Chemical Geology 405 (2015) 10–18

Contents lists available at ScienceDirect

Chemical Geology

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

Contribution of crustal materials to the mantle sources of Xiaogulihe ultrapotassic volcanic rocks, Northeast China: New constraints from mineral chemistry and oxygen isotopes of olivine

Yang Sun [a,b], Jifeng Ying [a,*], Benxun Su [a], Xinhua Zhou [a], Ji'an Shao [c]

[a] State Key Laboratory of Lithospheric Evolution, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, China
[b] College of Earth Science, University of Chinese Academy of Sciences, Beijing 100049, China
[c] Key Laboratory of Orogenic Belts and Crustal Evolution, School of Earth and Space Sciences, Peking University, Beijing 100871, China

ARTICLE INFO

Article history:
Received 25 November 2014
Received in revised form 8 April 2015
Accepted 8 April 2015
Available online 17 April 2015

Editor: K. Mezger

Keywords:
Ultrapotassic volcanic rocks
Oxygen isotopes
Crustal materials
Olivine

ABSTRACT

Ultrapotassic igneous rocks can generally be divided into two sub-groups based on the tectonic settings in which they formed. The orogenic sub-group occurs in subduction-related tectonic settings, while the anorogenic sub-group is confined to stable continental regimes. The Pleistocene Xiaogulihe ultrapotassic volcanic rocks outcrop in the western part of Heilongjiang province, northeast China, and are of intraplate origin with respect to its tectonic settings. Previous elemental and isotopic investigations have suggested that the mantle source of these volcanic rocks had been modified by continental-derived sediments resulting from an ancient subduction (at least older than 1.5 Ga). In this contribution, we performed in-situ oxygen isotope analysis on olivine grains in these ultrapotassic rocks using secondary ionization mass spectrometry (SIMS). The olivine grains generally have higher $\delta^{18}O$ values and CaO contents than those of mantle peridotite xenoliths in the nearby Keluo potassic rocks and show linear correlations between major and trace elements, and Fo, suggesting that they are cognate phenocrysts resulted from fractional crystallization processes. The restricted and non-correlated variations in $\delta^{18}O$ with the Fo of these olivine grains imply that the fractional crystallization processes might have negligible influence on their $\delta^{18}O$ values. The relatively higher $\delta^{18}O$ values of the olivine phenocrysts than the normal mantle imply the addition of an ^{18}O-rich crustal component into their mantle source after ruling out the crustal contamination of the host magmas. We propose that the high-$\delta^{18}O$ feature of the olivine phenocrysts was inherited from the subducted crustal component in their mantle source. Given the rapid oxygen isotopic diffusion under high temperature and the long period between mantle metasomatism event and volcanic eruption, it is postulated that the high-$\delta^{18}O$ signature could only be preserved in the relatively cold and stable subcontinental lithospheric mantle. Such speculation is consistent with our previous inference that the Xiaogulihe ultrapotassic volcanic rocks were mainly generated from the lower subcontinental lithospheric mantle which had been metasomatized by potassium-rich silicate melts derived from ancient subducted continental-derived sediments.

1. Introduction

Potassium-rich igneous rocks are characterized by high K_2O contents ($K_2O > 3$ wt.%) and K_2O/Na_2O ratios (molar $K_2O/Na_2O > 1$), usually accompanied by other geochemical features such as high $Mg^{2+}/Mg^{2+} + Fe^{2+}$ values and Ni and Cr contents, indicating that they have undergone relatively limited differentiation (Foley et al., 1987; Nelson, 1992). These rocks can occur in a variety of tectonic settings, such as island arcs (e.g. Sunda arc and Indonesia), post-collisional settings (e.g. Spain, Italy, Balkan and Southern Tibet) and intraplate continental settings associated with either active rifting (e.g. Toro-Ankole Province of the East African Rift) or hotspot activity (e.g. Western Australia, Gaussberg and Leucite Hills). This diversity of tectonic settings has led to many competing theories regarding their origin (Fraser et al., 1985; Nelson et al., 1986, 1992; Foley et al., 1987; Mitchell and Bergman, 1991; Foley and Peccerillo, 1992; Zhang et al., 1995; Murphy et al., 2002; Zou et al., 2003; Davies et al., 2006; Chen et al., 2007; Prelevic and Foley, 2007; Avanzinelli et al., 2008; Prelevic et al., 2008; Chu et al., 2013; Kuritani et al., 2013; Sun et al., 2014). Nevertheless, the eruptions of these potassium-rich magmas have been commonly attributed to rifting or hotspot activity, and all petrogenic models ever proposed somehow invoke the subduction of crustal materials into their mantle sources as possible mechanisms (Nelson, 1992; Murphy et al., 2002; Davies et al., 2006; Prelevic and Foley, 2007; Avanzinelli et al., 2008; Kuritani et al., 2013; Sun et al., 2014).

Cenozoic intraplate volcanic rocks are widely distributed in northeast (NE) China. These rocks have significant EMI-like isotopic characteristics,

---

* Corresponding author. Tel.: +86 10 82998532; fax: +86 10 62010846.
E-mail address: jfying@mail.iggcas.ac.cn (J. Ying).

http://dx.doi.org/10.1016/j.chemgeo.2015.04.005
0009-2541/

and constitute one of the largest expressions of the DUPAL anomaly in the Northern Hemisphere (Zhou and Armstrong, 1982; Zhou et al., 1988; Basu et al., 1991; Zhou and Zhu, 1992; Liu et al., 1994; Zhou and Zhang, 1994; Zhang et al., 1995, 1998; Zou et al., 2003; Choi et al., 2006; Chen et al., 2007; Chu et al., 2013; Kuritani et al., 2013; Sun et al., 2014; Zhao et al., 2014). Among them, are the Xiaogulihe ultrapotassic volcanic rocks in the WEK volcanic field (Fig. 1), which show unique geochemical features, such as extremely high K_2O contents (>7 wt.%), abnormally low $^{206}Pb/^{204}Pb$ ratios ($^{206}Pb/^{204}Pb = 16.44–16.55$), and moderately high $^{87}Sr/^{86}Sr$ ratios ($^{87}Sr/^{86}Sr = 0.7053–0.7057$), all considered to be typical characteristics of the LOMU (low-μ) end-member (Chen et al., 2007; Sun et al., 2014). The LOMU mantle end-member, introduced by Zhou and Zhang (1994); Douglass et al. (1996), has simlar Sr–Nd isotopic compositions to the EMI end-member, and is commonly considered as the source of potassium-rich igneous rocks. However, the LOMU end-member is quite different from EMI in terms of Pb isotopic compositions, in that the former shows extremely unradiogenic Pb isotopes, requiring the isolation of a low-μ mantle source with low initial Pb isotopic ratios for periods of greater than 1.5 Ga (Sun et al., 2014).

A number of geochemical investigations have been carried out to elucidate the magma genesis and mantle source composition of these potassium-rich rocks (Zhou and Zhang, 1994; Zhang et al., 1995, 1998; Zou et al., 2003; Choi et al., 2006; Chen et al., 2007; Chu et al., 2013; Kuritani et al., 2013; Sun et al., 2014), and most of the published results have consented to the fact that these potassium-rich rocks were mainly generated in the sub-continental lithospheric mantle (SCLM). Recent study further argued that the SCLM source of these ultrapotassic rocks had been metasomatized by potassium-rich silicate melts derived from continental sediments and these crustal materials probably had been recycled through ancient subduction processes (older than 1.5 Ga, Sun et al., 2014). However, the mantle transition zone source model (Murphy et al., 2002; Kuritani et al., 2011, 2013) and asthenosphere source model (Choi et al., 2006; Zhao et al., 2014) cannot be entirely ruled out at this stage because previous investigations were mostly based on bulk-rock elemental and radiogenic isotopic studies, and these bulk-rock geochemical studies may lead to several competing interpretations regarding their petrogenesis.

Oxygen isotope is widely used to trace the origin and evolution of mantle-derived magmas and to constrain geodynamic processes such as mantle metasomatism by crustal materials, due to the sharp contrast of oxygen isotopic compositions between the crustal and mantle rocks (Eiler, 2001; Valley, 2003; Bindeman, 2008; Dai et al., 2011; Zheng, 2012). Relative to traditional oxygen isotope analysis such as laser fluorination analysis of mineral separates, in-situ oxygen isotope analysis using secondary ionization mass spectrometry techniques (SIMS) has overwhelming advantages in determining the oxygen isotopic variation of single minerals or within a mineral. For instance, it can avoid the effect of impure components within mineral crystal, reveal the inter-mineral and intra-mineral oxygen isotopic heterogeneity and effectively reduce the influence of exotic fluids or melts.

In order to further constrain the role of ancient crustal materials and provide insight into the evolution of the mantle source of these ultrapotassic rocks, we present, for the first time, in-situ oxygen isotope analysis of the olivine grains in the Xiaogulihe volcanic rocks. The results show that almost all investigated olivine grains have relatively higher $\delta^{18}O$ relative to those of the normal mantle, indicating an origin from a cold and stable mantle source which had been modified by melts and/or fluids released from anciently subducted crustal materials.

2. Geological setting and sample descriptions

The Cenozoic WEK volcanic field, including Wudalianchi (WDLC), Erkeshan (EKS), Keluo and Xiaogulihe (GLH), is located in the Xing'an–Mongolia Orogenic Belt (XMOB) and on the boundary between the northwestern margin of the Songliao Basin and the Great Xing'an Ranges (Fig. 1). This NNW-trending, 400 km-long volcanic rock belt, together with the Tibetan Plateau is the main potassium-rich volcanism area in China (Zhang et al., 1995; Zou et al., 2003; Chen et al., 2007; Chu et al., 2013; Kuritani et al., 2013; Sun et al., 2014).

The XMOB, forming the eastern segment of the Central Asian Orogenic Belt, is a tectonic collage of roughly NE–SW trending micro-continental blocks, including, from west to east, the Erguna, Xing'an, Songliao, and Jiamusi–Khanka massifs (Fig. 1a). The tectonic evolution of this area is closely connected with the final closure of the Paleo-Asian ocean and the Mongolian–Okhotsk ocean, and the subsequent

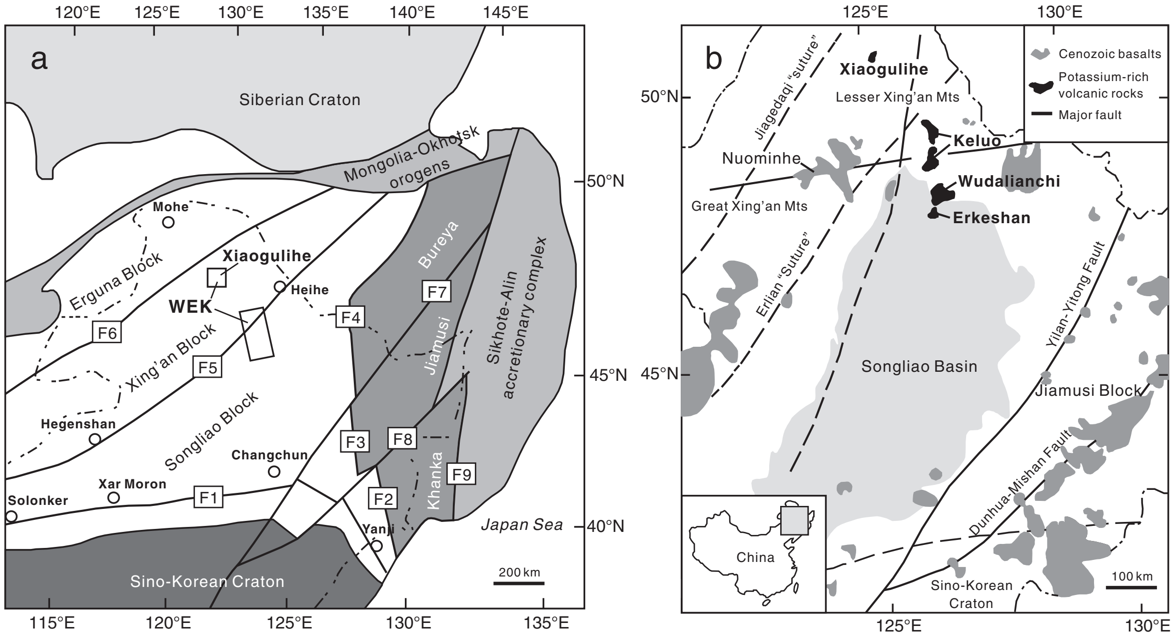

Fig. 1. (a) Tectonic framework of northeast China and far east Russia (modified after Zhou and Wilde, 2013). F1 = Solonker-Xar Moron-Changchun zone; F2 = Yanji Fault; F3 = Mudanjiang Fault; F4 = Heilongjiang Fault; F5 = Hegenshan–Heihe Fault; F6 = Xinlin–Xiguitu Fault; F7 = Yilan–Yitong Fault; F8 = Dunhua–Mishan Fault, and F9 = Primoria Fault. (b) A sketch map showing major faults and the location of the Xiaogulihe, Keluo, Wudalianchi and Erkeshan potassium-rich volcanic rocks in NE China (modified after Zhang et al., 2000).