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Cambrian volcanism in the Lhasa terrane, southern Tibet: Record of an early Paleozoic Andean-type magmatic arc along the Gondwana proto-Tethyan margin

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ABSTRACT

The present study reports new zircon LA–ICP–MS U–Pb ages, trace element and Hf isotope data, and whole-rock major and trace element data from Cambrian metarhyolites from Zhaqian and Zhakang in the central Lhasa subterrane of southern Tibet. One sample from Zhakang provides a weighted mean $^{206}Pb/^{238}U$ age of 510.4 ± 4.0 Ma and two samples from Zhaqian yield weighted mean $^{206}Pb/^{238}U$ ages of 510.6 ± 2.6 Ma and 524.8 ± 2.9 Ma, indicating that the Zhaqian and Zhakang metarhyolites were contemporaneous. Both are characterized by high SiO_2 and K_2O and low Na_2O. They are also primarily high-K calc-alkaline, are enriched in Th, U, and light rare earth elements (LREEs), and are depleted in Nb, Ta, Ti, and P. Thus, they are geochemically similar to typical arc volcanic rocks. Moreover, the Zhaqian metarhyolites exhibit varying zircon $\varepsilon_{Hf}(t)$ values (−3.8 to +0.3) that are comparable to those of the Zhakang metarhyolites (−4.9 to −1.0). Both metarhyolites are interpreted as resulting from partial melting of Proterozoic metasedimentary rocks with mantle-derived magma contributions. Contemporaneous magmatism in the early Paleozoic has also been recognized in other microcontinents along the Gondwana proto-Tethyan margin. The emplacement of these magmatic rocks and the development of a Cambro–Ordovician angular unconformity in the central Lhasa subterrane can be attributed to subduction of proto-Tethys Ocean lithosphere in a Andean-type magmatic arc setting following the assembly of various continental components within the Gondwana supercontinent.

1. Introduction

Late Neoproterozoic–early Paleozoic magmatism was relatively extensive in the Gondwana supercontinent and records a complicated tectonic history involving oceanic slab subduction along the peri-Gondwana margin and collision between various continental components within the Gondwana supercontinent (Meert, 2003; Collins and Pisarevsky, 2005; Cawood and Buchan, 2007; Cawood et al., 2007; Murphy et al., 2011; Zhu et al., 2012). Many interpretations have been proposed for this region within the last several decades. The final assembly of the eastern Gondwana is generally believed to have occurred between ca. 570 Ma and ca. 510 Ma (Meert, 2003), with subduction along the Gondwana proto-Pacific margin initiated from ca. 580 Ma to 550 Ma. However, the matter of whether the Gondwana proto-Tethyan margin was an active continental margin in the early Paleozoic remains controversial (Cawood and Buchan, 2007). For example, most of the early Paleozoic igneous rocks in southern Tibet and western Yunnan Province, China, have been designated as products of the pan-African orogeny, which occurred in response to continent–continent collision during the assembly of Gondwana (Xu et al., 2005; Song et al., 2007; Hu et al., 2010; Lin et al., 2012; Yang et al., 2012; Liu et al., 2012), although some authors have suggested a magmatic arc origin for these rocks (Zhang et al., 2008; Wang et al., 2011; Liu et al., 2009). The early Paleozoic granitoids (ca. 530–470 Ma) that were emplaced extensively along the Indian proto-Tethyan margin have been interpreted variously as relating to the final assembly of Gondwana (Baig et al., 1988; Gaetani and Garzanti, 1991), crustal extension in a non-arc environment (Miller et al., 2001), or supercontinental breakup (Murphy and Nance, 1991). The Cambro–Ordovician angular unconformity identified in the Himalayan terrane and in the Lhasa subterrane is generally interpreted as the record of a regional orogenic event in the northern Indian continent (Garzanti et al., 1986; Yin and Harrison, 2000; Gehrels et al., 2003, 2006; Cawood et al., 2007; Li et al., 2010); however, some scholars have recently challenged this interpretation, suggesting that this uniformity is related to an Andean-type orogen that occurred after the assembly of Gondwana (Myrow et al., 2006). The early Paleozoic metamorphism and deformation are typically overprinted by Cenozoic tectonothermal events; therefore, petrological and geochemical investigation of early

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Paleozoic magmatic rocks is the key to resolving these discrepancies.

The Lhasa terrane is commonly considered to represent one of the microcontinents that formed along the proto-Tethyan margin in the early Paleozoic (Yin and Harrison, 2000; Metcalfe, 2009). As shown in Fig. 1a, Cambrian–Ordovician granitoids have been identified by zircon U–Pb dating in Lhasa terrane (ca. 510 Ma, Gehrels et al., 2011) and its neighbouring terranes such as Southern Qiangtang–Baoshan (ca. 499 Ma, Liu et al., 2009; ca. 465 Ma, Hu et al., 2010; ca. 474 Ma, Pullen et al. 2011), Amdo (ca. 531 Ma, Xu et al., 1985; ca. 540–460 Ma, Guynn et al., 2012; ca. 488 Ma, Xie et al., 2010), Gongshan (ca. 487 Ma, Song et al., 2007; ca. 473 Ma and ca. 469 Ma, Liu et al., 2012), Tengchong (ca. 470 Ma, Chen et al., 2007; ca. 489 Ma, Lin et al., 2012) and Himalaya (ca. 496 Ma, Miller et al., 2001; ca. 473–484 Ma, Gehrels et al., 2003; ca. 477 Ma and ca. 478 Ma, Cawood et al., 2007; ca. 506 and ca. 527 Ma, Quigley et al., 2008; ca. 499 Ma, Shi et al., 2010; ca. 499 Ma, Wang et al., 2011) terranes. These granitoids indicate the occurrence of the Early Paleozoic magmatism, but the nature of this magmatism is still poorly understood. Recently, Cambrian volcanic rocks have been reported in Banglei (ca. 492 Ma, Zhu et al., 2012) (Fig. 1a), Zhaqian (ca. 511 Ma and ca. 525 Ma, this study) (Fig. 1b), and Zhakang (ca. 501 Ma, Ji et al., 2009a; ca. 510 Ma, this study) (Fig. 1b) in the central Lhasa terrane. The Cambro–Ordovician angular unconformity that postdates the emplacement of these volcanic rocks has also been identified by field investigations in Zhaqian (Li et al., 2010) and Zhakang (Ji et al., 2009a). The Cambrian bimodal volcanic rocks in Banglei have been interpreted as the record of an early Paleozoic Andean-type magmatic arc along the Gondwana proto-Tethyan margin. However, the origin and tectonic setting of the Cambrian volcanic rocks in Zhaqian and Zhakang remain enigmatic. In the present study, we present new zircon U–Pb ages, trace element and Hf isotope data, and whole-rock major and trace element analyses of the Cambrian volcanic rocks in Zhaqian and Zhakang. Then, we discuss the origin and tectonic significance of these volcanic rocks, and provide constraints on the tectonic setting of the proto-Tethys Ocean margin in the early Paleozoic with reference to the results of the present study in combination with existing data.

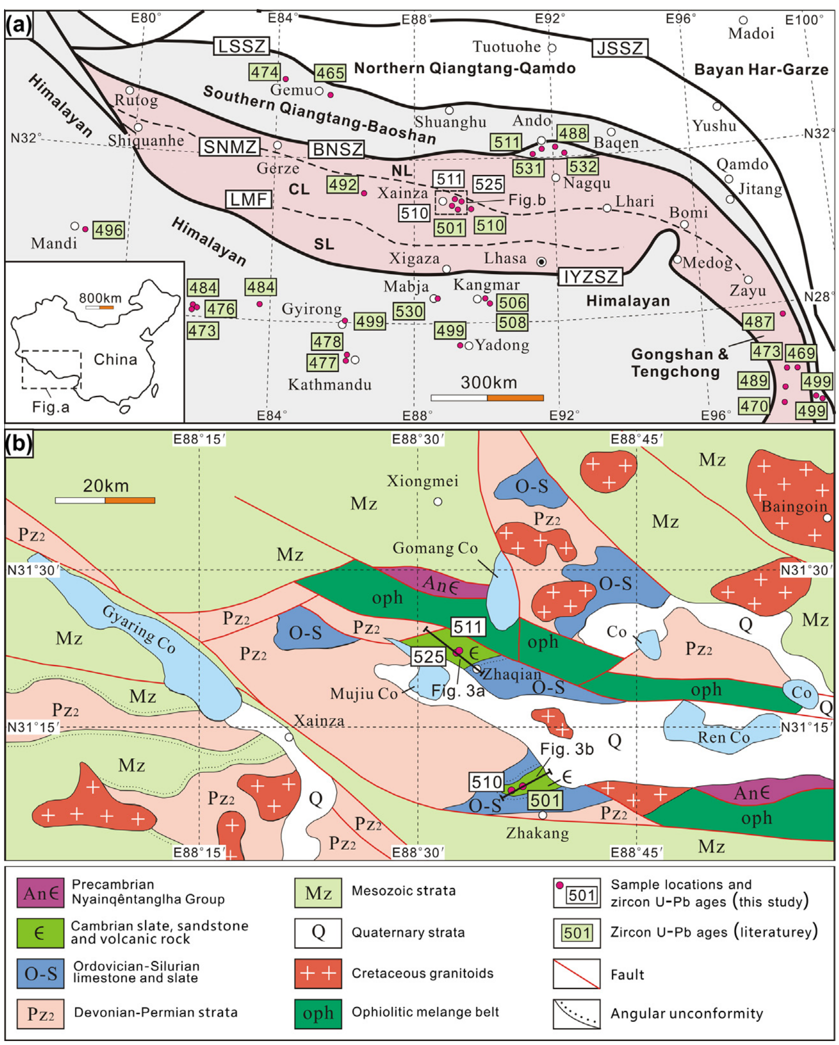

Fig. 1. (a) Tectonic framework of the Tibetan Plateau showing the subdivision of the Lhasa terrane (Zhu et al., 2011a, 2011b, 2012) and the distribution of early Paleozoic igneous rocks based on currently available data. Data sources: Southern Qiangtang–Baoshan (Liu et al., 2009; Hu et al., 2010; Pullen et al. 2011; Yang et al., 2012), Amdo (Xu et al., 1985; Xie et al., 2010; Guynn et al., 2012; unpublished data), central Lhasa (Ji et al., 2009a; Gehrels et al., 2011; Zhu et al., 2012; this study), Gongshan (Song et al., 2007; Liu et al., 2012), Tengchong (Chen et al., 2007; Lin et al., 2012), Himalaya (Lee et al., 2000; Godin et al., 2001; Miller et al., 2001; Gehrels et al., 2003; Cawood et al., 2007; Lee and Whitehouse, 2007; Quigley et al., 2008; Shi et al., 2010; Wang et al., 2011). JSSZ = Jinsha suture zone; LSSZ = Longmu Co–Shuanghu–Lancangjiang suture zone; BNSZ = Bangong–Nujiang suture zone; SNMZ = Shiquan River–Nam Co mélange zone; LMF = Luobadui–Milashan fault; IYZSZ = Indus–Yarlung Zangbo suture zone; NL = northern Lhasa subterrane; CL = central Lhasa subterrane; SL = southern Lhasa subterrane. (b) Geological map of Xainza in the central Lhasa subterrane, showing the locations of the Zhaqian and Zhakang metarhyolites.