Short communication

Noble gas isotopes in corundum and peridotite xenoliths from the eastern North China Craton: Implication for comprehensive refertilization of lithospheric mantle

Huaiyu He [a,*], Rixiang Zhu [b], John Saxton [c]

[a] Key Laboratory of the Earth's Deep Interior, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, China
[b] State Key Laboratory of Lithospheric Evolution, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, China
[c] Nu Instruments Ltd., Wrexham LL13 9XS, UK

ABSTRACT

Noble gas isotopic ratios provide unique and important constraints for the evolution of the subcontinental mantle. We present one-step crushing noble gas isotope data from corundum and co-existing mantle xenoliths and megacrystals from the Changle volcanic fields in the middle part of the Tan-Lu Fault Zone, eastern North China Craton. The $^3He/^4He$ ratio is 7.6–8.3 times the atmospheric ratio (Ra) in corundum, indicating contributions of fluids from convective asthenosphere. The $^3He/^4He$ ratio in titanomagnetite megacrystals ranges from 5.8 to 6.5 Ra, suggesting possible U–Th contamination in the crystal lattice, with the $^3He/^4He$ ratio of host magma being higher than 6.5 Ra. The olivine and opx in lherzolite show high helium contents and homogeneous isotopic helium ratios (6.9–7.0 Ra). The cpx in wehrlite show significantly higher helium contents and slightly higher helium ratio (7.6 Ra) than co-existing olivine (7.0–7.5 Ra). Combined with isotope correlation diagrams, the systematic difference in ^4He abundance, the $^3He/^4He$ and $^4He/^{40}Ar^*$ ratios of cpx, opx and olivine in pyroxenite, lherzolite and wehrlite suggest comprehensive refertilization of lithospheric mantle in the eastern North China Craton.

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1. Introduction

The North China Craton is one of the oldest cratons on Earth (3.8 Ga) (Liu et al., 1992) and is also one of the major Archean cratons in eastern Eurasia. However, the craton experienced fundamental lithospheric rejuvenation in the late Mesozoic and Cenozoic, resulting in replacement of the old, cold, thick (>180 km), and depleted lithospheric mantle by young, hot, thin (70–80 km), and fertile lithospheric mantle (Menzies et al., 1993; Griffin et al., 1998; Fan et al., 2000; Xu et al., 2004). The preexisting Tan-Lu Fault Zone, main active strike-slip fault zone in eastern China, is believed to have acted as a major channel for ascending asthenospheric melts and played an important role in the Mesozoic–Cenozoic thinning of the North China Craton lithosphere (Zheng et al., 1998; Xu et al., 2004; Chen et al., 2006). There are many mantle-derived xenoliths in the middle part of the Tan-Lu Fault Zone, which can provide direct information about lithospheric evolution and asthenosphere–lithosphere interaction.

The Changle Cenozoic volcanic area is located in the middle part of the Tan-Lu Fault Zone, eastern part of the North China Craton (Fig. 1). Ultramafic xenoliths, mainly lherzolite and pyroxenite, are common in Changle alkali basalt (e.g., Zheng et al., 1998). Detailed petrological and geochemical studies suggest that these low Mg# peridotites represent fragments of the newly accreted lithospheric mantle (Xiao et al., 2010). Thus Changle is an ideal place to study the lithospheric rejuvenation processes. Moreover, there are many corundum megacrysts together with peridotite xenoliths in the Changle alkaline basalt, and their origin is under debate.

Helium isotopic ratios can provide unique and important constraints for the evolution of the subcontinental mantle and delineate similarities and differences between the MORB reservoir and the subcontinental mantle (Stuart et al., 1995). However, previous published noble gas data on mantle xenoliths and megacrystals from the Changle area vary widely. For example, Ma et al. (2006) determined the $^3He/^4He$ ratio to be 0.9–2.7 times the atmospheric ratio (Ra) for olivine, orthopyroxene and clinopyroxene of mantle xenoliths using the fusion technique; Hu et al. (2007) determined the ratio to be 1.1–7.4 Ra by melting of the corundums; Tang et al. (2007a,b) measured the ratio for peridotite using the melting technique, and obtained a value of 2.5 Ra. These values of the $^3He/^4He$ ratio, measured by total fusion, range from 0.9 to 7.4 Ra. The wide range of $^3He/^4He$ values likely reflects contamination by in situ-produced ^4He from U–Th in mineral lattice, thus failing to give stringent constraints on its mantle source.

* Corresponding author. Tel.: +86 10 8299 8414.
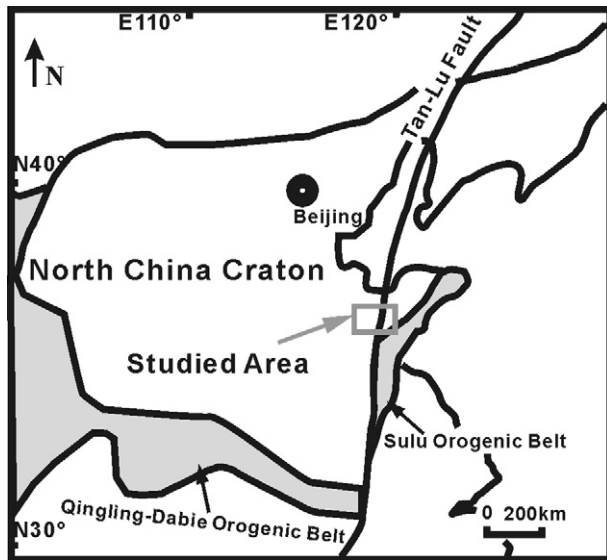   E-mail address: huaiyuhe@mail.iggcas.ac.cn (H. He).

Fig. 1. Schematic map showing the Changle volcanic area and its adjacent regions.

In contrast to the fusion technique, the crushing technique releases gas from fluid inclusions, free of the cosmogenic and radiogenic helium produced in the crystal lattice (^{3}He and ^{4}He, respectively) (Stuart et al., 1995). In this work we report helium isotopic data measured by one-step crushing from peridotite xenoliths, corundum, titanomagnetite megacrystals from the Changle volcanic fields in the eastern North China Craton. With the noble gas data measured by one-step crushing from corundum, which have not be done before, we investigate the mantle characteristics, and discuss the origin of corundum in the Changle alkaline basalt from the North China Craton.

2. Geological setting and sampling

The Changle volcanic field lies in the middle part of Tan-Lu Fault Zone (Fig. 1), eastern China. The major types of the volcanic rocks are alkali basalt and tholeiite. The ages of the basalts range from 17 to 20 Ma (He et al., 2011). Ultramafic xenoliths, mainly spinel lherzolite, wehrlite and pyroxenite, are common in alkali basalt. Due to strong deformation and recrystallization, they mainly show porphyroclastic and granuloblastic textures. Calcite is relatively common in the peridotites and occurs mainly as veins. Multiple analyses on the cores and the rims of the olivine, clinopyroxene and orthopyroxene show that all the mineral phases are homogeneous in major element composition within and between grains (Xiao et al., 2010).

Corundum is concentrated in massive alkali basalt flows that locally contain abundant ultramafic xenoliths, and there appears to be a positive correlation between the abundance of xenoliths and of corundum (Guo et al., 1992, 1996a,b).

Our mantle xenolith and corundum samples come from Wutu (WT) and Beiyan (BY) volcanic fields in Changle, as indicated by their sample ID (Fig. 1) (Dong et al., 1999). Most of our corundum samples are alluvial; a few are recovered directly from basaltic rocks (Table 1). They are mainly dark blue and yellowish brown in color. A hexagonal brown core and blue or yellow–brown fine-scale oscillatory zones are common in the crystals. Primary and pseudosecondary inclusions can be found in the corundum megacrysts in large amounts (Hu et al., 2007). Primary mineral inclusions within corundum include zircons, oligoclase, carbonates and sulfates (Guo et al., 1996a,b; Ding, 1998; Chen et al., 2007; Liu et al., 2007; Song et al., 2008; Song and Hu, 2009). Heating

experiment indicated that these inclusions were homogenized at 1100–1300 °C (Song, 2006). In this study, we measure different parts from one corundum grain. For example, BY-C1-1 and BY-C1-2 means different parts from corundum grain BY-C1. Sample WT-C7 is cloudy alluvial corundum grain, and samples WT-C9 is a cloudy corundum grain recovered directly from basaltic rocks in Wutu. Other corundum grains are quite transparent.

Samples BY-2-1 to BY-2-4 are different titanomagnetite megacrystal grains, which were supposed to be crystallized from Beiyan alkaline basalt (Chen et al., 2009). Samples WT-19-2 to WT-CL11-19-4 are pyroxenite mainly composed of cpx and opx in Wutu. Samples BY-XY, BY11-5, BY11-7 and BY11-10 are pyroxenite in Beiyan. Samples BY-S1 and BY11-3 are lherzolite consisting of ol + cpx + opx + sp. Sample BY-S2 is wehrlite consisting of ol + cpx + sp.

3. Analytical methods

3.1. Sample preparation

The mega-crystals and xenolith samples were crushed and sieved between 20–40 (450–850 μm) mesh fractions. Fresh crystals were picked by hand and washed with 5% HNO$_3$ in an ultra-sonic bath for 20 min to remove possible post eruption radiogenic component, which comes from grain boundaries or host lava and implanted in the first microns of the olivine surface by alpha decays (Moreira and Madureira, 2005). The grains were then rinsed with distilled water and dried. Approximately 1 g of sample was load into in vacuo one-step crusher.

3.2. System blank

Helium blanks were negligible (^{3}He blank <3 × 10^{-17} ccSTP); and Ar blanks were small, about 0.1% to the signals. However, neon blank contributions were much higher (about 10% for ^{20}Ne and ^{22}Ne, and about 30% for ^{21}Ne). Line blanks were run before samples.

3.3. Analysis procedure

Crusher was constructed from 316L stainless steel. Samples were loaded in the aluminum holder, and separated by aluminum plate to minimize the dead volume. The sample was crushed by applying a hydraulic press to the piston. (Andrawes and Gibson, 1979; Stuart et al., 1995). Gases were extracted by in vacuo one-step crushing at about 2000 psi pressure. Crushing minimizes the contribution of in situ produced isotopes and adsorbed atmospheric gases, although the method may be inefficient in rupturing all fluid inclusion. All samples were crushed at room temperature.

The released gases were purified with one cold finger at liquid N temperature and four SAES Zr–Al getters (two at room temperature, the other two at 450 °C). Argon was adsorbed on charcoal in a cold finger at liquid nitrogen temperature, and then helium and neon were trapped on charcoal at a temperature of 10 K by a cyropump. Helium and neon were analyzed successively by desorbing the helium and neon at 35 and 80 K, respectively. The noble gas isotopes analyses were performed on a Noblesse mass spectrometer operating in static mode. A cold GP50 getter and liquid nitrogen-cooled charcoal trap were used to minimize the partial pressure of residual gases during analysis.

The collector section is fitted with a Faraday cup and three ETP electron multipliers attached to ion counting electronics. The mass resolution of Noblesse is sufficient to allow complete separation of ^{3}He and HD, and hydride tail is checked before each measurement. Normally, when ^{3}He signal higher than 1cps, HD+ tail contribution is very small and it is not necessary to correct HD$^+$ + ^{3}He. Thus we