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Tectonic transition from Late Carboniferous subduction to Early Permian post-collisional extension in the Eastern Tianshan, NW China: Insights from geochronology and geochemistry of mafic–intermediate intrusions

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ABSTRACT

The closure of the Junggar Ocean between the Central Tianshan and Junggar terranes is essential in understanding the final assembly of the southern Central Asian Orogenic Belt. This study presents new whole-rock geochemical, Sr–Nd and zircon U–Pb–Hf isotopic data for mafic–intermediate intrusions from the Central Tianshan block to provide robust constraints on the final closure of the ocean. LA-ICP-MS U–Pb dating on magmatic-type zircons yields weighted mean $^{206}Pb/^{238}U$ ages of ca. 310 Ma and ca. 290 Ma, which are interpreted as the crystallization ages of the intrusions. Petrographic and geochemical analyses of the Late Carboniferous mafic–intermediate rocks, characterized by typical subduction-related signatures, low Sm/Yb (<2.0) but high Lu/Hf (≥0.2) ratios and positive $\varepsilon_{Nd}(t)$ (+1.2 to +3.1) and zircon $\varepsilon_{Hf}(t)$ (+4.1 to +7.8) values, suggest that their parental magmas were most likely generated by the partial melting of a metasomatized lithospheric mantle wedge in the spinel stability field and emplaced in a continental arc setting. This consideration is consistent with the occurrence of Carboniferous ophiolitic and arc-related granitoids in the region, probably as a result of the southward subduction of the Junggar oceanic plate. In contrast, the Early Permian mafic magmatism exhibits typical within-plate basalt affinities, such as high TiO_2 (2.7–3.2 wt.%) contents, elevated Ti/V (86.0–115.1) and Zr/Y (4.9–9.3) ratios, OIB-like trace element patterns and high $\varepsilon_{Nd}(t)$ (+1.1 to +4.5) and zircon $\varepsilon_{Hf}(t)$ (+3.0 to +9.8) values. In association with previous investigations, we suggest that their protoliths were most probably derived from the partial melting of an asthenospheric mantle source in the garnet stability field, plausibly induced by asthenosphere upwelling during the slab break-off of the Junggar oceanic plate, which agrees well with the linear distributions of Permian mafic–ultramafic rocks in the Eastern Tianshan. Collectively, our data pinpoint a tectonic transition from oceanic subduction to post-collisional extension during Late Carboniferous to Early Permian time, probably triggered by the closure of the Junggar Ocean and subsequent arc–continent collision between the Central Tianshan and Junggar terranes that gave rise to the final assembly of the Eastern Tianshan.

1. Introduction

The Central Asian Orogenic Belt (CAOB), lying between Europe–Siberia and Tarim–North China (Fig. 1a), experienced long-lived evolution involving multiple accretion of continents, microcontinents, seamounts, arc systems and accretionary complexes within the Paleo-Asian Ocean (Eizenhöfer et al., 2014, 2015a, 2015b; Jahn et al., 2000, 2006; Windley et al., 2007; Xiao et al., 2012, 2015; Zhu et al., 2015, 2016). The Junggar Ocean, bounded by the Central Tianshan and Yili blocks to the south (present coordinates) and the Junggar terranes (East and West Junggar and Junggar Basin) to the north (Fig. 1b), represents a pivotal southern segment of the Paleo-Asian Ocean, making its subduction and closure crucial to the understanding of the accretionary and collisional processes of the southern CAOB (Windley et al., 1990; Xiao et al., 2012, 2015). However, the timing of its closure is still hotly debated, with suggestions ranging from the Early Carboniferous (Gao et al., 1998), through the Late Carboniferous–Early Permian (Charvet et al., 2007, 2011; Chen et al., 2011; Zhang et al., 2015a, 2015b, 2016a), to the Permian–Triassic (Xiao et al., 2009), leading to various competing models proposed for the Paleozoic evolution of the Eastern Tianshan (an important component of the southern CAOB).

Late Paleozoic ultramafic–mafic–intermediate intrusions occur throughout the Eastern Tianshan, geochemical and isotopic studies of which can provide solid constraints on the nature of their mantle sources and melting conditions that can be used as promising indicators

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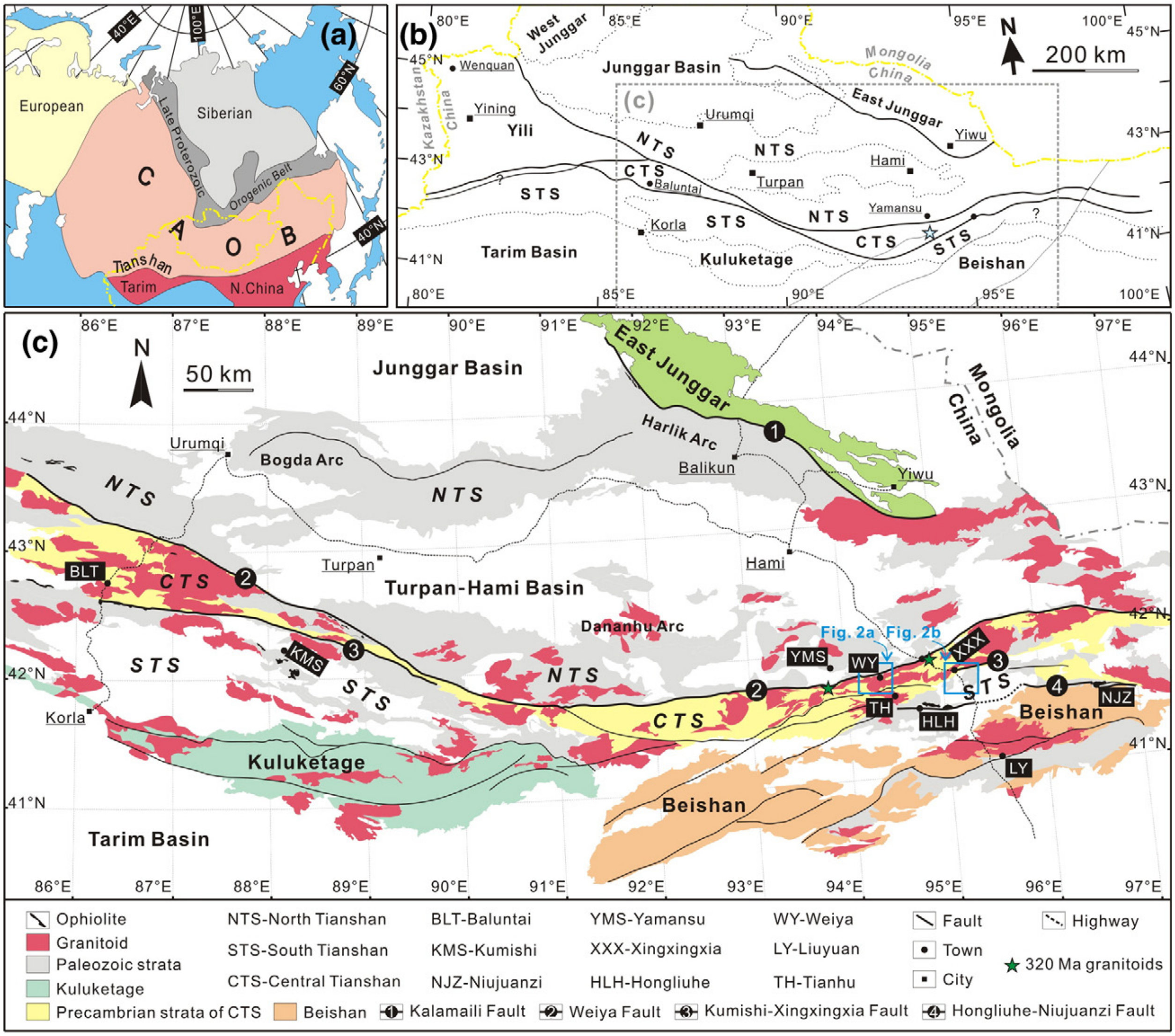

Fig. 1. Simplified geological maps of (a) Central Asian Orogenic Belt (modified after Klemd et al., 2011), (b) Chinese Tianshan and (c) Eastern Tianshan. The ca. 320 Ma granitoids are from Zhang et al. (2015b).

of tectonic regimes (Klein and Langmuir, 1987; Niu and O'Hara, 2008; Pearce and Cann, 1973; Wilson, 1989; Winchester and Floyd, 1977). In this study we carried out whole-rock geochemical, Sr–Nd and zircon U–Pb–Hf isotopic analyses on mafic–intermediate intrusions from the Central Tianshan block in order to provide new insights into the closure of the Junggar Ocean and final assembly of the Eastern Tianshan.

2. Geological background

Situated between the Tarim block to the south and the Junggar terranes to the north, the Chinese Tianshan Orogenic Belt (Fig. 1a, b) represents an essential component of the southern CAOB (Allen et al., 1993; Charvet et al., 2007, 2011; Gao et al., 1998; Windley et al., 1990; Xiao et al., 2012). This orogenic belt is geographically divided into the western and eastern segments roughly along 86°E longitude (Fig. 1b, c), which underwent remarkably different evolution during Paleozoic time (Gao et al., 1998; Han et al., 2015, 2016a, 2016b; W.J. Xiao et al., 2004). This study mainly focuses on the Eastern Tianshan, whose major geological features are briefly summarized as follows.

The Eastern Tianshan is separated from the East Junggar by the Kalamaili fault (fault 1 in Fig. 1c) and from the Beishan block by the Hongliuhe–Niujuanzi fault (fault 4 in Fig. 1c). Tectonically, it can be subdivided into the North (NTS), Central (CTS) and South Tianshan (STS), separated from each other by major strike-slip faults (e.g., faults 2 and 3 in Fig. 1c) (Charvet et al., 2007, 2011; W.J. Xiao et al., 2004). The tectonic framework of the Eastern Tianshan was primarily influenced by the development of two sub-oceans of the Paleo-Asian Ocean, namely (a) the Junggar Ocean between the CTS and Junggar terranes and (b) the South Tianshan Ocean between the CTS and Tarim blocks (Ma et al., 1997; Windley et al., 1990; W.J. Xiao et al., 2004).

The NTS accretionary belt is composed dominantly of a series of Devonian–Carboniferous island arcs (e.g., Bogda, Dananhu, Yamansu) and Carboniferous–Jurassic imbricated strata, genetically controlled by the subduction and closure of the Junggar Ocean (e.g., Han et al., 2010; Ma et al., 1997). Ophiolitic mélanges, including 494 ± 10 Ma supra-subduction-zone-type gabbros (Li et al., 2008) and 324.8 ± 7.1 Ma plagiogranites (Xu et al., 2006), testify to a prolonged (Early Paleozoic to Carboniferous) evolution of the Junggar Ocean. A primarily southward subduction of the Junggar Ocean beneath the Chinese Tianshan has been substantiated by not only detailed kinematic investigations in the region (Charvet et al., 2007, 2011; Laurent-Charvet et al., 2002; Shu et al., 1999, 2002) but also the findings of Late Ordovician (ca. 450 Ma) thickened lower curst-derived adakitic rocks (Zhang et al., 2016b), high-pressure basic-intermediate granulites (Shu et al., 2004) and Early Paleozoic to Late Carboniferous subduction-related magmatic rocks (e.g., Ma et al., 2014, Shi et al., 2014, Zhang et al., 2015b) along the