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Al-Mg chronology and oxygen isotope distributions of multiple melting for a Type C CAI from the Allende

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Ca-Al-rich inclusions (CAIs) in meteorites have undergone multiple melting processes in the early solar nebula, which indicates that transient heating events repeatedly occurred in the early Solar System (e.g., Yurimoto et al., 1998). A relative chronometer with Al-Mg systematics for the CAIs could be applied to determine the time interval of heating events. To determine the time interval of heating events for the CAIs, detailed histories of multiple melting events in the CAIs should be well understood. We have carried out a coordinated study of detailed petrographic observations and in-situ oxygen and Al-Mg isotope measurements for a Type C CAI, EK1-04-2, from Allende CV3. Precise petrographic observations and oxygen isotopic measurements were performed to understand the individual melting processes that occurred in the CAI. Investigation of the Al-Mg systematics was performed for minerals formed by different melting and recrystallization processes to determine the age differences of individual CAI melting events.

The CAI consists mainly of spinel, anorthite, olivine, and pyroxene, and has a core and mantle structure. Petrography of the core suggests that the crystallization sequences of the core minerals are spinel, anorthite, olivine, and pyroxene. The mantle has the same mineral assemblages as the core, and shows incomplete melting and solidification textures.

Oxygen isotopic compositions of the minerals are distributed along with a carbonaceous chondrite anhydrous mineral (CCAM) line (δ^{18}O = -44 to +9 ‰), which indicates to preserve a chemical disequilibrium status in the CAI. Spinel shows ^{16}O-rich signature (δ^{18}O ˜-43 ‰), while anorthite shows ^{16}O-poor signature (δ^{18}O ˜+8 ‰). Olivine and pyroxene in the core have the same oxygen isotopic composition (δ^{18}O ˜-15 ‰), which indicates 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 ‰) compared with the same minerals in the core. The ^{26}Al-Mg systematics is consistent with the disequilibrium status observed according to the petrography and oxygen isotopes. Spinel is plotted on a line of $(^{26}Al/^{27}Al)_0$ = (3.5$\pm$0.2) x 10^{-5}, anorthite is (-1$\pm$5) x 10^{-7}, and olivine and pyroxene in the core are (-1$\pm$7) x 10^{-6}. Plots of olivine and pyroxene in the mantle are scattered below the isochron of these minerals in the core.

The coordinated study of the oxygen and magnesium isotopes and the petrography indicates that the EK1-04-2 Type C CAI underwent multiple heating events after a precursor CAI formation. The precursor CAI was formed at 0.43 Myr after the formation of the Solar System defined by canonical CAI formation. At least 1.6 Myr after the precursor CAI formation, the CAI was partially melted and the partial melting melt exchanged oxygen isotopes with surrounding ^{16}O-poor nebular gas. ^{16}O-poor olivine and pyroxene in the core were recrystallized from the partial melting melt. Subsequently, Al-rich chondrules accreted on the CAI, and the CAI experienced partial melting again and recrystallized to form the mantle. The oxygen and magnesium isotopes in anorthite were redistributed during thermal metamorphism in the Allende parent body. Our study reveals that the CAI had been retained in the solar nebula for at least 1.6 Myr and underwent 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.