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Age and geochemistry of Early Cambrian post-collisional granites from the Ambatondrazaka area in east-central Madagascar

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ABSTRACT

New geochronological and geochemical data are presented on Early Cambrian granites from the Ambatondrazaka area in east-central Madagascar. U–Pb zircon dating reveals that these granites were emplaced at ~520 Ma within a post-collisional setting. They are metaluminous to weakly peraluminous and enriched in large ion lithophile elements. Using zircon Ce anomalies as proxy, it is indicated that they crystallized under moderately reduced conditions with an oxygen fugacity of FMQ+0.75/NNO−0.09. Their low initial $^{87}Sr/^{86}Sr$ ratios (0.706715 and 0.706869) and notably negative $\varepsilon_{Nd}(t)$ values (−24.1 and −23.4) imply a magma source of mafic continental crustal material, probably analogous to the Neoarchean mafic gneisses of the Tsaratanana Complex. The low zircon $\varepsilon_{Hf}(t)$ values (−16.4 to −12.9) further support a mafic crustal source with a $^{176}Lu/^{177}Hf$ ratio of ~0.017. On the other hand, their depletion in HREE and slight depletion in Nb help constrain the melting pressure between ~10 and 13 kbar. Taken together, a mafic lower crustal source is favored for these granites. Our results demonstrate the role of crustal anatexis in the origin of Late Ediacaran–Early Cambrian post-collisional magmatism in Madagascar.

1. Introduction

The supercontinent Gondwana was assembled along the East African Orogen (EAO) during the period of ~650–500 Ma (e.g. Stern, 1994; Jacobs and Thomas, 2004). Late Ediacaran–Early Cambrian post-collisional granitoids widely occur along the >8000 km length of the EAO (e.g. Küster and Harms, 1998; Jacobs et al., 2003, 2008). These igneous rocks provide a window into understanding the geodynamic processes operating in the late tectonic history of the EAO.

Madagascar occupied a central position within this extensive orogenic belt (Fig. 1a). Over the last two decades, large volumes of Late Ediacaran–Early Cambrian post-collisional intrusions have been recognized throughout the Malagasy basement (Paquette et al., 1994; Paquette and Nédélec, 1998; Kröner et al., 1999, 2000; de Wit et al., 2001; Meert et al., 2001; Buchwaldt et al., 2003; Tucker et al., 1999, 2007; Goodenough et al., 2010). However, available geochemical (especially isotopic) data for them are limited to the pioneering work of Goodenough et al. (2010), and consequently issues regarding the magma nature and origin remain open to debate.

In this paper, new geochronological and geochemical data are presented on post-collisional granites from the Ambatondrazaka area in east-central Madagascar. The results can help define the age, crystallization conditions and source characteristics of the latest magmatism within the central part of the EAO.

2. Geological background

The island of Madagascar is made up of a Precambrian shield in the eastern two-thirds and Phanerozoic sedimentary and igneous rocks overlying the western third (Fig. 1b). Based on the achievements of two recent projects funded by the World Bank (see Moine et al., 2014 and Tucker et al., 2014 for reviews), the Malagasy Shield can be divided into two Archean blocks (Antananarivo and Antongil–Masora Domains) and a Neoproterozoic metasedimentary belt (Betsimisaraka Domain) in the central part, a Neoproterozoic exotic terrane (Bemarivo Domain) at the northern boundary, and a Late Neoproterozoic–Early Cambrian fold-and-thrust belt (Itremo–Ikalamavony Domain) and three Proterozoic crustal units (Vohibory, Androyen and Anosyen Domains) at the southern boundary. In addition, the Antananarivo Domain includes three Neoarchean mafic gneiss and schist belts of the Tsaratanana

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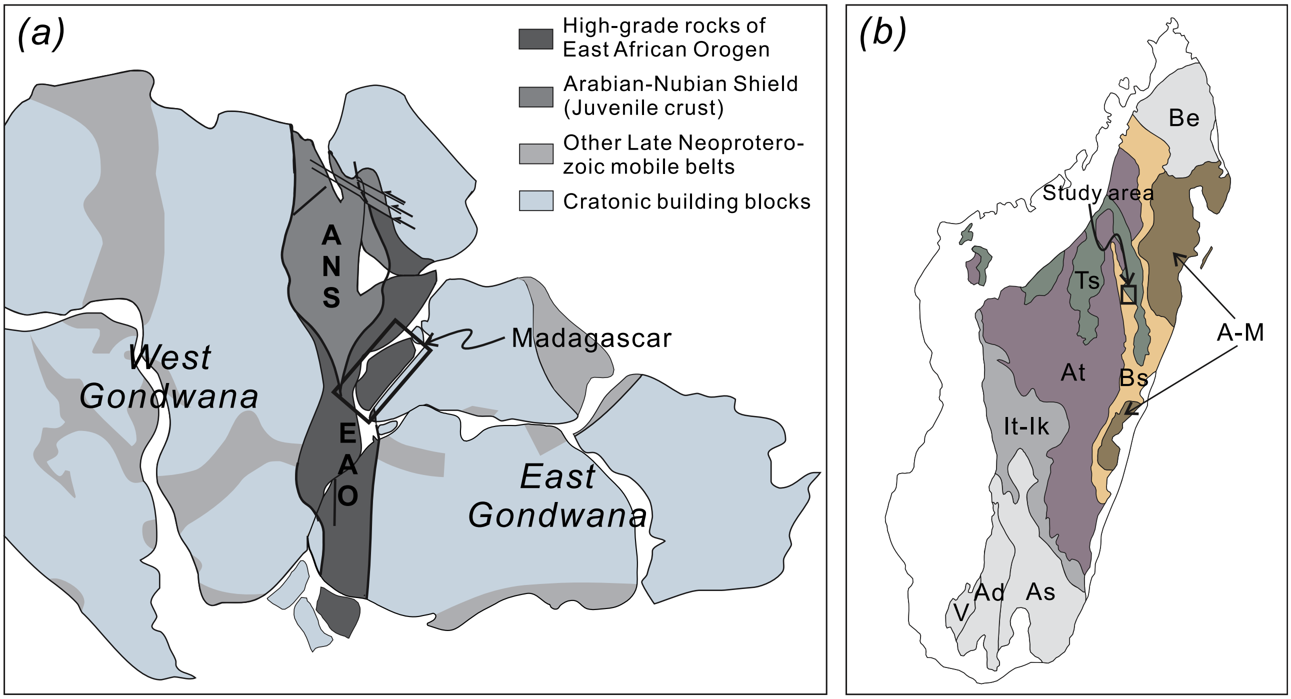

Fig. 1. (a) Gondwana reconstruction showing the spatial extent of the East African Orogen and position of Madagascar (after Jacobs and Thomas (2004) and Thomas et al. (2009)). (b) Tectonic subdivision of the Malagasy Shield with the location of the study area (after Tucker et al., 2011a). At = Antananarivo; A–M = Antongil–Masora; Bs = Betsimisaraka; Be = Bemarivo; It–Ik = Itremo–Ikalamavony; V = Vohibory; Ad = Androyen; As = Anosyen; Ts = Tsaratanana.

Complex as a major subdomain. They are, from west to east, Maevatanana, Andriamena, and Beforona–Alaotra belts.

The tectonic attribute of the Betsimisaraka Domain is critical to understanding the geological framework of the Malagasy Shield. Traditionally, this elongate sandwiched belt is interpreted as a Neoproterozoic suture zone delineating the western convergent margin of the Mozambique Ocean (Collins, 2006 and references therein). On the contrary, Tucker et al. (2011a,b, 2014) argue that the Archean rocks of Madagascar are part of the Greater Dharwar Craton and the Betsimisaraka Domain is indeed a Neoproterozoic intra-continental rift basin. The latter proposal is more consistent with several recent multidisciplinary investigations in Madagascar (De Waele et al., 2011; Grieco et al., 2012; Boger et al., 2014; Zhou et al., 2015; Zhou, 2015) and south India (Brandt et al., 2014; Rekha et al., 2014).

Cryogenian igneous rocks are present within most of the domains and are typified by the intrusive Imorona–Itsindro Suite (~840–760 Ma; e.g. Handke et al., 1999) throughout central Madagascar. Following the Cryogenian reworking, two tectono-thermal pulses overprinted the Malagasy Shield during Ediacaran–Early Cambrian time as a result of convergence between East and West Gondwana. The magmatic products of the early orogenic event are the "stratoid" granitoids of the Kiangara Suite (~630–610 Ma; Paquette et al., 1994) in central Madagascar, and those of the later orogenic event could be further subdivided into the Ambalavao Suite (~580–510 Ma; Tucker et al., 2014) in central and southern Madagascar and the Maevarano Suite (~540–520 Ma; Goodenough et al., 2010) in northern Madagascar.

This study focuses on a number of granite dykes in the Ambatondrazaka area (Fig. 1b). As shown in Fig. 2, the Precambrian stratigraphic sequences in this area consist of the Manampotsy Group of the Neoproterozoic Betsimisaraka belt and the Beforona Group of the Neoarchean Tsaratanana Complex, both of which are partly overlain by Cenozoic sedimentary cover. A total of 11 granite dykes were discovered during our 2011 field survey of the gabbros of the Imorona–Itsindro Suite. They occur as intrusive vertical dykes with thickness varying from 6 cm to 1.3 m and an approximate north–south trend (Fig. 3a and b). They typically show a fine-grained texture and a weakly foliated to unfoliated structure, and mainly consist of quartz (~50 vol.%), alkali feldspar (~30%) and plagioclase (~15%) (Fig. 3c). In addition, a small amount of biotite and Fe–Ti oxides as well as trace apatite and zircon are present as accessory phases. No xenoliths and mafic magmatic enclaves have been observed. Although some granite dykes are deeply weathered, the samples we collected are all fresh except for sample 11ZA6-1 and we utilized a range of analytical techniques to acquire their geochronological and geochemical data.

3. Analytical methods

3.1. U–Pb zircon dating

The representative sample 11ZA5-1 (S17°45′54.2″, E48°29′35.6″) was selected for U–Pb zircon dating. Zircons were extracted using conventional crushing and separation techniques. After selection with aid of a binocular microscope, zircon grains without cracks were set in a resin mount and polished to about one-half their original size. Cathodoluminescence (CL) images were acquired in order to observe internal textures and choose analytical sites. In-situ U–Pb dating was conducted by an Agilent 7500a ICP-MS coupled with a GeoLas 200 M laser-ablation system at the State Key Laboratory of Continental Dynamics, Northwest University (SKLCD–NWU) in Xi'an. A beam diameter of 30 μm was chosen for sampling. Detailed analytical procedures are similar to those reported by Yuan et al. (2004). Standard zircon 91500 was used for calibration. Raw data reduction was processed with the program GLITTER 4.4 (Griffin et al., 2008), and U–Pb ages were calculated and plotted using the program Isoplot 3.00 (Ludwig, 2003).