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Zircon Trace Element Compositions Reveal the Change of Tectonic Setting in Trans–North China Orogen

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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) (e.g. Zhao et al., 1998, 2001; Yu et al., 2013). However, the timing and tectonic processes involved in the collision of these blocks to form the NCC basement remain controversial (e.g. Kusky and Li, 2003; Zhao et al., 2005; Yu et al., 2013). The Xiaoqinling area is located in the interior of TNCO. Considering its special tectonic location, the geodynamic setting and tectonic evolution of the Xiaoqinling area can provide important insights into understanding the formation and evolution of the TNCO.

1 Samples, Ages and Zircon Trace Element Compositions

The samples were collected from surface exposures of the Xiaohe granite pluton and the granitic veins in Taihua Complex in the Xiaoqinling area. The age of the Xiaohe granite pluton was mainly limited to the Mesoproterozoic to Neoproterozoic in previous studies. In recent study, we report a new LA–ICPMS U–Pb zircon age of 2,328 ± 14 Ma of the Xiaohe granite pluton; whereas the granitic veins intruded into the granitic gneisses of the Taihua Complex give a U–Pb zircon age of 1,881 ± 24 Ma.

This paper conducted zircon trace element composition analysis of Xiaohe pluton and the granitic veins in Taihua Complex from the Xiaoqinling area. All the analyses are depleted in LREE and enriched in HREE in chondrite normalized REE patterns (Figure 1c, d). The zircon grains from the Xiaohe pluton show high positive Ce anomalies and variable Eu anomalies (Figure 1c). In contrast, zircon grains from granitic veins yield positive Ce anomalies and negative Eu anomalies (Figure 1d).

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2 Discussions

2.1 Ti-zircon temperature

Titanium content in zircons is a sensitive thermometer because of the temperature dependant incorporation of Ti^{4+} into crystallizing zircon. Watson and Harrison (2005) suggested that the temperature of zircon crystallization can be calculated with the following equation:

$$\log(\mathrm{Ti}) = 6.01 \pm 0.3 - \frac{5080 \pm 30}{T(K)}$$

This thermometer has been widely used to identify magma forming or metamorphism temperature. The Ti concentrations of zircons from Xiaohe pluton range from 1.96 to 14.15 ppm, and the calculated temperatures range from 615 to 772°C. The calculated temperature of zircons from granitic veins ranges from 592 to 708°C with Ti concentrations ranging from 1.37 to 6.77 ppm.

2.2 Magma oxidation state

Traditional oxidation probe, such as Fe-Ti and Fe^{3+}/Fe^{2+} oxidation probes are prone to resetting during slow cooling of magma, or are easily influenced by hydrothermal alteration or surface weathering. Zircon is a resistant mineral with high closure temperature. Incorporate Ce^{4+}, and thus the Ce anomalies in zircon, provides a qualitative estimate of the oxidation state of the magma.

Trail et al. (2011, 2012) conducted a series of experiments and proposed a calibration for determining the oxidation state of the melt based on the incorporation of cerium into zircon and Ti-in-zircon temperature, which can be expressed in the following empirical equation:

$$\ln\left(\frac{Ce}{Ce^*}\right)_{CHUR} = (0.1156 \pm 0.0050) \times \ln(f_{O_2}) + \frac{13860 \pm 708}{\mathrm{T}} - 6.125 \pm 0.484$$

Where fO_2 is oxygen fugacity, T is absolute temperature calculated by Ti-in-zircon thermometer. $(Ce/Ce^*)_{CHUR}$ on

the left side of the equation is Ce anomaly of zircon.

The average log oxygen fugacity for the Xiaohe granite is FMQ+1.47 (high oxygen fugacity), whereas that for granitic veins in Taihua Complex is FMQ-2.9 (low oxygen fugacity) (Fig. 1e, f).

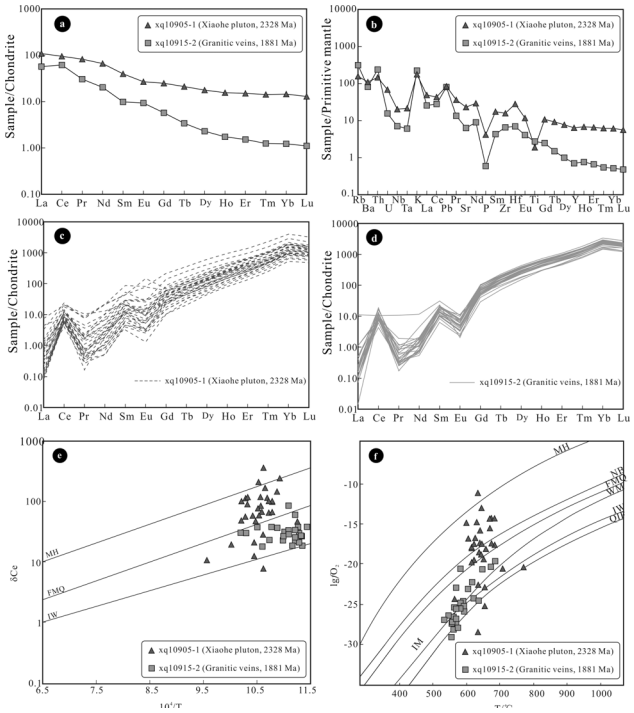

Fig. 1 Chondrite-normalized REE diagrams (a); Primitive mantle-normalized spider diagram (b); Zircon REE patterns of the Xiaohe granite pluton and the granitic veins (c, d); Magma oxidation states of the Xiaohe granite pluton and the granitic veins (e); Magma oxygen fugacities of the Xiaohe granite pluton and the granitic veins (f).

2.3 Mechanism of high oxygen fugacity magmas

Controlling factors of high fO_2 has long been a prominent topic. some scholars found that Mid-ocean ridge basalts (MORB) appear to have fO_2 systematically lower than that of arc lavas: relative to the fayalite–magnetite–quartz (FMQ) buffer, MORB have fO_2 between -2 and 0 log units from the FMQ buffer (FMQ–2 and FMQ), whereas arc lavas have fO_2 ranging between FMQ and FMQ+6 (Christie et al., 1986; Carmichael, 1991). Fluids released from subducted slabs were commonly invoked to explain the elevation of oxidation state in the arc lavas. For the recent study, Wang et al. (2013) proposed that the elevated fO_2 was related to the sediments carried by subducting slabs. Therefore, the high oxygen fugacity can suggest that magmas formed in volcanic-arc setting with subduction-related.

2.4 Tectonic implication

The difference in magma oxidation states strongly suggests distinct tectonic environments of Trans–North China Orogen in 2, 328 Ma and 1, 881 Ma. The Xiaohe pluton with high oxidation state is associated with subduction of oceanic crust or injection of metasomatized mantle, while the granitic veins with low oxidation state may be generated in a non-subducted environment where there were no adequate subducted fluids and materials that increase magma oxidation state. Combining with our previous works in the same region, the dataset in this paper suggests the ocean between the Eastern and Western Blocks were completely subducted at ~1.85 Ga. The oxygen fugacity probe may serve as a potential tool, in addition to bulk rock geochemistry, to constrain tectonic environment.

Key words: Zircon trace element compositions; Ti-zircon temperature; oxygen fugacity; Tectonic evolution; Xiaoqinling area; Trans–North China Orogen

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