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Evolution of the Bangong–Nujiang Tethyan ocean: Insights from the geochronology and geochemistry of mafic rocks within ophiolites

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ABSTRACT

The Bangong–Nujiang suture zone (BNSZ) is located in the central Tibetan Plateau, and represents the relict of the Bangong–Nujiang Tethyan Ocean (BNTO). This paper presents zircon U–Pb ages and whole-rock geochemical and Sr–Nd isotope data for the ophiolitic rocks from the Rutog, Dongco, Dongqiao, Amdo, and Dengqen areas (from west to east) in the BNSZ. Zircon U–Pb ages obtained from five gabbros and one leucogabbro from the five areas are 169 ± 2, 167 ± 2, 187 ± 2, 184 ± 2, 177 ± 3, and 164 ± 2 Ma, respectively. Mafic rocks (gabbros and basalts) in the BNSZ can be divided into MORB-like and OIB-type, based on geochemical data. The MORB-like rocks are tholeiitic and can be further divided into N- and E-MORB subtypes, marked by depleted and flat REE patterns, respectively. All MORB-like rocks show supra-subduction zone (SSZ) geochemical affinities such as mild enrichment in the large ion lithophile elements and depletion in the high field strength elements, coupled with high and positive whole-rock $\varepsilon_{Nd}(t)$ values (+8.1 to +5.4). The OIB-type rocks, which formed in the Early Cretaceous (~132–108 Ma), are exposed in the Dongco, Dongqiao, and Tarenben areas, and they consist mostly of alkali basalts with within-plate geochemical characteristics and positive $\varepsilon_{Nd}(t)$ values (+5.9 to +4.5). On the basis of these new data, combined with information from the literature, we further support that the BNTO was an intra-oceanic arc–backarc basin that existed between the North Lhasa subterrane (NLT) and the South Qiangtang subterrane (SQT) during the Early–Middle Jurassic. This basin may have been active until the Early Cretaceous, when the OIB-type basalts erupted.

1. Introduction

The Bangong–Nujiang suture zone (BNSZ) extends east–west for >2000 km in central Tibet (Fig. 1a), and it marks the site where the Bangong–Nujiang Tethyan Ocean (BNTO) was present during the Mesozoic, when the Tethyan oceanic lithosphere may have been subducting northwards under the South Qiangtang subterrane (SQT) (Zhang et al., 2012, 2014; Coulon et al., 1986; Guynn et al., 2006; Kapp et al., 2003, 2007; Pearce and Deng, 1988; Yin and Harrison, 2000; Zhang and Tang, 2009) or southwards under the North Lhasa subterrane (NLT) (Pan et al., 2012; Zhu et al., 2006a, 2006b, 2008, 2009, 2011a, 2011b, 2013, 2015). The BNSZ is made up of a discontinuous belt of ophiolitic rocks that are tectonically disrupted; nevertheless, rather complete sequences can still be observed in the Rutog, Dongco, Dongqiao, Amdo, and Dengqen areas, among others (Fig. 1b). However, the ages of the ophiolites, and thus the duration and evolution of the BNTO, remain uncertain. For example, some researchers have suggested that the BNTO existed during the Late Triassic to Early Cretaceous based on zircon U–Pb age data (Bao et al., 2007; Qiangba et al., 2009; Shi, 2007; Xia et al., 2008) or radiolaria in interbedded cherts (Wang et al., 2002a, 2002b). Others have proposed that the BNTO existed in the late Paleozoic based on stratigraphic and zircon age data from the Bangong, Dongqiao and Nagqu areas (Chen et al., 2005; Huang et al., 2012; Pan et al., 2006, 2012, 2013; Wang et al., 2013; Yin and Harrison, 2000; Zhang et al., 2012; Zhu et al., 2013).

On the basis of existing petrological, geochemical, and geochronological data of the ophiolitic mélanges within the BNSZ, Xu et al. (2014) proposed that the Bangong–Nujiang ophiolites represent a short-lived intra-oceanic back-arc basin system. In contrast, Zhang

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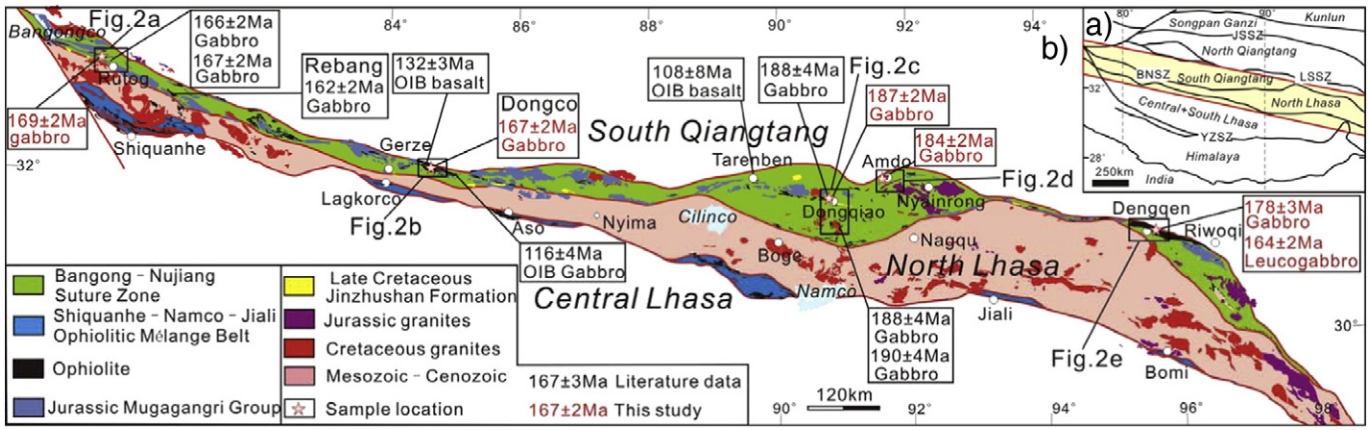

Fig. 1. (a) Tectonic outline of the Tibetan Plateau. JSSZ = Jinsha River suture zone; LSSZ = Longmuco–Shuanghu suture zone; BNSZ = Bangong–Nujiang suture zone; YZSZ = Yarlung Zangbo Suture Zone. (b) The W–E-trending Bangong–Nujiang suture zone and Shiquanhe–Yongzhu–Jiali ophiolitic mélange belt in central Tibet, showing zircon U–Pb ages of the major ophiolitic massifs (modified after Wang et al., 2013). Panel b data sources: Bangongco (Rutog) data are from Shi et al. (2007), Qu et al. (2009); Rebang data are from Liu et al. (2014b); Dongco data are from Bao et al. (2007), Fan et al. (2014); Tarenben data are from Zhu et al. (2006b); Dongqiao data are from Xia, et al. (2008), Huang et al. (2015a, 2015b).

et al. (2014) suggested that the mafic rocks within the ophiolites represent oceanic plateaus, with ages of ca. 184 Ma and ca. 120 Ma, within the BNTO. It should be noted that existing geochronological data are mainly Sm–Nd, K–Ar, and $^{40}Ar/^{39}Ar$ ages, along with a few U–Pb ages from zircons showing cathodoluminescence (CL) images similar to that of zircons from granitoids, meaning that existing age data for the ophiolites are somewhat unreliable (cf. Zhu et al., 2013). Therefore, existing models of the evolution of the BNTO need to be re-evaluated. The uncertainties in the ages can be resolved by dating mafic rocks (including basaltic lavas and gabbro intrusions) within the ophiolites based on radiolarians and zircon U–Pb geochronology.

In this paper we report new zircon U–Pb age data obtained by LA–ICP–MS and whole-rock elemental and Sr–Nd isotopic of the mafic rocks within the ophiolites from the Rutog, Dongco, Dongqiao, Amdo, and Dengqen areas. These new data, combined with the data from the literature, provide insights into the magmatic origin of the mafic rocks within the ophiolites and thus the evolution of the BNTO and neighboring regions.

2. Geological background

2.1. Regional geology

Tibet, in SW China, is a tectonic collage of the Kunlun, Qiangtang, Lhasa, and Himalaya continental terranes (blocks). The terranes are separated by suture zones that mark the positions of the now-closed Tethyan oceans, and from north to south, they are the Jinsha, Bangong–Nujiang, and Yarlung Zangbo suture zones (Fig. 1a) (Pan et al., 2012, 2013; Wang et al., 2013; Zhang et al., 2012; Zhu et al., 2012, 2013, 2015). The Qiangtang terrane is bound by the Jinsha suture to the north and the Bangong–Nujiang suture to the south (Fig. 1a). Recent geological studies have indicated that the Qiangtang terrane is subdivided into two subterranes (the South and North Qiangtang subterranes) by the Longmuco–Shuanghu suture zone (Fig. 1a, b; Zhang et al., 2006a, 2006b, 2011; Zhang and Tang, 2009; Liu et al., 2011; Zhai et al., 2011a, 2011b, 2013; Zhu et al., 2013). The South Qiangtang subterrane (SQT), also known as Western Qiangtang (Metcalfe, 2013; Zhang et al., 2006a, 2006b, 2011; Zhu et al., 2013), consists of Ordovician and older crystalline basement rocks (Pullen et al., 2011). Lower Ordovician to Triassic sedimentary sequences (mainly marine carbonate rocks together with some siltstone) are overlain by Jurassic to Cenozoic sedimentary rocks (including sandstone, mudstone, and limestone) (Pan et al., 2012, 2013; Wang et al., 2008a).

The Lhasa terrane has traditionally been regarded as a whole tectonic entity with the ophiolite fragments having been transported from the BNSZ (e.g., Girardeau et al., 1984, 1985; Kapp et al., 2003, 2007; Pearce and Deng, 1988; Zhang and Tang, 2009; Zhang et al., 2012, 2014). In contrast, recent studies have divided the Lhasa terrane into the North, Central, and South subterranes, separated by the Shiquanhe–Namco mélange zone (SNMZ) and the Luobadui–Milashan Fault (LMF), respectively (Fig. 1a) (Zhu et al., 2008, 2011a, 2011b, 2013). The North Lhasa subterrane (NLT) is mainly Jurassic–Cretaceous with minor amounts of Triassic material. Voluminous volcanic rocks in this subterrane are exposed within Lower Cretaceous volcano-sedimentary sequences (Wang et al., 2013).

The Shiquanhe–Namco–Jiali mélange zone (SNMZ) possibly extends SE–NW for ~2000 km across the northern part of the Lhasa terrane (Fig. 1b). It is bounded to the north by the North Lhasa subterrane and to the south by the Central Lhasa subterrane. The ophiolite sequences in the SNMZ are well preserved at Yongzhu and Lagkorco (Baxter et al., 2009; BGMR, Bureau of Geology and Mineral Resources of Xizang Autonomous Region, 1993; Pan et al., 2013; Wang et al., 2007, 2013; Zhang et al., 2007, 2014). They also occur discontinuously in the western part of the terrane at Shiquanhe, in the central part at Aso and western Namco, and in the eastern part at Jiali and Bomi (Fig. 1b) (BGMR, Bureau of Geology and Mineral Resources of Xizang Autonomous Region, 1993; Ye et al., 2004; He et al., 2006; Pan et al., 2006, 2013; Zhu et al., 2006b, 2011a, 2011b, 2013; Zhang et al., 2007, 2012, 2014; Wang et al., 2013).

In this paper, we examine the ophiolitic rocks from the Rutog, Dongco, Dongqiao, Amdo, and Dengqen areas.

2.2. Geology of the BNSZ

The BNSZ crosses the central Tibetan Plateau (Fig. 1a), and stretches from Bangong in the west (Fig. 1b) via Gerze, Nyima, Dongqiao, Amdo, and Dengqen (Fig. 1b) to the east, and then turns south to the Nujiang River (Pan et al., 2013). The BNSZ contains huge amounts of ophiolite. The ophiolitic mélange is in tectonic contact with Paleozoic–Mesozoic strata or has been thrust over Cretaceous–Neogene strata. Moreover, the BNSZ not only includes mid-ocean ridge basalts (MORB-type) but also supra-subduction zone (SSZ-type) ophiolites (Lai and Liu, 2003; Shi et al., 2005, 2008), oceanic island–seamount basalts (Bao et al., 2007; Zhu et al., 2006b, 2013), and oceanic ridge plagiogranites (Wang et al., 2013; Zeng et al., 2006).

2.2.1. Rutog ophiolite

The Rutog ophiolite is located south of Bangong and ~10 km north of Rutog county (Fig. 2a). It consists of a number of isolated mafic–ultramafic blocks, surrounded by Cretaceous sedimentary rocks. A