^{26}Al-Mg chronology and oxygen isotope distributions of multiple melting of a Type C CAI from Allende CV3.

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Introduction:

Ca-Al-rich inclusions (CAIs) in meteorites are composed of high-temperature minerals and the oldest objects in the Solar System formed at 4567 Ma [1]. Disequilibrium oxygen isotopic distributions among inter- and intra-crystals observed in CAIs correspond to multiple melting events in the solar nebula [2]. Despite highest temperatures and cooling rates of the CAI melting events have been determined by experimental petrologic studies [e.g., 3], age differences between individual CAI melting events have been poorly studied. Many CAIs show a record of live-^{26}Al at their formation, which is a short-lived radionuclide with a half-life of 0.73 Myr [4]. ^{26}Al-Mg systematics may be applicable for age differences between the melting events. We have carried out a coordinate study of precise petrographic observations and the oxygen and magnesium isotope measurements by secondary ion mass spectrometry (SIMS) for a Type C CAI, EK1-04-2 from Allende CV3 in order to determine melting events and the ages.

Experimental:

FESEM-EDS-EBSD system (JEOL JSM-7000F; Oxford X-Max 150; HKL Channel 5) was used for petrographic study. Oxygen and Al-Mg isotopic compositions of minerals were measured by using SIMS of Hokkaido University (Cameca ims-1270 and ims-1280HR).

Results:

EK1-04-2 is a Type C CAI fragment picked out from the Allende with a size of ~2 mm across (Fig. 1). The CAI mainly consists of spinel, anorthite, olivine and pyroxene, and has a core and mantle structure. Petrography in the core suggests that crystallization sequences of core minerals are spinel, anorthite, olivine and pyroxene. The mantle has the same mineral assemblage as the core, and shows incomplete melting and solidification textures.

Figure 2 shows the oxygen isotopic compositions of the minerals in EK1-04-2 plotted on a three oxygen isotope diagram. Oxygen isotopic compositions are distributed along a CCAM line (δ^{18}O = −44 to +9‰) indicating holding chemically disequilibrium status in the CAI. Spinel is ^{16}O-rich (δ^{18}O ~ −43‰), while anorthite is ^{16}O-poor (δ^{18}O ~ +8‰). Olivine and pyroxene in the core have the same oxygen isotopic composition (δ^{18}O ~ −15‰), indicating their equilibrium. Olivine and pyroxene in the mantle have variable oxygen isotopic compositions and are slightly depleted in ^{16}O (δ^{18}O = −13 to −4‰) comparing with these minerals in the core.

Figure 3 shows the magnesium isotopic compositions and Al/Mg ratios of the minerals plotted on ^{26}Al-Mg isochron diagrams. ^{26}Al-Mg systematics is consistent to the disequilibrium observed by petrography and oxygen isotopes. On the ^{26}Al-Mg isochron diagram, spinel was plotted on a line of $(^{26}\mathrm{Al}/^{27}\mathrm{Al})_0 = (3.4 \pm 0.2) \times 10^{-5}$, anorthite was plotted on a line of $(^{26}\mathrm{Al}/^{27}\mathrm{Al})_0 = (-1 \pm 5) \times 10^{-7}$ and olivine and pyroxene in the core were plotted on a line of $(^{26}\mathrm{Al}/^{27}\mathrm{Al})_0 = (-1 \pm 7) \times 10^{-6}$. Plots of olivine and pyroxene in the mantle were scattered below the isochron of these minerals of core.

Discussion:

The coordinate study of petrography, oxygen isotopes and ^{26}Al-Mg chronology indicated EK1-04-2 experienced the two partial melting events after the precursor CAI formation. The precursor CAI was formed at 0.45 Myr after the Solar System formation defined by canonical CAI formation [5]. After at least 1.6 Myr, the first partial melting event occurred. The precursor CAI containing ^{16}O-rich spinel partially melted in the ^{16}O-poor nebular gaseous reservoir and oxygen isotope exchange between melt and gas occurred. Subsequently, ^{16}O-poor olivine and pyroxene were crystallized from the melt. The heating temperature of the first melting event was ~1623 to ~1670 K according to the phase diagram [3]. After that, the admixing of Al-rich chondrule to the CAI was occurred and the CAI experienced partial melting again. The second partial melting event formed the core-mantle structure. The heating temperature of the second melting event was ~1580 to ~1637 K. The oxygen and magnesium isotopes in anorthite were selectively reset by solid-state diffusion during the thermal metamorphism in the Allende parent body with no disturbance of other minerals in EK1-04-2. Our study revealed that the CAI had retained in the solar nebula at least for 1.6 Myr and experienced multiple melting events in the nebula, and oxygen and ^{26}Al-Mg systematics has been partially disturbed depending on crystal sizes by metamorphism on the parent body.

References:

[1] Connelly J. N. et al. (2012) *Science, 338,* 651-655. [2] Yurimoto H. et al. (1998) *Science, 282,* 1874-1877. [3] Stolper E. (1982) *GCA, 46,* 2159-2180. [4] MacPherson G. J. et al (1995) *Meteoritics, 30,* 365-386. [5] Larsen K. K. et al. (2011) *ApJL, 735,* L37-L43.

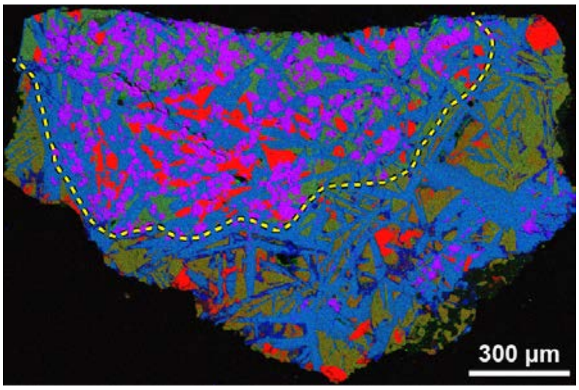

Figure 1. Combined X-ray elemental map of a Type C CAI, EK1-04-2, from Allende CV3 chondrite, with Mg (red), Ca (green) and Al (blue). Dashed line indicates an outline of boundary between core and mantle.

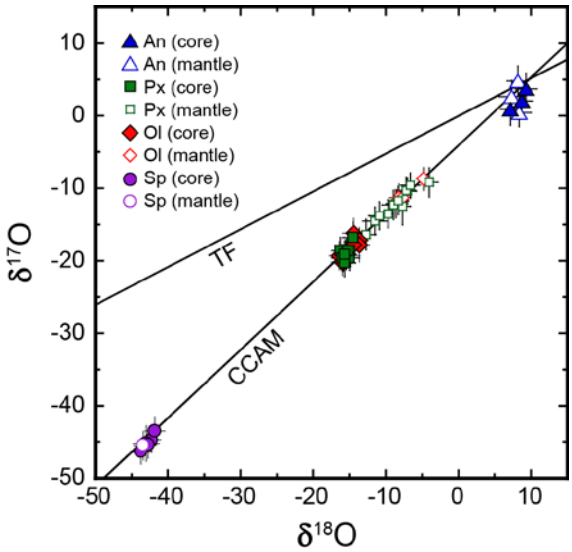

Figure 2. Oxygen isotopic compositions of minerals in EK1-04-2. Error bars are 2σ. TF, terrestrial fractionation line; CCAM, carbonaceous chondrite anhydrous mineral line; An, anorthite; Px, pyroxene; Ol, olivine; Sp, spinel.

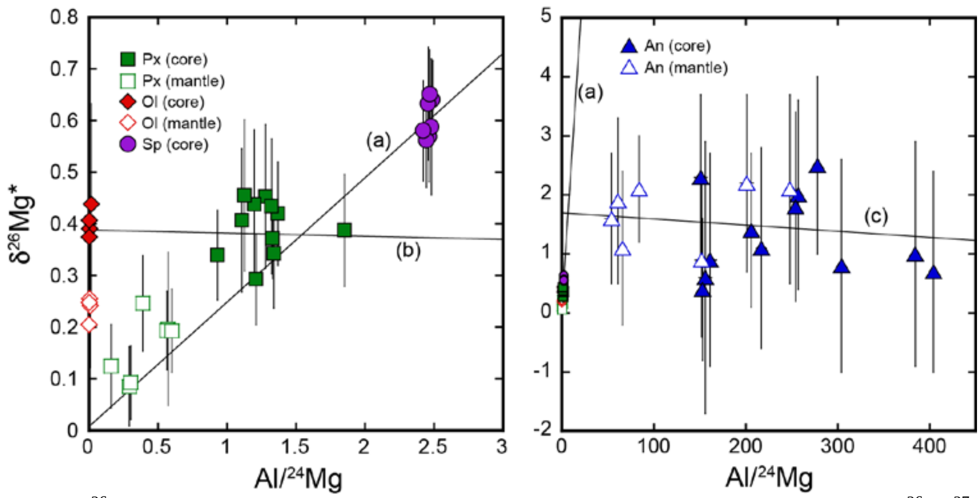

Figure 3. ^{26}Al-Mg isochrons in EK1-04-2. (a) An isochron of spinel with an initial value of $(^{26}Al/^{27}Al)_0 = (3.4 \pm 0.2) \times 10^{-5}$ with $(\delta^{26}Mg)_0 = 0.009 \pm 0.001$‰ assuming with solar initial $(^{26}Al/^{27}Al)_0 = (5.252 \pm 0.019) \times 10^{-5}$ and $\delta^{26}Mg_0 = -0.0159 \pm 0.0014$‰ [5]. (b) An isochron of olivine and pyroxene in the core with an initial value of $^{26}Al/^{27}Al_0 = (-1 \pm 7) \times 10^{-6}$ with $(\delta^{26}Mg^*)_0 = 0.39 \pm 0.06$‰. (c) An apparent isochron of anorthite corresponding to an initial value of $^{26}Al/^{27}Al_0 = (-1 \pm 5) \times 10^{-7}$ with $(\delta^{26}Mg^*)_0 = 1.7 \pm 0.7$‰. Errors are 2σ. An, anorthite; Px, pyroxene; Ol, olivine; Sp, spinel.