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Al-Mg mineral isochron of a Type C CAI from Allende

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Ca-Al-rich inclusions (CAIs) show the record of ^{26}Al, which is a short-lived radionuclide with a half-life of 0.73 Myr (e.g., MacPherson et al., 1995), thus a relative chronometer with Al-Mg systematics is applicable for determining a precise time interval of individual CAI formation process. In this work, we report full petrologic and mineralogical studies of a Type C CAI from Allende, EK1-04-2, with more detailed analyses of O isotopic distributions and Al-Mg systematics than presented by Ito et al. (2000).

FE-SEM equipped with EDS and EBSD system (JEOL JSM-7000F; Oxford X-Max 150; Oxford HKL) was used for petrologic and mineralogical studies. O and Al-Mg isotopic compositions were measured by SIMS (Cameca ims-1270).

The EK1-04-2 is a CAI fragment with a size of ~2 mm across. The CAI mainly consists of spinel, anorthite, olivine and diopside. The CAI has mantle and core structure. In the core part, euhedral spinel crystals are enclosed by other mineral grains. Anorthite and olivine grains show euhedral or subhedral shape. Diopside grains show anhedral shape and include spinel and olivine grains. Thus, crystallization sequences of core minerals are spinel, anorthite, olivine and diopside. The mantle part has a same mineral assemblage as the core part, however, amount of spinel is lower than the core part, and anhedral spinel and anorthite grains are present, and the diopside is more Mg-rich and Ti-poor comparing with core diopside.

O isotopic compositions of the minerals are distributed along CCAM line (delta-^{18}O = -44 to +9 permil). Spinel is ^{16}O-rich (delta-^{18}O ~-43 permil), while anorthite is ^{16}O-poor (delta-^{18}O ~9 permil). Any differences of O isotopic compositions are not observed for these minerals among core and mantle parts while olivine and diopside show different O isotopic compositions between core and mantle parts. Olivine and diopside in the core have an intermediate O isotopic composition between spinel and anorthite (delta-^{18}O ~-15 permil). In contrast, the oxygen isotopic compositions of olivine and diopside in the mantle are not homogeneous and distributed to ^{16}O-poor direction compared with those in the core (delta-^{18}O = -13 to -4 permil). Olivine and diopside grains in the mantle are not in chemically equilibrium with those in the core. The O isotopic distributions among mineral grains indicate that the CAI experienced multiple and individual crystallization events: a crystallization of spinel, a crystallization of core olivine and diopside, and a crystallization of mantle olivine and diopside.

On the Al-Mg isochron diagram, spinel grains are plotted on a line of $^{26}Al/^{27}Al_0 = (3.52\pm0.15) \times 10^{-5}$, while olivine, diopside and anorthite grains of core are plotted on a line of $^{26}Al/^{27}Al_0 = (5\pm5) \times 10^{-7}$. The difference of the initial values corresponds to a relative age of ~4.6 Myr. In contrast, olivine and diopside grains in mantle are plotted below the line of olivine and diopside in core. The ^{16}O-poor and low delta-$^{26}Mg_0$ compositions of mantle olivine and diopside suggest mixing of Al-rich chondrule-like materials. The composition of the mantle diopside is consistent with this scenario.

The petrographic, oxygen isotopic and chronological studies indicate that the CAI experienced multiple heating events after a precursor CAI formation. After ~4.6 Myr later than the precursor CAI formation, the CAI partially melted at ~1600K. The melt exchanged oxygen isotopes with the surrounding ^{16}O-poor solar nebular gas. ^{16}O-poor olivine, diopside and anorthite grains recrystallized from the partial melt. Subsequently, Al-rich chondrule-like materials accreted on the CAI and experienced partial melting and recrystallization, again. Distinctive ^{16}O-poor composition of anorthite is a result of a thermal metamorphism at the Allende parent body.

Our study revealed that the CAI has retained in the protosolar nebula at least for 4.6 Myr and experienced multiple melting events.

Keywords: Al-Mg, CAI, SIMS, oxygen isotopes, solar nebula