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Two episodes of Paleoproterozoic metamorphosed mafic dykes in the Lvliang Complex: Implications for the evolution of the Trans-North China Orogen

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ABSTRACT

Tectonic evolution of the Trans-North China Orogen (TNCO) at ~2.2–1.8 Ga is of great importance considering the prolonged controversial issue of when and how the Eastern and Western blocks were assembled to form the coherent basement of the North China Craton. We identified three types of mafic dykes in the Lvliang Complex, of which one was unmetamorphosed and two were subjected to amphibolite facies metamorphism. Zircon LA-ICP-MS U-Pb dating of six metamorphosed mafic dykes yields magmatic crystallization ages of 1919 ± 18 Ma, 1939.6 ± 8.2 Ma, 1949.9 ± 9.6 Ma, 1944 ± 17 Ma, 2116 ± 15 Ma and 2116 ± 13 Ma, indicating two major phases of mafic dykes emplacement at ~2.11 Ga and ~1.94 Ga, respectively. In situ zircon Hf isotope data of the ~2.11 Ga samples vary in large ranges (over fifteen epsilon units) with the highest $\varepsilon Hf_{(t)}$ value approaching the depleted mantle array and the lowest value plotting onto the evolution line of the ~3.1 Ga crust, indicating assimilation of depleted mantle-derived magma by old crustal material. For the 1.94 Ga samples, almost all the $\varepsilon Hf_{(t)}$ values are positive with abundant data near or equal to the contemporary depleted mantle implying limited crustal assimilation. Geochemical data suggest that, most of the ~2.11 Ga dykes are alkaline whereas almost all the ~1.94 Ga dykes are subalkaline. The ~2.11 Ga dykes show variable LREE enrichment (La/Yb = 1.9–10.3), prominent Nb-Ta troughs, high Zr contents and Zr/Y ratios while the ~1.94 Ga dykes display no pronounced fractionation between LREE and HREE, and also significant Nb-Ta-Ti negative anomalies, but low Zr contents and Zr/Y ratios. According to the Hf isotopic and the geochemical features, we suggest that the ~2.11 Ga dykes were probably derived from a sub-continental lithospheric mantle in a continental rift with some asthenospheric contribution, whereas, the ~1.94 Ga dykes were arc-related with little crustal contamination during forming and ascending process and the Nb-Ta troughs were probably attributed to subduction-related fluids and melts. Together with the previous researches of the TNCO and other parts of the North China Craton (NCC), we tend to think that there was a whole rift–subduction–collision cycle during the period of ~2.2–1.85 Ga and the subduction process initiated at ~1.94 Ga at least.

1. Introduction

As the largest and oldest block of China, the North China Craton (NCC) has been attracting a lot of focus since ten years ago. Geologists gradually reached consensus that the NCC could be divided into two discrete continental blocks, called the Eastern Block and the Western Block, and they were separated by the Trans-North China Orogen (Zhao et al., 1998, 1999, 2005). However, there is still considerable controversy about when and how the Eastern and Western Blocks were assembled to form the coherent basement of the NCC (Zhao et al., 2012; Zhao and Zhai, 2013). Some researchers suggested an eastward subduction with the subsequent collision at ~1.85 Ga (Zhao et al., 2001, 2006; Wilde et al., 2002; Kröner et al., 2005a,b; Zhang et al., 2006a, 2007, 2009; Li et al., 2010). Nevertheless, some other researchers proposed a westward subduction with collision at ~2.5 Ga (Zhai et al., 2000; Kusky and Li, 2003; Polat et al., 2005, 2006, 2007). In addition, there was a different tectonic model that suggested an Archean Fuping Block existing between the Western and Eastern Blocks, separated by the Lvliang and Taihang Oceans, respectively. The closure of the Taihang Ocean occurred at ca. 2100 Ma by westward subduction below the Fuping Block, followed by the second collision at 1900–1880 Ma between the Fuping and Western Blocks, which resulted in the final formation of the Trans-North China Belt (Faure et al., 2007; Trap et al., 2007, 2008, 2009a,b, 2012). Therefore, tectonic evolution of the

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TNCO at 2.5–1.8 Ga, especially between 2.2 Ga and 1.8 Ga is of vital importance (Faure et al., 2007; Trap et al., 2007; Li et al., 2010). A great deal of work has been done on granites, granitic gneisses, volcanic-sedimentary assemblages during this period. However, systematic researches of the mafic dykes are relatively limited, which are useful to constrain the tectonic environment, because they typically have a short life span and tend to preserve well their original chemical characteristics, in spite of later metamorphism (Peng et al., 2012).

Mafic dykes in the TNCO generated during 2.3–1.8 Ga have only been reported in the Hengshan, Wutai, Huaian and Fuping complexes, all of them are located in the northern part of the TNCO. The 1973 ± 4 Ma mafic dykes in Xiwangshan (Peng et al., 2005) and the 1964 ± 60/1964 ± 38 Ma mafic dykes in Manjinggou (Zhao et al., 2008a; Wang et al., 2010a) were reported in the Huaian Complex and both of them were metamorphosed into granulites. In the Hengshan Complex, there were reports of two ca.1914 Ma mafic dykes underwent high-pressure granulite facies metamorphism in Dashiyu (Kröner et al., 2006), ~2060 Ma mafic dykes experienced medium-pressure granulite facies metamorphism in Yixingzhai (Peng et al., 2005) and 2193 ± 5 Ma grabbo in Yanmenguan area (Wang et al., 2010b). Similarly, 2147 ± 5 Ma amphibolite-facies mafic dykes were recognized in Hengling area of the Wutai Complex (Peng et al., 2012). Beyond all that, the oldest mafic dyke in the TNCO up to now was found intruding into the Fuping gneisses with a single-zircon lead evaporation $^{207}Pb/^{206}Pb$ age of 2310 ± 11 Ma although nothing else has been done with the dyke (Liu et al., 2002a,b). Most recently, Deng et al. (2013) reported mafic dykes in the Zanhuang Complex and inferred that the dykes formed before ~2.5 Ga, in spite of pending determination of their precise ages.

Although mafic dyke swarms in the Lvliang Complex have been mentioned in many previous studies (Peng et al., 2007; Peng, 2010) the detailed isotopic and geochemical measurements on these dykes have not been conducted. In this paper, we present comprehensive zircon U-Pb and Lu-Hf isotopic and major- and trace-element geochemical analyses on the metamorphosed mafic-dykes in the Lvliang area for the first time. Furthermore, combining with the contemporaneous volcanic rocks, granitoids and sedimentary rocks in the Lvliang Complex and the nearby Hengshan–Wutai–Fuping complexes, we investigate the origin of these dykes and their geodynamic setting, in order to provide important constraints on the tectonic evolution of the TNCO during the transition from the Neoarchean into the Paleoproterozoic.

2. Geological setting

The North China Craton was formed by amalgamation of a series of micro-continental blocks. It has been suggested to consist of three main components, the Eastern and Western blocks, and the intervening Paleoproterozoic Trans-North-China Orogen (Zhao et al., 2001, 2005). The Eastern Block comprises Archean basement and the Paleoproterozoic Jiao-Liao-Ji Belt, with some Eoarchean to Mesoarchean rocks occurring in the Anshan area (Wan et al., 2005, 2013; Liu et al., 2008). The Western Block includes the Ordos and Yinshan blocks, separated by the Paleoproterozoic Khondalite Belt.

The Lvliang Complex is located in the central-western Shanxi Province and exposed as the westernmost part of the TNCO (Fig. 1). It is characterized by greenschist- to amphibolite-facies rocks as well as many undeformed and unmetamorphosed units, including paleoproterozoic supracrustal rocks and multiphasic granitoid intrusions. The supracrustal rocks were subdivided into four major units, which are the Jiehekou Group, the Lvliang Group, the Yejishan Group and the Lanxian Group. These groups are mainly distributed in the northwestern part of the complex, and present as residues in other places due to great invasion of granitoids (Fig. 1a). The Jiehekou Group is usually considered as part of the khondalite series (Wan et al., 2000, 2006; Liu et al., 2009a, 2011a, 2012a). There were much debate among the forming age and the tectonic setting of this group (Geng et al., 2000; Liu et al., 2001; Xia et al., 2009). The Lvliang Group was previously best known for the banded iron formations (BIFs) in its lower part and bimodal volcanics in the upper part (Liu et al., 2011a). It was generally thought to be formed in a continental rift at ~2.1 Ga (Yu et al., 1997; Geng et al., 2003), although some researchers proposed post-orogeny (Du et al., 2012) or back-arc basin environments (Wang et al., 2010b). The Lanxian Group was sometimes thought to belong to the Yejishan Group (Liu et al., 2011a), of which the forming age and the tectonic setting have long been controversial (Geng et al., 2003; Liu et al., 2009b, 2011a).

The granitoids in the Lvliang Complex mainly include ~2.5 Ga Yunzhongshan Tonalitic-Trondhjemitic-Granodioritic (TTG) gneisses, ~2.3 Ga Gaijiazhuang gneisses, ~2.2–2.1 Ga Chijianling-Guandishan gneisses, ~1.9–1.85 Ga gneissic granites and ~1.7–1.8 Ga massive granites. Among them, the Chijianling-Guandishan gneisses are the most widespread assemblages, which occupy most of the Complex (Fig. 1a). They are composed of plagiogneisses, monzogranitic gneisses, tonalitic gneisses and migmatitic gneisses (Geng et al., 2000; Zhao et al., 2008b; Du et al., 2012) and were intruded by abundant mafic and granitoid rocks.

3. Mafic dykes in the Lvliang Complex

Mafic dykes in the Lvliang Complex can be divided into metamorphosed and unmetamorphosed types (Fig. 2). Unmetamorphosed dykes are mainly diabase, most of them are distributed in the central-south part of the Complex and intrude into granites or gneissic granites. Our new unpublished geochronologic and geochemical data suggest that these unmetamorphosed mafic dykes in the Lvliang complex have the similar genesis to the ~1.78 Ga/~1.8 Ga mafic dykes cropped out all over the North China Craton (Hou et al., 2006a,b, 2008; Peng et al., 2007; Peng, 2010; Wang et al., 2004, 2007; Shao et al., 2005). The unmetamorphosed mafic dykes will not be further discussed in this paper because they are not the focus of this contribution.

In addition to the pervasive unmetamorphosed mafic dykes, there are a significant amount of mafic dykes occurred as plagioclase amphibolite due to an amphibolite facies metamorphism. Thin-section observations suggest these dykes have similar mineral assemblages, which include dominant hornblende (~60–65%), plagioclase (~25–30%) and minor quartz (~5%), magnetite (<1%), sphene (<1%), except that there are ~3% biotite in sample 11FS-26 and <2% chlorite in sample 11FS-31. Hornblendes are significantly oriented and clean without any alteration while plagioclases have undergone extensively sericitization (Fig. 3).

Metamorphosed mafic dykes principally occur within the Chijianling gneisses and relatively younger gneissic granites. Most mafic dykes are slant and mainly strike NE–SW, and usually in sharp contact with the country rocks with chilled margins. In places, both the dykes and their country rocks are intruded by late stages of granitic veins as shown in Fig. 2d. These dykes show similar orientation with gneissic schistosity of their country rocks, the same as those reported in the northern part of the TNCO by Peng et al. (2005, 2012). However, the cause of this coincidence is so far unknown. Although these occurrences make them look like sills or sheets, their tabular shape and preserved bayonet-like apophyses indicate that they are dykes (Fig. 2), as suggested by Peng et al. (2012). The obtained occurrence of gneissic schistosity of the dyke is 280° ∠65, which is consistent with their country rocks, indicating that the mafic dykes and the surrounding rocks have experienced a synchronous metamorphism. There are large amount of the Chijianling gneisses with mafic intrusions distributed in the central-south part