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Petrogenesis of Cretaceous adakite-like intrusions of the Gangdese Plutonic Belt, southern Tibet: Implications for mid-ocean ridge subduction and crustal growth

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ABSTRACT

We have conducted a whole-rock geochemical, U–Pb zircon geochronological, and in situ zircon Hf–O isotopic compositional study of rocks in southern Tibet from the Langxian igneous suite (including a lamprophyre dyke, mafic enclaves, a granodiorite, and a two-mica granite) and the Nuri igneous suite (a quartz–diorite). U–Pb zircon dating indicates that the timing of crystallization of the mafic enclaves and host granodiorite of the Langxian suite are ca. 105 Ma and 102 Ma, respectively, that the Langxian lamprophyre dyke and the two-mica granite were emplaced at ca. 96 Ma and 80–76 Ma, respectively, and that the Nuri quartz–diorite was emplaced at ca. 95 Ma. With the exception of the lamprophyre dyke and mafic enclaves in the Langxian area, felsic rocks from the Langxian and Nuri igneous suites all show signs of a geochemical affinity with adakite-like rocks. The high Mg-numbers, high abundance of compatible elements, high $\varepsilon_{Nd(t)}$ (2.7 and 2.8) and $\delta^{18}O$ (8.9 and 9.2‰) values, elevated zircon $\varepsilon_{Hf(t)}$ (11.0–17.0) values, and low $^{87}Sr/^{86}Sr_{(i)}$ ratios (0.7040), collectively indicate that the Nuri adakite-like quartz–diorite was derived from partial melting of the low temperature altered Neo-Tethyan oceanic crust, and that these dioritic magmas subsequently interacted with peridotite as they rose upwards through the overlying mantle wedge. The observation of identical differentiation trends, similar whole-rock Sr–Nd and zircon Hf isotopic compositions, and consistently low $(Dy/Yb)_N$ ratios among the Langxian igneous suite rocks, indicates that the adakite-like granodiorite was produced by low-pressure fractional crystallization of precursor magmas now represented by the (relict) mafic enclaves. However, relatively high Al_2O_3 contents, low MgO, Cr and Ni contents, and low $(La/Yb)_N$ and $(Dy/Yb)_N$ values indicate that the two-mica granite was derived from partial melting of the southern Tibetan mafic lower crust in the absence of garnet, while isotopic data suggest that at least 70% of the magma source region was juvenile materials. Combined with the presence of HT (high temperature) charnockitic magmatism, HT granulite facies metamorphism, and large volumes of Late Cretaceous batholiths, the oceanic-slab-derived Nuri adakitic rocks indicate a substantial high heat flux in the Gangdese batholith belt during the Late Cretaceous, which may have been related to subduction of a Neo-Tethyan mid-ocean ridge system. According to this model, hot asthenosphere would rise up through the corresponding slab window, and come into direct contact with both the oceanic slab and the base of the overlying plate. This would cause melting of both the oceanic slab and the overlying plate by the addition of heat that was ultimately linked with peak magmatism and the significant growth and chemical differentiation of juvenile crust in southern Tibet during the Late Cretaceous (105–76 Ma). In addition, the petrogenesis of the Langxian adakite-like two-mica granite indicates that the southern Tibetan crust was still of normal thickness prior to the emplacement of these intrusions at ca. 76 Ma. This probably means that large parts of southern Tibet were not very highly elevated prior to the Indian–Asian collision.

1. Introduction

The growth of continental crust is commonly ascribed to two distinct processes: subduction-zone magmatism and mantle plume-related magmatism (Rudnick, 1995; Taylor, 1977). However, geochemical calculations indicate that most of the continental crust (more than ~80%) was generated by subduction-zone magmatism (Barth et al.,

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2000; Plank and Langmuir, 1998); consequently, an understanding of magmatism in the subduction-zone is essential to unraveling processes of crustal growth and maturation (Lackey et al., 2005, 2006, 2008; Nelson et al., 2013). It was widely assumed that melting of mantle peridotite, induced by the addition of water and "hyperfusible materials" (Na, Si, Al) derived from subducted oceanic slab and sedimentary rocks, could be the most important crust-forming process in post-Archean subduction-zones (e.g., Rudnick, 1995; Tang et al., 2012a; Taylor, 1967, 1977). However, there is increasing evidence that ridge subduction, accompanied by ridge–trench interactions, may also impact strongly on magmatic activity and crustal growth along convergent margins (Bourdon and Eissen, 2003; Delong et al., 1979; Guivel et al., 2006; Kinoshita, 1995; Sisson et al., 2003; Tang et al., 2012a, b). Extensive studies of the effects of ridge subduction have been conducted along the modern Pacific Rim (Karsten et al., 1996; Sisson et al., 2003). These studies have mainly involved interpretations of geophysical data and the disruption of surficial materials, and there is little information about deep-seated processes; what little there is has been largely inferred from indirect evidence and from material exhumed from great depths (Pavlis and Sisson, 1995). If an ancient ridge subduction system is exhumed from great depth, the complex structural, metamorphic, igneous, and sedimentary events revealed can provide insights into the evolutionary processes of the ridge subduction system. However, there are only a few well-documented cases of ridge subduction systems in the ancient geological record (Pavlis and Sisson, 1995; Sisson et al., 2003; Tang et al., 2012a, b).

The Gangdese batholiths extend for more than 1500 km across southern Tibet (Fig. 1A), and they have generally been thought to represent a typical Andean-type convergent margin before the collision of the Indian and Asian continents (Chu et al., 2006, 2011; Chung et al., 2005; Yin and Harrison, 2000; Zhang et al., 2014). Geophysical studies indicate that the Tibetan crust beneath the Gangdese belt is twice as thick as average continental crust (~65–80 km) (Murphy et al., 1997; Nelson et al., 1996; Priestley et al., 2006). Recent whole-rock geochemical, Sr–Nd isotopic and in-situ zircon Hf–O isotopic studies indicate that the southern Tibetan crust is characterized by a juvenile crust with mantle contributions up to 50–90% (Hou et al., 2012, 2013; Zheng et al., 2012a; Zhu et al., 2011), which means that southern Tibet may have the thickest juvenile continental crust on Earth.

The growth of juvenile crust in southern Tibet was generally thought to have been associated with the northwards subduction of the Neo-Tethyan oceanic slab beneath the Lhasa terrane and the consequential melting of the subduction-modified mantle wedge (Chu et al., 2006; Mo et al., 2005; Ravikant et al., 2009; Zhu et al., 2011). However, some authors have recently emphasized that subduction of the Neo-Tethyan mid-ocean ridge system may also play an important role in the Late Cretaceous (Zhang et al., 2010b; Zhu et al., 2009b). The Late Cretaceous Gangdese granitoids and metamorphic complex are particularly well exposed and accessible in southeastern Tibet, which could provide critical constraints on the evolutionary processes of ridge subduction and ridge–trench interaction, as well as the growth and chemical differentiation mechanisms of the thickest juvenile continental crust on Earth.

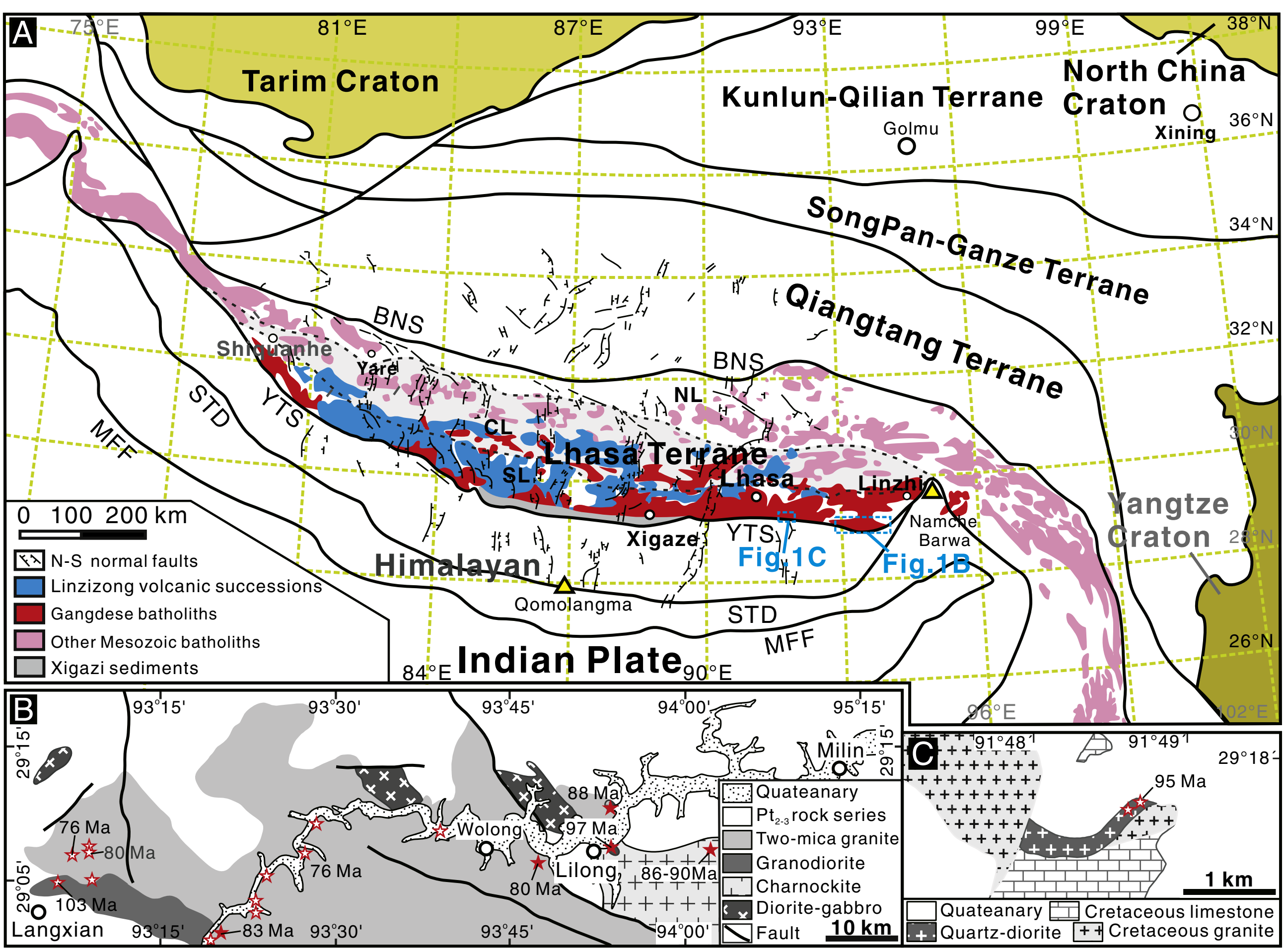

Fig. 1. (A) Simplified geological maps of the Tibetan–Himalayan orogen showing outcrops of the Gangdese batholiths along the south edge of the Lhasa terrane (after Chung et al., 2009; Zhao et al., 2009; Wu et al., 2010). Geological map showing outcrops of (B) the Langxian and (C) the Nuri suites on the southern margin of the Lhasa terrane (after Zhang et al., 2010b). Abbreviations: BNS = Bangong–Nujiang suture; YTS = Yarlung–Tsangpo suture; STD = south Tibet detachment system; MFF = main frontal fault, CL = central Lhasa subterrane, NL = northern Lhasa subterrane, SL = southern Lhasa subterrane.