Paleogeography of the Central Paratethys during the Karpatian and Badenian

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Introduction

The Karpatian and Badenian (uppermost Early Miocene to lowermost Middle Miocene) is exactly the time span when major paleogeographic changes occurred in the Carpathian--Pannonian realm and not earlier or later. That was the time when two separately moving lithosphere fragments Alcapa and Tisza – Dacia were linked together, when started to be formed the Carpathian chain in its present form, as well as when subsidence resulted in development of the Pannonian basin system.

Models of the Central Paratethys region paleogeography during the Karpatian and Badenian (17.3 – 13 MA) are based in two important parts: (1) models of sedimentary basins in the subduction zone and accretionary wedge of the Alpine – Carpathian chain and (2) models of the overriding plates movement and extent of the stretching during the back arc basin formation processes (Kováč et al. 2003).

Palinspastic model of the Karpatian paleogeography

The early Karpatian sedimentary basins of the present **Outer Carpathians** were represented by residual flysch troughs and foredeep basins with molasse deposits (Fig. 1). The axis of the residual flysch troughs ran along the active front of the Eastern Carpathian accretionary wedge in the Skole and Boryslav-Pokuttya zone in the northeast. In deep marine basins covering both the southern part of the North European Platform and the marginal part of the Outer Carpathian overthrust (Skole and Boryslav-Pokuttya sub-basins) marly shales were deposited (during the late Ottnangian/early Karpatian). On the platform it was the upper part of the Zebrzydowice Fm., whereas the residual flysch basin was filled with the upper Krosno and Vorotyscha Fms. in Poland and upper Krosno and Polyanica Fms. in Ukraine (Oszczypko, Oszczypko-Clowes 2003, Oszczypko et al. in print). In Romania the deposition within the Tarcau and Marginal Folds Units was represented by the shallow water Doftana Molasse Fm. (Marunteanu 2002).

The load of the orogene front, as well as the deep subsurface load of the downgoing plate, led to development of a flexure of the platform margin (Zoetemeier et al. 1999). The **Car-**

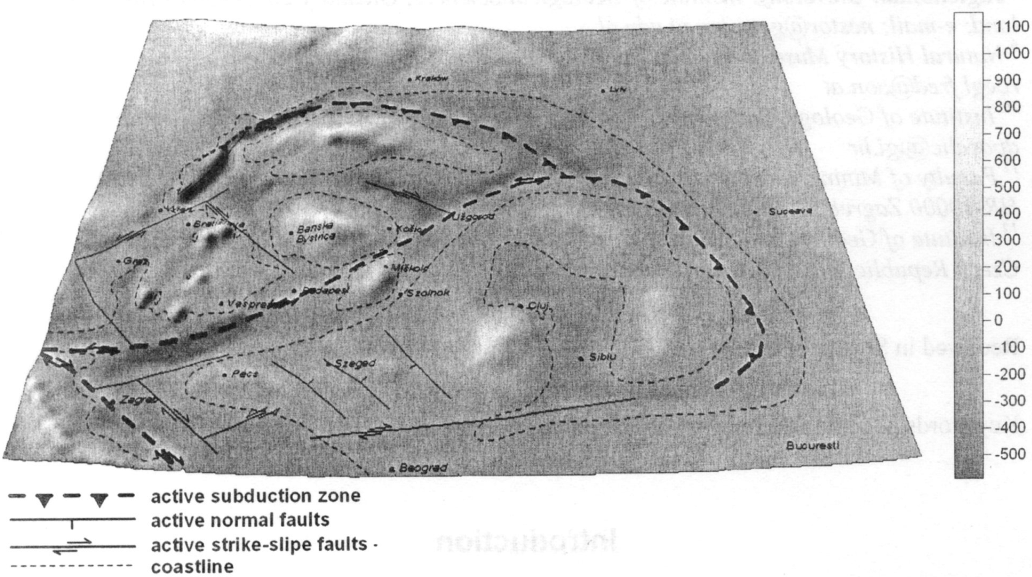

Figure 1. Paleogeography of the Karpatian (17.3 – 16.4 MA) based in palinspastic model of the Central Paratethys realm with presupposed paleorelief of continental parts of the Carpathian – Pannonian domain and paleodepth of sedimentary basins.

pathian Foredeep basins were situated partly on the top of the advancing nappes and partly on slopes of the platform. The formations firstly of an „inner“ and later „outer“ zone of the foredeep documents the gradual advance of the Outer Carpathian nappes toward the platform foreland. The foredeep deposits are at present represented by autochthonous and allochthonous sediments in various position: overlying platform basement covered/or not covered by Carpathian nappes, forming thrust sheets in front of the flysch zone accretionary prism or they are folded overlying the Outer Carpathian nappe units in form of a piggy-back basin fill.

The **Pannonian back arc basin** area, in the hinterland of the developing Carpathian mountain chain, was under influence of the asthenosphere mantle uplift leading to local changes in paleogeography. This consideration is supported by the observed isolation of sedimentary basins with brackish/anoxic or fresh water to alluvial sedimentary environments (Vass 1998) and widespread acid volcanic activity „first rhyolite tuff“ during the Ottnangian (Pécskay et al. 1995), followed by the early rifting process connected or even driven/preceded by the uplift of the asthenospheric mantle (Konečný et al. 2002). The Karpatian initial rifting phase was accompanied by rapid sedimentation in the basins and depocentres of the Pannonian back arc basin system. At first, the basin subsidence caused accumulation of terrestrial, alluvial, deltaic and brackish sedimentary successions which preceded marine transgression in many places.

The Ottnangian – early Karpatian paleostress field in the western part of the area – Eastern Alps and Dinarides can be characterized by N-S oriented compression. During the Ottnangian, partly hypothetically, we can count with activity of the dextral strike slip faults, of WNW-ESE and NW-SE direction accommodating compression in the Alpine and Dinaridic segments (Fodor et al. 1999). Along Periadriatic lineament, Drava and Sava fault zones started sedimentation of the Ottnangian fresh-water lacustrine deposits in the Slovenia and Northern Croatia (Pavelić 2001). The eastern part of the Central Paratethys area was under influence of the compression perpendicular to the developing accretionary wedge of the Carpathian chain. Compression bound to collision zone had N-S orientation in the north and NE-SW to E-W orientation in the east.

In the back arc basin region (during the Karpatian) WSW-ENE and NE-SW sinistral strike slips faults (SEMP, MML fault zones) in the Eastern Alps, Western Carpathians and along the Mid Hungarian shear zone were activated. From the eastern boundary of the Alcapa microplate dextral strike slip fault system oriented NW-SE can be documented from northern part of the Transcarpathian Basin – the East Slovak Basin (Kováč et al. 1995). Dextral movement along this boundary fault zone also compensated the post-Ottnangian counterclockwise rotation of the Western Carpathians (Kováč, Márton 1998). Similar NW-SE to NNW-SSE trending dextral strike slips were located in the Eastern Alps (Pöls-Lavanttal-Fault System) and western part of the Central Carpathians in Danube Basin (Fig. 1).

The basin opening was beside horizontal displacements (Vienna Basin) caused also by stretching of microplates. The formation of the Western Carpathian – North Pannonian basins depocentres mirrors stretching of the Alcapa microplate in E-W to NE-SW direction. It is documented by N-S to NNE-SSW trending normal and listric faults in the west (Styrian and Danube Basins) and N-S to NW-SE trending normal and listric faults in the east (Novohrad--Nógrád and East Slovak Basins) during this time. In the west (Danube Basin) the main faults are inclined toward E-SE, while on the east the main faults are inclined towards SW (East Slovakian Basin). The brittle deformations fan-shape fault pattern compensating the Alcapa microplate rotation was much clearly demostrated after the Karpatian due to the Middle Miocene structural development as well as Western Carpathians counterclockwise rotations

(Kováč, Márton 1998, Fodor et al. 1999). The basin formation associated with structural unroofing along low angle normal faults, what is well documented from the Danube Basin in the west or East Slovakian Basin in the eastern part of the Alcapa microplate (Tari et al. 1992, Kováč P. et al. 1994, Soták et al. 1994, Hrušecký et al. 1998).

In the area of North Croatia the early Karpatian sedimentation was controlled by strong subsidence in several elongated half-grabens of the NW-SE direction due to NE-SW oriented extension (Prelogović et al. 1995, Pavelić 2001). Similar structural pattern with NW-SE trending normal faults we can observe also towards east in the southern Tisza microplate, where the faults opened valleys entering the Karpatian sea of the Central Paratethys from the south.

During the Late Karpatian development of the NE-SW oriented sinistral strike slip faults can be documented in the whole area of the Pannonian back-arc basin. We consider that it was caused by the „active elongation" of both microplates amalgamated together in this time (Csontos 1995). These strike slip faults connected the locations of stretching of the inhomogeneous lithosphere of the Carpathian-Pannonian domain towards northeast-east. Such faults can be documented in the North Croatia at the Dinaride-Pannonian basin junction (Pavelić 2001), in the East Alpine – Western Carpathian area (SEMP and MML) – in the Vienna Basin (Kováč et al. 2004), Danube Basin (Kováč et al. 1998) as well as in the East Slovakian Basin, where they are of NE-SW to ENE-WSW orientation (Kováč et al. 1995). The Mid-Hungarian tectonic zone obtained character of transfer faults between the strongly extended lithospheric fragments.

Palinspastic model of the Badenian paleogeography

The Badenian geodynamic development of the Central Paratethys realm was still highly influenced by subduction in front of the Carpathians and by synrift development of an back arc basin system in the Pannonian domain. The different driving forces, the changing geometry of external Carpathian thrust system might have lead to a spatially and temporally variable stress field (Nemčok et al. 1998, Fodor et al. 1999, Kováč 2000), and induce different types of magmatism; extension-dominated in the western and subduction-related in the eastern Pannonian-Carpathian realm (Pécskay et al. 1995, Harangi 2001, Konečný et al. 2002).

Formation of the **Outer Carpathians** accretionary wedge was active only in the northern, northeastern and eastern segments of the mountain chain, in the front of the Western and Eastern Carpathians (Fig. 2). The Badenian stacking of thrust sheets was accompanied by compression oriented perpendicularly to the orogene axis, generally towards the northeast – east in the Western and Eastern Carpathians (Kováč et al. 1998). The westernmost part of the Carpathians formed an exception and it was inactive since Middle Badenian. In that western part the late Badenian paleostress field was marked by (W) NW-(E)SE extension in the Vienna Basin (Nemčok et al. 1989, 1993, Fodor 1995). The Southern Carpathians characterised a paleostress field with NW-SE oriented main compression (Maţenco et al. 1997).

Active thrusting of the Outer Carpathians resulted in the Subsilesian and Silesian units nappes movement in the northern segment of the Western Carpathians, while the Skole-Skiba and Tarcău nappes thrusted over Boryslav-Pokuttya and Marginal Fold units in the northeastern and Eastern Carpathians (Sandulescu 1988). Uplift of the accretionary wedge was not continuous along the whole Carpathian loop. The northern part started to emerge, unlike the eastern part which stayed submerged below the sea level, documented by the presence of the Lower Badenian sediments on the Tarcău nappe (Micu 1990).

The **Carpathian Foredeep** development is characterized by a migration of depocentres from West toward East during the Badenian (Meulenkamp et al. 1996). In the westernmost

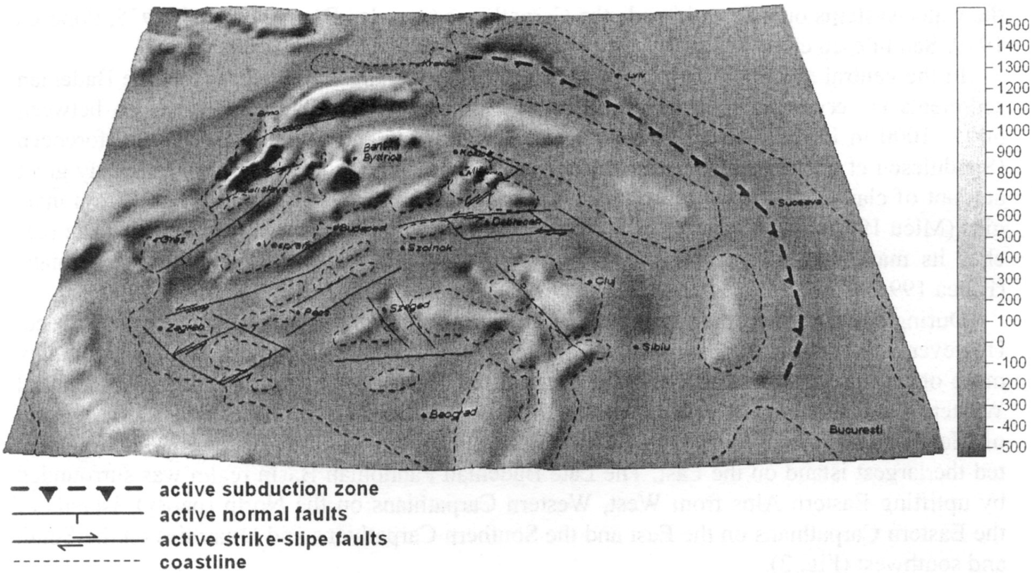

Figure 2. Paleogeography of the Late Badenian (13.6 – 13 MA) based in palinspastic model of the Central Paratethys realm with presupposed paleorelief of continental parts of the Carpathian – Pannonian domain and paleodepth of sedimentary basins.

part (Moravia, Czech Republic) the sedimentation already ended after the Early Badenian (Kováč et al. 1989). The "Middle Badenian" evaporite event, preceding the Late Badenian transgression, can be followed from the north towards southeast along the whole foredeep. It is dated to the boundary of the calcareous nannoplankton zone NN5 and NN6, or to the base of NN6 (sensu Martini 1971). Although, according some data of the Polish authors, in the northern part of the foredeep duration of the evaporite formation was heterochronous and lasted longer time during the whole Upper Badenian (Oszczypko 1997).

After "Middle Badenian" salinity crisis telescopic shortening of the Outer Western Carpathians accretionary wedge took place and the active orogene front moved 20 – 30 km towards northeast (Oszczypko 1997, Andreyeva-Grigorovich et al. 1997, 2003). During the Late Badenian the foredeep depocentres with the maximal subsidence developed along the Western and Eastern Carpathians junction mirroring not only the weight of the Carpathian thrust stack (Oszczypko 1997) but also deep subsurface load of the downgoing plate (Krzywiec, Jochym 1997, Krzywiec 1997) and its flexural deformation (Zoetemeier et al. 1999). Apart from development of the foredeep depocentres also a wide area of the Carpathian foreland was flooded.

For the understanding of the paleogeographical setting of the Eastern Carpathians during the Late Badenian an important moment is, that deep-sea, offshore deposits (Upper Badenian age) are folded into the Tarcău and Marginal Folds nappes: the radiolarian shale and the *Spiratella* (pteropode-bearing) marl. It means practically, that some parts of the Moldavides were still in sub-marine position during the Late Badenian and most of the East Carpathian chain was only a raw of major islands this time (Fig. 2). Among them several sea-troughs connected the water-systems outside and inside the Carpathians (see also Dumitrica et al. 1975, Popescu 1979, Sandulescu et al. 1981).

In the central and southern part of the Eastern Carpathians the thickness of the Badenian sediments is very variable and depends on the size of platform flexure. It ranges between 500 – 1000 m in the North and about 1000 – 1500 m in the southern part of the foredeep (Sandulescu et al. 1981; Dicea, 1995, 1996). The maturity of sandstones and relatively great amount of clays and silt clays support the absence of an "active" relief along the basin margins (Micu 1990). The thickness of the Badenian deposits covering the Moesian Platform reaches its maximum thickness (about 500 – 1000 m) in front of the Southern Carpathians (Dicea 1996).

During the Badenian the greatest part of the **Pannonian back-arc basin** area subsided. However, a narrow zone northwards of the Mid Hungarian tectonic zone was represented by more or less uplifted areas. That were the Transdanubian Range (partly), Bükk and Central Western Carpathians (partly) Mts. South of the Mid Hungarian tectonic zone an archipelago of islands consisting of the Tisza – Dacia microplate units is known, Apuseny Mts. represented the largest island on the East. The Late Badenian Pannonian Basin realm was surrounded by uplifting Eastern Alps from West, Western Carpathians on the North (partly), islands of the Eastern Carpathians on the East and the Southern Carpathians and Dinarides on the South and southwest (Fig. 2).

In the hinterland of the Outer Carpathian accretionary wedge nappe pile, the evolution of the Pannonian back-arc basin was characterised by variable tectonic styles and fault mechanisms during the Badenian. In the northwestern and western part a number of normal faults of NNE-SSW to NE-SW orientation were activated, often bearing character of sinistral oblique-normal slips. These faults were partly connected to low angle detachment faults, which continued to accumulate large normal offsets following their early Miocene initiation (Tari 1996). On the other hand, in the southwestern part of the Pannonian Basin system, in North Croatian Basin, the NE-SW to ENE-WSW oriented faults operated during the whole Badenian. Similarly the ENE-WSW oriented faults, mainly located along the broad Mid-Hungarian shear zone, gain left-lateral strike slip character during the latest Badenian and Sarmatian. These faults, accommodated the „elongation" of southern Tisza-Dacia unit, induced by the still active subduction in front of the Eastern Carpathian orogene (Csontos, Horváth 1995, Fodor et al. 1999).

Important crustal stretching of both the Alcapa and Tisza-Dacia microplates led to structural unroofing of metamorphic core complexes by low-angle detachment faults (Tari et al. 1992, Tari 1996). The occurrences of core complexes (loci of large extension) are located in the broad transitional zone between the Eastern Alps and Pannonian Basin and ductile to brittle extension exhumed different parts of the Alpine-Carpathian nappe pile. The deepest exhumation reached the Peninic unit in the Rechnitz windows (Tari et al. 1992, Tari 1994, 1996, Dunkl 1992, Dunkl, Demény 1997), while shallower Austroalpine units were unroofed in the Pohorje (Fodor et al. 2003) and in the Považský Inovec Mts. (Plašienka 1995). Deep exhumation occurred in the eastern part of the Alcapa microplate, where the "Peninic type" Inatchevo – Kritchevo unit was uplifted to the level of the Miocene strata in the northern part of the Transcarpathian Basin – in the East Slovak Basin (Soták et al. 1993). Exhumation of metamorphic rocks also associated the development of some deep syn-rift grabens below the Great Hungarian Plain (Tari et al. 1992, Tari 1996).

Related to these extensional or transtensional structures, syn-rift subsidence continued during the Badenian in several major depocentres, like the Vienna, Danube, Styrian, Zala, basins in the West, North Croatian Basins in the Southwest, Békés, Makó, Derecske etc. basins in central and eastern part of the Pannonian Basin realm and the Transcarpathian Basin in the East. The basin development was controlled by extensional stress field (Csontos et al. 1991, Kováč et al. 1994, 1997, Fodor et al. 2002).

Conclusions

The **Karpatian paleogeography** of the Central Paratethys realm (Fig. 1) can be characterized by transgression due to the tectonic activity and the global sea level rise. The marine flooding penetrated through the presumed „Trans Dinaridic Corridor" in the Slovenia and North Croatia following the Mid-Hungarian tectonic zone towards the Pannonian Basin. The Karpatian marine sediments in North Croatian sector of Pannonian Basin System (Pavelić 2001) conformably overlie the Ottnangian fresh-water lacustrine deposits (Šikić, 1968) and belong to the early syn-rift phase of the Drava and Sava Basins, from where widened the marine flooding towards Mura-Zala and the Styrian Basins. Along the southeastern margin of the Transdanubian Range and the northern border of the Mecsek Mts. the marine transgression crossed the North Hungarian – South Slovakian Novohrad-Nógrád Basin. The related paleovalleys descending from the Western Carpathians were also flooded (territory of the present Central Slovakian Neovolcanites). The sea transgression reached the Bánovská kotlina, Northern Danube and Vienna Basins. From here the sea widened towards the Carpathian Foredeep in the west and along the Váh river valley and via the peri-Klippen Belt Zone progressed toward the east. The East Slovakia Basin was connected with the Karpatian sea from the south-west (Novohrad-Nógrád Basin), as well as from the northwest via peri-Klippen Belt area (Kováč 2000). The lagoonal, brackish to freshwater deposits of the Ottnangian – Karpatian stage are known from the Transylvanian Basin and Eastern Carpathian Foredeep. Marine deposits containing *Praeorbulina* in foraminifera associations can not be regarded as Karpatian because they belong to the Langhian (Early Badenian) transgression.

The early **Badenian paleogeography** of the Central Paratethys realm is characterised by a widespread marine transgression after retreat of the Karpatian marine flooding and erosion on many places of the Carpathian – Pannonian domain. The sea flooding from the Mediterranean via Slovenia, northern Croatia ("Trans Dinaride Corridor") and Styrian Basin reaching the Pannonian back arc basin area and continuing toward the Carpathian Foredeep might lead across the Vienna Basin on the West and above straits in Carpathian mountain chain, which started to emerge during this time, especially in the North. The "southern" peak of thermophilic mollusc taxa resulted from immigration from the Mediterranean Sea via that gate way. Hypotheses about a connection via the southeast – e.g. the Vardar Corridor through the Axios Valley – are still controversial (Rögl 1998, Studencka et al. 1998).

The "Middle Badenian" closing of the southeastern seaways caused the salinity crisis in the eastern parts of the Central Paratethys. Thick evaporite sediments, above all table salt and gypsum were deposited in the northern and eastern part of the Carpathian Foredeep, in the Transcarpathian and Transylvanian basins (Ney et al. 1974, Sandulescu 1988). This regional sea level fall can be correlated with the global sea level fall at the end of TB 2.4 and with the lowstand at the beginning of the TB 2.5 cycle (sensu Haq 1991), e.g. at the Middle/Upper Badenian boundary or at the end of the calcareous nannoplankton Zone NN 5 and the beginning of NN 6 Zone (13.6 Ma).

The Late Badenian is a short time interval but very important from the point of view of the Central Paratethys paleogeography (Fig. 2). It represents the latest full marine flooding of the whole back arc basin and a great part (northern and eastern) of the foredeep. This transgressive event caused also the disappearing of some terrestrial ecosystems situated nearby coastal lines (Sabol, Holec 2002).The main problem is to create a model of sea connections, because the western "Trans Dinaride Corridor" was closed at that time (Rögl, Steininger 1983) and supposed strait towards the Eastern Mediterranean has no real proofs till now.

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