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Geochronology and geochemistry of Early Permian mafic–ultramafic complexes in the Beishan area, Xinjiang, NW China: Implications for late Paleozoic tectonic evolution of the southern Altaids

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ABSTRACT

The Hongshishan and Pobei mafic–ultramafic complexes outcrop in the Beishan area in the southernmost Altaids. They consist of olivine gabbros, dunites, and pyroxenites. Zircons from olivine gabbros from the Hongshishan complex yield a U–Pb age for emplacement of 281.8 ± 2.6 Ma. The olivine gabbros have low SiO_2 (47.08–48.66%), TiO_2 (0.14–0.29%), MnO (0.07–0.09%), and K_2O (0.06–0.09%), but high $Mg^{\#}$ values ($81 < Mg^{\#} < 81.4$) together with high MgO (8.95–12.54%) and $^{T}Fe_2O_3$ (4.93–6.29%). The Hongshishan and Pobei mafic–ultramafic complexes are characterized by negative anomalies in high field strength elements (Zr, Hf, Nb, Ta), which we interpret as arc-related signatures. They also have spikes in large ion lithophile fluid mobile elements (Ba, U, Pb, Sr) and high mobile/immobile element ratios (i.e. primitive mantle-normalized Sr/Nd, Ba/La >> 1), which are attributed to an aqueous fluid component in the source. Zircon Hf isotopes indicate that the source magma was derived either from a depleted mantle with some crustal contamination or from an enriched mantle. These data are interpreted to indicate that the Hongshishan and Pobei mafic–ultramafic complexes were emplaced in the Early Permian subduction-related environment, which suggests that the Paleo-Asian Ocean in the southernmost part of Altaids did not close until after Early Permian.

1. Introduction

In addition to those igneous bodies in ophiolite sequences, non-ophiolitic mafic–ultramafic complexes are significant components in the tectonic evolution of orogens (Cheng and Kusky, 2007; Garrido et al., 2006; Himmelberg and Loney, 1995; Pirajno et al., 2008; Rajesh et al., 2004; Santosh et al., 2009a; Seo et al., 2005; Soderlund et al., 2004; Srivastava and Sinha, 2004; Kusky et al., 2007a,b). In ancient orogens, such as the Altaids (or Central Asian Orogenic Belt), such mafic–ultramafic complexes are prominent (Gu et al., 1994a,b; Xiao et al., 2003, 2004a,b, 2008; Han et al., 2006a,b; Zhang et al., 2009). However, their role in the geodynamic evolution of the region has been controversial. Most workers believe that these mafic–ultramafic complexes formed at convergent plate margins, representing arc magmas (Irvine, 1974; Taylor, 1967) or arc-root complexes (Brugmann et al., 1997; DeBari and Coleman, 1989). However, some workers suggest that they mark the change from an arc setting to an extensional regime (Mues-Schumacher et al., 1996; Pirajno et al., 2008; Tistl et al., 1994).

The Beishan area, located in the southern Altaids in Xinjiang, northwestern China (Fig. 1), is characterized by many mafic–ultramafic complexes, which host magmatic Cu–Ni sulfide mineral deposits and crop out along regional large-scale faults or sutures (Mao et al., 2008; Pirajno et al., 2008; Zhang et al., 2008). These mafic–ultramafic complexes were most recently described as the products of post-orogenic extension (Mao et al., 2008; Pirajno et al., 2008; Zhang et al., 2008), formed as a result of within-plate magmatic activity (Jiang et al., 2006), although alternative tectonic environments had been previously suggested (Gu et al., 1994b; Xiao et al., 2004a). However, irrespective of their possible tectonic setting, determining the ages of these complexes is crucial for understanding the final amalgamation of the southern Altaids, a topic which is controversial (Xiao et al., 2008, 2009a,b; Charvet et al., 2007). Therefore these mafic–ultramafic complexes are of key importance for understanding the tectonic evolution of the Altaids and the general role they played in the geodynamic processes of accretionary orogenesis.

In this study, we present new geochronological, and major and trace element data from rocks and minerals, as well as Hf isotopic analyses, for the Hongshishan and Pobei complexes. We then discuss the significance of these data for helping to define the tectonic evolution of the southern Altaids.

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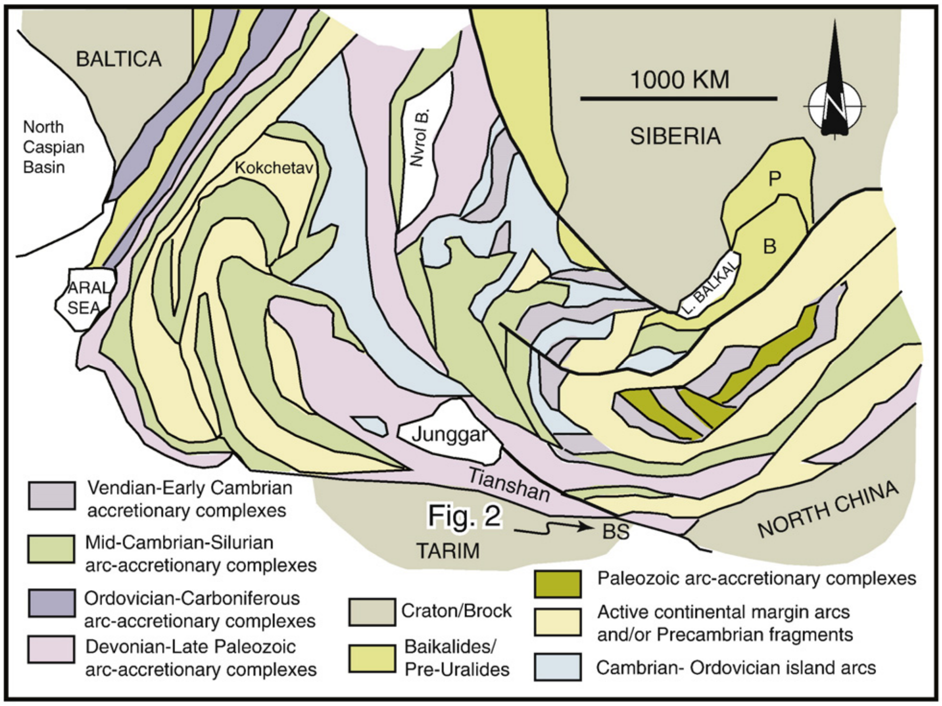

Fig. 1. Simplified tectonic map of the Altaids (modified after Şengör et al., 1993; Windley et al., 2007; Xiao et al., 2008).

2. Geological setting

In the Beishan area, located between the southern side of the East Tianshan and the Tarim craton (Fig. 2), there are numerous mafic–ultramafic intrusions that are situated along regional faults or sutures, and which are termed (from west to east): Luodong, Pobei, Hongshishan, Xuanwoling, and Bijiashan (Yang et al., 2002; Mao et al., 2008; Pirajno et al., 2008). Cenozoic regional NE-trending faults form the boundaries of the study area, some of which are a part of the system of continental-scale strike-slip faults of central Asia (Cunningham, 2005; Cunningham et al., 1996). Some of the huge strike-slip faults are reactivated Paleozoic faults, many of which were originally terrane boundaries. All of the mafic–ultramafic complexes intrude Carboniferous strata, known of the Hongliuyuan Formation, which is comprised of sandstone, siltstone, and limestone which are contact metamorphosed.

The Hongshishan complex, with an outcrop area of 2.63 km^2, is exposed along the Yigezitage fault that extends for hundreds of kilometers (Fig. 2). External contacts of this complex with its country rocks are sharp, steep, and generally marked by thermal aureoles. It consists of an early mafic unit (phase 1) and a late ultramafic–mafic unit (phase 2), and is irregularly layered, from bottom to top, with dunite, clinopyroxenite, troctolite, and gabbro. The contacts among the different rock units are transitional. Phase 1 comprises about 20% of the complex and includes olivine gabbro and gabbro. The olivine gabbro is composed of plagioclase (50%), pyroxene (20%), and olivine (30%). All olivine gabbros are massive and sub-euhedral granular, with a grain size of about 0.8 to 3 mm. Phase 2 comprises ~75% of the complex and includes troctolite, dunite, and clinopyroxenite. Troctolite, the major component of the complex, contains olivine, plagioclase, clinopyroxene, phlogopite, and magnetite; and is commonly poikilitic. Dunite is massive and generally serpentinized, and consists dominantly of olivine. In order to understand the evolution of the Hongshishan complex, samples for U–Pb dating, trace element geochemistry, and Hf isotopic analysis were collected from the olivine gabbros.

South of the Hongshishan complex, the oval-shaped Pobei complex is 2-km-long and 1.6-km-wide, and intrudes Carboniferous mica-schist, quartzite, and carbonate rocks (Fig 2). External contacts of the Pobei complex with country rocks are sharp, steep, and marked by thermal aureoles along its northern margin. The intrusive body is composed of a discontinuous outer gabbro unit surrounding an irregular, central ultramafic mass, and cut by later altered gabbro dikes (Zhao et al., 1990). The outer gabbro is comprised of olivine gabbro and hornblende gabbro. The olivine gabbro is massive and consists dominantly of bytownite, clinopyroxene, and minor olivine and hornblende. The ultramafic phase, in the core of the complex, contains clinopyroxenite, wehrlite, and peridotite, with disseminated pentlandite, pyrrhotite, chalcopyrite, and pyrite that define Ni- and Cu-rich ore deposits. The clinopyroxenite and wehrlite are massive, and consist dominantly of clinopyroxene and rarely hornblende. The contacts between the olivine gabbro and the clinopyroxenite–wehrlite unit are gradational. However, the contacts of peridotite with olivine gabbro and clinopyroxene are sharp, and dikes of peridotite locally cut the olivine gabbro.

3. Analytical procedures

All sample analyses were carried out at the Institute of Geology and Geophysics, Chinese Academy of Sciences in Beijing, and analytical procedures for each technique are described in detail below.

3.1. Zircon U–Pb dating and Hf analyses

Zircons were separated from about 2 to 3 kg samples using heavy liquids and magnetic separation technique. Approximately 200 zircons were hand-picked, mounted in epoxy resin, and polished until the grain centers were exposed. Cathodoluminescence (CL) images (Fig. 3) were obtained using a CAMECA microprobe, in order to identify internal structures and choose potential target sites for U–Pb and Hf analyses. The acceleration voltage during the CL imaging was 15 kV. Before zircon LA-ICP-MS U–Pb isotopic analysis and prior to carbon coating, the surface of the grain mounts was acid-washed in dilute HNO_3 and pure alcohol to remove any lead contamination. A total of 70–90 spots per sample were analyzed for age determination with every five spots bracketed by analyses of standard zircon 91500