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Age and geochemistry of the early Mesoproterozoic A-type granites in the southern margin of the North China Craton: Constraints on their petrogenesis and tectonic implications

Xiaoqin Deng [a,b], Taiping Zhao [a,*], Touping Peng [c]

[a] Key Laboratory of Mineralogy and Metallogeny, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou 510640, China
[b] University of Chinese Academy of Sciences, Beijing 100049, China
[c] State Key Laboratory of Isotope Geochemistry, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou 510640, China

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ABSTRACT

A-type granites are a spectrum of especial felsic rocks that are produced commonly within an extensional environment. They are rare before middle Paleoproterozoic but present abundantly since the late Paleoproterozoic, probably indicating a causal change of tectonics and geodynamic mechanism in the continental evolution of the Earth. An early Mesoproterozoic A-type granite belt was recognized in the southern margin of the North China Craton (NCC) in recent decades. The occurrence of this type of rocks indicates a possible spatial–temporal link between the tectonic evolution of the NCC and the breakup of the Columbia supercontinent during the Mesoproterozoic. The Zhangjiaping granitic pluton is located in the southern margin of the NCC and one part of the A-type granite belt. It can be divided into three zones according to their textural and compositional differences of the rocks with a gradually increasing degree of evolution inwards: wall zone, intermediate zone and core zone. LA-ICP-MS zircon U–Pb dating shows that it was emplaced at ca. 1.53 Ga. Petrologically, the Zhangjiaping granites contain perthite and calcic amphibole but are lack of alkali mafic minerals. Geochemically, all the Zhangjiaping granitic rocks show an affinity to fractionated aluminous A-type granites, with enrichment in silicon and total alkali, and depletion in MgO, CaO and P_2O_5 with negative Eu, Sr and Ti anomalies, as well as high FeOt/MgO, TiO_2/MgO and Ga/Al ratios and high HFSEs (i.e., Zr, Nb, Ce, Y) concentrations. Such signatures, along with their low $\varepsilon_{Hf}(t)$ values (−12.5 to −4.0) of all the granites from the Zhangjiaping pluton, obviously indicate that the Zhangjiaping aluminous A-type granites were derived from partial melting of the crustal calc-alkaline granitoids (i.e., the granodiorites of the Taihua Complex in the study area) and experienced fractional crystallization during magmatic evolution. Their generation would be related to the underplating of mafic magmas in an extensional regime. Integrated with regional data, the Zhangjiaping aluminous A-type granites were the products of anorogenic magmatism likely corresponding to the breakup of the Columbia supercontinent.

1. Introduction

Assembly, configuration, accretion and breakup history of the Columbia supercontinent have attracted researchers' considerable attention in the last decades (e.g., Condie, 2002; Rogers and Santosh, 2002; Wilde et al., 2002; Zhao et al., 2002a, 2004a, 2009; Zhang et al., 2007, 2009, 2012a,b; Ernst et al., 2008), because it is likely one of the most important events of supercontinent formation in the geological history which would provide significant information to decode early Precambrian plate tectonics and geodynamic processes profoundly. It is widely accepted that the Columbia supercontinent was amalgamated at ca. 2.0–1.8 Ga marked by numerous collisional orogenic belts (e.g., Zhao et al., 2002a, 2003, 2004a), and broke up at ca. 1.6–1.2 Ga marked by widespread Mesoproterozoic continental rifting, anorogenic magmatic activities and mafic dyke swarms (e.g., Gao et al., 2008a; Hou et al., 2008; Li et al., 2009; Peng et al., 2013). Paleomagnetic and paleogeographic studies have suggested that the NCC was involved in the assembly and breakup of the Columbia supercontinent (Halls et al., 2000; Zhao et al., 2002a; Zhang et al., 2012a; Xu et al., 2014). In fact, other lines of evidence including stratigraphic, structural, geochemical, metamorphic and geochronological data have also lent further support to this proposition (Condie, 2002;

* Corresponding author.
E-mail address: tpzhao@gig.ac.cn (T. Zhao).

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Wilde et al., 2002; Zhao et al., 2002a, 2004a, 2011; Peng et al., 2005; Hou et al., 2008; Zhao and Cawood, 2012; Liu et al., 2014), though the specific time when the NCC was involved in the breakup of the Columbia supercontinent remains controversial due to the lack of precise dating results for the Mesoproterozoic magmatism and tectonism (e.g., Buchan et al., 2001; Zhang et al., 2009, 2012b; Roberts, 2013; Cawood and Hawkesworth, 2014). Therefore, systematic investigation of the Mesoproterozoic magmatism in the NCC can offer insight into the crust-mantle interactions, and geodynamic processes during that time, which is crucial for better understanding the relationship between the evolution of the NCC and the breakup of the Columbia supercontinent.

A-type granites are an especial spectrum of felsic rocks, which are characterized by enrichment in iron, HFSEs (high field strength elements) contents and high Ga/Al ratios (e.g., Loiselle and Wones, 1979; Collins et al., 1982; Whalen et al., 1987; Eby, 1992; Bonin, 2007). They are commonly produced within an extensional environment, such as post-collisional or anorogenic setting (e.g., Eby, 1992; Bonin, 2007). This type of rocks are quite rare before middle Paleoproterozoic but abundant since the late Paleoproterozoic (e.g., Anderson and Bender, 1989; Rämö et al., 1995; Dall'Agnol et al., 2012). This probably reflects a causal relationship with the continental evolution and associated (modern-style) plate tectonic phenomena (e.g., Dall'Agnol et al., 2012). Hence, the generation of A-type granites has significant implications for secular evolution of continental crust (Collins et al., 1982; Bonin, 2007) and tectonics and geodynamics (Bonin, 2007). In recent decades, a Mesoproterozoic A-type granite belt has been recognized in the southern margin of the NCC, extending from Luonan, Shaanxi Province, to Luanchuan, Henan Province, mainly including the Longwangzhuang (e.g., Hu and Lin, 1988; Lu, 1989; Lu et al., 2003; Bao et al., 2009; Wang et al., 2013) and Maping A-type granites (e.g., Liu, 2011; Deng et al., 2015). These Mesoproterozoic A-type granites were attributed to be the products of anorogenic magmatism (Lu, 1989; Lu et al., 2003; Bao et al., 2009; Wang et al., 2013; Deng et al., 2015), although they originated from different source materials. The occurrence of these early Mesoproterozoic anorogenic magmatic rocks further indicates that the NCC was possibly involved in the breakup of the Columbia supercontinent (e.g., Bao et al., 2009; Deng et al., 2015). In addition, a younger (ca. 1.53 Ga) A-type granitic pluton (Zhangjiaping pluton) was also identified in the A-type granite belt. It would provide further information to decipher the geodynamic mechanism responsible for these Mesoproterozoic A-type granites and investigate the possible spatial–temporal link between the evolution of the NCC and the fragmentation of the Columbia supercontinent.

In this contribution, we present new geochronological, elemental and zircon Hf isotopic data for the early Mesoproterozoic A-type granites in the southern margin of the NCC. Our aims are to: (1) constrain their emplacement age, (2) characterize their petrogenesis and source nature, (3) provide an insight into the tectonic setting, and (4) advance our understanding of the correlation between the Mesoproterozoic magmatism in the NCC and the evolution of the Columbia supercontinent.

2. Geological setting

The NCC is bounded by the Central Asian orogenic belt to the north, the Kunlun-Qilian orogenic belt to the west, the Qinling-Dabie orogenic belt to the south and the Su-Lu ultrahigh-pressure metamorphic belt to the east (Fig. 1a). It is thought to have accomplished amalgamation as an integrated block at ~1.85 Ga (e.g., Wu and Xu, 1982; Qiao and Wang, 1984; Zhao, 1993; Bai et al., 1996; Zhao et al., 2002a, 2005; Zhai and Liu, 2003). Since then, the late Paleoproterozoic to Neoproterozoic sedimentary sequences were well developed with a thickness of >10,000 m, unconformably overlying the Archean to Paleoproterozoic metamorphosed basement rocks (e.g., Zhang et al., 1985, 1994; Guan et al., 1988; Li et al., 1995; Zhao et al., 2004b; Gao et al., 2008b, 2009; Lu et al., 2008; Peng et al., 2008; Zhao et al., 2009). The typical sedimentary sequences include the Xiong'er Group in the southern margin of the NCC (e.g., Sun et al., 1981; Hu and Lin, 1988; Hu et al., 2013, 2014 and references therein), and the Changcheng Group in the northern NCC (e.g., Li et al., 1995; Lu et al., 2008). The Xiong'er Group (1.78–1.75 Ga, possibly extend to 1.45 Ga) is possibly the earliest sedimentary cover recorded subsequent to the formation of the crystalline basement in the southern margin of the NCC (e.g., Sun et al., 1981; Hu and Lin, 1988; Ren et al., 2000; Zhao et al., 2002b, 2004b, 2009, 2015; Peng et al., 2008; He et al., 2009, 2010), which is older than the Changcheng Group in the north (1.73–1.60 Ga? Li et al., 1995, 2011, 2013; Gao et al., 2008b, 2008c, 2009; Lu et al., 2008; Peng et al., 2012; Wang et al., 2015; Zhang et al., 2015).

The southern margin of the NCC is bounded by the Sanmenxia–Lushan Fault to the north and the Luonan–Luanchuan Fault to the south (Fig. 1b). It shares the similar basement and cover sequences to those in other areas of the NCC, including the Archean to early Paleoproterozoic basement rocks and the overlying late Paleoproterozoic to Phanerozoic cover sequences (e.g., Zhang et al., 1985, 1994; Guan et al., 1988; Tu, 1998; Wan et al., 2006; Liu et al., 2009; Diwu et al., 2014; Hu et al., 2014). The oldest basement rocks in this area consist mainly of the Neoarchean-Paleoproterozoic Taihua Complex (2.84–1.97 Ga), which is also defined as Taihua Group composed of a suite of metamorphic rocks including graphite-bearing gneisses, greenstones, biotite gneisses, marbles and banded iron formations (e.g., Zhang et al., 1985, 1994; Guan et al., 1988; Tu, 1998; Wan et al., 2006; Diwu et al., 2007, 2010, 2013, 2014; Liu et al., 2009; Xu et al., 2009; Huang et al., 2010, 2012, 2013). It is locally unconformably overlain by the Paleoproterozoic Tietonggou Formation in the Xiaoqinling area, which is the boundary region between Shaanxi and Henan provinces. The Tietonggou Formation, a unique lithostratigraphic unit that was recognized only in the Xiaoqinling region of the southern margin of the NCC, consists predominantly of quartzites whose protolith depositional ages were dated at 1.91–1.80 Ga (e.g., Diwu et al., 2013, 2014). It is in turn overlain by the Xiong'er Group, which is extensively exposed in the area. The Xiong'er Group, covering an area of >60,000 km^2, composed mainly of intermediate to acidic lavas and pyroclastic rocks intercalated with minor sedimentary rocks (< 5%), which is in turn unconformably overlain by Meso- to Neoproterozoic sedimentary rocks (Fig. 1b).

Moreover, the volcanic series of the Xiong'er Group, along with its overlying terrigenous clastic and carbonate rocks (e.g., Hu and Lin, 1988; Hu et al., 2014) and voluminous late Paleoproterozoic to early Mesoproterozoic igneous rocks including mafic dyke swarms (e.g., Peng et al., 2004, 2005, 2008; Zhao et al., 2004b; Hu et al., 2010), A-type granites (SXBGMR, 1982; Yan and Xu, 1984; Hu and Lin, 1988; Lu, 1989; Lu et al., 2003; Bao et al., 2009; Zhao and Zhou, 2009; Wang et al., 2013; Zhang et al., 2013; Deng et al., 2015) and alkaline rocks (Ren et al., 2000; Bao et al., 2008; Liu, 2011), record the complete igneous and sedimentary successions in the southern margin of the NCC (Fig. 1b). However, the tectonic setting and geodynamic mechanism of the post-1.85 Ga tectono–magmatic events in the southern margin of the NCC remain controversial, including post-collisional extensional setting (e.g., Zhao et al., 2002a, 2005; Zhao and Cawood, 2012), mantle plume (e.g., Zhai and Liu, 2003; Peng et al., 2008), intra-continental rift (e.g., Zhao et al., 2002b; Zhai et al., 2015) and Andean arc setting (e.g., Hu and Lin, 1988; Chen et al., 1992; He et al., 2009, 2010; Zhao et al., 2009).

The Zhangjiaping granitic pluton is located in the Lantian county, Shaanxi Province, with an exposure area of about 46 km^2