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Deciphering the shoshonitic monzonites with I-type characteristic, the Sisdaği pluton, NE Turkey: Magmatic response to continental lithospheric thinning

Orhan Karsli [a,*], Abdurrahman Dokuz [a], İbrahim Uysal [b], Murat Ketenci [c], Bin Chen [d], Raif Kandemir [a]

[a] Department of Geological Engineering, Rize University, TR-53000 Rize, Turkey
[b] Department of Geological Engineering, Karadeniz Technical University, TR-61100 Trabzon, Turkey
[c] Department of Geological Engineering, Istanbul Technical University, TR-34000 Istanbul, Turkey
[d] School of Earth and Space Sciences, Peking University, 100871 Beijing, China

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ABSTRACT

Large-scale late Mesozoic to early Cenozoic plutons in the Eastern Pontide orogenic belt mostly show calc-alkaline and I-type geochemical features. However, we identify the Sisdaği pluton that has shoshonitic affinity and I-type character in the region. The pluton was emplaced at shallow depths (<5 km), revealed by Al-in hornblende barometry, in the northern margin of the orogenic belt, with SHRIMP zircon U–Pb age of 41.55 ± 0.31 Ma, interpreted as dating magma crystallization. It is composed of monzonite, monzodiorite and monzogabbro. The samples show low zircon saturation temperature (T_{Zr}) ranging from 603 to 769 °C compared to A-type rocks. They exhibit SiO_2 contents of 47.6–61.4 wt.%, and high $K_2O + Na_2O$ (5.0–8.8 wt.%) and K_2O/Na_2O (0.8–1.8). All the samples are characterized by low Mg# (<47) and relatively high but variable Al_2O_3 content (16.9–22.2 wt.%). They are also enriched in light rare earth elements (LREE), large ion lithophile elements (LILE) and depleted in high field strength elements (HFSE), with a weak negative Eu anomaly (Eu/Eu* = 0.58–1.26) in mantle-normalized trace element patterns.

The samples possess homogeneous initial Sr and Nd isotopic compositions, marked with low I_{Sr} = 0.70376–0.70408 and ε_{Nd} (42 Ma) = +1.3 to +2.4. T_{DM} ages of the samples range from 0.70 to 0.85 Ga. The Pb isotopic ratios are ($^{206}Pb/^{204}Pb$) = 18.64–18.72, ($^{207}Pb/^{204}Pb$) = 15.51–15.58 and ($^{208}Pb/^{204}Pb$) = 38.31–38.65. These geochemical features imply that the parental magma resulted from melting of chemically enriched lithospheric mantle source. In such a case, a hot upwelling asthenosphere is necessary to partially melt the lithospheric mantle in order to form the parental magma. The pluton is considered to be a post-orogenic intrusion that was emplaced in an environment of lithospheric extension, triggering asthenospheric upwelling. The thermal anomaly induced by asthenospheric upwelling resulted in partial fusion of chemically enriched subcontinental lithospheric mantle beneath the region. Then, the shoshonitic melt, which subsequently underwent fractional crystallization with minor crustal contamination, ascent to shallower crustal levels to generate a monzonitic rock series ranging from monzogabbro to monzonite. All these data combined with the regional geology suggest that the crustal thickening as a consequence of regional compression during the Paleocene changed into a lithospheric extension and thinning throughout the early Cenozoic (at ~42 Ma) in the Eastern Pontides. Hence, the middle Eocene shoshonitic I-type magmatism is a unique pluton, signifying initiation of lithospheric thinning and thus of hot asthenospheric upwelling in the region. These interpretations also argue against the presence of an early Cenozoic subduction of oceanic slab in the Eastern Pontides.

1. Introduction

The intensive late Mesozoic to early Cenozoic magmatic activity in the Eastern Pontides is manifested by presence of widespread plutonic bodies (e.g., Yilmaz and Boztuğ, 1996; Boztuğ et al., 2004, 2006; Topuz et al., 2005; Karsli et al., 2004, 2007, 2010a, 2011, 2012; Kaygusuz et al., 2008; Topuz et al., 2011). The plutonic bodies predominantly consist of calc-alkaline I-type granites. Minor amounts of shoshonitic intrusions encompassing the monzonitic series on which this work focuses and A-type plutons (Karsli et al., 2012) are associated closely in time and space with the calc-alkaline I-type plutons. Shoshonitic plutons have attracted much more attention from many petrologists. In general, shoshonitic magmas are assumed to transitional between calc-alkaline and alkaline magmas (Liegeois et al., 1998; Bonin, 2004). Although many shoshonitic plutons have been studied in detail, their generation and geodynamic settings are still under considerable debate. Whether the

* Corresponding author. Tel.: +90 5322087307; fax: +90 4562337567.
E-mail address: okarsli@gmail.com (O. Karsli).

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shoshonitic magmas are based on subduction or rifting scenarios, they may form: (i) by partial melting of enriched mantle without assimilation of crustal material during ascent (e.g., Wang et al., 1996, 2006; Jiang et al., 2002; Liu et al., 2002) and (ii) by partial fusion of depleted mantle with subsequent contamination by crustal material (e.g., Fu et al., 1997; Xing and Xu, 1999) in both arc and post-collisonal settings (e.g., Foley and Peccerillo, 1992; Turner et al., 1996). Indeed, petrogenetic models may reflect information about the geological settings where shoshonitic magmas are generated. Therefore, we focus on source composition of shoshonitic melt, timing of the tectonic regime change from compression to extension and the evidence provided by magmatic activity during this change.

The well-exposed Sisdaği pluton that is made up of a monzogabbro–monzodiorite–monzonite with a shoshonitic affinity in the Eastern Pontides provides a unique opportunity to test lithospheric thinning and to interpret how the shoshonitic plutons generated in a post-collision extentional setting. Here we present a detailed account of the petrology, whole-rock geochemical, mineral chemical, zircon U–Pb age and Sr–Nd–Pb isotopes for the early Cenozoic shoshonitic I-type monzonites in the northern margin of the Eastern Pontides to decipher their source region. These data are then used to point out the nature of the particular type of magmatism and tectonic setting of the pluton, particularly in relation to the initiation of lithospheric thinning events in an extensional tectonic regime in the region.

2. Geological setting of the Eastern Pontides

Anatolia comprises four major tectonic blocks or terranes that are separated by the suture zones (e.g., Okay and Tüysüz, 1999). The Sakarya block represents a series of Mesozoic–Cenozoic fold belts comprising a N-vergent foreland fold and thrust belt in the Western Pontides and a concave, upward-shaped fold belt in the Eastern Pontides (Fig. 1a). The Eastern Pontides are one of the best preserved large mountain belts, 500 km long and 100 km wide. Their northeast boundary is marked by the Achara-Trialet belt, while the Great Caucausus lies to the north and the Taurides to the south. The basement rocks beneath the Eastern Pontides are late Carboniferous granitoids together with early Carboniferous metamorphic rocks (e.g., Yilmaz, 1972; Topuz et al., 2007, 2010; Dokuz, 2011) and late Carboniferous to early Permian shallow marine to terrigeneous sedimentary rocks (Okay and Leven, 1996; Çapkınoğlu, 2003; Kandemir and Lerosey-Aubril, 2011). Late Permian and Triassic rocks are rare in the Eastern Pontides (Karsli, unpublished data). The basement is overlain by early and middle Jurassic volcano-sedimentary and upper Jurassic and lower Cretaceous limestones. The upper Jurassic and lower Cretaceous time interval is attributed to break-up of a continental margin that the rift-related volcano-sedimentary sequences (Kandemir, 2004; Dokuz and Tanyolu, 2006; Kandemir and Yilmaz, 2009) and basic volcanic rocks (Şen, 2007) formed. Late Jurassic granitoids and their dacitic volcanic equivalents were emplaced into the volcano-sedimentary rocks of Şenköy Formation during late Jurassic (Dokuz et al., 2006, 2010). These granitoids are interpreted as the products of an arc-continent collision event, in response to closure of Paleotethys during the middle Jurassic and the accretion of the Sakarya block to Laurasia in the north (Şengör et al., 1980; Şengör and Yilmaz, 1981; Yilmaz et al., 1997; Dokuz et al., 2010). During the late Cretaceous, a thick unit of arc-type volcanics and intrusive rocks were emplaced into the Eastern Pontide crust in response to northward subduction of Neotethyan oceanic crust along the southern border of the Sakarya block (e.g., Akin, 1979; Şengör and Yilmaz, 1981; Okay and Şahintürk, 1997; Yilmaz et al., 1997; Okay and Tüysüz, 1999; Şengör et al., 2003; Topuz et al., 2007; Altherr et al., 2008; Çinku et al., 2010; Karsli et al., 2010a, 2011; Ustaömer and Robertson, 2010). The magmatic arc is manifested by a more than 2 km-thick volcano-sedimentary sequence with local intrusion of hornblende–biotite granitoids in the northern part of the Eastern Pontides (Yilmaz and Boztuğ, 1996; Okay and Şahintürk, 1997; Karsli et al., 2004, 2010a, 2011; Boztuğ et al., 2006; Boztuğ and Harlavan, 2008; Kaygusuz et al., 2008). The southern part represents a fore-arc phase where flysch-facies sedimentary rocks with limestone olistoliths were accumulated. The early Paleocene plagioleucitites were considered as final products of the northward subduction (Altherr et al., 2008). The Paleocene time in the region corresponds to a continent-continent collision between the Pontides and the Tauride-Anatolide block due to the complete closure of Neotethys (Okay and Şahintürk, 1997; Boztuğ et al., 2004; Hisarli, 2011; Karsli et al., 2010b, 2011; Topuz et al., 2011) The timing and mechanism of the collision along the Izmir-Ankara-Erzincan suture zone are also interpreted differently, based on structural considerations and timing of igneous activity. Şengör and Yilmaz (1981) and Okay and Şahintürk (1997) propose a Paleocene to early Eocene (ca. 55 Ma) collision, causing crustal thickening. In this case, the collision represents a telescoping of the continental margin into a stack of north-vergent thrust slices, resulting in regional uplift of the Eastern Pontides. Şengör and Yilmaz (1981) suggest that the subduction had ceased in the early Paleocene and the collision occurred around the Paleocene to early Eocene in the Eastern Pontides. Also, Okay et al. (1997) suggested that the collision occurred in the late Paleocene to early Eocene based on field relationships and granitoid ages. Indeed, the Eastern Pontides have a quiescent period of magmatism during the Paleocene. Early Eocene adakitic rocks, pointing to a syn- to post-collision phase have been reported in the region (Topuz et al., 2005, 2001; Karsli et al., 2010b, 2011). Middle Eocene time is characterized by a large belt of E–W trending volcanic (e.g., Tokel, 1977; Çoban, 1997; Şen et al., 1998; Aliyazicioğlu, 1999) and granitoid rocks (Yilmaz and Boztuğ, 1996; Boztuğ et al., 2004; Karsli et al., 2007) towards Iran and the Caucasus (Fig. 1b). The magmatic activity is attributed to an extension as a consequence of the opening of the eastern Black Sea basin. Post Eocene terrigeneous units are observed in the area (e.g., Okay and Şahintürk, 1997). Neogene alkaline volcanics are ascribed to the post-collision extensional tectonic setting (Aydin et al., 2008, 2009). The pressure release in the crust, due to the escape, triggered volcanism along major fault planes in the Eastern Pontides during the Polio-Pleistocene (ca. 2 Ma; Yeğingil et al., 2002).

The shoshonitic, I-type Sisdaği pluton intruded into the northern part of the Eastern Pontides and developed a wide contact aureole against Eocene intermediate volcanic rocks of the Alibaba Formation (Fig. 1c). The pluton crops out a length of less than 8 km and a maximum width of 5 km. It is part of the composite Kaçkar Batholith, dated between 95 to 40 Ma [K–Ar and Ar–Ar on hornblende, Taner, 1977; Moore et al., 1980; K–Ar on biotite, Karsli et al., 2007; Ar–Ar on hornblende, Karsli et al., 2010a; SHRIMP zircon U–Pb, Kaygusuz et al., 2009; SHRIMP zircon U–Pb, Karsli et al., 2012; Ar–Ar on hornblende, Karsli et al., 2011]. The Sisdaği pluton is composed of monzogabbro, monzodiorite and monzonite. These rocks share several common petrographic and textural features. Most contacts between various rock types are transitional.

3. Analytical methods

3.1. Zircon SHRIMP U–Pb dating

One sample from the Sisdaği pluton was chosen for zircon SHRIMP U–Pb dating. Zircons were separated using standard magnetic and heavy liquid techniques, mounted in epoxy, and ground to about half their thickness. Cathodoluminescence images were taken to check the internal structures of zircon grains and to select a better spot for analyses. Zircon U–Pb dating was performed at the SHRIMP Ion Probe Centre, Chinese Academy of Geological Sciences, Beijing, following the