ELEMENTAL AND ISOTOPIC ABUNDANCES OF LITHIUM IN CHONDRULE CONSTITUENTS IN THE ALLENDE METEORITE.

T. Kunihiro, S. Maruyama, M. Watanabe, and E. Nakamura, The Pheasant Memorial Laboratory, Institute for the Study of the Earth's Interior, Okayama University, Japan (tkk@misasa.okayama-u.ac.jp)

Introduction: Most carbonaceous and ordinary chondrites—long touted as primordial material and relatively unchanged since their formation—have been altered by interaction with aqueous fluid on their parent asteroids [e.g., 1]. Lithium is highly soluble in aqueous fluids and can be a useful tracer to investigate fluid-related processes in a chondrite. Despite the potential role of Li as a geochemical tracer, its behavior in geologic processes (e.g., diffusion, equilibrium isotope fractionation) is not well understood. Hanon et al. [2] reported a wide range of Li abundances in chondritic components using secondary ion mass spectrometry (SIMS). Chaussidon and Roberts [3] found a significant range of Li isotopic compositions (δ^7Li from -13 to 35) in chondrules from the Semarkona LL3.0 chondrite and interpreted these variations as a result of heterogeneity inherited from chondrule precursors. McDonough et al. [4] and Seitz et al. [5] determined the Li isotopic compositions of bulk meteorites using inductivity coupled plasma mass spectrometry (ICP-MS) and found a negative correlation between δ^7Li and petrologic grade for carbonaceous chondrites. They inferred that isotopically heavy fluids had interacted with asteroidal materials to produce hydrous minerals that are enriched in ^{7}Li. Sephton et al. [6] demonstrated that Li isotopic compositions of dark inclusions in the Allende meteorite are consistent with that of the Allende matrix. Recently, Channon et al. [7] carried out in situ Li-isotopic analyses of chondrule olivines in the Allende meteorite using SIMS and suggested that there had been diffusive exchange of Li between the olivine inclusions and the Allende matrix. None of these studies have led to an understanding of the elemental behavior of Li in the asteroids. A chondrite, which is a piece of an asteroid, is an aggregate of high- and low-temperature components and is heterogeneous both in elemental and isotopic abundances within and among mineral phases at the micron scale. A microscopic phase-to-phase approach is necessary to characterize elemental behavior and processes on an asteroid. Chondrules are the most abundant components in most chondrites and are believed to have formed from clumps of precursor dust by repeated transient heating events in the early solar nebula. To understand the behavior of Li during nebular and asteroidal processes, we report here data on the distribution of Li elemental and isotopic abundances in chondrule constituents and in the neighboring matrix of the Allende meteorite.

Experimental Methods: Lithium elemental abundance [Li] was determined using a Cameca ims-5f SIMS at Institute for the Study of the Earth's Interior (ISEI). An energy offset of -45 eV was applied. Ion intensities of $^7\mathrm{Li}^+$ and $^{30}\mathrm{Si}^+$ were determined in magnetic peak-jumping mode by ion counting. Two basaltic glasses, an olivine, and three clinopyroxenes, were measured repeatedly as reference materials. The [Li] of these materials, except for the olivine, were determined using ICP-MS following the method of Moriguti et al. [8]. The relative ion yields estimated from reference materials were identical within an analytical uncertainty $\sim 5\%$ regardless of phase.

Lithium isotopic abundances ($\frac{^7\mathrm{Li}}{^6\mathrm{Li}}$) were determined using a Cameca ims-1270 SIMS at ISEI. The primary-beam current ranged from 1 to 20 nA to control secondary ion intensities. Entrance- and exit-slit widths were set to have a mass-resolution power $m/\Delta m \sim 1200$, which is sufficient to eliminate interference ($^6\mathrm{LiH}^+$). Ion intensities of $^6\mathrm{Li}^+$ and $^7\mathrm{Li}^+$ were determined in magnetic peak-jumping mode by ion counting. In order to determine an instrumental mass fractionation, two isotope–reference olivines were measured repeatedly [9]. Bell et al. [10] demonstrated that the Li-isotope matrix-effect for olivine is a function of forsterite content. We did not apply the matrix-effect correction according to the forsterite content. This uncertainty does not affect the discussion about the spatial distribution of Li isotopic abundance within each chondrule because variations of forsterite content within a single chondrule are small (at most $\Delta\mathrm{fo} = 3$).

Results: The [Li] in chondrule constituents vary by three orders of magnitude, from 10^{-2} to 10 $\mu\mathrm{g}\cdot\mathrm{g}^{-1}$, and overlap one another. In general, olivine and mesostasis are depleted in Li ($< [\mathrm{Li}]_\mathrm{bulk}$), whereas low-Ca pyroxene is enriched in Li ($> [\mathrm{Li}]_\mathrm{bulk}$).

δ^7Li of chondrule olivine ranges from -32 to 21. The distribution of δ^7Li in each chondrule (with $1\sigma_\mathrm{m}$ in parenthesis) is $-9(14)$, $3(11)$, $1(9)$, $-12(18)$, $8(11)$, and $-3(6)$. The variation of mean δ^7Li among chondrules is $\sim 10‰$ and is similar to that within chondrules. No systematic correlation between ($\frac{^7\mathrm{Li}}{^6\mathrm{Li}}$) and the textural type of chondrules (porphyritic olivine, porphyritic olivine-pyroxene, and barred-olivine chondrules) was observed.

Discussion: If the majority of Li in chondrule olivine was transferred from the matrix ([Li] ~ 2 $\mu\mathrm{g}\cdot\mathrm{g}^{-1}$) by a diffusion process in the asteroid, there should be a corre-

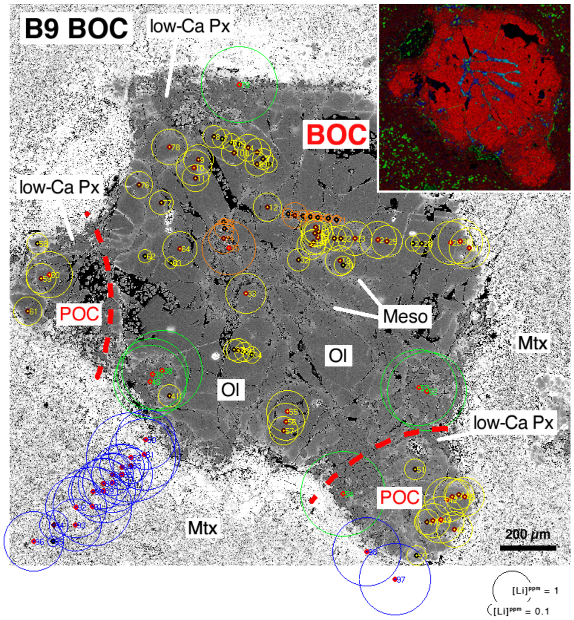

Figure 1: The [Li] distribution in chondrule shown on BSE image. The dimension of circles is proportional to [Li]. A combined Mg–Ca–Al map also is shown on upper-left corner.

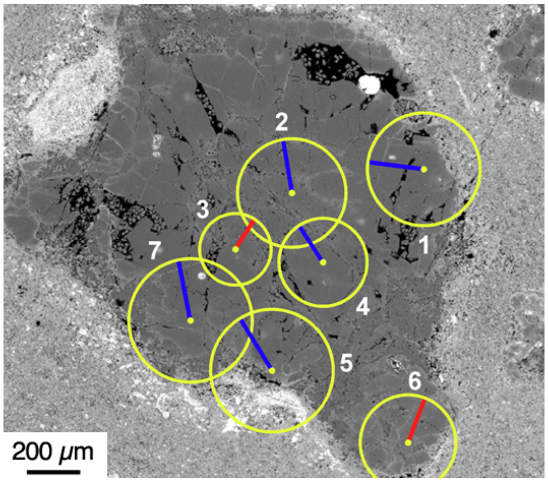

Figure 2: Distribution of $(\frac{^7\mathrm{Li}}{^6\mathrm{Li}})$ in chondrule olivines. The angle of the bar in the circles corresponds to the magnitude of δ^7Li, with a third of the circle (±120°) corresponding to ±20‰.

lation between [Li] and $(\frac{^7\mathrm{Li}}{^6\mathrm{Li}})$ and/or a systematic-spatial distribution (e.g., chondrule/olivine-rim is more enriched in Li than chondrule/olivine-core) because chondrule olivines and matrix olivines are in disequilibrium. There is no significant correlation between [Li] and $(\frac{^7\mathrm{Li}}{^6\mathrm{Li}})$, and spatial distributions in chondrule olivines are not systematic (Figures 1 and 2). Therefore, it is likely that the observed distributions of [Li] and $(\frac{^7\mathrm{Li}}{^6\mathrm{Li}})$ in olivines are not obtained by asteroidal processes although Fe/Mg zoning at the rims of the chondrule olivines could be produced in the asteroidal processes. Chaussidon and Roberts [3] suggested that $(\frac{^7\mathrm{Li}}{^6\mathrm{Li}})$ heterogeneity observed in chondrules is inherited from chondrule precursors that preserved signatures resulting from the mixing of two different nucleosynthetic sources (galactic cosmic rays and big-bang nucleosynthesis). The range of $(\frac{^7\mathrm{Li}}{^6\mathrm{Li}}) \sim 50‰$ observed in this study is consistent with that observed in Semarkona chondrules [3], and we also did not find pure galactic-cosmic-ray components. Considering that chondrules experienced multiple heating events, it is possible that $(\frac{^7\mathrm{Li}}{^6\mathrm{Li}})$ heterogeneity is caused during high temperature magmatic differentiation.

Because mesostasis in chondrule represents melt itself, it should have been enriched in Li at least relative to olivines. However, even relatively primitive mesostases are depleted in Li ($< 0.8\ \mu\mathrm{g} \cdot \mathrm{g}^{-1}$). It is likely that the distribution of [Li] in mesostasis resulted from asteroidal processes and not melt–mineral equilibrium processes in the solar nebular meanwhile chondrule olivine preserves Li distributions produced during chondrule-forming processes in the solar nebula.

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