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Petrogenesis of early Paleozoic peraluminous granite in the Sibumasu Block of SW Yunnan and diachronous accretionary orogenesis along the northern margin of Gondwana

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ABSTRACT

Zircon U–Pb and Hf isotopic data along with whole-rock elemental and Sr–Nd isotopic data for early Paleozoic granitoids from the Tengchong, Baoshan and Shan-Thai Blocks that originally formed along the northern margin of Gondwana and now lie in SW Yunnan constrain the character of early Paleozoic orogenesis along the margin. Twelve analyzed samples yield zircon U–Pb crystallization age of 492–460 Ma. These granitic rocks have CIPW-normative corundum and are strongly peraluminous with A/CNK of 1.10–1.39, similar to S-type granites. They are characterized by high SiO_2, Rb/Sr and Rb/Ba but low Al_2O_3, MgO, TiO_2, FeOt and CaO/Na_2O ratios, and are enriched in LILE and depleted in Nb, Sr, P, Eu and Ti. Initial $^{87}Sr/^{86}Sr$ ratios range from 0.7084 to 0.7230 and $\varepsilon_{Nd}(t)$ values from −5.3 to −8.1 with Nd model ages of 1.7–2.8 Ga, consistent with those of the published synchronous granitic rocks in South Tibet. Zircons with early Paleozoic magmatic ages have εHf(t) values ranging from −0.37 to −14.1 and Hf model ages from 1.49 Ga to 2.35 Ga. Their petrogenesis can be interpreted as melting of an ancient metapelite-dominated crustal source with the residual mineral assemblage of plagioclase ± hornblende ± garnet ± zircon. The Ordovician granitoids in SW Yunnan represent the southward continuation of the early Paleozoic granitic belt that extended along the northern margin Gondwana. The granites along with associated deformation, metamorphism and exhumation and erosion, mark a pulse of progressive along strike orogenesis that ranges in age from end Neoproterozoic to Cambrian in Turkey to Ordovician in Shan-Thai.

1. Introduction

Asia and South East Asia consist of a series of tectonostratigraphic belts that originated on the northern margin of Gondwana in the Neoproterozoic to Paleozoic prior to their rifting and drifting across the Tethys Ocean during the late Paleozoic to Mesozoic and their subsequent accretion into their current positions (e.g., Cawood et al. 2013; Metcalfe, 1996, 2002, 2006, 2011, 2013). Unraveling the age character, paleogeography and tectonic history of these belts is often hindered by subsequent Cenozoic deformation associated with collision of India to Eurasia (e.g., Dewey et al., 1988; Pan et al., 2012; Yi et al., 2011; Yin and Harrison, 2000). Recent detailed field and geochronological studies have recognized abundant Cambrian to early Ordovician granites and evidence for coeval metamorphism in the Himalaya in NW India, Nepal and South Tibet (e.g., Cawood et al., 2007; DeCelles et al., 2000, 2004; Wang et al., 2012a,b; Xu et al., 2005; Zhang et al., 2012b; Zhu et al., 2012). In addition, Cambrian and Ordovician sequences are separated by an angular unconformity in many areas of the Himalayas (e.g., Brookfield, 1993; Hughes, 2002; Le Fort et al., 1994; Liu et al., 2002; Myrow et al., 2006a,b; Valdiya, 1995; Zhou et al., 2004). These data suggest an early Paleozoic orogenic event, although its extent has been difficult to establish due to the intense Cenozoic tectonothermal activity (e.g., Cawood et al., 2007; Gehrels et al., 2003; Myrow et al., 2006a,b; Valdiya, 1995; Wang et al., 2012a,b; Zhu et al., 2012). The origin of the early Paleozoic event has been ascribed to either (1) Pan-African orogenesis in response to the final assembly of Gondwana at around 570 and 520 Ma and (2) an Andean-type orogeny along the northern margin of Gondwana at ~490 Ma in response to the Proto-Tethyan subduction (e.g., Cawood et al., 2007; Johnson et al., 2001; Miller et al., 2001; Murphy and Nance, 1991; Wang et al., 2012a,b; Zhang et al., 2012b; Zhu et al., 2012).

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Early Paleozoic igneous and metamorphic rocks are recorded in SW Yunnan (e.g., Chen et al., 2007; Liu et al., 2009), occurring with a series of the lithotectonic blocks (Tengchong, Baoshan and Shan-Thai) that originated from the north Gondwana margin (e.g., Feng, 2002; Metcalfe, 1996; Zhong, 1998). However, their age and petrogenesis are poorly known and their relationship to the time-equivalent granitoids in NW India, Nepal and South Tibet is still unknown. We present U–Pb and Lu–Hf zircon isotopic data as well as their whole-rock elemental and Sr–Nd isotopic results on the granitic rocks from the Tengchong, Baoshan and Shan-Thai Blocks in SW Yunnan, SW China, to unravel their origin and to constrain the tectonic setting of the Gondwana margin.

2. Geological setting and petrography

SW Yunnan lies at the change in orientation from the NWW trending Himalayan segment of the Tethyan–Alpine orogenic system to the northerly-trending Southeast Asian segment (Fig. 1a; e.g., Hutchison, 1989; Metcalfe, 1996, 2002, 2013; Zhang et al., 2008, 2012b). The area includes the Simao/Indochina, Baoshan/Shan-Thai and Tengchong Blocks (Fig. 1a), separated by the Changning–Menglian and Longling–Ruili faults, respectively. The Simao/Indochina Block consists of a Proterozoic metamorphosed succession of volcanoclastic rocks and carbonates (e.g., Zhong, 1998) unconformably overlain by a Paleozoic package of carbonate and siliciclastic rocks with typical Cathaysia flora and fauna (e.g., Feng, 2002; Yunnan BGMR, 1990; Zhong, 1998). The Baoshan, Tengchong and Shan-Thai Blocks are components of the Sibumasu continental fragment with stratigraphic and paleontological affinities to Gondwana (e.g., Fan and Zhang, 1994; Feng, 2002; Fontaine, 2002; Metcalfe, 1996, 2002; Zhong, 1998). The main stratigraphic package includes pre-Mesozoic high-grade metamorphic rocks and Mesozoic–Cenozoic sedimentary and igneous rocks (e.g., Yunnan BGMR, 1990; Zhong, 1998).

The Baoshan and Tengchong Blocks contain abundant granitic gneiss, migmatite and leucogranite that mainly outcrop in the Gaoligong, Nabang and Ximeng areas (Fig. 1b–d) and are previously considered to be Proterozoic in age (e.g., Yunnan BGMR, 1990). However, recent geochronology shows that the granitic gneiss, migmatite and leucogranite at Nabang is mainly early Eocene, and those at Gaoligong and Ximeng include early Paleozoic and Mesozoic granites (e.g., Xu et al., 2012; Ma et al., 2013; Song et al., 2007). The migmatite and leucogranite in the Ximeng area are part of the Shan-Thai Block and are emplaced into volcanoclastic, siliciclastic and carbonate rocks (Fig. 1c; e.g., Fan and Zhang, 1994; Yunnan BGMR, 1990). The granites at Gaoligong lie to the west of the Longling–Ruili fault (Fig. 1b) and have undergone strong shearing with a northerly trending foliation and a subhorizontally plunging mineral lineation (e.g., Wang and Burchfiel, 1997; Wang et al., 2006; Zhang et al., 2011, 2012a,b). They are overlain by the Ordovician Gongyanghe Group (Fig. 1b). At Longxin–Pingda to east of the Longlin–Ruili Fault, there outcropped the largest granitic batholith (Pingda) in the Baoshan Block (~800 km^2) and additional small plutons (e.g., Nansa, Pingda, Mengdui and Songpo). These plutons are massive and were emplaced into the low-grade metamorphic arkose, shale and limestone (Fig. 1d). They include granodiorite, two-mica granite, muscovite granite and leucogranite and have previously yielded U–Pb zircon ages of 502–448 Ma (Chen et al., 2007; Dong et al., 2013; Liu et al., 2009).

The granitic gneisses at Gaoligong and Ximeng are characterized by K-feldspar augen up to 2 cm. Intense shearing has locally imparted a mylonitic fabric (Fig. 2a–b). The mineral assemblage of the granitic gneisses is quartz (35–50%), K-feldspar (20–30%), plagioclase (10–35%) and biotite (10%), with minor amounts of muscovite, garnet and accessory minerals (e.g., apatite, zircon, and monazite and Fe–Ti oxides). Undeformed, massive granite occurs at Longxin–Pingda (Fig. 2c–d). The principal mineral phases are quartz (20–40%), K-feldspar (15–35%), plagioclase (20–50%), biotite (2–10%), and minor euhedral zircon, apatite, allanite, titanite, magnetite and ilmenite. Some granitic samples at Longxin–Pingda additional contain 3–8% muscovite. They commonly show a porphyritic texture with feldspar phenocrysts in a groundmass of fine-grained K-feldspar, plagioclase, quartz and minor biotite.

3. Analytical methods

Zircon grains for U–Pb dating were separated using standard density and magnetic separation techniques at the mineral separation laboratory of the Bureau of Geology and Mineral Resources of Hebei Province at Langfang. After mounting in epoxy, grains were polished and carbon coated and photographed in transmitted and reflected light. The internal structure of grains was examined using cathodolumineence (CL) imaging via a scanning electron microprobe prior to U–Pb isotopic analyses at the Institute of Geology and Geophysics (IGG), Chinese Academy of Sciences (CAS). The zircon U–Th–Pb measurements and in situ Hf isotopic analysis for the representative samples were conducted using a Nu Plasma HR MC-ICPMS (Nu Instruments) with ArF-193 nm laser-ablation system (Resolution M-50) at the University of Hong Kong with a spot size of 40–50 μm. Standards CN92-1, 91500, GJ-1 and Plesovice were used to calibrate the U–Th-Pb ratios and absolute U abundances. Instrumental settings and detailed analytical procedure are given in Wu et al. (2006). Errors for individual U–Pb analyses are given with 1σ error in data tables and in concordia diagrams and uncertainties in age results are quoted at 95% level (2σ). Data processing was carried out using the SQUID 1.03 and Isoplot/Ex 2.49 programs of Ludwig (2001). External calibration of in situ zircon Hf isotopes were measured using zircon standard 91500 interspersed with analyses of unknowns, and yielded a weighted mean ^{176}Hf/^{177}Hf ratio of 0.282307 $\pm$ 31 (2σ, Wu et al., 2006). Data were normalized to ^{176}Hf/^{177}Hf = 0.7325, using exponential correction for mass bias. The mean β_{Yb} value was applied for the isobaric interference correction of ^{176}Yb on ^{176}Hf on the same spot. The ratio of ^{176}Yb/^{172}Yb (0.5887) was also applied for the Yb correction.

Major element oxides were analyzed at the Guangzhou Institute of Geochemistry (GIG), CAS by a wavelength X-ray fluorescence spectrometry using a Rigaku ZSX100e spectrometer with relative standard derivations of <5%. Trace element contents were performed using Perkin-Elmer Sciex ELAN 6000 ICP-MS at the GIG, CAS. Detailed sample preparation and analytical procedure follows Wei et al. (2002). The analytical precision is better 5% for elements >10 ppm, less than 8% for those <10 ppm, and about 10% for transition metals. Sample powders for Nd isotopic analyses were spiked with mixed isotope tracers, dissolved in Teflon capsules with HF + HNO_3 acids, and separated by the conventional cation-exchange technique and run on single W and Ta–Re double filaments. Nd Isotope ratios were measured on the VG-354 mass-spectrometer at the GIG, CAS. The total procedure blanks were in the range of 200–500 pg for Sr and <50 pg for Nd. The mass fractionation corrections for isotopic ratios are based on ^{86}Sr/^{88}Sr = 0.1194 and ^{146}Nd/^{144}Nd = 0.7219. The measured ^{87}Sr/^{86}Sr ratios of the SRM 987 standard and ^{143}Nd/^{144}Nd ratios of the La Jolla standard are 0.710265 $\pm$ 12 (2σ) and 0.511862 $\pm$ 10 (2σ), respectively. During the analytical process, within-run errors of precision are estimated to be better than 0.000015 for ^{146}Nd/^{144}Nd in the 95% confidence level.

4. Zircon U–Pb dating results

Zircons from twelve representative samples were analyzed from the Tengchong, Baoshan and Shan-Thai Blocks at Gaoligong, Pingda and Ximeng, respectively, in SW Yunnan (SW China). Analytical results are listed in Supplementary Datasets 1 and 2. The sampling locations, lithology and dating results are summarized in Table 1 and Figs. 1b–d, 3 and 4. The separated zircons are generally euhedral, measuring up to 100–400 μm with length/width ratios of 2:1–4:1. Most crystals are colorless or light brown, prismatic and transparent to sub-transparent, and exhibit clear oscillatory zoning in CL images, typical of an igneous origin.