Journal of Asian Earth Sciences 79 (2014) 246–259

Contents lists available at ScienceDirect

Journal of Asian Earth Sciences

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

Time constraints on the inversion of the tectonic regime in the northern margin of the North China Craton: Evidence from the Daqingshan granites

Qingpeng Meng [a], Yuankai He [a,b], Wen Zhang [a,c], Rongguo Zheng [a], Cao Xu [a], Zhaoyu Zhang [a], Tairan Wu [a,*]

[a] Key Laboratory of Orogenic Belts and Crustal Evolution, Ministry of Education, School of Earth and Space Sciences, Peking University, Beijing 100871, China
[b] Institute of Mineral Resources Research, China Metallurgy Geology Bureau, Beijing 100025, China
[c] Department of Geological Sciences, Stockholm University, SE-106 91, Stockholm, Sweden

ARTICLE INFO

Article history:
Received 1 July 2013
Received in revised form 20 September 2013
Accepted 30 September 2013
Available online 9 October 2013

Keywords:
Early Cretaceous
Magmatism
Geochronology
Geochemistry
NCC destruction

ABSTRACT

The Daqingshan granites are located in a late Mesozoic tectono-magmatic belt at the northern margin of the North China Craton (NCC), and include the Deshengying, Xinisubei, Gulouban, and Kuisu plutons. Ion probe U–Pb zircon dating indicates that the granites were emplaced at 131 ± 1, 140 ± 4, 145 ± 1, and 142 ± 2 Ma, respectively. All of the granites are alkali- and potassium-rich, with high SiO_2 (73.2–76.7 wt.%), K_2O (4.50–5.57 wt.%), Na_2O (3.60–4.93 wt.%), and K_2O/Na_2O (0.99–1.49), and low Al_2O_3 (12.3–14.5 wt.%), CaO (0.45–0.79 wt.%), and MgO ($\leqslant$0.12 wt.%). The granites are light rare earth element enriched ($[La/Yb]_N = 5.6–48.7$). The Xinisubei and Gulouban monzogranites and the Kuisu mylonitic monzogranite have small Eu anomalies ($\delta Eu = 0.65–1.23$), low Zr + Nb + Ce + Y (132–321 ppm), and exhibit a negative correlation between P_2O_5 and SiO_2 contents, which are characteristic of highly fractionated I-type granites with a post-collisional origin. The Deshengying monzogranite is distinctive in being an aluminous A-type granite as evidenced by high $10{,}000 \times Ga/Al$ (>2.6) and Zr + Nb + Ce + Y (312–532 ppm), low Ba and Sr, marked negative Eu anomalies ($\delta Eu = 0.08–0.20$), strong Ba, Sr, P, and Ti depletions, and an absence of alkali minerals. This granite was probably produced by partial melting of continental crust heated by hot mantle-derived magmas during crustal extension. The Deshengying monzogranite represents a post-kinematic pluton emplaced into the Daqingshan fold-and-thrust belt, whereas the Kuisu mylonitic monzogranite is a syn-kinematic pluton intruded along the Hohhot detachment fault. It is evident that the Daqingshan area experienced a change from a compressional to an extensional tectonic regime during 145–140 Ma. The post-orogenic collapse may have resulted in extension of the upper continental crust. Subsequently, as the thrust-detachment system became inactive, the lower crust of the NCC underwent modification and melting from 131 Ma. We conclude that the Early Cretaceous tectonic evolution of the Daqingshan area was caused by post-orogenic collapse and melting of the lower crust of the NCC. Delamination of the lower crust in the northern NCC resulted in crustal extension and asthenospheric upwelling, which produced A-type granites. As such, melting of the lower crust in the northwestern part of the NCC took place as early as the late Mesozoic.

1. Introduction

The Mesozoic tectonic evolution of the northern North China Craton (NCC) records the transformation from late Palaeozoic–early Mesozoic orogenesis to late Mesozoic post-orogenic extension (Davis et al., 1998; Davis and Darby, 2010; Menzies et al., 2007; Ritts et al., 2001; Zhai and Santosh, 2013; Zhao et al., 2004; Zheng et al., 2000; Zhu et al., 2012a). Crustal thickening (Liu et al., 2002; Meng, 2003; Wu et al., 2005b) accompanied by the formation of fold-and-thrust belts (Hu et al., 2010; Lin et al., 2013a,b; Zhao et al., 1994; Zheng et al., 2000) was induced by the continuous southwards accretion of the Siberian Plate and westward subduction of the Paleo-Pacific Plate towards the northern NCC in the early Mesozoic (Shao et al., 1997; Zhao et al., 1994, 2013). From the Jurassic to Early Cretaceous, the tectonism changed from a compressional to an extensional regime, resulting in the formation of detachment faults and metamorphic core complexes (Davis et al., 1998; Davis and Darby, 2010; Menzies et al., 2007; Ritts et al., 2001; Zheng et al., 2000).

The timing of the transition from compression to extension in the NCC has been a longstanding matter of debate. Based on a study of the Jiao–Liao massif of the eastern block of the NCC, Li et al. (2004; 2012) proposed that the transition occurred from

---

* Corresponding author. Tel.: +86 010 62765534.
E-mail address: trwupku@163.com (T. Wu).

1367-9120/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jseaes.2013.09.032

145 to 135 Ma, although the precise age was unclear. Niu et al. (2003) suggested that the Yanshan Movement began at 136 Ma, based on ion probe zircon U–Pb dates of rhyolite from the Zhangjiakou Formation that were interpreted to represent the initiation of Mesozoic tectonic inversion. The study by Dong et al. (2007) of the Yanshan Movement concluded that the tectonic transition took place at ca. 135 Ma. A number of other studies have considered that the inversion occurred at 125 Ma (Zhu et al., 2012b; Lin et al., 2013a,b). Establishing the precise timing of the inversion is necessary to better understand the Mesozoic continent-wide extension, but few precise time spans of this event have been put forward (Lin et al., 2013a).

The Daqingshan fold-and-thrust belt and the Hohhot detachment fault are found in the eastern part of the Daqingshan area, and are part of the Yinshan orogen in the northwestern region of the NCC (Davis and Darby, 2010; Davis et al., 2002; Zhang et al., 2009a). Zhang et al. (2009a) proposed that the Daqingshan fold-and-thrust belt entered its waning stages during 120–119 Ma, based on ^{40}Ar/^{39}Ar dating of phyllonite from the footwalls of fault. Davis et al. (2002) concluded that extension on the Hohhot detachment fault occurred between 125 and 121 Ma, as constrained by ^{40}Ar/^{39}Ar ages of volcanic rocks and amphibolitic schists. However, the relationship between the Daqingshan fold-and-thrust belt and the Hohhot detachment fault remains unclear, along with the timing of the initiation of tectonic inversion.

Previous studies have proposed that not only did tectonic deformation of the upper crust in the northern NCC occur during the Mesozoic, but also that lithospheric thinning and upwelling of asthenospheric mantle took place (Deng et al., 2003; Fu et al., 2012; Gao et al., 2002, 2004, 2008; Jiang et al., 2007; Liu et al., 2002; Ma et al., 2012; Niu et al., 2012; Wu et al., 2011; Xu, 2002; Zhai et al., 2007; Zhang et al., 2013, 2009b, 2012b; Zhang et al., 2008), leading to multiple magmatic pulses and generating important metallogenic provinces (Guo et al., 2013; Yang et al., 2013; Zhai and Santosh, 2013). Presently, the lower crust beneath the NCC is completely different to that beneath the Precambrian NCC, leading to the suggestion that lithospheric modification and destruction largely occurred during the Mesozoic (Gao et al., 1998, 2002; Hao et al., 2012; Wu and Sun, 1999; Xu, 2002; Tang et al., 2012, 2013; Xia et al., 2013; Xu et al., 2006; 2008; Zhai and Fan, 2002; Zhang et al., 2002; , 2011; Zhou et al., 2002; Cai et al., 2013; Li et al., 2013; Zheng et al., 2012). Given the minor volume of magmatism to the west of the Taihang Mountain gravity anomaly belt, this late Mesozoic lithospheric modification and destruction is generally considered to have only taken place in the area from the eastern NCC to the Taihang Mountains (Menzies et al., 2007; Wu et al., 2008). However, lithospheric modification and destruction of the western NCC may have been more widespread than previously thought (Chen et al., 2009; He et al., 2009; Zhu et al., 2011). Although granitic plutons related to late Mesozoic crustal extension and lithospheric destruction are widely distributed in the northern NCC (Fu et al., 2012; Jiang et al., 2009; Wu et al., 2005a; 2011), few geochronological and geochemical studies of these rocks have been reported. In the present study, we provide geochronological and geochemical data for four granitic plutons from the east Daqingshan area; i.e., the Deshengying, Xinisubei, Gulouban, and Kuisu plutons. Our results constrain the ages and petrogenesis of these granites, and have implications for the late Mesozoic tectonic evolution of the northern NCC.

2. Geological setting

The northern NCC bounds the Central Asia Orogenic Belt (CAOB) to the north, and is one of the world's largest accretionary orogens (Jahn et al., 2000; Khain et al., 2003; Kovalenko et al., 2004; Kröner et al., 2007; Sengör et al., 1993; Windley et al., 2007). The Mongol–Okhotsk orogeny is also located to the north of the northern NCC, and was formed during closure of the Mongol–Okhotsk Ocean in the Late Jurassic to Early Cretaceous (Delvaux et al., 1995; Kravchinsky et al., 2002; Metelkin et al., 2010; Tomurtogoo et al., 2005; Wang et al., 2012; Zorin, 1999). In the eastern part of the northern NCC, subduction of the Paleo-Pacific Plate occurred from the Early Jurassic (Wu et al., 2007a; Xu et al., 2013a), which resulted in tectonic overprinting of the northern NCC (Isozaki, 1997; Maruyama et al., 1997; Ren et al., 1997) (Fig. 1a). The Mesozoic tectonic evolution of the northern NCC is still poorly constrained.

The Mesozoic Yinshan-Yanshan orogen within the northern NCC is a typical intraplate orogen, with the Yinshan and Yanshan orogens found in the west and east, respectively (Davis and Darby, 2010; Zhou and Wang, 2012). The Yinshan orogen is located in the northern Ordos block, and was constructed by collisional orogenesis related to closure of the Mongol–Okhotsk Ocean and subduction of the Paleo-Pacific Plate (Davis et al., 1998). In the eastern part of the Yinshan orogen, the development of an E–W trending fold-and-thrust belt was followed by intensive Early Triassic magmatism and emplacement of numerous igneous intrusions in the Daqingshan area (Xu et al., 2001) (Fig. 1b). Subsequently, E–W trending sedimentary basins developed in a weak extensional tectonic regime from Early to Middle Jurassic times (Peng et al., 2001). During the Late Jurassic, the formation of a large-scale thrust belt, marking a change to compressional tectonics, resulted in the cessation of basin formation (Peng et al., 2001). The development of detachment faults and metamorphic core complexes indicates an extensional tectonic regime from the Early Cretaceous (Davis et al., 2002). The major Mesozoic sedimentary rock units in the Daqingshan area are brown sandstones and siltstones of Jurassic age and purple to red conglomerates of Cretaceous age (Qi et al., 2007; Zhang et al., 2009a). The four granite plutons that form the basis of this study are closely related to the thrust and detachment fault systems (Fig. 2).

3. Sample description

The *Deshengying monzogranite* is a dyke exposed over an area of 5 km^2, which was emplaced into Proterozoic epimetamorphic and Jurassic sedimentary rocks (Fig. 2). The dyke is post-kinematic and undeformed, and intrudes the Huangtuyaozi – Majiadian – Deshengying thrust fault, which is part of the Mesozoic Daqingshan fold-and-thrust belt. No lithofacies are developed within the dyke. The Deshengying granite is a medium- to coarse-grained monzogranite; the modal minerals are plagioclase (25–30%), microcline (20–25%), perthite (15–20%), quartz (20–25%), and biotite (<5%). Zircon, apatite, and magnetite are the main accessory minerals. Irregular quartz intergrowths are present in cracks within microcline crystals.

The *Xinisubei monzogranite* is a weakly deformed stock with an area of ca. 25 km^2 that intrudes Archean gneiss (Fig. 2). The stock is also characterized by a lack of different lithofacies. The monzogranite is medium- to fine-grained, and the modal minerals are plagioclase (30–35%; partially sericitized), K-feldspar (30–35%), quartz (20–25%), and biotite (<5%; partially chloritized). The main accessory minerals are zircon, apatite, and magnetite.

The *Gulouban monzogranite* is a dyke that is covered by Cretaceous strata and unconsolidated Quaternary sediments (Fig. 2). The dyke crops out south of the Hohhot detachment fault and is weakly deformed and lithologically homogeneous. The monzogranite is coarse grained and consists of plagioclase (25–30%), alkali feldspar (30–35%; mostly perthite and subordinate microcline),