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Geochronology, geochemistry, and Hf isotopes of Jurassic intermediate-acidic intrusions in the Xing'an Block, northeastern China: Petrogenesis and implications for subduction of the Paleo-Pacific oceanic plate

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ABSTRACT

Zircon U–Pb dating, whole-rock geochemistry, Hf isotopic compositions, and regional geological observations of Jurassic intermediate-acidic intrusions in the Xing'an Block, northeastern China, are presented to constrain their petrogenesis and the tectonic evolution of the Paleo-Pacific Ocean. Zircon U–Pb age dating indicates that the intrusions were emplaced in three stages: during the Early Jurassic (180–177 Ma), Middle Jurassic (171–170 Ma), and Late Jurassic (~151 Ma). Despite the wide range in ages of the intrusions, the magmas of Jurassic acidic intrusions were likely derived from a similar or common source and experienced different degrees of magmatic differentiation, as inferred from their geochemical and Hf isotopic characteristics. The Jurassic acidic intrusions are characterized by high SiO_2 and total $Na_2O + K_2O$, low MgO, and I-type affinities, suggesting that the primary magmas were derived from partial melting of lower crustal material. These findings, combined with their $\varepsilon_{Hf}(t)$ values and two-stage model ages, indicate the primary magmas originated from partial melting of juvenile crustal material accreted during the Neoproterozoic to Phanerozoic. The Middle Jurassic intermediate-acidic rocks (diorites and granodiorites of the TJ pluton) have SiO_2 contents of 57.96–69.10 wt.%, MgO contents of 4.48–1.81 wt.%, and high Mg numbers (45–54). They are enriched in large ion lithophile elements (e.g., Rb, Ba, Th, U, and K) and light rare earth elements, depleted in high field strength elements (e.g., Nb, Ta, Zr, Hf, and Ti) and heavy rare earth elements, and have $\varepsilon_{Hf}(t)$ values of +6.5 to +9.1. These data suggest that the magma was derived from partial melting of a depleted mantle wedge that had been metasomatized by subduction-related fluids. According to these findings and previous studies that focused on contemporaneous magmatic–tectonic activity in northeastern China, we conclude that the generation of Jurassic intermediate-acidic intrusions in the Xing'an Block was related to subduction of the Paleo-Pacific oceanic plate.

1. Introduction

It was previously considered that most of the granitoids in northeastern (NE) China were emplaced during the Paleozoic (HBGMR, 1993; IMBGMR, 1991; JBGMR, 1988), whereas recent studies based on numerous precise age dates have shown that the granitoids are generally of Mesozoic age (Wu et al., 2011). These Mesozoic granitoids have become a research hotspot in recent years (Li et al., 2015; Liu et al., 2015; She et al., 2012; Shi et al., 2013; Tang et al., 2014, 2015; Tian et al., 2015; Wu et al., 2011), although the geodynamic history of their formation remains controversial (Dong et al., 2014; Li et al., 2015; Liu et al., 2015; She et al., 2012; Shi et al., 2013; Tang et al., 2014, 2015; Tian et al., 2015; Wang et al., 2012, 2015; Wu et al., 2011; Xu et al., 2013; Yu et al., 2012; Zhang et al., 2010a,b). One of the focal points of discussion is the origin of the Jurassic rocks in the Great Xing'an Range (GXR), and whether they are related to subduction of the Paleo-Pacific Ocean or the Mongol-Okhotsk Ocean (Ge et al., 2007; Sui et al., 2007; Tang et al., 2015; Wang et al., 2012, 2015; Zhang et al., 2010a,b). Traditionally, it was believed that formation of the massive Jurassic intrusive and volcanic rocks in the GXR was related to subduction of the Paleo-Pacific oceanic plate, based on zircon U–Pb ages and geochemical data (Ge et al., 2007; Sui et al., 2007; Zhang et al., 2010a,b). However, extensive Triassic-Jurassic intrusions and volcanics have recently been reported in the Erguna Block (Tang et al., 2014, 2015; Wang et al., 2015; Wu et al., 2011), and some workers have proposed that these rocks,

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located in the northernmost part of the GXR, could have formed from southwards subduction of the Mongol-Okhotsk oceanic plate. It is possible that the two scenarios presented above (subduction of the Paleo-Pacific versus Mongol-Okhotsk oceanic plates) indicate a complex evolutionary history of the GXR during the Jurassic, and that deep-seated geodynamic processes controlled the Jurassic tectonic evolution of the GXR. However, the Jurassic tectonic history of the GXR, especially the Xing'an Block, has not been resolved. Hence, we undertook zircon U–Pb dating and geochemical analyses (major and trace elements, and Hf isotopic compositions) of the Jurassic intermediate-acidic intrusions in the northern GXR. These data place important constraints not only on the sources and petrogenesis of the Jurassic intrusions, but also on the Jurassic tectonic evolution of the GXR.

2. Geological background and sample descriptions

Tectonically, NE China has generally been assigned to the eastern part of the Central Asian Orogenic Belt (CAOB), located between the North China and Siberian cratons (Jahn et al., 2000; Li, 2006; Sengör et al., 1993). The Phanerozoic tectonic evolution of NE China was dominated by different tectonic regimes (e.g., the Paleo-Asian, Mongol-Okhotsk, and Paleo-Pacific oceans), and the region experienced multiple stages of amalgamation of microcontinents, including the Erguna Block in the northwest, the Xing'an and Songnen blocks in central parts, and the Jiamusi and Nadanhada blocks in the east (Sengör et al., 1993; Wu et al., 2011). Moreover, most of the Phanerozoic granitoids and acidic volcanics in NE China are characterized by positive $\varepsilon_{Hf}(t)$ and $\varepsilon_{Nd}(t)$ values (Dong et al., 2014; Li et al., 2014a; Tang et al., 2015; Tian et al., 2015; Wu et al., 2011; Yu et al., 2014), indicating significant continental growth during the Phanerozoic.

The Jurassic intermediate-acidic intrusions sampled in this study are located in the northern part of Arong Banner, Inner Mongolia Autonomous Region. The study area is tectonically in the eastern part of the Xing'an Block (Fig. 1). It was previously believed that the oldest rocks in the Xing'an Block formed in the Precambrian or pre-Ordovician (i.e., the "Xinkailing" and "Fengshuigouhe" groups; IMBGMR, 1991), and they were correlated with the Xinghuadukou Group in the Erguna Block. However, recent studies have demonstrated that these rocks are metamorphic complexes related to Late Paleozoic to Early Mesozoic orogenic events (Miao et al., 2004, 2007; Xu et al., 2012). Notably, Ordovician porphyry Cu–Mo mineralization (~485 Ma) has been identified in the Duobaoshan area, which might be attributed to collision between the Xing'an and Erguna blocks (Ge et al., 2007). In addition, a narrow zone of Permian A-type granites (290–260 Ma) has been tentatively identified along the Hengenshan-Nenjiang-Heihe suture zone (Li et al., 2014a,b; Sun et al., 2000), which was previously believed to represent a post-collisional extensional environment, thereby constraining the timing of amalgamation of the Xing'an and Songnen blocks. However, Wu et al. (2002) proposed that the formation of these A-type granites was associated with slab break-off rather than amalgamation, indicating that the Xing'an and Songnen blocks had not amalgamated before the Early Permian. During the Mesozoic, large volumes of granitoids and volcanic rocks formed in the Xing'an Block (Dong et al., 2014; Tian et al., 2015; Wu et al., 2002, 2011; Xu et al., 2013; Zhang, 2009; Zhang et al., 2010a).

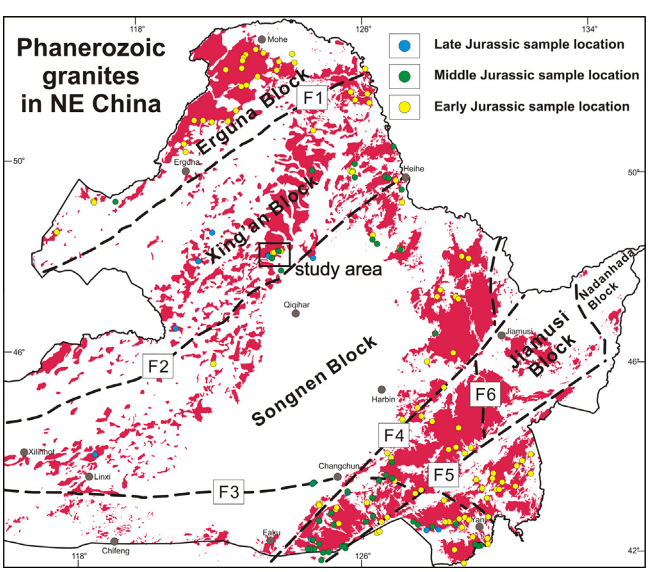

Fig. 1. Distribution of granitic rocks in NE China (showing sampling locations of Jurassic rocks collected in this study; also see Table 4) and simplified tectonic subdivisions of NE China. Abbreviations: F1 = Xiguitu–Tayuan Fault; F2 = Hegenshan–Heihe Fault; F3 = Solonker–Xar Moon–Changchun Suture Zone; F4 = Yitong–Yilan Fault; F5 = Dunhua–Mishan Fault; F6 = Jiayin–Mudanjiang Fault.

In this study, five Jurassic intermediate-acidic intrusions in the Xing'an Block, namely the XS, QY, SJ, TJ, and CBQ plutons, were chosen for geochronological and geochemical analyses (Fig. 2). Owing to dense forests in the study area, the geological boundaries between the plutons could not be accurately determined.

The XS pluton, located near the Xinsheng Village, intrudes the Paleozoic strata and is overlain by Cenozoic sediments (Fig. 2). It is composed of monzogranite (Fig. 3a) with a fine- to medium-granitic texture and a massive structure. It consists of alkali feldspar (~35%), plagioclase (~30%), quartz (~26%), biotite (~8%), and minor accessory zircon, apatite and magnetite (~1%).

The QY pluton, located near the Qiyi Gutter, intrudes the Paleozoic strata and is overlain by Cenozoic sediments (Fig. 2). The pluton is dominated by granodiorite (Fig. 3b) with a subhedral texture and a massive structure. It consists of plagioclase (~55%), alkali feldspar (~10%), quartz (~25%), hornblende (~5%), biotite (~4%), and minor accessory zircon, magnetite and apatite (~1%).

The SJ pluton, located near the Shijing Village, intrudes the Paleozoic strata and is overlain by Cenozoic sediments (Fig. 2). It consists mainly of syenogranite and alkali-feldspar granite (Fig. 3c and d), and displays a subhedral texture and a massive structure. The main rock-forming minerals are alkali feldspar (65–50%), plagioclase (5–15%), quartz (20–25%), garnet (~4%), muscovite (~3%), biotite (~2%), and minor accessory minerals including zircon and apatite (~1%).

The TJ pluton, located near the Tuanjie Village, intrudes the Paleozoic strata and is overlain by Cenozoic sediments (Fig. 2). It is composed of diorite (Fig. 3e) and granodiorite with a subhedral texture and a massive structure. The main rock-forming minerals are plagioclase (60–50%), hornblende (20–10%), quartz (10–25%), alkali feldspar (5–10%), biotite (~4%), and minor accessory minerals including magnetite, zircon and apatite (~1%).

The CBQ pluton, located near the Chabaqi Ewenki Village, intrudes the Paleozoic strata and is overlain by Cenozoic sediments (Fig. 2). It is classified as a monzogranite (Fig. 3f), with a fine- to medium-granitic texture and a massive structure and consisting of alkali feldspar (~35%), plagioclase (~30%), quartz (~30%), biotite (~4%), and minor accessory zircon, apatite and magnetite (~1%).

3. Analytical methods

3.1. Zircon U–Pb dating

Zircon crystals were extracted from whole-rock samples by combining magnetic and heavy liquid separation, and then by