Tertiary Tectonic Evolution of the Pannonian–Carpathian–Eastern Alpine Domain: a Personal View of from Pannonia in the Light of the Terminological Question of Tectonic Units

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Tectonic units are three-dimensional rock bodies with distinct physical boundaries and unique structural characters including temporal evolution. One of the main tasks of structural research is to define boundary surfaces or zones (structural elements), describe their geometry, characterize kinematic nature and determine temporal evolution. On the other hand, the presence of certain rock formations, their special facies or paleogeographic similarities are not distinctive features, although they can occasionally be useful to establish or better characterise some tectonic units.Tectonic units are evolving in time. Their boundaries can be shifted, their size can be increased or reduced. Frontal accretion, underplating, low-angle normal detachment, formation of strike-slip duplexes etc. may contribute to volume increase/decrease of a unit.

The definition of tectonic units (e.g. its boundaries and structural characters), and proper use of its name in temporal context is not merely a terminological problem. Although a perfect agreement on certain terms can hardly be achieved but on the other extremity, completely different usage of a tectonic unit reflect misunderstanding of the structural, and in consequence, the whole geological evolution. Tectonic units can be figured on geological maps, thus they are useful and necessary "tool" to disseminate results of "purely" structural geological research. On the other hand, results of modern structural research modify considerably geological maps and general knowledge. It is particularly true in Central Europe, where despite long research, and extensive geological knowledge, structural interpretation was not always integral part of the research and/or mapping. These are the reasons that I feel important to clearly define the units, discuss their nomenclature and structural characteristics.

I would like to embed the problem of tectonic units in a brief, simplified structural evolution of the area ain question, the western Carpathians, Pannonian area, and somewhat the Alps. As a sort of review, the presentation would be a selection of data what I feel important. Thus, it will be far from complete. The basic lines of the model were established by the clever reconstruction of Balla (1984), are coming from the first modern and straightforward structural synthesis of Tari (1994), from the genuine works of Frank Horváth, and from a great number of other colleagues, not listed below.

Looking from Pannonia, the Paleocene and early Eocene is a period of tectonic quiescence and terrestrial denudation, although geologists working in the Flysch Belt would argue for initial deformation of those areas. Basin subsidence started gradually from west to east from early Eocene to latest Eocene, a fact known from longtime (e.g. Báldi 1986) and re-summarized by Kázmér et al. (2003). Most authors agree on the compressional origin of the 'Central Carpathian' and Slovenian–Hungarian–South Slovakian Paleogene basins, although the obliquity of convergence, and the suggested forearc and retroarc position (Jablonsky et al. 1994, Tari et al. 1993) would not modify considerably the local structural geometry. Despite local problems, there is no doubt on the integrity of the Alpine-Carpathian orogen and the lack of a special 'Pannonian domain'.

One of the major structural elements of the entire Alpine–Carpathian–Pannonian–Dinaridic orogen is the Periadriatic Fault (PAF) which goes subsurface in north–eastern Slovenia. Following Kovács and Kázmér (1985), Balla (1984), Csontos et al. (1992, 1998), Kováč et al. (1994) the Hungarian (and hopefully all other "Carpathian") point of view is clear, that the continuation of this fault is within the "Mid-Hungarian Shear Zone", although the importance of any particular fault of this zone can be debated. Because the Periadriatic Fault and Mid-Hungarian Shear Zone is highly curved, it is improbable (although not completely excluded) that the entire fault system could still slip with a coherent kinematics. This shows that a unified, kinematically coherent PAF–MHZ system is a structural element of a certain time period, and was dismembered later (into PAF and MHZ) and then evolved separately. It is thus illogical to speak about *continuation* of the PAF into the MHZ in neotectonics; we can only speak occasional *connection* of the two fault zones.

Major issue is kinematics of the two fault zones, and the timing of the kinematics. Although the Western Alpine PAF seems to be better constrained in both respects (Schmid et al. 1996), the Pannonian area has still something to add. Intrusion of most of the tonalitic bodies along the PAF around ~30 Ma may indicate an important tectonic reorganisation, probably the establishment of dextral slip. This magmatism can be traced up to the Darnó Zone in NE Hungary (Benedek et al. 2004). On the other hand, this date may coincide with the major and dramatic subsidence in the whole Slovenian–Hungarian–South Slovakian Paleogene basin. Up to this date, the Paleogene basin was unique, but later was separated by the PAF–MHZ fault system.

Extrusion/escape tectonics is considered as a major event in the structural evolution. The displacing Alcapa unit is suggested to incorporate the eastern part of the Eastern Alps, the Western Carpathians and the northern and western Pannonian basin (Csontos et al. 1992). The process resulted in eastward motion of substratum of future Pannonian basin toward the stable European platform and ultimately resulted in shortening within and subduction below the Carpathian orogen.

Despite considerable research, physical boundaries of the Alcapa and the time span of its existence still merit a debate. The birth of Alcapa coincides with the onset displacement along its boundaries. To the west, extension of Penninic units of the Eastern Alps and boundary strike-slips are generally considered to be active from Early Miocene (Ratschbacher et al. 1989), from around 25 Ma. During the eastward motion of the extrusion, new nappes and slices of the former flysch basin(s) were accreted to the relatively rigid

Alcapa in its north-eastern periphery. In a strict sense, the consolidated flysch units became part of the Alcapa unit, because the major boundary structural element(s) were shifted from the front of one to the other (flysch) units.

Integration of paleomagnetic data may show differences between the Alpine and Carpatho-Pannonian segments of the Alcapa during the late Early Miocene (Márton 2001). While crustal extension ("orogenic collapse") and boundary strike-slip faults seem to persist in the early to mid-Miocene in the Eastern Alps, no notable extension existed before 19–18 Ma in Pannonia. The onset of upper crustal faulting coincides with the first rotation event, 30–50 ° counterclockwise rotation of the Western Carpathians – northern Pannonia between ~18–17 Ma. Because this rotation does not occur in the Eastern Alps, the rigid connection of western ('Alpine') and eastern Alcapa terminated (Márton and Fodor 2003). On the other hand, this rotation changed completely the southern boundary of the extruding Alcapa. While the Periadriatic Fault does not seem to be rotated, its continuation to Hungary, the Mid-Hungarian Zone sensu lato suffered the rotation. In consequence, the dextral slip along the Periadriatic Fault was transferred from the Mid-Hungarian to other fault zones in southern Pannonia or in the northernmost Dinarides (Fodor et al. 1998).

The Alcapa unit suffered considerable rearrangement at its south–eastern boundary. The Alcapa and the southern Tisza–Dacia units juxtaposed prior to or during the first major rifting phase (~18–14 Ma). From that moment, the Pannonian part of the Alcapa and the Tisza–Dacia units were moving eastward in a coordinated manner and their distinction as separate units is largely weakened. In my view, the only reason, which could still validate the usage of Alcapa and Tisza–Dacia units would be the verification of considerable strike-slip displacement between the two units, along the southern parts of the MHZ and its Eastern Carpathian continuation. In the lack of large displacement, I would say "Pannonian basin" and "Carpathians" or simply "Carpathian–Pannonian unit".

These considerations suggest that in the west the Alcapa was disintegrated around ~18 Ma into coherently moving, but distinct sub-units while increased by accreted new (flysch) units in the east. To solve the "terminological problem" we may have two solutions: (1) we can keep the term Alcapa from 25 Ma to 17 or 14 Ma, keeping in mind its continuous volume changes and accept at the same time that the rotations and rifting of the Pannonian basin (~18–14 Ma) is still part of the extrusion process, having affected a disintegrated unit; (2) we restrict the usage of Alcapa to post-25 to pre-18 Ma extrusion and speak about "rifting of the Pannonian–Western Carpathian–Eastern Alpine domain" after 18 Ma.

The disadvantage of the usage of the term Alcapa is more visible, when considering units during the late Miocene, the classical "post-rift phase", ca 11–6 Ma (Horváth 1993). Data available for me suggest that during the late Miocene subduction and frontal accretion ceased all along the Carpathians (expect probably the SE corner, Maţenco and Bertotti 2000), meaning a solid and fixed connection of the Carpathians and the European foreland. In this scenario, the definition of any Carpathian–Pannonian units would need a much better resolution of displacement rates along possible boundary structures than we have actually – there is only one tectonic unit merged with Europe(?).

The maintenance of the name Alcapa is more frustrating for the neotectonic phase (ca. 6–0 Ma). GPS-derived velocities, and structural data would indicate dextral motion along the Slovenian PAL, (Weber et al. 2005) a continuous (or reactivated?) eastward motion of the easternmost Alps, westernmost Pannonia and westernmost Carpathians, while the "north–eastern corner" (formerly part of the Miocene Alcapa) seems to be fixed to the European plate (Grenerczy and Kenyeres 2005). The projection back in time of the GPS data would result an "intra-Alcapa" accommodation zone with ca. 1 mm/y shortening. Despite similarities of certain structural elements, the boundaries of the Miocene Alcapa unit and neotectonic 'alter ego' are not the same, the southern PAF–MHZ was disintegrated and are moving with markedly different kinematics. This is the reason we used temporal names for three major neotectonic blocks of the Carpathian–Pannonian domain (Fodor et al. 2005) – hoping good suggestions and also better understanding of neotectonic movements and units.

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Kinematic and Rheological Model of Exhumation of High Pressure Granulites in the Variscan Orogenic Root: Example of the Blanský Les Granulite, Bohemian Massif, Czech Republic

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The structural pattern of the south Bohemian Moldanubian domain in the broad surroundings of Blanský les, Prachatice and Křišťanov granulite massifs is dominated by pervasive moderately NW dipping amphibolite facies foliation. This fabric parallels the trend of the Brunian and Saxothuringian margins and its attitude can be correlated to the flat lying amphibolite facies foliation dominating the eastern Moldanubian, ascribed by Schulmann et al. (2005) to a flow of Moldanubian rocks over the Brunia margin. In the vicinity of the granulite massifs this fabric is being disturbed to form irregular patterns passively adjusting a fold-like shape of rheologically stronger granulite massifs. Inside these rigid bodies, older Variscan fabrics have been well preserved, documenting two-stage exhumation history of the felsic granulites. Based on the kinematic model of granulite deformation history we use these fabrics to unravel the far-field stress changes in space and time during the Variscan collision.

The relict granulite facies fabrics allow for a reconstruction of the early exhumation mechanism in form of a vertical ascent channel because the subsequent cooling history froze these fabrics enabling us to observe them continuously on a km-scale. Analysis of the corresponding microstructure reveals very high plastic strain of quartz while the prevailing fine-grained feldspar dominated matrix shows only slight plastic deformation. Together with the presence of syndeformational intergranular partial melt this implies highly ductile behavior attaining characteristics of viscous flow. This offers an efficient way to transport the relatively small portions of lower crust rapidly upwards through the orogenic root.

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