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Geochemical fingerprints of Late Triassic calc-alkaline lamprophyres from the Eastern Pontides, NE Turkey: A key to understanding lamprophyre formation in a subduction-related environment

Orhan Karsli [a,*], Abdurrahman Dokuz [b], Melanie Kaliwoda [c], Ibrahim Uysal [d], Faruk Aydin [d], Raif Kandemir [a], Karl-Thomas Fehr [e]

[a] *Department of Geological Engineering, Recep Tayyip Erdoğan University, TR-53000 Rize, Turkey*
[b] *Department of Geological Engineering, Gümüşhane University, TR-29000 Gumushane, Turkey*
[c] *Mineralogical State Collection Munich, D-80333 München, Germany*
[d] *Department of Geological Engineering, Karadeniz Technical University, TR-61080 Trabzon, Turkey*
[e] *Department of Earth and Environmental Sciences, LMU, D-80333 München, Germany*

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ABSTRACT

The Eastern Pontides in NE Turkey is one of the major orogenic belts in Anatolia. In this paper, we report our new $^{40}Ar/^{39}Ar$ dating, mineral chemistry, major and trace elements and Sr–Nd–Pb isotopic analyses of the lamprophyre intrusions in this region. The lamprophyres are widely scattered and intrude Late Carboniferous granitoid rocks. The lamprophyres exhibit fine-grained textures and are mineralogically uniform. Hornblende $^{40}Ar/^{39}Ar$ dating yielded a plateau age of 216.01 ± 10.64 Ma. Based on their geochemistry, mineral compositions and paragenesis, the lamprophyres are classified as calc-alkaline lamprophyres in general and spessartites in particular, which are rich in large ion lithophile elements (e.g., Rb, Ba, K) but depleted in Nb and Ti. Our samples exhibit moderate fractionation in LREE patterns approximately 100 times that of chondrite but HREE abundances less than 10 times that of chondrite. These calc-alkaline lamprophyres display a range of I_{Sr} (216 Ma) values from 0.70619 to 0.71291 and ε_{Nd} (216 Ma) values from −1.4 to 4.1, with T_{DM} = 1.11 to 2.20 Ga. Their Pb isotopic ratios indicate an enriched mantle source. The enrichment process is related to metasomatism of a subcontinental lithospheric mantle source, which is caused by a large quantity of H_2O-rich fluids, rather than sediments released from oceanic crust at depth during the closure of the Paleotethys Ocean in Triassic times. All of the geochemical data and the trace element modeling suggest that the primary magma of the calc-alkaline to high-K calc-alkaline spessartites was generated at depth by a low degree of partial melting (~1–10%) of a previously enriched lithospheric mantle wedge consisting of phlogopite-bearing spinel peridotite. The ascendance of a hot asthenosphere triggered by extensional events caused partial melting of mantle material. The rising melts were accompanied by fractional crystallization and crustal contamination en route to the surface. All of the geochemical features combined with regional data suggest that the Eastern Pontides calc-alkaline lamprophyres originated in an extensional environment along an active continental margin throughout the Late Triassic. Such an extensional event, causing upwelling of hot asthenosphere, led to the opening of the northern branch of the Neotethys as a back-arc basin farther south of the Eastern Pontides.

1. Introduction

The Eastern Pontides, which is the eastern part of the Sakarya Zone, is considered an important natural laboratory for developing an understanding of deep lithospheric processes. Igneous rocks, such as lamprophyres, in this belt record the thermal and geochemical fingerprints of the lithosphere beneath the region. Lamprophyres, a unique type of mesocratic to melanocratic igneous rock with mafic phenocrysts set in a fine-grained matrix, sporadically form as dykes, sills, pipes or small intrusions in various geodynamic settings (Allan and Carmichael, 1984; Duggan and Jaques, 1996; Rock, 1991). These rock types are divided into five primary categories, alkaline lamprophyres, ultramafic lamprophyres, lamproitic lamprophyres, kimberlitic lamprophyres and calc-alkaline lamprophyres (Le Maitre, 1989; Rock, 1991). Calc-alkaline lamprophyres are commonly generated in convergent tectonic settings, whereas alkaline and ultramafic lamprophyres often form in divergent tectonic settings, and kimberlitic lamprophyres are found within plate settings (Carlier et al., 1997). Although lamprophyre outcrops are relatively small, they provide us with new insights into the understanding of large-scale geodynamic processes, in particular continental extension (e.g., Queen et al., 1996; Tappe et al.,

* Corresponding author. Tel.: +90 5322087307; fax: +90 464 2237514.
E-mail address: okarsli@gmail.com (O. Karsli).

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2006) and mantle enrichment (e.g., Beard et al., 1996; Guo et al., 2004; Srivastava and Chalapathi Rao, 2007). Lamprophyres are considered to be the products of a small degree of partial melting of enriched subcontinental lithospheric mantle sources (e.g., Müller and Groves, 1995; Rock, 1987). Therefore, their geochemical characteristics are closely related to enrichment of the source throughout the evolution of the lithosphere in a dynamic system.

In the study area, very little attention was paid to the calc-alkaline lamprophyre intrusions until recently (Aydin et al., 1997). Here, we present new data, including ^{40}Ar–^{39}Ar hornblende ages, mineral compositions and elemental and Sr–Nd–Pb isotopic compositions of the Late Triassic calc-alkaline lamprophyres from the Eastern Pontides, northeastern Turkey, and we discuss their origin, geodynamic setting and the nature of the lithospheric mantle beneath the region. Particular emphasis is placed on the causes of mantle heterogeneity and the nature of metasomatizing agents in the subcontinental mantle source beneath the Eastern Pontides during the Late Triassic.

2. Regional geology and previous works

Four major tectonic blocks or terranes that are separated by sutures occur in the Anatolia region (e.g., Okay and Tüysüz, 1999). Of these, the Sakarya block is the most important. It represents a series of Mesozoic–Cenozoic fold belts comprising a N-vergent foreland fold thrust belt and a concave, upward-shaped fold belt (Fig. 1a). The eastern part of the Sakarya block is known as the Eastern Pontides, which is a well preserved large mountain belt measuring 500 km long and 100 km wide. The northeast boundary is marked by the Achara-Trialet belt, and the Great Caucausus lies to the north and the Taurides to the south. The basement of the Eastern Pontides consists of Late Carboniferous intrusive and metamorphic rocks; this basement is unconformably overlain by Permo-Carboniferous clastic sedimentary rocks (e.g., Çapkınoğlu, 2003; Dokuz, 2011; Kandemir and Lerosey-Aubril, 2011; Okay and Leven, 1996; Topuz et al., 2007; Topuz et al., 2010; Yilmaz, 1972). Recently, a few upper-mantle serpentinized lherzolite and harzburgite blocks (up to 300 m^2) belonging to the Variscan basement of the Eastern Pontides have been described in the Beyçam (Gümüşhane) and Pulur (Bayburt) areas (Dokuz et al., 2011). The Variscan metamorphic–magmatic basement is unconformably overlain by post Triassic volcano-sedimentary rocks (Dokuz and Tanyolu, 2006; Kandemir and Yilmaz, 2009; Şen, 2007). Late Triassic events in the western part of the Sakarya block are interpreted as associated with a subduction setting, based on the blueschists and eclogites of the Karakaya complex (Okay and Göncüoğlu, 2004; Okay et al., 2002), although this time is poorly understood due to the rarity of the Late Triassic rocks in the Eastern Pontides. The Early Jurassic is dominated by a continental magmatic arc separated from the northern margin of Gondwana in response to the southward subduction of the Paleotethyan oceanic slab during the Early Triassic (Dokuz et al., 2006, 2010; Koçyiğit and Altiner, 2002; Şengör and Yilmaz, 1981; Yilmaz et al., 1997), based on the geochemical nature of the intrusive (Dokuz et al., 2006; Ustaömer and Robertson, 2010) and volcanic rocks (Şen, 2007). This southward subduction of the Paleotethys caused the formation of the northern branch of the Neotethys Ocean in the southern part of the Sakarya Zone (Şengör and Yilmaz, 1981). Middle to Late Jurassic granitoids and dacites emplaced within the volcano-sedimentary rocks of the Şenköy Formation (Dokuz et al., 2006, 2010) together with molasse sediments are interpreted as the products of an arc–continent collision in response to closure of the Paleotethys during the Middle Jurassic and the accretion of the Sakarya block onto Laurasia in the north (Dokuz et al., 2010; Şengör and Yilmaz, 1981; Şengör et al., 1980; Yilmaz et al., 1997). The Late Jurassic to Early Cretaceous was characterized by platform carbonates of the Berdiga Formation (Görür, 1997; Tüysüz, 1999). During the Late Cretaceous, the opening of the Black Sea in the northern part of the Eastern Pontides was triggered by the northward subduction of the Neotethys (Okay et al., 1994; Robinson et al., 1995; Şengör et al., 2003). This subduction resulted in a submarine magmatic arc (Altherr et al., 2008; Boztuğ and Harlavan, 2008; Boztuğ et al., 2004; Çinku et al., 2010; Karsli et al., 2010a, 2012a; Kaygusuz et al., 2008; Okay and Şahintürk, 1997; Okay and Tüysüz, 1999; Ustaömer and Robertson, 2010; Yilmaz et al., 1997). The Early Paleocene plagioleucitites in the Eastern Pontides have been interpreted as the final products of the northward subduction (Altherr et al., 2008). The Paleocene and Early Eocene in the Eastern Pontides were dominated by continent–continent collision between the Pontides and the Tauride–Anatolide block in response to the complete closure of the Neotethys (Boztuğ et al., 2004; Dokuz et al., 2013; Hisarli, 2011; Karsli et al., 2010b, 2011; Okay and Şahintürk, 1997; Rolland et al., 2012; Topuz et al., 2011). Middle Eocene high-K calc-alkaline intrusives and volcanics (Arslan and Aslan, 2006; Aydinçakir and Şen, 2013; Boztuğ et al., 2004, 2006; Karsli et al., 2007, 2012b) and Neogene alkaline volcanics (Aydin et al., 2008, 2009) formed in a post-collision extensional setting.

3. Sampling and analytical techniques

We collected fourteen lamprophyre samples at three locations of small intrusions near the village of Karamustafa, Gümüşhane (Fig. 1b). The sample locations are depicted in Fig. 1b. All of the samples are megascopically fresh, undeformed and unmetamorphosed. As these samples represent the first observation of such rocks in the region, $^{40}Ar/^{39}Ar$ dating, mineral chemical analyses, major and trace element analyses, and Sr–Nd–Pb isotopic measurements were performed to evaluate the origin of the calc-alkaline lamprophyres in the Eastern Pontides and the geodynamic setting in which they were generated.

3.1. $^{40}Ar/^{39}Ar$ dating

$^{40}Ar/^{39}Ar$ incremental heating experiments were performed in the Geochronology Laboratory at the Vrije University. For each sample, approximately 200 mg of washed groundmass was packed in 20-mm diameter Al-foil packages and was stacked with packages containing a mineral standard into a 23-mm OD quartz tube. The mineral standard was DRA-1 sanidine (with a K/Ar age of 25.26 Ma), and the quartz vial was packaged in a standard Al-irradiation capsule and irradiated for 1 h in a Cd-lined rotating apparatus at the NRG-Petten HFR facility in the Netherlands. Laser incremental heating was performed using a Synrad 48-5 CO_2 laser. A typical mass spectrometer run consisted of stepping through the argon mass spectrum. The details of the analytical method were those described by Wijbrans et al. (1995).

3.2. Microchemical analyses

The mineral compositions were determined in polished thin sections using a Cameca SX-100 electron microprobe at the Ludwig Maximilian University, Section for Mineralogy, Petrology and Geochemistry, Munich (Germany), equipped with five wavelength-dispersive spectrometers. The analytical conditions included an accelerating voltage of 15 kV, a beam current of 20 nA and a counting time of 10 to 30 s.

Fig. 1. (a) Main tectonic setting of Turkey in relation to the Afro-Arabian and Eurasian plates [modified from Okay and Tüysüz (1999)]. (b) Simplified geological map of the Gümüşhane area and (c) Detailed geological map of the Karamustafa area containing the calc-alkaline lamprophyres. Localities: KLM1 = 40°21′32″N, 39°19′26″E; KML10 = 40°21′10″N, 39°18′20″E; KML15 = 40°20′33″N, 39°18′33″E.