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Petrogenesis of Miocene alkaline volcanic suites from western Bohemia: whole rock geochemistry and Sr–Nd–Pb isotopic signatures

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A B S T R A C T

The Mid to Late Miocene intraplate alkaline volcanic suites of western Bohemia are relict of the intensive voluminous volcanism accompanied by large-scale uplift and doming. The association with the uplift of the NE flank of the Cheb–Domažlice Graben (CDG) is uncertain in view of the mostly transpressional tectonics of the graben. The volcanism is most probably of the Ohře/Eger Rift off-rift settings. Two cogenetic volcanic suites have been recognised: (i) silica-saturated to oversaturated consisting of olivine basalt–trachybasalt-(basaltic) trachyandesite–trachyte–rhyolite (13.5 to 10.2 Ma) and (ii) silica-undersaturated (significantly Ne-normative) (melilite-bearing) olivine nephelinite–basanite–tephrite (18.3 to 6.25 Ma). A common mantle source is suggested by similar primitive mantle-normalised incompatible element patterns and Sr–Nd–Pb isotopic compositions for the assumed near-primary mantle-derived compositions of both suites, i.e., olivine basalt and olivine nephelinite. Apparently, they were generated by different degrees of partial melting of a common mantle source, with garnet, olivine and clinopyroxene in the residuum. Negative Rb and K anomalies indicate a residual K-phase (amphibole/phlogopite) and melting of partly metasomatised mantle lithosphere. The evolution of the basanite–olivine basalt–trachybasalt-(basaltic) trachyandesite–trachyte–rhyolite suite suggests the presence of an assimilation–fractional crystallization process (AFC). Substantial fractionation of olivine, clinopyroxene, Fe–Ti oxide, plagioclase/alkali feldspar and apatite accompanied by a significant assimilation of magma *en route* by crustal material is most evident in evolved member, namely, trachytes and rhyolites. The magmas were probably sourced by both sub-lithospheric and lithospheric partly metasomatised mantle. The evolution of the (melilite-bearing) olivine nephelinite–basanite–tephrite suite is less clear because of its limited extent. Parental magma of both these rock suites is inferred to have originated by low-degree melting of the mantle source initiated at ca. 18 Ma and reflects mixing of asthenosphere-derived melts with isotopically enriched lithospheric melts. The older Oligocene alkaline rocks (29–26 Ma) occur within the Cheb–Domažlice Graben (CDG) locally but are significant in the closely adjacent neighbouring western Ohře Rift. The Sr–Nd–Pb isotopic composition of primitive volcanic rocks of both suites is similar to that of the European Asthenospheric Reservoir (EAR). Initial Pb isotopic data plot partly above the northern hemisphere reference line at radiogenic $^{206}Pb/^{204}Pb$ ratios of ~19 to 20, and indicate the presence of a Variscan crustal component in the source.

1. Introduction

Alkaline volcanic rocks in the Bohemian Massif belong to the easternmost part of the Cenozoic Western and Central European Volcanic Province (CEVP; Wimmenauer, 1974), which spreads from

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France through Germany to the Czech Republic and Poland (Wilson and Downes, 1991; Lustrino and Wilson, 2007). Magmatic activity produced large volumes of intraplate, prevalently alkaline volcanic rocks within rifts and their flanks or in off-rift settings. Cenozoic volcanic rocks of the Bohemian Massif are compositionally similar to those from other parts of the CEVP (Ulrych et al., 2011). However, the lithospheric source of the volcanic rocks was inferred to be less metasomatised and enriched in radiogenic Sr–Nd–Pb isotopes compared to that of the Massif Central and Rhenish Massif (Lustrino and Wilson, 2007). Based on the Pb isotopic data (Blusztajn and Hart, 1989), a strong HIMU signature of the basaltic rocks has been attributed to the recycling of subducted oceanic crust in the upper mantle (Alibert et al., 1987; Wilson and Downes, 1991; Lustrino and Wilson, 2007) associated with the Variscan Orogeny in the Late Paleozoic (Ulrych et al., 2002, 2003c, 2006).

The presence of the "triple junction point" involving three basement units (Saxothuringian–Moldanubian–Teplá–Barrandian), each with distinct seismic anisotropy characteristics, in the western part of the Bohemian Massif was proposed by Babuška et al. (2007). The ENE–WSW-striking Ohře/Eger Rift (OR) corresponds to a Cenozoic reactivated deep tectonic boundary in the Variscan Bohemian Massif, separating basement terranes of the Saxothuringian Unit in the NW and the Moldanubian Unit with the Teplá–Barrandian Unit in the SE (Kopecký, 1978; Ziegler, 1994). The Saxothuringian–Moldanubian boundary represented by the deep Litoměřice Fault is characterized by a lithospheric thinning to about 80–90 km beneath the ENE–WSW-striking western part of OR (Babuška and Plomerová, 2010; Geissler et al., 2010 and citations therein). The asymmetric NNW–SSE-striking CDG, with substantial uplift of the NE flank occurs at the Moldanubian–Teplá–Barrandian boundary (Kopecký, 1978). This structure is superimposed on the OR structure.

Two alkaline rock series occur in western Bohemia. One is silica-saturated to oversaturated suite comprised of trachybasalt–trachyandesite–trachyte–rhyolite, also termed the weakly alkaline series WAS (Ulrych et al., 2003b). The other is silica-undersaturated suite comprising (melilite-bearing) olivine nephelinite–basanite–tephrite, also termed the strongly alkaline series (SAS; Ulrych et al., 2003b). Within the CEVP, contrasting volcanic series have been reported from Siebengebirge (Wimmenauer, 1974; Vieten et al., 1988; Kolb et al., 2012) and Cantal in the Massif Central (Maury and Varet, 1980; Downes, 1989; Wilson and Downes, 1991; Briot et al., 1991 and Wilson et al., 1995). However, the more evolved cogenetic members of the SAS suites from these sites include phonotephrites and phonolites, which are missing in western Bohemia. Kindred alkaline magmas follow in their evolution either saturated to oversaturated path with rhyolite and/or quartz trachyte or undersaturated trend with phonolite differentiates reflecting differences in the chemistry of the primary magmas and their differentiation style (Foland et al., 1993). On the other hand, combined assimilation and fractionation crystallisation processes (AFC) within the lower crust are inferred to play a major role in the formation of both series in the Cantal volcanic field (Wilson et al., 1995).

In this study, we present new major and trace-element data together with Sr–Nd–Pb isotopic data for coexisting Miocene mafic and felsic alkaline rock suites from western Bohemia in order to discuss their petrogenesis with respect to mantle sources and role of assimilation-fractionational crystallization.

2. Geological setting

The Bohemian Massif (BM) has been divided into four major tectonic zones: the Teplá-Barrandian, Saxothuringian, Moldanubian, and Moravo-Silesian (Kossmat, 1927; Franke, 1989; Schulmann et al., 2014).

The distribution of Cenozoic volcanic rocks in the BM is mostly controlled by an ENE–WSW-trending rift structure about 280 km long. The Ohře Rift graben extends for about 180 km and reaches a maximum width of 25 to 30 km in its central part (Kopecký, 1978; Pivec et al., 1998; Fig. 1). The Neogene CDG is up to 150 km long and 5–10 km wide structure with volcanic manifestations limited only to the uplifted flank block situated to the NE of the morphologically expressive Mariánské Lázně Fault (Ulrych et al., 2003b).

Large scale uplift in western Bohemia occurred during the Middle and Late Miocene. During this time, high flat plateau was developed (Tomek et al., 1997). The intermittent earthquake swarm activity in western Bohemia/Vogtland is continuously monitored and usually does not exceed M_L 5 (Grünthal et al., 1990; Fischer et al., 2014 and citations therein). The deep-seated disposition of the CDG is evidenced by the composition and flux of CO_2-rich (>99 vol. %) gas emanations with high carbon ($\delta^{13}C$ −1.8 to −4.0 ‰) and helium ($^3He/^4He$ as high as $R/R_a = 5$) isotopic ratios, pointing to an active magma source in the upper mantle (Weinlich et al., 1999).

Cenozoic volcanic activity is widespread in the BM with three identified main periods (including Late Cretaceous): pre-rift (i) 79–49 Ma, (ii) syn-rift 42–16 Ma and (iii) late-rift 16–0.26 Ma (Ulrych et al., 2011). Volcanic rocks of an independent Mid to Late Miocene phase belonging to the late-rift period are concentrated to the south of the western Ohře Rift (Fig. 1) with some minor occurrences (relicts) situated also in the České Středohoří Volcanic Complex (Cajz et al., 2009). The predominant occurrences of the volcanic rocks are associated with the Ohře Rift and its western and eastern continuations. In western Bohemia, Miocene volcanic rocks penetrate the Teplá–Barrandian Unit and they are mainly concentrated within the Teplá and Slavkovský les crystalline complexes (Shrbený, 1979; Pivec et al., 2003; Ulrych et al., 2003a). Kopecký (1978) and Pivec et al. (2003) associated these Miocene volcanic series with the uplift of the NE flank of the neighbouring CDG. Nevertheless, Tomek et al. (1997) interpreted this volcanism in the Teplá–Manětín area as being of the off-rift settings; its connection with the CDG seems to be uncertain in view of the mostly transpressional tectonics of the graben. A significant and strong reflection event at 9 s of TWT (two way time), is present here, corresponding to a depth of some 30 km (Tomek et al., 1997) beneath the Teplá–Manětín part of the 9HR deep reflection profile. This reflection is interpreted as a lower crust–magmatic underplating reflection surface with a large reflection coefficient (Tomek et al., 1997). Underplated material about 3 km in thickness is present here, which corresponds to the observed uplift of 300 m (see McKenzie, 1984). While silica-undersaturated rocks occur mostly in the vicinity of major faults in the area (i.e., the Mariánské Lázně Fault and Litoměřice Deep Fault), the differentiated, silica-saturated volcanic rocks are characteristic for the central parts of the volcanic system (Fig. 1). However, Miocene basanites have been described also from the Ohře Rift area (Lustrino and Wilson, 2007) as at Hory near Karlovy Vary (15.5 Ma) and near Krušné Hory/Erzgebirge Mts. (Horní Rotava – 14.8 Ma), indicating that younger volcanism is not restricted to the CDG only.

3. Analytical methods

Fresh rock samples (~3 kg each) were crushed in a jaw crusher with tungsten carbide plates. An aliquot (~100 g) was ground to a fine powder in an agate swing mill to avoid Ta contamination.

Whole-rock major-element concentrations were determined at the Institute of Rock Structure and Mechanics, CAS and at the Faculty of Science, Charles University, Prague using wet chemistry techniques. The accuracy was monitored analysing the BCR-2 (USGS) reference material and yielded an average error (1σ) less than 10% for all determined elements.