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Th–U–Pb monazite geochronology of the Lüliang and Wutai Complexes: Constraints on the tectonothermal evolution of the Trans-North China Orogen

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Abstract

Recent lithological, metamorphic and geochronological studies show that the basement of the North China Craton (NCC) formed by collision of two discrete Archean to Paleoproterozoic blocks (Eastern and Western Blocks) along a Paleoproterozoic orogen, named the Trans-North China Orogen. However, the timing of the collision is controversial and post-collisional exhumation has not been precisely dated. This study applies the electron microprobe Th–U–Pb monazite dating technique to determine the ages of the peak metamorphic event and subsequent exhumation of the low- to medium-grade Lüliang and Wutai Complexes in the Trans-North China Orogen. Electron microprobe Th–U–Pb monazite data for the Lüliang Complex reveal five ThO_2^*/PbO age ranges: (1) 1940–1938 Ma, (2) 1880–1847 Ma, (3) 1795–1755 Ma, (4) 1720–1703 Ma, and (5) ∼1648 Ma. Of these age ranges, the first four have also been recorded in the Wutai Complex, which yields ThO_2^*/PbO ages of (1) ∼1930 Ma, (2) 1838–1822 Ma, (3) ∼1793 Ma, and (4) ∼1719 Ma. The oldest age range of 1940–1930 Ma is interpreted to record the widespread emplacement of mafic dikes in rocks of the Lüliang and Wutai Complexes. The age range of 1882–1822 Ma is in accord with the SHRIMP U–Pb ages of metamorphic zircons and mineral Sm–Nd and $^{40}Ar/^{39}Ar$ ages obtained for other complexes in the orogen, and is interpreted as the age of the major metamorphic event caused by amalgamation between the Eastern and the Western Blocks. The age range of 1795–1755 Ma is consistent with emplacement of large scale unmetamorphosed mafic swarms at 1800–1765 Ma, interpreted as the time of post-orogenic extension. The 1720–1703 Ma and ∼1648 Ma ages are considered to date later multiple stages of hydrothermal alteration, since monazites with such young ages only occur along fractures in older monazite grains and at the rims. These new monazite ThO_2^*/PbO ages support the tectonic model for the evolution of the North China Craton that envisages discrete Eastern and Western Blocks colliding along the Trans-North China Orogen at ∼1.85 Ga and then undergoing post-collisional extension in the period 1795–1755 Ma.
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Keywords: Electron microprobe dating; Th–U–Pb monazite ages; Crystal age mapping; Paleoproterozoic; Trans-North China Orogen; North China Craton

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1. Introduction

The most important progress in recent years in the study of the North China Craton (NCC) is the recognition of an orogenic belt, named the Trans-North China Orogen (Zhao et al., 1998), which divides the craton into two discrete units: the Western and Eastern Blocks (Zhao et al., 1998, 1999a, 1999b, 1999c, 2001a, 2001b, 2005; Wilde et al., 1998, 2002). Based on available lithological, structural, metamorphic and geochronological data, Zhao et al. (2001b) suggested that the Trans-North China Orogen represents a collisional orogen along which the Eastern and Western Blocks were amalgamated to form the North China Craton. This tectonic scenario has subsequently been accepted and advanced by many researchers (Wu and Zhong, 1998; Guan et al., 2002; Guo and Zhai, 2001; Guo et al., 2002; Liu et al., 2002a, 2002b, 2004a, 2004b; Wilde et al., 2002, 2004a, 2004b, 2005; Kröner et al., 2002, 2005a, 2005b; Wu and Zhong, 1998; O'Brien and Rotzler, 2003; Zhai and Liu, 2003; Zhai et al., 2003). However, controversy has surrounded the timing of collision between the Eastern and Western Blocks, with one school of thought proposing that the collision occurred at ∼2.5 Ga (Li et al., 2000; Kusky et al., 2001; Li et al., 2002; Kusky and Li, 2003; Polat et al., 2005), whereas others believe that the final amalgamation of the two blocks was completed at ∼1.85 Ga (Zhao, 2001; Guo and Zhai, 2001; Guo et al., 2002; Kröner et al., 2002, 2005a, 2005b; Guan et al., 2002; Zhao et al., 2002; Wilde et al., 2002, 2004a, 2004b, 2005).

In the last few years, some important geochronological data have been obtained for the Fuping, Hengshan and Huai'an Complexes, using the SHRIMP U–Pb zircon and mineral Sm–Nd dating techniques. These data show that metamorphism of these complexes occurred in the period 1880–1820 Ma, suggesting that the collision between the Eastern and Western Blocks took place at ∼1.85 Ga (Zhao et al., 2002, 2005; Guan et al., 2002; Wilde et al., 2002, 2005; Kröner et al., 2002, 2005a, 2005b; Guo et al., 2005; Wang et al., 2001; Wang et al., 2003, 2004a, 2004b; Liu et al., 2002a, 2002b). However, these ages were obtained from upper amphibolite to granulite facies rocks from complexes in the central part of the orogen, and few metamorphic ages have been obtained from low- to medium-grade metamorphic rocks. Recently, it has been established that the same tectonothermal imprint is recorded in the central eastern part of the orogen at Zanhuang (Wang et al., 2004a, 2004b) and at Lushan in the southern part of the orogen (Wan et al., 2006) (Fig. 1), alluding to the wide extent of the activity in the Trans-North China Orogen. However, few data can be used to constrain the timing of post-collisional events, which is crucial in understanding the full tectonothermal history of the orogen.

The electron microprobe Th–U–Pb monazite dating technique (including age mapping) has been widely used to date syn- and post-orogenic tectonothermal events, especially for low- to medium-grade metamorphic terrains where the application of SHRIMP U–Pb zircon dating is limited because of the lack of metamorphic zircon (Suzuki and Adachi, 1991, 1998; Montel et al., 1996, 2000; Braun et al., 1998; Cocherie et al., 1998; Cocherie and Albarede, 2001; Cocherie et al., 2005; Williams, 1998; Santosh et al., 2005). The major advantages of using the electron microprobe Th–U–Pb monazite dating technique include rapid analysis with minimal preparation, low cost and excellent spatial resolution (spot size <2 μm), which enables Th–U–Pb analysis on a small-scale, and in situ age mapping of individual monazite grains (Zhu et al., 1997; Zhu and O'Nions, 1999; Teufel and Heinrich, 1997; Catlos et al., 2002; Mathieu et al., 2001; Rasmussen et al., 2001). In addition, numerous studies have shown that monazite can easily dissolve and re-precipitate at low grades of metamorphism, but that Pb-diffusion in monazite is insignificant after its formation, which enables the Th–U–Pb dating of monazite to be a powerful tool for obtaining reliable metamorphic ages from low- to medium-grade metamorphic rocks (Zhu et al., 1997; Zhu and O'Nions, 1999; Catlos et al., 2002; Cocherie et al., 2005; Dahl et al., 2005; Goncalves et al., 2005; Seydoux-Guillaume et al., 2005). The electron microprobe chemical Th–U–Pb dating method is limited in its application to calcium-rich rocks, which have low monazite contents, and also to rocks altered strongly by later hydrothermal fluids, since any pre-existing monazite grains are easily altered through dissolution and precipitation. The precision of the electron microprobe method is also usually lower than the SHRIMP U–Pb, zircon dating technique. However, recently published data show that the precision of electron microprobe chemical dating of monazite for Precambrian geological samples can be improved from ca. 10% ten years ago (Montel et al., 1996) to ca. 1–3% of sample age either through the use of the new model of electron microprobes or by improved calculation methods (Cihan et al., 2006; Swain et al., 2005; Mezeme et al., 2005; Cocherie et al., 1998, 2005; Cocherie and Albarede, 2001; Pyle et al., 2005). This dating precision can now effectively distinguish metamorphic and deformation episodes within a single orogenic event, making the chemical Th–U–Pb dating of monazite a powerful tool when applied to medium- to low-grade metamorphism and associated deformation.

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