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Mesoproterozoic mafic and carbonatitic dykes from the northern margin of the North China Craton: Implications for the final breakup of Columbia supercontinent

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ABSTRACT

The North China Craton (NCC) has figured prominently in recent reconstructions on the Paleoproterozoic supercontinent Columbia. Here we report abundant carbonatitic and mafic dykes from around the giant Bayan Obo rare earth element deposit in the northern margin of the NCC, and present geochemical and isotope geochronological data. The carbonatite (1354 ± 59 Ma) and mafic dykes (1227 ± 60 Ma) have comparable whole rock Sm–Nd isochron ages and Sr–Nd isotope compositions, suggesting a common source characteristic. Their geochemical characters including major and trace elements as well as REE patterns also attest to a common tectonic environment of magma generation and emplacement within a continental margin rift. The extensive mafic and carbonatitic magmatisms are associated with an extensional event that resulted in the formation of the Bayan Obo rift in the northern margin of the NCC, which we correlate with the final stages of fragmentation of the Columbia supercontinent amalgam.

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1. Introduction

The late Mesoproterozoic globe witnessed extensive magmatic activity manifested in the form of mafic dyke swarms and related volcanic suites within a relatively short span of time ranging from ca. 1.35–1.21 Ga (Zhao et al., 2004, 2009; Ernst et al., 2008; Hou et al., 2008a) (Fig. 1). Imprints of this rift-related magmatic activity are preserved in various continents including North America (Le Cheminant and Heaman, 1989; Ernst et al., 1995, 2001; Ernst and Buchan, 2003), South America (Raposo and D'Agrella, 2000), Africa (Hunter and Reid, 1987), Greenland (Nielsen, 1987; Cadman et al., 2001), Australia (Mortimer et al., 1988; Pidgeon and Nemchin, 2001), India (Chalapathi Rao et al., 1996, 2010; Chalapathi Rao, 2007; Dharma Rao et al., 2010), and east Antarctica (Sheraton et al., 1990). One of the most widely distributed dyke swarms of this period is the Mackenzie swarm in northwest Canada (Ernst et al., 1995), which extends over an area of 2.7 million km^2 from a central domain comprising large ultramafic–mafic intrusions. Precise U–Pb dating has shown that these mafic dykes and intrusions were emplaced within a very short period of 1272–1267 Ma (Le Cheminant and Heaman, 1989). The other dike swarms with similar age in North America include the 1.24 Ga Sudbury dyke swarm and 1.25 Ga Mealy dike swarm (Ernst et al., 2008). These mafic dyke swarms are considered to signal the final breakup of the Columbia supercontinent in the late Mesoproterozoic (Rogers and Santosh, 2002, 2004, 2009; Hou et al., 2008a; Santosh et al., 2009; Hou et al., 2010). The North China Craton (NCC) has been considered as an integral part of the Paleoproterozoic supercontinent Columbia (Zhao et al., 2002; Kusky et al., 2007; Santosh et al., 2007a,b; 2010; Rogers and Santosh, 2009; Santosh, 2010). Among the various paleogeographic configurations of the NCC within the Columbia amalgam, the model proposed by Hou et al. (2008a,b) is based largely on the extensive mafic dyke swarms which traverse the NCC, and their robust correlation with similar suites in other crustal fragments of this supercontinent assembly. The NCC is traversed by a number of Mesoproterozoic continental rifts, both within the central part of the craton and at its margins (Fig. 2a). These include the Zhaertai–Bayan Obo rift in the north, Yanliao rift in the east, and Xiong'er rift in the south, with the timing of their formation since 1.8 Ga (Kusky and Li, 2003; Zhai, 2004; Zhao et al., 2004, 2009; Li et al., 2006; Peng et al., 2007). However, mafic dyke swarms of late Mesoproterozoic age, although common in many parts of the world, have seldom been reported from the NCC in previous studies.

In this study, we document abundant late Mesoproterozoic (1.35–1.21 Ga) mafic and carbonatitic dykes from the northern margin of the NCC (Fig. 2), associated with the famous Bayan Obo giant rare earth element (REE) ore deposit. Based on detailed investigations on the distribution and emplacement relationship of these dykes, as well as their petrology, geochemistry and isotope characteristics, we provide

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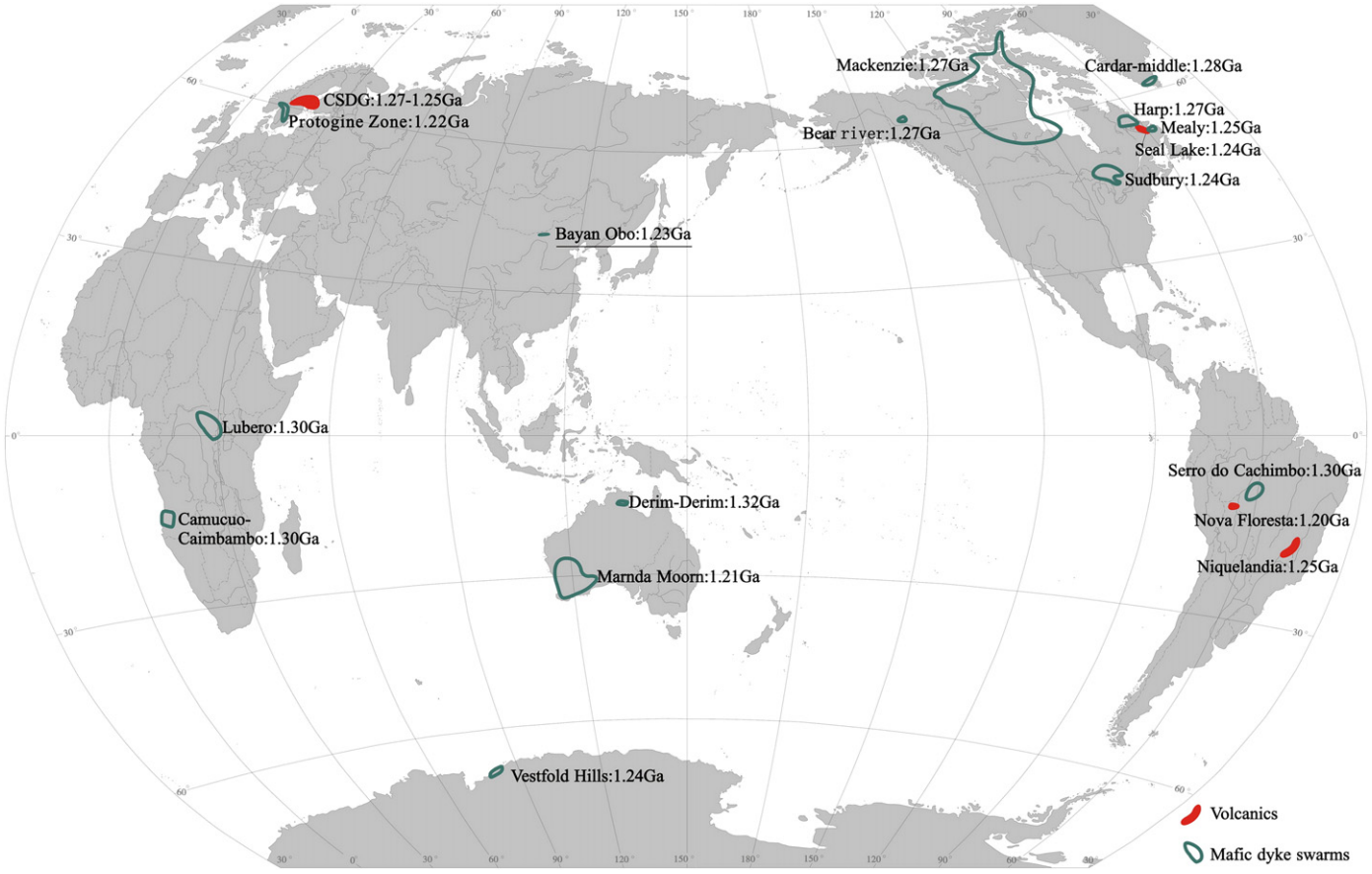

Fig. 1. Global distribution of mafic dyke swarms and volcanics between 1.35 and 1.20 Ga, (modified after Ernst et al., 2008).

new insights into mafic–carbonatitic magmatism associated with the final stages of the breakup of the Columbia supercontinent.

2. Geological background

The Bayan Obo district is located at the northern margin of NCC bordering the Central Asian Orogenic Belt to the north (Xiao et al., 2003, 2010; Xiao and Kusky, 2009) (Fig. 2a). Gentle fold structures, composed mostly of low grade metasedimentary units of the Mesoproterozoic Bayan Obo Group are distributed from south to north in the region (Fig. 2b). The famous Bayan Obo giant REE deposit occurs in one of the syncline cores. To the north of the ore body, a complete sequence of Bayan Obo Group is exposed in the Kuangou anticline, which developed on the Paleoproterozoic basement rocks with a distinct angular unconformity. The low grade clastic sequences of the Bayan Obo Group represent the sedimentary units deposited within the Bayan Obo marginal rift which developed during the Mesoproterozoic continental breakup event (Wang et al., 1992).

Adjacent to the giant REE deposit and especially within the Kuangou anticline, abundant carbonatite dykes are seen intruding the Bayan Obo Group of low grade metasediments, as well as the basement rocks (Fig. 2b). The dykes, almost vertically cutting the strata, are typically 0.5 to 2.0 m wide and 10 to 200 m long, and show a northeast or northwest strike. In addition, there are two small carbonatite stocks towards the northern domain of the ore body. Le Bas et al. (2007) considered them as a coarse-grained carbonatite which survived the extensive mineralization event in the Mesoproterozoic.

It is thought that the majority of continental carbonatites result from mantle magmatism following crustal stretching and thinning (Tilton and Bellk, 1994; Smithies and Marsh, 1998). Magmatism in such tectonic settings is often characterized by alkalic–basic anorogenic suites and may include kimberlite, lamprophyre and carbonatite (Dawson, 1989). The association of mafic magmatic dykes together with carbonatites in the Bayan Obo region therefore provides an excellent example of late Mesoproterozoic mantle magmatism and has therefore important implications on the rift tectonics associated with the NCC within the Columbia supercontinent.

3. Sampling and field relation

The mafic dykes are typically 1.0 to 2.0 m wide and 10 to 100 m long. In the Bayan Obo ore deposit, they incise the banded REE ore body as well as the overlying K-rich slate of the Bayan Obo group (Fig. 3a, b). The mafic dykes also cut through the carbonatite dykes at Jianshan (E109°59′10.2″, N41°49′02.9″) in the Kuangou anticline (Fig. 2c). We therefore infer that the emplacement of the mafic dykes might have post-dated the formation of the carbonatite dykes as well as the REE mineralization. In this study, the samples of the mafic dykes were collected from Dahua, Kuangou and the main Bayan Obo ore body. The locations and sample numbers are shown in Fig. 2b.

The carbonatite dykes, steeply cutting the strata, are typically 0.5 to 2.0 m wide and 10 to 200 m long, and show a northeast or northwest strike, the host rocks generally suffered extensive fenitization (Fig. 3d). Based on their mineralogical composition, the carbonatite dykes can be divided into three categories: dolomite type, coexisting dolomite–calcite type, and calcite type, with the calcite type showing higher REE content than the other two types (Wang et al., 2002). The carbonatite samples for this study were collected from around the ore body, especially in the Kuangou anticline, including two small carbonatite stocks and nine carbonatite dykes. The sampling locations and sample numbers are shown in Fig. 2b.

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