differing subequatorial displacement paths of lithosphere at rotation of the Earth. The supreme order discontinuities in lithosphere (ECMMCs), produced by the Earth's rotation within on the Earth's crust, are projected depthward and activating / allowing mantle convection currents. Principal at origin of different – global N-S trending discontinuities there are the differences inbetween physical parameters, rheology and the rotation kinematics of individual zones of the Earth (core, mantle, crust) producing a stress field contributing to N-S trending lithosphere / continents fracturing. The minor role there may play also uneven (undulated) base of lithosphere, which is interpreted under continental crust and differs from that at the base of oceanic crust. Because the ascending and descending submeridian mantle currents are present at rifts, but also subduction zones (cf. Fig. 16), it underlines the interconnection of tectonic processes in the lithosphere with the processes in the Earth's mantle.

At all interpretations we must have in mind that new discontinuities are preferably developing within older / already existing discontinuities, but above described global geodynamic rules are valid in polyorogenic zones as well as in all places within the globe, differing only by their size and importance, regarding on latitude and position where they act.

6 Concluding summary

The presentation of individual orogenic cycles and their phases in the case of the Western Carpathians, being part of polyorogenic Alpine-Carpathian-Himalayan belt, has been in this paper extended to global considerations. The W. Carpathians with a distinct zonal setting and symmetric moderate north convex oroclinal bending, as well as the small width in transverse direction only of ca 200 km represent an ideal study area of the geodynamic processes in polyorogenic belt.

As the drivers of polyorogenic evolution, but also of all global processes there are interpreted the linear sources of convectional heat – the subequatorial-course mantle bulge (ECMB), subequatorial-course mantle convection currents (ECMCCs), submeridian-course mantle convection currents (MCMCCs), and at some special cases also their interconnections. The mantle plumes (mantle diapirs) play a secondary role in global geodynamics. As demonstrated by numerous cited studies, all here listed mantle ascents are products of a permanent heat production by thermonuclear reactions in the innermost zones of the Earth. The shape and course of linear-course mantle ascents and related descends are a product of Earth's rotation (ECMB + ECMCCs), but probably also of uneven base of lithosphere under continents in meridian direction (at MCMCCs). All linear-course mantle ascents and descents can contribute to rifting as well as subduction. The concept of a slab pull is not understood here as the dominant at global geodynamics, especially due to revealing mega- or gigapophyroclasts of heavy rigid rounded blocks of HP-HT rocks (glaucophanites, metagabbros, peridotites) being exhumed by reversal rotation movement in the subduction slab. This synsubduction exhumation requires compression – and this is in contradiction with an interpretation of extension at subduction slab pull concept.

The multiple switch between divergence and convergence at polyorogenic zones of subequatorial direction, producing multiple continental breakup alternating with collision

Dominant in global geodynamics and in multiple equatorially directed polyorogenic continental breakups is a mantle convection. The positioning of convection currents is influenced by the rotation of the Earth. The supreme importance mantle convection belt has a subequatorial ring shape – being defined as a subequatorial-course mantle bulge (ECMB). Parallel with ECMB there exist also several subequatorial-course mantle convection currents (ECMCCs), being developed in weakened zones (in lithophere discontinuities), produced by different length of rotation pathes in parallel zones being developed in different latitudes. If no other aspects are considered – an extension produced by the rotation driven centrifugal forces contributes also to origin of subequatorial-course mantle convection currents and related equator parallel XD0 disintegration (breakup) of the lithosphere in polyorogenic zones and divergent wandering of disintegrated parts generally towards the north in northern hemisphere and towards the south in southern hemisphere. The start of the opposite XD1 convergent drift of disintegrated parts depends on relation of their weight and decrease of centrifugal forces in more distant zones from the equator: Reaching the critically distant position from the equator the centripetal forces start to act on the XD0 displaced parts of continental crust, and the former disintegrated parts at XD1 tend to collide owing the action of these centripetal forces.

Processes producing continental breakup by submeridian-course convection currents (MCMCCs)

The Western Carpathians as a part of polyorogenic belt of subequatorial direction do not provide good conditions for investigation of submeridian trending crust disintegration. Despite – long, regional scale faults of meridian course are present also in this territory (as well as in the whole European continent), encompassing also vertical uplift and subsidence of local mountain ranges related to the youngest orogenic cycle (in the Western Carpathian territory AnD – with very instructively developed AnD3 and AnD4 phases; cf. Németh et al., 2023). This young evolution was well deciphered also in other parts of European continent by Cloeting et al., 2005, 2007, and references herein.

The concept of the net rotation of the lithosphere with respect to deep mantle, as presented by Ricard et al. (1991) and later further elaborated by Doglioni (1993) and Doglioni et al. (1991, 1999, 2006) was included into our considerations and resulting model (Fig. 16). The delay of lithosphere rotation (in Fig. 16 shown by thin, generally equator parallel arrows, pointing west) and the differences inbetween physical parameters, rheology and the rotation kinematics of individual zones of the Earth (core, mantle, crust) produce a stress field contributing to N-S trending lithosphere / continents fracturing. Originating global scale N-S trending discontinuities are used for mantle uprise and the meridian-course mantle convection currents (MC-MCCs) originate by this way. Secondarily they contribute to continental breakup of submeridian direction – e.g. recent activity in the East African Rift System represents an embryonal phase of a new Wilson cycle, in the distant future probably reaching the mature stage of Mid-Atlantic ridge-type. Typical example of active subduction along the submeridian-course zone is represented by the Atacama subduction (cf. Figs. 2 and 16). The concept of eastward migration of the mantle relative to the lithosphere (Ricard et al., 1991, Fig. 3 ibid.) explains well the reason of steepening of the dip of subduction slabs dipping west and their shallow dip in cases when they are dipping east. Within Carpathian chain the first of these cases was interpreted (and proved) e.g. in Vrancea zone in the Eastern Carpathians.

Further non-regularities are common, too, being caused by the principle of preferred establishing of younger discontinuities on older ones, but also the common microplates / blocks shifts and rotation (preferably during XD3 phase), as well as the lithospheric plates / continents rotation due to thermal effect of columnar-type mantle plumes and related mantle flows. All these aspects must be taken into account when considering products of any orogenic phase in any region.

Role of transform / shear faults at drift of lithospheric plates on Earth's surface

The lithospheric plates are limited by rift zones, subduction zones and transform faults. The whole surface of the Earth is covered by lithospheric plates. At their drift – indicated by the drift of continents carried by the drifting lithospheric plates, the rift and subduction zones play a minor role if the divergence rates at the rift zones correspond with rates of subduction on the opposite side of lithospheric plate, or the rate differences are small. Therefore principal at the drift of lithospheric plates are the subvertical transform / shear faults which build a dense net on the Earth's surface, segmenting lithospheric plates (as well as their carried continents) to smaller plates / microplates / rock blocks, allowing them to migrate by sliding one next to the other.

Combining above presented interpretation of (A) a global geodynamic importance of hot lines (ECMB, ECMCCs and MCMCCs), with (B) lateral displacements along a dense net of transform / shear faults, being principal for global scale drift of lithospheric plates (bearing continents), together with further principles of plate tectonics provide a basis for establishing of a new hypothesis of New Global Tectonics 2.0. To become a theory, this hypothesis requires a detail study of mutual interaction between linear mantle convection currents and columnar mantle plumes, regarding their genetic relations and kinematic consequences on lithospheric plates displacement. This study will become easier now because of available numerous scientific studies proving the existence of thermonuclear reactions in innermost zones of the Earth, producing heat for all geodynamic processes in the Earth.

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Geodynamika polyorogenetických zón na príklade vývoja Západných Karpát

Dôkazmi o polyorogenetickom vývoji alpsko-karpatsko-himalájskej zóny (**obr. 1A, 2**) sú sporadické relikty paralelných sutúrnych zón so subekvatoriálnym (približne východno-západným) priebehom. Polyorogenéza, t. j. sekvencia viacerých po sebe nasledujúcich orogenetických (Wilsonových) cyklov, bola v tejto zóne najlepšie zdokumentovaná v Západných Karpatoch, pre ktoré je charakteristická symetrická oblúkovitá stavba, v strednej časti vyklenutá na sever (**obr. 1A, B**). Navyše, Západné Karpaty sa vyznačujú výraznou zonálnosťou a unikátnym detailným stupňom preskúmanosti.

V doterajších interpretáciách boli niektoré sutúrne zóny v Z. Karpatoch interpretované ako relikty zaoblúkových bazénov skorších „hlavných" oceánskych bazénov a s nimi súvisiacich subdukčných procesov. Tento sumarizujúci článok aplikovaním zjednodušujúcej prezentačnej metodiky *XD labelling* (Németh, 2021; **obr. 3**) zdôrazňuje doloženú existenciu troch kompletných orogenetických („horotvorných") cyklov v Z. Karpatoch. Pri tejto metodike premenná *X* vyjadruje názov orogenetického cyklu – napr. v prípade Z. Karpát variského – **VD** (paleozoický vývoj Z. Karpát), paleoalpínskeho – **ApD** (mezozoický vývoj Z. Karpát) a neoalpínskeho – **AnD** (generálne kenozoický vývoj Z. Karpát so začiatkom v závere mezozoika). Procesy a produkty pokadómskej cenerijskej orogenézy nie sú v tomto článku prezentované pre ich stále prebiehajúci výskum. Číselné vyjadrenie za symbolom *XD* pri konkrétnom orogenetickom cykle uvádza jeho konkrétnu orogenetickú fázu. Symbol **XD0** označuje divergentnú riftogénnu etapu vývoja, a to: **0a** – subfázu začiatku riftogenézy ešte na kontinentálnej kôre súvisiacu s regionálnou extenziou, **0b** – stenčovanie kontinentálnej kôry, **0c** – prebiehajúcu riftogenézu už s produkciou oceánskej kôry. **XD1** označuje proces konvergencie – **XD1s** subdukciu, **XD1o** obdukciu a **XD1c** kolíziu. Orogenetické cykly **XD0** a **XD1** tvoria základ orogenetického (platňovo-tektonického) cyklu, ktorý bol podľa prác J. T. Wilsona zo šesťdesiatych rokov minulého storočia nazvaný aj Wilsonov cyklus. J. T. Wilson sa považuje za zakladateľa koncepcie platňovej tektoniky, ktorá platí dodnes.

Množstvo nových poznatkov, ktoré boli získané v ostatných desaťročiach predovšetkým z Vnútorných Západných Karpát, iniciovalo potrebu rozšírenia klasického orogenetického (Wilsonovho) cyklu o ďalšie tri orogenetické fázy. Tým bol definovaný tzv. **rozšírený orogenetický cyklus** (Németh, 2021), v ktorom sú ku klasickému Wilsonovmu cyklu pridané fázy pokolíznych vnútroplatňových procesov: **XD2** – pokolízne odstrešovanie v dôsledku prehrievania a výzdvihu osi orogenetickej zóny teplom z horúcej línie (ako dôsledku subekvatoriálneho plášťového konvekčného prúdenia = *subequatorial-course mantle convection current* – **ECMCC**), **XD3** – označuje zvýšenú aktivitu párového systému strižných zón smeru SZ – JV (pravostranný strih) a SV – JZ (ľavostranný strih), **XD4** – obdobie zvýšenej regionálnej extenzie spôsobujúce vznik regionálnych zlomov (lineamentov) vyznačujúcich sa kinematikou čistého strihu a nezriedka presahujúcich hranice jednotlivých regiónov či dokonca štátov. Orogenetická fáza XD4 predznamenávala začiatok nového orogenetického cyklu. Genetickú a sukcesívnu spätosť orogenetických fáz XD3 a XD4 doložili Németh et al. (2023). Metodika *XD labelling* je veľmi vhodná na časové/evolučné zaraďovanie litotektonických jednotiek, ich rozhraní, ale aj na sukcesívne zaraďovanie metamorfných/rekryštalizačných prepisov horninových súborov s využitím indexu *MX* a pri zachovaní ďalších detailov ako pri *XD* indexovaní.

Ťažisko článku pozostáva z prehľadnej sumarizácie prejavov jednotlivých orogenetických cyklov a ich fáz v súslednom poradí od variského cez paleoalpínsky po neoalpínsky orogenetický cyklus. Text je doplnený výpovednými obrázkami prevažne tektonického a geodynamického charakteru (**obr. 4 – 15**). Dôraz kladie na vysvetlenie, prečo autor ani jeden z analyzovaných pretiahnutých bazénov s oceánskou kôrou v jeho osi nepovažuje za produkt zaoblúkovej extenzie, ale za novo vygenerovaný bazén v dôsledku extenzie nad lineárnym zdrojom konvekčného tepla (horúcou líniou, ECMCC). V záverečných kapitolách *5. Geodynamické úvahy vedúce k zrodeniu hypotézy novej globálnej tektoniky 2.0* a *6. Záverečné zosumarizovanie* autor prehľadnou formou približuje inovatívne interpretácie, ktoré prináša tento článok. Zároveň poskytuje námety na ďalšie bádanie, ktoré môžu posunúť súčasné znalosti z problematiky geodynamiky:

1. Súčasný astrofyzikálny výskum viacerých autorov (Fowler, 1984; Herndon, 1996, 2011; Raghavan, 2002; Anisichkin et al., 2005; Schuiling, 2006; Rusov et al., 2007; de Meijer a van Westrenen, 2008; Terez a Terez, 2011, 2013, 2015; Fukuhara, 2016; Sobolev a Bilan, 2018; Pawula, 2022) potvrdzuje existenciu kontinuálnych termonukleárnych reakcií vo vnútorných zónach Zeme, ktoré korešpondujú s reakciami prebiehajúcimi na Slnku. Tieto reakcie vo vnútorných zónach Zeme prispievajú energiou k udržovaniu vysokej teploty plášťových hmôt a ich konvekčnému prúdeniu globálneho rozsahu. V našej interpretácii ide o **subekvatoriálne plášťové vydutie** (generálne v smere V – Z v oblasti rovníka v dôsledku rotácie Zeme) = *subequatorial-course mantle bulge* ECMB, o paralelné **subekvatoriálne plášťové konvekčné prúdenie** (vo vyšších zemepisných šírkach) = *subequatorial-course mantle convection current* ECMCC a **submeridiánne plášťové konvekčné prúdenie** (generálne v smere S – J) = *submeridian-course mantle convection current* MCMCC), ale aj o plášťové diapíry (*mantle plumes* v klasickom chápaní, ktorých prejavom na zemskom povrchu sú *hot spots*, tzv. horúce škvrny). Plášťové diapíry *(mantle plumes)* môžu byť „vnútrozemskou verziou“ erupcií na povrchu Slnka (erupcie, na rozdiel od jadra Zeme, sú tam do prostredia vákua a teploty absolútnej nuly).
2. Na situovanie lineárnych zón globálneho plášťového konvekčného prúdenia (ECMB, ECMCCs a MCMCCs) má dominantný vplyv rotácia Zeme a zaostávanie rotácie zemskej kôry oproti rotácii plášťa Zeme v zmysle koncepcií autorov Ricard et al. (1991; obr. 2 ibid.), Doglioni (1993), Doglioni et al. (1999) a Courtillot et al. (2003). V súlade s týmito skoršími prácami sa autor tohto článku stotožňuje s názorom, že určujúcim faktorom geodynamiky Zeme je konvekčné prúdenie v plášti a nie „ťah subdukujúcej studenej oceánskej kôry“ *(subduction slab pull)*. Všeobecne je známe, že „studená“ oceánska kôra je hrubá asi 3 km (ale hrúbka horúcich plášťových hmôt pod ňou je niekoľko tisíc kilometrov) a ponáranie oceánskej kôry v subdukčných zónach je spôsobené prúdením plášťa, a nie ponáranie tenkej oceánskej kôry spôsobuje prúdenie plášťových hmôt a súvisiaci pohyb litosférických platní. Vo svete aj na Slovensku (**obr. 13**) je známych veľa prípadov tzv. synsubdukčne exhumovaných blokov vysokotlakovo metamorfovaných hornín. V podmienkach Západných Karpát tieto bloky zaobleného až dokonale guľovitého tvaru pochádzajú z plášťovej litosféry a bázy kontinentálnej kôry (metagabrá; Radvanec, 1999; Radvanec a Németh, 2018) alebo reprezentujú peridotit (Radvanec, 2000). Tieto exhumované bloky vysokotlakovo metamorfovaných hornín guľovitého tvaru (**obr. 13**) reprezentujú megaporfyroklasty. Keďže ide o horniny s vysokou mernou hmotnosťou, ich pohyb v subdukčnom kanáli proti prúdu subdukovaného mäkkého a spravidla nespevneného materiálu vyžaduje výrazne kompresné prostredie, nie extenziu, ktorá je hlavným faktorom interpretácie *subduction slab pull*.
3. Možnosť pohybu kontinentov po povrchu Zeme („kontinentálny drift“) v zmysle interpretácie A. Wegenera (1912 a následné práce) vyvrátil P. S. Epstein, matematik rusko-amerického pôvodu. Kontinenty ako také sa po povrchu Zeme nemôžu presúvať. Presúvajú sa litosférické platne a niektoré z nich na sebe nesú kontinenty. Túto zásadu vyjadril John Tuso Wilson (1965, 1966, 1967) vo svojich principiálnych prácach, ktoré položili základy platňovej tektoniky. Z histórie geovied je zaujímavá skutočnosť, že A. Wegener v dvadsiatych rokoch minulého storočia pôsobil ako profesor na univerzite v Grazi (Rakúsko) synchrónne s profesorom R. Schwinnerom, ktorý sa zaoberal konvekčným prúdením v plášti. Keby boli obaja profesori vzájomne komunikovali, mohli svoje koncepcie zjednotiť. Tým by boli položili základy platňovej tektoniky o približne štyri desaťročia skôr ako J. T. Wilson. Paralelne s pomerne komplikovaným vysvetlením pohybov litosférických platní kombináciou divergencie v riftových zónach, konvergencie v subdukčných zónach a bočných posunov na transformných zlomoch (Wilson, 1965) autor tohto článku prezentuje možnosť výrazne jednoduchšieho vysvetlenia pohybu litosférických platní po povrchu Zeme: početnosť a hustota distribúcie transformých zlomov (strižných zón) je oveľa vyššia, než bolo v minulosti známe. Dlhoročné terénne výskumy vo Vnútorných Západných Karpatoch, doložené aj geofyzikálnym profilovaním (Grecula et al., 1990), dokumentovali bočné posuny na stovkách zlomov párového (konjugovaného) systému strižných zón smeru generálne SZ – JV (pravostranné posuny) a SV – JZ (ľavostranné posuny). Týmto spôsobom sú litosférické platne pomerne husto segmentované na mikroplatne či bloky hornín, ktoré majú možnosť vzájomnými bočnými posunmi meniť vzájomnú konfiguráciu a takto prispievať k vzniku ohybov *(orogenic bend)* v priebehu horninových pruhov, či dokonca celých orogenetických zón. Najmarkantnejším prejavom takýchto ohybov sú tzv. syneklízy – dvojité ohyby v tvare písmena S. Sú známe z Karpát (dvojitý ohyb priebehu Západných Karpát, Východných Karpát a Južných Karpát), Himalájí (v ich východnom zakončení), ale aj z priebehu západnej časti kontaktnej zóny gemerika s veporikom (**obr. 1, 2 a 15C**). Vzájomný pohyb litosférických platní či mikroplatní uvedenou kinematikou sa dominantne viaže na orogenetické či polyorogenetické zóny; v kratonizovaných častiach Zeme je stabilita litosférických platní s pomerne hrubou lifosférou budovanou kryštalinikom výrazne vyššia.

Inovatívne aspekty geodynamiky Zeme uvedené v bodoch 1, 2 a 3 predstavujú vhodné témy na ďalší komplexný výskum a následné potvrdenie či vyvrátenie hypotézy, ktorú autor článku nazval *Nová globálna tektonika 2.0*. V každom prípade, poznatky získané mnohými desiatkami vysoko erudovaných bádateľov zo Západných Karpád výrazne obohacujú vedy o Zemi v celosvetovom meradle.

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