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Middle Neoarchean magmatism in western Shandong, North China Craton: SHRIMP zircon dating and LA-ICP-MS Hf isotope analysis

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ABSTRACT

Western Shandong Province is a typical area of the North China Craton (NCC) where Neoarchean plutonic and supracrustal rocks are widely distributed. Early studies documented that ~2.7 Ga and ~2.5 Ga magmato-tectono-thermal events are well developed in the area. Here we report SHRIMP U–Pb ages and Hf-in-zircon isotopic data from ten samples of different magmatic rock types including hornblendite, gneissic tonalite, gneissic trondhjemite and gneissic granite. Magmatic zircon grains have $^{207}Pb/^{206}Pb$ ages ranging from 2667 to 2598 Ma. Some rocks contain ~2.5 Ga metamorphic rims and ~2.7 Ga zircon cores. The magmatic zircon grains have $\varepsilon_{Hf}(t)$ values and Hf crustal model ages of −1.1 to +11.3 and 3.02–2.4 Ga, respectively. Combined with an earlier study, our main conclusions are that the middle Neoarchean rocks mainly occur together with early Neoarchean rocks in the northeastern portion of the central belt. Juvenile additions to continental crust and crustal recycling played important roles in the middle Neoarchean of western Shandong Province, and the entire Neoarchean tectonic evolution can be divided into middle to early Neoarchean (2.75–2.6 Ga) and late Neoarchean (2.6–2.5 Ga) events.

1. Introduction

The Neoarchean appears to have been an important period for global formation of continental crust (Condie et al., 2009; Condie and Aster, 2010). Compared with the late Neoarchean (2.6–2.5 Ga), the early Neoarchean (2.8–2.7 Ga) was a more important period for crust formation. At around 2.7 Ga, juvenile additions from mantle sources as well as crustal recycling played significant roles worldwide during these magmato-tectono-thermal events as indicated by whole-rock Nd and zircon Hf isotopic studies (Ayer and Dostal, 2000; Belousova et al., 2010; Condie and Aster, 2010; Griffin et al., 2004; Guitreau et al., 2012; Halla, 2005; Henry et al., 1998; Kovalenko et al., 2005). It would appear that global major magmato-tectono-thermal events were more extensive in the middle Neoarchean (2.7–2.6 Ga) than in the late Neoarchean (Fig. 1a).

The North China Craton (NCC) is characterized by widespread late Neoarchean (mainly 2.55–2.5 Ga) tectono-thermal events, which resulted in the formation of supracrustal and magmatic rocks as a result of juvenile additions to the continent and reworking of older continental material (Diwu et al., 2010, 2011; Dong et al., 2012a; Geng et al., 2012; Jian et al., 2012; Kröner et al., 2005a, 2005b; Liu et al., 2009; Ma et al., 2013; Shen et al., 2005; Wan et al., 2010a, 2011a; Wang and Liu, 2012; Wu et al., 2005; Wilde et al., 2005; Zhao et al., 2002; Zhai and Santosh, 2011). Such events occurred only in a few areas on other cratons such as southern India, Antarctica, Brazil and northwestern Australia (Clark et al., 2009; Condie et al., 2005; Druppel et al., 2009; Jayananda et al., 2000; Veevers and Saeed, 2009). Recent studies have revealed that, similar to many other cratons, the NCC also experienced its main period of crustal growth in the late Mesoarchean to early Neoarchean (mainly 2.85–2.7 Ga) (Dong et al., 2012b; Han et al., 2012; Jahn et al., 2008; Jiang et al., 2010; Kröner et al., 2005a, 2005b; Lu et al., 2008; Ma et al., 2013; Wan et al., 2010b, 2011b, 2014; Yang et al., 2013; Zhu et al., 2013). Middle Neoarchean (2.7–2.6 Ga) tectono-thermal events were so far recorded only in a few areas of the NCC, including Zhongtiaoshan, Hebi and western Shandong Province (WSP) (Cao, 1996; Lu et al., 2008; Zhang et al., 2012; Zheng et al., 2012). It is uncertain how strong the middle Neoarchean event was and what the relationship was between the middle and early Neoarchean

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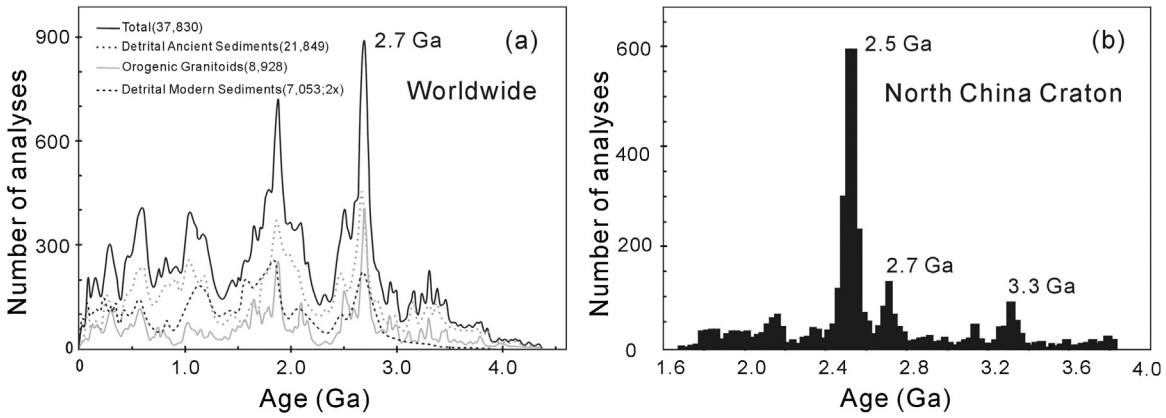

Fig. 1. Histograms showing distribution of magmatic zircon ages. (a) Worldwide (simplified after Condie and Aster, 2010), the detrital ancient sediment database is multiplied by two for comparative purposes and (b) North China Craton (Wan et al., 2011a).

events. We report SHRIMP U–Pb ages and Hf-in-zircon isotopic data for various magmatic rocks of middle Neoarchean age in the WSP, indicating that this event may also be widespread in the NCC, whereas the ~2.6 Ga tectono-thermal event may have been a final phase in a long evolution from 2.75 to 2.6 Ga.

2. Geological background

The WSP is located in the eastern NCC and is an area where Neoarchean magmatic rocks (mainly granitoids) and supracrustal assemblages are widely distributed, constituting the WSP granite-greenstone terrane, with a total area of ~10,000 km^2 (Fig. 2). Based on numerous studies, great progress on understanding the Archean geology of the WSP have been made (Cao, 1996; Cheng et al., 1977; Du et al., 2003, 2005, 2010; Jahn et al., 1988; Jiang et al., 2010; Lu et al., 2008; Peng et al., 2012; Polat et al., 2006; Wan et al., 2010a, 2011b, 2012; Wang et al., 2008, 2009a, 2013a, 2013b; Zhang et al., 1998, 2001; Zhuang et al., 1997) which we briefly summarize below.

(1) The WSP granite–greenstone belt extends roughly in a northwest-southeast direction and is truncated by the huge Tanlu Strike-Slip Fault in the east. Based on formation ages and rock types, the WSP can be divided into three belts: a late Neoarchean crustally derived granite belt in the northeast that consists predominantly of 2525–2490 Ma monzogranite and syenogranite and banded gneisses (Belt A), a middle to early Neoarchean belt in the center which is mainly composed of 2.75–2.60 Ga TTGs and supracrustal rocks (Belt B), and a late Neoarchean belt of juvenile rocks in the southwest that is dominated by granodiorite, gabbro, quartz diorite and tonalite, with some monzogranite and syenogranite (Belt C).

(2) Supracrustal rocks of the Taishan "Group" were once considered to have formed in the early Neoarchean (we use the terms "group" and "formation" with quotation marks since these are not lithopstratigraphic terms and refer to Wan et al. (2006) for discussion of this issue). However, contrary to earlier opinion, zircon dating has revealed that the Shancaoyu "Formation" and the upper part of the Liuhang "Formation" of the Taishan "Group" were deposited in the late Neoarchean (2.55–2.525 Ga), and not in the early Neoarchean (2.8–2.7 Ga). Also, the Jining "Group" was deposited in the late Neoarchean (2.55–2.525 Ga) and not in the early Paleoproterozoic (~1.8 Ga). The WSP is currently the only terrane in the NCC where both early and late Neoarchean supracrustal rocks have been identified. The early Neoarchean supracrustal rocks, named the Yanlingguang-Liuhang succession, include the original Yanlingguang "Formation" and the lower part of the Liuhang "Formation" of the Taishan "Group" and the Mengjiatun "Formation". They mainly occur in Belt B and consist of amphibolite and meta-ultramafic rocks with a few clastic metasedimentary layers. Some meta-ultramafic rocks show spinifix textures, and some amphibolites show massive or pillow structures. Most amphibolites are similar in composition to MORB.

(3) The late Neoarchean supracrustal rocks, named the Shancaoyu-Jining succession, include the original Shancaoyu "Formation" and the upper part of the Liuhang "Formation" of the Taishan "Group" and the Jining"Group" and occur in all three belts and consist mainly of fine-grained biotite gneiss, conglomerate, BIF and felsic metavolcanic rocks. Metasedimentary rocks show bedding with interlayered coarse-grained and fine-grained sandstone or fine-grained sandstone and pelitic siltstone. There are three potential sources for the late Neoarchean supracrustal rocks. (1) Intrusive late Neoarchean rocks which are represented by granitoids and minor gabbro in Belt C; (2) the middle to early Neoarchean basement in Belt B provided detritus containing zircon grains older than 2.6 Ga; (3) late Neoarchean volcanic rocks have the same ages as the intrusive rocks.

(4) The WSP is the largest area within the NCC where early Neoarchean (mainly 2.75–2.7 Ga) rocks have been identified, with a total area up to 500 km^2. This is the main evidence that the NCC is similar to many other cratons worldwide where magmato-tectono-thermal events of the early Neoarchean are well developed. The early Neoarchean magmatic rocks are mainly composed of TTGs and quartz diorite, occurring at different scales, with some intruding the Yanlingguang-Liuhang succession as veins. They commonly underwent significant metamorphism and deformation, resulting in local anatexis, due to ~2.6 Ga and ~2.5 Ga overprinting. More work is required to further determine the spatial relationship and relative proportion of the early and middle Neoarchean TTGs.

(5) The late Neoarchean magmatic rocks have zircon ages between 2560 and 2480 Ma. Rocks formed during the first phase (2560–2525 Ma) include gabbro, quartz diorite, granodiorite, tonalite, monzonite, quartz monzonite and syenogranite that are significantly deformed and metamorphosed. In contrast, similar rock associations formed during the second phase (2525–2480 Ma) are undeformed or only weakly deformed. This change suggests that the tectonic regime in the WSP changed from compression to extension between 2530 and 2520 Ma, a period when the magmatic activity reached a peak.