Formation process of a compact Type A Ca-Al-rich inclusion from Northwest Africa 7865 reduced CV3 chondrite : the condensation process after the igneous process

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Ca-Al-rich inclusions (CAIs) in chondrites are the oldest objects in the Solar System and are commonly used as benchmarks to constrain the evolution of solid objects in the early Solar System. CAIs have experienced thermal events such as the condensation process and the igneous process. According to Al-Mg isotope measurements for condensate CAIs and igneous CAIs, it is suggested that the condensation process and the igneous process occurred simultaneously if the ^{26}Al was homogeneously distributed. On the other hand, it is not well understood the relationship between the condensation process and the igneous process in the CAI-forming region regarding the oxygen isotopic environment, temperature, formation order, and time interval. One CAI which recorded the condensation and the igneous processes would constrain the relationship between the condensation process and the igneous process from a perspective of material science regardless of the possibility of heterogeneous distributions of ^{26}Al. However, it has not yet been studied for one CAI which recorded the condensation process that occurred after the igneous process. In this thesis, I conducted the integrated study of the petrographic observation, oxygen isotope measurement, and Al-Mg systematics for the KU-N-02 compact Type A (CTA) CAI from Northwest Africa 7865 reduced CV3 chondrite. This CAI is composed of a core part and a mantle part, and has experienced the condensation process and the igneous process.

In Chapter 2, the oxygen isotope measurement combined with the petrographic-mineralogical observations was conducted for the core part of this CAI. The core part has an igneous texture and mainly consists of ^{16}O-rich spinel (Δ^{17}O ~ −23‰), ^{16}O-poor melilite (Δ^{17}O ~ −2‰), and fassaite. Spinel crystals are poikilitically enclosed by melilite and fassaite, and their occurrences can be explained by the crystallization from their melt. The distinct oxygen isotopic compositions of spinel and melilite were caused by the partial melting process with the oxygen isotope exchange between ^{16}O-rich melt and ^{16}O-poor gas at a temperature between approximately 1820 K and 1720 K. According to the line profile of Ti contents and oxygen isotopic compositions, the oxygen isotopic compositions of blocky and intergranular fassaite changed from ^{16}O-poor (Δ^{17}O ~ −6‰) to ^{16}O-rich (Δ^{17}O ~ −23‰) with crystal growth. These oxygen isotopic variations and petrography indicate that the oxygen isotopic compositions of the core part change from ^{16}O-rich (Δ^{17}O ~ −23‰) to ^{16}O-poor (Δ^{17}O ~ −2‰), and then toward ^{16}O-rich again (Δ^{17}O ~ −23‰) during the formation.

In Chapter 3, the integrated study of petrographic observations and oxygen isotope analysis was carried out for the mantle part of this CAI. The mantle part surrounds the whole core part, and consists of spinel, melilite, and minor perovskite. The melilite shows the concentric reverse zoning from core to rim and exhibits variable oxygen isotopic compositions (Δ^{17}O ~ −2‰ to −9‰). It is difficult to find any correlations between their oxygen isotopic compositions and not only their chemical composition but also the distances from the margin of KU-N-02. On the other hand, there are grain-to-grain variations of oxygen isotopic compositions of them. These petrographic textures and oxygen isotopic features indicate that the mantle melilite was formed by condensation from the solar nebular gas with various oxygen isotopic compositions at a temperature approximately of 1450 K to 1400 K, indicating that the formation of the mantle part occurred after those of the core part.

In Chapter 4, high-precision Al-Mg isotope analysis was carried out for the core and mantle of this CAI. The minerals in the mantle part show a significant depleted δ^{25}Mg variation compared to the constant δ^{25}Mg values of the minerals in the core part. This signature is consistent with that the core part is the igneous origin and the mantle part is the condensation origin. Al-Mg isotopic compositions of minerals in the core part and in the mantle part yield well-defined mineral isochrons with inferred initial ^{26}Al/^{27}Al, (^{26}Al/^{27}Al)$_0$ of (4.68 ± 0.15) × 10^{-5} and initial δ^{26}Mg*, (δ^{26}Mg*)$_0$ of 0.041 ± 0.036‰, and (^{26}Al/^{27}Al)$_0$ of (4.74 ± 0.14) × 10^{-5} and (δ^{26}Mg*)$_0$ of 0.041 ± 0.066‰, respectively. These inferred (^{26}Al/^{27}Al)$_0$ values are indistinguishable from each other, suggesting that the condensation process would have occurred after the igneous process within about 0.03 Myr even if it is long.

The summary of this thesis is that (1) the core part was formed by the igneous process with multiple heating events and the oxygen isotopic environment surrounding the core part would evolve from ^{16}O-rich to ^{16}O-poor and then toward ^{16}O-rich during their formation, (2) the mantle part was formed by condensation from the solar nebular gas with various oxygen isotopic compositions after the formation of the core part, and (3) the condensation process occurred after the igneous process in a short period within about 0.03 Myr if the ^{26}Al was homogeneously distributed in the CAI-forming region. The main points of this thesis are that it is revealed that the condensation process occurred after the igneous process and that the genetic relationship between the core part and the mantle part regarding the oxygen isotopic environment, temperature, formation sequence, and time interval. These results suggest that the condensate CAI-forming region and the igneous CAI-forming region are identical to each other. It would be the first step to connecting the igneous and condensation processes in order to understand the thermal events in the CAI-forming region.