Journal of Asian Earth Sciences 95 (2014) 147–163

Contents lists available at ScienceDirect

Journal of Asian Earth Sciences

journal homepage: www.elsevier.com/locate/jseaes

Crustal recycling through intraplate magmatism: Evidence from the Trans-North China Orogen

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ARTICLE INFO

Article history:
Received 6 December 2013
Received in revised form 28 January 2014
Accepted 1 February 2014
Available online 18 February 2014

Keywords:
Zircon U–Pb geochronology
Lu–Hf isotopes
Intraplate magmatism
Trans-North China Orogen
North China Craton

ABSTRACT

The North China Craton (NCC) preserves the history of crustal growth and craton formation during the early Precambrian followed by extensive lithospheric thinning and craton destruction in the Mesozoic. Here we present evidence for magma mixing and mingling associated with the Mesozoic tectonic processes from the Central NCC, along the Trans-North China Orogen, a paleo suture along which the Eastern and Western Blocks were amalgamated at end of Paleoproterozoic. Our investigations focus on two granitoids – the Chiwawu and the Mapeng plutons. Typical signatures for the interaction of mafic and felsic magmas are observed in these plutons such as: (1) the presence of diorite enclaves; (2) flow structures; (3) schlierens; (4) varying degrees of hybridization; and (5) macro-, and micro-textures. Porphyritic feldspar crystals show numerous mineral inclusions as well as rapakivi and anti-rapakivi textures. We present bulk chemistry, zircon U–Pb geochronology and REE data, and Lu–Hf isotopes on the granitoids, diorite enclaves, and surrounding basement rocks to constrain the timing of intraplate magmatism and processes of interaction between felsic and mafic magmas. Our LA-ICP-MS zircon U–Pb data show that the pophyritic granodiorite was emplaced at 129.7 ± 1.0 Ma. The diorite enclaves within this granodiorite show identical ages (128.2 ± 1.5 Ma). The basement TTG (tonalite–trondhjemite–granodiorite) gneisses formed at ca. 2.5 Ga coinciding with the major period of crustal accretion in the NCC. The 1.85 Ga age from zircons in the gabbro with positive Hf isotope signature may be related to mantle magmatism during post-collisional extension following the assembly of the Western and Eastern Blocks of the NCC along the Trans-North China Orogen. Our Hf isotope data indicate that the Neoarchean–Paleoproterozoic basement rocks were derived from complex sources of both juvenile magmas and reworked ancient crust, whereas the magma source for the Mesozoic units are dominantly reworked basement rocks. Our study provides a window to intraplate magmatism triggered by mantle upwelling beneath a paleosuture in the North China Craton.

1. Introduction

As one of the oldest cratonic nuclei in East Asia, the North China Craton (NCC) has received much attention with regard to studies on Precambrian crustal evolution and related tectonic and metallogenic processes (e.g., Zhai and Santosh, 2011, 2013; Zhao and Zhai, 2013, and references therein). The NCC has also been central to the investigations on the mechanisms of building and breaking of cratons (e.g., Menzies et al., 1993; Gao et al., 2009; Xu et al., 2009; Zhang et al., 2002, 2011a, 2011b). The timing, characteristics, processes and implications of the destruction and refertilization of the NCC have been addressed in various geological, geochemical and geophysical studies (e.g., Chen, 2009; Zhang, 2009; Santosh, 2010; Zhu et al., 2011). The emplacement of voluminous magmatic suites during Mesozoic along the craton margins and paleo-sutures, and the extensive destruction of the cratonic architecture of the NCC, have invoked considerable attention since these processes were also accompanied by lithospheric thinning and formation of a number of important mineral deposits (e.g., Guo et al., 2013; Yang et al., 2013; Li and Santosh, 2014; Goldfarb and Santosh, 2013; Zhai and Santosh, 2013). Various models have been invoked to explain the Mesozoic magmatic pulses including back-arc extension, delamination, mantle upwelling, Pacific plate subduction, among others, with extensive mantle–crust interaction and input of both juvenile and recycled components (Guo et al., 2013; Yang et al., 2013, and references therein).

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http://dx.doi.org/10.1016/j.jseaes.2014.02.011
1367-9120/

The destruction of the NCC during Mesozoic is considered as a classic example for the removal of the ancient cratonic mantle lithosphere, similar to that present beneath the Kaapvaal, Siberian, Dharwar and other Archean cratons, and its replacement by a younger, less refractory lithospheric mantle (Menzies et al., 2007; Zhang et al., 2011a, 2011b). Various models have been considered for the 'decratonization' process including foundering, stretching or thermal/chemical erosion through asthenospheric upwelling (Gao et al., 2004; Wu et al., 2005; Huang et al., 2007; Menzies et al., 2007; Zhang et al., 2011a, 2011b).

Lithospheric processes associated with intraplate tectonics has emerged as an important topic to understand continental dynamics and supercontinent tectonics (Aitken et al., 2013, and references therein). The magmatic response to deep mantle plumes and asthenospheric upwelling include layered mafic–ultramafic intrusions, mafic dyke swarms, continental and oceanic flood basalts, giant dyke swarms and anorogenic A-type granitic rocks, and a variety of associated mineral deposits (Pirajno, 2004). Mantle plumes are defined as thermal and or/chemical upwellings of mantle material from either the mantle transition zone or from the core-mantle boundary (e.g., Schubert et al., 2001; Campbell and Davies, 2006; Maruyama et al., 2007; Kawai et al., 2013). Petrographic, geochemical and geochronological investigations of intraplate magmatism provide information on mantle upwelling, and the mechanism of crustal recycling.

In this study, we focus on the Mesozoic magmatism along the Trans-North China Orogen, the paleo suture along which the Eastern and Western Blocks of the NCC were amalgamated during the late Paleoproterozoic. We present petrological, geochemical and zircon U–Pb and Lu–Hf data from representative granitoid plutons and their mafic enclaves, as well as from the basement rocks in the region with a view to address magmatism within intraplate setting and its implications on the lithospheric thinning and crustal reactivation in the NCC.

2. Geological background

The North China Craton is one of the oldest cratonic blocks in the world, containing rocks as old as ~3.85 Ga (Zhai and Santosh, 2011, and references therein). The craton is bound by the early Paleozoic Qilianshan Orogen to the west, the late Paleozoic Central Asian Orogenic Belt to the north, and the Paleozoic–Triassic Qinling–Dabie and Sulu high–ultrahigh pressure metamorphic belt to the south and east respectively (Fig. 1b). The NCC is composed of three major crustal blocks. The Yinshan Block to the north and the Ordos Blocks to the south built the unified Western Block through a prolonged Paleoproterozoic subduction-accretion-collision history leading to the formation of the 'Khondalite Belt' (Zhao et al., 2005) along the Inner Mongolia Suture Zone, as well as a thick accretionary sequence including imbricated continental and oceanic sequences (Santosh, 2010; Santosh et al., 2012, 2013). Eventually, the unified Western Block and the Eastern Block were amalgamated along the Trans-North China Orogen by late Paleoproterozoic (Zhao et al., 2001, 2005; Zhao, 2009; Zhao and Zhai, 2013). The 'double-sided' subduction between the Yinshan and Ordos Blocks and the Eastern Block with the unified Western Block is considered to have marked the final phase of cratonization of the NCC as the craton was incorporated within the Paleoproterozoic Columbia supercontinent (Santosh, 2010).

The N–S trending Trans-North China Orogen (TNCO) separating the Eastern and Western Blocks exposes a variety of rocks including Neoarchean greenstone belts, amphibolites, TTG (tonalite–trondhjemite–granodiorite) gneisses, granulites and several suites of arc magmatic rocks, together with supracrustal sequences and volcanic rocks. The TNCO is bordered by the Xinyang-Kaifeng-Jianping Fault in the east and the Datong–Duolun and Lishi–Huashan faults in the west (Fig. 1a). Our study area is located in the Fuping area in the northern Taihang Mountain (TM) region, along the eastern part of TNCO.

The lithological units in the Fuping Complex have been classified into three units: (1) Neoarchean Fuping TTG gneisses; (2) Neoarchean to Paleoproterozoic Wanzi paragneisses; and (3) Paleoproterozoic Nanying granitic gneisses (Liu et al., 2002, 2004; Zhao et al., 2002). The basement rocks of the Fuping complex are mainly composed of schists, gneisses, amphibolite, marble and banded iron formation (BIF) which are locally covered by Proterozoic to Paleozoic carbonate sequences (e.g. Liu et al., 2004; Zhao et al., 2005; Zhai and Santosh, 2011).

The Fuping complex was intruded locally by Mesozoic granitoids (Fig. 1c). The voluminous Jurassic to Cretaceous intrusions exposed in the TM (Fig. 1c) include the Sunzhuang, Dahenan, Wanganzhen, Chiwawu, and Mapeng plutons. These intrusions are mainly intermediate-acid calc-alkaline monzonitic granite and granodiorite in composition, and are mostly distributed in the north Taihang Mountain in the north of Taiyuan–Shijiazhuang (Fig. 1c) (Gao et al., 2012; Li et al., 2013a, 2013b). The plutons in the southern part of Taihang Mountain consist of Fushan, Wu'an, and Hongshan batholith, which are dominantly composed of intermediate calc-alkaline pyroxene- or hornblende-diorite, monzonite, and syenite (Li et al., 2013a, 2013b). Our study focuses on the Mesozoic Chiwawu and Mapeng plutons as well as their surrounding Paleoproterozoic basement rocks in the Fuping area of northern Taihang Mountain. A summary of our field observations on these rocks from the present study are described in the next section.

2.1. Mesozoic plutonic rocks

2.1.1. Chiwawu pluton

The Chiwawu pluton has an oval shape (Fig. 2), and is exposed around an area of 63 km^2 with a diameter of about 5 km. The pluton shows textural and compositional variation from the inner to the outer zones ranging from coarse grained porphyritic granite at the inner zone to fine grained diorite at the periphery with several diorite porphyry dykes.

The samples analyzed in this study are from the northern part of the Chiwawu porphyritic granodiorite collected from outcrops of the outer phase of the pluton. The rock is light gray, medium- to coarse-grained displaying porphyritic texture (Fig. 3b), and characterized by prominent disequilibrium textures such as anti-rapakivi (Fig. 4a and c) where the plagioclase phenocryst is mantled by the K-feldspar rim, as well as poikilitic textures with numerous hornblende and occasional clinopyroxene inclusions (Fig. 4a and c). K-feldspars in the host pluton occur as coarse grained phenocrysts and their serrated margins reflect reaction with surrounding matrix (Fig. 4a and c). The matrix shows fine granular structure, and is mainly composed of feldspar and quartz, with the presence of fine grained carbonates and iron sulfides (Fig. 4a and c). Another representative sample (CW1-2) of this rock was collected from the contact zone of the granodiorite and diorite enclave, where the porphyritic granodiorite is fresh pink color with an assemblage similar to the one from the previous location described above. The rock shows compositional variation from host granodiorite to diorite enclave, with the grain size ranging from coarse to fine grained.

The diorite enclaves are dark colored with a marked variation in size from 2 cm to more than 10 cm (Fig. 3a). The mafic enclaves are ellipsoidal and lenticular in shape and commonly show sharp contact with their host (Fig. 3a). The long axis of the elliptical enclaves are oriented approximately N–S (N350°).