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Noble gas composition of subcontinental lithospheric mantle: An extensively degassed reservoir beneath Southern Patagonia

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A B S T R A C T

Patagonia, in the Southern Andes, is one of the few locations where interactions between the oceanic and continental lithosphere can be studied due to subduction of an active spreading ridge beneath the continent. In order to characterize the noble gas composition of Patagonian subcontinental lithospheric mantle (SCLM), we present the first noble gas data alongside new lithophile (Sr–Nd–Pb) isotopic data for mantle xenoliths from Pali-Aike Volcanic Field and Gobernador Gregores, Southern Patagonia. Based on noble gas isotopic compositions, Pali-Aike mantle xenoliths represent intrinsic SCLM with higher (U + Th + K)/(^{3}He, ^{22}Ne, ^{36}Ar) ratios than the mid-ocean ridge basalt (MORB) source. This reservoir shows slightly radiogenic helium (^{3}He/^{4}He = 6.84–6.90 R_A), coupled with a strongly nucleogenic neon signature (mantle source ^{21}Ne/^{22}Ne = 0.085–0.094). The ^{40}Ar/^{36}Ar ratios vary from a near-atmospheric ratio of 510 up to 17700, with mantle source ^{40}Ar/^{36}Ar between 31100^{+9400}_{-6800} and 54000^{+14200}_{-9600}. In addition, the ^{3}He/^{22}Ne ratios for the local SCLM endmember, at 12.03 ± 0.15 to 13.66 ± 0.37, are higher than depleted MORBs, at ^{3}He/^{22}Ne = 8.31–9.75. Although asthenospheric mantle upwelling through the Patagonian slab window would result in a MORB-like metasomatism after collision of the South Chile Ridge with the Chile trench ca. 14 Ma, this mantle reservoir could have remained unhomogenized after rapid passage and northward migration of the Chile Triple Junction. The mantle endmember xenon isotopic ratios of Pali-Aike mantle xenoliths, which is first defined for any SCLM-derived samples, show values indistinguishable from the MORB source (^{129}Xe/^{132}Xe = $1.0833^{+0.0216}_{-0.0053}$ and ^{136}Xe/^{132}Xe = $0.3761^{+0.0246}_{-0.0034}$).

The noble gas component observed in Gobernador Gregores mantle xenoliths is characterized by isotopic compositions in the MORB range in terms of helium (^{3}He/^{4}He = 7.17–7.37 R_A), but with slightly nucleogenic neon (mantle source ^{21}Ne/^{22}Ne = 0.065–0.079). We suggest that this MORB-like metasomatism was capable of overprinting the noble gas composition of Gobernador Gregores due to recent metasomatism of the SCLM because of asthenospheric mantle upwelling in response to opening of the Patagonian slab window. The ^{40}Ar/^{36}Ar ratios vary from a near-atmospheric ratio of 380 up to 6560, with mantle source ^{40}Ar/^{36}Ar between 8100^{+1400}_{-700} and 17700^{+4400}_{-3100}. The lower ^{40}Ar/^{36}Ar ratio of the

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Gobernador Gregores mantle source, compared with that of Pali-Aike, attests that the Patagonia SCLM was affected significantly by atmospheric contamination associated with the recycled oceanic lithosphere.

1. Introduction

Ultramafic mantle xenoliths that are derived from wedges overlying subduction zones associated with ridge subduction and slab window formation are very rare. Patagonia, the southernmost portion of South America, is one of the few locations where active subduction of a spreading ridge occurs and its effects on ridge axis magmatism can be investigated. Since the middle Miocene, the Chile active spreading ridge has been subducting beneath South America, resulting in a slab-free zone, or slab window, through which asthenospheric mantle can flow. Thus, the collision of the Chile Ridge against the Chile trench offers an opportunity to investigate the composition of the subcontinental lithospheric mantle (SCLM) in this particular geological setting, which is represented by mantle xenoliths, and the influence of the shallow asthenospheric mantle beneath the Andean continental back-arc region.

Abundant spinel- and/or garnet-bearing xenoliths hosted by intraplate alkaline basalts, found in the Pali-Aike Volcanic Field (PAVF) and Gobernador Gregores (GG), provide invaluable information about the nature of southern Patagonian SCLM evolution. Subcontinental mantle xenoliths often have small quantities of noble gases trapped in fluid inclusions (e.g., Gautheron et al., 2005); however, these gases are powerful tracers of the mantle sources. Although the noble gas isotopic ratios of mid-ocean-ridge basalts (MORBs) and ocean island basalts (OIBs) are relatively well defined (e.g., Sarda et al., 1988; Moreira et al., 1998; Trieloff et al., 2000; Mukhopadhyay, 2012), the composition of the SCLM source remains poorly understood. This limitation is enhanced by the significant contribution of an air-like component to the noble gas composition of mantle-derived xenoliths. This complicates the characterization of the mantle endmember composition because these rocks generally display a binary mixture between a mantle-derived and an atmospheric component (e.g., Buikin et al., 2005; Gautheron et al., 2005; Hopp et al., 2004).

In order to determine the noble gas composition of Patagonian SCLM at the latitude of the Austral Volcanic Zone (AVZ; 49°S–55°S), we present the first helium, neon, argon, krypton, and xenon isotopic ratios plus new lithophile isotopes (Sr–Nd–Pb) in the whole-rock and in mineral separates from anhydrous and hydrous peridotites.

2. Geological setting

Geodynamically, the Patagonian continental back-arc represents a complex region formed by several continental accretion events related to the subduction of different oceanic plates (e.g., Pankhurst et al., 2006), some of which contain seismic and aseismic ridges (e.g., Chile Ridge and Juan Fernandez Ridge).

At present, the Patagonian western margin is characterized by the continuous subduction of the Nazca and Antarctic oceanic plates beneath the South American continental plate, resulting in the formation of the Andean volcanic arc. Approximately 16 Ma ago, the South Chile Ridge (SCR) collided with the Chile trench at the latitude of Tierra del Fuego (55°S) and formed a ridge–trench–trench triple junction known as the Chile Triple Junction (CTJ; Cande and Leslie, 1986). This triple point has since migrated northward to its present position north of the Taitao Peninsula (46.5°S). The subduction of four oblique active ridge segments that entered the trench at 12 Ma (SCR–2), 6 Ma (SCR–1), 3 Ma (SCR0), and 0.3 Ma (SCR1) resulted in a series of slab windows beneath the South American plate (e.g., Cande and Leslie, 1986). Subduction of these segments is associated with asthenospheric mantle upwelling and with the extensive eruption of plateau lavas from the late Miocene to the present (e.g., Gorring et al., 1997; D'Orazio et al., 2000). The ultramafic xenoliths analyzed in this study (Supplementary Table S1) were sampled from the GG volcanic center (PM23; Fig. 1) and from PAVF (PM14 and PM18; Fig. 1).

Gobernador Gregores is located ∼400 km east of the Chile trench, at the southwest border of the Deseado Massif, and within the Meseta Central. The xenoliths were brought to the surface by Plio–Pleistocene alkaline basalts and hawaiites that form a post–plateau sequence (ca. 3.5 Ma; Gorring et al., 1997). The samples studied here are spinel–bearing xenoliths with anhydrous or hydrous (amphibole ± phlogopite ± apatite) assemblages that locally contain glass. These samples are similar to those reported in previous studies (e.g., Gorring and Kay, 2000; Laurora et al., 2001; Zaffarana et al., 2014).

Two different localities of PAVF (4500 km^2; D'Orazio et al., 2000) are considered in this study: 1) Laguna Ana (PM14) and 2) Laguna Timone (PM18). PAVF represents the southernmost Patagonian plateau basalts in the Andean back-arc, located ∼400 km south of GG and east of the present day Chile trench (Fig. 1). PAVF is composed of more than 450 monogenetic volcanic centers composed mainly of alkaline basalts and basanites, with minor olivine basalts (e.g., D'Orazio et al., 2000). The xenoliths hosted by post–plateau alkaline basalts (3.78–0.17 Ma; e.g., D'Orazio et al., 2000 and references therein) are composed of spinel, spinel–garnet, and garnet harzburgites and lherzolites with hydrous phases such as amphibole and phlogopite (e.g., Stern et al., 1999; Gervasoni et al., 2012).

3. Analytical techniques

By using a heating method, noble gases were extracted from GG spinel peridotite samples and PAVF peridotite samples containing garnet and spinel or only spinel. Three whole-rock samples and at least one olivine sample containing the largest amounts of ^{4}He between 1.3×10^{-6} and 5.3×10^{-5} cm^3 STP/g, were selected from each locality to determine noble gas isotopic ratios by using the crushing method (Supplementary Tables S2–S3). Details of sample processing prior to noble gas analysis are described in the Supplementary Material. The analysis was performed at the Geochemical Research Center, Graduate School of Science, University of Tokyo. Single step heating experiments were applied to derive helium, neon, and argon isotopic ratios in the whole-rock samples (∼0.5 g). All noble gas isotopic ratios (helium, neon, argon, krypton, and xenon) were obtained by stepwise crushing in a vacuum to release the noble gases trapped in fluid inclusions within the whole-rock and olivine (Supplementary Tables S2–S5). For the crushing experiments, samples >1 g were crushed in a stainless-steel tube with a sequential number of strokes from a nickel piston driven from outside the vacuum by a solenoid magnet (Sumino et al., 2001). A variable number of strokes was applied to crush the samples, such as 100, 500, 1000, and 2000; the last was applied repeatedly if the sample had sufficient quantities of noble gases. The purification, separation, and isotope ratio analysis procedures of noble gases extracted by single step heating or crushing are described in detail in the Supplementary Material. Based on the reproducibility of measurements of a Japanese helium standard (HESJ) and those