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Early Permian Qiangtang Mantle Plume, Northern Tibet, China: Evidence from Geochemistry, Geochronology and Geological Responses

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Late Paleozoic igneous rocks are extensively developed in Qiangtang terrene, including west Qiangtang (WQT), east Qiangtang (EQT) and the central Qiangtang (CQT) metamorphic belt. The igneous rocks distributed in WQT display the typical characters of rifted igneous rock (e.g. Wang et al., 1987, 2001; Deng et al. 1996; Zhang and Zhang, in press). The blueschist- and eclogite-bearing CQT metamorphic belt is characterized by ubiquitous blocks of OIB-type meta-basalts (Zhang et al., 2006a, 2006b, 2007a; Tang and Zhang, 2012a, 2012b, 2014; Zhang and Zhang, in press). However, the distribution, age and geological responses of these igneous rocks remain open to be discussed.

We report petrography, geochemistry, geological responses, and correlate the Early Permian basaltic rocks from WQT and CQT, with those in EQT, which totally covered an area of > 3.3 × 10^5 km^2, with a maximum thickness of 1.5–2.0 km. Similar Early Permian basalts are also present in the Lhasa terrane (e.g. Jiangrang and Ranwu), the present-day South Tibet–northern India (including Panjal Traps, Selong–Bhote Kosi and Abor), Sanjiang area (e.g. Woniusi) and the Tarim basin (*Zhang and Zhang, in press, and references therein*). These basalts originally have an extent of > 8.84 × 10^5 km^2 and a volume of > 6.76 × 10^5 km^3. A Sakmarian–Kungurian mantle plume is proposed to be responsible for such large-scale eruption of flood basalts, which could have initiated the disintegration of northern Gondwana (*Zhang and Zhang, in press*).

The SiO_2 contents of the WQT basaltic samples range from 37.34% to 57.18%, while the CQT basalts samples contain 35.55%~53.76% SiO_2. The remarkable high ratios of Ti/Y and La_n/Yb_n preclude these Early Permian basalts being derived from a depleted mantle source. And most of the sample have relative high LOI value and variable initial $^{87}Sr/^{86}Sr$ ratios, suggesting rocks have undergone alteration. The East Qiangtang basalts are characterized by high TiO_2, low Al_2O_3, significant HREE concentrations, apparent LREE enrichment, and lack Eu anomaly. The basalts and mafic dykes also display similar low MgO, $Mg^{\#}$ and Ni contents, and the strong correlations between $Mg^{\#}$ and major and trace element indicate they had experienced fractional crystallization process (Zhang and Zhang, 2016). Compared with ocean island basalts (OIB) of primitive mantle-normalized incompatible trace element patterns, most of the Qiangtang basalt samples show a notable resemblance and suggest a mantle plume origin. Moreover, the geochronological and paleontological data suggest most of the Early Permian widespread magmatism occurred in a few million years, with a peak at ~ 287 Ma (e.g. WQT mafic rocks).

The Permian magmatism is widespread occurring over 1000 km from the continental margin, and implies that anomalously hot mantle extended over a very wide area and melted extensively. Generally, the basalts in our research coincide with models that suggest an upwelling plume head was trapped beneath the lithosphere and separated from the plume tail (Chung et al., 1998; Leitch et al., 1998), with plume material spread over a very large area by ambient mantle flux (Wilson, 1997).

Early Permian OIB-type basalts also distribute in three main Tibetan–Himalayan suture zones (the Bangong–Nujiang, Shuanghu, and Yarlung-Zangpo sutures), or in their nearby continental margins. Therefore, this mantle plume could have not only initiated the separation of Tarim and entire Tibet from Gondwana, but also initiated the corporate separations of the WQT, EQT, Lhasa, and Tarim terranes during the Early Permian, and could be responsible for the *formation of main suture zones within the Tibetan plateau (e.g. Zhang et al., 2007, 2012, 2014a, in press).*

The middle Permian warm-water limestone bear rich warm-water faunas, while glacial-water fauns exist in the

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Late Carboniferous–Early Permian tillites or glacial marine siliciclastic rock. Unlike any other large igneous provinces that are temporally closely related to mass extinction events (Condie, 2004), the Early Permian basalts in the northern margin of Gondwana correlate with peak in marine organism originations at ~ 287 Ma (Condie, 2004). It also coincided with the transition of the Late Carboniferous–Early Permian cool climate to the Middle warm climate in the Southern Hemisphere Gondwana (Honegger et al., 1982;Condie, 2004; Zhang et al., 2007). This supports the speculation that a ~ 287-Ma plume event injected enough greenhouse gases into the atmosphere to overcome the extensive glaciation in the Late Carboniferous and Early Permian and to cause the originations of marine organism (Condie, 2004).

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