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# Postcollisional mafic igneous rocks record recycling of noble gases by deep subduction of the continental crust

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ABSTRACT

Recycling of noble gases from crustal rocks into the mantle is indicated not only by oceanic basalts and mantle xenoliths, but also by ultrahigh-pressure metamorphic rocks in collisional orogens. It is intriguing whether noble gases in continental crust were recycled into the mantle by deep subduction of the continental crust to mantle depths. Here we firstly report the He, Ne and Ar isotopic compositions of pyroxene from postcollisional mafic igneous rocks in the Dabie orogen, China. The results show that the pyroxene separates from the mafic rocks have low $^3He/^4He$ ratios of 0.002 to 1.8 Ra and air-like Ne isotope compositions. Furthermore, the pyroxene exhibits low $^{40}Ar/^{36}Ar$ ratios of 393.6 to 1599.8, close to those of the air. In combination with whole-rock geochemistry it is found that pyroxene $^3He/^4He$ ratios are correlated with whole-rock $(La/Yb)_N$ and Sr/Y ratios, $\varepsilon_{Nd}(t)$ values and MgO contents. These observations demonstrate the mass transfer from the deeply subducted continental crust to the overlying mantle wedge, recording the source mixing between the crust-derived melt and the mantle peridotite in the continental subduction zone. A direct addition of the crustal He via crust-derived melt to the mantle leads to the extremely low $^3He/^4He$ ratios in the orogenic lithospheric mantle, and the dissolved atmospheric Ar and Ne in the subducted supracrustal rocks results in the air-like Ar and Ne isotope ratios. Therefore, the noble gas isotopic signatures of supracrustal rocks were carried into the mantle by the continental deep subduction to subarc depths and then transferred to the postcollisional mafic igneous rocks via the melt–peridotite reaction at the slab–mantle interface in a continental subduction channel. Our finding firstly establishes the slab–mantle interaction model for recycling of supracrustal noble gases in the continental subduction zone.



## 1. Introduction

Earth's mantle, crust and atmosphere exhibit distinct element and isotope compositions of light noble gases such as He, Ne and Ar (e.g., Graham, 2002; Hilton et al., 2002; Lee et al., 2006; Marty, 1989; O'Nions and Oxburgh, 1988; Porcelli et al., 2002), which make them a powerful tool to decipher the recycling of crustal materials and the chemical evolution of the Earth's mantle (e.g., Czuppon et al., 2010; Hilton et al., 2002; Hopp and Ionov, 2011; Yamamoto et al., 2004). Extensive studies have indicated that noble gas isotope compositions showing crustal (enriched) and atmospheric signals are significant in mantle xenoliths and mantle-derived mafic rocks. These have been interpreted to record the recycling of subducted oceanic crust (Barry et al., 2015; Day et al., 2015; Holland and Ballentine, 2006; Martelli et al., 2004; Yamamoto et al., 2004). Furthermore, ultrahigh-pressure (UHP) eclogite-facies metamorphic minerals such as phengite and omphacite are shown to contain atmospheric Ar and Ne (Baldwin and Das, 2015), indicating that continental crustal subduction carried the atmospheric noble gases to the subarc depth. Because UHP metamorphic rocks are common in continental collision orogens (Chopin, 2003; Liou et al., 2009; Zheng, 2012), it is intriguing whether postcollisional mafic igneous rocks record the recycling of noble gas isotopes by deep subduction of the continental crust in the collisional orogens where UHP metamorphic rocks occur.

Previous noble gas isotope studies have focused mainly on oceanic basalts (e.g., Abedini et al., 2006; Graham et al., 2001; Graham, 2002; Hilton et al., 2002; Kurz et al., 2009; Marty, 1989; Parai et al., 2012), including mid-ocean ridge basalts (MORB), oceanic arc basalts (OAB) and oceanic island basalts (OIB). There are only limited noble gas isotope data of minerals in mafic igneous rocks from the continental crust (e.g., Hou et al., 2011; Smith, 1984; Xu et al., 2014; Zhang et al., 2013). It is noteworthy that the noble gases were extracted from olivine and pyroxene in these studies, which crystallized very early during the magmatic evolution. In this regard, they can provide the information on the mafic magmas from which they crystallized. Postcollisional mafic igneous rocks are common in collisional orogens (e.g., Dilek and Altunkaynak, 2007; Liégeois et al., 1998; Zhao and Zheng, 2009; Zhao et al., 2015; Zheng et al., 2015). However, there is no noble gas isotope study of postcollisional mafic igneous rocks from continental collision

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orogens so far. The noble gases extracted from minerals such as olivine and pyroxene in the postcollisional mafic igneous rocks may provide important information on the geochemical recycling of continental crust through deep subduction to subarc depths of 80–160 km.

In this study, we firstly report the mineral noble gases compositions of postcollisional mafic igneous rocks from the Dabie orogen, east-central China. The results are integrated with whole-rock element and isotope compositions in order to place constraints on the nature of their mantle sources. It is demonstrated that the recycling of noble gases in supracrustal rocks into the mantle would be realized by the melt–peridotite reaction at the slab–mantle interface in a continental subduction channel. The extremely low $^3He/^4He$ ratios and air-like Ne–Ar isotope compositions for the postcollisional mafic igneous rocks record the mass transfer from the deeply subducted continental crust to the subcontinental lithospheric mantle (SCLM) wedge during the continental collision.

## 2. Geological setting

The Dabie orogen was built by the Triassic subduction of the South China Block (SCB) beneath the North China Block (NCB) in east-central China (e.g., Li et al., 1999; Liu and Liou, 2011; Zheng et al., 2009). The UHP metamorphism of deeply subducted continental crust is indicated by the occurrences of coesite and microdiamond inclusions in metamorphic minerals (e.g., Okay et al., 1989; Wang et al., 1989; Xu et al., 1992). According to metamorphic P–T conditions on the outcrop scale, Zheng et al. (2005) subdivided the Dabie orogen into five major lithotectonic units from north to south (Fig. 1): (1) Beihuaiyang low-T/low-P greenschist-facies zone, (2) North Dabie high-T/UHP granulite-facies zone, (3) Central Dabie mid-T/UHP eclogite-facies zone, (4) South Dabie low-T/UHP eclogite-facies zone, and (5) Susong low-T/HP blueschist-facies zone. Although there is no synsubduction arc magmatism in the southern margin of the North China Block close to Dabie orogen, postcollisional magmatic rocks of Early Cretaceous age are common in the both regions (Zhao and Zheng, 2009; Zhao et al., 2013). These postcollisional magmatic rocks were extensively intruded into the metamorphic units, providing us with an excellent opportunity to study reworking and recycling of the deeply continental crust in this collisional orogen.

Postcollisional magmatic rocks in the Dabie orogen are composed of massive granitoids and sporadic mafic rocks. Zircon U–Pb dating for these magmatic rocks yields ages of 112 to 143 Ma for magma crystallization (Zhao and Zheng, 2009), remarkably later than the Triassic age for the continental deep subduction and UHP metamorphism that led to the continental collision orogen (Liu and Liou, 2011; Zheng et al., 2009). Geochemical studies show that postcollisional granitoids exhibit similar element and isotope features to UHP metagranites, indicating their derivation from partial melting of the subducted South China

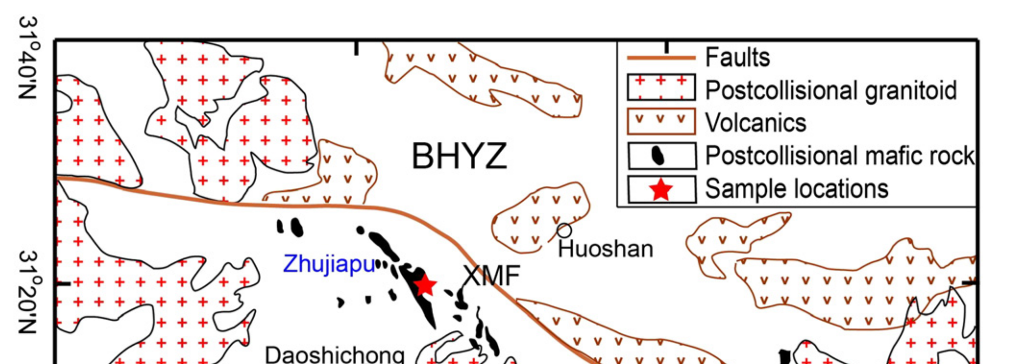


**Fig. 1.** Distributions of postcollisional magmatic rocks in the Dabie orogen (modified after Dai et al., 2011). Abbreviations: BHYZ = Beihuaiyang low-T/low-P greenschist-facies zone, NDZ = North Dabie high-T/UHP granulite-facies zone, CDZ = Central Dabie mid-T/UHP eclogite-facies zone, SDZ = South Dabie low-T/UHP eclogite-facies zone, SZ = Susong low-T/HP blueschist-facies zone.