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Ca. 1318 Ma A-type granite on the northern margin of the North China Craton: Implications for intraplate extension of the Columbia supercontinent

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ABSTRACT

Identification of the Mesoproterozoic A-type Jining granite and granite porphyry, which with abundant coeval mafic dike sills and volcanic rocks on the northern margin of the Precambrian North China Craton (NCC), may suggest intraplate extension of Columbia supercontinent. Major and trace elements of the Jining granite show an affinity to A-type granites, and may reflect an intraplate rift setting (A_1-type granite). High Rb, Y, Yb, and Ta contents also show features of within-plate granites. SHRIMP zircon dating yielded concordant weighted mean $^{207}Pb/^{206}Pb$ ages of 1318 ± 7 Ma and 1321 ± 15 Ma, which define a Mesoproterozoic magmatic event. The zircons have negative $\varepsilon_{Hf(t)}$ of −3.6 to −8.6 and corresponding old T_{DM2} of 2330–2609 Ma (mean 2436 Ma), suggesting the involvement of a crustal source in the magma genesis. The Hf-in-zircon isotopic compositions are aligned along an evolution line for the average continental crust. These results suggest that the granite and granite porphyry originated from partial melting of an Archean crustal source in a within-plate anorogenic setting during the Mesoproterozoic. The discovery of this A-type granite and granite porphyry with coeval mafic sills suggests that the NCC was involved in the fragmentation of the Columbia supercontinent, and the intraplate extension of the supercontinent occurred during Mesoproterozoic, probably at ca. 1318 Ma.

1. Introduction

Anorogenic granitoids and coeval abundant mafic dike swarms play an important role in the reconstruction of paleo-supercontinents (Condie, 2002; Hoffman, 1989; Hou et al., 2008a,b; Peng, 2010; Rogers and Santosh, 2002; Windley, 1995; Zhao et al., 2004a). Assembly and breakup history of a Mesoproterozoic supercontinent, referred to by Nuna (Hoffman, 1997) or Columbia (Rogers and Santosh, 2002) is still controversial (Condie, 2002; Dalziel, 1991; Ernst et al., 2008; Hoffman, 1991; Hoffman, 1997; Kröner and Cordani, 2003; Li et al., 2000, 2008; Moores, 1991; Reddy and Evans, 2009; Rogers and Santosh, 2002; Zhai and Liu, 2003; Zhao, et al., 2000, 2002, 2004a). The late Paleoproterozoic (ca. 1.8–1.85 Ga) Lüliang Orogeny was interpreted as a final consolidation event to form the North China Craton (NCC) (Lu et al., 2008; Sun and Lu, 1987; Wilde et al., 2002; Zhao et al., 2000) and has recently been interpreted to reflect the assembly of the Columbia supercontinent about 1.85 Ga ago (Hou et al., 2008a; Lu et al., 2008; Wilde et al., 2002; Zhao et al., 2002). The NCC underwent late Paleoproterozoic extension with emplacement of mafic dike swarms, anorthosite–mangerite–alkali granitoids and rapakivi granites during 1.78 to 1.68 Ga (Halls and Heaman, 2000; Peng et al., 2005, 2008; Wang et al., 2004; Yang et al., 2005; Zhang et al., 2007; Zhao et al., 2004b) and eruption of K-rich volcanic rocks at around 1.62 Ga (Lu and Li, 1991) after cratonization. Mesoproterozoic K-bentonite beds (1.37 Ga) and diabase sills (1.35 Ga) have also been identified in the northern NCC that document mafic magmatism (Gao et al., 2008; Su et al., 2008; Zhang et al., 2009).

A-type granites were first defined by Loiselle and Wones (1979) to describe granites that were generated along continental rift zones (anorogenic), and then discussed by Collins et al. (1982), Whalen et al. (1987), and Creaser et al. (1991). Based on trace element discrimination diagrams, A-type granitoids can be divided into two chemical groups (A_1 and A_2) with different tectonic settings (Eby, 1992). A_1 types are emplaced, usually with abundant coeval mafic rocks in continental rifts or during intraplate magmatism whereas A_2 types can form in a wide range of tectonic settings (e.g., post-orogenic extension of collisional orogens) (Eby, 1992). We have undertaken a geochemical, geochronological and isotopic study on a Mesoproterozoic A-type granite and granite porphyry from the Jining area, Inner Mongolia of China and provide evidence for intraplate felsic magmatism.

2. Geological setting and sample descriptions

Jining is located in central Inner Mongolia, on the northern margin of the North China Craton (Fig. 1a). The basement of central Inner

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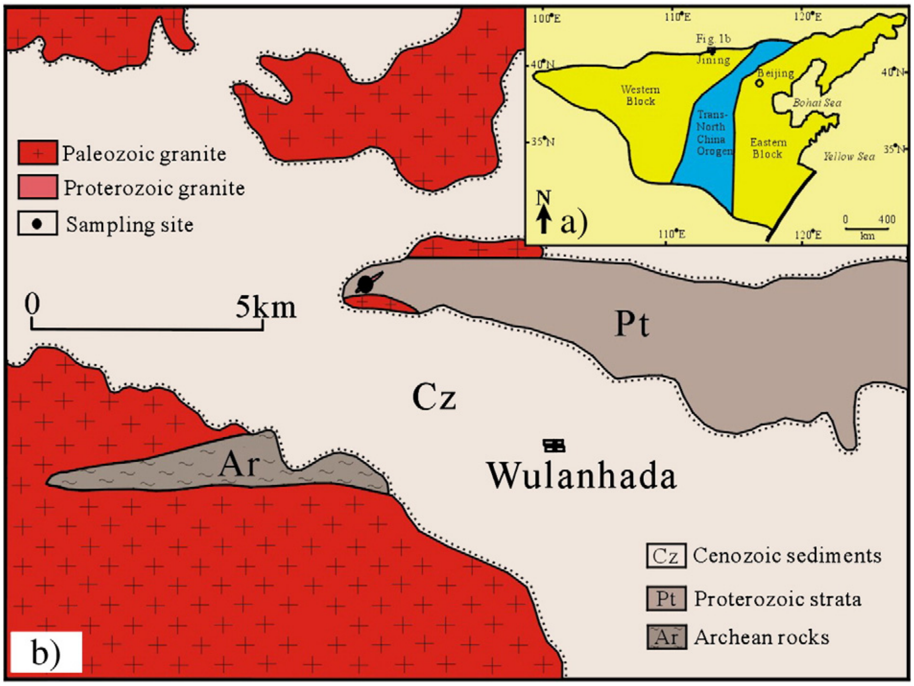

Fig. 1. Geological map of the Jining granite and granite porphyry, Inner Mongolia. (Modified from 1:20,000 geological map of Shangdu, 1971).

Mongolia is composed of strongly metamorphosed Archean and Paleoproterozoic rocks, e.g. gneisses, quartzite, marble, hornblendite, and granulite, which are covered by Meso- to Neoproterozoic marine clastic and carbonate platformal sediments (Sun and Lu, 1987).

The granite and granite porphyry of this study occur as ca. 20 m wide dikes (Fig. 1b) in the Mesoproterozoic strata with northeast strike (50° NE). Sample JN1 (E113°08′07″; N41°39′45.5″) is a granite composed of K-feldspar (40–45%), quartz (25–30%), plagioclase (20–25%), biotite (<5%), minor opaque mineral (magnetite, 1%), and trace amounts (<1%) of zircon and apatite. Plagioclase is partially sericiticized and replaced by calcite. Sample JN2 is a granite porphyry collected 5 m away from sample JN1 (Fig. 2) and contains phenocrysts of quartz (15%), K-feldspar (10–15%) and plagioclase (5%) set in a groundmass composed of K-feldspar (25–30%), plagioclase (20–25%), quartz (25–30%), biotite (<5%), and trace amounts (<1%) of magnetite, zircon and apatite.

Fig. 2. Photo of an outcrop of the Jining granite and granite porphyry.

3. Analytical results

3.1. Major and trace elements

Major and trace element concentrations for the Jining granite and granite porphyry are listed in Table 1. The samples are rich in silica (SiO_2 = 74.59–76.26 wt.%) and potassium (K_2O = 4.35–5.13 wt.%), but poor in magnesium (MgO = 0.15–0.44 wt.%), titanium (TiO_2 = 0.07–0.15 wt.%), manganese (MnO = 0.03–0.05 wt.%). In a plot of A/NK vs. A/CNK, the rocks are peraluminous (Fig. 3). Chondrite-normalized REE patterns (Fig. 4) exhibit negative Eu anomalies (δEu = 0.06–0.17). Moreover, the granites show trace element features of A-type granites such as high values in Th, K, Hf, and Y, and low Ba, Sr, P, and Ti (Fig. 5). The 10,000× Ga/Al ratios range from 2.6 to 3.1, with an average of 2.8, slightly lower than the global average of 3.75 for A-type granites (Whalen et al., 1987). In the diagrams 10,000× Ga/Al vs. related element compositions and calculated values (Fig. 6), the rocks are clustered in or near the A-type granite field.

3.2. Zircon ages

Zircons from samples JN1 and JN2 are 50–150 μm long, 40–100 μm wide, euhedral, and brown in color. CL images mostly show oscillatory zonation, indicative of a magmatic origin. Sixteen of 19 analyses on 19 zircon grains from sample JN1 form a coherent group and cluster tightly on or around concordia (Table 2; Fig. 7a), yielding a weighted mean $^{207}Pb/^{206}Pb$ age of 1318 ± 7 Ma, with MSWD = 1.01. This age is interpreted as reflecting the time of emplacement of the granite. Three grains have much older $^{207}Pb/^{206}Pb$ ages of 3324 ± 7 Ma, 2409 ± 9 Ma, and 1895 ± 21 Ma (1σ) and are interpreted as inherited xenocrysts. Twelve of 17 analyses on 17 zircon grains from granite porphyry sample JN2 yielded a weighted mean $^{207}Pb/^{206}Pb$ age of 1321 ± 15 Ma (MSWD = 1.13) (Table 2; Fig. 7b). This age is also interpreted as approximating the age of emplacement of porphyry dike. Five inherited