Journal of Asian Earth Sciences 96 (2014) 308–331

Contents lists available at ScienceDirect

Journal of Asian Earth Sciences

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

Petrogenesis and tectonic implications of early Paleozoic granitic magmatism in the Jiamusi Massif, NE China: Geochronological, geochemical and Hf isotopic evidence

Jun-Hui Bi [a], Wen-Chun Ge [a,*], Hao Yang [a], Guo-Chun Zhao [b], Jie-Jiang Yu [a], Yan-Long Zhang [a], Zhi-Hui Wang [a], De-Xin Tian [a]

[a] College of Earth Sciences, Jilin University, Changchun 130061, China
[b] Department of Earth Sciences, The University of Hong Kong, Pokfulam Road, Hong Kong

ARTICLE INFO

Article history:
Received 30 June 2014
Received in revised form 5 September 2014
Accepted 11 September 2014
Available online 20 September 2014

Keywords:
Jiamusi Massif
Early Paleozoic
Granitic magmatism
Post-collisional collapse

ABSTRACT

This paper reports geochronological, whole-rock geochemical and zircon Hf-isotopic data for the early Paleozoic granitic rocks in the Jiamusi Massif in the eastern segment of the Central Asian Orogenic Belt (CAOB), in order to investigate their precise geochronological framework, petrogenesis, sources and tectonic setting. LA-ICP-MS zircon U–Pb age data indicate that the syenogranite, monzogranite and granodiorite were emplaced during the period of 530–484 Ma. Geochemically, these granitoids have high SiO_2 (64.66–79.17%) and K_2O (3.08–7.33%), low MgO (0.14–2.63%) and CaO (0.37–3.87%), with A/CNK and δEu values of 0.89–1.10 and 0.16–1.77, respectively. These rocks are characterized by enrichment in Rb and Nd, and depletion in Nb, Ta, P and Ti. In addition, *in-situ* Hf isotopic analyses of zircons from the granitic rocks reveal that they have $\varepsilon_{Hf}(t) = -5.8$ to +2.3, with two-stage Hf model ages (T_{DM2}) varying from 1.3 Ga to 2.4 Ga, indicating that they probably originated from the partial melting of a dominantly "old" Paleo-Mesoproterozoic crustal source. Additionally, these granites have variable major and trace element concentrations. Magmatic zircons from these rocks record consistent homogeneous U–Pb ages but have heterogeneous $\varepsilon_{Hf}(t)$ values, reflecting that they resulted from fractional crystallization and crustal assimilation. Based on these geochemical data combined with regional geological investigations, we propose that the early Paleozoic granitic magmatism in the study area occurred in a post-collisional extensional setting, which was probably related to the collapse of a thickened crust.

1. Introduction

Northeastern (NE) China is located in the eastern part of the Central Asian Orogenic Belt (CAOB) (Jahn et al., 2000a; Wu et al., 2000), one of the largest Phanerozoic accretionary orogenic belt in the world, and considered to have formed between 500 and 100 Ma through accretion of arc complexes with the emplacement of large volumes of granitic rocks during Paleozoic and Mesozoic times (Sengör et al., 1993; Chen et al., 2000; Jahn et al., 2000b; Sun et al., 2008, 2009; Geng et al., 2009, 2011; Yin et al., 2009, 2010; Cai et al., 2010, 2011a, b; Eizenhöfer et al., 2014). The granitoids in the CAOB, especially in Tuva, Tansbaikalia and China, have rarely been precisely dated and many aspects of their petrogenesis and tectonic environments were still controversial (Safonova et al., 2011; Wu et al., 2011). The focus of this paper is the granitic magmatism in the eastern segment of NE China, in where the tectonism includes not only the late Permian-Early Triassic closure of the Paleo-Asian Ocean but also Mesozoic–Cenozoic subduction events associated with the Paleo-Pacific Plate (Tang, 1990; Tang et al., 1995; Li et al., 1999; Li, 2006; Wu et al., 2007a; Jiang et al., 2010, 2011, 2012; Yuan et al., 2010, 2011; Wang et al., 2011; Zhang et al., 2011; Cai et al., 2012a, b, 2014). In the easternmost segment of the CAOB, the tectonic units, from NW to SE, include the Erguna, Xing'an, Songliao, Jiamusi and Khanka Massif and Nadanhada Terrane. The Jiamusi Massif was traditionally considered as an important tectonic unit in the CAOB of NE China (Sengör et al., 1993). In the last decade, a major advancement has been made in the geochronology and petrogenesis of the granitoids in the Jiamusi Massif following recognition of the late Pan-African metamorphic event of

* Corresponding author at: College of Earth Sciences, Jilin University, No. 2199 Jianshe Street, Changchun 130061, China. Tel.: +86 0431 88502278; fax: +86 0431 88584422.

E-mail addresses: biying2746@126.com (J.-H. Bi), gewenchun@jlu.edu.cn (W.-C. Ge), yanghao12@mails.jlu.edu.cn (H. Yang), gzhao@hkucc.hku.hk (G.-C. Zhao), yujiejiang@jlu.edu.cn (J.-J. Yu), zhangyanlong@jlu.edu.cn (Y.-L. Zhang), 1003562316@qq.com (Z.-H. Wang), 2272450096@qq.com (D.-X. Tian).

http://dx.doi.org/10.1016/j.jseaes.2014.09.013
1367-9120/

the Mashan Complex (Dorsett et al., 1996; Song et al., 1997; Wilde et al., 2000, 2003; Wen et al., 2008; Ren et al., 2010, 2012) and the widespread exposure of the Phanerozoic granites (Huang et al., 2008; Wu et al., 2001, 2011; Yang et al., 2012, 2014; Yu et al., 2013a,b). In recent years, analysis of SHRIMP zircon U–Pb dating from the Mashan Complex has identified a major ~500 Ma granulite facies metamorphic event in the Jiamusi Massif, in which determination of the age of magmatism was reasonable, but the metamorphic age are from darker (higher uranium content) or recrystallization magmatic zircons, it may have large uncertainty. For example, (1) the biotite granitic gneiss (DM1) from Sandaogou contains zircons with well-defined oscillatory zoning that define a crystallisation age of 523 ± 8 Ma, meanwhile, it also gives a upper intersection age of 498 ± 16 Ma, which were explained to be the later metamorphic age (Wilde et al., 2003); (2) the porphyritic biotite granite (00-SAW-204) from northeast Jiamusi, which contains zircons with oscillatory zoned portions of grains and provides a weighted mean $^{206}Pb/^{238}U$ age of 515 ± 8 Ma. This is taken to be the age of crystallisation of the granitoid, whereas younger ages obtained from dark, homogeneous and turbid zoned portions of zircon reflect the ~500 Ma regional metamorphism (Wilde et al., 2003). Moreover, the tectonic environments and geodynamics of the widely distributed early Paleozoic granitic intrusions are still a matter of considerable debate. The early Paleozoic granitoids were considered to have been emplaced in the period between 530 Ma and 510 Ma, following by a granulite facies metamorphic event at ~500 Ma (Wilde et al., 1997, 1999, 2001, 2003, 2010; Zhou et al., 2010a, b, 2011a), but recent studies have shown that they were formed after the granulite facies metamorphic event (Ren et al., 2010, 2012). The latter speculation was proposed on the basis of the following lines of evidence: (1) the early granulite facies metamorphism and the late migmatization are independent tectono-thermal-magmatic events, (2) the widespread migmatization (c. 500 Ma) in the Mashan Complex was caused by the intrusion of magmas, and (3) the granulite facies metamorphism of the Mashan Complex was characterized by a tight clockwise P–T path (Jiang, 1992; Lu and Xu, 1996).

The above controversies result from a lack of precise dating and detailed geochemical study for early Paleozoic granitic rocks in the Jiamusi Massif. So we have carried out geochronological, whole-rock geochemical and zircon Hf-isotopic investigations on the early Paleozoic granitic rocks in the Jiamusi Massif in the eastern segment of the Central Asian Orogenic Belt (CAOB), with aims: (1) to ascertain the precise emplacement ages of these granitoids, (2) to study their magma sources and petrogenesis, and (3) to constrain the tectonic environments and geodynamics of early Paleozoic granitic intrusions in the Jiamusi Massif.

2. Geological background

The north–south-trending Jiamusi Massif is tectonically located between the Siberian and North China Cratons. It extends southward into the Khanka Massif near the border of the Russian Far East and NE China, and to further extend northward into the Bureya Massif of the Russia Far East, which is referred to as the Khanka-Jiamusi-Bureya Massif (Sorokin et al., 2002, 2004a, b; Sorokin and Kudryashov, 2004c; Wilde et al., 2010; Zhou et al., 2009, 2010a, b, c, 2011a, b; Yang et al., 2012, 2014; Yu et al., 2014). In the Chinese segment, the Jiamusi Massif is bounded by the Songliao Massif to the west and the Nadanhada Terrane to the east, separated by the Jiayin-Mudanjiang Fault and the Yuejinshan Complex, respectively (Fig. 1a).

The basement of the Jiamusi Massif consists of the Mashan Complex and various granitoids. The Mashan Complex is composed of khondalitic rocks, which was metamorphosed to amphibolite and granulite facies with a tight clockwise P–T path. The peak metamorphic conditions were estimated at 0.74 GPa and 850 °C (Jiang, 1992). The granitoid rocks in the Jiamusi Massif can be subdivided into two phases, of which the earlier phase was emplaced at 530–515 Ma, in association with the Late Pan-African orogenic event, and the younger one were emplaced at 270–254 Ma, probably in an active continental margin setting. In addition, the Permian (288–268 Ma) volcanic rocks have also been recognized in the eastern part of this massif (Meng et al., 2008).

The Yuejinshan Complex, trending NE–SW between the Jiamusi Massif and the Nadanhada Terrane (Fig. 1a), is consisted of the strong deformed metasedimentary rocks, granitoids and mafic–ultramafic rocks. Geochemical data indicate that the protolith of the metamorphic ultramafic rocks has affinities to the mid ocean ridge basalt (MORB) (our unpublished data), whereas the protolith of those in the Nadanhada Terrane belongs to the ocean island basalt (OIB) (Tian et al., 2006). The Rb–Sr isochron age of 188 ± 4 Ma obtained for the deformed greenschist facies rocks (Yang et al., 1998), in combination with the study of stratigraphy, petrography and palaeontology of the Yuejinshan Complex, suggests that the unit was an early Mesozoic accretionary complex in the eastern margin of the Jiamusi Massif, the counterpart of which has also been found in the eastern margin of the Khanka Block within the Russian Far East (Ishiwitari and Tsujimori, 2003; Khanchuk et al., 1996).

The Nadanhada Terrane is located to the east of the Jiamusi Massif (Fig. 1a). It has been suggested that this terrane was part of the Mino-Sikhote Alin terrane, accreted to the Asian continental margin from low-latitude during Late Mesozoic time (Mizutani and Kojima, 1992). It consists mainly of Late Paleozoic limestone, Mesozoic strata, mafic–ultramafic rocks and widespread Mesozoic granites. Recent zircon U–Pb dating indicates that these undeformed granites were emplaced into the Raohe Complex at 131–115 Ma (Cheng et al., 2006a), whereas a deformed gabbro in the Raohe Complex was emplaced at 166 ± 1 Ma (Cheng, 2006b). Moreover, the latest radiolarians in the siliceous rock have been dated at around 165 Ma (Zhang, 1990; Shao et al., 1991; Shao and Tang, 1995; Zhang, 1997). Therefore, the Nadanhada Terrane is interpreted as a part of accretionary complex that resulted from the subduction of the Pacific plate in the Late Jurassic-Early Cretaceous.

The Khanka Massif in the southernmost part of the CAOB (Shao and Tang 1995) is largely situated in Far East Russia, with only a small segment cropping out in NE China (Fig. 1a), which consists of two components: Precambrian metamorphic basement rocks and various granitoids, of which the former are sporadically exposed, with metamorphic grades and geological characteristics similar to those of the Mashan Complex of the Jiamusi Massif (HBGMR, 1993; Zhao and He, 1995). The granitoids in the Khanka Massif are divided into three phases: (1) the early Paleozoic granitoids associated with the Late Pan-African orogeny (Wilde et al., 2003); (2) the undeformed Permian granites forming un an active continental margin setting (Yang et al., 2012, 2014); and (3) the Late Triassic granites developing in a post-orogenic extensional environment (Yang et al., 2014).

3. Sample selection and petrography

The present study was carried out in the Baoqing-Shuangyashan area in eastern Heilongjiang Province, situated within the eastern part of the Jiamusi Massif (Fig. 1b). The outcropping strata include the Paleo-proterozoic Dapandao Formation, the Devonian Heitai, Laotudingzi and Qilikashan Formations, the Carboniferous Beixing Formation, and the Permian Erlongshan Formation (HBGMR, 1993). In addition, the Mesozoic–Cenozoic