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The Carboniferous ophiolite in the middle of the Qiangtang terrane, Northern Tibet: SHRIMP U–Pb dating, geochemical and Sr–Nd–Hf isotopic characteristics

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A B S T R A C T

Ophiolite plays a key role in identifying paleo-ocean and paleo-plate and rebuilding the evolutionary history of ancient orogen. Mafic–ultramafic rocks are distributed in a broadly E–W direction in the middle of the Qiangtang terrane, northern Tibetan plateau. However, interpretation of these rocks as ophiolite and subsequent tectonic implications have been much disputed, and they were regarded by some to have an origin in a continental rift setting. A detailed zircon dating and geochemical and Sr–Nd–Hf isotopic study of this suite of rocks has been undertaken in order to clarify this important issue. The mafic–ultramafic suite was collected from the Gangma Co and Guoganjianian localities and is composed of cumulate and isotropic gabbro, basalt, actinolitite and plagiogranite. All basaltic rocks are tholeiitic and have low rare earth element (REE) abundances with variable REE patterns and slight negative Nb and Ti anomalies. These features are comparable with those of normal mid-ocean ridge basalts (N-MORB) and/or enriched mid-ocean ridge basalts (E-MORB). The positive whole-rock $\varepsilon_{Nd}(t)$ and zircon $\varepsilon_{Hf}(t)$ values indicate that these rocks were derived from a long-term depleted mantle source. Zircon U–Pb dating using a sensitive high-resolution ion microprobe (SHRIMP) on two cumulate gabbros and two plagiogranites samples yielded Carboniferous ages of 357 ± 2.5 Ma, 356.1 ± 3.0 Ma, 354.7 ± 4.7 Ma and 345.4 ± 4.6 Ma. The ophiolite marks a Paleo-Tethys Ocean basin in middle of the Qiangtang terrane, and it is interpreted as the western extension of the Changning–Menglian Paleo-Tethys ophiolite in the eastern margin of the Tibetan plateau.

1. Introduction

Ophiolite represents fragments of oceanic crust and upper mantle that was tectonically emplaced onto continents during orogenic events. They are generally exposed along suture zones, and play a key role in the identification of ancient oceanic lithosphere and paleo-plate suture in orogenic belts (e.g., Coleman, 1977; Dewey and Bird, 1971; Dilek, 2003). The Tibetan plateau was formed by the closure of the Neo- and Paleo-Tethys oceans and amalgamation between the Laurasia and Gondwana supercontinents since the Paleozoic (Dewey et al., 1988; Sengor and Natalin, 1996; Yin and Harrison, 2000; Zhu et al., 2012). Ophiolites are widely distributed within the Tibetan plateau (e.g., BGMR, 1993; Zhang et al., 2008). The most well-known are the Neo-Tethys ophiolites from the Yarlung Zangbo (e.g., Aitchison et al., 2000; Guilmette et al., 2009; Hébert et al., 2012; Malpas et al., 2003; Nicolas et al., 1981; Tapponnier et al., 1981) and Bangong–Nujiang (e.g., Girardeau et al., 1984) suture zones in southern Tibet (Fig. 1), and the Paleo-Tethys ophiolites from the Jinsha, Changning–Menglian (e.g., Jian et al., 2008, 2009a,b; Sone and Metcalfe, 2008; Zhong, 1998) and Kunlun (e.g., Xiao et al., 2002; Yang et al., 1996) suture zones in eastern and northern margin of Tibetan plateau (Fig. 1).

The Qiangtang terrane is located in the core parts of the Tibetan plateau (Fig. 1). A >500 km-long high pressure metamorphic belt (including eclogite and blueschist) occurs in the middle of the Qiangtang terrane (Kapp et al., 2003; Li et al., 1995; Zhai et al., 2011a,b) and has been attributed to the subduction of the Paleo-Tethys Ocean in this area (e.g., Li et al., 1995; Liang et al., 2012; Liu et al., 2011; Zhai et al., 2011a,b; Zhang et al., 2006b). Mafic and ultramafic rocks are also present in the middle of the Qiangtang terrane, but interpretation of these rocks as ophiolites and subsequent tectonic implication has long been disputed (Deng et al., 1996; Li et al., 1995, 2008; Wang et al., 1987, 2001; Zhai et al., 2007, 2010). Two contrasting hypotheses of their formation are (1) they are true ophiolite and represent a Paleo-Tethys suture zone (Li et al., 1995, 2008; Zhai et al., 2007, 2010); and (2) they have geochemical features of within-plate basalt, but formed in a continental rift setting (Deng et al., 1996; Wang et al., 1987, 2001).

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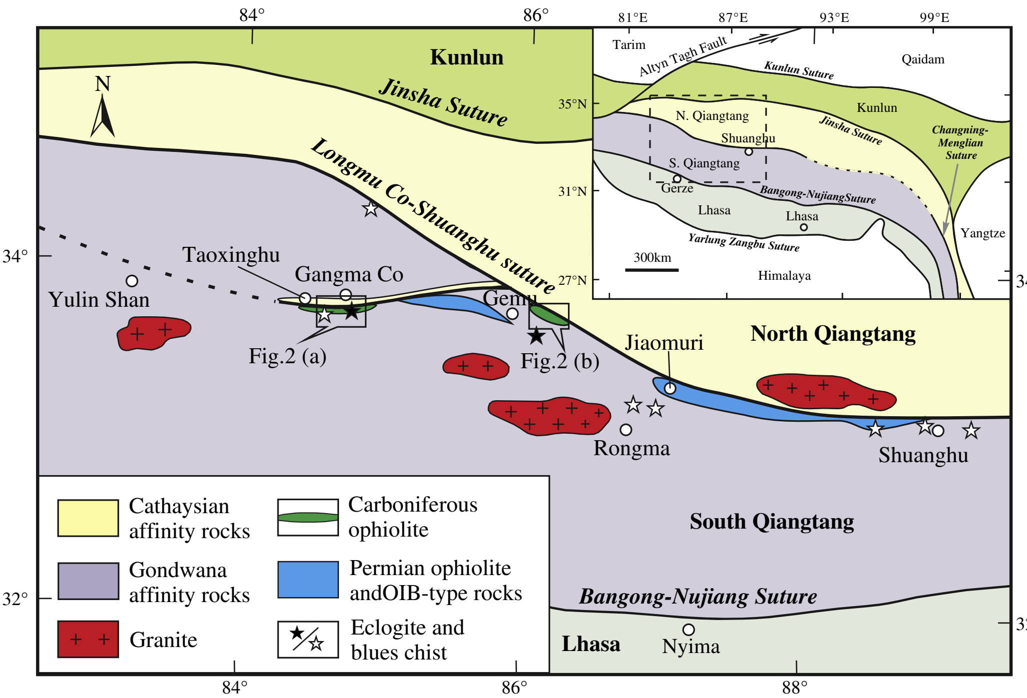

Fig. 1. Simplified geologic map showing the distribution of ophiolite in the Qiangtang area, northern Tibet.

In the past few decades, studies have been focused on high pressure metamorphic rocks (eclogite and blueschist) in the middle of the Qiangtang terrane (Kapp et al., 2000, 2003; Li et al., 1995, 2006; Liang et al., 2012; Liu et al., 2011; Pullen et al., 2008; Zhai et al., 2011a,b; Zhang et al., 2006b) with only limited work on the associated ophiolite suite. In this paper, new SHRIMP U–Pb zircon ages, whole-rock geochemistry and Sr–Nd–Hf isotopic data of the ophiolite will be presented; they will then be used to discuss the geodynamic evolution of the Qiangtang terrane.

2. Geological setting

The Tibetan plateau lies in the eastern part of the great Himalayan-Alpine orogen. It is composed of the Kunlun, Qiangtang, Lhasa and Himalaya terranes. These terranes are separated by several suture zones that are the remnants of the Tethys oceans. From north to south, they are the Jinsha, Bangong–Nujiang and Yarlung Zangbo suture zones (Fig. 1) (Dewey et al., 1988; Sengor and Natalin, 1996; Yin and Harrison, 2000; Zhu et al., 2012). The Qiangtang terrane is bounded by the Jinsha Paleo-Tethys suture zone to the north and the Bangong–Nujiang Neo-Tethys suture zone to the south (Fig. 1). Thus, the terrane lies in the transition zone between the Paleo- and Neo-Tethys oceans. Recently, a suture zone, named the Longmu Co-Shuanghu suture zone, was identified in the middle of the Qiangtang terrane (Li et al., 1995; Liang et al., 2012; Liu et al., 2011; Zhai et al., 2011a,b; Zhang et al., 2006b; Zhu et al., 2012). Thus, the Qiangtang terrane can be subdivided into the north and south Qiangtang subterranes by this suture zone (Fig. 1). The Paleozoic sedimentary rocks from the south Qiangtang subterrane are characterized by glaciomarine deposit and cold-water biota; this is the typical feature of the Gondwana affinity (BGMR, 1993; Jin, 2002; Li and Zheng, 1993; Li et al., 1995; Zhang et al., 2009). On the other hand, the Paleozoic sedimentary rocks from the north Qiangtang subterrane contain abundant warm-water fossils of the Cathaysian affinity (such as fusulinid, coral and Gigantopterides) (BGMR, 1993; Jin, 2002; Li and Zheng, 1993; Li et al., 1995; Zhang et al., 2009), hence the two subterranes are quite distinct in terms of their sedimentary successions.

The Longmu Co-Shuanghu suture zone was originally proposed by Li (1987) as an in-situ Paleo-Tethys suture zone. It is a tectonic complex composed of blueschist, eclogite, ophiolite, OIB-type (ocean island basalts) basalt, meta-sedimentary rocks and minor chert (BGMR, 1993; Kapp et al., 2000, 2003; Li et al., 1995; Zhai et al., 2011a,b; Zhang et al., 2006b). Recent field mapping shows that the eclogite and blueschist from the Gangma Co, Gemu, Rongma and Shuanghu areas (Fig. 1) form a ~500 km-long high pressure metamorphic belt in the middle of the Qiangtang terrane (Kapp et al., 2000, 2003; Li et al., 1995; Pullen et al., 2008; Zhai et al., 2011a,b; Zhang et al., 2006b). Zircon SHRIMP U–Pb ages of 230–237 Ma (Zhai et al., 2011b) and Lu–Hf mineral isochron ages of 233–244 Ma (Pullen et al., 2008) constrained the Triassic time of the peak eclogite-facies metamorphism. Moreover, the P–T condition of peak metamorphism was estimated to be 410–460 °C and 2.0–2.5 GPa for the eclogite (Zhai et al., 2011b). Geochemical and Sr–Nd isotopic data suggest that the eclogite and blueschist were derived from subducted E-MORB and OIB (Zhai et al., 2011a).

Ophiolite suites in the middle of the Qiangtang terrane were first reported by Li et al. (1995) and were regarded as the remnant of the Paleo-Tethys Ocean and marked an in-situ Paleo-Tethys suture zone. However, no complete sequence of ophiolite has been preserved. Preliminary investigations indicated that the age of these ophiolites were Early Paleozoic (Li et al., 2008; Zhai et al., 2010) and Permian (Zhai et al., 2004), and they exhibited geochemical characteristics similar to N-MORB (Zhai et al., 2007, 2010) and OIB (Zhai et al., 2006).

3. Field occurrence

In this study, we focus on ophiolites from the Gangma Co (Fig. 2a) and Guoganjianian (Fig. 2b) areas. The former is a newly documented locality that is ~10 km to the southeast of the Gangma Co, whereas the latter lies in the Guoganjianian, which has been reported by Zhai et al. (2007).