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Late Ordovician to early Devonian adakites and Nb-enriched basalts in the Liuyuan area, Beishan, NW China: Implications for early Paleozoic slab-melting and crustal growth in the southern Altaids

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ABSTRACT

We report newly-defined Nb-enriched basalts, adakites and dacites from the Beishan, NW China of the southern Altaids based on field, geochemical, isotopic and geochronology studies. Two phases of adakites (adakite-I and adakite-II) have been defined, which are calc-alkaline, and characterized by high Na_2O/K_2O ratios (1.49–1.71 and 2.32–3.64) and Sr contents (494–1213 ppm and 325–494 ppm), negligible to positive Eu anomalies, strong depletion of HREE (e.g., Yb = 0.48–0.93 ppm and 0.50–0.99 ppm) and Y (6.87–9.80 ppm and 6.02–10.30 ppm), and enriched in Rb, Sr, Ba, K and depleted Nb and Ti. They are characterized by relatively low $\varepsilon_{Nd}(t)$ values (−0.8 to −0.9 and +0.6 to +3.8) and relatively constant high $(^{87}Sr/^{86}Sr)_i$ ratios (0.70635–0.70636 and 0.70583–0.70651). The zircons of adakite-I have relatively low $\varepsilon_{Hf}(t)$(−0.8 to +2.7). The Nb-enriched basalts are sodium-rich (N_2O/K_2O = 1.31–4.44), with higher TiO_2, P_2O_5, Zr and Nb contents and $(Nb/Th)_{PM}$, $(Nb/La)_{PM}$ and Nb/U ratios than typical arc basalts. They are relatively enriched in Rb, Ba, U, Pb and K, depleted in Nb, and minor negative to positive Ba, Zr, Sr and Ti. They have low positive $\varepsilon_{Nd}(t)$ (+0.9 to +2.3) and relatively high $(^{87}Sr/^{86}Sr)_i$ (0.70556–0.70691) ratios. The dacites are typical arc magmas, with moderately enriched LILE, distinctly negative Eu, Nb, Sr and Ti anomalies. They have positive $\varepsilon_{Nd}(t)$ (+2.2) and relatively high $(^{87}Sr/^{86}Sr)_i$ (0.70786). We argue that the Liuyuan adakites were most probably related to the melting of young/hot subducted crust of the Paleo-Asian Ocean, which included tectonically-subducted radiogenic crustal material and/or inheritance from highly radiogenic oceanic crust (e.g. OIB). The Nb-enriched basalts likely resulted from mantle wedge peridotites metasomatized by adakites and/or further changed by components other than adakites (e.g., minor slab-derived fluids). Based on own zircon SIMS U–Pb dating of these key rock types, we further propose that from the late Ordovician to early Devonian, large volumes of magma consisting of late Ordovician Nb-enriched basalts (451 Ma) and dacites (442 Ma), late Silurian adakite-I (424 Ma), early Devonian adakite-II (374 Ma) and I-S-A-type granites (436 Ma–380 Ma), developed in the southern Altaids. Together with other geochronological data from the literature, we conclude that subducted oceanic slab-melting was frequent from 470 Ma to 370 Ma. Our results suggest that frequent hot (and/or young) oceanic crustal subduction and slab-melting were important mechanisms in the accretionary growth of the Southern Altaids.

1. Introduction

The Altaids or Central Asian Orogenic Belt, situated between the Siberian, North China, Tarim and East European cratons, represents one of the most important sites of juvenile crustal growth in the Phanerozoic (Fig. 1a). After decades of studies, there is general consensus that the Altaids formed by successive lateral accretion of arcs, accretionary complexes and a few continental blocks (Coleman, 1989; Şengör et al., 1993; Dobretsov et al., 1995; Şengör and Natal'in, 1996; Gao et al., 1998; Buchan et al., 2002; Bazhenov et al., 2003; Xiao et al., 2003; Li, 2004; Xiao et al., 2004a,b; Li et al., 2006; Windley et al., 2007; Xiao et al., 2008; Shi et al., 2010; Rojas-Agramonte et al., 2011; Wainwright et al., 2011). The major vertical crustal growth was accompanied by emplacement of immense volumes of magmas in lateral accretionary, post-collision and/or intraplate extensional settings during the late Paleozoic and early Mesozoic (Han et al., 1997, 1998; Chen et al., 2000; Jahn et al., 2000; Wu et al., 2000; Han et al., 2004; Jahn et al., 2004; Chen et al., 2006; Wu et al., 2006; Windley et al., 2007; Yuan et al., 2007).

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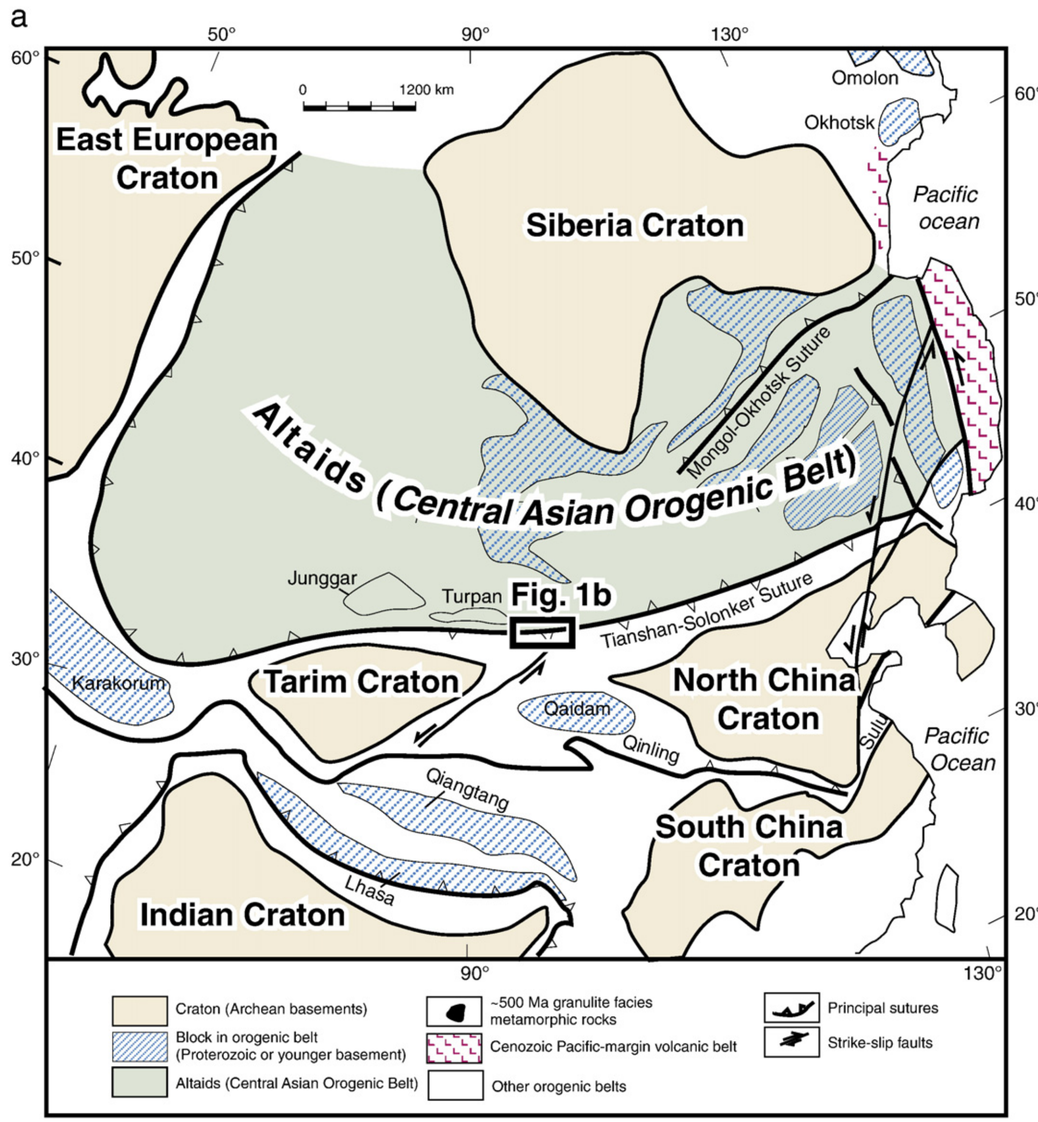

Fig. 1. (a) Schematic tectonic map of Central Asia and adjacent areas (modified after Şengör et al., 1993; Xiao et al., 2003; Zhou et al., 2009, 2010, 2011). (b) Schematic tectonic map of the Beishan mountains and adjacent areas (based on our observations and modified after Zuo et al., 1990; Liu and Wang, 1995; Ma et al., 1997; Nie et al., 2002b; W.J. Xiao et al., 2004a,b).

The mechanisms of the crustal growth remain an important international geological problem. Many geologists argue that oceanic crust subduction led to major crustal growth in the high thermal gradients in the Archean. Adakites, also formed in a high thermal gradient setting, have been interpreted as a means of crustal growth in the Phanerozoic (Defant and Drummond, 1990; Martin, 1999). Adakites, accompanied by Nb-enriched basalts and large volume magmas, generated by hot and/or young oceanic crust subduction in the late Paleozoic, contributed to the major crustal growth in the Altaids (Zhang et al., 2004; Zhang et al., 2004; Zhao et al., 2004; Xiong et al., 2005b; Zhang et al., 2006; Zhao et al., 2006; Wang et al., 2007; Windley et al., 2007).

The Beishan area is located in the middle of the Tianshan–Solonker suture of the southern Altaids, and thus is a key area for unraveling the accretionary processes and continental growth of the Altaids. In this paper we describe new discoveries of early Paleozoic adakites, Nb-enriched basalts (NEBs) and coeval dacites from the Liuyuan area, Beishan (NW China), southern Altaids. We present detailed field, geochronological and geochemical data for an early Paleozoic arc and its growth. We further discuss the continental crustal growth mechanism of partial melting of subducted oceanic crust in Central Asia during the early Paleozoic.

2. Geological setting

The Tianshan–Solonker suture located along the southern margin of the Altaids (Fig. 1a) is the final suture zone of the Altaids or Central Asian Orogenic Belt. Following the collision of the Tarim and North China blocks with the active margin of the Siberian craton, the Paleo-Asian Ocean closed and formed the Tianshan–Solonker suture zone (Fig. 1a) (Coleman, 1989; Windley et al., 1990; Shi et al., 1994; Ma et al., 1997; Gao et al., 1998; Xiao et al., 2004a,b; Windley et al., 2007; Xiao et al., 2008, 2010c). The Beishan orogenic collages are in a key tectonic position, connecting the eastern Tianshan suture to the west with the Solonker suture to the east (Fig. 1a and b).

The tectonic architecture of the Beishan collages is characterized by several blocks/arcs separated by several ophiolitic belts, which are regarded as suture zones (Zuo et al., 1990, 1991; Liu and Wang, 1995; Nie et al., 2002b; Xiao et al., 2010a). These ophiolitic belts include the Hongshishan, Xingxingxia, Hongliuhe and Liuyuan belts that occur along large-scale faults named after these ophiolitic belts, respectively (Fig. 1b). A detailed description of these faults and terranes can be found in related references (Zuo et al., 1990, 1991; Liu and Wang, 1995; Nie et al., 2002b; Gong et al., 2003; Zuo et al., 2003; He et al., 2005; Xiao et al., 2010a). Here, we mainly introduce the regional