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Geochronological and geochemical constraints on the petrogenesis of the Ailaoshan granitic and migmatite rocks and its implications on Neoproterozoic subduction along the SW Yangtze Block

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ABSTRACT

The Neoproterozoic tectonic pattern of the South China Block (SCB) is considered to be a key element in the Rodinia reconstruction and subsequent Gondwana assembly. Numerous studies have been done on the Neoproterozoic igneous rocks along the SE and NW Yangtze Block of the SCB, but the contemporaneous igneous rocks in the SW Yangtze Block has poorly been known so far. This paper documents a comprehensive set of U–Pb geochronological, elemental and Sr–Nd–Hf isotopic data for the granitic gneiss and migmatite from the Ailaoshan tectonic zone of the SW Yangtze Block on the basis of field investigations. These granitic rocks are mainly granodiorite, monzogranite and quartz diorite and spatially associated with the synchronous mafic and dioritic rocks. On the basis of the A/CNK values and CIPW-normative corundum contents, these samples are subdivided into Group 1 with A/CNK > 1.1 and corundum of 1.5–6.5 vol.% and Group 2 with A/CNK = 0.87–1.09 and corundum = 0–1.5 vol.%, generally similar to the S- and I-type granitic rocks, respectively. The representative samples from Group 1 and 2 give the weighted mean ages of 810–785 Ma and 790–764 Ma, respectively, interpreted as the crystallization ages. They show strong Nb–Ta and P–Ti negative anomalies and variable Eu/Eu* (0.10–0.92). The $\varepsilon_{Nd}(t)$ and $\varepsilon_{Hf}(t)$ values are in the ranges of $-6.5 \sim -4.2$ and $-3.8 \sim +3.1$ for Group 1 and of $-6.2 \sim +1.8$ and $-6.3 \sim +5.7$ for Group 2, respectively. These Neoproterozoic granitic rocks might originate from a hybridization source of metagreywacke with proportionally "ancient" mafic component for Group 1 but with abundant juvenile mafic-derived rocks for Group 2. Our data, along with the available geological observations, demonstrate the extensive occurrence of the Neoproterozoic (761–833 Ma) igneous rocks in the Ailaoshan tectonic zone. The previously-mapped Ailaoshan and Yaoshan groups might be the Complexes including the Neoproterozoic, Triassic and Cenozoic igneous rocks. A persistent and long-lived Neoproterozoic (~830–760 Ma) subduction zone along the southwestern and northwestern margins of the Yangtze Block from Ailaoshan to Panxi and then to Hannan is proposed. The Yangtze Block might locate at the periphery of Rodinia during the early Neoproterozoic.

1. Introduction

The Neoproterozoic period is a key geological time in Earth history that saw the assembly and dispersal of Rodinia and the subsequent assembly of Gondwana (e.g., Cawood et al., 2010, 2013). The South China Block (SCB), which is created by the Neoproterozoic amalgamation between the Yangtze Block to the northwest and the Cathaysia Block to the southeast, is considered to have played a key role in the Rodinia reconstruction since it has been proposed as the "missing-link" between Australia and Laurentia (e.g., Li et al., 1995, 2002). Numerous data show the extensive development of the Neoproterozoic igneous rocks along the southeastern and northwestern margins of the Yangtze Block in the SCB (e.g., Li et al., 2002; Yan et al., 2004; Zhou et al., 2006a,b; Zheng et al., 2008; Wang et al., 2008; Zhao et al., 2010; Dong et al., 2011, 2012; Zhang et al., 2013a,b, 2015; Zhang and Wang, 2016; Zhao and Cawood, 2012; Yao et al., 2014; Zhu et al., 2014). These igneous rocks have been well-studied and overwhelmingly gave the Neoproterozoic crystallization age of 860–740 Ma, in spite of the on-going dispute over the associated tectonic setting (plume

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vs subduction; e.g., Li et al., 1995, 2008; Cawood et al., 2013; Dong et al., 2011, 2012; Zhao and Cawood, 2012; Zhou et al., 2002, 2006a,b; Zhao et al., 2008; Zhang et al., 2013a,b, 2015; Zhang and Wang, 2016). However, it is poorly known whether the Neoproterozoic igneous rocks also occurred in the southwestern margin of the Yangtze Block (e.g., Qi et al., 2012; Cai et al., 2014, 2015).

In the Diancangshan-Ailaoshan area of the SW Yangtze Block, there exists a WNW-trending metamorphic zone, geologically named the Ailaoshan tectonic zone. The metamorphic igneous rocks in this zone are mainly composed of granitic gneiss, migmatite, diorite and amphibolites, and have undergone strong Mesozoic and Cenozoic structural overprinting. Due to the absence of precise geochronological data, they are traditionally mapped as the Paleo- and Meso-proterozoic basement with an affinity to the Yangtze Block (e.g., Yunnan BGMR, 1983; Zhai et al., 1990). However, several Neoproterozoic (∼761–833 Ma) diorites, gabbros and plagioclase amphibolites were recently identified (Chung et al., 1997; Liu et al., 2008; Qi et al., 2012; Cai et al., 2014, 2015; Lai et al., 2014). This gives an important hint for the possible preservation of abundant Neoproterozoic igneous rocks in this zone. To determine whether these extensively-outcropped granitic gneisses and migmatites in this zone were generated during the Neoproterozoic period in association with the Rodinia assembly, a comprehensive geochronological and geochemical study for new data is obviously necessary.

On the basis of our field investigations, this paper presents a set of zircon U–Pb geochronological and Lu–Hf isotopic data, along with whole-rock elemental and Sr–Nd isotopic data for the granitic gneisses and migmatites from the previously-mapped Ailaoshan and Yaoshan groups along the Ailaoshan tectonic zone. Our data identify numerous Neoproterozoic (∼764–810 Ma) felsic rocks along the southwestern Yangtze Block, and provide insight into the hybridization source of metagreywacke with "ancient" or juvenile mantle-derived components. These results place important constraints on the Neoproterozoic tectonic regime of the southwestern Yangtze Block and reconcile the controversy on the tectonic location of the SCB in Rodinia (i.e. intracratonic versus peripheral; e.g., Li et al., 1995, 2008; Shu et al., 2011; Cawood et al., 2013; Zhao and Cawood, 2012; Zhao et al., 2008; Wang et al., 2013, 2014; Zhang et al., 2013b, 2015; Zhang and Wang, 2016).

2. Geological setting and petrography

The Ailaoshan tectonic zone in SW China is bounded by the Red River fault to the north and the Lixianjiang fault to the south (Fig. 1). It extends over 300 km with a width of 20–30 km, southeastward into the DayNuiConVoi metamorphic Domain (Song Ma tectonic zone) in North Vietnan and northwestward into the Diancangshan and Eastern Himalayan Syntaxis in SW Yunnan (inset in Fig. 1; Yunnan BGMR, 1983; Mo et al., 1993; Zhong, 1998). The Lixianjiang fault is considered the Paleozoic tectonic boundary separating the South China from Indochina Blocks. The Red River fault is a Cenozoic strike-slip shearing discontinuity associated with the eastward extrusion of the Tibet Plateau in response to the India-Asia collision (e.g., Wang et al., 2006). Along the Ailaoshan tectonic zone, there extensively occurred greenschist-facies metamorphic rocks to the southwest and high-grade metamorphic rocks to the northeast, separated by the WNW-trending Ailaoshan fault where numerous Paleotethyan relicts (e.g., late Paleozoic ophiolitic fragments, schist, chert, exotic limestone, arc-like igneous and granites) are preserved (Fig. 1, Zhong, 1998; Metcalfe, 2006; Jian et al., 2009; Fan et al., 2010). The greenschist-facies metamorphic package is characterized by the Paleozoic–Mesozoic metasedimentary and metaigneous rocks, with a small amount of late Paleozoic ophiolite fragments (e.g., Yunnan BGMR, 1983; Jian et al., 2009; Fan et al., 2010). The high-grade metamorphic rocks are overlain by the Paleozoic or Upper Triassic sequence and composed of gneiss, schist and marble, along with minor plagioclase amphibolite. These metamorphic rocks have been traditionally mapped as the Paleo- and Meso-proterozoic Ailaoshan and Yaoshan groups, regarded as the Yangtze crystalline basement (e.g. Yunnan BGMR, 1983; Zhai et al., 1990; Chang et al., 1998; Zhong, 1998; Leloup et al., 1995; Metcalfe, 2002). However, recent data show that the amphibolites, preserved as lens, pods and fragments in the previously-mapped Ailaoshan Group, were crystallized in the Neoproterozoic (∼800–820 Ma) rather than Paleo-/Meso- Proterozoic period (Cai et al., 2014).

The granitic gneisses and migmatites, the major elements of the Ailaoshan and Yaoshan groups as previously thought, extensively outcrop in the Manghao (Mangzi)- Adebo (Jinping)-Yuanyang-Jiayan (Honghe)-Bangmai (Xinping) and Pingbian–Hekou areas along the Ailaoshan zone (Fig. 1; e.g., Yunnan BGMR, 1983). They are gray or gray–white and have strong magmatic fabrics with gneissic or migmatitic structure. These rocks have commonly undergone Cenozoic sinistral shearing and exhibit a WNW- or NW-trending foliation and a subhorizontally plunging mineral lineation (e.g., Wang et al., 2006; Zhang et al., 2012a,b,c; Guo et al., 2015). The majority of these rocks are originally characterized by muscovite-, two-mica- or tourmaline-bearing granites. The mineral assemblage of the granitic gneisses mainly consists of plagioclase (∼15–40%), K-feldspar (∼25–45%), quartz (∼25–55%), biotite (∼5–15%) or muscovite (∼5%) with minor amounts of garnet, tourmaline, apatite, zircon, and monazite and Fe–Ti oxides (Fig. 2a–b). Migmatites have the mineral assemblage of plagioclase (∼30–45%), quartz (∼25–60%) and biotite (∼10–20%) with minor amounts of muscovite, tourmaline, apatite, zircon, sillimanite, monazite, garnet and Fe–Ti oxides. Several intrusions are characterized by granodiorite and quartz diorite and have mineral compositions of plagioclase (∼30–60%), hornblende (∼5–15%), quartz (∼10–30%), K-feldspar (∼5–20%), biotite (∼2–5%) with a small amount of biotite, magnetite, ilmenite, apatite and zircon (Fig. 2c–d). In these granitic gneisses, angular to round paragneiss and amphibolite enclaves are observed. Recent geochronological data show that a small amount of gneissic rocks and migmatites are of a Cenozoic origin in the Ailaoshan zone (e.g., Leloup et al., 1995; Lin et al., 2012). However, the formation time of the majority of the granitic gneiss and migmatite in the so-called Ailaoshan and Yaoshan groups is poorly known.

3. Analytical methods

The representative samples were crushed to 200-mesh in a steel mortar and grounded in a steel mill for the elemental and isotopic analyses. The contents of whole- rock major oxides and trace elements were determined by X-ray fluorescence spectrometry (XRF) and Elan6000 inductively coupled plasma mass spectrometry (ICP-MS), respectively, at the Guangzhou Institute of Geochemistry (GIG), the Chinese Academy of Sciences (CAS). The relative standard derivations (RSD) is less than 5% for the major oxide contents and the analytical precision is better than 5% for elements >10 ppm, less than 8% for those <10 ppm, and ∼10% for transition metals. Detailed sample preparation and chemical separation procedures follow Li et al. (2005) and Wei et al. (2002), respectively. Analyses of Sr and Nd isotopic ratios were performed on the Micromass IsoProbe™ MC-ICPMS at the GIG, CAS. The mass fractionation corrections for isotopic ratios are based on $^{86}Sr/^{88}Sr = 0.1194$ and $^{146}Nd/^{144}Nd = 0.7219$. The total procedure blank is in the range of 200–500 pg for Sr and <50 pg for Nd. The measured $^{87}Sr/^{86}Sr$ ratios of thirteen analyses for the SRM 987 standard and $^{143}Nd/^{144}Nd$