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Sediment recycling and crustal growth in the Central Asian Orogenic Belt: Evidence from Sr–Nd–Hf isotopes and trace elements in granitoids of the Chinese Altay

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ABSTRACT

Felsic igneous rocks are common constituents of volcanic arcs, and contain valuable information about subduction-related magmatism. In this study we investigate nine granitoids with S-type volcanic arc affinity from the Chinese Altay, emplaced from 507 to 391 Ma in an active subduction zone during the early–middle Paleozoic. These granitoids are characterized by moderate to high SiO_2 contents (61.01–75.30 wt.%), moderate total alkalis ($Na_2O + K_2O$, 3.43–7.64 wt.%), and high Al_2O_3 contents (13.29–17.18 wt.%). Negative εNd(t) values (−6.1 to −1.0), the wide range of εHf(t) values (−7.0 to +9.0), and enrichment of LILEs such as Pb, Th and U, all suggest that the granitoids were probably derived from the partial melting of subducting oceanic sediments and the associated mantle wedge. This inference is further supported by the Nd-isotope data. The high initial $^{87}Sr/^{86}Sr$ ratios (0.703963–0.719428), low Ba/Th ratios (7.00–118.93), and uniformly negative εNd(t) values (−6.1 to −1.0) indicate that slab-derived aqueous fluids were vital in generating the initial magma of these granitoids, and assimilation played only a minor role. Our data demonstrate that residual zircon retains a substantial amount of Hf during the partial melting of oceanic sediments, therefore, Hf may not be an effective tracer for the input of recycled sediments. We conclude that sediment recycling played an important role in the generation of arc magmatism and the growth of the Central Asian Orogenic Belt (CAOB).

1. Introduction

During the subduction of oceanic crust, aqueous or hydrous fluids released from the hydrous minerals in the subducting slab are critical in generating arc magmas that contribute to the growth of new continental crust (Kushiro, 1969; Tatsumi and Eggins, 1995). Partial melting of oceanic sediments generates felsic magmas (Nicholls and Ringwood, 1972; Kay, 1980; Ishizuka et al., 2003) that intrude the overlying crustal material as granitoid plutons (Spandler and Pirard, 2013).

The effects of sedimentary recycling on elemental chemistry and isotopic systems are complex (Nebel et al., 2011). A large component derived from continental sediments results in more crust-like radiogenic isotope ratios in arc rocks (Marini et al., 2005; Barry et al., 2006; Todd et al., 2010; Sun et al., 2014; Conticelli et al., 2015; Malyshev et al., 2016). Hf is a high field strength element (HFSE), and is assumed to behave conservatively, due to its low solubility in aqueous fluids (Woodhead et al., 2001). As a result, it is expected to largely escape transportation to the mantle wedge during the dehydration of subducting sediment or crust. Experimental investigations (You et al., 1996; Kessel et al., 2005) and geochemical studies of arcs (Münker et al., 2004; Turner et al., 2009) suggest that Nd is also a relatively immobile element in aqueous fluids, compared to other elements such as Sr. Although only limited data are available on Hf isotopes in altered oceanic crust (AOC), recent case studies have shown that altered basalts are indistinguishable from unaltered mid-ocean ridge basalts (MORB) in terms of their Hf–Nd isotopic ratios (Chauvel et al., 2009; Safonova et al., 2011a, 2011b, 2012, 2016). This supports previous suggestions (White and Patchett, 1984) that hydrothermal alteration has little or no effect on these ratios (Staudigel et al., 1995) and, importantly, allows for the characterization of sedimentary recycling at island arcs (Handley et al., 2011).

The Central Asian Orogenic Belt (CAOB), the largest Phanerozoic accretionary orogen in the world, was developed by episodic accretions of island arcs, ophiolites, accretionary complexes, seamounts, and

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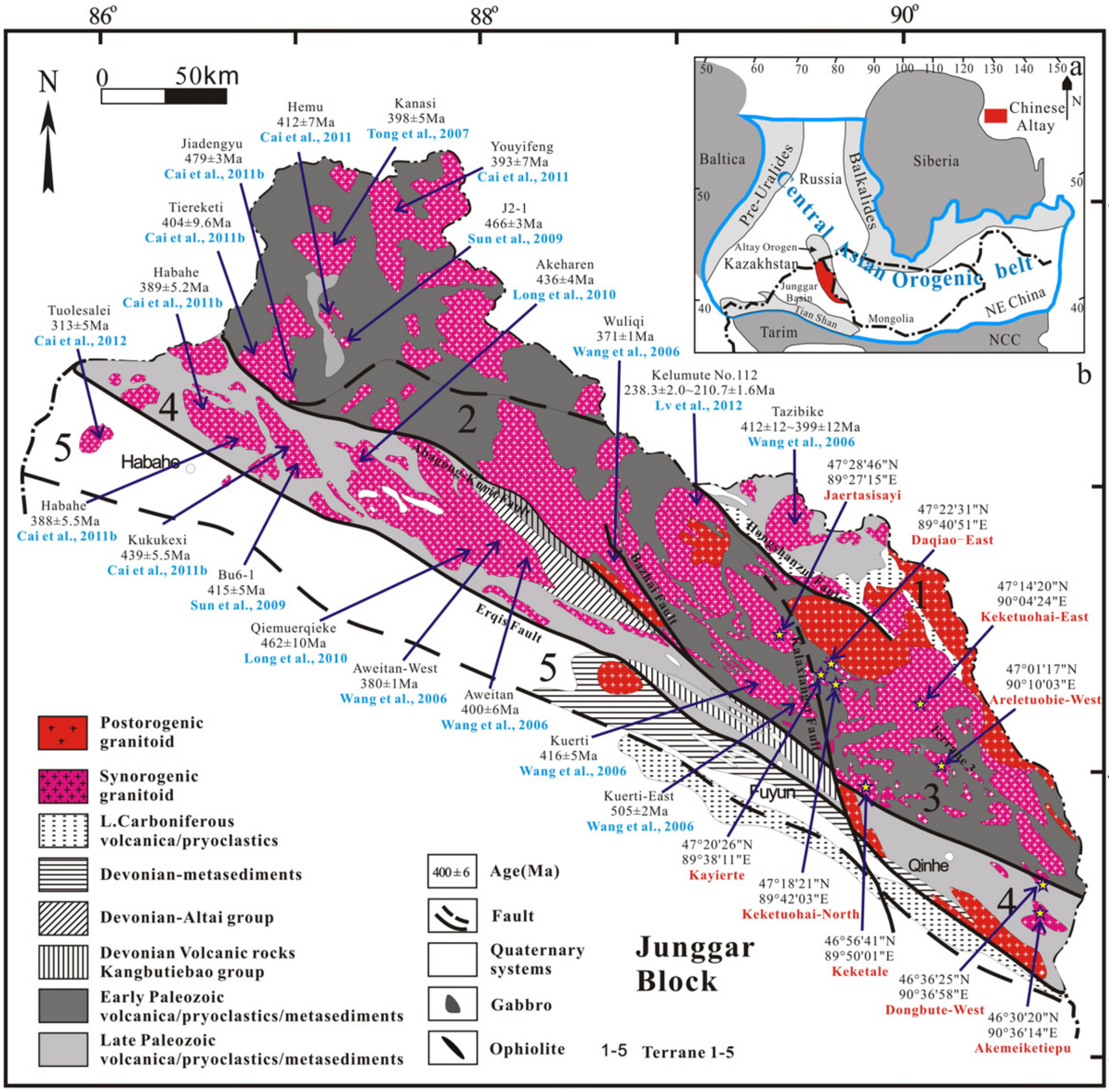

Fig. 1. (a) Location of Northern Xinjiang in the Central Asian orogenic belt (modified after Jahn et al., 2000), and (b) geological map of the Chinese Altay (modified after Xiao et al., 2009; Long et al., 2010; Cai et al., 2011a,b; Xiao and Santosh, 2014). Pt-O: Proterozoic-Ordovician gneiss-schists, S: Proterozoic-Silurian volcanics/pryoclastics, O: Proterozoic-Ordovician schists, Z-Є: Sinian-Camb. metasediment-volcanics, D: Proterozoic-Devonian schists.

micro-continental blocks during the Paleozoic (Fig. 1a; Sengör et al., 1993; Sengör and Natalin, 1996; Chen and Jahn, 2004; Xiao et al., 2009; Biske and Seltmann, 2010; Xiao et al., 2010; I. Safonova et al., 2011; Kröner et al., 2014; Safonova and Santosh, 2014; Xiao et al., 2014; Xiao and Santosh, 2014; Xiao et al., 2015). This orogenic belt represents a site of substantial Phanerozoic crustal growth, and it is believed that at least half of its expansion was due to the addition of mantle-derived juvenile material (Sengör et al., 1993; Jahn et al., 2000; Zhang et al., 2011; Cai et al., 2012; Zhang and Zou, 2013). However, the mechanisms of crustal growth in the CAOB are not well understood; Sengör et al. (1993) and Sengör and Natalin (1996) proposed that growth of the CAOB was due to the addition of arc complexes from the Early Cambrian (~540 Ma) through the Permian (~260 Ma). Numerous other studies have argued that the Phanerozoic granitoids of the CAOB, which are characterized by positive εNd values, were generated by extensive underplating of mantle-derived basaltic magmas in a post-orogenic or intra-plate extensional setting (Jahn et al., 2000; Wu et al., 2002; Zhou et al., 2008; Shen et al., 2011; Lv et al., 2012). More recently, Windley et al. (2007) suggested that the CAOB contains important features that are likely related to Paleozoic ridge subduction, and many local case studies support this model (Geng et al., 2009; Jian et al., 2008; Sun et al., 2008, 2009; Safonova et al., 2011a; Tang et al., 2012).

The Chinese Altay, in the southwestern part of the CAOB, is a key area for deciphering the tectonic evolution and crustal growth of the orogenic belt (Fig. 1b). Recent studies have suggested that the Chinese Altay comprises early Paleozoic subduction complexes from within the Paleo-Asian Ocean, and that it formed as an active continental margin during the middle Paleozoic after being accreted to the southern margin of the Siberia block (Yuan et al., 2007; Sun et al., 2008; Cai et al., 2011a,b), similarly to their counterparts in the Russian Altai (Safonova et al., 2008, 2011a; Safonova, 2014). Over 40% of the exposed rocks in the Chinese Altay are granitoids (Zou et al., 1989), and arc-related magmatism was almost continuous during the Paleozoic, reaching a peak in the Devonian (Wang et al., 2011; Cai et al., 2011a,b, 2012; Lv et al., 2012). Therefore, in addition to its role in comparative studies of subduction processes at modern island arcs (e.g., the Japanese arc, Buslov and Watanabe, 1996; Safonova, 2014), the Chinese Altay also serves as a natural laboratory for investigating ancient subduction.