Halogen heterogeneity in the subcontinental lithospheric mantle revealed by I/Br ratios in kimberlites and their mantle xenoliths from South Africa, Greenland, China, Siberia, Canada, and Brazil

Chiaki Toyama1,2, Hirochika Sumino3,*†, Nobuaki Okabe2,4, Akira Ishikawa5, Juni Yamamoto6, Ichiro Kaneoka7, and Yasuyuki Muramatsu2

1Institute of Geology and Geoinformation, Geological Survey of Japan, The National Institute of Advanced Industrial Science and Technology (AIST), Ibaraki 237-0061, Japan
2Department of Chemistry, Gakushuin University, Tokyo 171-8588, Japan
3Department of General Systems Studies, Graduate School of Arts and Sciences, The University of Tokyo, Tokyo 153-8902, Japan
4Health and Environmental Risk Division, National Institute for Environmental Studies, Tsukuba 305-8506, Japan
5Department of Earth and Planetary Sciences, School of Science, Tokyo Institute of Technology, Tokyo 152-8851, Japan
6Department of Earth and Planetary Sciences, Graduate School of Science, Kyushu University, Fukuoka 819-0395, Japan
7Earthquake Research Institute, The University of Tokyo, Tokyo 113-0032, Japan

Abstract

To investigate halogen heterogeneity in the subcontinental lithospheric mantle (SCLM), we measured the concentrations of Cl, Br, and I in kimberlites and their mantle xenoliths from South Africa, Greenland, China, Siberia, Canada, and Brazil. The samples can be classified into two groups based on halogen ratios: a high-I/Br group (South Africa, Greenland, Brazil, and Canada) and a low-I/Br group (China and Siberia). The halogen compositions were examined with the indices of crustal contamination using Sr and Nd isotopes and incompatible trace elements. The results indicate that the difference between the two groups was not due to different degrees of crustal contamination but from the contributions of different mantle sources. The low-I/Br group has a similar halogen composition to seawater-influenced materials such as fluids in altered oceanic basalts and eclogites and fluids associated with halite precipitation from seawater. We conclude that the halogens of the high-I/Br group are most likely derived from a SCLM source metasomatized by a fluid derived from subducted serpentine, whereas those of the low-I/Br group are derived from a SCLM source metasomatized by a fluid derived from seawater-altered oceanic crust. The SCLM beneath Siberia and China could be an important reservoir of subducted, seawater-derived halogens, while such role of SCLM beneath South Africa, Greenland, Canada, and Brazil seems limited.

Keywords: Halogens, kimberlite, subcontinental lithospheric mantle, subduction, metasomatism; Halogens in Planetary Systems

Introduction

Subduction of oceanic plates carries large amounts of surface materials into the Earth’s interior. Among these subducted materials, water released from the subducting oceanic plate plays an important role in the dynamic processes occurring in the mantle wedge, including: (1) the generation of arc magmas beneath subduction zones because of the lowering of the melting temperature of the wedge mantle peridotite (e.g., Ulmer 2001); (2) generation of deep earthquakes by weakening of the mechanical strength of the subducted lithosphere and coupling between the subducted slab and the superjacent mantle wedge (e.g., Seno 2009); and (3) control of mantle rheology that affects the efficiency of mantle convection (e.g., Bolfan-Casanova 2005).

Most of the water carried by plate subduction is bound in hydrous minerals in altered and metamorphosed igneous oceanic crusts and sediments (e.g., Bebout 1996). Almost all pore water (water trapped in pore spaces in sediments and oceanic crust) is expelled from the plate subducted to a depth of 5 km and returned to the surface, resulting in deep seepage within accretionary prisms (e.g., Jarrard 2003). However, deep subduction of the marine pore fluid has been suggested based on the noble gas isotopic data from continental well gases (Holland and Ballentine 2006) and halogen compositions obtained from exhumed mantle wedge peridotites and metasomatized mantle xenoliths (Sumino et al. 2010; Broadley et al. 2016; Kobayashi et al. 2017). The serpentinitized lithospheric mantle in a subducted oceanic plate has been suggested as the transport medium of the marine pore-fluid-derived noble gases and halogens (Sumino et al. 2010; Kendrick et al. 2011, 2013, 2017; Kobayashi et al. 2017). However, little is known about the behavior of halogens during the subduction processes and their fate in the Earth’s mantle.

Halogens [chlorine (Cl), bromine (Br), and iodine (I)] have high-partition coefficients in aqueous fluids (Bureau et al. 2000). Pore fluids are enriched in halogens as they are originated from seawater; however, the high content of I (and of Br to a lesser extent) in organic matter in sediments results in higher I/Cl and Br/Cl ratios in the pore fluids than seawater (Riley and Skirrow 1975; Déruelle et al. 1992; Jambon et al. 1995; Muramatsu and Wedepohl 1998; Bureau et al. 2000; Johnson et al. 2000). The halogen elemental ratios are distinctive in the seawater,