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Geochronology and geochemistry of Early Cretaceous volcanic rocks from the Baiyingaolao Formation in the central Great Xing'an Range, NE China, and its tectonic implications

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ABSTRACT

We undertook zircon U–Pb dating and geochemical analyses of volcanic rocks from the Baiyingaolao Formation in the central Great Xing'an Range, northeastern China, with an aim to determine their age, petrogenesis and sources, which are important for understanding the Late Mesozoic tectonic evolution of the eastern section of the Central Asian Orogenic Belt. Lithologically, the Baiyingaolao Formation is composed mainly of rhyolites and rhyolitic tuffs, with minor trachy dacites. The zircons from three rhyolitic tuffs and two rhyolites are euhedral–subhedral in shape, display fine-scale oscillatory growth zoning and have high Th/U ratios (0.72–2.60), indicating a magmatic origin. The results of LA–ICP-MS zircon U–Pb dating indicate that the volcanic rocks from the Baiyingaolao Formation in the study area formed during the Early Cretaceous time with ages of 134–130 Ma. Petrological and geochemical characteristics of these volcanic rocks suggest that they are all highly fractionated I-type igneous rocks, and their parental magmas were likely derived from the partial melting of lower crustal materials with plagioclase, hornblende and apatite as the residual phases. In addition, the volcanics sampled in this paper, tectonically located in the Xing'an terrain, have high initial $^{176}Hf/^{177}Hf$ ratios (0.282770–0.283035) and positive $\varepsilon_{Hf}(t)$ values (2.42–11.96), combined with young Hf two-stage model ages of 1134–541 Ma, reflecting that the crustal growth of the Xing'an terrain occurred during Neoproterozoic and Phanerozoic times. These data, combined with previous studies on the contemporaneous magma-tectonic activities in NE China, suggest that the generation of the Early Cretaceous volcanic rocks in the central Great Xing'an Range was related to the lithospheric delamination caused by the subduction of the Paleo-Pacific plate.

1. Introduction

Volcanic rocks are important components of the Earth's continental crust. Their formations are largely the result of mass and/or heat transfer from the mantle to the crust in a variety of tectonic environments (Wu et al., 2011). As a result, like granitoids, volcanics play an equally important role in deciphering both crustal growth and tectonic evolution (*e.g.* Wang et al., 2011; Zheng et al., 2007), although their distribution is less than that of the granitic intrusions on the earth surface. The Great Xing'an Range is characterized by immense volumes of Mesozoic volcanic rocks as well as coeval granitoids (Jiang and Quan, 1988; Lin et al., 1998; Wu et al., 2011; Zhang, 2006, 2009; Zhao et al., 1989), and these volcanics constitute the major part of the Mesozoic stratigraphic units of the Great Xing'an Range (IMBGMR, 1991). It was previously thought that the Mesozoic volcanic rocks in the Great Xing'an Range formed during Jurassic to Early Cretaceous time, mainly based on the stratigraphic correlation and minor amounts of Rb–Sr and K–Ar age data (IMBGMR, 1991). However, recent dating results (*e.g.* Gou et al., 2010; Wang et al., 2013; Yang et al., 2012; Zhang, 2006, 2009; Zhang et al., 2008a, 2010) have shown that these Mesozoic volcanics were mainly formed in the Early Cretaceous, with a minority erupting in the Late Jurassic (Chen et al., 2006; Ge et al., 2001; Wang et al., 2006; Wu et al., 2005b; Zhang et al., 2008a). Moreover, it is of particular importance to note that the volcanic rocks from different recognized formations within the Great Xing'an Range, such as the Manketouebo, Manitu, Baiyingaolao and Meiletu formations, exhibit similar age ranges (Zhang et al., 2008a). In addition, more and more lines of evidence have indicated that the ages of these volcanic rocks are in good accordance with those of the Mesozoic granites in the region (Wu et al., 2003a, 2005a, 2011; Zhang et al., 2008a, 2010). Nevertheless, compared with the Mesozoic granitoids, rarely have detailed

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petrographic and geochemical studies been carried out on these volcanic rocks, and their petrogenesis is still unclear (Ge et al., 2001; Gou et al., 2010; Zhang, 2009; Zhao et al., 1989), which has hampered our understanding of the Mesozoic magma-tectonic evolution of NE China. This forms the justification of this contribution in which we carried out extensive field-based petrological, geochemical and geochronological studies on the Baiyingaolao Formation in the Xing'an Terrain in central Great Xing'an Range. The new data will not only allow us to discuss the petrogenesis of the volcanics of the Baiyingaolao Formation, but will also provide constraints on the crustal growth and tectonic evolution of NE China.

2. Geological setting and sample descriptions

The Xing'an–Mongolian Orogenic Belt (XMOB) is considered to be the eastern segment of the Central Asian Orogenic Belt (CAOB), located between the Siberia and North China cratons (Cai et al., 2011a, b, 2012a, b; Jahn et al., 2000a; Jiang et al., 2012; Li, 2006; Sengör et al., 1993; Fig. 1a). During Phanerozoic time, the XMOB experienced complex tectonic evolution, including multiple stages of accretion and collision (Sengör et al., 1993). In the Paleozoic, it evolved from the amalgamation of several micro-continental blocks and/or terranes (Wu et al., 1995), including the Erguna Terrane in the northwest, the Xing'an Terrane in the center, and the Songliao Terrane in the east, separated by Tayuan–Xiguitu and Hegenshan–Heihe faults, respectively (Wu et al., 2000a, 2001, 2005a, 2011; Yang et al., 2014; Zhou et al., 2009, 2010a, b, c, 2011a; Fig. 1a). During Mesozoic time, the XMOB was dominated by the subduction of the Paleo-Pacific plate, which resulted in the accretion of the Jiamusi Massif and Nadanhada Terrane in the Jurassic–Cretaceous (Wu et al., 2007, 2011) and the development of massive basaltic magmatic activities in the Cenozoic (Xu et al., 2008).

The volcanic rocks of the Baiyingaolao Formation sampled in this paper are located in the Wuchagou area of the Horqin Right Front Banner, Inner Mongolia Autonomous Region. Tectonically, the study area is considered to be the eastern part of the Xing'an Terrane (Fig. 1a). The Xing'an Terrane, one of the important microcontinental massifs in NE China, is mostly situated in the Great Xing'an Range, and is characterized by huge volumes of Mesozoic volcanic rocks and granitoids. Previously considered Proterozoic metamorphic rocks (*i.e.*, "Xinkailing" and "Fengshuigouhe" groups; see in IMBGMR, 1991) in the study area have now been proved to be metamorphic complexes related to Late Paleozoic to Early Mesozoic Orogenic processes (Miao et al., 2004, 2007; Xu et al., 2012). Also, an Ordovician island arc at Duobaoshan, with coeval porphyry Cu mineralization, has been recognized in the northern part (Ge et al., 2007b; HBGMR, 1993). In addition, the early Paleozoic limestones, late Paleozoic clastic sedimentary rocks and Mesozoic volcanic rocks also widely occur in the region (HBGMR, 1993; Wang et al., 2006; Zhang et al., 2008a; 2010).

Lithologically, the Baiyingaolao Formation is composed mainly of rhyolites and rhyolitic tuffs, with minor trachy dacites. Meanwhile, field observations suggest that the Baiyingaolao Formation is in unconformable contact with the underlying intermediate volcanic rocks of the Manitu Formation (Fig. 2). The rhyolite (samples D0010-9 and PM002-18-1) is gray white in color, displaying a porphyritic texture and a fluxion structure with a groundmass of a glassy or microcrystalline texture. Its phenocrysts (~15%) are alkali feldspar, quartz, plagioclase, and minor biotite. The rhyolitic tuff (samples PM011-19-1 and PM015-1-1) is gray white and shows a tuff texture and a massive structure. It is composed of ~15% crystal fragments (alkali feldspar, plagioclase, and quartz), ~10% rock detrituses (rhyolite, granite porphyry, granite, and tuff), ~5% vitroclastic, and ~70% volcanic ash. The trachy dacite (sample D2243-1-1) is gray, and displays a porphyritic texture and a massive structure with a groundmass of a typical trachytic texture, containing phenocrysts (~15%) mainly of orthoclase, plagioclase, biotite and minor hornblende.

3. Analytical methods

3.1. Zircon U–Pb dating

Zircons from five volcanic rock samples were separated by combining magnetic and heavy liquid separation, and then by handpicking under a binocular microscope at the Langfang Regional Geological Survey, Hebei Province. The handpicked zircons were mounted in epoxy and polished

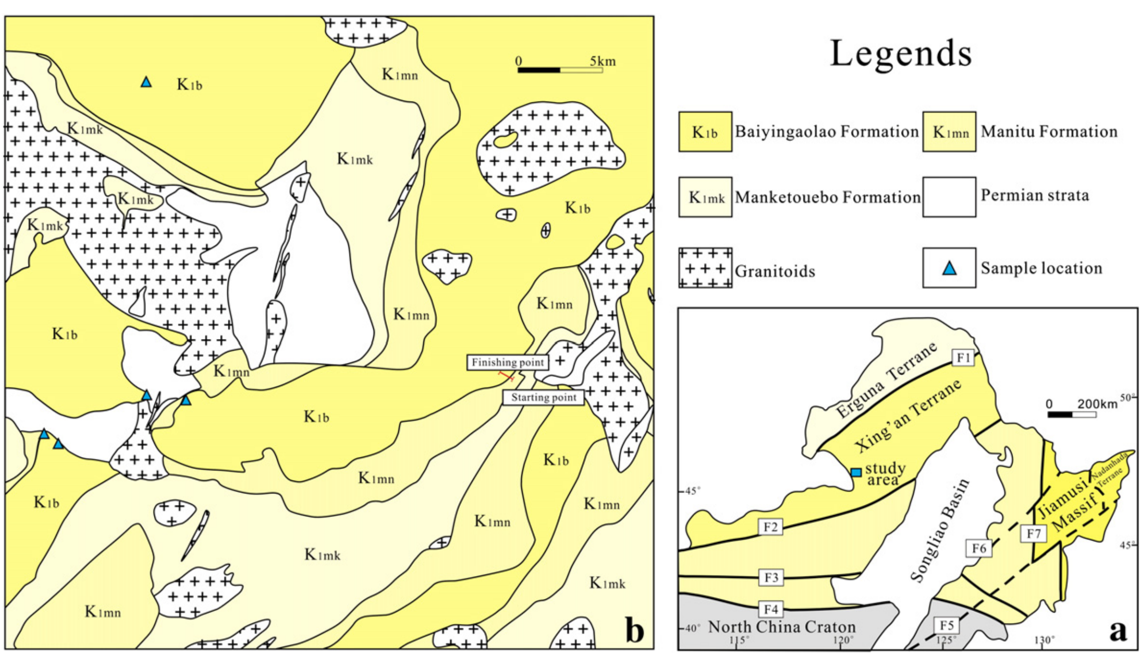

Fig. 1. (a) Simplified tectonic subdivision of NE China. Abbreviations: F1 = Xiguitu–Tayuan Fault; F2 = Hegenshan–Heihe Fault; F3 = Solonker–Xar Moon–Changchun Suture Zone; F4 = Chifeng–Bayan Fault; F5 = Dunhua–Mishan Fault; F6 = Yitong–Yilan Fault; F7 = Jiayin–Mudanjiang Fault. (b) A detailed geological map of the Wuchagou region in central Great Xing'an Range showing sample locations.