A COMPARISON OF RECRYSTALLIZATION IN CAIS FROM THE CV3 CHONDRITE ALLENDE WITH IGNEOUS PHENOCRYSTS FROM TERRESTRIAL METAVOLCANIC ROCKS.

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Introduction: Primary minerals in Ca-Al-rich inclusions (CAIs) formed at high temperatures in the solar nebula [1,2]. Secondary minerals in CAIs are relatively fine-grained and occur along grain boundaries and veins in primary minerals. These textures, combined with thermodynamic data, indicate that secondary minerals formed at relatively low temperatures during partial decomposition of primary minerals [2].

Secondary minerals may have formed in the solar nebula or during fluid-assisted metamorphism on asteroidal parent bodies [2-4]. In this study, we describe mineral alteration of Allende CAIs and compare with altered relict phenocrysts in terrestrial metavolcanic rocks. We infer that most secondary minerals in Allende CAIs formed during asteroidal metamorphism.

Analytical Methods: The main textural observations and mineral compositions were collected from polished thin sections (PTS) of Allende CAIs 3655A (type B1), 4022 (B2), 3529-47 (fluffy type A) all on loan from the Smithsonian Institution, and several Allende PTS in the Waseda University (WU) collection. Imaging was conducted using petrographic microscopes and a JEOL JXA-8900 electron microprobe at WU. Quantitative mineral analyses were determined using the same JXA-8900. Additional back-scattered electron (BSE) imaging and qualitative analyses by EDS were conducted using a JEOL JSM-5900 secondary electron microscope (SEM) at the National Insititute of Polar Research in Tokyo and a Hitachi S-4500 SEM at University of Tokyo.

Terrestrial metavolcanic rocks with variably replaced igneous phenocrysts were collected from the Slate Creek Complex (SCC), northern Sierra Nevada, California, USA in summer 2010. The SCC is a Jurassic arc-ophiolite that was accreted to the margin of North America, and was intruded by granitic plutons from 170 Ma to 140 Ma [5,6]. Regional metamorphism occurred ca. 150 Ma and varied from amphibolite to sub-greenschist facies [5]. For this study, samples were collected from sub-greenschist facies pillow basalts and crystal tuffs. The pillows likely have undergone metamorphism shortly after eruption (when heat in pillow interiors drove water-rock reactions) and during subsequent tectonic burial and regional metamorphism. In contrast, the tuffs are susceptible primarily to metamorphism during tectonic burial.

Reaction Textures and Minerals: *Allende CAIs.* Reaction textures can be recognized in coarse-grained CAIs, which furnish a clear textural distinction between primary and secondary minerals. Grossular-rich veins are concentrated in and along primary melilite and along melilite-anorthite grain boundaries throughout CAI interiors (Fig. 1A). Grossular occurs with or without monticellite and rare wollastonite, secondary anorthite, hedenbergite, diopside and a Cl-bearing Ca-silicate. In contrast to the grossular-rich domains, BSE-dark patches of feldspathoids, Fe-bearing spinel and an elongate secondary mineral (ESM) rich in Ca and Al are concentrated along margins of CAIs, where they replace primary melilite adjacent to Wark-Lovering rims (Fig. 1B). Some of the lath-like ESM may be anorthite, but recent TEM work suggests that ESM may be a Ca-mica [7]. Replacement of melilite by the BSE-dark minerals suggests a gain of Fe, Na, K and Cl, and a loss of Ca from CAIs. A Ca-rich aureole in matrix around a type A CAI was reported by [8]. We have identified Ca-rich aureoles around six of nine coarse- and fine-grained CAIs from one slab of Allende.

Slate Creek Complex metavolcanics. SCC pillow basalts formed originally with high Ca-pyroxene and plagioclase feldspar phenocrysts. Plagioclase has been albitized in pillow interiors and replaced by muscovite near pillow rims. Pyroxene is replaced by chlorite with or without other phases near pillow rims (Fig. 2A). This contrasts with tuffaceous protoliths, where pyroxene is not replaced, but is mantled by metamorphic amphibole (Fig. 2B). Observations from the tuffs are key because they show that replacement of pyroxene in pillow margins occurred on the sea-floor rather than during tectonic burial.

A Second Look at Allende. The SCC observations highlight the importance of observations from different protoliths. Forsteritic olivine crystals in Allende chondrules and matrix have Fe-rich rims ranging from < 1 µm to a few µm across (Fig. 2C). Electron microprobe analyses of relatively wide rims indicate compositions near Fo_{45-60}, similar to compositions of the lath-like olivine crystals characteristic of Allende matrix [9]. Some rims are probably overgrowths; but rims completely surrounding individual olivines in chondrules and aggregates in the matrix (Fig. 2C) suggest that some original Mg-rich olivine was replaced by Fe-rich olivine. This implies a gain of Fe in olivines similar to Fe-enrichment in BSE-dark domains of CAIs. Similar Fe-enrichments in these distinct "protoliths" support a metasomatic event after assembly of chondrite components in an asteroidal setting. This is supported further by the presence of Ca-rich aureoles around some Allende CAIs.

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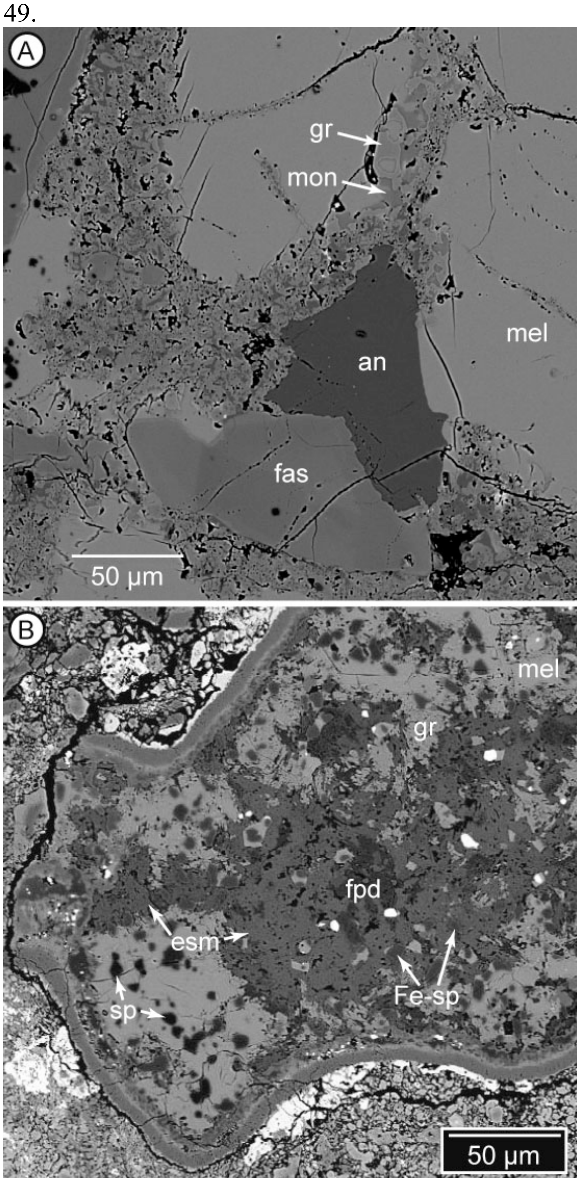

Fig. 1. (A) Grossular-rich vein from type B2 CAI 4022-1. (B) BSE-dark domain in melilite-rich nodule of fluffy type A CAI 3529-47. Mineral abbreviations: an = anorthite; esm = elongate secondary mineral; fas = fassaite; Fe-sp = Fe-bearing spinel; fpd = feldspathoid; gr = grossular; mel = melilite; mon = monticellite; sp = Mg-spinel.

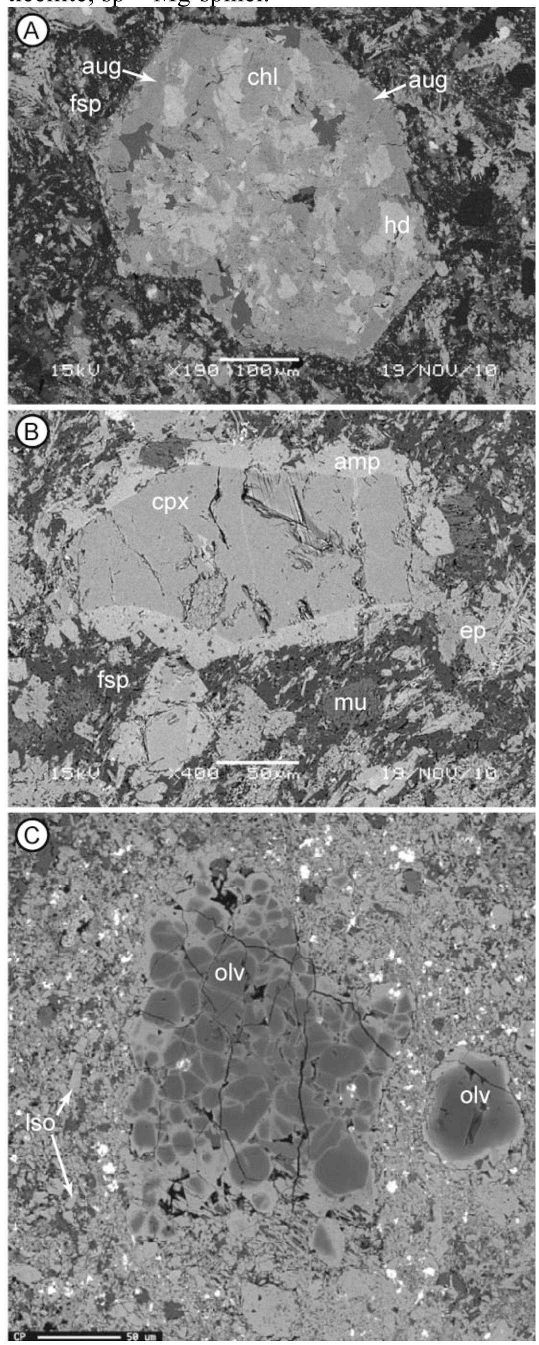

Fig. 2. (A) Partially replaced relict pyroxene near SCC pillow rim. (B) Relict pyroxene mantled by metamorphic amphibole in SCC tuff. (C) Forsteritic olivine with Fe-rich rims from Allende matrix. Mineral abbreviations: aug = augite (relict igneous pyroxene); chl = chlorite; ep = epidote; fsp = feldspar; hd = hedenbergite; lso = lath-shaped olivine; mu = muscovite; olv = olivine.