FORSTERITE-RICH ACCRETIONARY RIMS AROUND CAIs FROM THE REDUCED CV3 CHONDRITE EFREMOVKA: I. MINERALOGY AND PETROGRAPHY.

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Introduction: Accretionary rims were first described around several Ca, Al-rich inclusions (CAIs) from the oxidized CV chondrite Allende [1, 2]. These rims are characterized by multilayered structures, with layers differing from another in texture, mineralogy and mineral-chemistry. As defined by [2], the innermost layer consists of either pyroxene needles + olivine + clumps of hedenbergite and andradite (IA) or olivine “doughnuts” (IB) (i.e., crystals with central cavities). The next layers outward (II, III) contain olivine plates and laths. The final layer (IV) separating accretionary rims from the Allende matrix occurs as clumps of andradite + hedenbergite surrounded by salitic pyroxene needles. Nepheline and Fe,Ni-sulfides are common constituents in all layers. Based on the observed disequilibrium mineral assemblages, abundant uhehdral crystals with pore space between them, and rim thickness controlled by the underlying topography of their host inclusions, it was concluded that the layered accretionary rims in Allende are aggregates of gas-solid condensates which reflect significant fluctuations in physico-chemical conditions in the solar nebula and grain/gas separation processes [2].

In order to test this model, we studied the mineralogy of accretionary rims around one type A CAI (E104) and one type B CAI (E48) from the reduced CV3 chondrite Efremovka, which is less altered than Allende. Oxygen-isotopic compositions of the CAI E104 and its accretionary rim are reported in [3].

Mineralogy and Petrography: Refractory inclusion E104 is an irregularly-shaped compact Type A CAI consisting of several rounded, concentrically-zoned objects with cores composed of anorthite, pyroxene, and spinel; the cores are surrounded by melilitic mantle, Wark-Lovering rim composed of spinel, anorthite, and pyroxene and forsterite-rich rim (Fig. 1). Secondary Na-bearing phases are very minor. The E48 CAI has been previously described by [4].

The Fo-rich rims consist of coarse-grained (20-40 µm), anhedral forsterite (Fa₁₈), Fe,Ni-metal nodules, and a refractory component composed of amoeboid olivine aggregates (AOAs), fine-grained CAIs composed of Al-diopside, anorthite, and spinel or fine-grained intergrowths of these minerals (Fig. 2). Most of these CAIs and AOAs show no evidence for alteration; a hibonite-spinel-perovskite CAI in the E48 rim is the only exception. It experienced extensive alteration, which resulted in the formation of Fe-rich, Zn-bearing spinel, and a Ca, Al, Si-hydrous mineral. Forsterites in the rims have an aggregational nature and consist of small olivine grains with numerous pores and tiny inclusions of Al-diopside and anorthite. No evidence for the replacement of forsterite by enstatite was found; no chondrule fragments were identified in the rims. The Fo-rich rims contains no anorthite, wollastonite, salite-hedenbergite pyroxenes, nepheline or lath-shaped ferrous olivine, which are typical constituent minerals in Allende accretionary rims.

Discussion: Similar to the Allende accretionary rims [1, 2], Fo-rich rims in Efremovka are thickest in topographic depressions on the surfaces of the host CAIs and overlay Wark-Lovering rims. In addition to forsterite and Fe,Ni-metal, these rims contain a refractory component composed of Al-diopside, anorthite, and minor spinel. These minerals are predicted to have condensed from a cooling nebular gas of solar composition at total pressure of ~10⁻³-10⁻⁵ bar and temperatures of ~1300-1400 K simultaneous with or just after forsterite [5, 6].

Based on the textures and mineralogy of the Efremovka Fo-rich rims, we infer that these rims formed by accretion of gas-solid condensates at or slightly below the forsterite condensation temperature. The accretion must have postdated melting of the host CAIs and formation of their Wark-Lovering rims. The presence of refractory component in the rims, absence of chondrule fragments, and ¹⁸O-rich isotopic composition of forsterite (δ¹⁸O and δ¹⁸O ~ -45‰) of the E104 accretionary rim [3] suggests that accretion took place in the CAI-forming region. Relatively high porosity of forsterite and presence of fine-grained CAIs in the accretionary rims suggest that the rimmed CAIs escaped extensive melting. The absence of enstatite in the accretionary rims suggests that either gas-solid condensation of enstatite was kinetically prohibited or the rimmed CAIs were removed from the CAI-forming region prior to condensation of enstatite, which occurs ~50-70 K below condensation temperature of forsterite. The absence of nepheline, sodalite, andradite, wollastonite, and hedenbergite from the Efremovka rims indicates that these minerals, rimming Allende CAIs [2], resulted from late-stage metasomatic alteration under highly-oxidizing conditions of CAIs surrounded by Efremovka-like accretionary rims. The observed differences in O-isotope compositions of olivine (¹⁸O-rich) and Ca-Fe-rich silicates (¹⁸O-poor) in a single accretionary rim in Allende [7] suggests that the oxidizing fluid had ¹⁸O-poor isotope composition.

Fig. 1. Combined X-ray elemental map in Mg (red), Ca (green) and Al Kα (blue) of a Type A CAI E104 from Efremovka. The CAI consists of multiple concentrically-zoned bodies with cores composed of spinel (purple), Al-diopside (dark-green) and anorthite (blue) and a mantle composed of melilite (light-green), Al,Ti-diopside, perovskite, and unidentified Ca,Ti,Al-silicate. It is surrounded by a Wark-Lovering rim composed of spinel, anorthite, and Al-diopside and a thick accretionary forsterite rim (red). The accretionary rim consists of forsterite and a refractory component composed of fine-grained intergrowths of Al-diopside, anorthite, and minor spinel; it is surrounded by fine-grained matrix largely composed of ferrous olivine.

Fig. 2. Backscattered electron images of the accretionary rim around CAI E104. a – Rim material largely composed of forsterite (fo) fills a depression on the outer edge of the CAI. The CAI is surrounded by a Wark-Lovering rim consisting of spinel (sp), anorthite (an), and Al-diopside (cpx). The CAI consists of Al-diopside (bottom right) and melilite (mel) poikilitically enclosing perovskite (pv). b – Anhedral forsterite grains of the accretionary rim with numerous pores and tiny inclusions of anorthite and Al-diopside. c, d – Fine-grained CAI composed of spinel, anorthite and Al-diopside are common in the accretionary rim.