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Permian bimodal volcanism in the Zhangguangcai Range of eastern Heilongjiang Province, NE China: Zircon U–Pb–Hf isotopes and geochemical evidence

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ABSTRACT

In this paper, we report on zircon U–Pb dating, Hf isotopes, major and trace elements, and Sr–Nd isotope data, with the aim of constraining the petrogenesis and regional tectonic evolution of late Paleozoic volcanic rocks in the Zhangguangcai Range of eastern Heilongjiang Province, NE China. Located in the eastern segment of the Central Asian Orogenic Belt (CAOB), between the Siberian and North China cratons, the late Paleozoic volcanic rocks in the Zhangguangcai Range are composed mainly of basalt, basaltic andesite, rhyolite, and minor dacite. The results of LA–ICP–MS zircon U–Pb dating for two basaltic rocks, three rhyolites, and one dacite indicate that they formed in the early Permian (ca. 292 Ma). The mafic rocks have SiO_2 = 50.13–53.80 wt.%, K_2O = 0.98–2.28 wt.%, Mg# = 0.51–0.71, Cr = 144–541 ppm, Ni = 74–260 ppm, $(^{87}Sr/^{86}Sr)i$ = 0.7044, and ε_{Nd} (t) = +4.28, whereas the felsic rocks have SiO_2 = 69.12–77.98 wt.%, K_2O = 3.09–5.33 wt.%, Mg# = 0.17–0.36, $(^{87}Sr/^{86}Sr)i$ = 0.7032, and ε_{Nd} (t) = +4.32. These data are typical of bimodal volcanism. The mafic volcanic rocks are characterized by a strong enrichment in large ion lithophile elements (LILEs) such as Rb, Ba, Sr, and Pb, depletion in high field-strength elements (HFSEs) such as Nb, Ta, and Ti, depletion in heavy rare-earth elements (HREEs), and weak negative Eu anomalies (Eu/Eu^* = 0.88–0.94). On the other hand, the felsic rocks show a strong depletion in Nb, Ta, Sr, P, and Ti, enrichment in Th, U, and K, and relatively large negative Eu anomalies (Eu/Eu^* = 0.28–0.95). Taken together, these data suggest that the mafic magma was derived from the partial melting of a depleted lithospheric mantle, modified by subducted slab-derived fluids, and that the felsic magma originated by partial melting of newly accreted crust. The early Permian bimodal volcanic rocks, together with the coeval A-type granites, indicate an extensional environment, similar to a back-arc basin. Such a setting was possibly related to subduction of the Paleo-Asian oceanic plate beneath the Jiamusi and Songnen–Zhangguangcai Range massifs.

1. Introduction

In terms of its tectonics, NE China has traditionally been considered the eastern segment of the Central Asian Orogenic Belt (CAOB), located between the Siberian and North China cratons (Sengör et al., 1993; Jahn et al., 2000, 2004; Xiao et al., 2004; Li, 2006; Windley et al., 2007) (Fig. 1a). The region belongs to the Paleo-Asiatic tectonic domain and was overprinted by circum-Pacific orogens during the Mesozoic and Cenozoic (Wu et al., 2000, 2004, 2007a; Jia et al., 2004; Zhang et al., 2004; Shen et al., 2006; Xu et al., 2009).

The early Paleozoic tectonic evolution of NE China is characterized by the amalgamation of microcontinental massifs (Ye and Zhang, 1994; Zhao et al., 1996; Li et al., 1999; Wu et al., 2000, 2005; Xie, 2000; Wilde et al., 2001, 2003; Xiao et al., 2004; Li, 2006; Windley et al., 2007; Liu et al., 2008; Meng et al., 2010) which include, from west to east, the Erguna, Xing'an, Songnen–Zhangguangcai Range, and Jiamusi massifs (Fig. 1b). However, the late Paleozoic tectonic evolution of NE China remains controversial, particularly with regard to the Permian. Some researchers suggest that subduction of the Paleo-Asian oceanic plate beneath the North China Craton and the Jiamusi Massif occurred during the early Permian (Li, 2006; Shen et al., 2006; Pei et al., 2007; Meng et al., 2008), and that the final closure of the Paleo-Asian ocean occurred during the late Permian or early Mesozoic (Jia et al., 2004; Zhang et al., 2004; Li, 2006, 2007; Wu et al., 2007a,b; Meng et al., 2010). On the other hand, on the basis of bimodal volcanism, an extensional environment has been suggested for the eastern

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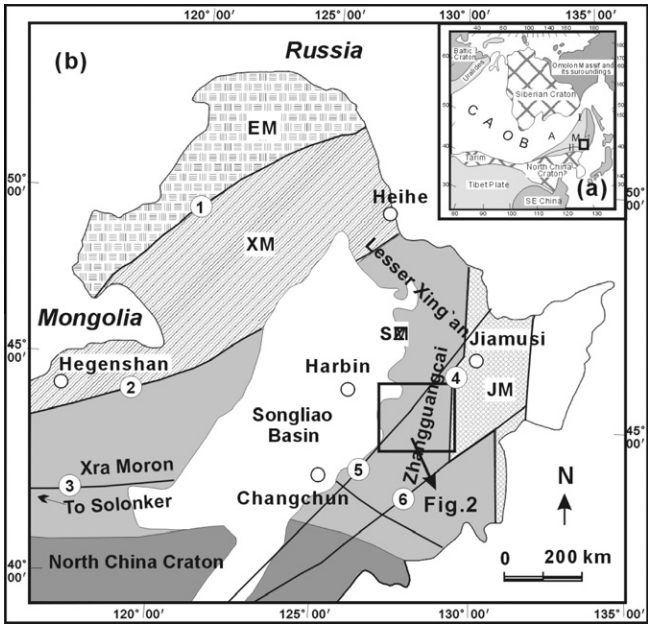

Fig. 1. Tectonic sketch maps of NE China, modified after Wu et al. (2007b). The inset (a) shows the tectonic setting of NE China. A and M represent the Altaids and Manchrides, respectively, of Sengör and Natal'in (1996). EM–Erguna Massif. XM–Xing'an Massif. SM–Songnen–Zhangguangcai Range. JM–Jiamusi Massif. (I) Hegenshan–Heihe suture zone, (II) Solonker–Xra Moron–Changchun suture zone. 1. Xiguitu–Tayuan Fault; 2. Hegenshan–Heihe Fault; 3. Solonker–Xra Moron–Changchun suture; 4. Jiayin–Mudanjiang Fault; 5. Yitong–Yilan Fault; 6. Dunhua–Mishan Fault. The location of Fig. 2 is indicated by the rectangle.

part of Inner Mongolia during the early Permian (Chen et al., 2000, 2009; Zhu et al., 2001; Zhang et al., 2008). This raises the question of the tectonic nature of the Songnen–Zhangguangcai Range Massif during the Permian. Is its evolution related to subduction of the Paleo-Asian oceanic plate beneath the eastern margin of the Jiamusi and Songnen–Zhangguangcai Range massifs during the Permian? This question has remained unanswered, until now. As shown here, the voluminous late Paleozoic volcanic rocks of the eastern Heilongjiang Province provide insights that constrain the nature of the late Paleozoic tectonic evolution of the Zhangguangcai Range.

2. Geological setting and sample descriptions

NE China is located in the eastern section of the CAOB, and includes the Erguna and Xing'an massifs in the northwest, the Songnen–Zhangguangcai Range Massif in the center, and the Jiamusi Massif in the east, with the various massifs separated by major faults (Ye et al., 1994; Ye and Zhang, 1994; Li et al., 1999; Xie, 2000; Wu et al., 2007b) (Fig. 1b). The present study area is the Zhangguangcai Range of eastern Heilongjiang Province, NE China, situated in the Songnen–Zhangguangcai Range Massif, separated from the Jiamusi Massif by the Mudanjiang Fault (HBGMR, 1993; Li, 1998, 2006; Wu et al., 2004, 2007b) (Fig. 1).

The Songnen–Zhangguangcai Range Massif is made up mainly of the Songliao Basin and the Lesser Xing'an–Zhangguangcai Ranges (Fig. 1b). The Songliao Basin formed during the late Mesozoic, based on the geochronology of the basement of the basin, which consists of weakly deformed and metamorphosed Phanerozoic granites and Paleozoic strata (Wu et al., 2001; Gao et al., 2007; Pei et al., 2007). The Lesser Xing'an–Zhangguangcai Ranges are characterized by voluminous Phanerozoic granitoids, with rare Paleozoic strata and late Mesozoic volcanic and sedimentary strata occurring as remnants in a "sea" of granitoids (Wu et al., 2000, 2002). The volcanic rocks, located in the Zhangguangcai Range, occur mainly in the Tangjiatun Formation (C_2t), previously thought to be middle Carboniferous in age, the Wudaoling Formation (P_2w), previously thought to be late Permian, and the Taiantun Formation (J_2t), previously thought to be middle Jurassic (HBGMR, 1993; Fig. 2a).

The Tangjiatun Formation (C_2t), only located in the southwestern Bin county (Fig. 2a and b), is composed mainly of basalt and

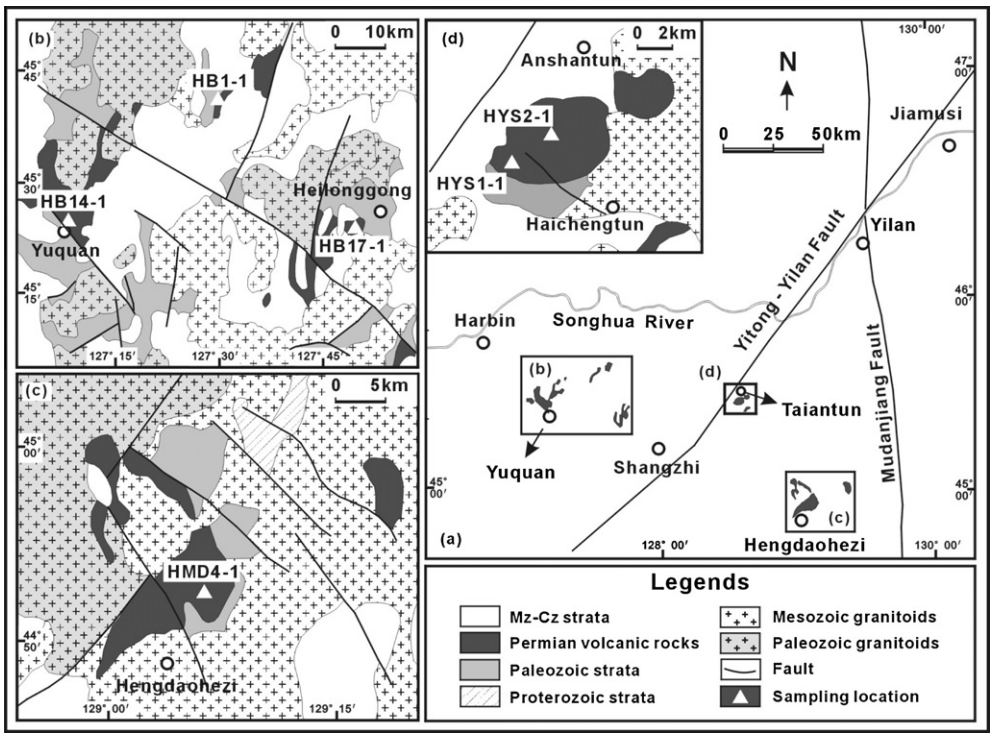

Fig. 2. Distribution of the early Permian volcanic rocks in the Zhangguangcai Range of eastern Heilongjiang Province, NE China. Insets a–c show enlarged geological maps in the areas of Yuquan, Hengdaohezi, and Taiantun, respectively.