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Geochemistry and petrology of the Early Miocene lamproites and related volcanic rocks in the Thrace Basin, NW Anatolia

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ABSTRACT

The extensional Thrace basin (NW Anatolia) contains an association of early Miocene diopside–leucite–phlogopite (Doğanca) and diopside–phlogopite (Korucuköy) lamproites with Oligocene medium-K calc-alkaline andesites (Keşan volcanics), early Miocene shoshonitic rocks (Altınyazı trachyte) and middle Miocene Na-alkaline basalts (Beğendik basalts). The Doğanca lamproite (K_2O = 5.1–5.5 wt.%; K/Na = 2.78–2.89; MgO = 11.4–11.8 wt.%) consists of olivine ($Fo_{71–86}$), diopside (Al_2O_3 = 1.0–5.0, Na_2O = 0.2–0.6), phlogopite (TiO_2 = 1.1–9.4, Al_2O_3 = 11.1–13.9), spinel (Mg# = 22.9–32.6; Cr# = 64–83.4), leucite, apatite, zircon, Fe–Ti-oxides and magnetite in a poikilitic sanidine matrix. The potassic volcanic units (lamproites and trachytes) in the region have similarly high Sr and low Nd isotopic compositions ($^{87}Sr/^{86}Sr_{(i)}$ = 0.70835–0.70873 and $^{143}Nd/^{144}Nd_{(i)}$ = 0.51227–0.51232). The major and trace element compositions and Sr–Nd–Pb isotopic ratios of the shoshonitic, ultrapotassic and lamproitic units closely resemble those of other Mediterranean ultrapotassic lamproites (i.e., orogenic lamproites) from Italia, Serbia, Macedonia and western Anatolia. The Beğendik basalts show intraplate geochemical signatures with an Na-alkaline composition, an absence of Nb negative anomalies on primitive mantle-normalized multi-element diagrams, as well as low Sr (~0.70416) and high Nd (0.51293) isotopic ratios; and include olivine ($Fo_{72–84}$), diopside, spinel, Fe–Ti-oxides and magnetite.

The Oligocene Keşan volcanics were emplaced in the earlier stages of extension in Thrace, and represent the typical volcanic products of post-collisional volcanism. The continental crust-like trace element abundances and isotopic compositions of the most primitive early Miocene ultrapotassic rocks (Mg# up to 74) indicate that their mantle sources were intensely contaminated by the continental material. By considering the geodynamic evolution of the region, including oceanic subduction, crustal accretion, crustal subduction and post-collisional extension, it is suggested that the mantle sources of the potassic volcanic units were most likely metasomatized by direct subduction of continental blocks during accretion and assemblage of various Alpine tectono-stratigraphic units. Overall, the magma production occurred in an extensional tectonic setting that controlled the core-complex formation and related basin development, with the middle Miocene Beğendik basalts being derived from asthenospheric sources during the late stages of extension.

1. Introduction

Lamproites are mantle-derived volcanic rocks with ultrapotassic geochemical affinities (MgO and K_2O >3 wt.%; K_2O/Na_2O >2; K_2O + Na_2O/Al_2O_3 >1; Foley et al., 1987), and are of particular importance to petrologists because they reflect the distinct geochemical features of the highly enriched mantle sources from which they originated (e.g., Nelson et al., 1986; Bergman, 1987; Foley et al., 1987; Prelević et al., 2008, 2013). These rocks are unusual in that they show both mantle- (high-MgO, Ni contents) and crust-like (high incompatible trace element and radiogenic Sr isotope compositions) geochemical features. Those derived in post-orogenic extensional settings (orogenic lamproites) have most commonly been described from along the Alpine–Himalayan system in Spain (Benito et al., 1999; Duggen et al., 2005), Italy (Peccerillo, 1998; Avanzinelli et al., 2008), Serbia & Macedonia (Altherr et al., 2004; Prelević et al., 2005; Yanev et al., 2008), Turkey (Çoban and Flower, 2006; Ersoy and Helvacı, 2007; Akal, 2008; Prelević et al., 2012), and China (Ding et al., 2003; Gao et al., 2007; Zhao et al., 2009). Orogenic lamproites are generally associated with other calc-alkaline and potassic (or even ultrapotassic) rock types and are frequently interpreted as having originated from orogenic mantle sources that have been intensely metasomatized (enriched) during subduction and collision events throughout the closure of the Tethyan oceanic branches. The mechanism of the enrichment process is, however, still debated. Some authors favor long-term isolation of

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the subducted sediments and/or accretionary complexes in mantle domains (e.g., Prelević et al., 2005; Peccerillo and Martinotti, 2006; Gao et al., 2007; Tommasini et al., 2011), while others suggest direct subduction of continental crust into the mantle during crustal accretion (e.g., Schreyer et al., 1987; Arnaud et al., 1992; Parkinson and Kohn, 2002; Zhao et al., 2009; Çoban et al., 2012; Ersoy et al., 2012; Prelević et al., 2013).

Eastern Rhodope and northwestern Anatolia are part of the Alpine–Himalayan orogenic system. In these regions, post-orogenic extension led to the formation of high-K, calc-alkaline to shoshonitic and locally-developed ultrapotassic volcanic extrusives during late Paleogene to Miocene times (Aldanmaz et al., 2000; Marchev et al., 2004; Altunkaynak and Genç, 2008; Dhont et al., 2008; Kirchenbaur et al., 2012a). In both areas, a number of continental blocks were accreted along suture zones, via oceanic subduction. Continental collision and continental subduction then led to high- to ultrahigh-pressure metamorphism, followed by extensional processes that are typically associated with magma generation (Kostopoulos et al., 2000; Mposkos and Kostopoulos, 2001; Jahn-Awe et al., 2012; Kirchenbaur et al., 2012b; Ersoy and Palmer, 2013, and references therein). In the eastern Rhodopes, the magmatic activity started during the latest Eocene and continued up to the early Miocene (Christofides et al., 2004; Marchev et al., 2004; Kirchenbaur et al., 2012a), and in the northern part of W Anatolia, the magmatic activity commenced during the early Eocene (52–47 Ma) and continued up to the middle Miocene (Aldanmaz et al., 2000; Altunkaynak and Genç, 2008; Kürkçüoğlu et al., 2008; Gülmez et al., 2012). Although this pattern of magmatism has been linked to a general southward migration of Aegean magmatic activity in parallel to retreat of the Hellenic subduction zone (e.g., Fytikas et al., 1984; Ring et al., 2010), Ersoy and Palmer (2013) pointed out that this hypothesis conflicts with observations that Oligocene to Miocene magmatic activity also took place to the north of the early Eocene magmatic rocks.

The Thrace basin is located between eastern Rhodope and western Anatolia, and is one of the largest extensional basins in the region. It began to develop during the Eocene, marking the beginning of extensional tectonics in the N Aegean. The sedimentary infill of the basin contains Oligocene–Miocene volcanic rocks, lying to the north of the Eocene magmatic belt in NW Anatolia, and thus precluding simple southward migration of magmatism with time. Oligocene medium-K calc-alkaline rocks, high-MgO, shoshonitic to ultrapotassic rocks, including lamproites, and Na-alkaline basaltic rocks occur in the basin fill. This association, may therefore link the eastern Rhodope Oligocene–Miocene magmatic belt to that of Western Anatolia.

Here, we present the first detailed description of Miocene leucite lamproitic rocks in northwest Turkey, including whole-rock geochemical data (major and trace elements, and Sr–Nd–Pb isotopes) from the associated rocks from the Keşan region in the Thrace basin.

2. Geological setting and sample locations

The northern part of the Aegean region (to the north of the Vardar and İzmir–Ankara suture zones), including the eastern Balkans, NW Anatolia and the Thrace Basin, lies in the Eastern Mediterranean orogenic domain, which was shaped by closure of the Tethyan oceans (e.g., Şengör and Yılmaz, 1981; Okay and Tüysüz, 1999; Stampfli, 2000). Pre-Tertiary basement units in this region comprise the Strandja Massif to the north, the Sakarya Zone of the Pontides to the south and the Rhodope Massif to the west, which constitute the dissected Rhodope–Pontide fragment (Fig. 1; e.g., Ricou et al., 1998; Okay et al., 2001). The Strandja Massif is composed of a Paleozoic basement and Triassic metasedimentary cover, and is bound by the Thrace fault zone in the south (e.g., Natalin et al., 2012; and references therein). The Sakarya Zone is composed of Paleozoic granitoids and Triassic subduction–accretion complexes, which are unconformably overlain by Jurassic and younger sediments (Okay et al., 1996). The Rhodope Massif consists of pre-Alpine and Alpine nappes of continental and oceanic units, which were assembled during subduction and closure of the Vardar Ocean (e.g., Bonev and Stampfli, 2011). The NE part of the Rhodope Massif is separated from the late Cretaceous Srednogorie magmatic arc by the Maritza fault zone (Boccaletti et al., 1978; Georgiev et al., 2012). The NE part of the Rhodope and southern part of the Strandja massifs are covered by Tertiary sedimentary units of the Thrace Basin (Elmas, 2011; Kilias et al., 2013; Fig. 1). The Rhodope Massif was exhumed as a number of extensional metamorphic core complexes that comprise: (1) the Southern Rhodope Core Complex, (2) the central Rhodope Core Complex (Arda dome), and (3) the Kesebir and Biala Reka domes (e.g., Dinter and Royden, 1998; Bonev and Beccaletto, 2007; Brun and Sokoutis, 2007; Jahn-Awe et al., 2012).

In the eastern Rhodopes, calc-alkaline to shoshonitic rocks (basalt to rhyolite) are located mainly in the Borovitsa and Momchilgrad-Arda volcanic areas, with radiometric ages ranging from late Eocene to Oligocene (~39–25 Ma; Dhont et al., 2008 and references therein). To the southeast of the Momchilgrad-Arda volcanic area, the Krumovgrad alkaline basaltic rocks (with intraplate geochemical features) were emplaced at 28–26 Ma (Marchev et al., 2004). The calc-alkaline felsic volcanism continues further south (the Evros volcanic area), with ages of ~33–19 Ma (Christofides et al., 2004). To the southeast of the Evros volcanic area, lie the andesitic to rhyolitic Hisarlıdağ volcanics (35.0 ± 0.9 Ma; Ercan et al., 1998). Overall, these ages indicate that volcanism in the region continued until the early Miocene in the south of eastern Rhodopes and Thrace. Large exposures of early Miocene volcanic rocks are also located on the islands of Samothrace (Vlahou et al., 2006) and Limnos (Pe-Piper et al., 2009), and the Biga Peninsula (Aldanmaz et al., 2000). Importantly, basaltic to andesitic volcanic rocks were also emplaced further south in the Biga Peninsula and south of the Marmara Sea during the Eocene (~52–37 Ma; Ercan et al., 1998; Altunkaynak and Genç, 2008; Kürkçüoğlu et al., 2008; Gülmez et al., 2012), arguing against simple southward migration of magmatism throughout the Aegean region. Finally, during the late Miocene, small Na-alkaline basaltic extrusives with OIB-type geochemical affinity were emplaced in the Biga Peninsula (Ezine alkaline basalts) and in the eastern part of the Thrace basin (Thrace alkaline basalts, Ercan et al., 1998; Aldanmaz et al., 2006).

The study area (Fig. 2) is located in the S-SW part of the Thrace Basin. Overall, the basin is a triangular extensional basin, including Eocene to Pliocene sedimentary units which are up to 9 km thick (e.g., Elmas, 2011; Kilias et al., 2013 and references therein). Kilias et al. (2013) proposed that the basin developed as a supradetachment basin, related to exhumation of the metamorphic rocks of the Rhodope Massif during middle–late Eocene to Oligocene times. According to Elmas (2011), the stratigraphy of the study area begins with turbidites of the middle–late Eocene Keşan Formation, and continues upwards with fine-grained fluvial sediments of the late Eocene to early Oligocene Mezardere, followed by the late Oligocene to early Miocene Danişment formations. These units are then unconformably overlain by middle–late Miocene sedimentary rocks of alluvial, fluvial and lacustrine origin. Additionally, several volcanic units with small outcrops and distinct compositions were emplaced during the Oligocene–Miocene.

To the south of Keşan, andesitic–dacitic volcanic rocks occur as dykes, lava flows and domes (of which one sample (K-20) has been analyzed in this study). These volcanic rocks yield a 26.2 ± 0.5 Ma K–Ar age (Ercan et al., 1998), and are thus coeval with the Hisarlıdağ volcanics that lie in the southwest of the Thrace Basin. A small volcanic unit lies to the north of the study area, close to Altınyazı village (Fig. 2), which crosscuts the sedimentary rocks of the Danişment Formation and yields 21.27 ± 0.24 and 18.47 ± 0.20 Ma K–Ar radiometric ages (Ercan et al., 1998). To the east of the study area, south of Doğanca village, a small volume lava dome, which contains large mica phenocrysts, cuts the lignite-bearing sedimentary units of the late Oligocene–early Miocene Danişment formation. On the basis of its petrographic and geochemical features, this unit is named here as the Doğanca lamproite.