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Early-Cretaceous highly fractionated I-type granites from the northern Tengchong block, western Yunnan, SW China: Petrogenesis and tectonic implications

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Western Yunnan, an important constituent of the southeastern segment of the East Tethyan tectonic domain, lies along a transformed orientation from the NWW trending Himalayan–Tethyan segment to the northerly trending Southeast Asian segment. However, the geodynamical setting of the Early Cretaceous tectonothermal magmatism along the Bangong–Nujiang–Lushui–Luxi–Ruili belt as the Tethyan branch in western Yunnan (SW China) remains controversial. The Donghe granitoid, which is located between the Gaoligong and Tengliang belts in the northern Tengchong block, reveals its petrogenesis and its tectonics, both of which play a vital role in resolving previous disputes. Our zircon laser ablation inductively coupled plasma mass spectrometry U–Pb dating of granites from the Donghe batholith yields ages of 119.9 ± 0.9–130.6 ± 2.5 Ma. These granites display features typical of highly fractionated I-type granites: high SiO_2 contents (>71 wt.%), high K contents (K_2O = 3.88–5.66 wt.%), calc-alkaline character, slight peraluminosity (A/CNK = 1.02–1.16), and a highly differentiated index ranging from 83.6 to 95.6. In addition, as SiO_2 contents increase, the rare earth element (REE) abundances, especially heavy REE abundances, and REE pattern slopes change gradually, but the negative Eu anomalies increase sharply, while the degree of enrichment in Rb, Th, U, and Pb and depletion in Ba, Nb, Sr, P, and Ti are enhanced. These features indicate that K-feldspar, ±plagioclase, ±biotite, ±amphibole, ±apatite, ±sphene/garnet, and ±Fe–Ti oxides such as ilmenite play the major role in the fractional crystallization process. The high initial $^{87}Sr/^{86}Sr$ (0.7067 and 0.7079) and negative $\varepsilon_{Nd}(t)$ values (−8.6 to −10.1), with T_{2DM} ranging from 1.39 to 1.49 Ga, indicate that the sources were mainly derived from the mature ancient middle to lower crust and minor mantle-derived materials. The initial $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$ ratios of 18.462–18.646, 15.717–15.735, and 38.699–39.007, respectively, signify that some subduction-related material such as ocean island volcanic rocks and mature arc primitive rocks may be involved as sources. Based on an analysis of similar zircon saturated temperature and geochemical characteristics of typical highly fractionated I-type granites in SE and SW China, and consideration of the regional geological setting, we suggest that the parent magma may be derived from the ancient middle to lower continental crust and mantle-derived basaltic magma. These were generated in the setting of a westward subducted Lushui–Luxi–Ruili (LLR) Tethyan oceanic slab, where mantle-wedge-derived sources provided enough heat and material to melt the middle to lower ancient crust. Taking into account the temporal–spatial distributions of Early Cretaceous magmatic rocks in the region, we further suggest the existence of an Andean-type active continental margin from the Lhasa block to the Tengchong block along the Bangong–Nujiang–LLR Tethys Ocean during the Early Cretaceous.

1. Introduction

The study of Tethys has been ongoing for more than a century since Suess (1893) proposed it as an equatorial ocean ancestral to the Alpine–Himalayan mountain ranges. The theory of plate tectonics provides valuable insight into the mechanisms by which Tethys has evolved (Condie, 1997). Western Yunnan, an important constituent of the southeastern segment of the East Tethyan tectonic domain, lies along a transformed orientation from the NWW trending Himalayan–Tethyan segment to the northerly trending Southeast Asian segment (Hutchison, 1989; Metcalfe, 1996a,b, 2002, 2013; Zhang et al., 2008, 2012a; Wang et al.,

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2013, 2014; Deng et al., 2014), so it well records the evolutionary history of Tethys. Two stages are primarily involved: (1) the accretion of some continents and microcontinents of Gondwana biotic affinity to continents and/or microcontinents of Cathaysian biotic affinity from the Late Paleozoic to the Early Mesozoic (Metcalfe, 2011a, 2011b, 2013) and (2) the accretion of Gondwana to the Asian continent during the Mesozoic to Cenozoic (Hall, 1997, 2002, 2011, 2012; Metcalfe, 2013).

The Tengchong block, a crucial constituent of the Neo-Tethys domain in SW China, being located between the Banggong–Nujiang–Lushui–Luxi–Ruili (LLR) suture zone and the Yarlung–Zangbo–Myitkyina suture zone, exposes abundant Mesozoic granitoids (Cao et al., 2014; Chen et al., 1991; Cong et al., 2009, 2010a, 2011b; Li et al., 2012a,b; Luo et al., 2012; Qi et al., 2011; Xie et al., 2010; Xu et al., 2012; Yang et al., 2006, 2009; Yang and Xu, 2011; Zou et al., 2011a) and Cenozoic granitoid rocks (Ma et al., 2014). These ribbon-pattern magmatic belts were dominated by Early Cretaceous granitoids, forming the southeastern extension of the northern magmatic belt including the central and northern Lhasa block (Cao et al., 2014; Li et al., 2012a,b; Qi et al., 2011; Xie et al., 2010; Xu et al., 2012; Yang et al., 2006; Zou et al., 2011a) along the Bangong–Nujiang–LLR suture zone. However, the geodynamical setting of the Early Cretaceous tectonothermal magmatism along the Bangong–Nujiang–LLR belt in the Tengchong block has remained controversial because of the following pieces of conflicting evidence: (1) the active continental margin is related to the eastward subduction of the Putao–Myitkyina paleo-oceanic slab as a branch of the Neo-Tethys Ocean (Cong et al., 2010a, 2011a, 2011b); (2) the active continental margin is related to the southward subduction of the Bangong–Nujiang Tethyan oceanic slab (Li et al., 2012a, 2012b); (3) the southward subduction of the Bangong–Nujiang Tethyan oceanic slab occurred during the collision between the Lhasa–Tengchong and the Qiangtang–Baoshan blocks (Qi et al., 2011; Zou et al., 2011a); (4), there is a post-collisional setting after the southward subduction of the Bangong–Nujiang Tethyan oceanic slab (Cao et al., 2014; Luo et al., 2012; Yang et al., 2006; Yang and Xu, 2011); and (5) there is a post-collisional setting between the Lhasa and Qiangtang blocks being partly influenced by the far field of the Neo-Tethyan oceanic slab (Xu et al., 2012). In other words, a post-collision-related setting is supported by the peraluminous S-type granites in the northern Gaoligong belt, and a subduction-related setting is supported by the metaluminous to peraluminous I-type granites, granodiorites, and diorites in the southern Tengliang belts. The Donghe granitoid, located between the Gaoligong and Tengliang belts, therefore, reveals its petrogenesis and tectonics, both of which play a pivotal role in understanding the geodynamical setting of the Mesozoic magmatism along the Bangong–Nujiang–LLR suture as the branch of the Neo-Tethyan domain from Tibet to western Yunnan, SW China.

We first present zircon U–Pb age and major and trace element and Sr–Nd–Pb isotopic composition data for the Donghe granitoid in the northern Tengchong block. Our main aims are twofold: (1) to constrain their petrogenesis and tectonic implications in the northern Tengchong block and (2) to explore the geodynamical setting of the Early Cretaceous magmatism along the Bangong–Nujiang–LLR suture from the Lhasa terrane in the Tibetan Plateau to the Tengchong block in western Yunnan and further understand the temporal–spatial evolution of Tethys in western Yunnan, SW China. The highly fractionated I-type granites in the Tengchong block as the southeast extension of the Tibetan Plateau are reported for the first time. Coupled with consideration of the other published evidence in the literature, our results may imply an Andean-type active continental margin along the Bangong–Nujiang–LLR belt triggered by the southwestern subducted Bangong–Nujiang–LLR Tethyan oceanic slab during the Early Cretaceous.

2. Geological setting and petrography

Western Yunnan is an important constituent of the southeastern segment of the East Tethyan tectonic domain (Kou et al., 2012) (Fig. 1a). From east to west, this region comprises the Simao–Indochina, Baoshan–Shan-Thai, and Tengchong blocks (Wang et al., 2006a,b; Chen et al., 2007; Cong et al., 2011a,b; Xu et al., 2012; Wang et al., 2013, 2014; Deng et al., 2014; Metcalfe, 2013), separated by the Changning–Menglian suture and the Lushui–Luxi–Ruili fault (LLRF), respectively.

The Simao–Indochina block of South China affinity (Metcalfe, 1996a,b; Wopfner, 1996; Zhong, 1998; Ueno, 2000) comprises a Proterozoic metamorphic succession of volcano-clastic rocks and carbonates (Zhong, 1998), unconformably overlain by a Paleozoic package of carbonate and siliciclastic rocks, with typical Cathaysia flora and fauna (Feng, 2002; YNBGMR, Yunnan Bureau of Geology and Mineral Resources, 1991; Zhong, 1998). The Baoshan, Tengchong, and Shan-Thai blocks (Metcalfe, 1988, 1996a,b, 1998, 2002, 2013; Shi and Archbold, 1995, 1998) have stratigraphic and paleontological affinities to Gondwana (Fan and Zhang, 1994; Feng, 2002; Fontaine, 2002; Metcalfe, 1996a, 1996b, 2002, 2013; Zhong, 1998). The main stratigraphic package includes pre-Mesozoic high-grade metamorphic rocks and Mesozoic–Cenozoic sedimentary and igneous rocks (YNBGMR, 1991; Zhong, 1998).

The Tengchong block, the northern part of Sibumasu, is bounded to the eastern Baoshan block by the LLRF and to the western Burma block by the Putao–Myitkyina suture zone (Li et al., 2004) (Fig. 1b). Based on the occurrence of Permo-Carboniferous glacio-marine deposits and overlying post-glacial black mudstones, as well as the Gondwana-like fossil assemblages in the blocks, one can conclude that it was derived from the margins of western Australian on the eastern Gondwana supercontinent (Jin, 1996). Its characteristic strata have a Mesoproterozoic metamorphic basement (Gaoligong Mountain Group), which is overlain by Late Paleozoic clastic sedimentary rocks and carbonates, Mesozoic–Tertiary granitoids, and Tertiary–Quaternary volcano-sedimentary sequences (YNBGMR, 1991). The Gaoligong Mountain Group is composed of quartzites, two mica quartz schists, feldspathic gneisses, migmatites, amphibolites, and marble. Zircons from a paragneiss sample and an orthogneiss sample give ages of 1053–635 and 490–470 Ma, respectively (Song et al., 2010). The Paleozoic sedimentary strata are dominated by Carboniferous clastic rocks, Upper Triassic to Jurassic turbidites, Cretaceous red beds, and Cenozoic sandstones (YNBGMR, 1991; Zhong, 2000).

There are abundant granitic gneiss, migmatite, and leucogranite that mainly outcrop in the Tengchong block and most of them have been previously considered to be Proterozoic in age (YNBGMR, 1991). According to recent geochronology, however, there are also massive granitoids from the Paleozoic to the Cenozoic in the Tengchong block (with zircon U–Pb ages of 232–206 Ma) present south of Tengchong county and north of Lianghe county (Li et al., 2011; Zou et al., 2011b). Younger granitoids with zircon U–Pb ages of 139–115 Ma are common in the eastern part of the Tengchong block near Tengchong and Lianghe counties (Chen et al., 1991; Yang et al., 2006; Yang and Xu, 2011; Xie et al., 2010; Cong et al., 2010a, 2011a,b; Qi et al., 2011; Zou et al., 2011a; Li et al., 2012a,b; Luo et al., 2012; Xu et al., 2012; Cao et al., 2014). Late Cretaceous S-type and A-type granites with zircon U–Pb ages of 76–68 Ma are also present in the mid-western part of the Tengchong block (Jiang et al., 2012; Xu et al., 2012; Ma et al., 2013). In addition, granites with zircon ages as young as 66–52 Ma have been found near the border between China and Burma in the Tengchong block (Booth et al., 2004; Liang et al., 2008; Chiu et al., 2009; Xie et al., 2010; Xu et al., 2012), and all of these granitoids intruded into the Paleozoic and Mesozoic strata. The granites at Gaoligong