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An overview of the 2018 second class State Natural Science Award—North China Craton: formation and revolution of the oldest continent in China

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The formation, composition and evolution of the oldest continental crust is the logical starting point for discussing the differentiation and development of the crust-mantle system and the tectonic evolution of the Earth. Searching for and identifying the oldest continental crust and investigating the processes and periodicity of crust formation and its subsequent development into cratons is a primary scientific topic of worldwide research [1]. The other important issues related to early Precambrian evolution include identifying tectonic divisions and determining the onset of plate tectonics. However, the rarity of preserved ancient continental crust due to its long-term reworking makes this research extremely challenging. Thus, finding and identifying the oldest rocks and zircons is the beginning of very exciting and important research. The occurrence of ≥3.8 Ga rocks in northern and eastern Canada, West Greenland and eastern Antarctica are difficult to access and so it is important to identify other occurrences of such rocks.

The North China Craton (NCC) is the largest Archean to Paleoproterozoic craton in China. Compared to other cratons worldwide, most rocks of the NCC were reworked by complicated and extensive multiphase tectono-metamorphic processes that led to obliteration of much of its older history. Searching for and identifying records of the oldest continental crustal material in the NCC and reconstructing its evolution is therefore a major challenge.

Zircon is one of the most common accessory minerals in crustal rocks and has various advantages that make it the most suitable mineral for U-Pb dating. The Sensitive High Resolution Ion Microprobe (SHRIMP) has an extremely high mass and space resolution and enables in-situ analysis of different domains within a single zircon grain [2], which greatly facilitates research on early continental crust formation and evolution, especially since it is generally characterized by a prolonged and complicated history.

The second class State Natural Science Award "Age and evolution of the oldest continental crust in China", won by Yu-Sheng Wan, Dun-Yi Liu, Biao Song, Jiashan Wu and Qihan Shen from the Institute of Geology, Chinese Academy of Geological Sciences, is a result of long-term research utilizing field geology, zircon geochronology and geochemistry across the NCC. The primary scientific discoveries are three-fold and are summarized below.

During the project, 3.8 Ga rocks were discovered in three ancient complexes in the Anshan area, namely Baijiafen, Dongshan and Shengousi [3–6]. The rock types comprise mylonitized trondhjemite, banded trondhjemite and meta-quartz diorite. The discovery was a breakthrough in early Precambrian geology and rewrote the beginning of Archean crust formation and evolution in China. The three complexes have similar zircon age records from 3.8 to 3.1 Ga, suggesting that the Anshan area generally experienced a long-term high heat flow related to an ancient tectonic scenario dominated by magmatic underplating which was different from modern plate tectonics. In addition to the three old complexes, many 3.0–3.3 Ga relatively large scale intrusions and areas of supracrustal rocks were confirmed.

Based on a large number of geochronological and geochemical studies [3–7], the project produced the following fundamental results: (1) the source of some 3.8 Ga trondhjemitic rocks was intermediate and felsic crustal material rather than basaltic protoliths, indicating that there must have been older crustal material in the Anshan area. This is consistent with the conclusion that trondhjemite can be formed by parting melting of early TTG rock [8]. (2) During each tectono-magmatic event, including the 3.8 Ga event, magma additions derived from the mantle and crustal recycling both played important roles. However, crustal recycling became progressively more important with time from 3.8 to 3.0 Ga. (3) Differentiation of the light and heavy rare earth elements (REE) in the granitoids between 3.3 and 3.35 Ga varied from weak to strong, suggesting that the thickness of the crust in the Anshan area changed dramatically during that period. This is in accordance with the tectono-thermal events recorded by metamorphic and anatectic zircons. (4) Ancient crustal material not only exists in the Anshan area but most likely also at depth in the entire Anshan-Benxi area, expanding the spatial distribution of ancient crustal material in the NCC considerably.

During this project, a detailed study of the Archean basement was carried out in other areas of the NCC. Western Shandong is one such example. This region is almost exclusively occupied by Neoarchean crust and did not experience overprinting by Paleoproterozoic tectono-thermal events, revealing the following significant and innovative insights into Archean crust formation and evolution of the NCC [9]. (1) The Archean basement of western Shandong can be divided into three belts, which are mainly composed of (a) late Neoarchean migmatite and crustally-derived

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granites, (b) early Neoarchean rocks and (c) late Neoarchean mantle-derived rocks, respectively. (2) Supracrustal rocks were re-classified and sub-divided based on their lithological associations and time of formation. Supracrustal rocks deposited in the early and late Neoarchean are different in both association and mineralization. (3) Two continuous periods of magmatism were established at 2.6–2.75 and 2.49–2.55 Ga, respectively, whereas the period between2.56 and 2.59 Ga was interpreted as a "quiet period". (4) Two widespread tectono-thermal events were confirmed at ~2.6 and ~2.5 Ga as recorded by metamorphic and anatectic zircons. (5) The geological evolution was divided into two phases at the boundary of 2.6 Ga, namely an early and a late Neoarchean phase. The tectonic scenario changed from compression to extension during 2.52–2.53 Ga. (6) The early Neoarchean was characterized by major additions of mantle-derived material, whereas the late Neoarchean was characterized by a mixture of mantle-derived magmatism and crustal recycling, with the latter becoming more dominant through time.

This study revealed the common features of Archean geology of the NCC [9,10]. Multiphase tectono-magmatic-thermal events were identified throughout the Archean history for the first time, with new insights into the origin and evolution of 2.7 Ga granitoid rocks in the NCC, where significant crust formation occurred at 2.7–2.9 Ga. Furthermore, an extensive magmatic event at 2.5 Ga is a unique feature of the NCC that makes it different from many other cratons in the world. The spatial and temporal distribution of 2.5 Ga syenogranite in the NCC was first described in detail. The project confirmed that the majority of banded iron formations formed during the late Neoarchean. Hf isotopic compositions of zircons from Archean rocks indicate that rocks of 3.0–3.8 Ga show clear inheritance relationships, whereas huge mantle addition to the crust occurred between 2.5 and 2.9 Ga (Fig. 1). Three ancient (>2.6 Ga) continental blocks and a huge tectonic belt were recognized in the NCC, being considered to be important marks of plate tectonics.

The depositional age of khondalites is difficult to determine, and widespread strong metamorphism and deformation has led to extensive overprinting of the original depositional features. This resulted in a long-lasting debate in China on the formation age of these khondalites. Benefiting from the SHRIMP dating technique, systematic zircon geochronology was undertaken on khondalites and associated rocks [11]. The results showed that the khondalites mainly formed during the middle to late Paleoproterozoic rather than in the Archean as thought before. They were strongly reworked by an extensive and severe late Paleoproterozoic high-grade tectono-thermal event, as supported by recent study on Paleoproterozoic garnet-bearing mafic granulites from the Huai'an Complex [12]. Extensive middle to late Paleoproterozoic mafic and intermediate-felsic intrusions were identified. The Ordos Block to the south of the khondalites was traditionally regarded as a typical Archean craton. However, there occur abundant Paleoproterozoic khondalites in its basement, and these were strongly reworked by a late Paleoproterozoic tectono-thermal event. In areas where Archean basement coexists with Paleoproterozoic rocks, the former were almost always reworked by both late Neoarchean and late Paleoproterozoic tectono-thermal events. The revision of the likely Paleoproterozoic khondalite depositional age and identification of two overprinting tectono-thermals events greatly changed and improved the interpretation of the early Precambrian geological evolution of the NCC.

Two groups of researchers led respectively by Professors Mingguo Zhai and Guochun Zhao also won the second class State Natural Science Award in past years. Zhai et al. [13] reconstructed a lower-crustal section in the NCC, which is one of the most integrated sections in the world. It is further emphasized by the contributions of vertical differentiation to the cratonization process. This group discovered high pressure metamorphic rocks for the first time in the NCC, including high pressure granulites and retrograded eclogites. This provided evidence for the initiation of plate tectonics at the Paleoproterozoic, setting the initiation time before 0.8–0.9 Ga [14]. Zhao et al. [15] recognized three discrete metamorphic zones in the NCC, namely: the Trans-North China Orogen, Khondalite Belt and Jiao-Liao-Ji Belt. The Trans-North China Orogen divides the NCC into the Eastern and Western blocks, whereas the Palaeoproterozoic Khondalite Belt divides the Western Block into the Yinshan Terrane in the north and the Ordos Terrane in the south; whereas the Jiao-Liao-Ji Belt is a Paleoproterozoic rift. These belts indicate that the collision between the Eastern and Western blocks occurred during the late Paleoproterozoic, resulting in the formation of the Trans-North China Orogen and final amalgamation of the NCC [15].

All research achievements were concerned with crust formation and evolution of the NCC in the early Precambrian. They not only greatly enriched the perception of crustal evolution of the early Earth but also made the NCC more prominent in the international field of research on early Precambrian crustal evolution.

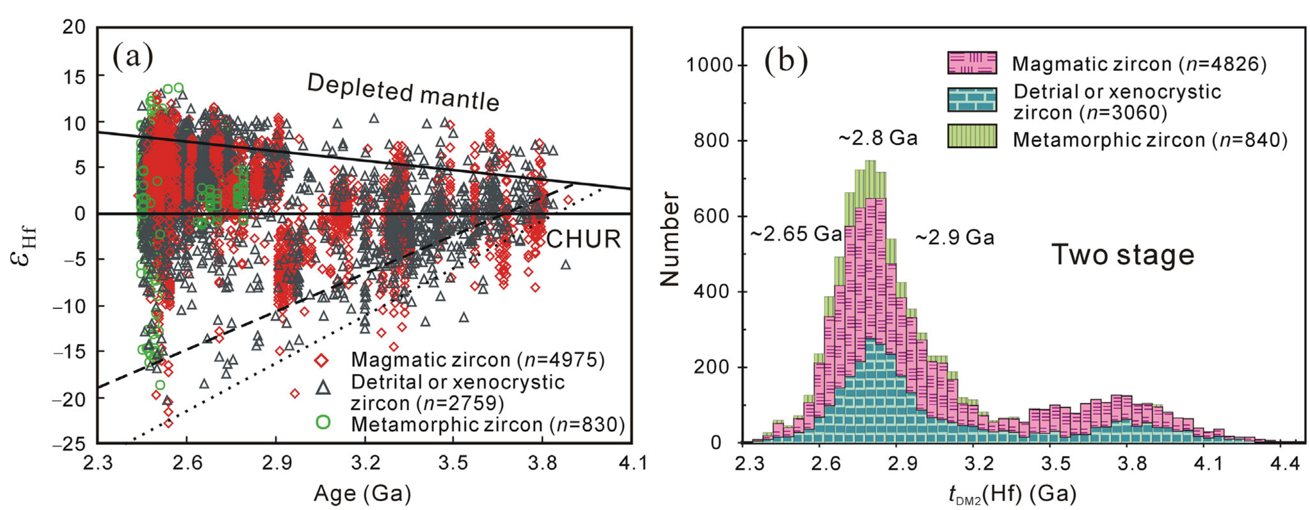

Fig. 1. Age-ε_{Hf} diagram (a) and crustal Hf model age histogram (b) for zircons from Archean rocks of the North China Craton [9].

Conflict of interest

The authors declare that they have no conflict of interest.

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