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Devonian Alaskan-type ultramafic–mafic intrusions and silicic igneous rocks along the southern Altai orogen: Implications on the Phanerozoic continental growth of the Altai orogen of the Central Asian Orogenic Belt

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ABSTRACT

In this contribution, we have carried out an integrated study of the petrography, geochronology, geochemistry and mineral chemistry for the Devonian Alaskan-type ultramafic–mafic complexes and granitoids widely distributed along the southern Altai orogen, in order to provide a better understanding of the continental growth process and the regional tectonic evolution. LA-ICPMS zircon U–Pb dating of three mafic samples, one acidic volcanic rock sample and one granitic sample yielded the concordia ages of ca. 400 Ma. Olivine chemical compositions indicate these mafic intrusions crystallized from evolved mafic magmas and compositions of the clinopyroxene and hornblende show typical arc affinities. Whole-rock compositions reveal their tholeiitic signature with enriched LREEs and LILEs and intensive depleted HFSEs (Nb, Ta, Zr and Hf), leading to low HFSE/LREE ratios (Nb/La = 0.1–0.4). Isotopically, these mafic intrusions have positive zircon $\varepsilon_{Hf}(t)$ (+7.6 to +14.3, mostly +10) and positive whole-rock $\varepsilon_{Nd}(t)$ (+0.8 to +5.3) values, which suggest that their parental magmas were derived from a time-integrated depleted mantle source. These features, together with the presence of primary water-bearing minerals (biotite and/or hornblende), suggest that their primitive magmas were derived from a time-integrated depleted lithosphere mantle which were metasomatized by fluids released from subduction slab. These findings, in combination with coeval voluminous granitoids and arc-signature volcanic rocks, indicate that the underplating of mafic magmas at the continental arc root leads to the partial melting of the continental crust. It is inferred that mafic magmatic underplating in the Altai orogenic belt significantly contributed to the Phanerozoic vertical continental crust growth in the Altai orogen.

1. Introduction

The Chinese Altai orogen is one of key parts of the Central Asian Orogenic Belt (CAOB), the largest Phanerozoic accretionary orogen in the world (Jahn et al., 2000a, b, 2004b; Şengör and Natalin, 1996; Şengör et al., 1993; Xiao et al., 2009a) (Fig. 1a). Recent studies show the Altai belt is composed of a complicated collage of various terranes, including ophiolites, accretionary prisms and possibly some microcontinents (Windley et al., 2007; Xiao et al., 2004, 2008, 2009a, 2010). Although many studies have been carried out in this orogenic belt, the tectonic settings and continental growth of the Altai orogen are still hotly debated (Briggs et al., 2007, 2009; Cai et al., 2011a; Cunningham, 2005; Hu et al., 2000; Xiao et al., 2004, 2008, 2009a; Xiao and Santosh, 2014).

Voluminous igneous rocks are widespread along the Altai orogen, including massive granitoid plutons (about ca. 70% of the area, e.g., Windley et al., 2002) and minor ultramafic–mafic intrusions (Fig. 1b). Petrological and geochronological studies of these magmatic rocks provide insights into the tectonic background and continental growth. Previous studies have mostly focused on the granitoids (Cai et al., 2011b, c; Han, 2008; Jahn et al., 2000a, b; Tong et al., 2006, 2007; Wang et al., 2006, 2009; Zhang and Zou, 2013). Recent works have revealed two phases of ultramafic–mafic activities at ca. 280 Ma and ca. 400 Ma. The ca. 280 Ma ultramafic–mafic intrusions were interpreted to be genetically related to post-orogenic collapse (Chen and Jahn, 2004; Song et al., 2011; Zhang et al., 2009a), volcanic arc (Ao et al., 2010; Wan et al., 2013; Xiao et al., 2008, 2009a) or the Permian Tarim mantle plume (Pirajno

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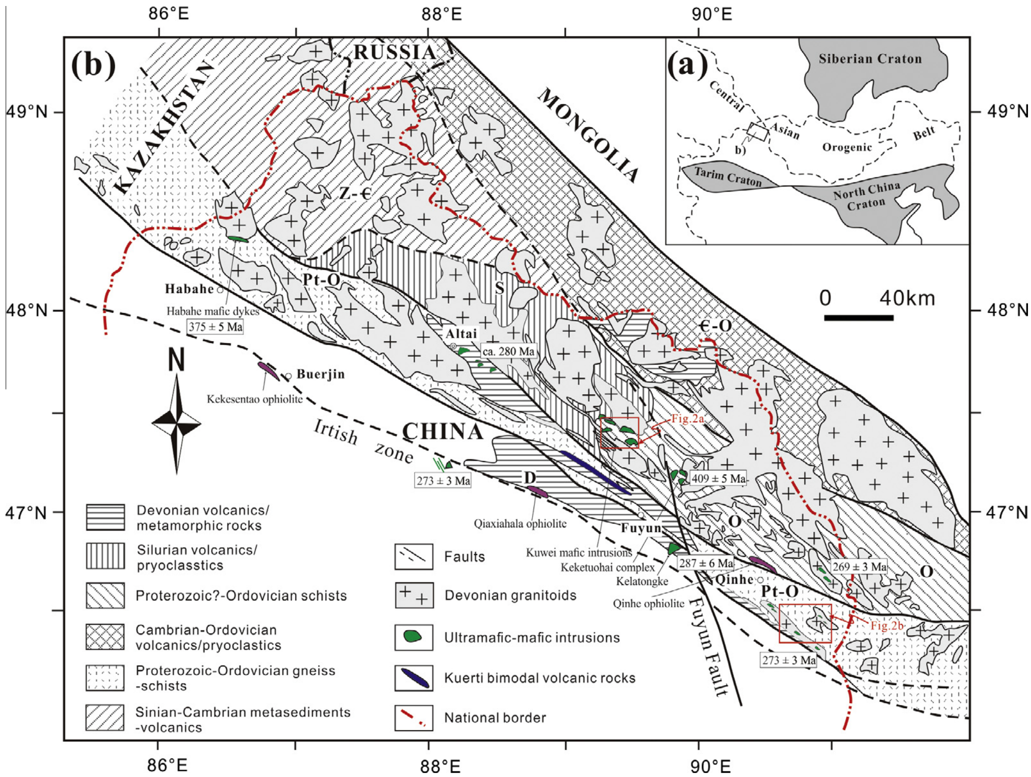

Fig. 1. (a) Schematic geological map of the Central Asian Orogenic Belt (CAOB); (b) generalized geological map of the Chinese Altai orogen (modified after Wang et al. (2009), Zhang et al. (2014)).

et al., 2008; Zhang and Zou, 2013; Zhang et al., 2008a; Zhang et al., 2010a, 2010b, 2014). The early phase of ultramafic–mafic activity, however, is still poorly known (Cai et al., 2012).

In this study, we report detailed field observations, petrography, systematic zircon U–Pb ages and Hf isotope results, whole-rock major and trace element geochemistry, Sr–Nd isotope and mineral compositions for the Devonian gabbroic intrusions along the south Altai orogen, as well as zircon Hf isotope of the coeval granites and volcanic rocks. The objectives of this study are to (1) provide a better understanding of the petrogenesis of these gabboric intrusions and their tectonic background and (2) to evaluate the vertical continental growth of the Altai orogen.

2. Regional geology

The Central Asian Orogenic Belt (CAOB) extends 7000 km east to west, bounded in the north by the Siberia Craton and in the south by the Tarim Craton (Hu et al., 2000; Jahn et al., 2000a, b; Şengör et al., 1993; Windley et al., 2007; Xiao et al., 2009a) (Fig. 1a). The tectonic framework of the Chinese Altai section can be divided into three major units, i.e., the Altai orogenic belt (including Altai-Mongolian terrain and Rudny Altai terrain), the Irtish suture zone and the Junggar terrain (Xiao et al., 2009a; Yin et al., 2010; Zhang et al., 2012). Recent studies demonstrated that the basement of the Chinese segment of Altai-Mongolian terrain was formed during the Neoproterozoic to early Paleozoic rather than early Precambrian. As for the Junggar terrain, it was formed by multiple accretions of seamounts, intra-ocean arc, ophiolites fragments, and subduction complex from middle Cambrian to carboniferous (Chen and Jahn, 2004; Han et al., 2006; Jahn et al., 2004a; Xiao et al., 2004, 2009b; Zhang et al., 2009b). The Irtish belt, formed at ca 320 Ma, was regarded as the final suture zone between the Altai-Mongolian terrain and the Junggar terrain (Zhang et al., 2012).

Relative to the extensive distribution of granitoids along the southern margin of the Altai orogen, Devonian gabbroic intrusions in this area are of small volume. These gabbroic intrusions formed a NW–SE-trending belt (Fig. 1b), including, from east to west, the Keketuohai mafic–ultramafic complex (Cai et al., 2012), the Kuwei gabbroic intrusions and South Kuwei ultramafic–mafic complex, and the gabbroic and doleritic intrusions and dykes in Habahe area (Fig. 1b) (Xinjiang, 1993; Zhou et al., 2006).

3. Petrography

3.1. The Kuwei intrusion

In the Kuwei area, dozens of northwest-trending mafic intrusions (Figs. 1b and 2a) are emplaced in the middle-upper Ordovician metamorphic volcanic–sedimentary sequences. Among them the Kuwei intrusion is the largest one. The oval intrusions are typically 8 km long and 0.5–2.3 km wide, with total outcropping area of ca.13 km^2.

The Kuwei intrusion has olivine gabbro in the core, fringed by gabbro and hornblende gabbro. All the rocks are fresh and of coarse- to medium-grained. Most of them show massive structures and cumulate texture. Rhythmic layering of the plagioclase and pyroxene is commonly observed at several outcrops in the field (Fig. 3a). Among of them, granular olivine is often enclosed in granular clinopyroxene (Fig. 3d). Reaction rim was observed in thin section (Fig. 3e), indicating that the early-formed olivine reacted with the remaining melt. The gabbro has typical gabbroic textures with semi-euhedral plagioclase and pyroxene in the section (Fig. 3f and g). Olivine gabbro consists of pyroxene (40–45% clinopyroxene +5–10% orthopyroxene), 25–40% plagioclase and 5–10% olivine with minor apatite and Ti–Fe oxides. Gabbro is composed of about 35% clinopyroxene, 10% orthopyroxene, 50% plagioclase, and 5–10% opaque minerals (mostly magnetite). Hornblende gabbro consists