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Heterogeneous source components of intraplate basalts from NE China induced by the ongoing Pacific slab subduction

Huan Chen [a,b], Qun-Ke Xia [c,*], Jannick Ingrin [b], Etienne Deloule [d], Yao Bi [a]

[a] CAS Key Laboratory of Crust-Mantle Materials and Environments, School of Earth and Space Science, University of Science and Technology of China, Hefei, 230026, China
[b] UMET, UMR CNRS 8207, Université de Lille1, Bât. C6, 59655 Villeneuve d'Ascq, France
[c] School of Earth Sciences, Zhejiang University, Hangzhou, 310027, China
[d] CRPG, UMR 7358, CNRS Université de Lorraine, 15 rue Notre-Dame-des Pauvres, 54501 Vandoeuvre-les Nancy, France

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ABSTRACT

The subduction of oceanic slabs is widely accepted to be a main reason for chemical heterogeneities in the mantle. However, determining the contributions of slabs in areas that have experienced multiple subduction events is often difficult due to possible overlapping imprints. Understanding the temporal and spatial variations of source components for widespread intraplate small volume basalts in eastern China may be a basis for investigating the influence of the subducted Pacific slab, which has long been postulated but never confirmed. For this purpose, we investigated the Chaihe-aershan volcanic field (including more than 35 small-volume Quaternary basaltic volcanoes) in NE China and measured the oxygen isotopes and water content of clinopyroxene (cpx) phenocrysts using secondary ion mass spectrometry (SIMS) and Fourier transform infrared spectroscopy (FTIR), respectively. The water content of magma was then estimated based on the partition coefficient of H_2O between cpx and the basaltic melt. The $\delta^{18}O$ of cpx phenocrysts (4.28‰ to 8.57‰) and H_2O content of magmas (0.19 wt.%–2.70 wt.%) show large variations, reflecting the compositional heterogeneity of the mantle source. The $\delta^{18}O$ values and H_2O content within individual samples also display considerable variation, suggesting the mixing of magmas and that the magma mixing occurred shortly before the eruption. The relation between the $\delta^{18}O$ values of cpx phenocrysts and the H_2O/Ce ratio, Ba/Th ratio and Eu anomaly of whole rocks demonstrates the contributions of three components to the mantle source (hydrothermally altered upper oceanic crust and marine sediments, altered lower gabbroic oceanic crust, and ambient mantle). The proportions of these three components have varied widely over time (~1.37 Ma to ~0.25 Ma). The Pacific slab is constantly subducted under eastern Asia and continuously transports recycled materials to the deep mantle. The temporal heterogeneity of the source components may be caused by ongoing Pacific slab subduction. Combined with other basalt localities in eastern China (Shuangliao basalts, Taihang basalts and Shangdong basalts), the contributions of recycled oceanic components in their mantle source are heterogeneous. This spatial heterogeneity of mantle sources may be induced by variable alterations and dehydration during the recycling process of the Pacific slab. Our results show that the source components of Cenozoic intraplate small-volume basalts in eastern China are temporally and spatially heterogeneous, which is likely induced by the ongoing subduction of the Pacific slab. This demonstrates that integrating the temporal variations in geochemical characteristics and tectonic history of a study region can identify the subducted oceanic plate that induced enriched components in the mantle source of intraplate basalts.

1. Introduction

Continental intraplate small-volume basaltic magmatism is of great interest when tracing the evolution of mantle sources (Farmer, 2014). The widespread Cenozoic alkaline basalts in eastern China provide a noteworthy opportunity to study this magmatism. A great deal of work has been conducted over the last 30 yr to study the genesis of this intraplate volcanism. The associated challenges are primarily concentrated on the components of the mantle source (e.g., Chen et al., 2007; Kuritani et al., 2011; Niu, 2005; Xu et al., 2012; Zhou and Armstrong, 1982; Zou et al., 2000). In the last ten years, seismic imaging has identified the remnants of the subducted Pacific slab in the mantle

* Corresponding author.
E-mail address: qkxia@zju.edu.cn (Q.-K. Xia).

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transition zone (MTZ) of eastern China (Huang and Zhao, 2006; Wei et al., 2012). New geochemical approaches have been developed to trace different components that are involved in the mantle source, such as the H_2O content of magma (Chen et al., 2015a, 2015b; Liu et al., 2015a, 2015b), O isotopic compositions of phenocrysts (Liu et al., 2015a, 2015b; Wang et al., 2015), Mg isotopic compositions of bulk rock (Huang et al., 2015), and composition of melt inclusions (Li et al., 2016). The recycled oceanic slab has increasingly been credited as being one of the major enriched components in these mantle sources. The recycled oceanic slab is a mixture of sediments, upper oceanic crust and lower gabbro oceanic crust. The slab undergoes various forms of alterations and dehydration during the recycling process (e.g., Pietruszka et al., 2013). Understanding the temporal and spatial influences of these different components of the mantle source will be helpful for recognizing the effect of the Pacific plate on mantle heterogeneity and comprehending the relationships between the Pacific plate and the genesis of intraplate basalts.

The Chaihe-aershan volcanic field includes more than 35 small-volume Quaternary basaltic volcanoes (<2 Ma) and is located near the Daxing'anling-Taihang Gravity Lineament (DTGL, Fig. 1), above the front edge of the subducted Pacific slab (Ho et al., 2013; Huang and Zhao, 2006; Wei et al., 2012; Zhao and Fan, 2012). This area is an appropriate place to explore the possible effects of the spatial extent of the Pacific slab. The large number of volcanic eruptions over a short period in the Chaihe-aershan volcanic field also provides an opportunity to study the evolution of mantle sources in detail and explore the small-scale geochemical heterogeneity of the mantle sources. Previous studies have shown the OIB-like trace elements and moderately depleted Sr–Nd isotopic compositions of basalts in this area, which are similar to those of other basalts in eastern China. These studies have suggested that the Chaihe-aershan basalts originated from the partial melting of garnet lherzolites in the asthenosphere, but there has been no discussion of the source of the enriched components (Ho et al., 2013; Zhao and Fan, 2012).

The variations in the oxygen isotopic composition in silicate rocks are primarily the result of water–rock interactions on the earth's surface and crust; thus, these variations are a powerful tool for tracing crustal components in the mantle (Eiler, 2001; Eiler et al., 1997). The recycled components have distinct H_2O/Ce ratios that remain unchanged during magma processes (partial melting and crystal fractionation) (Michael, 1995). The H_2O/Ce ratios of magmas can thus be used to estimate the recycled components in the mantle sources (e.g., Chen et al., 2015b). In this work, the major and trace element compositions of bulk rocks and the O isotope compositions, water contents and major element compositions of clinopyroxene (cpx) phenocrysts were measured in Chaihe-aershan basalts to investigate the possible contributions of recycled components and the small-scale geochemical heterogeneity in the mantle sources caused by the subduction of the Pacific plate. The results were then combined with the results of previous studies on other basalts (Shuangliao basalts, Taihang basalts, Shangdong basalts) to determine the temporal and spatial heterogeneity of the source components for these intraplate basalts from eastern China.

2. Geologic background and samples

Northeast China (NE China) lies within the eastern portion of the Paleozoic Central Asian Orogenic Belt, which was amalgamated with several minor blocks (e.g., Xing'an, Songliao, Jamusi, etc.), between the Siberian Craton and the North China Craton (Sengör et al., 1993). Cenozoic intraplate basaltic magmatism is widely distributed in eastern China, particularly in NE China (Fig. 1a). The Chaihe-aershan volcanic field lies in the center of Daxing'anling to the west of NE China. The majority of the volcanoes are small cinder cones, and the lava flows are distributed along the rivers, such as the Halaha, Chaoer, and Dele Rivers, extending over an area of 400 km^2. K–Ar dating has shown that the volcanoes erupted over a short period, 2.30 to 0.16 Ma (Fan et al., 2011; Ho et al., 2013). The basalts are primarily alkaline olivine basalts with OIB-like trace element patterns, with depleted $^{87}Sr/^{86}Sr$ (0.703485–0.704172) and $^{143}Nd/^{144}Nd$ (0.512812–0.512975) (Ho et al., 2013; Zhao and Fan, 2012).

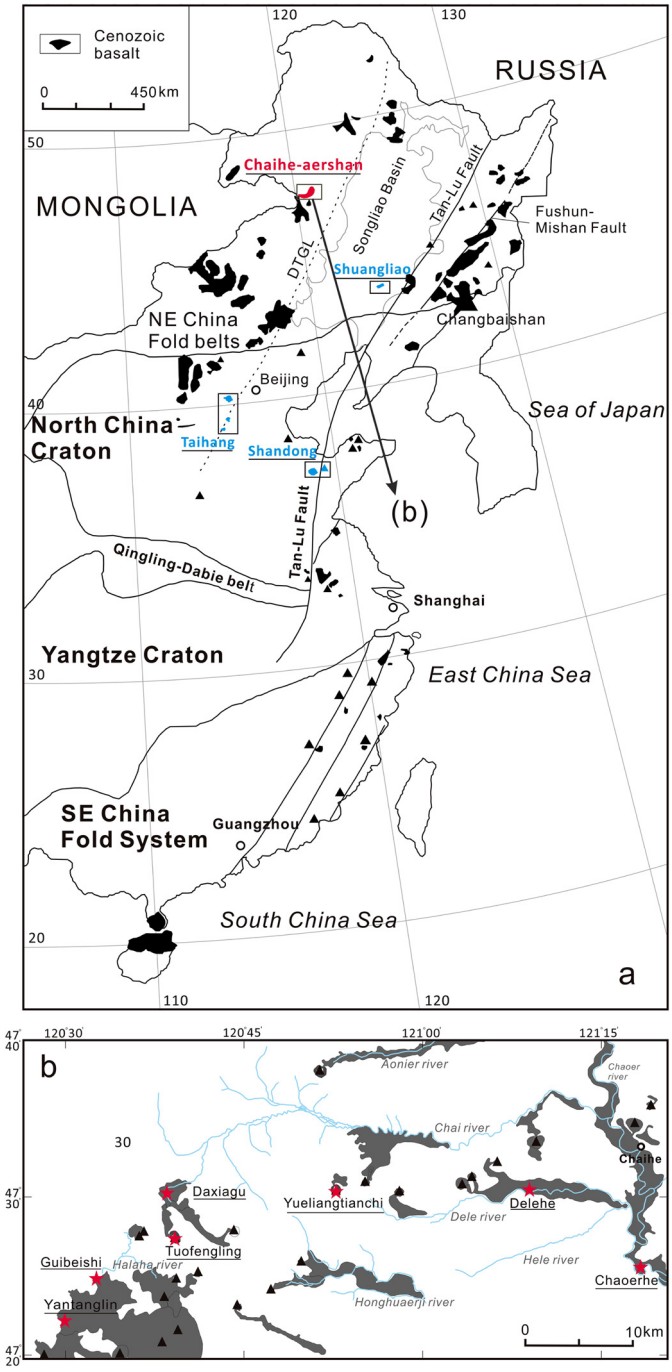

Fig. 1. Simplified tectonic units and distribution of Cenozoic basalts in eastern China as well as the location of the Chaihe-aershan volcanic field (modified according to Xu et al., 2012 and Fan et al., 2011).

The samples were collected from Chaoerhe (CEH), Delehe (DLH), Tuofengling (TFL), Guibeshi (GBS), Yantanglin (YTL), Daxiagu (DXG) and Yueliangtianchi (YLTC) (Fig. 1b). All of these eruptive rocks car-

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