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Geochemistry, isotope systematics and petrogenesis of the volcanic rocks in the Zhongtiao Mountain: An alternative interpretation for the evolution of the southern margin of the North China Craton

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Abstract

The Xiong'er volcanic rocks constitute a large Paleo-Mesoproterozoic volcanic belt along the southern margin of the North China Craton, which are composed primarily of basaltic andesites and andesites, with minor dacites and dacitic rhyolites. The basaltic andesites and andesites from the Xiong'er volcanic rocks in the Zhongtiao Mountain show consistent $\varepsilon_{Nd}(t)$, La/Nb and Th/Nb values irrespectively of SiO_2, which preclude significant crustal contamination during ascent. Both of these volcanic rocks share similar incompatible ratios (e.g. La/Sm, Zr/Nb, La/Nb), indicating that the basaltic andesites and andesites originated from the same source. The basaltic andesites are characterized by high Mg-number (45–55%), precluding the possibility of their derivation from the melting of the lower crust. Variable Ti/Eu, Zr/Sm and Nb/La ratios for the basaltic andesites with higher partial melting degree suggest that amphiboles remained as residues in the magma source, indicating that the Xiong'er volcanic rocks were derived from hydrous magma. Non-radiogenic Nd isotopes for the Xiong'er volcanic rocks are inherited from a mantle source which had been enriched by the subduction-related crustal recycling during Archean to Paleoproterozoic time. Basaltic andesites show HFSE enrichments (especially $Nb > 4.7$ ppm) and high Fe–Ti contents, comparable with Nb-enriched basalts, suggesting that the Xiong'er volcanic rocks were derived from a metasomatized mantle source, similar to that of Nb-enriched basalts. Therefore, the mantle source of the Xiong'er volcanic rocks in the Zhongtiao Mountain has been enriched in Fe–Ti oxides and HFSE by equilibrium reactions with the slab melts during late Archean and Paleoproterozoic subduction processes, as evidenced by Nd isotopes. In the primitive mantle normalized trace element diagrams, the Xiong'er volcanic rocks show enrichments in the LILE and LREE and negative anomalies on the Nb–Ta–Ti, similar to arc-related volcanic rocks produced by the hydrous melting of the metasomatized mantle wedge. In the Paleo-Mesoproterozoic, the Xiong'er volcanic rocks in the Zhongtiao Mountain were produced by the slab dehydration-induced melting of an existing metasomatized mantle source, and the fluids from the slab dehydration introduced significant LILE and LREE to the source, masking its inherent HFSE-enriched characteristics. The arc-related characteristics of the Xiong'er volcanic rocks in the Zhongtiao Mountain suggest the Xiong'er volcanic belt constructs a subduction zone along the southern margin of the North China Craton in the Paleo-Mesoproterozoic, implying that the craton may have recorded the outbuilding history of the Columbia Supercontinent during Paleo-Mesoproterozoic time.

Keywords: Xiong'er volcanic rocks; Paleo-Mesoproterozoic subduction zone; Mantle source enrichment; North China Craton

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1. Introduction

Major advancements in understanding the geological history of the North China Craton have been made in the past a few years, following recognition of two major Paleoproterozoic orogenic belts: the Trans-North China Orogen and the Khondalite Belt (Fig. 1A) (Zhao et al., 1998, 1999, 2000, 2001). The Trans-North China Orogen (TNCO) divides the North China Craton into two discrete blocks, named the Eastern and Western Blocks, whereas the Paleoproterozoic Khondalite Belt divides the Western Block into the Yinshan Block in the north and the Ordos Block in the south (Fig. 1A). There is a broad consensus that the Khondalite Belt and TNCO represent two independent Paleoproterozoic continent–continent collisional belts, with the Khondalite Belt formed at ~1.9 Ga (Zhao et al., 2005; Xia et al., 2006a,b; Santosh et al., 2006, 2007), and the TNCO formed at ~1.85 Ga by the amalgamation of the Western and Eastern Blocks to form the North China Craton (Zhao et al., 2001; Wilde et al., 2002; Zhao et al., 2005; Kröner et al., 2005, 2006; Liu et al., 2006; Zhang et al., 2006, 2007). This provides an outline of the timing and tectonic processes involved in the Paleoproterozoic amalgamation and much knowledge concerning the pre-collisional history of these blocks has subsequently been incorporated into the history of the North China Craton (Kröner et al., 1998; Wu and Zhong, 1998; Zhao et al., 1998, 1999; Zhai et al., 2000; Zhao et al., 2000, 2001; Guan et al., 2002; Guo et al., 2002; Liu et al., 2002; Wilde et al., 2002; Zhao et al., 2003a; Wang et al., 2003; Zhai and Liu, 2003; Liu et al., 2004; Wang et al., 2004; Guo et al., 2005; Kröner et al., 2005; O'Brien et al., 2005; Wilde and Zhao, 2005; Wilde et al., 2005; Wu et al., 2005; Zhao et al., 2005; Kröner et al., 2006; Zhao et al., 2006). However, the Paleo-Mesoproterozoic post-collisional history of the craton remains poorly resolved.

Paleo-Mesoproterozoic rocks in the North China Craton are mainly present in the central part and along the southern and northern margins of the craton, including the Changcheng and Jixian Groups (Systems) in the central part, the Xiong'er volcanic rocks (called the Xiong'er Group) along the southern margin, and the Zhaertai, Bayan Obo and Huade Groups along the northern margin. The Changcheng and Jixian Groups are considered to represent deposition in an intracontinental rift-controlled basins, whereas the Zhaertai, Bayan Obo and Huade Groups are interpreted as the infills of a crustal-scale Mesoproterozic rift that formed by the breakup of the North China Craton from an unknown continental block during fragmentation of the Paleo-Mesoproterozoic supercontinent Columbia (Zhao et al., 2002a,b, 2004a). However, the tectonic significance of the Xiong'er volcanic rocks along the southern margin of the North China Craton is still controversial, with one school of thought considering that they developed in a continental rift environment (Sun et al., 1981; Zhao et al., 2002b), whereas others argue that they formed at an Andean-style continental margin (Jia, 1985; Hu, 1988; Chen and Fu, 1992; Chen et al., 1992). To resolve this issue, we carried out extensive geological, geochemical and geochronological investigations on these volcanic rocks and here report new data for the Xiong'er volcanic rocks in the Zhongtiao Mountain, which place important constraints on the tectonic setting of the volcanic rocks along the southern margin of the North China Craton.

2. Geological setting of the Xiong'er volcanic rocks in the Zhongtiao Mountain

The North China Craton refers to the Chinese part of the Sino-Korean Craton, covering most of northern China, the southern part of northeastern China, Inner Mongolia, the Bohai Bay and the northern part of the Yellow Sea. It is bounded by faults and younger orogenic belts, with the early Paleozoic Qilianshan Orogen and late Paleozoic Central Asian Orogenic Belt to the west and the north, respectively, and the Mesozoic Qinling-Dabie and Su-Lu ultrahigh-pressure metamorphic belts, to the south and east (Fig. 1A). The basement of the Eastern and Western Blocks is dominated by late Archean tonalitic–trondhjemitic–granodioritic (TTG) domiform batholiths, tectonically interdigitated with local supracrustal rocks. The basement rocks in the Trans-North China Orogen differ in containing fragments of oceanic crust, mélanges, high-pressure granulites, retrograded eclogites and crustal-scale ductile shear zones (Zhao et al., 2001 and reference therein).

Along the southern margin of the North China Craton is a large Paleo-Mesoproterozoic volcanic belt represented by the Xiong'er volcanic rocks that cover a bulk area of more than 25, 000 km^2 (Fig. 1B). The belt is bounded by the Lintong–Tongguan–Sanmenxia–Jiangxian (LTSJ). Fault in the northwest and the Tieshanhe–Luoyang–Yichuan–Baofeng–Luohe Fault in the northeast, and is separated from the Mesoproterozoic Kuanping ophiolite complex in the south by the Luonan–Luanchun Fault (Fig. 1B). The Xiong'er volcanic belt is exposed in the Zhongtiao, Xiao, Xiong'er and Waifang Mountains (Fig. 1B), and is dominated by basaltic andesite, andesite, dacite and rhyolite, with minor dacitic porphyry and intermediate to silicic tuff, lithologically similar to rock associations of modern continental margin arcs, but different from those of continental rifts, which are bimodal, with basaltic and ultramafic volcanic rocks are associated