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An anorogenic pulse in a typical orogenic setting: The geochemical and geochronological record in the East Serbian latest Cretaceous to Palaeocene alkaline rocks

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ABSTRACT

This study focuses on the East Serbian latest Cretaceous to Palaeocene Mafic Alkaline Rocks (hereafter, ES-MAR). This alkaline magmatism developed along the Eurasian border after the closure of the Mesozoic Tethys in the Balkan sector. Olivine(±clinopyroxene)-phyric and olivine- and nepheline-normative basanite, tephrite and theralite rocks are studied using Ar/Ar ages and major elements, trace elements and Sr–Nd–Pb isotopes. The ES-MAR are geochemically similar to other alkaline rocks of the Circum-Mediterranean Anorogenic Cenozoic Igneous (CiMACI) province, showing elevated contents of high field strength elements (HFSE) (e.g., Nb = 50–100 ppm) and high HFSE/LILE (large ion lithophile elements) ratios coupled with relatively low $^{87}Sr/^{86}Sr_i$ (mostly 0.7028–0.7040) and high $^{143}Nd/^{144}Nd_i$ (mostly >0.5127). In contrast to the majority of CiMACI rocks, the ES-MAR exhibit low $^{206}Pb/^{204}Pb_i$ (<18.5) ratios, similar to those displayed by Plio-Pleistocene volcanics of Sardinia. The Pb-unradiogenic signature of the ES-MAR is explained as the involvement of either an enriched mantle I-like source or highly depleted mantle. However, Sr–Nd–Pb and trace element variations (U/Nb, Ce/Pb, Th/Nb, and Th/La ratios and K_2O and Th contents) suggest that mixing between an asthenospheric magma (similar to the average primitive CiMACI) and a lamproite-like melt also played a significant role in the ES-MAR petrogenesis. It is assumed that the lamproite-like magma originated by the melting of crustally modified lithosphere. A similar mantle is believed to be the source of primitive Serbian Oligocene lamproites. The model fails to explain the elevated K_2O contents shown by samples that have low Th/Nb, Th/La and U/Nb and low Ce/Pb ratios. This subset of ES-MAR samples probably implies that there was an additional, presumably 'anorogenic' source of potassium.

1. Introduction

From the Late Mesozoic to the present day, widespread intraplate alkaline magmatism occurred in the Circum-Mediterranean area (Lustrino and Wilson, 2007; Wilson and Downes, 1991; and references therein). This magmatism is generally characterised by the presence of alkaline basaltoid rocks with geochemical signatures similar to sodic alkaline lavas occurring within oceanic and continental plates worldwide. They display relatively low La/Nb (0.4–1.1) and high Nb/U (20–60) and Ce/Pb (10–50) ratios and radiogenic isotope ratios ranging from $^{87}Sr/^{86}Sr = 0.7023–0.7049$, $^{143}Nd/^{144}Nd = 0.51319–0.51240$, ($\varepsilon Nd = +10.8–4.7$), $^{206}Pb/^{204}Pb = 17.71–20.76$, $^{207}Pb/^{204}Pb = 15.49–15.72$ and $^{208}Pb/^{204}Pb = 37.84–40.43$. This geochemical signature is called 'anorogenic' (see Lustrino and Wilson, 2007). It is in sharp contrast to the composition of so-called 'orogenic' magmas displaying substantially higher La/Nb (>2) and $^{87}Sr/^{86}Sr$ (sometimes above 0.710), and lower Ce/Pb (≪5), $^{143}Nd/^{144}Nd$ (<0.51319) and $^{206}Pb/^{204}Pb$ ratios (<19) (e.g., Harangi et al., 2006; Wilson and Bianchini, 1999). The terms 'anorogenic' and 'orogenic' are here used sensu Lustrino et al. (2009, 2011) and are for geochemical purposes only. Thus, the terms are applied only to distinguish between the above listed geochemical affinities and not to strictly denominate the geotectonic setting. In a geodynamic sense, these terms should be used with caution because, for instance, many geochemically 'anorogenic' magmas originated within the life span of an orogen (e.g., Marchev et al., 1998; this study), whereas a great deal of geochemically 'orogenic' magmas formed during post-collisional/extensional (i.e., anorogenic) phases (e.g., Prelević et al., 2005).

Although generally uniform in composition, the anorogenic alkaline rocks can display variable relative enrichments in high field-strength elements (HFSE: Ti, Nb, Ta, Zr, etc.) over large ion lithophile elements (LILE: Rb, K, Ba) or variable Sr–Nd–Pb isotopic patterns. These differences are commonly controlled by subtle changes in the geotectonic

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setting, mantle dynamics and mantle source characteristics. It is, hence, important to understand the relationship, both in time and space, between such anorogenic rocks and their orogenic counterparts, and to establish a link to the particular aspects of the pre-, syn- and post-collisional development of a given lithospheric segment. In most areas, anorogenic magmatism clearly postdates the formation of orogenic magmatic rocks (e.g., Pannonian Basin, Balogh et al., 1994; Calatrava Spain, Cebria and Lopez-Ruiz, 1995, etc.). In some regions, both orogenic and anorogenic magmatic suites develop roughly contemporaneously (East Carpathians, Pécskay et al., 1995; East Rhodopes, Marchev et al., 1998) or orogenic rocks appear later (e.g., Veneto Province, Macera et al., 2003). Eventually, there are relatively small volcanic districts that are characterised by gradual transitions from orogenic to anorogenic magmatic phases (e.g., Pontine Islands; Cadoux et al., 2005, central Anatolia; Wilson et al., 1997; W. Anatolia; Fischer et al., 2010; Ersoy and Palmer, this issue, Prelević et al., 2012) or even vice versa (Mt. Etna; Schiano et al., 2001).

The East Serbian Mafic Alkaline Rocks (hereafter ES-MAR) are sandwiched between two igneous provinces of a clear orogenic affinity in both time and space. In the east, there are Late Cretaceous calc-alkaline rocks of the Banatite–Timok–Srednogorie Magmatic and Metallogenetic Belt (e.g., Berza et al., 1998; Ciobanu et al., 2002), and in the west, widespread Oligocene/Pliocene medium-K calc-alkaline to ultrapotassic rocks occur (Cvetković et al., 2004a; Prelević et al., 2005). These two orogenic magmatic suites resulted from complex Mesozoic and Cenozoic tectonics involving the subduction of oceanic lithosphere followed by continental collision and transpressional/transtensional relaxation (Karamata and Krstić, 1996; Marović et al., 2002; Robertson et al., 2009; Schmid et al., 2008). The Late Cretaceous eastern province, called the Timok Magmatic Complex, was interpreted as related to the subduction of the Tethyan oceanic lithosphere under the southern margin of the European continent (Karamata et al., 1997; Kolb et al., 2013; von Quadt et al., 2002). The western province is explained by post-collisional tectonics involving melting of previously metasomatised subcontinental lithosphere (Cvetković et al., 2004a; Prelević et al., 2005).

The geodynamic significance of the ES-MAR province was emphasised by Jovanović et al. (2001), and Cvetković et al. (2004a) provided an overview of K/Ar ages (39–62 Ma) and petrochemical features of all Serbian Cenozoic basaltoids. The latter authors noted a clear intraplate affinity of the ES-MAR suite in contrast to other Cenozoic basaltoid rocks with predominant high-K calc-alkaline to ultrapotassic character. More recently, Cvetković et al. (2010) presented a trace element geochemical model of source processes based on the most primitive ES-MAR and mantle xenoliths entrained therein. They confirmed the intraplate and asthenospheric signature of the ES-MAR source although they suggested that this signature was first acquired by the very lithospheric bottom, which was previously refertilised by the percolation of mafic alkaline melts.

The above mentioned studies have revealed important features of the ES-MAR, which can be summarised as follows: 1) clear anorogenic geochemical affinity in contrast to the adjacent rocks of the Late Cretaceous Timok Magmatic Complex and Cenozoic provinces of the Vardar Zone and Dinarides, 2) geochemical signature of the convecting mantle but with trace element enrichments suggesting that their primary magmas originated in the lithospheric bottom previously metasomatised by CO_2-rich mafic alkaline melts, 3) fault-controlled mode of occurrence indicating that the ES-MAR are unrelated to plume activity, and 4) the emplacement age is roughly between two orogenic magmatic phases.

In this study, we focus on many aspects related to the ES-MAR petrogenesis, which has been insufficiently constrained by earlier studies. We bring a more complete picture on the ES-MAR whole-rock major and trace element geochemistry and Sr–Nd–Pb isotopes with the main aim of elucidating the characteristics of their mantle source(s). We also report a new set of Ar/Ar data that help resolve the age of this magmatic pulse. By illuminating the source processes in greater detail and with more accurate age constraints, this study provides better understanding of this anorogenic event, adding new knowledge about the anorogenic magmatism in the entire Circum-Mediterranean area.

2. Geological setting

The ES-MAR crop out along an almost N–S extending line starting from Danube in the north and terminating near Pirot, near the Serbian–Bulgarian border (Fig. 1). Similar rocks occur more northward in the Poiana Ruscă region in Romanian Banat (Downes et al., 1995; Tschegg et al., 2010). Geotectonically, the ES-MAR volcanic chain belongs to the East Serbian Carpatho-Balkanides, i.e., to the Dacia Mega-Unit representing the Eurasian continental margin during the latest Mesozoic geodynamics (Schmid et al., 2008 and references therein). More precisely, the ES-MAR occur along the line splitting the Serbo-Macedonian Massif (e.g., Supragetic) and the Getic Unit (including the Srednogorie Zone and the Danubian Unit) in the west and the east, respectively.

The ES-MAR formed after the last convergence–collision tectonic events that were related to the final closure of the Mesozoic Tethys (Robertson et al., 2009). It is generally accepted that the oceanic lithosphere of the eastern Tethys was subducting beneath the European continent (Popov et al., 2002). This resulted in the formation of voluminous calc-alkaline magmas that are associated in time and space with large porphyry and epithermal Cu–Au deposits of the Banatite–Timok–Srednogorie Magmatic and Metallogenetic Belt (Berza et al., 1998) or Apuseni–Banat–Timok–Srednogorie belt (Mitchell, 1996). The products of this calc-alkaline magmatism exhibit a clear westward (Timok Magmatic Complex in Serbia) and southward (Srednogorie in Bulgaria) age progression most likely associated with oblique subduction or slab roll-back (Kolb et al., 2013; von Quadt et al., 2005). The ES-MAR postdated the formation of this calc-alkaline belt, i.e., they formed after convergent/subduction processes at the end of the Cretaceous (e.g., Fügenschuh and Schmid, 2005; Krstić and Karamata, 1992; Schmid et al., 2008). After terminating the ES-MAR magmatism, the focus of igneous processes moved further to the west where numerous Cenozoic plutonic/volcanic provinces developed (e.g., Cvetković et al, 2000). They predominantly occur along the Vardar Zone, which is the major Mesozoic tectonic suture consisting of ophiolites, accretionary mélange and various exotic blocks of different provenance (Karamata, 2006; Robertson et al., 2009). These Cenozoic plutonic/volcanic provinces most likely formed in response to transpressive to transtensive tectonic events that are known to have played an important role in the Carpathian–Pannonian–Dinaride region throughout the Cenozoic (Marović et al., 1998; Seghedi and Downes, 2011). This Cenozoic magmatism is compositionally heterogeneous comprising calc-alkaline, high-K calc-alkaline and ultrapotassic rock series.

Accordingly, the studied alkaline basaltoid rocks that are emplaced along the western margin of the European plate are represented by the Dacia Unit. The volcanic basement is represented by the so-called Getic–Supragetic nappe series and their unconformable cover. The former comprises medium- to high-grade metamorphic Neoproterozoic to Early Palaeozoic gneisses and sub-greenschist to epidote–amphibolite grade Palaeozoic rocks (e.g., Karamata and Krstić, 1996). They are overlain by Upper Carboniferous/Permian continental clastics and Mesozoic carbonate sediments. The overstep sequences postdating the mid-Cretaceous nappe stacking (Săndulescu, 1984) mainly comprise Cenomanian molasse-like sediments.

The geographical and geotectonic distribution of the nine ES-MAR localities is shown in Fig. 1. The ES-MAR occur as relicts of small, presumably monogenetic volcanoes. Most are along or very close to major dislocation structures. Three samples were collected as pebbles from the river banks of the southern Danube tributaries and are marked as a single locality of **Tisa** (following the numeration of the localities of Cvetković et al., 2004a; Jovanović et al., 2001). The locality of **Osoje** is approximately 120 km southeastward. It geographically belongs to the Timok Magmatic Complex and is represented by a single outcrop