PETROLOGY, RARE EARTH ELEMENT COMPOSITION AND OXYGEN ISOTOPIC COMPOSITION OF A COMPOUND CAI-CHONDRULE INCLUSION FROM ALLENDE S. Wakaki[1], S. Itoh[1], T. Tanaka[2] and H. Yurimoto[1], [1]Natural History Sciences, Hokkaido University, Sapporo 060-0810, Japan (wakaki@ep.sci.hokudai.ac.jp), [2]Department of Earth and Environmental Sciences, Nagoya University, Nagoya 464-8602, Japan.

Introduction: Compound CAI-chondrule objects studied in chondrites are either chondrules that contain relict CAIs [1,2,3] or CAIs that contain relict chondrules [4,5]. Mixing of CAI and chondrule materials had possibly played a role in the formation of Al-rich chondrules [6,7] and type-C CAIs [8]. Thermal history of a compound object that contains both CAI and chondrule materials is important in studying the relationship and timings of processes that formed varieties of CAIs and chondrules. We report here a new type of a compound CAI-chondrule object, CAI-025, from CV3 chondrite Allende, which consist of partially melted CAI-chondrule mixture and surrounding igneous rim with condrule like composition.

Analytical methods: Petrology of the inclusion was studied using a JEOL JSM-7000F field-emission scanning electron microscope equipped with Oxford INCA energy dispersive spectrometer. REE composition was measured on a small portion (~0.2mg) of the inclusion by instrumental neutron activation analysis (INAA). Samples were irradiated for 30h at Japan Atomic Energy Research Institute and counted at Nagoya University Radioisotope center. Mixed REE reagents were used as a standard. Oxygen isotopic analysis was performed *in situ* by Hokkaido University Cameca ims 1270 ion microprobe. Primary ion beam was $^{133}Cs^+$ ions. Spot size was 3~5 micron. Oxygen isotopes were measured as negative secondary ions with a mass resolution of ~5000. Instrumental mass fractionation and matrix effect were corrected by analyzing terrestrial standards: anorthite, augite, olivine and spinel.

Results and Discussion: CAI-025 is an irregularly shaped inclusion with a size of ~2.5 mm x 6 mm. It consists of two textually distinct portions: Ca, Al-rich interior and Fe, Si-rich igneous rim (Fig. 1).

Petrology The interior portion of CAI-025 contains 48% anorthite, 35% framboidal spinel, 13% olivine and 2% Al-bearing low-Ca pyroxene in modal composition. Spinel is subhedral and sometimes surrounded by olivine. Spinel show concentric Cr-zoning pattern within a single grain. It decouples with the distribution of Fe which increases from inside toward outside of the interior portion. Some olivine grains are overgrown by Al-bearing low-Ca pyroxene. Anorthite poikilitically encloses the other phases. Abundant spinel in the interior portion suggests that the interior portion is genetically related to CAIs. However, the mineralogical composition does not match with the typical CAIs. Major element chemistry of the interior part is Mg, Si-rich compared to the typical CAIs and resembles Al-rich chondrules (Fig. 2). Phase equilibrium relationship of the interior portion is consistent with the crystallization sequence inferred from texture. These observations suggest that the interior part represents a mixture of CAI (composition similar to fine-grained spinel-rich CAIs or type C CAIs) with less refractory chondrule-like material.

The igneous rim is primarily composed of olivine, low-Ca pyroxene, FeS nodule and rare anorthite. Fine-grained Na-rich feldspathoids are also present. It is textually and chemically similar to magnesian chondrules. The rim surrounds the interior portion entirely.

REE composition The bulk REE composition of the interior portion is similar to those of group II CAIs (Fig. 3). This indicates that the interior portion was originally formed by fractional condensation process [9]. However, the REE composition of the interior portion has some distinct features compared to the typical group II CAIs: low LREE abundances (< x10 CI), small Eu anomaly and small La/Lu fractionation. These features can be explained by a simple mixing between typical group II CAI and chondrule material with CI-like REE composition roughly in a weight proportion of 3 to 7.

O isotopic composition Oxygen isotopic compositions of CAI-025 are heterogeneous among different minerals. All the data points plot on the Carbonaceous Chondrite Anhydrous Minerals (CCAM) mixing line (Fig. 4). Spinel in the interior portion is enriched in ^{16}O ($\Delta^{17}O$ = -14.7 ~ -25.7) and clustered into three groups with distinguishable isotopic compositions. Because of the small O self-diffusion coefficient in spinel [10], the difference in O isotopic compositions among spinel indicates that spinel have crystallized several times from a melt with different ^{16}O enrichments. Anorthite in the interior portion is depleted in ^{16}O ($\Delta^{17}O$ = -2.2). This may either reflect the nebular environment when the anorthites crystallized or had been changed by parent body alteration process. Olivine and low-Ca pyroxene in the interior portion are slightly enriched in ^{16}O and have indistinguishable isotopic compositions within analytical errors ($\Delta^{17}O$ = -7.0 and –6.8, respectively). Olivine and low-Ca pyroxene in the igneous rim also have O isotopic compositions indistinguishable with those of the interior olivine and pyroxenes. The O isotopic compositions of olivine and pyroxenes both in the interior and in the rim are within the range of the O isotopic compositions of chondrules [11].

Formation model: The results above are summarized in a three-stage formation model as follows.

Stage I: Precursor CAI formation CAI-025 is originally formed as a group II CAI by fractional condensation process under ^{16}O-rich solar nebular condition. Major element composition suggests that it was fine-grained spinel-rich or type C CAI. The precursor CAI subsequently underwent at least two incomplete melting processes under nebular gas with slightly different ^{16}O enrichments and crystallized different generations of spinel.

Stage II: Mixing with chondrule material The precursor CAI coexists with a chondrule-composition material under slightly ^{16}O-enriched environment. This CAI and chondrule materials have underwent incomplete melting and mixed in a proportion of 3 to 7 and formed the interior part. A change in major element chemistry allows olivine and low-Ca pyroxene crystallization. Chromium from the chondrule material diffused into relict spinel at this stage.

Stage III: Igneous rim formation Another chondrule material melted under same nebula environment attached to the already solidified interior portion and formed the igneous rim.

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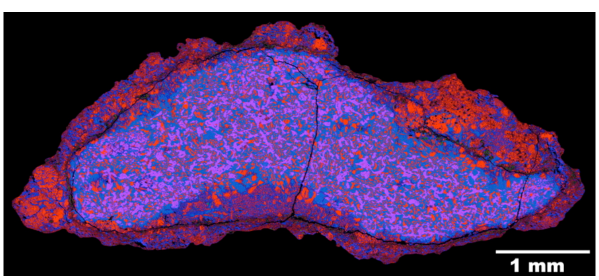

Fig. 1 Combined elemental map of Allende CAI-025 from Mg (red), Ca (green) and Al (blue) x-rays.

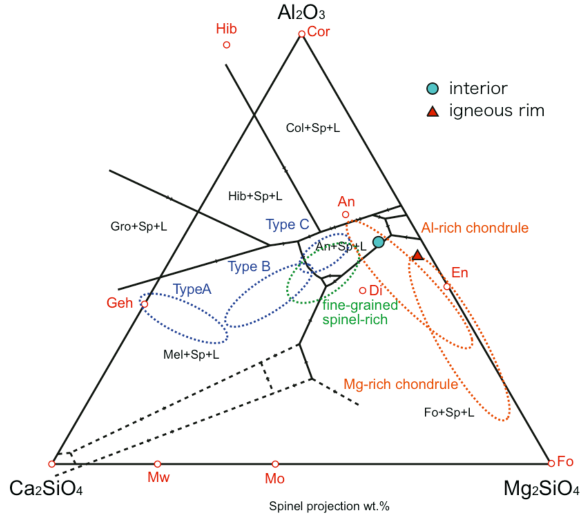

Fig. 2 Cosmochemical phase diagram [7] showing the bulk chemical compositions of the interior portion and igneous rim of CAI-025.

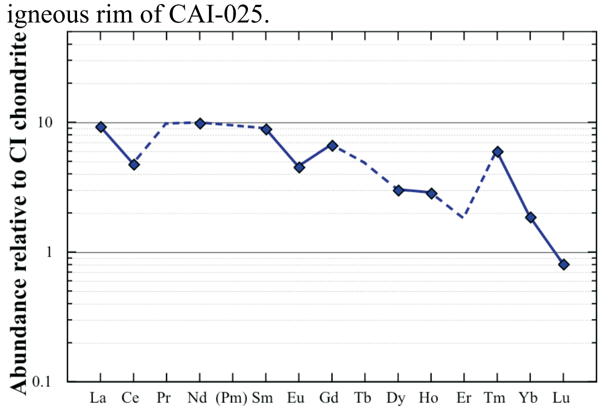

Fig. 3 Bulk REE composition of the interior portion.

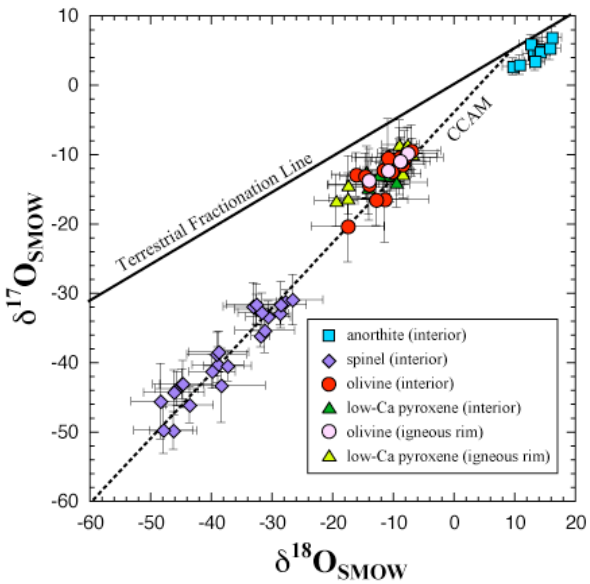

Fig. 4 Oxygen isotopic compositions of minerals in Allende CAI-025. Errors are 2σ.