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Petrogenesis of the Early Permian volcanic rocks in the Chinese South Tianshan: Implications for crustal growth in the Central Asian Orogenic Belt

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ABSTRACT

The Paleozoic and Early Mesozoic magmatic suites in the Central Asian Orogenic Belt (CAOB) provide important insights on the crustal growth and reworking process associated with the construction of the largest Phanerozoic orogen on the Earth. Among the tectonic blocks of the CAOB, the South Tianshan Terrane (STT) occupies the southwestern margin and is located adjacent to the Tarim Craton. Here we investigate the Early Permian Xiaotikanlike Formation in the central part of the Chinese STT in Xinjiang in Northwest China. The formation is composed of a series of terrestrial volcanic lava flows and volcanic breccia, interbedded with siltstones, sandstones and sandy conglomerates. Zircon U–Pb and Lu–Hf isotopic analysis, whole-rock major oxide, trace element and Sr–Nd isotopic data are presented for the volcanic lava flows of the Xiaotikanlike Formation exposed in the Boziguo'er, Laohutai and Wensu regions. The new zircon ages from our study, together with those reported in previous investigations on the rhyolitic lava flow from the Wensu region, suggest that the volcanic rocks of the Xiaotikanlike Formation simultaneously erupted at ca. 285 Ma. The lavas of the formation show a wide range of SiO_2 (49.88 to 78.56 wt.%). The basaltic rocks show SiO_2 from 49.88 to 53.78 wt.%, MgO from 3.73 to 7.01 wt.% and Mg# from 41 to 61. They possess slightly enriched Sr–Nd isotope signature [$(^{87}Sr/^{86}Sr)_t = 0.70495$–$0.70624$ and $\varepsilon_{Nd}(t) = -0.5$ to $+0.6$], and have trace and rare earth element patterns similar to those of oceanic island basalts (OIBs). Petrographic and whole-rock chemical characteristics indicate that the basaltic lava flows are dominantly tholeiitic, and were likely derived from a spinel-dominated peridotite asthenospheric mantle source. The felsic lavas of the Xiaotikanlike Formation show SiO_2 in the range of 60.71 to 78.56 wt.% and display overall similar immobile element pattern characterized by notable troughs at Nb–Ta, P and Ti and gently sloping REEs. Zircon Lu–Hf analysis yields $\varepsilon_{Hf}(t)$ values of -8.7 to -0.3 for the felsic lavas from the Boziguo'er region. Geochemical and isotopic data suggest that the felsic lava flows were likely derived from an ancient crustal source(s). Our study suggests that the Xiaotikanlike volcanic lava flows erupted after the collision between the Tarim Craton and the Kazakhstan–Yili–Central Tianshan Terrane, and that the South Tianshan Terrane was not affected by Permian Tarim mantle plume activities. Furthermore, our data also suggest that the lithosphere under the eastern part of the STT at ~285 Ma had been considerably thinned, whereas the lithosphere under the western part of STT was still thick enough to allow the presence of a garnet-bearing source in the lower lithospheric mantle. Such distinction in the lithospheric thickness may be attributed to the oblique collisional tectonics. The widespread Late Paleozoic igneous rocks from the Western Tianshan were genetically associated with regional-scale post-collisional extension. These rocks provide robust evidence for net vertical continental growth at the final stage of evolution of the CAOB.

1. Introduction

The Central Asian Orogenic Belt (CAOB), sandwiched between the Siberian and Europe Cratons to the north and the Tarim and North China Cratons to the south, has been considered as a geological museum for largest Phanerozoic continental growth on earth. The crustal evolution in the CAOB has been one of the focal themes in the recent years (e.g., Wilhem et al., 2012; Windley et al., 2007; Xiao et al., 2013, 2014; Zhou and Wilde, 2013; Kröner et al., 2014; Xiao and Santosh, 2014, and references therein). Some authors (e.g., Jahn et al., 2000), estimate the proportion of juvenile crust that formed during the Phanerozoic as 70% or more. The Late Neoproterozoic and Paleozoic crustal growth in Central Asia is considered to have involved: 1) accretion of oceanic

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plateaus and islands together with magmatic underplating of mantle-derived materials and subduction of oceanic crust in island arc or/and active continental margin settings (Safonova and Santosh, 2014, and references therein), and 2) mass transfer from the upper mantle to the crust during post-collisional magmatism associated with orogenic collapse (Han et al., 1997; Long et al., 2011a, and references therein). Both mechanisms are related to the accretion-collision tectonics closely associated with the evolution of the Paleo-Asian domain followed by the collisions of several terranes.

However, based on the recent identification of Permian mantle plume activities in the neighboring regions (such as the Siberian Craton in the north as well as in the Tarim Craton in the south, see Zhou et al., 2009; Zhang et al., 2008a, 2010a; Zhang and Zou, 2013; Sobolev et al., 2011; Holt et al., 2012), some geologists suggest that crustal growth of the CAOB took place dominantly in anorogenic intraplate settings, unrelated to subduction and collision (e.g., Kröner et al., 2014). For instance, in a recent article reviewing Nd–Hf isotopic studies on magmatic rocks from several tectonic units of the CAOB, Kröner et al. (2014) argued that the production of the newly formed crust during the orogenic evolution has been "grossly overestimated". Alternatively, Kröner et al. (2014) suggest that much of the vertical juvenile growth in Central Asia, which was previously believed to be related to the post-collisional extension (see Long et al., 2011a, and references therein), occurred after the completion of the CAOB evolution, and perhaps was related to major plume activities. If it is the case, the significance of orogenic vertical crustal accretion in the CAOB, and perhaps even in some of the other orogenic belts in the world, needs to be re-evaluated.

The widespread Paleozoic and Early Mesozoic igneous rocks are directly related to the Phanerozoic crustal growth/reworking of the CAOB, and may serve as compositional and thermal probes of their sources and indicators of tectonic regimes (Jahn et al., 2000; Kröner et al., 2014; Long et al., 2011a; Seltmann et al., 2011). The majority of rocks in these suites are of Late Carboniferous to Permian age (Long et al., 2011a; Seltmann et al., 2011). Previous studies have shown that the Siberian plume activity had a peak at ~251 Ma, and that only the Latest Permian and Early Mesozoic magmatism in some parts of the CAOB may be related to a far-field effect of the Siberian plume (e.g., Holt et al., 2012; Sobolev et al., 2011). However, as revealed by geochronological results of kimberlitic intrusions, OIB-like mafic intrusions and basalts and A1-type syenites and granites exposed in the Tarim Craton (e.g., Zhou et al., 2009; Zhang et al., 2008a, 2010a; Zhang and Zou, 2013; Huang et al., 2012b; Zhang et al., 2013a, and references therein), the Permian Tarim large igneous province (Tarim LIP) has been widely proposed by many authors, and the Tarim plume-related magmatism is constrained as ~300 Ma to ~270 Ma, which significantly overlaps with the age span of the major phase of magmatism in the adjacent regions of the CAOB. Thus, the Late Carboniferous and Early Permian magmatic rocks in the CAOB, in particular those exposed in regions close to the Tarim Craton, are important in evaluating the genetic link to plume, anorogenic crustal growth or orogenic magmatism.

Among the tectonic terranes of the CAOB, the South Tianshan Terrane (STT) occupies the southwestern margin and is located immediately adjacent to the northern margin of Tarim Craton. If the non-subduction continental growth of the STT took place in a plume-related setting, the magmatic suites in this terrane, especially the mafic–ultramafic bodies, must bear isotopic and chemical features similar to those belonging to large igneous provinces (LIPs) generated by plume activities. The Early Permian Xiaotikanlike Formation exposed in the central part of the Chinese STT contains basaltic to rhyolitic volcanic rocks, and thus offer excellent proxies to test the influence of a plume activity, and its constraints on the spatial distribution of the Tarim LIP.

In this paper, we present new LA-ICP-MS U–Pb zircon ages, MC-ICP-MS zircon Hf isotopic data, bulk-rock major and trace element and Sr–Nd isotope results of representative samples collected from the Xiaotikanlike basaltic to rhyolitic lava flows. Based on the results, we discuss the nature of source composition, and the mechanisms of Late Paleozoic vertical crustal growth of the southwestern CAOB.

2. Geological outline of Chinese Southern Tianshan Terrane

As suggested in previous studies (e.g., Şengör and Natal'in, 1996; Sengör et al., 1993; Xiao et al., 2013), the CAOB can be subdivided into eastern and western parts. The western CAOB is composed of several tectonic terranes which have different origins and evolutionary histories and are presently preserved in Kazakhstan, Kyrgyzstan, Uzbekistan, Tajikistan, southern Russia, NW China (Northern Xinjiang), and southwestern Mongolia (Fig. 1a). The Northern Xinjiang is located in the southern segment of the western CAOB, and consists of, from north to south, the Chinese Altai, Junggar, Chinese Tianshan and northern margin of Tarim Craton (Fig. 1b). Among these, the Chinese Tianshan is traditionally subdivided into eastern and western parts broadly separated by Tuokexun–Kumishi High Road. Tectonically, the Western Tianshan comprises the North Tianshan Terrane (NTT), the Kazakhstan–Yili Block (KYB), the Central Tianshan Terrane (CTT), the South Tianshan Terrane (STT) and the northern margin of Tarim Craton.

The South Tianshan Terrane investigated in this study includes various rocks exposed in the ribbon region bounded by the Northern Tarim Fault to the south and the Southern-Central Tianshan Suture to the north. As shown in Fig. 1c, the STT consists of two segments divided by the Talas–Fergana diagonal dextral strike-slip fault, and the Chinese part of STT is mostly located in the eastern segment. The nature and origin of the STT remain debated. Some workers suggest that the STT dominantly represents an accretionary complex formed by the northward subduction of the South Tianshan Ocean, whereas others regard it as a Paleozoic passive margin of the Tarim Craton with minor accretionary components (Gao et al., 2011). In our understanding from the nature and overall distribution of the rock types in the region, the STT is a composite terrane composed of high/ultrahigh pressure metamorphic rocks, ophiolitic components, Early Paleozoic arc-type magmatic rocks, passive margin sequence from the Tarim Craton and the underlying Tarim basement.

Some HP/UHP metamorphic rocks have been identified within Paleozoic ophiolites/ophiolitic mélanges along the South-Central Tianshan Suture. These rocks include blueschist-, eclogite- and greenschist-facies meta-sedimentary rocks and some mafic metavolcanic rocks with N-MORB, E-MORB, OIB and arc basalt affinities (Gao et al., 1998, 2011; Zhang et al., 2013b). The HP/UHP metamorphism was likely associated with the subduction of the South Tianshan Ocean. Ophiolitic mélanges are randomly distributed in the STT and occur generally parallel to the strike of the STT. According to published dataset, the oldest age of mafic rocks in these mélanges are ~600 Ma, and majority of these possess Late Ordovician to Middle Devonian crystallization ages (see Jiang et al., 2014). In addition, Middle Devonian to Early Carboniferous microfossils, i.e., radiolarians and conodonts, are well-preserved within the sedimentary rocks of mélanges. The basement rocks of this terrane, which form part of the Tarim basement, are represented by Paleoproterozoic Xingditagh and Muzha'erte formations and Mesoproterozoic Akesu Formation, all exposed in the central part of the STT (Yang and Zhou, 2009). Paleozoic strata consist predominantly of Lower Cambrian black shales and phosphoric silicates, Cambrian–Carboniferous marine/non-marine carbonates, clastic rocks, cherts and interlayered volcanics (Allen et al., 1992; Jiang et al., 2014). Based on the assumption of a Late Paleozoic northward subduction model, Xiao et al. (2013) postulated that the late Paleozoic sequence should be a part of the accretionary complex initially accreted onto the Central Tianshan Terrane. As shown in Fig. 1c, Permian strata are generally sparse in the STT, and mainly occur in the middle section of the Chinese part of the STT.

The outcrops of igneous rocks, most of which are granitoids, comprise ~5% of the total area of the STT. As shown in Figs. 1c and d, the Paleozoic magmatism seems to have occurred mainly during the Late Silurian and Early Permian. Furthermore, available geochronological