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Petrogenesis of Late Cretaceous I-type granites in the southern Yidun Terrane: New constraints on the Late Mesozoic tectonic evolution of the eastern Tibetan Plateau

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ABSTRACT

The collision between the Lhasa and Qiangtang terranes, prior to the Indo–Asian collision, is a critical aspect in terms of development of the Tibetan Plateau. It has been demonstrated that the occurrence of the Late Cretaceous granites (110–80 Ma) in the Yidun Terrane, eastern Tibetan Plateau (ETP) associates with the Lhasa–Qiangtang collision. The Xiuwacu Late Cretaceous pluton in the southern Yidun Terrane, consists three phases including biotite granitic porphyry (phase 1), monzogranite (phase 2), and alkali–feldspar leucogranite (phase 3), which have zircon U–Pb ages ranging from 85.5 Ma to 84.4 Ma. All these three phases are metaluminous or slightly peraluminous granites (A/CNK = 0.96–1.07), with high SiO_2 (70.0–76.0 wt.%), $K_2O + Na_2O$ (7.5–10.7 wt.%), and Ga/Al (2.5–4.7), and relatively low CaO (0.39–1.67 wt.%), MgO (0.01–0.57 wt.%), and P_2O_5 (0.01–0.17 wt.%). The granites are enriched in light rare earth elements (LREEs), Rb, Th, U and Ta, but depleted in heavy REEs (HREEs), Ba, Sr, P, and Ti, with significantly negative Eu anomalies ($Eu/Eu^* = 0.24–0.59$). Comparing to classic A-type granites, these samples present higher Sr (10.1–256 ppm, mostly > 100 ppm) and lower FeO^*/MgO ratios (1.2–9.9) and Zr + Nb + Ce + Y (248–483 ppm, mostly < 350 ppm). However, they show highly fractionated I-type granites affinities. All these phases have relatively high $(^{87}Sr/^{86}Sr)_i$ (0.7075–0.7098), negative $\varepsilon_{Nd}(t)$ (−8.0 to −6.9) and $\varepsilon_{Hf}(t)$ (−7.6 to −3.2) values, and ancient Nd and Hf model ages (1.7–1.3 Ga), which indicates similar origins predominately through partial melting of ancient mafic-intermediate lower continental crust. Besides, variable zircon $\delta^{18}O$ values (5.9‰ to 8.4‰, partly < 6.5‰) and the occurrences of mafic microgranular enclaves (MMEs) within the granites probably indicate a contribution of mantle components. Although the Xiuwacu Late Cretaceous intrusions show higher SiO_2 values and lower Sr/Y ratios comparing to other three high Sr/Y I-type intrusions (Relin, Hongshan, and Tongchanggou) in the southern Yidun Terrane, similar $(^{87}Sr/^{86}Sr)_i$, $\varepsilon_{Nd}(t)$, $\varepsilon_{Hf}(t)$, and $\delta^{18}O$ contents in all of these four intrusions point to a common source. We propose that both the Xiuwacu intrusions and the other three intrusions in the southern Yidun Terrane were generated under a late- or post-collision environment related to the Lhasa–Qiangtang collision during the Late Cretaceous. Decompression induced upwelling of mantle-derived magmas to underplate and provided heat for the anatexis of thickened lower crust. Then, those Late Cretaceous magmas were brought into the southern Yidun Terrane by mixing of lower continental crust-derived melts and minor mantle-derived magmas, and the following fractional crystallization. Occurrence of these late- or post-collision magmas probably indicates that the timing of both the Lhasa–Qiangtang collision and the eastern Tibetan Plateau uplifting was earlier than the Late Cretaceous, and that the Lhasa–Qiangtang collision did not cease at least until ca. 80 Ma. Afterwards, tectonic setting of the eastern Tibetan Plateau was progressively to be under a control mainly of the subduction of the Neo-Tethys Ocean and subsequent Indo–Asian collision.

1. Introduction

Although crustal recycling, i.e., remelting of preexisting supracrustal sedimentary rocks or infracrustal igneous rocks, seems to control the composition of majority granites (Chappell and White, 1992, 2001), it is also widely suggested that mantle-derived magmas play a significant role in providing heat and/or mass input (Kemp et al., 2007; Li et al.,

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2007; Yang et al., 2004; Zhong et al., 2009). Highly fractionated I-type granites consist pervasively of multi-phases with several stages of magmatisms (Li et al., 2009b; Whalen et al., 1987; Wu et al., 2003a; Zhu et al., 2009b). It is of first importance to understand if the component changes of those phases are related to additional contributions from mantle melts or from crustal materials during fractional crystallization processes. Those processes could not be easily recognized through traditional approaches (Li et al., 2009b), because the Sr and Nd isotopic compositions likely trend to be homogenous during the mixing between mafic and felsic magmas (Yang et al., 2006). However, newly developed in situ zircon Hf–O isotopic analysis provides an effective constraint on tracing the involvement of supracrustal materials or mantle-derived magma in granite genesis (Griffin et al., 2002; Kemp et al., 2005, 2007).

The surface uplift history of the Tibetan Plateau has been among the most interesting topics in geosciences because of its significance in changing not only Cenozoic regional climate but also large scale atmospheric circulations such as the Asian monsoon intensity (Wang et al., 2008a; Zhang et al., 2012; Zhu et al., 2013). It has long been recognized that the collision between the Lhasa Terrane and Qiangtang Terrane is, prior to the Indo–Asian collision, critical aspect in development of the Tibetan Plateau (Murphy et al., 1997; Sengor, 1979, 1987), however, any conclusions regarding when did the Bangong Meso-Tethys Ocean close and how long did the Lhasa–Qiangtang collision last remain open to intense debate. Murphy et al. (1997) proposed that significant crustal thickening caused by the Lhasa–Qiangtang collision occurred during the Early Cretaceous. Later researches suggested that the Lhasa–Qiangtang collision occurred during the Cretaceous (Kapp et al., 2005, 2007; Yin and Harrison, 2000), and that significant shortening of the Lhasa Terrane occurred during the Late Cretaceous (Guynn et al., 2006; Kapp et al., 2003; Zhu et al., 2011a, 2013). Additionally, Zhang et al. (2012) suggested that the Bangong Meso-Tethys did not close and the Qiangtang Terrane did not collide with the Lhasa Terrane until the Late Cretaceous. Generally, previous models mostly focused on data from the interior of central Tibet (Wang et al., 2008a), and were seldom constrained by geologic data from the eastern Tibetan Plateau. The Yidun Terrane, which is located on the eastern margin of the Qiangtang Terrane (Fig. 1a), is notable for its large-scale distribution of Late Cretaceous intrusions (110–80 Ma) along the north–south strike (Fig. 1b; Hou et al., 2003; Hou and Zhou, 2001). Although our earlier study demonstrated that these intrusions were genetically related to the Lhasa–Qiangtang collision (Wang et al., 2014), further studies on their petrogenesis and geodynamic setting would give additional constrains on the tectonic evolution of the eastern Tibetan Plateau (ETP) during Late Cretaceous.

In this study, we investigated the Xiuwacu Late Cretaceous multi-phases pluton in the southern Yidun Terrane. Zircon Hf and O isotopic, whole-rock Sr–Nd isotopic, geochemical, and mineralogical compositions were analyzed for each phase of the Late Cretaceous intrusions to better understand the petrogenesis of the Xiuwacu pluton. In addition, new zircon Hf–O isotopic, whole-rock Sr–Nd isotopic, and mineralogical data of other Late Cretaceous intrusions (Relin, Hongshan, and Tongchanggou) in the southern Yidun Terrane were also achieved to constrain their petrogenesis and geodynamic setting.

2. Regional geology

The Tibetan Plateau is the most extensive region of elevated topography in the world. The eastern Tibetan Plateau is generally composed of the West Songpan–Ganzi Fold Belt, West Sichuan Basin, the Yidun Terrane and West Yunnan (Fig. 1a; Wilson and Fowler, 2011; Xu and Kamp, 2000). The uplifting of the Tibetan Plateau is generally considered to have been related to the Lhasa–Qiangtang collision during the Late Mesozoic and the Indo–Asian collision during the Late Cenozoic (Murphy et al., 1997; Wang et al., 2008). The Bangong–Nujiang Suture is the northern branch of the Meso-Tethys between the Lhasa and Qiangtang terranes (Metcalfe, 2011; Morley, 2012). The geological evolution of the Bangong–Nujiang Suture Zone (BNSZ) remains intensely debated. Some researchers proposed a northward subduction (Kapp et al., 2005, 2007; Zhang et al., 2012), whereas others suggested a south-dipping slab (Sui et al., 2013; Zhu et al., 2009b, 2011a). A bidirectional subduction model has also been presented in many studies (Du et al., 2011; Pan et al., 2012; Qu et al., 2012). Although the subduction direction of the Bangong Meso-Tethys Ocean remains controversial, most researchers suggested that the Lhasa Terrane initially collided with the Qiangtang Terrane during the Late Jurassic and Early Cretaceous (earlier in the east and later in the west), the premise of which is supported by stratigraphy and sedimentology studies along the BNSZ (Kapp et al., 2005, 2007; Zhu et al., 2011a, 2013). In addition, slab break-off probably developed during the Early Cretaceous (~113 Ma) after the initial collision (Zhu et al., 2011a). However, Zhang et al. (2012) suggested that the Bangong Meso-Tethys Ocean did not close and the Qiangtang Terrane did not collide with the Lhasa Terrane until the Late Cretaceous (~80 Ma); these remarks were based on the discovery of 132–108 Ma aged ophiolites in central Tibet that contained abundant Middle Cretaceous radiolarians.

The Yidun Terrane lies between the Qiangtang Terrane (west), Songpan–Ganzi Fold Belt (northeast) and Yangtze Craton (southeast), and it is bounded to the west by the Jinshajiang Suture and to the east by the Ganzi–Litang Suture (Fig. 1a and b; Yin and Harrison, 2000). In addition, the Yidun Terrane is located on the eastern side of the Bangong Suture. It is composed of two parts: the Zhongza Massif (the western Yidun Terrane) and the eastern Yidun Terrane (Reid et al., 2005b). The Zhongza Massif is composed of carbonate-rich Paleozoic metasedimentary rocks intercalated with mafic volcanic rocks (Chang, 1997). Some researchers inferred that the Zhongza Massif is a 'microcontinent' that separated from the Yangtze Craton in the Late Permian during the opening of the Ganzi–Litang Ocean. This is supported by the following three lines of evidence. First, these Paleozoic metasedimentary rocks have fossil assemblages similar to the sediments of the western Yangtze Craton (Chang, 1997). Second, the Triassic volcanic rocks in the eastern Yidun Terrane show geochemical affinities with the continental arc volcanics (Hou et al., 2003; Leng et al., 2014; Mo et al., 2001). Finally, some inherited zircons with ancient ages from the Triassic igneous rocks in the eastern Yidun Terrane are correlated with the Yangtze Craton (Leng et al., 2014; Reid et al., 2007; Wang et al., 2013a). The eastern Yidun Terrane is composed of north–south extending Late Triassic volcanic–sedimentary successions and Late Triassic granitoids formed by the westward subduction of the Ganzi–Litang Ocean crust (Hou and Zhou, 2001; Leng et al., 2012; Wang et al., 2011a). The occurrence of Jurassic granites in the Yidun Terrane and Songpan–Ganzi Fold Belt is generally considered to be an indicator of a post-orogenic environment after the collision event between the two terranes (Table 1; Hu et al., 2005; Qu et al., 2003; Wang et al., 2008b; Zhao et al., 2007).

3. Petrography and sampling

Late Cretaceous intrusions are widely distributed along the north–south strike in the Yidun Terrane (Table 1; Fig. 1b). These intrusions mainly comprise biotite granite, biotite monzogranite, and granitic porphyry. Previous studies have suggested that intrusions in the northern Yidun Terrane are A-type granites with their ages ranging from 115 Ma to 75 Ma (Table 1; Hou and Zhou, 2001; Hou et al., 2003, 2004; Qu et al., 2002; Zhang, 1994; Zhang and Zhang, 1993), and that in the southern Yidun Terrane there are four contemporaneous (87–81 Ma) intrusions (Wang et al., 2014; Table 1), i.e., the Xiuwacu, Relin, Hongshan, and Tongchanggou intrusions (Fig. 1c). Expect for the Xiuwacu, the Relin, Hongshan, and Tongchanggou intrusions are I-type granites with high Sr/Y and La/Yb ratios showing adakite-like affinities (Wang et al., 2014).