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A new model for the granite–pegmatite genetic relationships in the Kaluan–Azubai–Qiongkuer pegmatite-related ore fields, the Chinese Altay

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ABSTRACT

Pegmatites commonly form in the waning stage of magma evolution by fractional crystallization of volatile-rich magmas and may be important host rocks of strategic metals (e.g., Li, Be, Cs, Ta, and Nb) and high-quality gem minerals. This study reports new zircon U–Pb dating results and Hf isotopic compositions of the KLA803 pegmatite, the AZB-01 pegmatite, the JMK-09 pegmatite (abbreviated as the K–A–J pegmatites) and the Halong granite from the Chinese Altay to determine the potential petrogenetic relationships between them. The geochronological data document that the K–A–J pegmatites were emplaced at 224.6 ± 2.3 Ma, 191.6 ± 2.0 Ma and 192.0 ± 2.3 Ma, respectively, and they are characterized by negative to low positive εHf(t) values (from −1.0 to +6.3) and old model ages (T_{DM}) (with the T_{DM1} from 874 to 597 Ma and T_{DM2} from 1298 to 833 Ma). In contrast, the Halong granite has an emplacement age of 398.3 ± 2.4 Ma and is characterized by higher positive εHf(t) values (from +9.9 to +15.2) and younger model ages (T_{DM}) (with the T_{DM1} from 626 to 414 Ma and T_{DM2} from 760 to 423 Ma). They all have intruded into the Kulumuti group stratum, which has negative initial εNd(t) values (from −4.3 to −0.2) and old T_{DM} model ages (between 1.22 and 1.56 Ga). Based on the calculated results of the mixing ratios (f) of the initial magmas and the prevailing Paleozoic tectonic framework of the Chinese Altay, we establish two petrogenetic models for the K–A–J pegmatites: Model 1 refers to that these pegmatites originated from a mixed magma that was composed of 72–91 wt.% depleted mantle components and 9–28 wt.% lower crust components; and Model 2 refers to that they were derived from the partial melting of 38–83 wt.% Halong granite and 17–62 wt.% sedimentary rocks from the Kulumuti group. We also suggest that the initial magma of the Halong granite was significantly contributed by juvenile materials with a slight involvement of crustal materials. In Model 1, because LCT-type pegmatites (classified as Li–Cs–Ta enriched pegmatites associated with S-type granite that was produced by the partial melting of preexisting sedimentary rocks) have close geochemical affinities with crustal materials, the excessively high weight percentages (72–91 wt.%) of the depleted mantle components in the initial magma of the K–A–J pegmatites indicate that this model is unrealistic. Therefore, we consider that Model 2 is more reasonable at present for interpreting the petrogenesis of the K–A–J pegmatites, and it needs to be verified in other pegmatite fields of the Chinese Altay.

1. Introduction

Pegmatites are unique rocks, primarily granitic in composition, that are usually characterized by extremely coarse but variable grain size and an abundance of crystals with skeletal, graphic or other strongly directional growth habits (London, 2008). It is widely assumed that pegmatites are formed by magmatic fractional-crystallization and are genetically linked with fertile granitic sources at depth (Jahns and Burnham, 1969; Norton, 1983; London, 1990; Jolliff et al., 1992; Webster et al., 1997; Fuertes-Fuente et al., 2000; Selway and Breaks, 2006; Hulsbosch

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et al., 2014). To recognize the granite–pegmatite genetic relationships and evaluate the degree of fractionation, a growing number of studies investigate the geochemical and textural features of the different mineral phases of pegmatites (Baijot et al., 2012; Roda-Robles et al., 2012; Vieira et al., 2011; Lira et al., 2012; Neiva et al., 2008, 2012; Shearer et al., 1992). However, because it is difficult to truly characterize the representative whole-rock geochemical and isotopic features of these coarse-grained rocks, the genetic relationship between pegmatites and host granites is usually not simple to address (Goad and Černý, 1981; Stilling et al., 2006; Černý et al., 2012; Lima et al., 2014).

Zircon is a widely used mineral for isotopic and geochemical studies because of the high contents of trace elements in its crystalline structure and the strong resistance to erosion, weathering and alteration processes. Owing to the close chemical affinities between Hf and Zr, Hf could replace the latter in the zircon crystal lattice with concentrations between 0.3 and 3.3 wt.% (Hoskin and Schaltegger, 2003; Yin et al., 2013). This behavior makes Hf more compatible in zircon than the REEs, especially Lu, leading to low Lu/Hf ratios (typically <0.001). Accordingly, the radioactive decay of ^{176}Lu does not significantly change the Hf isotope composition of zircon with time. Moreover, the low intra-crystalline diffusion rate of Hf in zircon and the high closure temperature of the Lu–Hf isotope system (Cherniak and Watson, 2003) suggest that the effect of post-crystallization thermal events on the Hf isotope composition was small. Hence, the εHf values and T_{DM} model ages of the zircons from pegmatites may provide reliable and significant information on the magma source and the potential genetic relationship with the parental granites (Vervoort et al., 1996; Amelin et al., 2000; Scherer et al., 2000; Griffin et al., 2002; Kinny and Maas, 2003; Hawkesworth and Kemp, 2006; Wang et al., 2008; Lv et al., 2012).

The Central Asian Orogenic Belt is situated among the Siberia, East European, Tarim and North China Cratons, and it represents the largest Phanerozoic accretionary orogenic belt in the world (Fig. 1; Sengör et al., 1993; Sengör and Natalin, 1996; Jahn et al., 2000; Badarch et al., 2002; Chen and Jahn, 2004; Yakubchuk, 2004; Yuan et al., 2007; Xiao et al., 2008, 2009, 2010; Zhou et al., 2008; Biske and Seltmann, 2010; Zhang and Zhang, 2014). As the key part of the CAOB, the Altay orogenic belt lies in Russia, northeastern Kazakhstan, northwestern China and southwestern Mongolia (Fig. 1; Chen and Jahn, 2002). More than 100,000 granitic pegmatite veins are exposed in the Chinese Altay (the Chinese part of the Altay orogenic belt), and many of these pegmatites host economic rare metals such as lithium, beryllium, niobium and tantalum (Wu and Zou, 1989; Wang et al., 2002, 2004). Following earlier work, the geochemistry and mineralogy of the Koktokay No. 3 pegmatite and the Kelumute No. 112 pegmatite continue to be extensively studied (Wang et al., 2002, 2003; Zhu et al., 2006; Lv et al., 2012). More recently, an increasing number of Permian to Jurassic pegmatites have been reported, and the origin of these pegmatites is suggested to be closely related to the late Paleozoic to early Mesozoic post-collision tectonic setting of the Chinese Altay (Fig. 1; Wang et al., 2007; Chen, 2011; Ren et al., 2011; Lv et al., 2012; Ma, 2014). However, the petrogenesis of these pegmatites and the granite–pegmatite genetic relationships still remain uncertain.

The Kaluan ore field, the Azubai ore field and the Qiongkuer ore field (abbreviated as the Kaluan–Azubai–Qiongkuer ore fields or the KAQ ore fields), surrounding and to the west of the Halong granite, contain the pegmatite-type rare-metal deposits of the Kaluan No. 806 and 807 Li deposit, the Kukalagai No. 650 Li deposit and the Qiongkuer No. 1 Nb–Ta deposit (Wu and Zou, 1989; Ma, 2014). Within the KAQ ore fields, the Kaluan No. 803 (KLA803) pegmatite, the Azubai-01 (AZB-01) pegmatite and the Jiamukai-09 (JMK-09) pegmatite (the K–A–J pegmatites) (Fig. 2) are typical of LCT-type pegmatites (classified as Li–Cs–Ta enriched pegmatites associated with S-type granite that was produced by the partial melting of preexisting sedimentary rocks; Černý, 1991; Shelley, 1993; London, 2008), and they are characterized by intensive Be and Ta mineralizations. Geographically, the Halong granite is located approximately 500 m east of the KAQ ore fields and is considered to be the largest granitic batholith in the region (Wu and Zou, 1989; Ma, 2014). Because of the close spatial relationship with the pegmatites in the KAQ ore fields, the Halong granite was assumed to be the parental granite of the pegmatites (Wu and Zou, 1989). Apparently, the identification of the petrogenetic relationship between the K–A–J pegmatites and the Halong granite plays an important role in characterizing the magmatic processes and may greatly benefit further rare metal exploration in the KAQ ore fields. In this study, we perform the geochronological and Hf isotopic studies of the Halong granite and the K–A–J pegmatites to reveal the magmatic sources and the petrogenesis of these formations. Based on the calculated results of the components of the initial magmas, we propose a new petrogenetic model for the K–A–J pegmatites.

2. Geological background

2.1. Regional geology

The Chinese Altay is located in the northern part of Xinjiang Province, extending eastward to Mongolia and westward to Kazakhstan and Russia (Fig. 1, Windley et al., 2002, 2007; Xiao et al., 2004; Long et al., 2007, 2008, 2010; Sun et al., 2008, 2009). On the basis of the stratigraphy, metamorphism, deformation pattern, magmatic activity and geochronology, the Chinese Altay can be divided into five fault-bounded terranes separated by the Hongshanzui, Kalaxianger, Abagong-Kurit and Maerkakuli Faults (Fig. 1; Sengör et al., 1993; Long et al., 2007; Yuan et al., 2007; Sun et al., 2008; Cai et al., 2011a,b). Terrane 1 is made up of Late Devonian to Early Carboniferous clastic sediments, limestones and some minor island-arc volcanic rocks metamorphosed at lower greenschist facies. Terrane 2 is composed of a Middle Ordovician turbidite sequence of lower greenschist facies. Terrane 3 is the largest terrane and is comprised of early Paleozoic sediments metamorphosed at a medium to high grade. Terrane 4 consists of Devonian turbiditic sandstones, pillow basalts and some siliceous volcanic rocks. Terrane 5 is mainly composed of Devonian fossiliferous successions that are, in turn, overlain by Late Carboniferous formations.

The lowermost sedimentary sequence in the Chinese Altay is the Habahe Group, which mostly consists of Ordovician to Sinian thick marine-facies terrigenous clastic rocks including sandstones, siltstones and mudstones (BGMRX, 1993; Windley et al., 2002; Long et al., 2007). The recent U–Pb dating of the detrital zircons and the whole-rock geochemical studies of the sedimentary rocks of the Habahe Group suggest that these strata were deposited along an active continental margin predominately during the Silurian (Long et al., 2007, 2008, 2010). Additionally, the marine-facies metasediments of the Kulumuti Group (S_{2-3}KL) unconformably overlie the Habahe sequence in the central part of the Chinese Altay (BGMRX, 1993). All of these strata were intruded by early to middle Paleozoic arc-related plutons and late Paleozoic post-collision A-type granites (Fig. 1; Han et al., 1997; Chen and Jahn, 2002, 2004; Chen and Arakawa, 2005; Su et al., 2006; Wang et al., 2006; Yuan et al., 2007; Zhou et al., 2008; Tang et al., 2010; Cai et al., 2011a,b, 2012; Shen et al., 2011).

Abundant NW-SE trending faults occur in the Chinese Altay, such as the Hongshanzui, Kalaxianger, Abagong-Kurit, Bazhai, Maerkakuli and Erqis Faults (Fig. 1). As one of the largest transcurrent