ASTEROIDAL FLUID ACTIVITY PRESERVED ON CHONDRULE MESOSTASIS. C. Sakaguchi[1], T. Kunihiro[1] and E. Nakamura[1], [1] The Pheasant Memorial Laboratory, Institute for Planetary Materials, Okayama University, Misasa, Tottori 682-0193, Japan (csaka@misasa.okayama-u.ac.jp).

Introduction: Results of Pb–Pb and Rb–Sr dating for the whole-rock Allende meteorite showed different ages [1,2,3]. Such differences could be interpreted as a result of elemental redistribution of Rb–Sr system by aqueous alteration after asteroidal accretion whereas the Pb–Pb clock was not. The most abundant component in chondrites, that can constitute up to 80% of the mass, is chondrule. Their Pb–Pb age is determined to be 4.567 Ga [4,5,6,7] with the chondrule-forming duration ≤ 2 My (e.g., [8]). In order to understand asteroidal process that may have caused discrepancies between whole-rock Pb–Pb and Rb–Sr age, chondrules are the ideal targets because how and when they formed in the solar nebular (before asteroid accretion) are constrained. Especially, mesostasis in chondrules is melt quenched in the Solar nebular, and is susceptible and sensitive to fluid-rock interaction, with its origin and age known. The element distribution of mesostasis should reflect the process on the asteroid, and thus, Rb-Sr age obtained from a series of chondrule mesostasis should indicate age of fluid-rock interaction on the asteroid instead of chondrule formation age on the solar nebula. Mesostasis consists of glass, plagioclase, and pyroxenes with typical size of a few µm, and the Rb–Sr age determination requires separation of elements Rb and Sr. We examine chondrule mesostasis using acid leaching technique to determine isotope ratios of Sr and Nd, and trace-element abundances of the Allende meteorite to constrain timescale of possible fluid-mediated process on an asteroid parent-body.

Sample and Methods: Thirteen chondrules were mechanically separated from the Allende meteorite. The chondrules were divided into two pieces of approximately equal size. One of these samples was used to have a thin section for observation by SEM-EDX. The other was used for chemical analysis. The sample was leached with 0.1M distilled HCl for an hour at 80°C. The leachate and the residue were separately decomposed [9] for chemical analysis to determine trace-element abundances by ICP-MS and isotope systematics (Rb–Sr and Sm–Nd) by TIMS.

Results: Thirteen studied chondrules are classified as type-I FeO-poor and type-II FeO-rich chondrules. The REE abundance pattern of bulk (=leachate + residue) chondrules are flat with 2–3 times enrichment over that of CI chondrite (Fig. 1). The leachate in general is enriched in light REE with a positive Eu anomaly, and shows relatively low-REE abundance compared with the bulk chondrules. In comparison, the residue shows slightly heavy REE-enriched to flat pattern. By the Rb–Sr isotope analyses (Fig. 2), the age of chondrules from leachate, residue, both, and bulk are 4.323 ± 110 (2σ), 4.274 ± 170, 4.354 ± 95, and 4.311 ± 97, respectively. The age estimated by four regressions are consistent within uncertainty. The difference between Pb–Pb and Rb–Sr age, considering this uncertainty, is significant.

Discussion: The light REE-enriched pattern observed in the leachate is explained by mesostasis component dissolved into leachate. The positive Eu-anomaly observed in leachates implies the presence of plagioclase components in chondrules [10]. The REE pattern of the residue is generally depleted in light REE and likely to be dominated by high-Ca pyroxene [11]. Based on the REE pattern and variation of absolute abundances of the leachate, it is confirmed that the leachate preferentially extracted mesostasis and olivine from chondrules. The time interval between formation of refractory inclusions and chondrules, using short-lived nuclide ^{26}Al, is estimated to be ≤ 2 My (e.g., [8]).

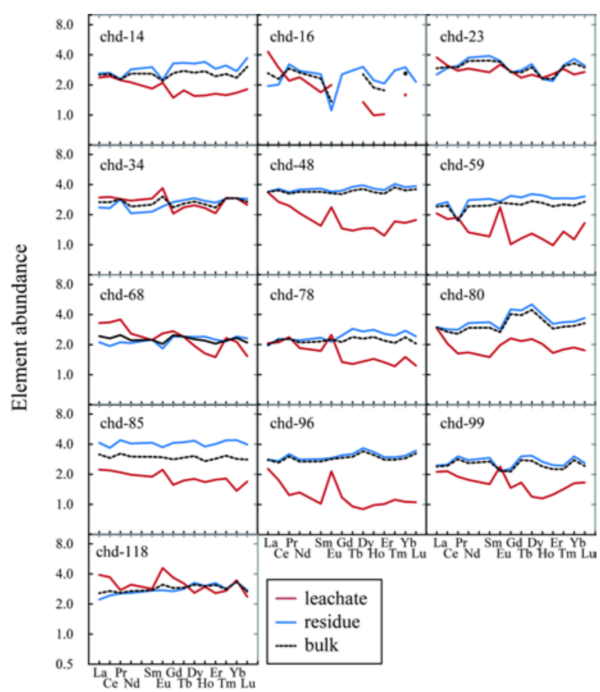

Figure 1: REE abundances of chondrule-leachate, -residue, and -bulk: Element abundances are normalized to those of CI chondrite [15].

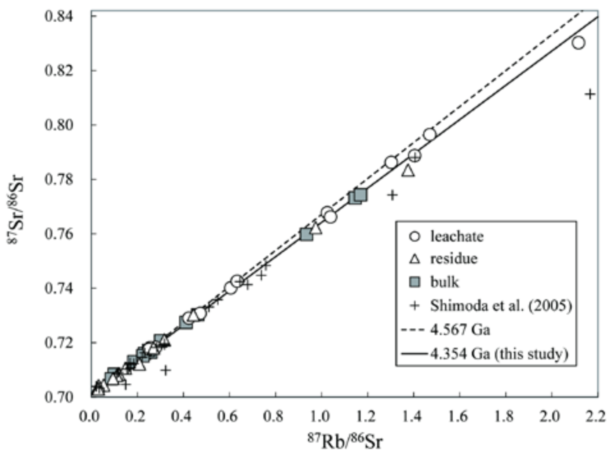

Figure 2: ^{87}Rb–^{87}Sr isochron diagram for chondrule-leachate (circles), -residue (triangle), and -bulk (square). The absolute age estimated from a regression slope for both residue and leachate (solid line) were 4.354 ± 95 Ga. Bulk chondrules by [12] are also shown (cross). Dotted line is 4.567 Ga line that corresponds to Pb–Pb age of chondrules [5].

The Pb–Pb age of Allende chondrules by [7] is 4.5666 ± 10 Ga based on the use of combined acid leachate and residue Pb isotope composition and showed that the Pb–Pb age of Allende chondrules is, on average, 0.6 My younger than refractory inclusions. The chronological order estimated from Pb–Pb age is consistent with the ^{26}Al chronometry and chondrule formation in the solar nebular might have started contemporaneously with or shortly after the formation of refractory inclusions, and lasted for 1–2 million years. Rubidium–Sr data for Allende chondrules, reported by [1,3] form scattered arrays suggesting late re-distribution of Rb and/or Sr. Eight chondrules were analysed and the data plot between 4.2–4.6 Ga [3]. Fourteen chondrules were analysed and the most chondrules plot near the 4.2 Ga [1]. Twenty-two chondrules by [12] obtained even younger age 4.0±4 Ga. Recorded time difference between chondrule formation [5] and ages (this study) estimated from Rb–Sr system of leachate, residue, both, and bulk (this study) are 244 ± 110, 293 ± 170, 213 ± 95 and 256 ± 97 My, respectively. The consistent young age (> 200 My after chondrule formation) between leachate and residue suggests that alkali elements were re-distributed by fluid-mediated process regardless phases although alkali elements in chondrules are concentrated in mesostasis and olivine and pyroxenes are less susceptible to alteration than mesostasis [13]. The Rb/Sr ratio might be obtained when chondrule constituents last reacted with fluid and the Rb–Sr chronological system restarted from the last fluid-chondrule interaction. The deviations on the isochron probably is due to incomplete homogenization of Sr isotopes during this last reaction between fluids and mesostasis. The interpretation is consistent with uncorrelated Rb–Sr age and alteration degree observed on [12] because re-distribution of trace alkali element (i.e., Rb) is more sensitive than phase control to maintain mineral phases (i.e., nepheline and sodalite). If so, the difference between Pb–Pb age [5,6,14] and Rb–Sr age ([1,3,12], this study) of chondrules implies the presence of fluid on the asteroid at >200 My after the chondrule-forming event.

A heat source to melt ice or maintain fluid in the asteroid at 200 My after chondrule formation and to cause later thermal metamorphism cannot be neither ^{26}Al nor ^{60}Fe because of their half life (0.73 and 1.5 My, respectively).

Summary: Trace element abundances and isotope ratios of Sr and Nd in chondrule constituents including mesostasis in the Allende CV3 meteorite were determined. Based on the REE pattern and variation of absolute abundances of the leachate, it is confirmed that the leachate preferentially extracted mesostasis and olivine from chondrules. Because alkali elements in chondrules were re-distributed during the aqueous alteration, the Rb–Sr age should correspond to last fluid-chondrule interaction. The Rb–Sr isochron from chondrules yields 4.35 Ga. This implies the existence of fluid on the asteroid at 200 My after the chondrule-forming event.

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