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Geochemistry and zircon U–Pb–Hf isotopes of the late Paleoproterozoic Jianping diorite–monzonite–syenite suite of the North China Craton: Implications for petrogenesis and geodynamic setting

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ABSTRACT

The late Paleoproterozoic Jianping diorite–monzonite–syenite suite (JDMSS), in the Western Liaoning Province (WLP) along the northern margin of the North China Craton (NCC), is composed mainly of magnetite diorites, clinopyroxene monzonites, syenites, and quartz syenites. LA-ICP-MS zircon U–Pb isotopic dating indicates that this complex emplaced between 1696 and 1721 Ma, almost synchronously with the 1680–1750 Ma anorthosite–mangerite–alkali granitoid–rapakivi granite suite (AMGRS) in northern Hebei Province. The JDMSS in the WLP is the eastwards extensional part of the AMGRS in northern Hebei Province along the northern margin of the NCC. All samples from the JDMSS are characterized by a wide and continuously variable geochemical spectrum of 46.3–64.9 wt.% SiO_2 and 0.528–4.14 wt.% MgO, with high K_2O (1.080–7.01 wt.%) and total alkalis (Na_2O+K_2O, 5.08–12.55 wt.%). These rocks are enriched in LREEs and LILEs but depleted in HFSEs (Nb, Ta, and Ti), and they show negative zircon $\varepsilon_{Hf}(t)$ values of −12.6 to −0.3 and a low whole-rock initial $^{87}Sr/^{86}Sr$ value of 0.703564. These geochemical features, together with trace element modeling, suggest that all the rocks of the JDMSS were generated chiefly by fractional crystallization of a common parental magma that was derived by partial melting of an amphibole-bearing enriched subcontinental lithospheric mantle source (mixed EMI and HIMU mantle), and that the magma assimilated crustal materials during ascent and emplacement. Integrating our data with those of previous studies of the contemporaneous magmatic rocks throughout the NCC (mafic dykes, volcanic rocks, and AMGRS; 1680–1780 Ma), we propose that both the northern and southern margins of the NCC, as well as the TNCO (Trans-North China Orogen), evolved under a post-collisional tectonic setting during the late Paleoproterozoic, postdating the final amalgamation of the NCC, and that the NCC at this time was probably located between Laurentia (North America and Greenland) and Siberia within the interior of the Columbia supercontinent.

1. Introduction

The assembly and breakup of the Paleo-Mesoproterozoic Columbia supercontinent are key issues focused on by numerous geologists and geophysicists (Condie, 2002; Ernst et al., 2008; Meert, 2002, 2012; Rogers, 1996; Rogers and Santosh, 2002, 2003; Wilde et al., 2002; Zhang et al., 2007, 2009, 2012; Zhao et al., 2002, 2004). On the basis of geological and geophysical data, several distinct scenarios for the reconstruction of the supercontinent have been proposed over the past decade (Piper et al., 2011; Rogers and Santosh, 2002, 2003; Zhang et al., 2009; Zhao et al., 2002). In these scenarios, the debates have focused mainly on the specific paleogeographic location of the North China Craton (NCC) within the Columbia supercontinent, and various proposals include a connection of the NCC with the India (Zhao et al., 2002, 2004), Siberia (Condie, 2002; Zhang et al., 2009), or Baltica (Wilde et al., 2002) cratons. These different opinions result mainly from a lack of precise Precambrian geophysical and geochronological data (Buchan et al., 2001; Long et al., 2011; Zhang et al., 2009). Therefore, systematic geochronological and petrogenetic studies and comparisons of the late Paleoproterozoic to Mesoproterozoic magmatic rocks can provide crucial clues for global crustal growth, crust–mantle interactions, and geodynamic processes during the assembly and breakup of the Columbia supercontinent.

The NCC is one of the oldest cratons in the world. For example, in the Anshan area, eastern Liaoning Province, ~3.8 Ga rocks have been identified (Liu et al., 1992, 2008; Nutman et al., 2009), although Wu et al. (2008, 2009) have argued that the rocks hosting the ~3.8 Ga

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zircons actually formed at ~3.1–3.3 Ga, as indicated by the younger zircon age populations. Though hotly debated, it is generally accepted that the NCC amalgamated as a result of the collision of the Eastern Block (EB) with the Western Block (WB) along the Trans-North China Orogen (TNCO) at around 1.85 Ga (Fig. 1; Guo et al., 2002; Kröner et al., 2005; Kusky and Li, 2003; Liu et al., 2002, 2004, 2005, 2006, 2012; Santosh, 2010; Wilde and Zhao, 2005; Zhai and Santosh, 2011; Zhao et al., 1999, 2001, 2005, 2006). After the amalgamation, the NCC experienced intense extensional processes during the period 1.68–1.78 Ga, with the formation of mafic dyke swarms within the TNCO, and the formation of an anorthosite–mangerite–alkali granitoid–rapakivi granite suite (AMGRS) along the northern margin and volcanic rocks along the southern margin of the TNCO (Peng et al., 2005, 2008; Wang et al., 2010; Xie, 2005; Zhang et al., 2007; Zhao et al., 2009a,b). During the period ~1.62–1.68 Ga, K-enriched volcanic rocks erupted in the central segment of the northern margin of the NCC contemporaneously with the deposition of the late Paleoproterozoic Tuanshanzi and Dahongyu formations of the Changcheng Group (Gao et al., 2008; Li et al., 1995; Lu et al., 2008). Then, a long period of tectonic quiescence dominated the NCC, with only sporadic intrusions of Mesoproterozoic (ca. 1.35 Ga) and Neoproterozoic (ca. 0.90 Ga) mafic dykes and sills (Peng et al., 2011a; Zhang et al., 2009, 2012).

The ~1.68–1.78 Ga extension-related igneous rocks throughout the NCC have been extensively studied, since they represent the first craton-scale magmatism following the final amalgamation of the NCC (Jiang et al., 2011; Peng et al., 2005, 2008; Rämö et al., 1995; Wang et al., 2010; Xie, 2005; Yang et al., 2005a; Zhang et al., 2007; Zhao et al., 2009a, b; Zhao and Zhou, 2009). However, their origins and geodynamic settings are poorly understood, with several contrasting tectonic models proposed: (1) intra-continental rifting (Rämö et al., 1995; Yu et al., 1994); (2) a large igneous province (LIP), triggered by a mantle plume (Peng et al., 2005, 2008); (3) a post-collisional setting (Wang et al., 2010; Zhang et al., 2007); and (4) an Andean-type continental marginal setting (He et al., 2008; Zhao et al., 2009a). Particularly, a series of late Paleoproterozoic intrusive complexes, including the Damiao anorthosite complex, the Miyun rapakivi granites, and other A-type granites (e.g. the Wenquan and Changsaoying granites) is widely distributed along the northern margin of the NCC (Fig. 1). In the case of the Damiao high-Al gabbros and anorthosites, it has been proposed that they originated either by partial melting of an enriched mantle source (EMI; Zhang et al., 2007) or of the ancient lower crust (Zhao et al., 2009b), though some researchers have argued against the existence of an EMI-type lithospheric mantle along the northern margin of the NCC at around 1700 Ma (Jiang et al., 2011). It has also been proposed that the spatially related felsic intrusive rocks originated either by fractional crystallization of an enriched mantle-derived parental magma or by partial melting of the late Archean lower crust (Jiang et al., 2011; Xie, 2005; Yang et al., 2005a; Zhang et al., 2007). Therefore, the sources of magma for these intrusive rocks, the genetic relationships between the various lithologies (such as gabbros and anorthosites vs. granites), and the nature of the underlying lithospheric mantle at that time remain unresolved.

The Western Liaoning Province (WLP), a key region for exposures of early Precambrian crystalline basement, is located along the northern margin of the EB of the NCC (Fig. 2A; Liu et al., 2010, 2011a; Wang et al., 2011, 2012a, 2013). Recently, a late Paleoproterozoic diorite–monzonite–syenite suite (the Jianping diorite–monzonite–syenite suite, JDMSS) has been identified to the north of Jianping town within the WLP (Fig. 2), and this suite provides a key to study the nature of mantle sources, crust–mantle interaction, and the tectonic setting during this period along the northern margin of the NCC. In this paper, we present systematic geological, petrological, whole-rock geochemical and zircon U–Pb–Hf isotopic data for the late Paleoproterozoic JDMSS with the aim of (1) determining the timing of emplacement; (2) deciphering the petrogenesis and genetic relationships of the different lithologies, and the nature of their magma sources; and (3) discussing the late Paleoproterozoic tectonic setting along the northern margin of the NCC. Integrating our results with those from previous studies of synchronous magmatic rocks within the NCC, we further reassess the issues of the late Paleoproterozoic tectonic setting of the TNCO and the southern margin of the NCC. Finally, we discuss the previously proposed scenarios for reconstruction of the NCC within the Columbia supercontinent.

2. Geological setting

2.1. Early Precambrian crystalline basement

Based on diverse lithological assemblages, geochronological data, and P–T–t paths of the metamorphism in the exposed Precambrian rocks, the NCC has been subdivided into the WB, the TNCO, and the EB. The TNCO was considered to have formed during the collision of the WB and EB at ~1.85 Ga, leading to the final consolidation of the NCC (Guo et al., 2002; Liu et al., 2002, 2004, 2005, 2006, 2012; Zhao et al., 2001, 2005). Subsequently, this tectonic model was further refined by suggesting (1) that the WB was formed around 1.95 Ga by the amalgamation of the Yinshan Block in the north and the Ordos Block in the south along the E–W trending tectonic belt that is named either the Khondalite Belt or the Inner Mongolia Suture Zone (Santosh et al., 2007a,b; Yin et al., 2011; Zhao et al., 2008, 2010), and (2) that the EB underwent Paleoproterozoic rifting and subsequent subduction–collision processes during the period 2.1–1.9 Ga, at which time the Jiao–Liao–Ji Belt formed (Li and Zhao, 2007; Luo et al., 2008; Tam et al., 2011), followed by the final cratonization of the NCC.

The Western Liaoning Province (WLP) is located at the northwestern margin of the EB (Figs. 1 and 2A), and its Precambrian crystalline basement consists of the North Chaoyang–Fuxin–Yixian granite–greenstone belt (NCFY–GGB) in the northeast, with low to medium grades of metamorphism, and the Jianping high-grade gneissic terrane (JPGT) in the southwest (Kröner et al., 1998; Liu et al., 2010, 2011a; Wang et al., 2011, 2012a). The NCFY–GGB is a typical Archean granite–greenstone belt, and it is dominated by supracrustal sequences and large volumes of plutonic granitoid gneisses (Fig. 2A; Lin et al., 1997; Wang et al., 2011, 2012a). The magmatic precursors of the supracrustal metavolcanic rocks formed prior to 2520 Ma, and they have geochemical features akin to those of normal-Mid Ocean Ridge Basalts (N-MORB), boninite-like rocks, adakite-like rocks, and high magnesium andesites (HMA), respectively (Liu et al., 2010; Wang et al., 2011). The voluminous granitoid rocks emplaced between 2495 and 2521 Ma are considered to have formed by partial melting either of subducted oceanic slabs or of lower continental crustal material composed chiefly of metamorphosed basaltic and pelitic rocks (Wang et al., 2012a). Accordingly, the NCFY–GGB could have developed at an Andean-type active continental margin during the Neoarchean to early Paleoproterozoic (Liu et al., 2011a; Wang et al., 2011, 2012a).

The JPGT is a NE-trending fault-block of a large basement uplift belt (Fig. 2A), and it contains two major lithological units, namely metamorphosed supracrustal rocks and plutonic gneisses. The protoliths of the supracrustal sequences were mainly mafic to felsic volcanic rocks, Banded Iron Formations (BIFs), and quartzites, and they formed during 2550–2555 Ma and up to 2615 Ma. The plutonic gneisses display compositions from diorite through tonalite and granodiorite to monzogranite, and the emplacement of the magmatic precursors took place during the period 2495 to 2538 Ma. The emplacement was followed at ca. 2485 Ma by a granulite facies metamorphism, and at ca. 2401–2450 Ma by a retrograde event (Liu et al., 2011a; Wang et al., 2013). The NCFY–GGB and the JPGT should have experienced similar crustal evolutions from the Neoarchean to the early Paleoproterozoic, and they may have evolved at the same Andean-type active continental margin at the end of the Archean (Wang et al., 2013).