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SHRIMP zircon U–Pb geochronology, geochemistry and Sr–Nd–Hf isotopic compositions of a mafic dyke swarm in the Qiangtang terrane, northern Tibet and geodynamic implications

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ABSTRACT

Regional mafic dyke swarms are commonly emplaced in extensional tectonic settings and are typically considered to be linked with continental break-up. A large number of mafic dykes (areal extent of ~40,000 km^2) have recently been documented in the middle of the Qiangtang terrane, northern Tibet. Zircon U–Pb isotope analyses using a sensitive high-resolution ion microprobe (SHRIMP) indicate that the dykes were emplaced in the Early Permian (279 ± 2 Ma, 283 ± 1 Ma, 285 ± 1 Ma and 285 ± 3 Ma). Whole-rock geochemical data show that the Qiangtang mafic dykes are tholeiitic in composition and exhibit relative enrichment in light rare earth element (LREE) and depletion in Nb, Ta and Ti, resembling continental intra-plate basalts. Whole-rock Sr–Nd and zircon Hf isotopic data suggest that mafic dyke magma was derived from a depleted mantle source ($\varepsilon_{Nd}(T) = +5.1$ to $+7.6$ and $\varepsilon_{Hf}(T) = +4.9$ to $+14.8$). The chemical and isotopic characteristics make the mafic dykes similar to the Panjal Traps and Permian basalts in the Tethyan Himalayas. The contemporaneous and widespread emplacement of ca. 283 Ma continental intra-plate basaltic rocks in the Qiangtang terrane and in the Himalayas is suggestive of a Large Igneous Province (LIP). This LIP is linked to the initial rifting and opening of the Meso-Tethys Ocean during the Permian.

1. Introduction

It is generally accepted that the opening of the Tethys oceans in the Paleozoic was associated with the rifting and fragmentation of the Gondwana supercontinent (e.g., Metcalfe, 2006; Sengor, 1979, 1987; Yin and Harrison, 2000). An extensional tectonic setting probably existed on the northern margin of Gondwana in the Late Paleozoic as shown by the emplacement of Permian continental intra-plate basalts at Panjal, Abor and Bhote in the Himalayas (e.g., Chauvet et al., 2008; Vannay and Spring, 1993; Zhu et al., 2010). The Permian basalt from Oman (Lapierre et al., 2004) provides additional evidence. These basalts may have been parts of a Large Igneous Province (LIP) linked to the break-up of Gondwana, which may have been triggered by mantle plume activity (Bryan and Ernst, 2008; Chauvet et al., 2008; Lapierre et al., 2004; Zhu et al., 2010). However, the areal distribution of these intra-plate basalts is limited, and more evidence on the extent of associated magmatism and its geochemical characteristics is required in order to constrain the mechanism and process of the break-up of Gondwana, and whether there was a mantle plume link.

Regional mafic dyke swarms are commonly emplaced in an extensional tectonic setting and are often linked with mantle plume activity and associated continental break-up (e.g., Ernst and Buchan, 2001; Ernst et al., 2005; Halls and Fahrig, 1987; Zhu et al., 2009). The Qiangtang terrane in the north-central Tibetan plateau is a tectonic unit associated with the northern margin of Gondwana. In recent years, intense geological investigation at 1:250,000 scale has been carried out and a large number of WNW or E–W trending mafic dykes were documented in the middle of the Qiangtang terrane (Pan et al., 2004; Zhai et al., 2009). We name them the Qiangtang dyke swarm in this study. These mafic dykes were proposed to be related to the break-up of Gondwana and the opening of the Tethys Ocean (Zhai et al., 2009). Herein, we report precise U–Pb zircon ages using a sensitive high-resolution ion microprobe (SHRIMP) and geochemical and Sr–Nd–Hf isotopic compositions for the mafic dykes in the Qiangtang terrane. The new data allow us: (1) to constrain the emplacement age of the mafic dykes; (2) to study their

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origin and petrogenesis; and (3) to discuss their tectonic implications and possible genetic links with a mantle plume during Gondwana break-up.

2. Geologic setting

The Qiangtang terrane is situated in the north-central Tibetan plateau, bounded by the Jinsha suture to the north and the Bangong–Nujiang suture to the south (Fig. 1) (BGMR, 1993; Tapponnier et al., 2001; Yin and Harrison, 2000). A >500 km E–W trending metamorphic belt, including blueschist, eclogite and ophiolitic mélanges, occurs in the middle of the Qiangtang terrane (Kapp et al., 2000, 2003; Li et al., 2006; Pullen et al., 2008; Zhai et al., 2007, 2010, 2011a,b; Zhang et al., 2006a). Two contrasting interpretations have been given for the tectonic evolution of this Qiangtang metamorphic belt: (1) a Paleo-Tethys suture between the South Qiangtang subterrane with a Gondwana affinity and the North Qiangtang subterrane with a Cathaysia affinity (e.g., Li et al., 1995; Zhai et al., 2011a,b; Zhang et al., 2006a,b); or (2) the Qiangtang terrane represents a single terrane of Gondwana affinity in which the Songpan–Ganzi flysch deposit was underthrust southward from the Jinsha suture and was exhumed in the interior of the Qiangtang terrane (Kapp et al., 2000, 2003; Yin and Harrison, 2000). Regardless of the tectonic interpretation, the mafic dyke swarm addressed in this study lies entirely in the South Qiangtang subterrane, and therefore has definite Gondwana affinity (Fig. 1).

The main rock units exposed in the South Qiangtang subterrane are the Carboniferous, Permian and Jurassic sedimentary sequences (Pan et al., 2004). The Paleozoic rocks mainly comprise sandstone and limestone, and some of them have undergone low-grade metamorphism (as quartzite, metapelite and marble). Intercalated in the sedimentary sequences are basaltic rocks, glaciomarine deposits and fossils of cold-water biota (BGMR, 1993; Pan et al., 2004). Carboniferous–Permian cold-water biota and glaciomarine deposits are widespread in the northern margin of Gondwana (Jin, 2002; Li and Zheng, 1993), further supporting a Gondwana affinity. Additional support for a Gondwana link is also provided by geochronological study of detrital zircons from the South Qiangtang subterrane (Pullen et al., 2008; Zhu et al., 2011).

Mafic dykes occur mainly within the Carboniferous quartzites, metapelites and sandstones (e.g., Chameng and Zhanjin Groups). Geochronological studies yielded U–Pb zircon ages of 284 ± 3 Ma and 302 ± 4 Ma for two diabase dykes; these are interpreted as emplacement ages (Zhai et al., 2009). Individual mafic dykes are mostly vertical, and typically WNW or E–W trending; they are 0.5–100 m wide and can be traced for distances of 0.1–50 km (Fig. 2a,b,c). The dykes are mainly diabase, with small amounts of gabbro and minor picrite. The diabasic rocks are composed of 30–40% clinopyroxene, 60–70% plagioclase and minor amount of Fe–Ti oxide, apatite and zircon (Fig. 2d,e). Clinopyroxene is commonly subhedral to anhedral. Plagioclase is euhedral. The coarse-grained interiors of wide diabasic dykes are gabbroic textured, but they have similar mineral assemblages to the diabasic rocks (clinopyroxene, plagioclase and minor magnetite). The interior (gabbro) and margin (diabase) also have similar chemical compositions, suggesting insignificant differentiation from the margin to the interior of the dykes. The picritic dykes are narrow and commonly occur as strongly retrograded pyroxenite. Compositionally they typically consist of clinopyroxene, with minor amounts of plagioclase and olivine. Some dykes have experienced variable degrees of saussuritization and chloritization.

3. Analytical methods and results

3.1. SHRIMP zircon U–Pb age

Four mafic dyke samples were chosen for zircon dating using the SHRIMP II of Curtin University of Technology, Western Australia. The instrument was controlled and data acquired from a remote control center in the Beijing SHRIMP Center, Institute of Geology, Chinese Academy of Geological Sciences, Beijing. The detailed analytical

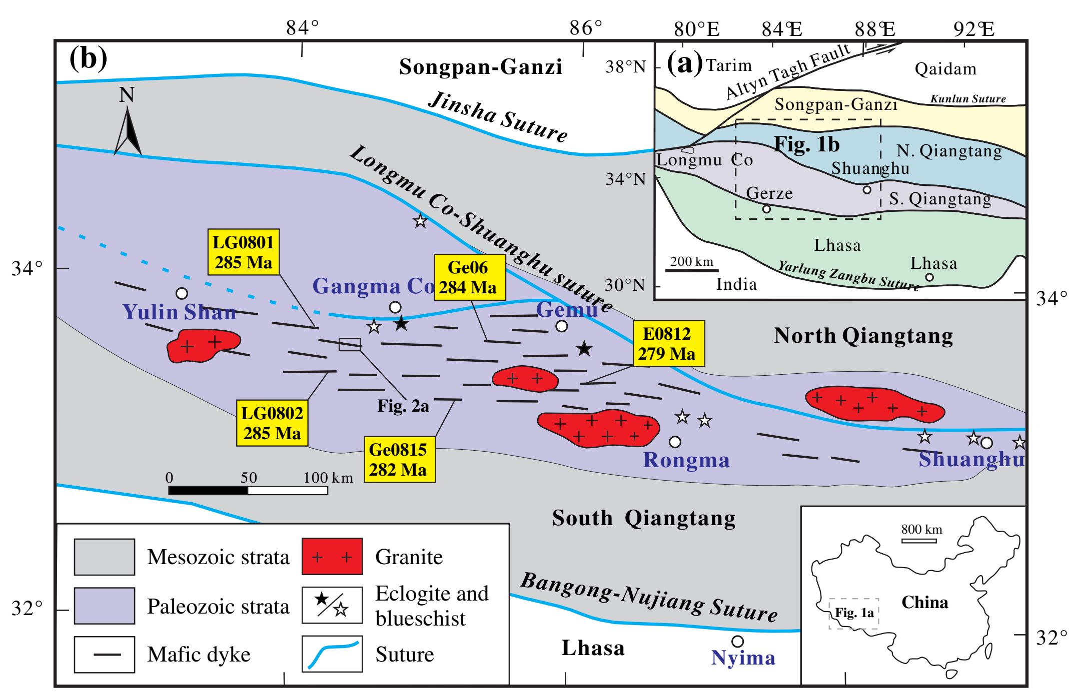

Fig. 1. Tectonic framework of the Qiangtang area, northern Tibet, showing the sample locations for zircon dating in this study. The age of sample Ge06 is after Zhai et al. (2009).