Amoeboid Pyroxene Aggregates in CO3 Yamato 81020: Implications for Nebular Condensation

Timothy J. Fagan[1] and Mutsumi Komatsu[2]
[1]*Department of Earth Sciences, Waseda University, Tokyo, Japan (fagan@waseda.jp)*, [2]*SOKENDAI (The Graduate University for Advanced Studies), Kanagawa, Japan*

Amoeboid olivine aggregates (AOAs) in carbonaceous chondrites formed by gas-solid condensation in a hot ($T > 1350K$) part of the solar nebula [1,2]. The origin of Ca-Al-rich inclusions (CAIs) also involved gas-solid interactions in a similar setting [3]. In general, CAIs record higher temperatures than AOAs, though it has been shown recently that rapid cooling can result in formation of an AOA from ultrarefractory conditions ($T \sim 1{,}800K$) to temperatures well below the onset of olivine condensation [2]. In addition to their high temperature origins, primitive (unaltered) AOAs and CAIs share ^{16}O-rich oxygen isotopic compositions similar to that of the Sun [4,5]. As such, AOAs and CAIs preserve a record of gas-solid interactions in a hot ^{16}O-rich setting of the protoplanetary disk during embryonic stages of our solar system.

During our petrologic survey of AOAs in the CO chondrite Yamato 81020 (Y-81020), we discovered two objects similar to AOAs, but dominated by low-Ca pyroxene instead of olivine (Fig. 1). We refer to these objects as amoeboid pyroxene aggregates (APAs) and argue that they formed by gas-solid interactions and annealing at temperatures lower than the temperatures of typical AOAs. If so, the temperature range of gas-solid condensation in ^{16}O-rich setting(s) of the nebula extended to lower temperatures than indicated by typical AOAs and CAIs.

Sample and Methods: Yamato 81020 (Y-81020) is a primitive CO chondrite; [6] suggested a classification as type 3.05 based on Cr_2O_3 concentrations in chondrule olivine. A primitive classification (near 3.0) is supported by Fo-rich concentrations of AOA olivine [7] and Raman spectra of matrix domains [2]. One polished thin section (pts) was borrowed from NIPR for a survey of chondrite components focusing on AOAs.

X-ray elemental and back-scattered electron (BSE) maps of the Y-81020 pts were collected using a JEOL JXA-8900 electron probe micro-analyzer (EPMA) at Waseda University (WU). Initially, a step size of 8 μm was used for elemental mapping, however, the spatial resolution was considered insufficient, and the pts was mapped again using a spatial resolution of 4 μm. Six adjacent maps were collected and mosaicked together. Several more detailed maps were collected of AOAs and other areas of interest using the EPMA. Photomicrographs were collected in plane polarized and cross-polarized light. Additional BSE images were collected using a Hitachi S-3400N scanning electron microscope (SEM). Quantitative elemental analyses of olivine and pyroxene were conducted by wavelength dispersive spectroscopy (WDS) by EPMA.

Results: Approximately 4 mode % of our Y-81020 pts consists of AOAs (and APAs), within the range of 2.2 to 4.4 mode % AOAs in a set of five CO chondrites studied by [8]. The Y-81020 AOAs are dominated by equant crystals of olivine on the order of 10 μm across as viewed in thin section. AOA olivine grains often form ring-like structures ("donuts") enclosing diopside and anorthite ±spinel (Fig. 1a,b). Fe,Ni-metal occurs in most of the AOAs, but in minor amounts, and some low-Ca pyroxene also occurs in some AOAs. As noted by [7], secondary phases typical of AOAs in metamorphosed chondrites are essentially absent from the Y-81020 AOAs.

Of 37 AOA-like objects, two objects (labelled V-37 and AU-30, see Fig. 1c-f) are dominated by low-Ca pyroxene instead of olivine and thus are classified as APAs. Minor low-Ca pyroxene has been reported previously in some AOAs [9], however pyroxene is much more abundant than olivine in APAs V-37 and AU-30. The following textures are reminiscent of AOAs: low-Ca pyroxene (enstatite) crystals appear equant, granular and on the order of 10 μm across; minor anorthite and diopside are enclosed by enstatite; external margins have irregular, ameoboid shapes. Fe,Ni-metal often occurs in AOAs, but is relatively abundant in the two APAs (Fig. 1). APA AU-30 can be divided into two textural domains: one with coarse and one with fine metal grains (Fig. 1e,f). A small porphyritic olivine pyroxene (POP) chondrule is embedded in APA V-37 (Fig. 1c,d).

Textural similarities between the two APAs and typical AOAs suggest formation by similar processes, namely gas-solid condensation and annealing. However, the lower condensation temperature of orthopyroxene vs. olivine indicates stability below the formation temperatures of typical AOAs [10,11], approximately $<1350K$ at $P \sim 10^{-4}$ bar. High abundances of metal in the APAs are consistent with the relatively low condensation temperatures. The chondrule embedded in APA V-37 indicates an overlap in formation time of chondrules and APAs, and possibly AOAs and CAIs (see [12]).

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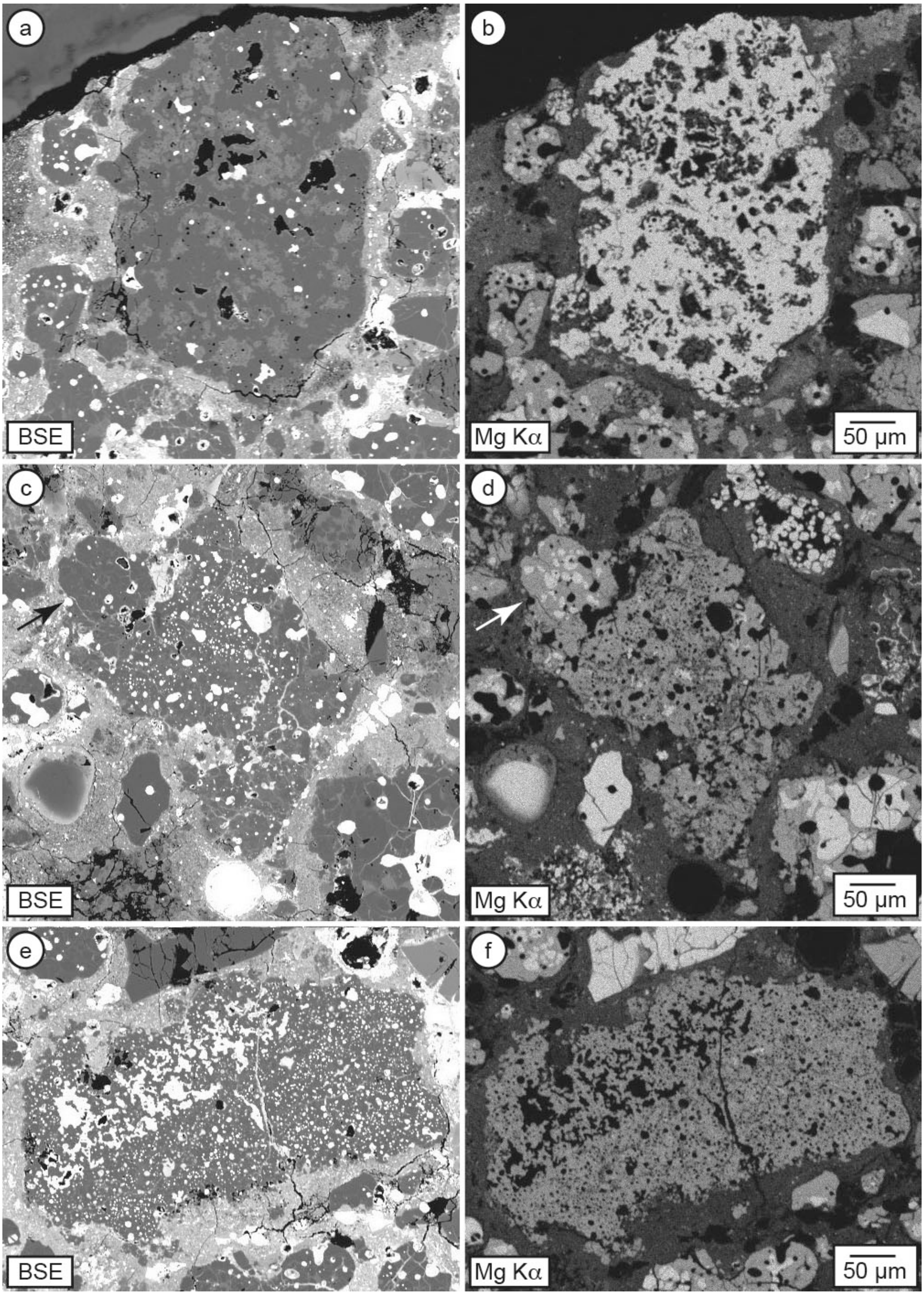

Figure 1. Paired BSE and Mg Kα X-ray maps of amoeboid olivine aggregate (AOA) U-6 (a,b), amoeboid pyroxene aggregate (APA) V-37 (e.f) and APA AU-30 (e.f), all from CO3 chondrite Y-81020. In these images, olivine and low-Ca pyroxene are similar in BSE, but olivine is brighter in Mg. Arrows in (c,d) point to a POP chondrule embedded in APA V-37.