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Petrogenesis and tectonic implications of Permian post-collisional granitoids in the Chinese southwestern Tianshan, NW China

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ABSTRACT

Permian porphyritic granite and leucogranite from the Kekesu and Muzhaerte Valleys in the southwestern (SW) Tianshan orogenic belt, NW China have been studied to decipher their petrogenesis and tectonic implications. For porphyritic granite in the Kekesu Valley, *in situ* LA-ICPMS zircon U–Pb dating yields crystallization ages of 295–291 Ma. The granite is a high potassic calc-alkaline, slightly peraluminous type, enriched in large ion lithosphere elements (LILE) and light rare earth elements (LREE), but depleted in high field strength elements (HFSE). Zircon Hf isotopic analysis (zircon $\varepsilon_{Hf}(t)$ of −5.8 to −0.2, two-stage Hf model ages of 1323–1680 Ma) and Ti-in-zircon thermometry, which yields crystallization temperatures of 744–749 °C, indicate the parent magma was likely formed by partial melting of a Mesoproterozoic crustal source. By contrast, leucogranite in the Kekesu valley yields crystallization ages of 274–267 Ma. It contains muscovite and garnet, has high silicon and potassium, and is strongly peraluminous. Multiple inherited zircon cores and low zircon crystallization temperatures (687–701 °C), combined with negative zircon $\varepsilon_{Hf}(t)$ values (−7.0 to −4.0), indicate its parent magma was sourced from supracrustal metasedimentary rocks by muscovite–breakdown partial melting. In the Muzhaerte Valley, porphyritic granite has similar major and trace elements characteristics to the Kekesu porphyritic granite. However, its higher zircon $\varepsilon_{Hf}(t)$ values (−0.9 to +3.8) and corresponding lower two-stage Hf model ages (1070–1367 Ma) indicate that the parent magma likely included an input from a more juvenile mantle source. Ti-in-zircon thermometry gives lower crystallization temperature of ~705 °C. The intrusive relationships between the Permian granitoids and Paleozoic arc plutons, and the LP-HT and (U)HP metamorphic belts, combined with geochronological studies, suggest that these Permian granitoids were generated in a post-collisional environment. It is suggested that the formation of the porphyritic granites in the Kekesu and Muzhaerte Valleys could be related to slab breakoff, while the leucogranite could be formed by hydrate-breakdown melting in an extensional tectonic regime in response to intra-continental adjustments after collision.

1. Introduction

The Central Asian Orogenic Belt (CAOB), bounded by the east European craton to the west, the Siberian craton to the north and the Tarim and the North China cratons to the south, is believed to be the largest Paleozoic accretionary orogenic belt in the world (Sengor et al., 1993). It's evolution involved amalgamation and suturing of island arcs, oceanic plateaus, seamounts, terranes and continental blocks (e.g. Sengor et al., 1993; Coleman, 1989; Kröner et al., 2007, 2012; Windley et al., 1990, 2007; Xiao et al., 2010; Xiao et al., 2008, 2013) between the Neoproterozoic and the late Paleozoic, and was largely completed by the late Carboniferous to Permian (e.g. Kröner et al., 2007; Han et al., 2011; Zhao et al., 2016). The long-lived evolution of the CAOB has resulted in considerable continental reworking as well as continental growth in the Phanerozoic (e.g. Sengor et al., 1993; Jahn et al., 2000; Windley et al., 2007; Xiao et al., 2010). Both syn-subduction lateral accretion of arc complexes and terranes (Sengor et al., 1993; Xiao et al., 2010), and/or post-collisional vertical accretion of underplated mantle material (Jahn et al., 2000; Wang et al., 2009; Long et al., 2011) have been proposed as mechanisms of continental growth in the CAOB. Therefore, exploring the petrogenesis of late Paleozoic post-collisional intrusions in the CAOB can contribute to understanding the late-stage orogenic evolution of the CAOB

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and the proportion of continental reworking to continental growth (e.g. Han et al., 2011 and references therein; Zhao et al., 2016).

The Chinese SW Tianshan, situated along the southernmost edge of the CAOB in western China, marks the final closure of the western part of the paleo-Asian ocean (Fig. 1a; Gao et al., 2009; Han et al., 2011). Corresponding to the age of amalgamation of the Tarim craton with the Yili and central Tianshan blocks, Permian granitic intrusions are commonly developed along the south Nalati Fault (also referred to as the south Tianshan suture zone, Fig. 1a and b; e.g. Konopelko et al., 2007, 2009; Wang et al., 2007; Gao et al., 2009; Han et al., 2011; Long et al., 2011; Gou et al., 2015; Ma et al., 2015). The granites are variably deformed and are interpreted as products of post-collisional magmatism. Ages of these intrusions are 300–260 Ma, commonly considered to represent one single thermal event in post-collisional tectonic settings (e.g. Han et al., 2011 and references therein; Ma et al., 2015; Gou et al., 2015). However, different crystallization ages and petrogenetic features among the granites could be related to different tectonothermal events in the collisional orogenic belt (Han et al., 2011).

In this study, we distinguish two periods of post-collisional magmatism in the SW Tianshan orogenic belt. We present new geochemical data, zircon U–Pb ages and Hf isotope data, and Ti-in-zircon thermometry to determine the petrogenesis of granite from each period as a contribution to understanding the late-stage tectonic evolution of the CAOB.

2. Geological background

The Chinese SW Tianshan is part of the Tianshan orogenic belt. From the late Neoproterozoic to the early Paleozoic, several blocks and terranes in the western paleo-Asian ocean amalgamated to form the paleo-Kazakhstan block, resulting in the Tianshan orogenic belt (Fig. 1a; Windley et al., 2007; Biske and Seltmann, 2010). The Tianshan orogenic belt in China was traditionally divided into the north Tianshan, the central Tianshan and the south Tianshan, with the Chinese SW Tianshan representing the western segment of the south Tianshan (e.g. Li et al., 1980; Zhang et al., 2007). The Yili block has been regarded as either part of the central Tianshan terrane (e.g. Gao et al., 2009), or to have an affinity with the Kazakhstan block, in which case it was not amalgamated with the central Tianshan until the late middle Silurian (e.g. Wang et al., 2010). Here we follow the division into four units such that the Yili block in the west is considered to be separate from the central Tianshan terrane in the north.

The closure of the south Tianshan paleocean and subsequent collision of the Tarim craton to the south and the Yili block to the north led to the emergence of the Chinese SW Tianshan orogenic belt. Five lithotectonic units can be identified in the SW Tianshan; from south to north, they are: the passive continental margin of the Tarim craton, the (ultra-) high pressure ((U)HP) metamorphic belt, the forearc sedimentary basin, the low pressure-high temperature (LP-HT) metamorphic belt and the unmetamorphosed strata of the southern Yili block (Fig. 1b; Xia et al., 2015).

The (U)HP metamorphic belt in the south and the LP-HT metamorphic belt in the north represent a paired metamorphic belt (Fig. 1b; Li and Zhang, 2004; Zhang et al., 2007; Xia et al., 2015). The (U)HP belt includes a large proportion of ultramafic rocks (serpentinite) but no granites. Lithologies in the (U)HP belt consist mainly of metafelsic-metapelitic rocks mixed with eclogite, blueschist and marble as blocks, lenses and/or interlayers forming a mélange that is inferred to have developed near the trench during subduction. Multiple dating techniques, including U–Pb on zircon, whole rock-mineral Sm–Nd and Lu–Hf isochrones, and Ar–Ar geochronology, have been applied to constrain the age of eclogite facies metamorphism and the subsequent exhumation. The age of the eclogite facies metamorphism is well constrained at 321–315 Ma (e.g. Su et al., 2010; Klemd et al., 2011; Yang et al., 2013) with exhumation in the interval 320–305 Ma (e.g. Klemd et al., 2005; Wang et al., 2010; Xia et al., 2015).

On the other hand, the LP-HT belt comprises mainly granite gneiss with minor metapelites; both lithologies have undergone partial melting. Geochronology has revealed at least two stages of high-grade metamorphism and partial melting in the LP-HT belt. The first occurred at ca. 400 Ma throughout the whole belt while the second occurred at ca. 290 Ma appears to be localized in the Muzhaerte Valley (Xia et al., 2014; Gou et al., 2015). Unlike the (U)HP metamorphic belt, the LP-HT belt, as well as the south margin of the Yili block, has been intruded by massive granitoids with either continental arc or post-collisional chemical signatures (Figs. 1b and 2). Devonian to Carboniferous arc-related volcanic rocks are also widespread in the LP-HT belt and in the southern Yili block.

3. Field relationships and sample description

3.1. Field relationships

In the Chinese SW Tianshan, a belt of porphyritic granites about 0.5–2.0 km in width, roughly parallel to the boundary of the (U)HP and the LP-HT belts (BGRXUAR, 1993), has been identified in the LP-HT belt in the Kekesu, Akeyazi and Muzhaerte Valleys (Figs. 1b and 2). Clear chilled margins and baked zones can be found at the contact between the porphyritic granites and host migmatite and granitic gneiss.

In the Kekesu Valley, the contact between the porphyritic granite and the LP belt is clear in the north, but obscure in the south due to strong deformation in the south Nalati shear zone. In the north, weakly-deformed porphyritic granite is characterized by large euhedral pink K-feldspar phenocrysts (2–4 cm in length) in a phaneritic groundmass (Fig. 3a). To the south, the phenocrysts gradually change into deformed and fractured K-feldspar augen (Fig. 3b), possibly due to the influence of the south Nalati shear zone. The augen of K-feldspar are surrounded by fine-grained ribbon quartz, granular two feldspars and tiny dark minerals (Fig. 3b), indicating solid-state recrystallization after the formation of the K-feldspar phenocrysts.

Also in the Kekesu Valley, weakly deformed leucogranitic bodies and dikes have been found intruding into migmatite, granitic gneiss and porphyritic granite (Fig. 3e and f). Xenoliths of migmatite and amphibole schist can be found locally in the leucogranite intrusions.

3.2. Sample description

Three samples of porphyritic granite and two samples of leucogranite were selected for whole-rock geochemistry, zircon U–Pb dating, zircon Hf isotopic analysis and Ti-in-zircon thermometry. Two samples of porphyritic granite were obtained from the intrusion in the Kekesu Valley, one from each of the weakly-deformed (Figs. 2 and 3a, TK118) and strongly-deformed (Fig. 3b, TK111) zones (TK111 was sampled about 50 m south of TK118), and one sampled from the intrusion in the Muzhaerte Valley (Figs. 1b and 3d, X02). For the leucogranite, sample TK233 was obtained from a dike about 80 cm in width and sample TK235 was acquired from an intrusive body in the Kekesu Valley (Fig. 3e and f).

The weakly deformed porphyritic granite (sample TK118) comprises a mineral assemblage of K-feldspar (55–60 vol.%) + quartz