Miocene-Recent magmatism and geodynamic processes in the Carpathian-Pannonian region - relations with Balkan and Aegean areas

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This presentation will review and interpret recent data on magmatic processes in the Carpathian – Pannonian Region (CPR) during Early Miocene to Recent times, and will compare them with contemporaneous magmatism in the Balkan Peninsula and the Aegean, all of which belong to the Eastern Mediterranean realm. This geodynamic system was controlled by the collision of part of Africa (Adria or Apulia) with Europe that generated the Alps to the north, the Dinaride-Hellenide belt to the west, and caused the extrusion and inversion tectonics in the CPR. The present-day tectonic configuration is a result of the Cretaceous to Neogene Africa–Eurasia convergence and collision that formed a complex lithosphere supplied with numerous subduction components. The CPR contains Neogene to Quaternary magmatic rocks of highly diverse compositions that were generated in response to complex post-collisional tectonic processes. These processes formed back-arc extensional basins in response to an interplay of compression and extension (e.g. subduction with roll-back, collision, slab break-off, delamination, strike-slip tectonics, core complex type extension, and block rotations) of two microplates: Alcapa and Tisia (Tisza)-Dacia. Competition between the different tectonic processes (syn- and diachronous) on both local and regional scale caused variations in the associated magmatism that were mainly a result of extensional processes, the rheological properties, and the specific lithosphere composition of the two microplates. No volcanic activity directly related to pre-collisional subduction is recorded in the CPR area. Meanwhile in the Balkans a regional extensional tectonic setting developed in Oligocene-Miocene times and progressed to the present-day in the Aegean where it was dominantly associated with calc-alkaline, ultrapotassic and Na-alkaline magmatism and formation of small sedimentary basins.

Major oxide, trace element, and isotopic data of lavas and mantle xenoliths from the CPR suggest that subduction components were preserved in the lithospheric mantle after the Cretaceous-Miocene subduction and were reactivated by asthenosphere uprise via various processes (subduction roll-back, rotation-induced extension, slab detachment, slab-break-off or slab-tearing). Changes in the composition of the mantle through time support various geodynamic scenarios that are linked to the evolution of the main blocks and their boundary relations: Alcapa (1), Tisia-Dacia (2) and Balkans (3):

1a. In the Western Carpathians and Pannonian Basin, magmatism occurred in a back-arc setting producing felsic volcanic rocks at 21-18 Ma, followed at 18-8 Ma by felsic and intermediate calc-alkaline lavas and ended with Na-alkaline basaltic volcanism (10-0.1 Ma). Volcanism became younger towards the north. Geochemical data imply both a change in source from a crustal one, through a mixed crustal/mantle source, to a mantle source with a decrease of the subduction component in the mantle lithosphere through time. Garnet-bearing varieties occurred at 16.4-15 Ma. Extrusion tectonics, block rotation, subduction roll-back and continental collision triggered partial melting by delamination and/or asthenosphere upwelling. Generation of Na-alkaline magmatism at the western margin of Alcapa suggests a north-east-directed asthenosphere mantle flow acting as small finger plumes that caused high thermal anomalies at the base of the lithosphere and triggered magma generation along NW-SE strike-slip faults. The process was most likely controlled by mantle perturbations resulting from the counterclockwise rotation of the Adriatic microplate and tectonic inversion in the Pannonian Basin. The continuous volcanic activity in central Slovakia, firstly as calc-alkaline (16.5-11 Ma), then as transitional calc-alkaline (11-8 Ma) and finally as Na-alkaline basalts (8-0.13 Ma) supports a mantle plume scenario, with increasing asthenospheric input through time;

1b. The westernmost Pannonian sub-basins (Styrian basin and adjacent areas) contain felsic and intermediate calc-alkaline, K-alkaline and ultrapotassic volcanic rocks generated at 17.5-14 Ma. They are related to extension and extrusion tectonics and core-complex generation at 21.9-13.4 Ma that produced strong mantle perturbations and triggered melt generation. Na-alkaline basalts occurred at 11-12 Ma and ended at 4-1.8 Ma. They show heterogeneous isotopic features that suggest an association with the Adria push and tectonic inversion, causing a north-east directed asthenospheric mantle flow;

1c. In the north-westernmost part of the Pannonian Basin, at 15-9 Ma, felsic and normal calc-alkaline volcanism erupted in the Transcarpathian basin at a triple junction between Alcapa, Tisia-Dacia and the European foreland. This is a result of extension via counter-clock rotation of Alcapa, causing core-complex exhumation. Geochemical studies indicate a heterogeneous lithospheric mantle source associated with fractionation-assimilation processes in crustal magma chambers. Melting was most likely triggered by back-arc rotational extension and asthenosphere uprise;

2a. Calc-alkaline magmatism generated at 12-8 Ma in the northern part of the Tisia-Dacia block follows the Dragoş Vodă-Bogdan Vodă transcurrent fault and is entirely intrusive, ranging from basalts to rhyolites. Each body evolved independently with specific fractionation, crustal assimilation and/or magma mixing processes, suggesting decompression melting of the local heterogeneous mantle lithosphere. Garnet-bearing varieties occurred at 9.5-10.5 Ma. Sinistral transtensional stress regimes at 12-10 Ma along the transcurrent fault system controlled the generation and emplacement of the intrusive bodies. This may be the result of oblique convergence of Tisia–Dacia with the NW–SE striking European margin, evidenced by eastward thrusting in the external Miocene thrust belt;

2b. Calc-alkaline and adakite-like magmas were erupted in the Apuseni Mountains at 15-9 Ma. Garnet-bearing rocks occurred at 13-12 Ma. Lithosphere breakup during extreme block rotations (~60 degree) at 14-12 Ma was responsible for extension with core-complex formation at the easternmost continuation of Bekes basin. This led to decompression melting of an enriched lithospheric source. Magmatic activity ended with small volume Na-alkaline basalts (2.5 Ma), shoshonitic (K-alkalic) at 1.6 Ma and ultrapotassic magmas at 1.3 Ma. This suggests a close relationship with Pliocene inversion tectonics along the South Transylvanian fault due to the Adria push, with small volume melt generation from diverse lithospheric and asthenospheric sources;

2c. Calc-alkaline magmatism occurred along the easternmost margin of Tisia-Dacia forming the Călimani-Gurghiu-North Harghita volcanic chain, with diminishing age and volume southwards at 10-3.9 Ma. This marked the end of subduction-related magmatism along the post-collision front of the European convergent plate margin. Magma generation was associated with progressive break-off of a subducted slab and asthenosphere uprise. Fractionation and crustal assimilation were typical;

2d. At ca. 3 Ma, magma compositions changed in South Harghita to adakite-like calc-alkaline and continued until recent times (< 0.03 Ma) interrupted at 1.6-1.2 Ma by simultaneous generation of Na and K alkaline varieties in nearby areas, suggestive of various sources and melting mechanism. This complex magmatism situated in front of the Moesian platform was associated with two main geodynamic events: (a) slab-pull and steepening, with opening of a tear-window in the vertical Vrancea lithospheric block hanging into the asthenospheric mantle (forming adakite-like calc-alkaline magmas) and (b) inversion tectonics along reactivated fault systems that allowed decompression melting of asthenospheric and lithospheric sources, thus generating the Na and K-alkaline magmas;

3a. Calc-alkaline volcanic rocks occur at the southern border of Tisia–Dacia with the Dinarides along the Drava–Sava depression in several successive periods between 22.8 and 7.4 Ma, with K-alkaline rocks at 17.5-15.4 and 9.8-7.4 Ma. The area acted as a strike-slip fault at the terrane boundary that was probably reactivated several times in transtensional mode, generating magmas via decompression melting of heterogeneous lithospheric mantle, also influenced by fractionation and assimilation;

3b. Miocene-Pliocene magmatism characterizes the Serbian and FYR Macedonian part of the Vardar zone. Ultrapotassic, shoshonitic and high K-calc-alkaline magmas were erupted at 23-21 Ma; at 12.9-10 shoshonitic rocks were generated and ended with K-potassic and ultrapotassic magmas at 9.1-1.5 Ma, becoming younger toward the south. Magmas were generated in a metasomatized depleted mantle related to different extensional events in the Pannonian Basin and Aegean region;

3c. In the Thrace Evros basin, Early Miocene (22-19.5 Ma) calc-alkaline and K-alkaline rocks occur, suggesting an origin from both lithospheric mantle and crust related to post-collisional extensional processes and core complex exhumation. In the Thrace basin, Na-alkaline basalts occurred at 8.9-4.5 Ma; decompression melting of an asthenospheric source may be related to a westward mantle flow generated by the block movement along the North Anatolian fault system;

3d. The South Moesian block has an N-S line of Na-alkaline basalts that started in the Oligocene and become younger toward the south at 21.4-19.4 Ma. They have an asthenospheric source that may be connected to local fractures related to Tisia-Dacia block rotation movements around stable Moesia.

Thus, the mantle dynamics and melt generation in CPR and surrounding areas are echoes of many subduction, collision, rotation and extension processes of several microplates that acted variably in the convergence between Africa (chiefly Apulia) and Europe since the Cretaceous period until Recent time.

From local geology to global plate tectonics

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There is no plate tectonics modelling without local geological investigations, and a few square meters of well-dated radiolarian cherts can completely change a tectonic model. If ample geological information can be obtained from a given outcrop, the next step consisting in interpreting these in terms of geodynamic environment will often generate contradicting points of view. That is where the larger plate tectonics modelling will bring some constraints.

Most disagreements are rooted in 2D cross sectional approaches of local information, usually considering all the presently juxtaposed geological units as potential actors of a single geodynamic history. Plate tectonics modelling certainly helps in solving the exotic nature of a given unit, and it can be shown that large scale displacement of terranes is rather the rule than the exception.

This can be tested in the Pacific region during the last 250Ma. Terranes have been crossing this large expanse of water, colliding with each other, and then being re-dispersed from tropical to polar regions. Still, these processes are constrained through properly done local investigations. Similarly the Variscan terranes have experienced long distance travelling, from their peri-Gondwana position to their amalgamation along the Eurasian margin. Their final juxtaposition resulted from further displacement during the formation of Pangea. In this instance, the final juxtaposition cannot be used readily to decipher the wander path of these terranes, and only a well constrained plate tectonics model will offer a possible solution.

It is clear from our plate model that the European Variscan terranes occupied the whole border of Gondwana, from South China to South America. The different geodynamic settings along that margin allow defining the former location of the different terranes. The intra-alpine Variscan and Mediterranean terranes were located close to South China, the Iberian terranes were close to the Libyan-Egyptian part of Gondwana, and the Armorican terranes s.l. were located further west. The so-called Rheic margin of Gondwana experienced quite different geodynamic evolutions before the detachment of the Variscan terranes. This can be used as a guideline to put in place this amazing puzzle.

The western Tethyan realm is dominated by the closing of the Paleotethys and the concomitant opening of the Neotethys in the Permo-Triassic times. This process followed the assembly of Pangea and amalgamation of Variscan terranes. However, if continent-to-continent collision took place from the Alleghanian N-American domain to the west Mediterranean area, further east (from Italy to the Middle East) the southern margin of Eurasia remained an active margin. This generated the opening of numerous back-arc basins along that margin from the Late Permian to Late Triassic. The continuing subduction of Paleotethys northward also generated slab pull forces that triggered detachment of the Cimmerian ribbon terrane from Gondwana in the Permian, as did the Variscan terranes in the Devonian.