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Integrated elemental and Sr-Nd-Pb-Hf isotopic studies of Mesozoic mafic dykes from the eastern North China Craton: implications for the dramatic transformation of lithospheric mantle

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ABSTRACT

Evolution of the lithospheric mantle beneath the North China Craton (NCC) from its Precambrian cratonic architecture until Paleozoic, and the transformation to an oceanic realm during Mesozoic, with implications on the destruction of cratonic root have attracted global attention. Here we present geochemical and isotopic data on a suite of newly identified Mesozoic mafic dyke swarms from the Longwangmiao, Weijiazhuang, Mengjiazhuang, Jiayou, Huangmi, and Xiahonghe areas (Qianhuai Block) along the eastern NCC with an attempt to gain further insights on the lithospheric evolution of the region. The Longwangmiao dykes are alkaline with LILE (Ba and K)- and LREE-enrichment ($(La/Yb)_{N} >$ 4.3) and EM1-like Sr-Nd-Pb-Hf isotopic signature ($(^{87}Sr/^{86}Sr)_{i} >$ 0.706; $\varepsilon_{Nd}(t) < -6.3$, $(^{206}Pb/^{204}Pb)_{i} > 16.6$, $(^{207}Pb/^{204}Pb)_{i} > 15.4$, $(^{208}Pb/^{204}Pb)_{i} > 36.8$, $\varepsilon_{Hf}(t) < -22.4$). The Weijiazhuang dykes are sub-alkaline with LILE (Ba and K)- and LREE-enrichment ($(La/Yb)_{N} > 3.7$), and display similar EM1-like isotopic features ($(^{87}Sr/^{86}Sr)_{i} >$ 0.706; $\varepsilon_{Nd}(t) < -7.0$, $(^{206}Pb/^{204}Pb)_{i} > 16.7$, $(^{207}Pb/^{204}Pb)_{i} > 15.4$, $(^{208}Pb/^{204}Pb)_{i} > 36.9$, $\varepsilon_{Hf}(t) < -23.3$). The Mengjiazhuang dykes are also sub-alkaline with LILE (Ba and K)- and LREE-enrichment ($(La/Yb)_{N} > 2.4$) and EM1-like isotopic features($(^{87}Sr/^{86}Sr)_{i} >$ 0.706; $\varepsilon_{Nd}(t) < -18.4$, $(^{206}Pb/^{204}Pb)_{i} > 16.7$, $(^{207}Pb/^{204}Pb)_{i} > 15.4$, $(^{208}Pb/^{204}Pb)_{i} > 36.9$, $\varepsilon_{Hf}(t) < -8.6$). The Jiayou dykes also display sub-alkaline affinity with LILE (Ba and K)- and LREE-enrichment ($(La/Yb)_{N} > 3.7$) and EM1-like Sr-Nd-Pb-Hf isotopic features ($(^{87}Sr/^{86}Sr)_{i} >$ 0.706; $\varepsilon_{Nd}(t) < -15.3$, $(^{206}Pb/^{204}Pb)_{i} > 16.7$, $(^{207}Pb/^{204}Pb)_{i} > 15.4$, $(^{208}Pb/^{204}Pb)_{i} > 36.9$, $\varepsilon_{Hf}(t) < -18.4$). The Huangmi dykes are alkaline (with $Na_2O + K_2O$ ranging to more than 5.9 wt.%)) with LILE (Ba and K)- and LREE-enrichment ($(La/Yb)_{N} > 9.3$) and EM1-like isotopic composition ($(^{87}Sr/^{86}Sr)_{i} >$ 0.705; $\varepsilon_{Nd}(t) < -15.1$, $(^{206}Pb/^{204}Pb)_{i} > 16.9$, $(^{207}Pb/^{204}Pb)_{i} > 15.5$, $(^{208}Pb/^{204}Pb)_{i} > 36.9$, $\varepsilon_{Hf}(t) < -12.2$). The Xiahonghe dykes are alkaline with LILE (Ba and K)- and LREE-enrichment ($(La/Yb)_{N} = 2.12\text{-}2.84$) and similar EM1-like Sr-Nd-Pb-Hf isotopic signature ($(^{87}Sr/^{86}Sr)_{i} > 0.705$; $\varepsilon_{Nd}(t) < -18.0$, $(^{206}Pb/^{204}Pb)_{i} > 16.9$, $(^{207}Pb/^{204}Pb)_{i} > 15.5$, $(^{208}Pb/^{204}Pb)_{i} > 36.9$, $\varepsilon_{Hf}(t) < -8.6$). Our data from the various mafic dyke suites suggest that the magmas were derived from EM1-like lithospheric mantle, corresponding to lithospheric mantle modified by the previously foundered lower crust beneath the eastern NCC. Our results suggest contrasting lithospheric evolution from Triassic (212 Ma) to Cretaceous (123 Ma) beneath the NCC. These mafic dykes mark an important phase of lithospheric thinning in the eastern North China Craton.

1. Introduction

Following its cratonization during Neoarchean through the assembly of several micro-blocks (Yang and Santosh, 2017), the North China Craton (NCC) remained as a relatively stable craton until Mesozoic when there was extensive reactivation, magmatism and craton destruction (Menzies et al., 2007; Griffin et al., 1998; Xu, 2001; Liu et al., 2005; Zheng et al., 2006; Gao et al., 2002, 2004, 2008, 2009; Wu et al., 2003a,b, 2005, 2006a,b; Zhang,

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2005; Yang et al., 2008). This was also accompanied by the formation of wide-spread extensional basins (Zhu et al., 2008), detachment fault zones and metamorphic core complexes (Liu et al., 2008a,b,c, 2009), large-scale mineralization (Nie et al., 2010; Zhai, 2010; Li and Santosh, 2017), generation of adakites and bimodal volcanic rocks (Xiong et al., 2011), and large-scale mafic dykes (Liu, 2004; Liu et al., 2008a,b,c, 2009, 2010, 2013; Wu et al., 2008; Zhai et al., 2004; Dong et al., 2007). Thus, the evolution of the lithospheric mantle of the NCC has been a topic of wide interest, particularly following the documentation of a dramatic change from Paleozoic cratonic mantle to Cenozoic "oceanic" lithospheric mantle (Griffin et al., 1992, 1998; Xu, 2001; O'Reilly et al., 2001; Zhang et al., 2003a,b). This transformation warrants sizeable lithospheric thinning, which is considered to have occurred in the Mesozoic (Menzies and Xu, 1998; Lu et al., 2000, 2006; Gao et al., 2002; Zhang et al., 2003a,b; Wu et al., 2000, 2008; Zhang et al., 2007; Zheng et al., 2007). However, the mechanism leading to this change remains controversial, and various models proposed include the destabilization of the cratonic lithosphere through India-Eurasia collision (Menzies et al., 1993), and replacement of the Archean cratonic lithosphere by young Phanerozoic lithosphere resulting in removal of the Archean lithospheric keel (Zheng, 1999; Zheng et al., 2001; Poudjom Djomani et al., 2001). Some studies suggest that the lithospheric replacement might have occurred as early as Paleoproterozoic (1.9 Ga), based on Re-Os isotopic data on mantle xenoliths entrained in basalts (Gao et al., 2002). Several studies have proposed thermo-mechanical erosion from the base of the lithosphere and subsequent chemical erosion resulting from asthenosphere upwelling (Menzies and Xu, 1998; Xu, 2001; Xu et al., 2004; Wu et al., 2008; Santosh, 2010). The subduction of oceanic crust beneath both the northern and southern margins of the NCC in the Paleozoic (Meng and Zhang, 2000; Davis et al., 2001; Ren et al., 20002) is considered to be responsible for destabilization of the eastern NCC and the resulting thinning and replacement of the lithospheric mantle (Zhang et al., 2003a,b). The delamination of thickened lithosphere is also considered as an important mechanism leading to the Mesozoic lithospheric thinning (Gao et al., 1992, 1998a,b, 2002, 2004; Wu et al., 2003a,b, 2005, 2006a,b; Xu et al., 2006, 2008; Liu et al., 2008a,b,c, 2009). Investigations on Mesozoic extensional structures in the NCC have also provided important information on the lithospheric thinning (Wang et al., 2007a,b; Wu et al., 2008). In spite of the various mechanisms proposed including peridotite-melt interaction (Zhang et al., 2002, 2007; Tang et al., 2008; Zhang, 2009), magma extraction (Chen et al., 2004) and hydration (Niu, 2005), the replacement process remains enigmatic.

Mesozoic magmatism is widespread in the NCC, and the distribution of these magmatic suites shows both temporal and spatial regularity. The middle-early Triassic magmatic suites are mainly distributed in the northern margin of the NCC (Yinshan-Yanshan-western Liaoning, Yanji-northern Liaoning) whereas those between middle-late Triassic and early Jurassic are mainly located along the Yinshan-Yanshi-western Liaoning, Yanji-northern Liaoning, Liaodong Peninsula, Korean Peninsula, the western Hills of Beijing, little Qinling Mountains and western Shandong. The Middle-late Jurassic magmatic rocks are mainly distributed in the Yanshan-western Liaoning, Liaodong Peninsula, Jiaodong Peninsula and western Hilis of Beijing, and those of early Cretaceous occur along the eastern NCC, with the western boundary reaching up to the western margin of the Ordos Basin. The rock types include extrusive volcanics (basalt), shallow volcanic suites (rhyolite porphyry, andesite porphyry and trachyte porphyry), and hypabyssal rocks (granite, granite porphyry and syenite porphyry, and plutonic rocks (granodiorite, syenite porphyry, diorite, mafic dyke, and syenite). Furthermore, more than 300 mafic dykes were identified in the Liaoning Province, the Inner Mongolia Autonomous Region, Shanxi Province, Hebei Province, Shandong Province, Henan Province, Gansu and Shaanxi Province (Regional Geology of Hebei Province, Beijing, Tianjin, 1982; Regional Geology of Liaoning Province, 1989; Regional Geology of Shanxi Province, 1989; Regional Geology of Henan Province, 1989; Rgional Geology of Gansu Province, 1989; Regional Geology of Shaanxi Province, 1989; Regional Geology of Inner Mongolia Autonomous Region, 1991; Yang et al., 2007a,b; Liu et al., 2010). More than 150 mafic dykes (110-220 Ma) occur in the Hebei province including those around the Weichang, Chicheng, Fengning, Yixian, Laiyuan, Luxian, Quyang, Lingshou, Fuping, Yanliao, Fanshan, Zhuolu, and Sanchakou areas (Yang, 1991; Mu and Yan, 1992; Mu et al., 2001; Shao and Zhang, 2002; Shao et al., 2005; Liu et al., 2010; Yang et al., 2012, 2013; Yang, 2013; Tang, 2013; Tang et al., 2014). These Triassic-Cretaceous dykes provide an excellent opportunity to probe the underlying lithospheric mantle. In this study, we selected a suite of newly-discovered mafic dykes from this region within the Xingtai County (Fig. 1b) for detailed elemental-isotopic analysis. Our new data provide important constraints on the origin of the Mesozoic dykes and on their mantle sources beneath the eastern NCC. Using these data, together with those from previously published works from this region, we attempt to identify the spatio-temporal variations in the Mesozoic lithospheric mantle across the eastern NCC.

2. Regional geology

The NCC is one of the major Archean cratonic nuclei in Asia and preserves vestiges of crustal records ranging up to 3.8 Ga age (Liu et al., 1992; Zheng et al., 2005; Zhai and Santosh, 2011). The Archean tectonic architecture of the NCC is considered to be a mosaic of several microcontinental blocks (Zhai and Bian, 2000; Zhao, 2009), and recent studies have confirmed extensive magmatism and high grade metamorphism associated with the subduction-collision tectonics and suturing of the microblocks (Yang et al., 2016; Yang and Santosh, 2017). The NCC has been traditionally divided into the Eastern Block and the Western Block, which amalgamated along the Paleoproterozoic Trans-North China Orogen (Zhao et al., 2001, 2002, 2005; Wilde et al., 2002; Guo et al., 2005; Yang and Santosh, 2015). The Precambrian crystalline basement in the NCC is dominantly composed of tonalite-trondhjemite-granodiorite (TTG) gneisses together with meta-volcanic and metasedimentary rocks, covered by Sinian-Ordovician marine sedimentary rocks, Carboniferous-Permian continental clastic rocks, and Mesozoic basin deposits (Zhao et al., 2002; Zhang et al., 2003a,b). The Western Block is composed of the Yinshan Block in the north and the Ordos Block to the south, separated by the E-W-trending Paleoproterozoic Inner Mongolia Suture Zone, also known as the Khondalite Belt (Xia et al., 2008; Yin et al., 2009, 2011; Li et al., 2011; Wang et al., 2011; Santosh et al., 2012). The Eastern Block consists of the Longgang (also known as the Yanliao Block) and Langrim blocks, separated by the Paleoproterozoic Jiao-Liao-Ji Belt (Li et al., 2006; Li and Zhao, 2007; Zhou et al., 2008; Zhao et al., 2010, 2012; Tam et al., 2012a,b; Zhao and Zhai, 2013).

In the Western Block, the cratonic lithosphere has been relatively stable sine Precambrian. In contrast, extensive magmatic activity occurred in the Eastern Block after its cratonization (Zhang et al., 2003a,b). The NCC is bound on the south by the Palaeozoic to Triassic Qinling-Dabie-Sulu Orogenic Belt (Li et al., 1993; Meng and Zhang, 2000; Zhang et al., 2003a,b; Dong and Santosh, 2016) and on the north by the Central Asian Orogenic Belt (Davis et al., 2001). The Qinling-Dabie-Sulu Orogenic Belt resulted from the continental collision between the NCC and the Yangtze Craton in the Triassic (Li et al., 1993). The EW-trending Central Asian Orogenic Belt was formed through south-directed subduction and arc-arc, arc-continent, and continent-continent collision mainly during the Palaeozoic (Robinson et al., 1999; Davis et al., 2001; Zhang et al., 2003a,b). During this time, multiple Ordovician to Permian oceanic arcs and the Mongolian microcontinent were amalgamated to the active margin of the NCC (Davis et al., 2001; Zhang et al., 2003a,b; Safonova et al.,2017).

In the present study, we analyzed Mesozoic mafic dykes from the Longwangmian, Weijiazhuang, Mengjiazhuang, Jiayou, Huangmi, and Xiahonghe in the Qianhuai Block of the eastern NCC (Fig. 1a). These dykes belong to three major periods of magmatic activity (212.0-199.6 Ma, 136.4 Ma, 123.5 Ma; Table 1; Fig. 2-2).

3. Petrography

Mafic dykes are widespread in the areas investigated in this study such as the Longwangmian, Weijiazhuang, Mengjiazhuang, Jiayou,