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Diverse Permian magmatism in the Tarim Block, NW China: Genetically linked to the Permian Tarim mantle plume?

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ABSTRACT

Zircon U–Pb ages and geochemical data are reported for the Piqiang oxide-bearing ultramfic–mafic complex, the Bachu mafic dyke swarm, the Yingan and Kaipaizileike basalts and the Halajun A-type granites in the Tarim Block, Northwest China. The Piqiang complex and the Halajun A-type granites were emplaced at ca. 276 Ma and ca. 278 Ma, respectively. Together with previously reported geochronological data, the diverse intrusive and extrusive rocks in Tarim show a peak age at ca. 275 Ma. Elemental and Nd isotope geochemistry suggests that the spatially and temporally related Piqiang complex (including some dolerite dykes or stocks) and the Halajun A-type granites were formed via crystal fractionation/accumulation of a common plume-derived parental mafic magma (melting degree >10%), coupled with variable extents of crustal contamination. Crystal fractionation/accumulation in one or several magma chambers resulted in the diversity of rocks types. The Bachu mafic dyke swarm shares a similar mantle source with the intrusive rocks in the Piqiang–Halajun area but with a relatively lower degree of partial melting (~5%). In contrast, the basalts were derived from a time-integrated, enriched lithospheric mantle source as suggested by their high-Ti, LREE- and LILE-enriched trace element signature and negative $\varepsilon_{Nd}(t)$ values ($-2.0 \sim -2.6$). The synchronous yet diverse range of Permian igneous rocks in Tarim can best be accounted for by a Permian mantle plume, which is about 15 Ma earlier than the Emeishan plume in southwestern China.

1. Introduction

Mantle plumes are thermal anomalies that rise from the lower mantle or even the core–mantle boundary (Campbell and Griffiths, 1990). The ascent of a mantle plume can cause melting in the mantle and the crust, resulting in the formation of diverse igneous rocks (Bryan and Ernst, 2008; Xu et al., 2008). The diversity of extrusive and intrusive rocks genetically related to a single mantle plume is well documented in the Siberian traps (Czamanske et al., 1995; Fedorenko and Czamanske, 1997; Arndt et al., 1998, 2003), the Emeishan large igneous province (ELIP) (Zhou et al., 2002, 2008; Xu et al., 2004, 2008; Xu and He, 2007; Wang et al., 2008) and even in some Precambrian large igneous provinces (Li et al., 2003, 2008; Ernst et al., 2008). Such diversity has been attributed to the variability in mantle sources, variable degrees of plume–lithosphere interaction, variable degrees of crustal melting and assimilation, or a combination of these processes (Arndt et al., 1998, 2003; Zhou et al., 2008, 2009; Wang et al., 2009).

Recent work suggests that a possible mantle plume was responsible for the early to middle Permian large igneous province in Tarim and the southern part of the Central Asian Orogenic Belt (CAOB) (Zhou et al., 2004; Chen et al., 2006; Borisenko et al., 2006; Mao et al., 2008; Pirajno et al., 2008, 2009; Polyakov et al., 2008; Zhang et al., 2008, 2010; Zhou et al., 2009; Tian et al., 2010) (Fig. 1), which was termed the Tarim LIP by Borisenko et al. (2006) (also known as Bachu LIP or Tarim-Bachu LIP, *e.g.*, Zhang et al., 2008, 2010; Pirajno et al., 2009). However, the genetic links between the intrusive and extrusive rocks in the Tarim LIP, especially those in the Tarim Block, have not yet been established and thus the processes that formed the diverse igneous rocks are not well understood. In this study, we carried out geological, geochronological and geochemical analyses on the Piqiang oxide-bearing intrusive complex, the Halajun granite plutons (pluton I and pluton II), the Bachu mafic dyke swarm and basalts in the Tarim Block, NW China. The aims of the study were to constrain the timing of the emplacements and to address the petrogenesis of these diverse igneous rocks by identifying possible sources involved in magma generation and deciphering their relationship to the mantle plume.

2. Regional geology and petrography

The Tarim Block in northwestern China covers an area of more than 600,000 km^2. It is one of the least known continental blocks in Asia due to its extensive coverage by desert. Nevertheless, several

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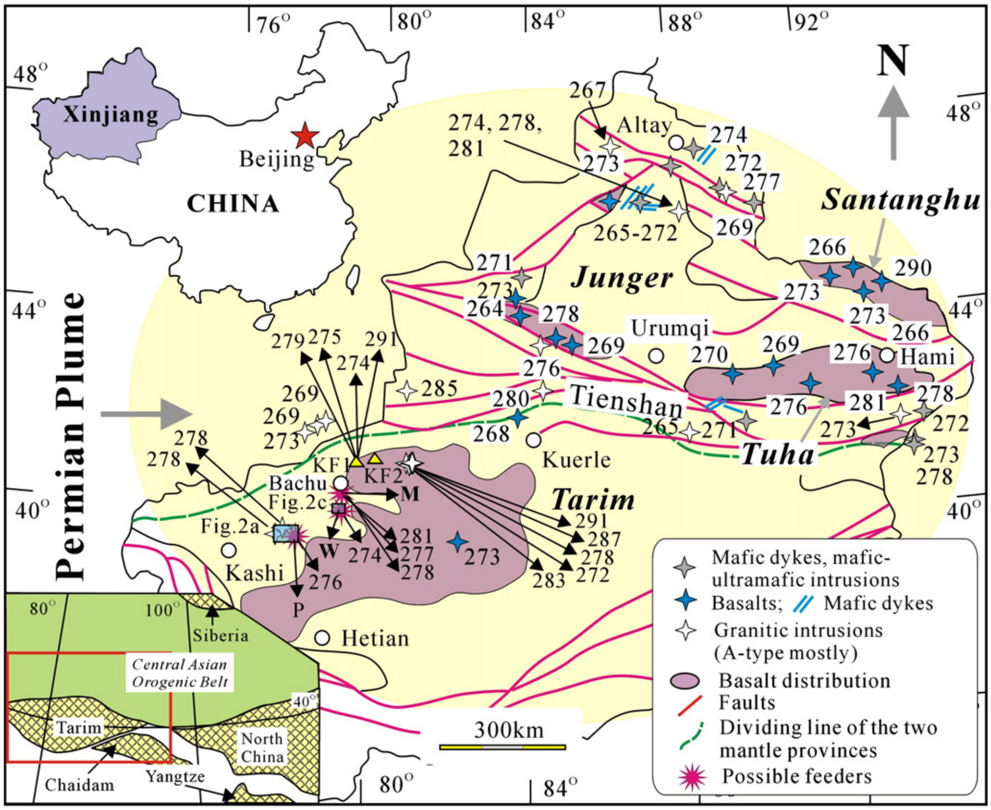

Fig. 1. A geotectonic sketch map of the Tarim Block and part of the Central Asian Orogenic Belt (CAOB) in Xinjiang, showing the distribution of the Permian basalts, ultamafic–mafic intrusions, mfic dykes and A-type granites, with their ages shown in Ma (grey, blue and blank stars represent the locations of dated mafic–ultramafic intrusions, basalts and mafic dykes, and granitic intrusions, respectively). Inset in the lower-left corner shows the locations of the CAOB and the main crustal blocks to the north and south of the CAOB. The locations of the studied Piqiang complex, Halajun granite plutons, Bachu mafic dyke swarm, and basalts are shown. Discussions about the dividing line between the two mantle provinces (or domains) can be found in Zhang et al. (2010). KF1—the Kupukuziman Formation at the Yingan section; KF2—the Kapaizileike Formation at the Kaipaizileike section; M—the Mazaertage complex; W—the Wajilitage complex; P—the Piqiang complex.

important phases of igneous activities have been identified in Tarim, *i.e.*, the Neoarchaean, early Palaeoproterozoic, Neoproterozoic and early Permian events (Hu et al., 2000; Zhang et al., 2007, 2008, 2010; Lu et al., 2008). Among these igneous activities, the early Permian phase is the latest and was considered to be related to mantle plume activity (Pirajno et al., 2008; Mao et al., 2008; Zhang et al., 2008, 2010; Zhou et al., 2009; Tian et al., 2010).

The study region is close to Bachu in the northwestern part of the Tarim Block (Figs. 1 and 2). Some geological, geochronological and geochemical data have previously been reported on the ultramafic–mafic–syenite complex, mafic dykes and syenite plutons (or dykes) in the Bachu region, and on the basalts in the Yingan and Kaipaizileike sections (marked as KF1 and KF2 in Fig. 1) (Yang et al., 1995, 2005, 2006, 2007; Rui et al., 2002; Jiang et al., 2004a,b; Li et al., 2007; Zhou et al., 2009). However, most of these data are published in the Chinese literature and precise geochronology and systematic geochemical data are still scarce, and no age and geochemical data have yet been reported for the oxide (magnetite)-bearing Piqiang ultramafic–mafic complex and the nearby Halajun granites.

2.1. The Piqiang ultramafic–mafic complex

The oxide (magnetite)-bearing Piqiang intrusive complex crops out ca. 120 km northeast of Atushi City (Fig. 2a). It intrudes Devonian sedimentary rocks with the contact dipping 70–80° toward the interior of the complex, and has an outcrop area of ca. 25 km^2 (Fig. 2a). Thin-section examinations and field observations, together with previous field mapping and petrographic studies (*e.g.*, Rui et al., 2002), indicate that the complex is composed mainly of gabbro (accounting for ca. 95% of the outcrop) with minor olivine-bearing gabbro and dolerite (Fig. 2b). Most of the crystalline rocks are cumulates (except for the dolerite). The gabbros are medium- to coarse-grained, and consist of clinopyroxene (30–50%), plagioclase (40–45%) and variable amounts of orthopyroxene (5–15%), magnetite (5–20%, mostly vanadium titanomagnetite) and olivine (1–10%). Accessory minerals include apatite and zircon. Magnetite is commonly disseminated in the gabbros but in places it occurs as veins or blocks, forming economic orebodies (Fig. 2b). The dolerite is fine-grained or microcrystalline and consists mainly of plagioclase (45–55%), clinopyroxene (35–45%) and Ti–Fe oxides (5–10%). No phenocrysts have been observed.

One sample (08KT01) collected from coarse-grained gabbro in the Piqiang complex (08KT01, 40º24′42″N, 77º38′10″E) was selected for U–Pb zircon dating. Eleven gabbro cumulates and two dolerite samples were chosen for geochemical analyses.

2.2. The Bachu mafic dyke swarm

Mafic dykes around the Wajilitage complex intrude the upper Devonian sedimentary rocks with variable strikes (Figs. 1 and 2c). The local geological map (1:5000) shows that the dykes also intrude the

Fig. 2. (a) Simplified geological map of the Piqiang complex and the Halajun granite plutons (plutons I and II); (b) detailed geological map of part of the Piqiang complex showing the rock types of the complex; (c) detailed geological map of the mafic dyke swarm around the Wajilitage complex showing the broadly radiating distribution (based on the 1:5000 geological mapping by local geologists).