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Zircon U–Pb dating and Hf isotope analysis on the Taihua Complex: Constraints on the formation and evolution of the Trans-North China Orogen

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ABSTRACT

Precise age determination and source tracing of the granitic and pegmatitic gneisses of the Taihua Complex in the Xiaoqinling area are important to address the debates on the timing and processes of the amalgamation of the Western and Eastern Blocks along the Trans-North China Orogen. This paper conducted zircon dating of metamorphic rocks from the Xiaoqinling area. The results demonstrate that the collision between the Western and Eastern Blocks occurred in the Paleoproterozoic. Laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS) zircon uranium–lead (U–Pb) analyses yielded consistent results. The Early Paleoproterozoic (the first period) age of 2346 ± 28 Ma was determined for granitic gneiss in the Taihua Complex and 2328 ± 14 Ma for the Xiaohe granite pluton that intruded into the granitic gneiss. The gneissose pegmatitic granite and granitic veins that intruded into the granitic gneiss yielded LA-ICP-MS zircon ages of 1881 ± 24 and 1866 ± 19 Ma, respectively. These Paleoproterozoic ages strongly indicate that the ocean between the Eastern and Western Blocks were completely subducted at ~1.85 Ga. The $\varepsilon_{Hf}(t)$ values of the zircons from the granitic gneiss can be divided into a positive group (0.44 to 3.77) and a negative group (−3.11 to −1.27). The two-stage hafnium (Hf) model ages (T_{DM2}(Hf)) corresponding to the positive values are between 2672 and 2887 Ma. The $\varepsilon_{Hf}(t)$ values of the zircons from the Xiaohe granite range from −2.49 to 2.58, with the Hf isotope model ages ranging from 2742 to 3022 Ma. Thus, the Xiaohe granite could have resulted from the partial melting of the Late Archean lower crust caused by subduction and the presence of juvenile mantle material. The primary magma of the granitic gneiss of the Paleoproterozoic Taihua Complex was derived from the differentiation of the depleted Late Archean mantle source with a small portion derived from the remelting of the subducted lower crust.

1. Introduction

In the past decade, extensive geological and geophysical investigations have been carried out in the Trans-North China Orogen (TNCO), which is considered a continent–continent collision belt along which the Eastern and Western Blocks amalgamated to form the coherent basement of the North China Craton (NCC) (Zhao et al., 1998, 1999a,b,c, 2000a,b, 2001a; Liu et al., 2000, 2006; Wilde et al., 2004; Kröner et al., 2006; Xia et al., 2009; Liu et al., 2011a,b; Deng et al., 2012; Huang et al., 2012). However, the timing and tectonic processes involved in the collision of these blocks to form the NCC basement remain controversial (Zhao et al., 2001b, 2005; Wilde et al., 2002; Kusky and Li, 2003; Wang et al., 2004a,b; Wilde and Zhao, 2005; Wu et al., 2005; Kröner et al., 2006; Li and Kusky, 2007; Trap et al., 2007, 2009, 2012; Zhang et al., 2007, 2009, 2012; Hou et al., 2008; Li et al., 2010; Kusky, 2011; Liu et al., 2012d; Zhao and Cawood, 2012; Zhao and Guo, 2012; Zhao et al., 2012). In this regard, the ages of zircons from the granitic and pegmatitic gneisses of the TNCO, such as those in the Precambrian Taihua Complex and the Xiaohe granite in the Xiaoqinling area, may provide explanations on the issue of when the Eastern and Western Blocks collided to form the TNCO.

Considering the special tectonic location of the Xiaoqinling area within the TNCO, the geodynamic setting, petrogenesis, and geochronology of the Taihua Complex can provide important insights into understanding the formation and evolution of the TNCO (Zhao et al., 2001a, 2002, 2003a,b, 2006a,b,c, 2009; Huang et al., 2010; Zhao and Zhou, 2009; Li et al., 2010; Liu et al., 2012d). The Taihua Complex is the second largest gold-producing area in China (Chen and Fu, 1992; Mao et al., 2002, 2005; Jiang et al., 2009). Thus, the characteristics of the structures (Zhang et al., 1998, 2003; Zhang and Zheng, 1999; Li et al., 2006a) and strata (Ding, 1996a,b; Chen et al., 1997; Zhou et al., 1997, 1998b; Shi et al., 2011) as well as the tectonic evolution (Zhang et al., 1999; Jiang, 1986; Zhou et al., 1997, 1998b; Zhao et al., 2006c, 2009) of the Taihua Complex have attracted considerable attention.

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The Taihua Complex, previously known as the Xiaoqinling Precambrian terrain, is generally regarded as a group of lithostratigraphic units with metamorphic grades formed at different times (Ding, 1996a,b; Chen et al., 1997; Zhou et al., 1997, 1998b). However, whether the Taihua Complex formed in the Late Archean or in the Paleoproterozoic remains controversial. Through many geochronological methods such as paleontology (Ding, 1996a,b) and strontium–neodymium (Sr–Nd) (Huang et al., 1995), robidium–strontium (Rb–Sr) (Zhang and Li, 1998), samarium–neodymium (Sm–Nd) (Zhang and Li, 1998; Zhou et al., 1998a), zircon lead–lead (Pb–Pb), and argon–argon (Ar–Ar) dating methods (Ni et al., 2003), previous researchers have reported various ages for the Taihua Complex ranging from the Late Archean to the Paleoproterozoic. Recently, Wan et al. (2006a,b) reported sensitive high-resolution ion microprobe (SHRIMP) U–Pb zircon ages of 2730–2260 Ma for the Taihua Complex. Li et al. (2007) reported a whole-grain zircon $^{207}Pb/^{206}Pb$ mean age of 1955 ± 30 Ma (MSWD = 1.4) for the pegmatitic gneiss in the Taihua Complex and the metamorphic zircon age of 2462 ± 20 Ma (MSWD = 2.0).

The age of formation of the Xiaohe granite pluton is also highly controversial. Previous research suggested that formed during the Neoproterozoic Jinning because it was believed to intrude into the Gaoshanhe Group, a Mesoproterozoic layer overlying the Taihua Complex (Fig. 1). However, this claim was not supported by the discovery of a small granitic stock with a zircon age of ~999 Ma in the Gaoshanhe Group (Feng, 1998). The detection of a 0.2–1.5 m – thick sedimentary layer composed of clastic granite in the contact zone between the Gaoshanhe Group and the Xiaohe pluton in Yanzhihe, Luonan City, suggested that the Gaoshanhe Group unconformably overlies the Xiaohe pluton (Deng and Wang, 1998). Deng and Wang (1998) later proposed that the Xiaohe granite pluton was formed during the Mesoproterozoic (1600–1400 Ma).

In this study, we report new LA-ICPMS U–Pb zircon ages and Hf isotopic compositions for the granitic gneiss, gneissose pegmatitic granite, granitic veins, and Xiaohe granite in the Taihua Complex. Our results provide not only a critical limit on the formation age of the Taihua Complex, but also important insights into the tectonic history of the TNCO.

2. Geological setting

As mentioned above, the NCC consists of the Western and Eastern Blocks that were assembled along the TNCO (Fig. 1a) (Zhao, 2001; Zhao et al., 2001a; Li et al., 2010). The Western Block consists of the Yinshan Block in the north and the Ordos Block in the south, which amalgamated along the Khondalite Belt at ~1.95 Ga (Xia et al., 2008; Yin et al., 2009, 2011; Zhou et al., 2010; Li et al., 2011c,d; Wang et al., 2011). The Eastern Block is considered to have developed from a rift basin in the Paleoproterozoic, which was closed at 1.93–1.90 Ga, forming the Paleoproterozoic Jiao–Liao–Ji Belt (Li et al., 2005, 2006a, 2011a, 2012; Luo et al., 2004, 2008; Li and Zhao, 2007; Zhou et al., 2008; Zhao et al., 2011; Tam et al., 2012). The Taihua Complex is the central component of the Xiaoqinling area. It is located in the southern segment of the TNCO in the west–east direction and is structurally bound by the northern Taiyao Fault and the southern Xunmadao–Xiaohe Fault (Fig. 1c). The Taihua Complex consists of granitic and pegmatitic gneiss, magnetite quartzites, hornblende gneiss, granulites, hornblende–plagioclase gneiss, and localized eclogite enclaves. Several granitic veins are emplaced into the granitic gneiss.

The rock assemblages in the Taihua Complex can be easily divided into two parts by geological survey (Yu, 1995). The lower part of the Taihua Complex is composed primarily of orthometamorphite, namely, tholeiite and tonalite–trondhjemite–granodiorite (TTG) suites metamorphosed into amphibolite and TTG gneiss. Within the lower part of the complex, the eclogite with 60–64% pyrope (Zhang et al., 1999) in the Shancheyu Valley likely resulted from HP metamorphism related to the subduction of the South China plate beneath NCC during the Mesozoic (Li et al., 2010, 2011a). Petrographically, the hornblende–plagioclase gneiss is a high-pressure basic granulite occurring as a discontinuous boudin and dyke within the TTG gneisses, much like those in the Hengshan Complex in the TNCO (Zhao, 2009; Li et al., 2010). The upper portion of the Taihua Complex is a khondalite series from the Paleoproterozoic (Yu, 1995; Ding, 1996a,b; Jiang, 1986; Liu and Gao, 1990; Li et al., 2007) unconformably overlying different layers of the lower part (Yu, 1995).

Aside from the unconformity between the lower and the upper portions, several tectonic interfaces of various scales and characteristics are widely distributed within the Taihua complex (Zhang et al., 1985; Zhang and Zheng, 1999). A metamorphic core complex structure (Zhang et al., 1998, 2003; Zhang and Zheng, 1999) or extensional tectonics (Li et al., 2006b) was suggested for the Xiaoqinling area under an extensional setting of the Jurassic.

Three large Cretaceous granite plutons exist in the Xiaoqinling area, including the Huashan, Wenyu and Niangnianshan granites (Fig. 1c), which yielded SHRIMP U–Pb zircon ages of 133.8 ± 1.1 Ma (Guo et al., 2009), 138.4 ± 2.5 Ma, and 141.7 ± 2.5 Ma (Wang et al., 2010), respectively.

3. Samples and analytical methods

3.1. Sample collection

Samples for the bulk-rock geochemical analyses, LA-ICPMS U–Pb zircon dating, and Hf isotopic analyses were collected from the western Xiaohe granitic pluton to the eastern Wenyu pluton (Fig. 1c).

(1) Granitic gneiss of the Taihua Complex

The grayish-white granitic gneiss displays a medium- to fine-grained texture, with main mineral phases, including quartz (25%), K-feldspar (40%), plagioclase (25%), hornblende (5%), and biotite (5%). Some enclaves of early gray to dark gray hornblende gneiss within the granitic gneiss show clear intrusive contact relationships (e.g. with chilled margins) or cutting relationships. Several light-colored metamorphic differentiation bands are present within the hornblende gneiss. Pegmatitic dykes are also emplaced along several late joints or fractures. Both the granitic and hornblende gneiss are intruded by weakly metamorphosed mafic dykes with sharp and straight boundaries.

Sample xql0909-1 obtained from the granitic gneiss of the Taihua Complex exhibits a granular granoblastic texture and a weak gneissic or gneissic structure. The average quartz grains are larger than the feldspar grains (ca. 0.2–3 mm in diameter). The plagioclase grains are mostly euhedral–subhedral in shape.

(2) Gneissose pegmatitic granite in the Taihua Complex

Gneissose pegmatitic granite occur as irregular stocks or east–west oriented dykes of varying sizes and shapes in the Taihua Complex. Generally, a gradual and diffusive transition exists from the pegmatite to the wall rocks. Intense pegmatitization is developed in the outer contact zone, whereas hybridism is heavily developed in the inner contact zone.

Sample xql0912-2 obtained from the gneissose pegmatitic granite has a non-equigranular granitic pegmatitic texture and a weak gneissic or massive structure. The main mineral phases