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Permian flood basalts from the Tarim Basin, Northwest China: SHRIMP zircon U–Pb dating and geochemical characteristics

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ABSTRACT

This study documents the Permian basalts from the Tarim large igneous province, northwest China. Detailed field work has led to recognition of eight basalt units (BU) in the Permian sequences exposed in the Keping area, northern Tarim Basin. These basalt units are interbedded with terrestrial clastics, and thus represent eight discrete eruptive episodes. The basalt sequence is divided into two major eruption cycles, with an earlier cycle comprising two BUs within the uppermost Kupukuziman Formation, separated by ~1000 m of clastic sediments from an upper eruptive cycle represented by a further six BUs in the upper part of the Kaipaizileike Formation. SHRIMP U–Pb zircon ages of 289.5 ± 2.0 Ma (MSWD = 2.2) for the lowermost BU1 and 288 ± 2.0 Ma (MSWD = 3.1) for the uppermost BU8 are statistically indistinguishable, and limit the duration of the entire eruptive phase to no more than 5.5 Ma. The Keping basalts exhibit OIB-like trace element patterns, enrichment of LILE and HFSE, high $(^{87}Sr/^{86}Sr)_i$ ratios and negative $\varepsilon Nd(t)$ values — all of which are consistent with the mantle plume derivation. The parental magmas for these basalts were extracted from spinel to garnet lherzolite by low-degree (less than 8%) partial melting. The magmas underwent pre-eruption fractional crystallization, but did not experience significant crustal contamination.

1. Introduction

The Permian successions of the Tarim Basin, northwest China, are characterized by numerous basalt flows (Chen et al., 1997a; Chen and Shi, 2003) that have recently been the subject of significant petrologic and geochemical investigations (Yang et al., 1996, 2005, 2006a, 2007b; Chen et al., 1997a; Jiang et al., 2006; Li et al., 2007, 2008; Tian et al., 2010).

These basalts are co-genetic with a wider suite of mafic-ultramafic and acidic intrusions across the Tarim region (Yang et al., 1996, 2006b, 2007a, 2007b; Jiang et al., 2004a, 2004b, 2005; Li et al., 2007), with Yang et al. (2006c) and Yu et al. (2009) suggesting that the overall Permian igneous assemblage should be classed as a Large Igneous Province, and noting a possible correlation with the Emeishan LIP in southwest China.

Large igneous provinces (LIPs) are increasingly recognized as having significant regional, and even global scales, biological impacts (e.g. Wignall, 2001; Lo et al., 2002; Reichow et al., 2009). The presence of a LIP in the Tarim Basin, and possibly extending across the entirety of western China has accordingly attracted the attention of many workers in recent years (e.g. Zhang et al., 2008a, 2008b; Li et al., 2008; Zhou et al., 2009; Tian et al., 2010). However, much of this work has been focused on the characterization of regional igneous outcrops related to the Tarim LIP, with the overall petrogenesis of the large igneous province not yet fully resolved (e.g. Zhang et al., 2008a, 2008b; Li et al., 2008; Zhou et al., 2009; Tian et al., 2010). Even the precise age of the eruptions is still in doubt, due to the debate over the veracities of the K–Ar and ^{40}Ar–^{39}Ar analyses that have been applied to date the basalts (Liu, 1991; Chen et al., 1997a, 1997b; Zhang et al., 2003; Yang et al., 2006a; Li et al., 2007, 2008) — preventing assessment of the relationships of the Tarim LIP to wider regional geology. With a view to resolving this ambiguity, we have undertaken petrological, geochronological and geochemical studies of the Permian basalts from the Tarim Basin. The onset and duration of the basaltic eruptions are resolved here through precise SHRIMP zircon U–Pb dating, and our new petrological, geochemical and isotopic constraints provide significant insight into the petrogenesis of the basalts including the degree of metasomatism and partial melting of the mantle source, and the fractional crystallization, crustal contamination and periodic replenishment experienced by the basaltic magmas prior to their eruption.

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2. Geological setting and basalt distribution

The Tarim Basin represents a superimposed basin with a complex evolutionary history (Jia, 1997; Zhang et al., 2009a). This basin, the largest in China, is situated in the southern part of Xinjiang Province, northwest China, surrounded by the Tienshan Mountains to the north, the Kunlun Mountains to the south and the Altyn Mountains to the southeast (Fig. 1). Before the Mesozoic, the Tarim Block was tectonically independent from the South China and North China blocks, and was situated to the north of the Tethys Ocean (Fang et al., 2006).

Large volumes of both mafic and felsic igneous rocks were emplaced in the Tarim block during the Permian. The mafic series consists mainly of basalt, diabase, andesitic basalt, and ultramafic rocks, while the felsic bodies are dominated by syenite, rhyolite, dacite, granodiorite, and pyroclastic rocks (Jia et al., 1995; Jia, 1997).

The Permian basalts crop out largely in the western part of the basin, with significant exposures found in the Xiahenan and Keping areas (Fig. 1). In the latter, the complete Permian basalt succession is exposed in the continuous Yingan, Kaipaizileike and Sishichang sections (Fig. 2).

Although less well exposed than their counterparts around Keping, Permian basalts in the Xiahenan area form spectacular geomorphic features parallel to stratigraphic beds (Fig. 1). Further minor exposures of Permian basalts are also recognized in the southwest Tarim, although these basalts are restricted to the Qipan and Damusi sections (Fig. 1), where they form 2–3 m thick beds in the upper part of the Qipan Formation (Chen and Shi, 2003; Li et al., 2008). In the central Tarim desert area, although not occurring in outcrop, further occurrences of Permian basalts are widely noted in boreholes (Fig. 1), and the overall distribution of these distinctive basalts in the Tarim Basin may extend across to 250,000 km^2 (Yang et al., 1996; Chen et al., 1997a, 1997b; Yang et al., 2005, 2007a, 2007b; Chen et al., 2006).

The Permian basalt successions are up to 500 m thick in the Yingan section of the Keping area (Fig. 2). Comparable thicknesses of 549 m are recognized in the subsurface record from borehole TZ-22 on the Tazhong Uplift, with 478 m and 443 m in boreholes He-4 and Shan-1 on the Bachu Uplift, and 372m, 442 m and 207 m found in boreholes YM-5 on the Tabei Uplift and boreholes MX-2 and HD-5 in the Manjaer Depression, respectively (Chen et al., 2006).

3. Studied sections and stratigraphy

As outlined earlier, the Permian basalts are widely distributed across the Tarim Basin (Fig. 1). We have selected the three most complete outcropping sections, at Yingan, Keping and Shishichang, to study the character of the successions (Figs. 2 and 3).

3.1. The Yingan section

Spectacular Permian successions are exposed in the Yingan section, which is located near Yingan village, about 45 km northeast of Keping, in southern Xinjiang (Fig. 2). Two pronounced basalt sequences stand out dramatically in a section dominated by pale siliciclastic sediments (Fig. 2) assigned to Kupukuziman (P_{2kk}) and Kaipaizileike (P_{2kp}) Formations respectively (Chen and Shi, 2003).

The Kupukuziman formation consists of alternating reddish mudstone and siltstone, interbedded with numerous conglomerate

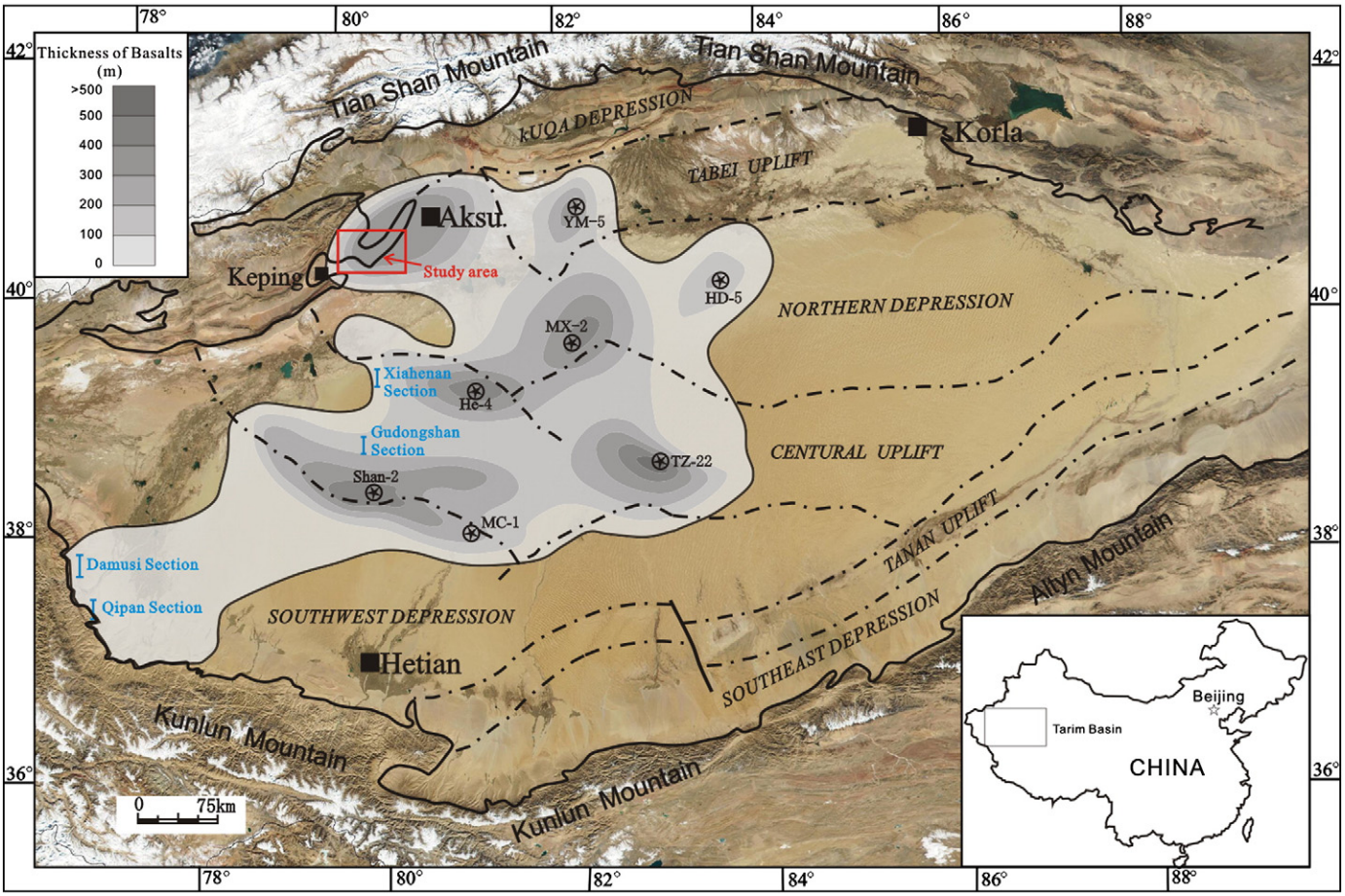

Fig. 1. General map of the Tarim Basin, southern Xinjiang Province, northwest China showing locations of the study sections and distributions of Permian basalts. Base map follows Yang et al. (2005) and Chen et al. (2006). Basalt isopach data are derived from both exposures and boreholes, and isopach contours are indicated by grayscale. The rectangle shows the locality of the studied area (see Fig. 2 for more details).