STRONTIUM STABLE ISOTOPE ANOMALIES IN ALLENDE CHONDRULES

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Introduction: At the time of planetary formation, a significant fraction of solids in the inner part of the solar nebula has been thought to be composed of chondrules. Identification of the mechanism for the chondrule formation can provide an important constraint to discuss how Solar System precursor solids formed, were transported, and mixed in the early solar nebula. However, the origin of chondrules is still controversial. In particular, large variation of chemical compositions in chondrules makes the interpretation of chondrule formation much more complicated.

For better understanding the chondrule formation, we have examined nucleosynthetic Sr isotope anomalies and mass dependent stable Sr isotopic fractionation in bulk-rocks of carbonaceous, ordinary and enstatite chondrites, and their chondrules [1]. We observed that Allende chondrules have nucleosynthetic Sr isotope anomalies which are larger than the bulk Allende, suggesting that Allende chondrules and matrix have formed in separated locations for time and/or space in the early solar system. However, despite the correlation between the chondrule formation ages and their major element compositions [2], our previous investigation [1] lacks detailed geochemical (other than Sr) isotopes and mineralogical information.

In this study, we simultaneously determine the extent of nucleosynthetic anomalies and mass dependent fractionation for Sr in chondrules from Allende by the double spike technique using TIMS, aimed to understand the origin and formation process of chondrules, followed by classifying chondrules based on major element compositions in olivine and pyroxene, and REE compositions in each bulk chondrule.

Experimental: We performed petrographical and mineralogical description of individual chondrules (N = 25, dia. = 0.3 to 2.1 mm) in a polished slab specimen of Allende using SEM-EDX (S-3400N at Tokyo Tech, Hitachi). In this abstract, we report major element compositions for these chondrules. Sr isotope data for these chondrules will be reported shortly after the SEM observations.

Apart from the polished Allende specimen, we analyzed Sr isotope compositions in chondrule grains separated from Allende by the freeze-thaw method. We collected ten chondrule grains for which the trace element concentrations were measured by ICP-MS. To collect sufficient amount of Sr (~100 ng) for a single isotope run, we separated the chondrules into two groups based on the trace element compositions. The sample digestion method, chemical separation procedure, and TIMS analysis are described in [1]. For TIMS analysis, purified Sr solution was split into two aliquots, which were used for determining $^{84}Sr/^{86}Sr$ ratios (unspiked run) and $^{88}Sr/^{86}Sr$ ratios (double-spike run), respectively. In the unspiked run, mass fractionation was corrected by assuming $^{86}Sr/^{88}Sr = 0.1194$. We report $^{84}Sr/^{86}Sr$ ratios in μ-unit ($\mu^{84}Sr$) for unspiked Sr measurements and in δ-unit ($\delta^{88/86}Sr$) for the mass dependent stable Sr isotope variations, respectively. The μ-unit and δ-unit are 10^6 and 10^3 relative deviations from the average of NIST 987, respectively.

Results: Chondrules are usually classified as magnesian (type I) or ferroan (type II), with olivine-dominant (A), intermediate (AB), and pyroxene-dominant (B) subtypes, because chondrule petrographic texture systematically correlate with Fe/(Fe+Mg) ratios in olivine and phroxene [3].

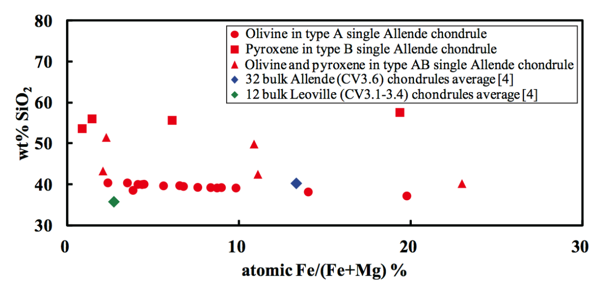

Fig. 2. Average Si concentrations (wt%) and atomic Fe/(Fe+Mg) % ratios of olivines and pyroxenes in single 25 chondrules. Bulk chondrules from other CV chondrites [4] are presented for comparison.

Fig. 3 shows Eu/Eu* and Sr/Y ratios in ten separated chondrules. The Eu/Eu* is nearly constant at Sr/Y = >1 but relatively varies at Sr/Y = <1. Thus, we separated these chondrules into two groups as shown in Fig. 3. Chondrule grains in the individual groups were all merged and subjected to Sr isotope analysis.

The $\mu^{84}Sr$ values in the Allende chondrules groups (+57 ppm, +90 ppm) are similar to that of the bulk-rock (+76 ppm), whereas single Allende chondrules have higher $\mu^{84}Sr$ values (+140 ppm, +110 ppm, Fig. 3). The $\mu^{84}Sr$ value of group A chondrule is lower than that of bulk Allende, whereas that of group B chondrule is marginally higher than the bulk (Fig. 4).

The $\delta^{88/86}Sr$ values of the chondrules are lower than the terrestrial value (Fig. 5), which are consistent with previously published data [7].

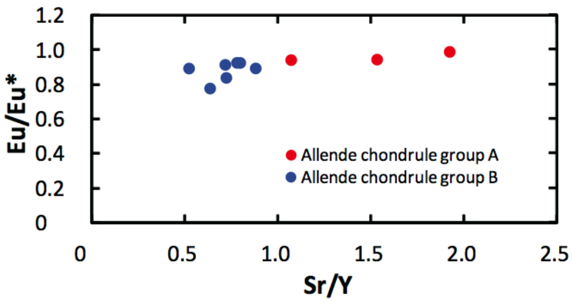

Fig. 3. Eu/Eu values and Sr/Y values of Allende chondrules. Eu/Eu** $= 2Eu_{CI\text{-}norm.}/(Sm_{CI\text{-}norm.} + Gd_{CI\text{-}norm.})$

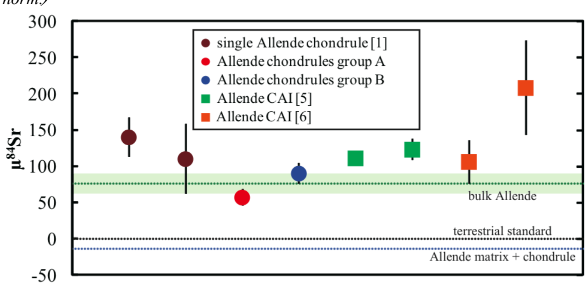

Fig. 4. $\mu^{84}Sr$ *values of bulk rock and chondrules from Allende. CAI data from [5,6] are presented for comparision.*

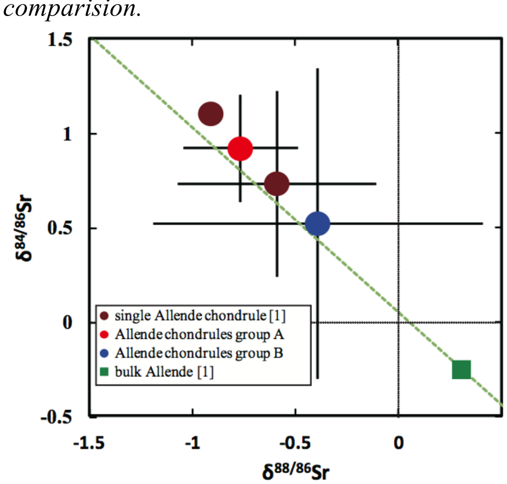

Fig. 5. $\delta^{84/86}Sr$ *and* $\delta^{88/86}Sr$ *for bulk rock and chondrules from Allende. Bulk Allende fractionation line is plotted as green line.*

Discussion: Because Allende CAIs have elevated $^{84}Sr/^{86}Sr$ ratios ($\mu^{84}Sr > 100$ppm), subtraction of the CAI component from the Allende bulk (i.e. matrix and chondrule) yields a $^{84}Sr/^{86}Sr$ ratio lower than the bulk ($\mu^{84}Sr = -14$ ppm) by mass balance calculation, implying that the $\mu^{84}Sr$ values in the Allende chondrules obtained are resolvable from the Allened matrix. This suggests that Allende chondrules and matrix might have formed in separated locations for time and/or space in the early solar nebula. The result would suggest that carbonaceous chondrites contain materials migrated from near the Sun. Such material was irradiated by the young Sun and obtained proton rich components that could have increased the $^{84}Sr/^{86}Sr$ ratios, although this model does not explain the difference of $\mu^{84}Sr$ values in two chondrule groups.

Chondrules from Allende exhibit lower $\delta^{88}/^{86}Sr$ and higher $\delta^{84}/^{86}Sr$ ratios than those of the bulk Allende (Fig. 5). Such mass dependent Sr isotopic fractionation is generally consistent with the inference that fluid assisted metamorphism on the Allende parent body modified $\delta^{88}/^{86}Sr$ values, because this metamorphism fractionated Sr during low-T element redistribution and required mobilization of Sr from matrix into chondrules, as chondrules are isotopically lighter than matrix [7]. If this is the case, the metamorphism must be restricted so as not to erase the effect of nucleosynthetic Sr isotope anomalies ($\mu^{84}Sr$) in chondrules.

References: [1] Okui and Yokoyama, (2013) LPSC 2776. [2] Kurahashi et al., (2008) GCA, 72, 3865. [3] Scott and Taylor, (1983) J. Geophys. Res. Suppl. 88, B275. [4] Kimura et al., (1998) Meteorit. Planet. Sci. 33, 1139. [5] Paton et al., (2013) ApJL. 763, 1. [6] Moynier et al., (2012) EPSL 300, 359. [7] Moynier et al., (2010) EPSL 300, 359.