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Tectono-magmatic evolution of Late Jurassic to Early Cretaceous granitoids in the west central Lhasa subterrane, Tibet

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ABSTRACT

There is ongoing debate as to the subduction direction of the Bangong–Nujiang Ocean during the Mesozoic (northward, southward or bidirectional subduction). Arc-related intermediate to felsic intrusions could mark the location of the subduction zone and, more importantly, elucidate the dominant geodynamic processes. We report whole rock geochemical and zircon U–Pb and Hf isotopic data for granitoids from the west central Lhasa subterrane (E80° to E86°). All rocks show metaluminous to peraluminous, calc-alkaline signatures, with strong depletion of Nb, Ta and Ti, enrichment of large ion lithophile elements (e.g., Cs, Rb, K), a negative correlation between SiO_2 and P_2O_5, and a positive correlation between Rb and Th. All these features are indicative of I-type arc magmatism. New zircon U–Pb results, together with data from the literature, indicate continuous magmatism from the Late Jurassic to the Early Cretaceous (160 to 130 Ma). Zircon U–Pb ages for samples from the northern part of the west central Lhasa subterrane (E80° to E82°30′) yielded formation ages of 165 to 150 Ma, whereas ages of 142 to 130 Ma were obtained on samples from the south. This suggests flat or low-angle subduction of the Bangong–Nujiang Ocean, consistent with a slight southward decrease in zircon εHf(t) values for Late Jurassic rocks. Considering the crustal shortening, the distance from the Bangong–Nujiang suture zone, and a typical subduction zone melting depth of ~100 km, the subduction angle was less than 14° for Late Jurassic magmatism in the central Lhasa interior, consistent with flat or low-angle subduction. Compared with Late Jurassic rocks (main εHf(t) values of −16 to −7), Early Cretaceous rocks (145 to 130 Ma) show markedly higher εHf(t) values (mainly −8 to 0), possibly indicating slab roll-back, likely caused by slab foundering or break-off. Combined with previously published works on arc magmatism in the central Lhasa and west part of the southern Qiangtang subterranes, our results support the bidirectional subduction of the Bangong–Nujiang Ocean along the Bangong–Nujiang Suture Zone, and indicates flat or low-angle southward subduction (165 to 145 Ma) followed by slab roll-back (145 to 130 Ma).

1. Introduction

The geological evolution of the Tibetan Plateau is generally accepted to have involved amalgamation of several terranes including, from north to south, the Qaidam, Songpan–Ganzi, Qiangtang, Lhasa and Himalayan terranes (Fig. 1a; Allègre et al., 1984; Dewey et al., 1988; Yin and Harrison, 2000; Pan et al., 2012). In southern Tibet, the northward subduction of the Neo-Tethyan Ocean along the Indus–Yarlung suture zones led to Jurassic to Cretaceous magmatism and associated porphyry Cu–Au deposits in the southern Lhasa subterrane (Wen et al., 2008; Ji et al., 2009; Zhu et al., 2011; Tafti et al., 2014; Tang et al., 2015). However, three different models have been proposed to explain the origin of Jurassic to Cretaceous magmatism in the central and northern Lhasa subterranes: (1) low-angle northward subduction of the Neo-Tethyan Ocean along the Indus–Yarlung suture zones (Coulon et al., 1986; Ding et al., 2003; Zhang et al., 2004; Kapp et al., 2005, 2007; DeCelles et al., 2007); (2) southward subduction of the Bangong–Nujiang Ocean (Zhu et al., 2009, 2011; Sui et al., 2013); and combined effects of northward subduction of the Neo-Tethyan Ocean and southward subduction of the Bangong–Nujiang Ocean (Yin and Harrison, 2000; Qin et al., 2006; Du et al., 2011; Pan et al., 2012).

Zircon U–Pb geochronology and Hf isotopic studies of intermediate to felsic arc magmas not only provides information on the origin and

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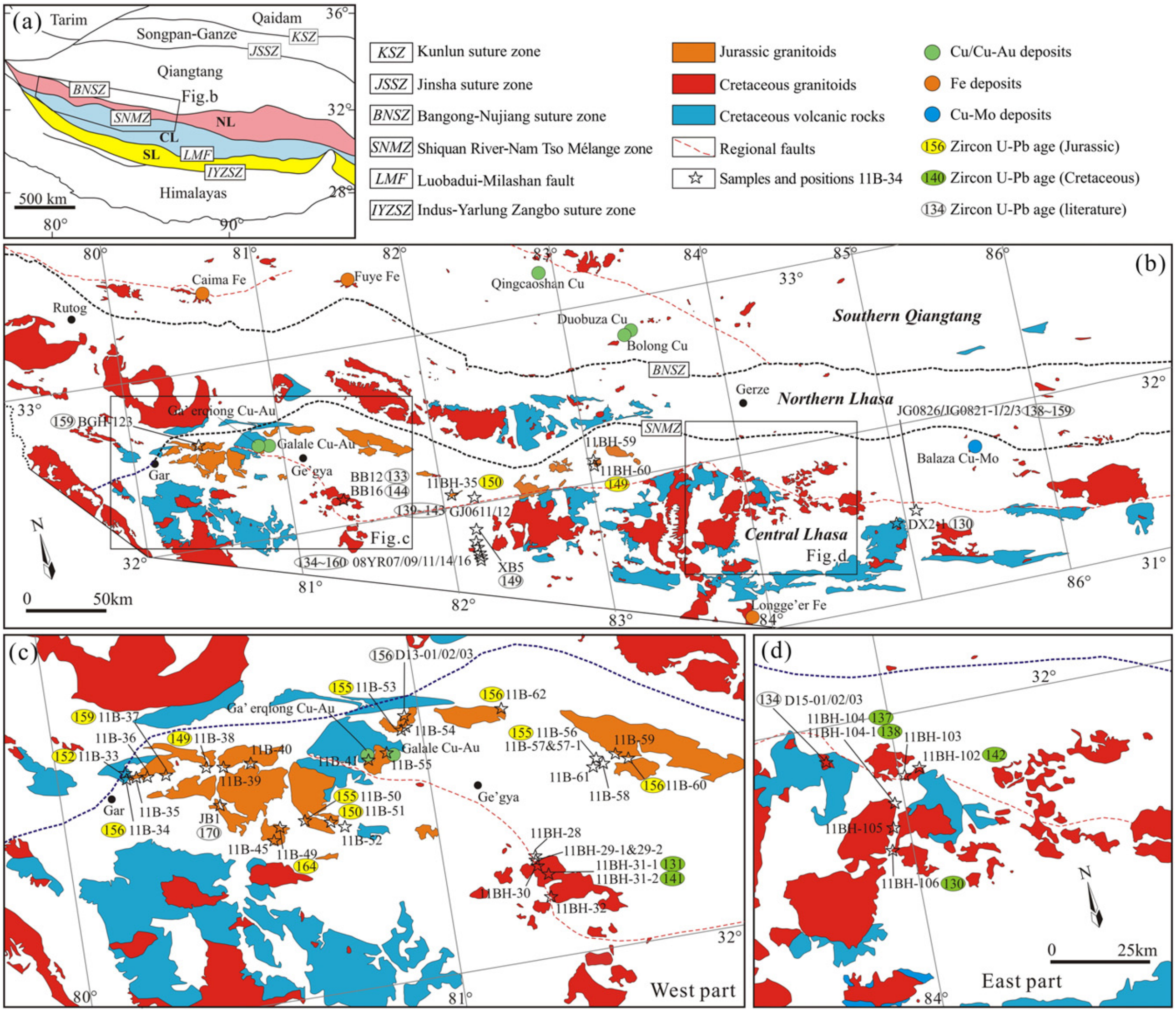

Fig. 1. (a) Sketch map showing the Qiangtang and Lhasa terranes of the Tibetan Plateau (after Zhu et al., 2011). (b) Geological map of the southern Qiangtang, northern Lhasa and central Lhasa subterranes. (c–d) Detailed occurrences of Mesozoic magmatic rocks from the central Lhasa subterrane. Published ages are from Volkmer et al. (2007), Qu et al. (2009), Zhu et al. (2009, 2011), Jiang et al. (2010) and Du et al. (2011).

age of the rocks, but can also be used to reveal details of key geodynamic processes (Gutscher et al., 2000a; Li and Li, 2007; Cao et al., 2011, 2016; Li et al., 2016a). For example, with the development of flat or low-angle subduction, arc magmatism will migrate towards the continental interior, as clearly illustrated in the Andes (Pilger, 1981; Gutscher et al., 1999, 2000b; Kay and Mpodozis, 2002; Espurt et al., 2008) and South China (Zhou and Li, 2000; Li and Li, 2007).

Li et al. (2014) conducted systematic zircon U–Pb dating, Hf isotopic and geochemical analyses of Mesozoic granitoids distributed throughout the western part of the southern Qiangtang terrane. The magmatism displayed typical arc magma characteristics with two distinct magmatic periods (169–150 Ma and 127–113 Ma), and was proposed to have formed in a continental arc setting due to the northward subduction of the Bangong–Nujiang Ocean. Although Late Jurassic arc magmatism occurred in the central Lhasa subterrane (Murphy et al., 1997; Volkmer et al., 2007; Qu et al., 2009; Du et al., 2011; Zhu et al., 2009; Jiang et al., 2010; Zhu et al., 2011; Zhang et al., 2012), the main magmatic pulse was at 110 ± 3 Ma (Zhu et al., 2009, 2011). If southward subduction of the Bangong–Nujiang Ocean occurred since the Late Jurassic, there should be widespread occurrences of rocks generated during Late Jurassic arc magmatism in the west central Lhasa subterrane (WCLS).

In this study, we present whole rock geochemical and zircon U–Pb data, along with Hf isotopic analyses for intermediate to felsic intrusions from the WCLS. Combined with previously published data, the results are used to discuss the formation and origin of the samples and to elucidate the broader regional context for the granitoids petrogenesis.

2. Geological background and sampling

The Tibetan plateau consists of the Qaidam, Songpan–Ganzi, Qiangtang, Lhasa and Himalayan terranes (from north to south) which are separated by the Kunlun, Jinsha, Bangong–Nujiang, and Indus–Yarlung suture zones, respectively (Fig. 1a; Allègre et al., 1984; Dewey et al., 1988; Yin and Harrison, 2000; Pan et al., 2012; Qin, 2012; Li et al., 2015). The Shiquan River–Nam Tso Mélange zone (SNMZ) and the Luobadui–Milashan Fault (LMF) subdivide the Lhasa terrane into the northern, central and southern Lhasa subterranes, respectively (Fig. 1a; Zhu et al., 2011).

The Bangong–Nujiang Suture Zone (BNSZ) is widely considered to be the main oceanic basin of the central Tibetan Neo-Tethys Ocean (Allègre et al., 1984; Yin and Harrison, 2000; Zheng et al., 2006; Shi, 2007; Xu et al., 2014b). Geochronological studies of the BNSZ indicate that