BANATITIC MAGMATISM IN EASTERN EUROPE WITH EMPHASIS ON ROMANIAN TERRITORY; OPINIONS ON THE PUBLISHED DATA

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This is a short compilation of the main published geochronological and petrological results regarding the Banatitic magmatism in the Eastern Europe with emphasis on Romania. The age data suggests that most of the magmatism was generated during Campanian (81–75 Ma). The bulk rock data proposes a mantle origin of magmas which have been affected by a complex processes involving fractional crystallization, assimilation and magma mixing with characteristic features for each individual area. Additionally, there is a debate about the direct subduction arc-related *vs*. post-collisional-related generation of Banatitic magmatism, which for the moment is controversial.

Key words: Banatite, Romania, geochemistry, geodynamics.

INTRODUCTION

The Banatitic magmatism, on Alpine-Mediterranean scale, is located in eastern Europe It is discontinuous and located as a belt (~20–80km wide), which currently takes the shape of the letter L (Fig. 1).

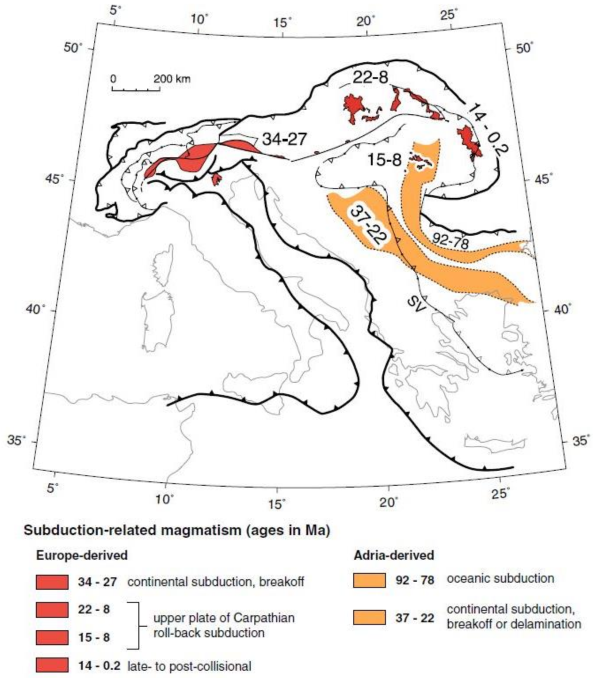

Figure 1 – Magmatic domains in the Alps, Carpathians and Dinarides with ages in millions of years (after Handy *et al*., 2014, with data from Harangi *et al.* (2006), Pécskay *et al.* (2006), Seghedi & Downes (2011) (Carpathian-Pannonian area), Rosenberg & Kissling, 2013 (Alps) and Schefer *et al.* (2011) (Dinaride).

It was generated during the Upper Cretaceous and is represented by a series of volcano-plutonic complexes, generally isolated. They extend, starting from the north in the Apuseni Mountains, continuing in Banat, Romania and crossing into Serbia (Timok), and then into the Panagyurishte–Srednogorie area of Bulgaria.The term Banatitic magmatic and metallogenetic belt is based on the petrographic name given to some diorites in the Banat area by von Cotta (1864). Popov *et al*., (2000, 2002) used the term Apuseni–Banat–Timok–Srednogorie belt (ABTS) for the whole area, a term generally accepted by most researchers. The intrusive complexes host ~15 porphyry deposits (e.g., Heinrich & Neubauer, 2002).

The ABTS magmatic province associated with the Upper Cretaceous is located in various tectonic situations and extends into northern Anatolia, Transcaucasia, eastern Iran and further east. The interruption in the western Black Sea area makes the correlation between the European and Asian segments difficult (e.g., Morelli &Barrier, 2004).

Among the more important works that studied the Banatites in Romania, should be noted: Giuşcă *et al*., (1965, 1969); Cioflica, Vlad, (1973); Berza *et al*., (1998); Ciobanu *et al*., (2002); Neubauer, (2002); Gallhofer *et al*., (2015); Vander Auwera *et al*., (2015).

GEOLOGICAL CONTEXT

In the following, the regional geological and tectonic framework within which the Banatitic magmatism developed will be discussed synthetically, with an accent for the territory of Romania.

In the Apuseni Mountains, which currently form an internal mountain range facing the Carpathians and the Dinarides, the major tectonic units belong to the tectonic blocks of Tisia (or Tisza), Dacia and the Jurassic ophiolitic zone of Mureș, assimilated to the East Vardar. The northern slopes are formed by a series of metamorphic basement tectonic nappes deformed in the Variscan orogeny and covered by Permian-Cretaceous sediments (e.g., Pană *et al*. 2002; Balintoni *et al*. 2009). On large areas, the gradual subsidence associated with the formation of grabens generated, according to some authors, a post-collisional sequence of the "Gosau" type (Balintoni, 1994; Willingshofer *et al*., 1999; Schuller, 2004; Merten *et al*., 2011). The beginning of the Banatitic magmatism is also associated with this moment. The South Apuseni represents a wide ophiolitic sequence of Middle Jurassic age, which is traversed and overlain by Upper Jurassic calc-alkaline igneous rocks associated with Upper Jurassic-Lower Cretaceous sedimentary deposits, all trapped in a series of north-facing tectonic nappes (e.g., Bortolotti *et al*., 2002; Nicolae &Saccani, 2003; Gallhofer *et al*, 2015).

South of the Mureş River, the Banatitic volcanics lie both over the ophiolites of the southern Apuseni and also on metamorphic formations, attributed to the southern Carpathians, the area of the crystalline basement of the Poiana Ruscă Mountains. In the southern Carpathians, the Banatites cross or overlie the upper metamorphic nappes of the basement (Supragetic/ Getic), but also the lower Danubiannappe, without affecting the Severin nappe. All these units belonging to the southern Carpathians are an integral part of the Dacia tectonic block that continues in the Balkan orogen from Serbia to Bulgaria (e.g., Csontos & Vörös, 2004; Schmid *et al*., 2008). Other basement units, such as Strandzha, Circum-Rhodope and Rhodope are attributed to the European continental margin (e.g., Schmid *et al*., 2008).

GEOCHRONOLOGY

Over time, many age determinations have been done for Banatitic magmatites. In particular, the K–Ar, Rb–Sr methods on whole rock and more recently U–Pb dating on zircon were used. Re-Os ages were also performed on molybdenite. A compilation of these ages was done by Ciobanu *et al*., (2002). Taking into account all the existing data results a large age range between 110–38 million years (Ma), but ca. 80% of the samples fall within the 85–65 Ma range. A more recent compilation from several sources was made by Gallhoffer (2015) based solely on more reliable $^{206}Pb/^{238}U$ dates on zircon (Fig. 2). According to it, the entire ABTS was active during the period 81–75 Ma, representing the Campanian subdivision of Upper Cretaceous.

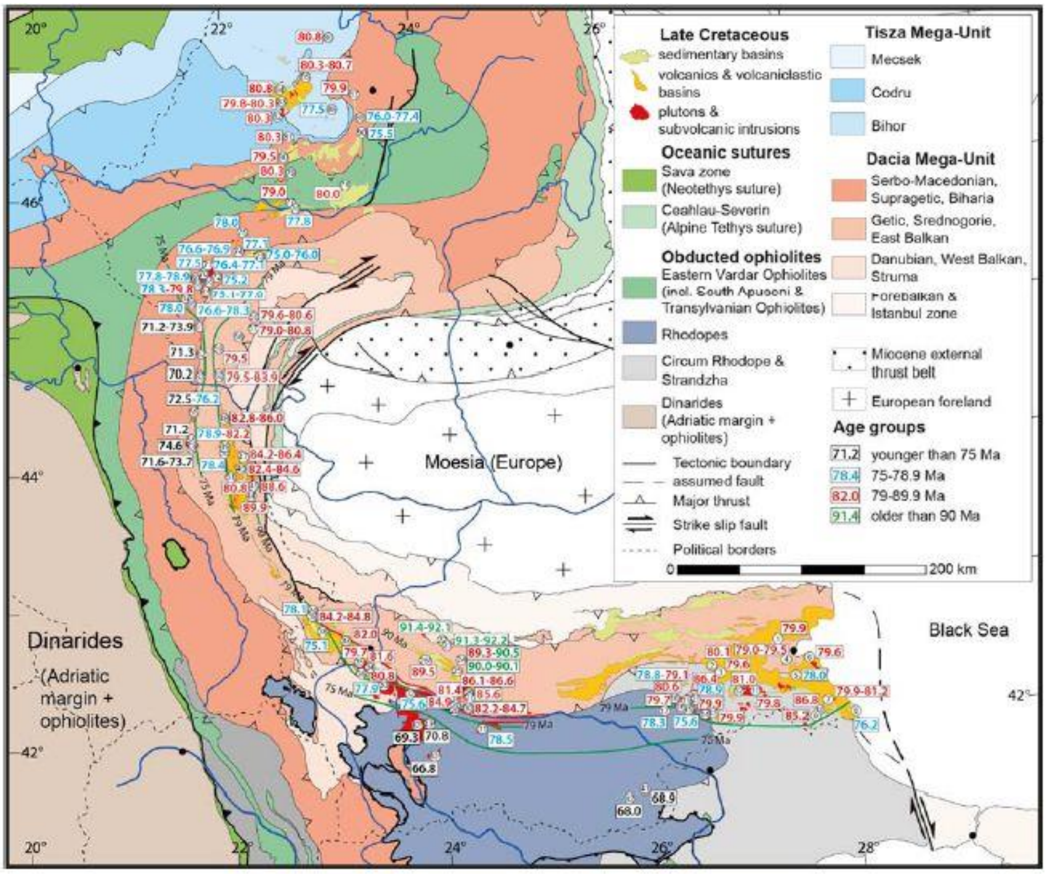

Figure 2 – Tectonic map of the ABTS belt (Schmid *et al*., 2008) showing $^{206}Pb/^{238}U$ ages of the Banatitic rock (Gallhofer, 2015).

The oldest $^{206}Pb/^{238}U$ zircon dates are ~92 Ma (Turonian) in the northern Panagyurishte segment (von Quadt *et al*., 2002; Stoykov *et al*., 2004; Chambefort *et al*., 2007; Kamenov *et al*., 2007); the following, between 90–87 Ma come from Timok and the eastern part of the Srednogorie segment (Kolb, 2011; Georgiev *et al*., 2012). In Banat and Apuseni, the magmatism begins between 84–81 Ma (Gallhofer *et al*., 2015). Younger ages were measured in the Banat and Timok segments (Fig. 2). However, the youngest ages (67–71Ma) were determined in the Rhodopes (67–71Ma) (von Quadt & Peytcheva, 2005; Marchev *et al*., 2006; Peytcheva *et al*., 2007).

GEOCHEMISTRY

There are a large number of geochemical analyses done over time. Let's not forget that the name dacite, used since the 19th century, and now universal for rocks with a chemical composition between 57–63% SiO_2, comes from a Banatitic rock located in the Apuseni Mountains (Gizella quarry, Poieni, e.g., Ştefan *et al*., 1996).

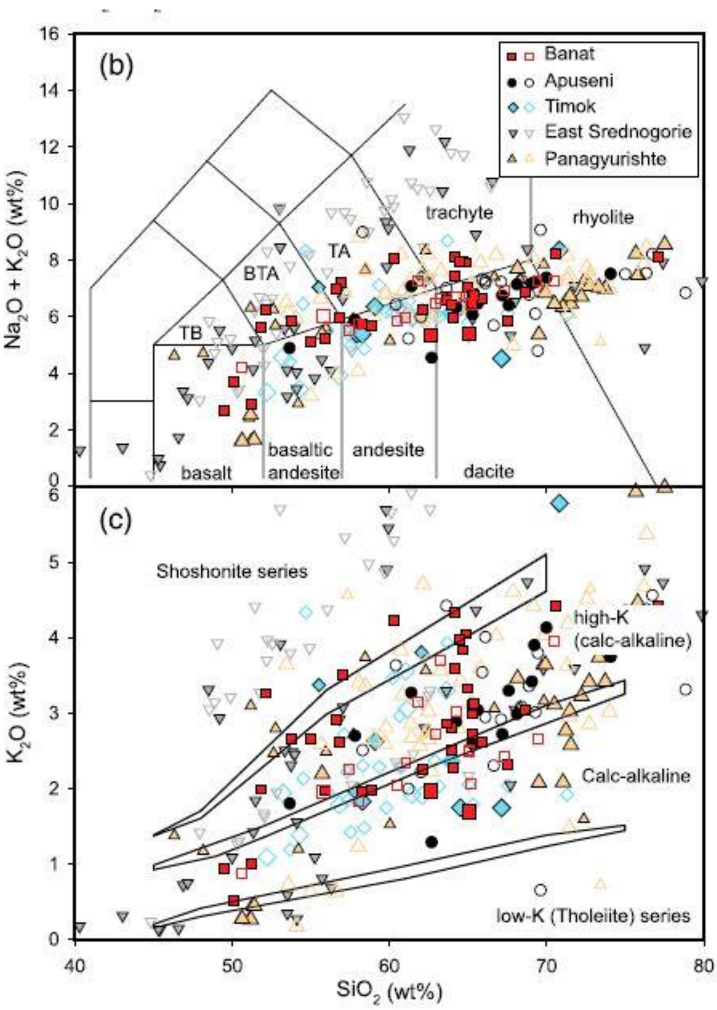

Figure 3 – Diagram of TAS (b) and K_2O *vs*. SiO_2 (c) for Banatites from ABTS (after Gallhofer *et al*., 2015).

Recent geochemical data for Romania was given by Gallhofer *et al*., (2015) and Vander Auwera *et al*., (2015). In the following, we will make a presentation based on the compilation made by Gallhofer *et al*., (2015), but we will also considered the conclusions of Vander Auwera *et al*., (2015).

According to the classic classifications, the Banatitic magmatic rocks are mostly calc-alkaline in nature, and some have alkaline characters (Fig. 3). The rocks have a wide compositional variation from basalts to rhyolites, with the predominance of andesites and dacites. The rocks of Eastern Srednogorie are the richest in alkalies (Na_2O+K_2O), belonging to the field of K-rich calc-alkaline and shoshonitic series (Georgiev *et al*., 2009). Most of the Apuseni rocks have SiO_2 > 60 wt%, and are projected in the K-rich calc-alkaline field. The samples from Banat are intermediate to acidic and are also projected in the K-rich calc-alkaline field.

Regarding the trace elements, in the normalization diagrams for chondrites (C1) and N-MORB (Sun & McDonough, 1989) a specificity is observed for each region, but in general, there is an enrichments in incompatible minor elements (large-ion lithophile elements – LILEs), as Ba, K, Sr and Pb; a lower enrichment in U and Th; a depletion in Nb, Ta, and other less compatible minor elements (high field strength elements – HFSEs, e.g., Zr and Hf) (Fig. 4).

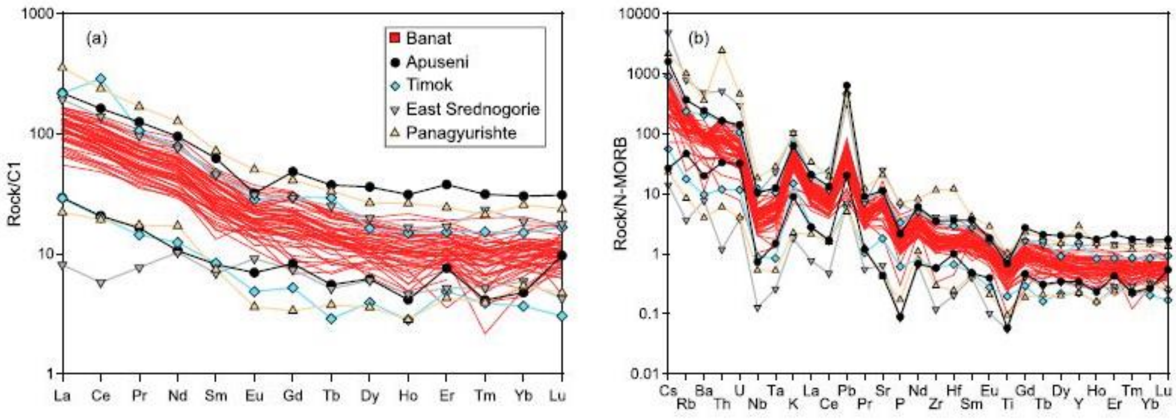

Figure 4 – Characteristic of the minor elements of the upper Cretaceous rocks of the ABTS (after Gallhofer *et al*., 2015). (a) Chondrite normalization diagram of the Rare Earths. The samples from Banat were designed in their entirety (red lines); for the other segments there are representative lines for the minimum and maximum values (b) Rocks normalized to N-MORB.

An "adakite-like" specificity was observed, defined by La/Yb and Sr/Y ratios in excess of 20 and Yb and Y contents below 1.9 and 18 ppm (Defant & Drummond, 1990) for the Timok, Banat, and Panagyurishte.

The ratio of age-corrected isotopic Sr_i and values of εNd_i shows a significant variation for each area (Fig. 5). The corresponding data varies between a mantle source of the "mid-ocean ridge basalt" (MORB) type in the case of Timok and a crustal one represented by Variscan (Apuseni) granitoids (Duchesne *et al*., 2008).

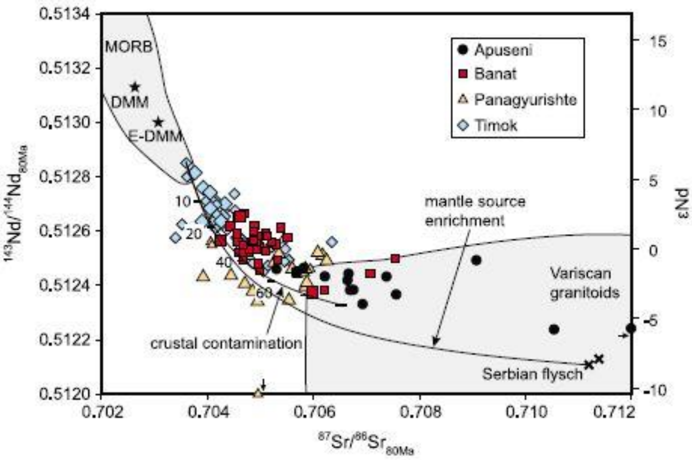

Figure 5 – Initial Sr and Nd isotopic ratios for samples from the ABTS Upper Cretaceous belt (after Gallhofer *et al*., 2015).

PETROGENETIC ASPECTS

The parental magmas of the Banatitic magmatism generally suggest a mantle origin, more evident in Timok. Subsequent processes of differentiation by fractional crystallization can lead to rhyolitic compositions. Geobarometric data indicates the generation of rhyolites in magma chambers located in the upper crust. Mixing processes are also present. The lack of evidence of primitive rocks in the Apuseni and their rarity in the Banat may rather suggest a process of fractionation of the mantle magmas at the mantle/crust boundary. Adakitic rocks are assumed to be generated by high-pressure fractionation of amphibole in the lower crust, followed by a fractionation of plagioclase in magma chambers in the upper crust, which implies incorporation of the element Sr and assimilation (e.g., Gallhofer *et al*., 2015). The isotopic difference between the samples from Banat and Apuseni can be explained by different processes of contamination (assimilation) between Apuseni and Banat, taking into account that they belong to different basement, with specific crustal characteristics, Dacia in Banat and Tisia dominant in Apuseni (Gallhofer *et al*., 2015; Vander Auwera *et al*., 2015).

GEODYNAMIC IMPLICATIONS

Palinspastic reconstructions of the Upper Cretaceous period reveal complex movements of the blocks (plates), which are, in general, of relatively small size (hundreds of km), and which, in addition to local subduction processes, underwent rotation and extension processes (eg., Handy *et al*., 2014, Fig. 6).

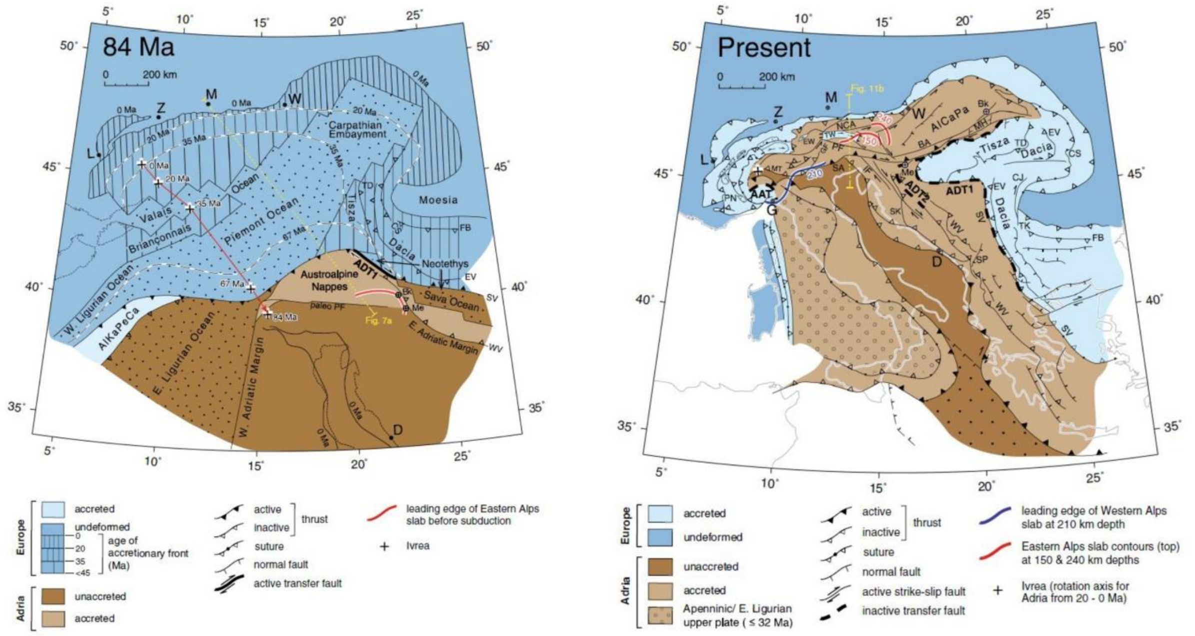

Figure 6 – **A.** Paleotectonic situation at 84 Ma (after Handy *et al.*, 2014): Initiation of subduction of the Alpine Tethys, end of the Eo-Alpine orogeny. ADT1–Upper Cretaceous-Middle Eocene transfer fault in the Alps–Dinarides, AlKaPeCa–Alboran–Kabylia–Peloritani–Calabria continental fragment, CS – Ceahlău–Severin suture, EV–East Vardar ophiolites, FB–Forebalkanic Front, paleo-PF – the terminal pre-Eocene precursor of the Periadriatic fault, WV – ophiolites from the western Vardar. Circles with crosses represent the Bükk Mts (Bk) and the Medvednica Unit (Me) used as markers. The black dots represent the oceanic lithosphere. The black crosses connected with the red line show the sequence of locations for Ivrea that defines the step of movement of the Adriatic plate in relation to Europe. The black and white dashed lines indicate the future location of the Alpine orogenic front at 67.35 and 20 Ma. **B.** Tectonic map at present time of the Alps, the Apennines, the Carpathians and the Dinaris showing the main faults and tectonic units. The red and blue lines indicate the depth contour (km) of the positive P-wave velocity anomaly (+Vp) projected at the surface, for the weak eastern Alpine slab and the apical part of the European slab. Cities: D Dubrovnik, G Genoa, L Lyon, M Munich, W Wien (Vienna), Z Zürich. Tectonic and structural units: AAT – Transfer Fault Alps–Apennines, ADT1 and ADT2 – Transfer Fault Alps–Dinaride, AlCaPa – block Alps–Carpathians–Pannonia, CJ – Cerna Jiu fault, CS – Ceahlău–Severin suture, EN – window Engadin, EV – East Vardar ophiolitic front, FB – Pre-Balkanic front, GF – Giudicarie fault, If – Idrija fault, PN – Penninic front, MH – Mid-Hungarian fault zone, MT – Milan belt webs, NCA – Calcary Alps North, PF – Periadriatic fault system, including the Balaton fault(BA), SA – Southern Alps front, SK – Split-Karlovac fault, SV – Sava suture zone, SP – Scutari-Peç fault, TD – Tisza fault boundary – Dacia, TK – Timok fault, TW – Tauern window, WV – west Vardar ophiolitic front. Circles with crosses represent the Bükk Mountains unit (Bk) and the Medvednica unit (Me) used as structural markers. The black dots represent the oceanic lithosphere.

In the Alps at 84 Ma, the accretion of the Austroalpine sheets with the Adriatic plate is suggested. Further south, the different polarity of the Alpine and Dinaric subductions requires the presence of a major transform fault, called the Alps–Dinaric Transfer Fault (ADT1) at the Upper Cretaceous level, which connects the Alpine thrust front with the Dinaric front along the future suture line Sava (Fig. 6). In this model, ADT1 is parallel to the direction of the Adriatic–Europe convergence and is subparallel to the direction of the rift of the Adriatic margin of the Sava Basin. Taking into account this interpretation, it can be observed that at 84 Ma only remnants of the Neotethys Ocean remained and it can assume that the Banatitic magmatism, which was generated in the interval 84–65 Ma, is in fact post-collisional and not directly related to subduction processes. For example, in Apuseni and Banat, the presence of Upper Cretaceous sedimentary basins of the Gosau type, which were formed after the placement of the Meso-Cretaceous sheets (end of subduction), indicates an extensional regime, according to some authors as a result of orogenic collapse (Willingshofer *et al.* 1999). The generation in the Upper Cretaceous of some core-complex extensions accompanied by tectonic uplifts, which post-date the formation of the nappes and the associated metamorphism, corresponds to the evolution of the crystalline foundation in the Apuseni, the western Meridionals, but also further to the southeast (Giuşcă *et al*. 1969; Antonijević *et al*. 1974; Popov 1981; Berza *et al*. 1998; Willingshofer *et al*. 1999; Popov *et al*. 2002; Georgiev *et al*. 2012; Schuller, 2004).

In favor of post-collisional magmatism, it is also worth mentioning the presence of Paleogene Na-alkaline basalts generated from the end of the Banatitic magmatic activity in Banat and Serbia (Downes *et al*., 1995, Tchegg *et al*., 2010, Cvetkovic *et al*., 2004), situation specific to a post-collision characteristic (Prelevic & Seghedi, 2013).

In spite all the evidence from a rigorous reconstruction, mentioned above, which suggests a post-collisional magmatism, Gallhofer *et al*., (2015) present a model for the entire banatitic belt in which they argue that the entire procession of magmatic products from the ABTS formed directly through subduction processes of the Neotethys Ocean, which would have been widely open (~300km) at that time and would have generated typical "arc" magmatites (Fig. 7). The following is invoked, among other features: the dominant calc-alkaline character and a transversal age progression on the "magmatic arc" (see Fig. 2).

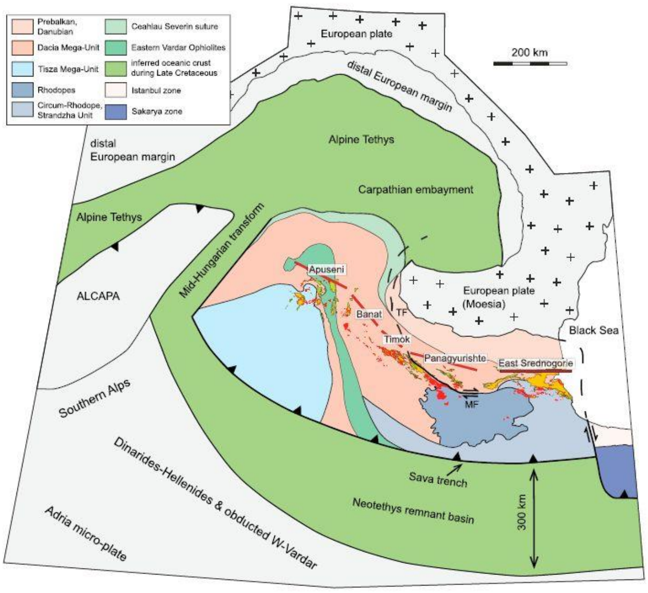

Figure 7 – Restoration of the ABTS magmatism at ~ 90 Ma and the suggestion of its genesis as a result of a typical "arc" magmatism generated as a result of the subduction of the Neotethys basin (after Gallhofer *et al*., 2015).

CONCLUSIONS

Despite all the efforts so far, which generally give concrete answers to the complex issue regarding the generation of dominantly calc-alkaline magmas along the ABTS, there are still controversies regarding the tectonic models of magma generation. On the one hand, the generation of magmas in post-collision conditions is suggested, and on the other, as a result of subduction processes of the Neotethys basin remnants from that period. Future studies are designed to come up with valid arguments in favor of one or the other of the two hypotheses.

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