Experimental study of high temperature annealing of amoeboid olivine aggregates

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Amoeboid olivine aggregates (AOAs) are irregularly shaped, fine-grained objects that constitute a few volume-percent of meteorites in most carbonaceous chondrite groups. The significance of AOAs is that they are ferromagnesian material associated with Ca-Al-rich components, indicating they may be a link between Ca,Al-rich inclusions (CAIs) and chondrules. Although previous studies concluded that AOAs are aggregates of solar nebula condensates which continued to react with the solar nebula vapor to the temperature to form phyllosilicates, these studies are largely from the AOAs from the oxidized CV3 chondrite Allende which experienced secondary alteration. In order to characterize the primary mineralogy of AOAs, and to understand their thermal and alteration history, I investigated the mineralogical and petrological studies of AOAs from the reduced CV3 chondrites Efremovka, Leoville and Vigarano which are less altered than oxidized CV3 chondrites. On the basis of mineralogical observation in this study, it is shown that AOAs have several textures which are in conflict with the equilibrium condensation calculations, implying that AOAs may not be produced by a simple one-stage condensation. Heating experiments have been conducted to examine the origin of constituent minerals of AOAs and their textural relationships. The main goal of this study is to establish the formation history of AOAs, and to understand the relationship among AOAs, CAIs and chondrules in CV3 chondrites.

The most characteristic texture of AOAs is that anorthite (sometimes associated with spinel and Al,Ti-diopside) core is rimmed by Al-diopside which overgrows olivine. Isothermal and cooling experiments of forsterite+anorthite mixture showed that high-Ca pyroxene like phase forms by incipient melting of both minerals. Although the texture observed in the forsterite+anorthite charges from the cooling experiments is slightly different from the AOAs in having euhedral anorthite grains, the chemical compositions of high-Ca pyroxene like phase in the charges overlap with those from Al-diopside in AOAs. Electron back scattering diffraction pattern measurement (EBSD) proved that both Al-diopside in AOAs and high-Ca pyroxene like phase from the cooling experiments are crystalline. Comparative studies of heating experiments with the mineralogy of AOAs suggest that Al-diopside in AOAs can be produced from a small degree of melting of forsterite and anorthite. The formation of Al-diopside from forsterite and anorthite is consistent with the annealing textures observed in AOAs, and it may account for the inconsistency of the observed mineralogy of AOAs with the equilibrium condensation calculations, different occurrences of two types of diopside (Al,Ti-rich diopside and Al-diopside), and variable Al_2O_3 content of Al-diopside. Although the detailed conditions of annealing have not been determined in this study, both CAI-forming regions and chondrule-forming regions can be assumed for the place of annealing.

Bulk compositional analysis of AOAs showed that they overlap with those of Aluminum-rich chondrules, implying that some of the chondrules have formed by remelting of AOAs. In addition, the relic CAIs in Al-rich chondrules are mineralogically similar to those in AOAs and consist of fine-grained anorthite and Al-diopside. In spite of these mineralogical signatures in Al-rich chondrules relating them to CAI-related precursors including AOAs, these chondrules are characterized by high concentrations of Ti and Cr in Al-diopside, relatively high concentrations of Na in plagioclase and abundant Fe,Ni-metal nodules. These observations suggest that Al-rich chondrules could not have been produced by direct remelting of AOAs.