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Geochronology and geochemistry of leucogranites from the southeast margin of the North China Block: Origin and migration

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ABSTRACT

Systematic geochronological, geochemical and geological data for the Late Jurassic granitic intrusions from the Bengbu area in the southeastern margin of North China Block (NCB) are presented in this paper. The very low FeO + MgO + TiO_2 contents and ferromagnesian mineral abundance as well as low Al-saturation indexes (ASI = 0.92–1.09) of the rocks document that these granitic intrusions are metaluminous leucogranites. The Bengbu leucogranites contain abundant both inherited Neoproterozoic igneous and Triassic metamorphic zircons, showing a high agreement in ages with the ultrahigh-pressure (UHP) metamorphic rocks from the adjacent Dabie–Sulu orogen, but significant different from the country rocks. The magmatic overgrown zircon rims give the ages of 167–148 Ma, consistent with the time of Jurassic migmatization in the Sulu orogenic belt. Mineral inclusions such as quartz, feldspar, apatite, titanite, biotite, muscovite and phengite (Si = 3.58) without coesite occurring within the Triassic metamorphic zircons suggest that the source rocks of the leucogranites might have experienced only high-pressure (HP) rather than UHP metamorphism. Furthermore, steep HREE patterns of the inherited metamorphic zircons, plus very low bulk REE contents and Sr–Nd–Pb isotopic characteristics, suggest that the leucogranites were most likely derived from partial melting of subducted felsic gneiss rather than basaltic eclogite in Dabie–Sulu orogen, with residual allanite in the source. Their low Rb, high Sr contents and low Rb/Sr ratios suggest that the metaluminous leucogranites are derived from mica-poor orthogneiss. Melting temperature for the leucogranites is about 700–710 °C as estimated using combined Ti-in-zircon and zirconium saturation thermometries. Inherited metamorphic zircons yielded metamorphic Ti-in-zircon temperature of 681 ± 60 °C, representing that for protolith-forming, which shows no significant difference from the melting temperature. H_2O-present melting is thus required to generate the low-temperature melt. Sedimentary facies analysis of the Jurassic strata in the Hefei basin suggests that the Sulu orogen had been northward moved to the east of the Bengbu uplift by the Tan–Lu Fault in the Late Jurassic, resulting into a contrasting topography in this area and lateral pressure gradient in the local middle-lower crust. This lateral pressure gradient may drive the partially molten crust (migmatite) in Sulu orogen westward flow into the middle-lower crust of the Bengbu uplift in NCB. Gravity then drove melt to ascent into the middle-upper crust of the Bengbu uplift to form the leucogranitic intrusions. The NWW–SEE distribution of the later Jurassic leucogranites in Bengbu uplift may indicate the direction of ancient channel flow.

1. Introduction

Leucogranites as products of crustal melting are well developed in collisional orogen, which reveal when and where the crust has melted since continent–continent collision began. In the past few decades, channel flow of a weak crustal layer has been proposed to explain the thickening and outward growth of the Tibetan plateau as well as surface deformation in other orogenic belts (e.g., Nelson et al., 1996; Royden et al., 1997; Clark and Royden, 2000; Beaumont et al., 2001; Grujic, 2006; Harris, 2007; Schulmann et al., 2008; Raimondo et al., 2009; Jamieson et al., 2011). Leucogranite has been considered as petrological evidence for this crustal flow model. For example, the High Himalaya metasedimenatry rocks have been considered to be southward flow of mid-crustal rocks beneath southern Tibet and its petrological evidences mainly come from the High Himalaya leucogranites (e.g., Inger and Harris, 1993; Harris and Massey, 1994; Jamieson et al., 2011). All reported leucogranites, so far, are developed within the orogen belt and most of them were derived from melting of their host rocks (e.g., Clarke et al., 1993; Inger and Harris, 1993; Harris and Massey, 1994; Pressley and Brown, 1999; Nabelek and Bartlett, 1998; Van de Flierdt et al., 2003). Therefore, it is interesting to find out whether

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a melt-weakened crust or leucogranites as their melting products can flow from one continent block to another during continental collision.

The Jingshan granitic intrusion in the Bengbu uplift is located in the southeast margin of the North China Block (NCB), nearby the Dabie–Sulu UHPM belt. It has been reported that the Jingshan intrusion crystallized in the Late Jurassic and contains abundant inherited zircons with Neoproterozoic magmatic and Triassic metamorphic ages, which are comparable to those of ultrahigh pressure (UHP) metamorphic rocks from the Dabie–Sulu orogen (W.L. Xu et al., 2005). In addition, the inherited metamorphic zircons from the Jingshan intrusion have extremely low and highly heterogeneous $\delta^{18}O$ values ranging from −9.4‰ to 8.6‰, consistent with the values and variations exhibited by metamorphic zircons from Dabie–Sulu orogen (Wang et al., 2013b). These observations aroused great interests of the geological society (W.L. Xu et al., 2005; Guo and Li, 2009a; Wang et al., 2009; Li et al., 2010; Wang et al., 2010; Yang et al., 2010; Wang et al., 2013b), because it may contain important information on the crustal material migration from the Dabie–Sulu orogen to the southeast margin of the NCB. However, the origin of the Jingshan intrusion and their potential implications to the evolution of Dabie–Sulu orogen are in debate (W.L. Xu et al., 2005; Guo and Li, 2009a; Wang et al., 2009, 2010; Yang et al., 2010). In addition, the protolith of the Jingshan intrusion and its metamorphic and melting conditions are unknown, despite their importance to constrain the tectonic process related to the origin of the Jingshan intrusion. Though all published data indicate the migration of subducted SCB crust to the Bengbu area, the mechanism of crustal migration and the origin of the Jingshan intrusion need further studies.

In order to provide constraints on these controversial issues and to understand better the protolith, melting condition and migration mechanism of leucogranites in continental collision zone, we have performed detailed studies of zircon U–Pb dating, mineral inclusions and trace elements in zircons, bulk major and trace elements, Sr–Nd–Pb isotope geochemistry, and fabric of the gneissosity of the leucogranites from the Bengbu uplift. Based on the present data and regional geology analysis, we conclude that the Sulu orogen was transected and moved to the north by Tan–Lu Fault during the Jurassic and a lateral melt-weakened crust flow from the Sulu orogen has been westward injected into the middle crust of the NCB in the Late Jurassic. The Bengbu leucogranitic intrusions are formed by melt accumulation at a shallow level derived from the crustal flow.

2. Geological background and samples

The Qinling–Dabie–Sulu orogen as a continental collision zone between the South China Block (SCB) and the NCB (Fig. 1a) experienced a long period of convergence of the blocks from the Early Triassic to the Late Jurassic (e.g., Lin et al., 1985; Li et al., 1993). During the collision, the continental crust of the SCB was subducted northward beneath the NCB in the Triassic (e.g., Li et al., 1993). The protoliths of the UHPM rocks in the Dabie–Sulu orogen are mostly Neoproterozoic igneous bimodal rocks with ages of ~750 Ma (Zheng et al., 2003), which experienced UHP metamorphism in the Triassic (242–225 Ma) (Li et al., 1989, 1992, 1993, 1994, 2000; Ames et al., 1993; Chavagnac and Jahn, 1996; Hacker et al., 1998; Ayers et al., 2002; Li et al., 2004; F.L. Liu et al., 2005; Y.C. Liu et al., 2005; Liu et al., 2006; Liu et al., 2007, 2011; Liu et al., 2013). Studies on the cooling history of UHPM rocks from the Dabie–Sulu orogen suggest that the UHPM rock slices were exhumed to the middle or lower crust level during the period of 226 ± 3 Ma to 199 ± 3 Ma (Li et al., 2000; Li et al., 2003; F.L. Liu et al., 2008; Wang et al., 2012).

The Dabie–Sulu orogen was transected by the Tan–Lu sinistral strike slip fault during the period from the Middle Triassic to the Early Cretaceous with northward movement of the Sulu UHP metamorphic terrane (Zhu et al., 2009; Fig. 1a). The magmatisms are different in the Dabie orogen and Sulu orogen, despite the consistent HP/UHP metamorphic events in both terranes. In Dabie orogen, the Cretaceous magmatism including granitoids and mafic intrusions as well as migmatite are very developed, but no magmatic activity has been observed until the Early Cretaceous (e.g., Jahn et al., 1999; Li et al., 1999; Zhao et al., 2007a,b; Huang et al., 2008; He et al., 2011; Wang et al., 2013a; Fig. 1a). By contrast, the Middle Triassic (225–205 Ma) syn-orogenic granitoids are developed in eastern Sulu belt (Chen et al., 2003), beside the Early Cretaceous magmatism. Recently, the Middle Triassic (219–215 Ma) and Late Jurassic (167–145 Ma) migmatites have been also recognized in the whole Sulu belt suggesting two episodes of partial meting events in the Sulu orogenic crust (F.L. Liu et al., 2012; Fig. 1a).

The Bengbu area, situated ~150 km north to the Dabie orogen, is an uplifted region, in the southeastern margin of the NCB (Fig. 1a), bordered by the Tan–Lu Fault to the east and Hefei basin to the south (Fig. 1b). The exposed metamorphic basement in Bengbu uplift is the Archean complex called as the Wuhe Group (Fig. 1b), which is mainly composed of supracrustal rocks, such as marble, meta-sediments and amphibolite layers. Paleozoic sedimentary rocks are developed in its adjacent areas to the north and south (Fig. 1a). Its eastern and southern boundaries are two important Mesozoic tectonic zones in East China. The Tan–Lu Fault on the east is a continental scale fault in eastern China. Although the origin of the Tan–Lu Fault remains controversial, it has been recently documented to be a syn-collisional transfer fault, which is initiated in the Middle–Late Triassic and experienced a large scale sinistral strike slip in the Jurassic (Zhu et al., 2001, 2009). Since the Early Cretaceous, the Tan–Lu Fault was transformed into a normal fault (Zhu et al., 2009) and became a graben-type basin covered by Cenozoic sediments (Fig. 1a). The Hefei basin, a compressional foreland basin resulting from the convergence of the NCB and SCB in the Jurassic (Xue et al., 1999), is adjacent to the Bengbu uplift to the south and the Tan–Lu Fault to the west (Fig. 1a). There are no Triassic deposits, but Jurassic foreland deposits occurred in the Hefei basin (Liu et al., 2006; Zhu et al., 2010). However, the Hefei basin was transformed into an extensional basin since Early Cretaceous, because the region was involved in younger extension during the period of Cretaceous to Paleogene (Liu et al., 2006; Zhu et al., 2010). The Archean metamorphosed basement rocks (the Wuhe complex) exposed in the Bengbu uplift experienced granulite-facies metamorphism in the Early Proterozoic (1.8–1.9 Ga) accompanied by synchronous magmatism, which is comparable with other Early Proterozoic complex belts in the NCB (Guo and Li, 2009b; Liu et al., 2009).

A few episodic Mesozoic magmatisms in the Bengbu uplift have been identified. The Jurassic Jingshan granitic intrusion with weak gneissosity (Fig. 2) occurs in the west part of the Bengbu uplift. It intruded into the Wuhe complex at ~160 Ma as suggested by zircon U–Pb dating data (W.L. Xu et al., 2005; Yang et al., 2010). Guo and Li (2009a) considered the Jingshan intrusion as leucogranite based on a petrochemical study, whereas others named it as either migmatitic granite (W.L. Xu et al., 2005), or biotite–syenogranite (Yang et al., 2010), or monzogranite (Wang et al., 2010). The nomination of leucogranite is mainly based on the very low Mg–Fe contents and dark-colored mineral abundance (see details in below) in Jingshan intrusion. The intrusion is composed of gneissic leucogranite with a few biotite–garnet-rich restite and leucoaplite veins (Guo and Li, 2009a). Similar leucogranites have been identified elsewhere in the Tushan, Mayishan (Guo and Li, 2009a), and Laoshan (Wang et al., 2009) intrusions, which together with the Jingshan intrusion comprise an NWW–SEE trending leucogranitic belt in the Bengbu uplift and we call them as Bengbu leucogranites (Fig. 1b). Previous studies only reported zircon U–Pb ages of the Jingshan intrusion (W.L. Xu et al., 2005; Li et al., 2010; Wang et al., 2010; Yang et al., 2010; Wang et al., 2013a, 2013b) and Laoshan intrusion (Wang et al., 2009, 2013b). Whether or not the leucogranites in Tushan and Mayishan have the similar Jurassic intrusive ages keeps unknown.

The Cretaceous granitic intrusions, including granodiorites and granites, are distributed on the two sides of the Jurassic leucogranitic belt in the Bengbu uplift (Fig. 1b; Yang et al., 2010; S.A. Liu et al., 2012).