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Early Permian slab breakoff in the Chinese Tianshan belt inferred from the post-collisional granitoids

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We present U–Pb–Hf isotopic and elemental data for granitoid intrusions formed during the early Permian in Eastern Tianshan (eastern part of Chinese Tianshan), with the aim of deciphering their magma sources and geodynamic evolution. These granitoids were formed at ca. 300–270 Ma and generally exhibit alkali-calcic to alkali compositions, and metaluminous and high-K calc-alkaline to shoshonitic characteristics. Commonly, steep REE patterns with significant enrichment of LREE relative to HREE showing $(La/Yb)_{CN}$ (4.4–43), distinctive negative Eu anomalies and depletion of Nb, Ta and Ti are noteworthy features of these granitoids, akin to the typical I-type granitoids implying an influx of mantle-derived magma. The tectonic setting of these granitoids in combination with the regional geology, suggests that the granitoids were generated in a post-collisional setting. The $\varepsilon_{Hf}(t)$ values from −10 to +14 (with four peaks at ca. −4, +5, +8.5 and +12) and T_{DM}^{C} model ages (with four populations at ca. 1500, 970, 720 and 500 Ma) imply that the reworking of early Mesoproterozoic ancient crust related to Columbia and Neoproterozoic crust associated with Rodinia along with the early Permian input of juvenile material were variably sourced during the generation of the magmas studied herein. During the post-collisional process, the slab breakoff played a key role in the genesis of the granitoids and involved the reworking of ancient crust and mantle-derived sources, consistent with the Hf isotopic compositions.

1. Introduction

The Central Asian Orogenic Belt (CAOB), consisting of the southern Manchuride and the northern Altaid tectonic domains (Sengör et al., 1993; Sengör and Natal'in, 1996), was formed by long-lived amalgamation of various arc complexes, continental slivers, seamount terranes, oceanic plateaus, accretionary wedges and ophiolites, that were scattered within the Paleo-Asian Ocean and are now sandwiched between the southern Tarim and North China blocks and the northern Siberia and European blocks (Fig. 1A and B; Coleman, 1989; Windley et al., 1990; Shu et al., 2000; Badarch et al., 2002; Shu et al., 2002; Khain et al., 2003; Shu et al., 2003; Charvet et al., 2007; Kröner et al., 2007; Windley et al., 2007; Kröner et al., 2008; Xiao et al., 2010; Zheng et al., 2010; Zhu et al., 2010; Charvet et al., 2011; Glorie et al., 2011; Zhu et al., 2011; He et al., 2012; Kröner et al., 2012; Wilhem et al., 2012; Xiao et al., 2013). In the Paleozoic, closure of the Paleo-Asian Ocean led to the final suture of the Manchuride and Altaid domains (Sengör et al., 1993). The collisional phase of CAOB assembly was largely complete by the late Carboniferous to Early Permian.

As the southernmost part of the CAOB, the Chinese Tianshan belt is a pivotal component in deciphering the tectonic evolutionary history of the CAOB (Fig. 1B and C; Charvet et al., 2001, 2004, 2007). In an effort to better understand the development of the CAOB, numerous studies were undertaken in the past three decades (Li, 1981; Windley et al., 1990; Gao et al., 1998; Shu et al., 1998, 1999, 2001; Laurent-Charvet et al., 2002, 2003; Xiao et al., 2004; Li, 2006; Sun et al., 2008; Xiao et al., 2008; Gao et al., 2009; Lin et al., 2009; Xiao et al., 2009; Han et al., 2010; Shu et al., 2010; Charvet et al., 2011; Chen et al., 2011; Gao et al., 2011; Han et al., 2011; Wang et al., 2011a,b; Ge et al., 2012; Ma et al., 2012a,b; Wilhem et al., 2012; Lin et al., 2013; Ma et al., 2013; Xiao et al., 2013). Those studies noted that voluminous active-arc granitoids are located in the Chinese Tianshan belt and were related to the southward subduction of the Paleo-Asian Ocean in the early Paleozoic (Han et al., 2004a; Zhu and Song, 2006; Hu et al., 2007; Huang et al., 2012; Ma et al., 2012c). In spite of the numerous studies, the actual timing of final closure of the Paleo-Asian Ocean is still under considerable debate.

In the Chinese Tianshan belt, there are voluminous outcrops of late Carboniferous to early Permian post-collisional rocks. Most of the intrusive activity took place between 300 and 270 Ma and includes ultramafic intrusions, mafic dyke swarms, K-feldspar granites, alkaline granites and bimodal volcanic rocks, that are thought to mark the early stages of post-collisional tectonism (Gu et al., 1999; Li et al., 2003; Han et al., 2004b; Gu et al., 2006; J.Y. Li et al., 2006; Chen and Shu, 2010; Chen et al., 2011). Previous studies aimed at deciphering the petrogenetic setting of region (Gu et al., 1999; Shu et al., 2005; Gu et al., 2006; H.Q. Li et al., 2006; Z.X. Zhu et al., 2008; Shu et al., 2010) argued for a late-stage

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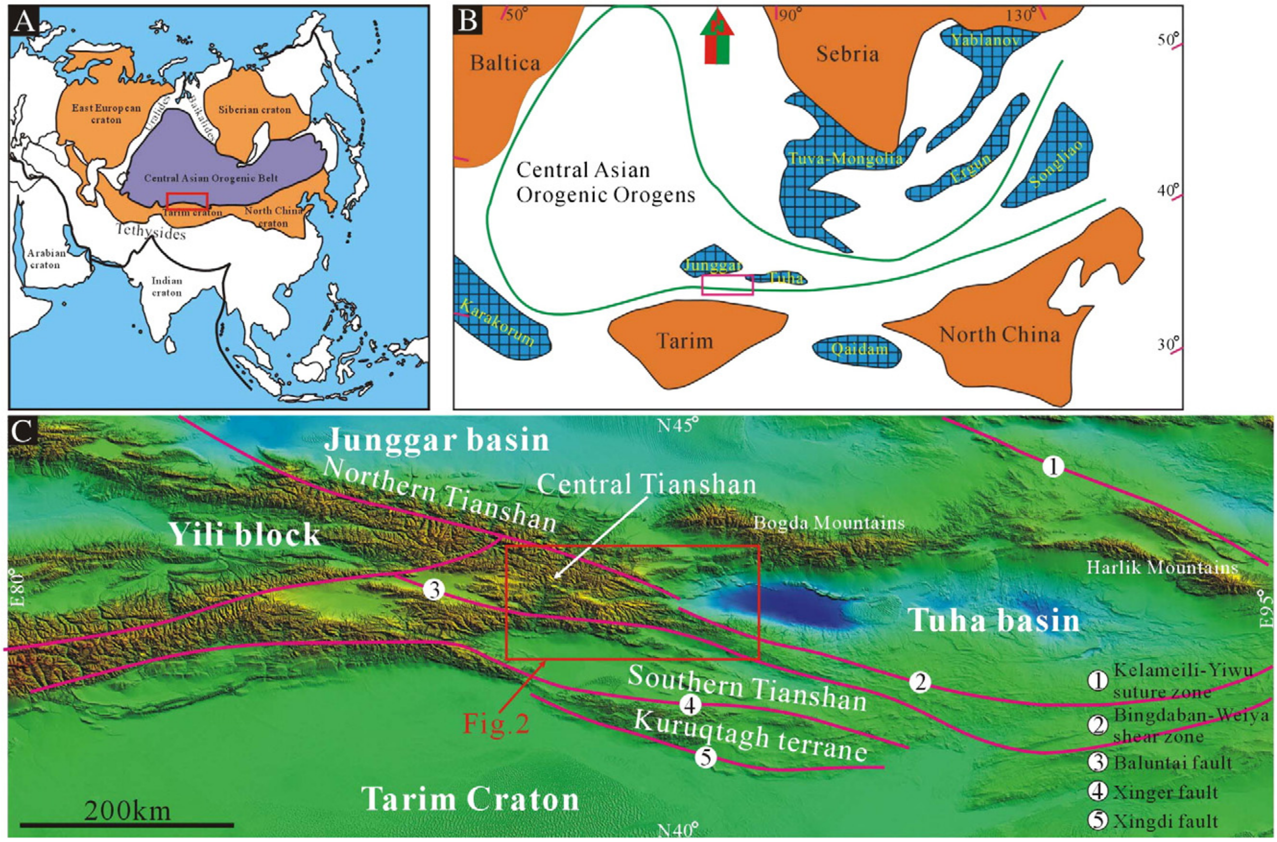

Fig. 1. (A) Tectonic outline of the Central Asian Orogenic Belt. (B) Tectonic sketch map showing the location of study area. (C) Simplified tectonic framework of the Chinese Tianshan. Panel a is after Xiao et al. (2010). Panel b is modified from Zhou et al. (2009).

emplacement with some differences in timing. One model posited that these rocks were formed during the transition from compression to extension (Gu et al., 1999, 2006; Q.G. Li et al., 2008; C.S. Wang et al., 2009a), whereas other workers suggested that these rocks were entirely post-collisional (Shu et al., 2005; Wu et al., 2005; Shu et al., 2010; Chen et al., 2011; G. Huang et al., 2011; H. Huang et al., 2011). In addition, numerous geodynamic models were proposed for the formation of the granitoid rocks in the Chinese Tianshan belt. These include generation via a Late Carboniferous–Early Permian mantle plume beneath the CAOB (Zhou et al., 2004; Mao et al., 2008), ridge subduction (Windley et al., 2007) or slab breakoff (Shu et al., 2010; Yuan et al., 2010; Chen et al., 2011; Gou et al., 2012). These debates have hindered our understanding on the tectonic evolution of the Chinese Tianshan belt and the CAOB. In an effort to resolve these issues, we carried out detailed geochemical analyses of the relevant rocks in the Central Tianshan region.

Granitoid rocks document key stages of the tectonic evolution of the Earth's crust (Chappell and White, 1974, 1983; Bonin et al., 1998; Chappell and White, 2001; Frost et al., 2001; Bonin, 2004; Wu et al., 2007). Granitoids and other rocks from the Chinese Tianshan region related to post-collisional tectonism are listed in Table 1. Most of the studied granitoids listed in this table are from three regions including Northern Tianshan, eastern part of Eastern Tianshan and the Beishan region. Relatively few studies have been conducted from the Southern Tianshan and the westernmost segments of Eastern Tianshan. Investigations focused on these understudied regions are vital to provide a complete understanding of the accretionary history of the Chinese Tianshan and the CAOB.

Within the context of developing a more cohesive model for the Chinese Tianshan, this contribution provides geochronological, geochemical and Hf isotopic data of the early Permian granitoids from the Central Tianshan subregion of the Eastern Tianshan (Fig. 2), and centers on the remarkable post-collisional geological features. Based on previous work, combined with our new data and findings, we provide a comprehensive geodynamic evolutionary history of granitoid emplacement in this critical segment of the Chinese Tianshan belt.

2. Geological background

2.1. Tectonic framework

The Central Asian Orogenic Belt (CAOB) or Altaids in Central Asia (Fig. 1A; Sengör et al., 1993) is one of the longest and largest accretionary orogens worldwide (Wilhem et al., 2012). The CAOB extends from the Urals to the Pacific and from the Baltica and Siberian cratons to the Tarim and North China cratons (Windley et al., 2007). The CAOB is interpreted to be a result of the progressive accretion of different elements to the southern margin of Eurasia. Within the CAOB, the Tianshan belt forms the southern margin (Sengör et al., 1993; Jahn et al., 2000; Charvet et al., 2007; Windley et al., 2007). The E–W-trending Tianshan belt in Central Asia connects the Tarim block to the south with the Siberian block to the north. This complex orogenic system thus plays a critical role in the evolution of the CAOB (Shu et al., 2002, 2003).

At the northern boundary of the Tarim tectonic domain, the Kelamaili–Yiwu ophiolitic mélange zone marks a late Paleozoic suture between southern Tarim and northern Siberia. Within the mélange, distinctive Gondwana fauna are associated with the Tarim block (thought to be peri-Gondwana; Filippova et al., 2001; Kheraskova et al., 2003; Wilhem et al., 2012) along with distinctive Siberian fauna and elements of the intervening ocean. Specifically, there are (1) numerous Alpine-type ultramafic and N-MORB type tholeiitic terranes (Shu et al., 2000); (2) southern Gondwana-type *Agnostus*-bearing Cambrian–Ordovician limestones, *Sinoceras*-bearing Ordovician mudstones and *Graptolite*-