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Nature of three Proterozoic (1680 Ma, 1230 Ma and 775 Ma) mafic dyke swarms in North China: Implications for tectonic evolution and paleogeographic reconstruction

Chong Wang [a,b], Peng Peng [a,*], Xinping Wang [a,b], Shuyan Yang [a,b]

[a] State Key Laboratory of Lithospheric Evolution, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, China
[b] University of Chinese Academy of Sciences, Beijing 100049, China

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ABSTRACT

Three Proterozoic mafic dyke swarms are identified in the periphery of the Yan-Liao rift in eastern Hebei Province, and all these dykes intruded the Archean basement with clear chilled margins. Precise U–Pb SIMS analysis yields $^{207}Pb/^{206}Pb$ average ages of 1677 ± 12 Ma (baddeleyite), 1236 ± 7 Ma (baddeleyite), and 775 ± 5 Ma (zircon) for the representatives, which all exhibit ages of crystallization. These dykes are referred to as Tujiagou (~1680 Ma; NW trending, >20 m wide for each), Maojiagou (~1230 Ma; 0°–10° trending, around 40 m wide), and Dingjiagou (~775 Ma; 30°–70° trending, 12–20 m wide) dyke swarms, respectively.

All these dykes are diabase, showing ophitic texture and mineral assemblages that are mainly composed of plagioclase and clinopyroxene, and underwent various degrees of epidotization, chloritization, and uralitization. They are tholeiitic (for the 1680 Ma and 775 Ma dykes) and alkaline (for the 1230 Ma dykes) in composition, with different degrees of fractionation and indistinctive crustal contamination. The Tujiagou dykes (1680 Ma) have low Mg# (44–49) and show negative Sr− anomalies and minor negative Eu− anomalies ($Eu/Eu^* = 0.91–0.96$), which indicate clinopyroxene- and plagioclase-dominated fractionation. They exhibit $(La/Yb)_N$ of 5.3–7.7 and are depleted in some HFSEs, such as Zr and Hf. The Maojiagou dykes (1230 Ma) present relatively high Mg# values with the fractionation of clinopyroxene. The dykes exhibit light REE enrichment ($(La/Yb)_N = 6.48–12.8$) and slight or no depletion in HFSEs. Both the 1680 Ma and 1230 Ma dykes exhibit similar $\varepsilon_{Nd}(t)$ values (−1.9 to 1.3), indicating similarly depleted mantle sources. The Dingjiagou dykes (775 Ma) show negative Eu− anomalies (0.88–1.07) and negative Ce− anomalies with medium light REE enrichment ($(La/Yb)_N = 2.3–4.12$). They are depleted in HFSEs such as Nb, Ta, Zr, etc. and have enriched $\varepsilon_{Nd}(t)$ values (−7.2 to −5.1). The Mg# values are 47–60. The 775 Ma dykes could be from the metasomatized sub-continental lithospheric mantle and have experienced plagioclase-dominated fractionation.

The 1680 Ma Tujiagou dykes are coeval and chemically similar to and could be equivalents of the Laiwu dykes in Luxi. The 1230 Ma Maojiagou dykes are similar to some other 1230–1210 Ma mafic dykes/intrusions in this craton. The 775 Ma Dingjiagou dykes are newly reported. These dyke swarms developed in an area adjacent to the Yan-Liao rift, and could represent a stepwise rifting in the northern parts of the craton. In a global scale, these dyke swarms could be potential geological records that were dismembered during the breakup of supercontinents and are markers to paleogeographic reconstruction. Specifically, the 1230 Ma dykes, which are comparable with the synchronous Sudbury dykes in Laurentia, could be parts of a large igneous province. The North China Craton separated from the Laurentia only until approximately 775 Ma. However, this hypothesis must be confirmed further, particularly in paleomagnetic studies.

1. Introduction

Mafic dyke swarms are generally known to be short-lived intrusions that are important in tectonic interpretations, particularly for rifting events (Ernst and Buchan, 2001; Ernst, 2014). During the

* Corresponding author.
E-mail address: pengpengwj@mail.iggcas.ac.cn (P. Peng).

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past decade, generations of Precambrian mafic dykes/sills have been investigated and revealed in the North China Craton (NCC). Researchers identified more than 20 episodes of Precambrian dyke swarms (Fig. 1a; Peng, 2015b and references therein). Petrogenesis studies on dyke swarms have significantly improved our understanding of the tectonic evolution of the NCC (e.g. Halls et al., 2000; Hou et al., 2001, 2005; Li et al., 2015; Wang et al., 2004, 2007; Peng et al., 2005, 2006, 2007, 2011a,b; Peng, 2015b; Xiang et al., 2012; Zhang et al., 2009, 2012), whereas the geometry reconstruction of dyke swarms, as well as the paleomagnetism study on dykes, clarified the paleogeographical reconstruction of North China in the Precambrian supercontinents (e.g. Hou et al., 2008a, b, 2009; Peng et al., 2006, 2011a; Peng, 2015b; Zhang et al., 2012).

The NCC has long been considered to experience long-term rifting and platform sedimentation since 1800 Ma (e.g., Lu et al., 2008; Peng, 2015a; Zhai et al., 2014). Among the several Proterozoic rifts, the Yan-Liao rift is a prolonged one, which opened at 1730–1680 Ma (He et al., 2011a,b; Li et al., 2011, 2013; Peng et al., 2012; Wang et al., 2015a; Zhang et al., 2015). The region has experienced significant non-orogenetic magmatism at ~1720–1680 Ma, e.g., the anorthosite-rapakivi granite-dyke complex (Yang et al., 2005; Zhang et al., 2007; Zhao et al., 2004, 2009), and magmatism at ~1620 Ma (potassium volcanics; Gao et al., 2008b; Liu et al., 2013a; Lu and Li, 1991; Lu et al., 2008) and ~1320 Ma (sills; Fig. 1a; Li et al., 2009; Wang et al., 2014; Zhang et al., 2009, 2012). Yan-Liao rift is mainly evolved in the northern parts of the NCC (Fig. 1a), and is therefore important in reconstructing the northern (at present coordinates) neighbors. For example, Zhang et al. (2009) thought that the northern margin of the NCC was connected with North America (Laurentia) based on the ~1320 Ma sill swarm and paleomagnetic data. Meanwhile, the connections of the Indian (Hou et al., 2008a) and Baltic and Brazil cratons (Peng, 2015b) with the North China to the south/southeastern margins during the Proterozoic period were proposed. To better understand the magmatism and tectonic evolution of the Yan-Liao rift and the connection of the NCC with other paleo-blocks, we conducted a geological investigation, combined with multiple geological principles on the eastern flank of the rift in eastern Hebei Province.

2. Geological background

The Zunhua high-grade terrain is located in eastern Hebei Province in the northern part of the NCC (Fig. 1). This region is known for the distribution of the roughly 2520 Ma high-grade greenstone belts (Bai et al., 2014, 2015; Guo et al., 2013, 2015; Nutman et al., 2011), the Caozhuang complex with detrital zircons as old as 3.8 Ga (Liu et al., 2013b), and the ~3.3 Ga TTG gneisses (Nutman et al., 2011). This region is also known as the basement of the eastern arm of the Yan-Liao rift, which is a well-known Mesoproterozoic rift with clastic-carbonate sediments of over 10 km thick (e.g., Meng et al., 2011). Accordingly, the succession in this rift is divided into the Changcheng, Jixian, and Qingbaikou Groups, which is arranged from bottom to top (Fig. 2).

The Changcheng Group consists of four lithostratigraphic units, namely, Changzhougou, Chuanlinggou, Tuanshanzi, and Dahongyu Formations (Fms.) from bottom to top. This group, which is unconformably sitting on the crystalline basement, consists of conglomerate, sandstone, siltstone, and shale in the lower part, and thick dolomite with minor sandy shale, sandy dolomite, and potassium-rich volcanic layers (~1620 Ma; Fig. 2; Gao et al., 2008; Lu and Li, 1991; Lu et al., 2008; Wang et al., 2015a) in the upper part (Peng, 2015a). Changzhougou Fm. could deposit at 1730–1670 Ma according to constrains from mafic dykes (Fig. 2; Peng et al., 2012) and granites (He et al., 2011a,b; Li et al., 2011, 2013), when anorthosite-rapakivi granite-dyke complex developed in the rift at the same time (Yang et al., 2005; Zhang et al., 2007; Zhao et al., 2004). Besides, the unconformity beneath the Dahongyu Fm., which is called the "Xingcheng uplift"(Fig. 2), was caused by marine transgression (Meng et al., 2011; Qu et al., 2010; Zhu et al., 2005). Whereas, researchers are still on the debate about the implications of the unconformity above the Dahongyu Fm. ("Qinglong uplift"; Fig. 2; Meng et al., 2011; Qu et al., 2010; Zhu et al., 2005). Meng et al. (2011) underlined the point that the NCC could be separated from the adjacent India block at ~1600 Ma for the diachronous unconformity during the Dahongyu Fm. periods.

The Jixian Group is dominated by carbonates and made up of five units, namely, Gaoyuzhuang, Yangzhuang, Wumishan, Hongshuizhuang, and Tieling Fms., which are arranged from bottom to top (Fig. 2; Peng, 2015a). Tuff presents within the upper part of Gaoyuzhuang Fm. yields a U–Pb age of 1560 Ma (Fig. 2; Li et al., 2010a), indicating that the maximum depositional age of this formation could be ~1600 Ma. The Tieling Fm. developed typical stromatolites, and bentonite from the layer has zircon age of about 1440 Ma (Fig. 2; Li et al., 2014; Su et al., 2010).

The Qingbaikou Group is made up of the Xiamaling Fm., Changlongshan Fm. and Jing'eryu Fm. (or the Luotuoling Fm.). The lower part is dominated by multicolor sandy shale and the middle part is made of feldspathic sandstone, quartz sandstone, glauconite-bearing sandstone and shale, whereas the upper part mainly contains dolomitic limestone with some glauconite-bearing feldspathic sandstone (Fig. 2; Peng, 2015a). High-precision baddeleyite and zircon data yield an age of ~1320 Ma for the mafic sills which intruded the Xiamaling Fm., suggesting that this formation formed before 1320 Ma (Fig. 2; Li et al., 2009; Wang et al., 2014; Zhang et al., 2012). However, no reliable information exists on age of the Changlongshan and Jingeryu Fms. yet (Fig. 2). Importantly, researchers reached an agreement on the unconformities beneath the Xiamaling Fm.(~1400 Ma; Qinyu uplift) and Changlongshan Fm. (Yuxian uplift) (Fig. 2), and they thought that the two unconformities were related to crustal shortening (Qu et al., 2010; Zhu et al., 2005). The starting and ending times of the unconformity between the Xiamaling Fm. and the Changlongshan Fm. (Yuxian uplift) is still pending since the limited strata dating, and Zhai et al. (2015) suggested that it could be happened at ~1320–900 Ma.

Several igneous events occurred, including several dyke/sill swarms being discovered in the study area (Fig. 1a), e.g., the 1730 Ma Miyun dyke swarm (Peng et al., 2012), ~1720–1680 Ma anorthosite-rapakivi granite-dyke complex (Gao et al., 2008; Zhang et al., 2007; Zhao et al., 2004, 2009), ~1620 Ma volcanic associations in the Dahongyu Formation (Gao et al., 2008b; Lu and Li, 1991; Lu et al., 2008), ~1320 Ma sills intruding the Wumishan, Tieling and Xiamaling Fms. (Fig. 1a; Li et al., 2009; Wang et al., 2014; Zhang et al., 2009, 2012). Approximately a dozen of dykes with unknown ages were identified in the Yan-Liao rift region, e.g., dykes near Taipingzhai town, Qianxi County (Li, 1999; Song, 1990).

3. Petrography and occurrence

A series of dykes are investigated in the Jidong area (major in Qianxi County and Lulong County). Based on their distinct occurrence, these dykes are classified into three swarms (Fig. 1b).

The first group is NW trended, and it is referred to as the Tujiagou dyke swarm. This group intruded the Archean Qianxi Complex (Fig. 1b). Two mafic dykes, which are both about 12 m in wide, are sampled. The rocks are unmetamorphosed diabase with typical ophitic texture (e.g. Fig. 3b, c, e, f). They are characterized by a large amount of Fe–Ti oxides (10 vol.%), without alkali feldspar