

The early-stage evolution of the Neo-Tethys ocean: Evidence from granitoids in the middle Gangdese batholith, southern Tibet

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ABSTRACT

The Gangdese magmatic belt, located along the southern margin of the Lhasa terrane, plays a critical role in understanding the tectonic framework associated with the Indian–Eurasian collision and the crustal growth of the southern Tibet. In this paper, we present a series of results from new petrological, geochemical and geochronological investigations of the granitoid rocks. The granitoids mainly have sub-alkaline compositions and show medium K calc-alkaline affinities, as well as I-type granitoid characteristics. Significant depletions of Nb and Ta, combined with other geochemical features including enrichments of LILEs and LREEs confirm that the parental magmas of these rocks were generated in a subduction-related active continental margin (continental arc environment). Lu–Hf isotopic compositions and relatively low MgO contents indicate that the granitoids might be generated from partial melting of juvenile crust and basaltic lower crust, which is caused by the underplating of mantle materials, and the mantle materials that have been involved in this process. The 191.2–169.2 Ma zircon U–Pb ages of the granitoids reveal middle-early Jurassic magmatic events. Combined with published data in the Gangdese magmatic belt, our study suggests that the northward subduction of the Neo-Tethys oceanic crust beneath the southern margin of the Lhasa terrane probably started no later than 191.2 Ma. Zircons from the granitoids suite display positive $\varepsilon_{\text{Hf}}(t)$ values between 10.1 and 15.4 (mean value is 12.7), which correspond to the two-stage model ages (t_{DM2}) in the range of 198–415 Ma, attesting to crustal growth in the southern Lhasa terrane associated with the subduction of the Neo-Tethys oceanic crust. Our study is a systematic report of the granitoid suite in the Gangdese magmatic belt and strengthens the concept that the Neo-Tethys oceanic crust might have experienced a long evolution history.

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1. Introduction

The Tibetan plateau consists of four terranes, mainly including the Himalaya, Lhasa, Qiangtang, and Songpan–Ganze terranes from south to north, assembled via a complex geological history (Allegre et al., 1984; Chang et al., 1986; Debon et al., 1986; Yin and Harrison, 2000; Xu et al., 2007, 2011, 2013a,b; Zhu et al., 2011; Li et al., 2015). These terranes are separated by the Indus–Yarlung Tsangpo suture zone (IYTSZ), the Bangong–Nujiang suture zone (BNSZ), and the Jinshajiang suture zone (JSSZ), respectively (Yin and Harrison,

2000; Xu et al., 2011; Li et al., 2015) (Fig. 1a). The Lhasa terrane has an Andean-type active continental margin developed along the southern part of Lhasa prior to collision with the Indian plate in the Cenozoic period, marked by the IYTSZ, which is speculated to have rifted from the Gondwana supercontinent in the Triassic or even earlier (Li et al., 2010, 2014) then drifted northward across the Paleo-Tethys oceanic basin before it collided with the Asian plate along the BNSZ during the early Cretaceous (Zhu et al., 2011).

The Lhasa terrane has witnessed the opening and closure of the Neo-Tethys oceanic crust (Wen et al., 2008; Ji et al., 2009a,b; Dong et al., 2011; Zhu et al., 2011; Guo et al., 2013; Webb et al., 2013; Meng et al., 2015) and hosts for over 80% of the igneous rocks in Tibet region (Mo et al., 2005a,b, 2009; Pan et al., 2006; Zhu et al., 2008a,b, 2011; Mo, 2011a,b; Li et al., 2015). The elongated belt of igneous rocks, distributed along the southern margin of the Lhasa terrane, has been termed as the Gangdese magmatic belt. The Gangdese magmatic belt, adjacent to the IYTSZ, has a close relationship with the Neo-Tethys oceanic crust (Ji et al., 2009a,b;

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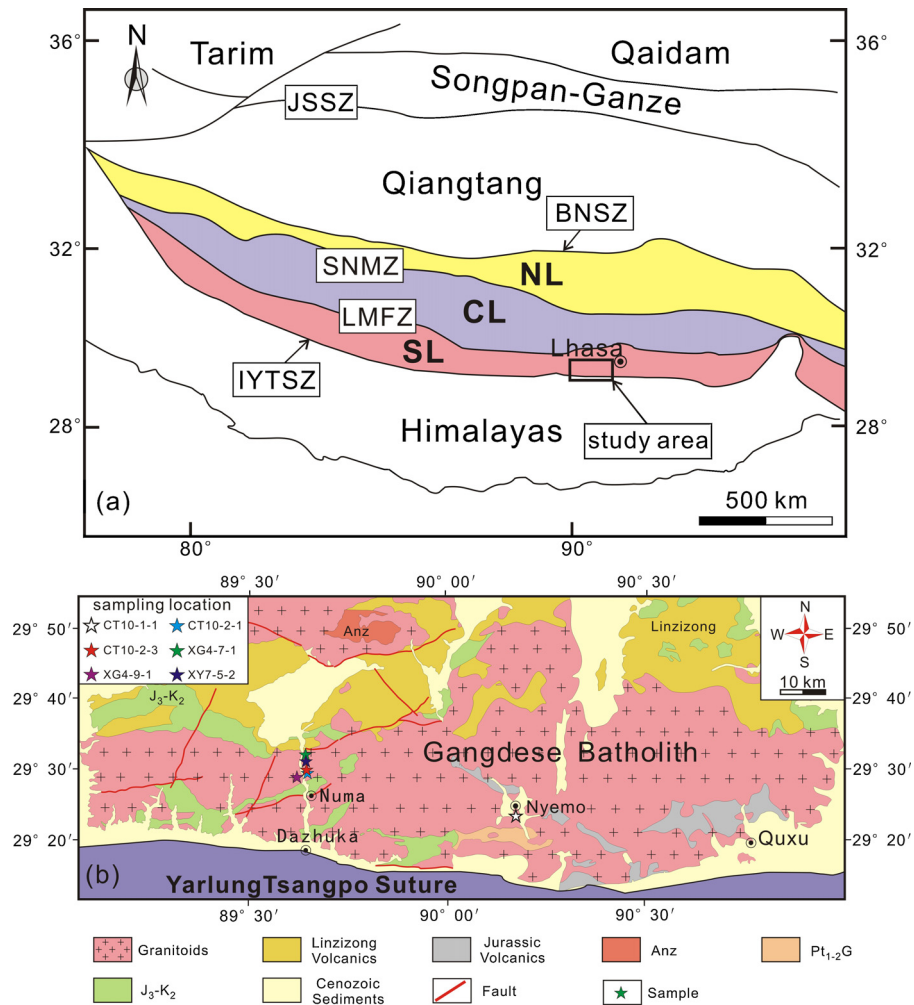


Fig. 1. (a) Simplified tectonic sketch map of the Qinghai-Tibetan plateau (modified from Zhu et al., 2011); NL-north sub-Lhasa terrane, CL-central sub-Lhasa terrane, SL-south Lhasa sub-terrane, IYTSZ-Indus Yarlung Tsangpo suture zone, BNSZ-Bangong-Nujiang suture zone, JSSZ-Jinsajiang suture zone, LMFZ-Luobadui-Milashan fault zone, SNMZ-Shiquanhe-Namco ophiolitic zone; (b) geologic map of study region and adjacent region with sampling locations; Anz for Nyainqentanglha group, including marble member, gneiss member, quartzite member and feldspar quartzite member; Pt₁₋₂G for Gangdese metamorphic group, consisted of gneiss, amphibolite and biotite leptynite; J₃-K₂ for Linzizong formation (J₃K₁), Bima formation (K₁b), Chumulong formation (K₁c), Takena formation (K₁t) and Shexing formation (K₂s), mainly consisted of sandstone, mudstone, marble, slate, phyllite and minor volcanics.

Mo, 2011a,b; Zhu et al., 2011; Guo et al., 2013; Kang et al., 2014; Wang et al., 2015). Previous studies indicated that the Neo-Tethys oceanic slab underwent subduction during the Cretaceous, which is indicated by the abundant Cretaceous granitoids and volcanic rocks (e.g., the Sangri group), and the subduction process continued until the collision of the Paleogene Indian and Asian plates (e.g., Mo et al., 2005a,b; Dong et al., 2006a,b,c; Ji et al., 2009a,b; Mo et al., 2009; Wen et al., 2008; Xu, 2010a; Zhu et al., 2011; Kang et al., 2014). Although the geochemical and geochronological data of the Jurassic or late Triassic igneous rocks from the Gangdese magmatic belt have been reported previously (Chu et al., 2006; Zhu et al., 2008a,b, 2011; Ji et al., 2009a,b; Dong and Zhang, 2013; Peng et al., 2013; Kang et al., 2014; Song et al., 2014; Meng et al., 2015), systematic geochemical characteristics and affinities of the magmatic suite still remain unclear.

Compared with the widespread Cretaceous and Cenozoic magmatic rocks, the pre-Cretaceous granitoids and associated volcanic rocks are less common, and have been reported sporadically in the Gangdese magmatic belt (Chu et al., 2006; Zhang et al., 2007; Ji et al., 2009a; Tang et al., 2012; Guo et al., 2013; Peng et al., 2013; Kang et al., 2014; Song et al., 2014; Meng et al., 2015). In this study, we report a detailed systematic geochemical and lithological study of the older granitoids of the Numa batholith and the Nyemo pluton in

the middle Gangdese batholith, southern Tibet. These include diorite, granodiorite and granite, with a wide range of SiO₂ contents (5–74 wt%). In general, the igneous rocks and enclaves contain important records of the deep crustal formation, mantle materials, and crust-mantle dynamic processes, so they have been considered as litho-probes or windows into the Earth (Mo et al., 2009; Mo, 2011a,b). The rock suites that we study from the Gangdese batholith are records of the late Triassic evolution of the Neo-Tethys oceanic crust and provide a robust case of subduction-related evolution in southern Tibet. Our results provide new insights into the middle-early Jurassic tectonic setting and evolutionary history of the Gangdese magmatic belt and evaluate the significance of these results in the context of the Neo-Tethys oceanic crust opening and closure in southern Tibet.

2. Geological setting

The Lhasa terrane lies between the BNSZ and the IYTSZ and can be divided into northern, central and southern sub-terrane from north to south, along the Shiquanhe-Namco ophiolitic Mélange Zone (SNMZ) and the Luobadui-Milashan Fault Zone (LMFZ) (Zhu et al., 2008b, 2011; Mo et al., 2009) (Fig. 1a). The southern Lhasa sub-terrane locates is the southernmost part of the Asian plate, and

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