ULTRA-REFRACTORY CAI IN A LOW-CA PYROXENE- AND SILICA-BEARING AMOEBOID OLIVINE AGGREGATE IN A CR CHONDRITE: FORMATION BY GAS-SOLID CONDENSATION OVER A WIDE TEMPERATURE RANGE.

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Introduction: Calcium-aluminum-rich inclusions (CAIs) and amoeboid olivine aggregates (AOAs) are thought to have formed in a high-temperature region of the protoplanetary disk, most likely near the proto-Sun, characterized by approximately solar chemical and oxygen isotopic compositions [e.g., 1]. The AOAs are enriched in equant grains of forsterite with variable proportions of embedded CAIs; AOAs have avoided significant melting after the aggregation. Therefore, AOAs from the weakly-metamorphosed chondrites may retain records of nebular gas-solid interactions. Here we describe an AOA from the CR chondrite Y-793261 providing an evidence for gas-solid condensation over a wide temperature range.

Analytical methods: A polished thin section of Y-793261 was studied using SEM, EPMA, Raman spectroscopy at NIPR, and SIMS oxygen isotopic analyses with the University of Hawai‘i Cameca ims-1280. Condensation temperatures and cooling rates were modeled using the GRAINS thermodynamic/kinetic code [2].

Results and Discussion: Mineralogy and Petrography. Y-793261 consists of chondrules, refractory inclusions, mineral fragments, and a fine-grained matrix. It experienced a minor degree of aqueous alteration, including partial replacement of chondrule glass and matrix by phyllosilicate and of Fe,Ni-metal by magnetite and Fe,Ni-sulfides; olivine and pyroxene phenocrysts in chondrules are largely unaltered. These alteration features and Raman characteristics of matrix areas suggest that the petrologic type of Y-793261 is ~2.5–2.6 [3].

One of the Ca-Al-rich domains of AOA #4 in Y-793261 is mineralogically distinct: it consists of Zr,Sc,Al,Ti-rich pyroxenes, compositionally similar to davisite [4], enclosing submicron grains of Zr-rich oxides and spinel, all surrounded by Al,Ti-diopside. The Zr,Sc-rich pyroxene and oxides are characteristic minerals of ultrarefractory (UR) CAIs, and in light of the high condensation temperatures of Zr and Sc, are indicators of crystallization at UR conditions [e.g., 5]. A detailed description of AOA #4 is reported in [6].

A peculiar characteristic of AOA #4 is the presence of silica at a few localities in the AOA interior, where it occurs as anhedral, ~5 µm-sized grains associated with low-Ca pyroxene. Raman spectra of the silica grains show a sharp peak at 464 cm⁻¹ diagnostic of quartz.

Oxygen-Isotope Compositions. Forsterite, Al-diopside, low-Ca pyroxene, quartz, and Zr,Sc-rich pyroxenes in AOA #4 have similar 16O-rich compositions (Δ17O ~ −22±2‰) typical of CAIs and AOAs from unmetamorphosed chondrites (Δ17O ~ −24‰; e.g., 7). The uniformly 16O-rich composition of the AOA is distinct from the 16O-poor compositions of whole rock samples of CR chondrites [e.g., 8], olivine and pyroxene phenocrysts in CR chondrules (Δ17O ~ −6 to 0‰) [9], and secondary carbonates and magnetite that precipitated from aqueous solutions in CR matrices (Δ17O ~ −3 to +2‰) [10]. These observations indicate that the minerals in AOA #4 originated in an 16O-rich gaseous setting of approximately solar composition, and subsequently avoided oxygen isotopic exchange with 18O-poor reservoirs, such as a nebular gas associated with chondrule formation and an aqueous fluid associated with alteration of CR chondrites.

Origin and Astrophysical Implications. The presence of an UR CAI, forsterite, low-Ca pyroxene and silica in the Y-793261 AOA#4 records its formation by gas-solid reactions over a wide temperature range from ~1800 to ~1150 K. Based on the condensation calculations, we find that the observed forsterite grain size (~5 µm) and chemical composition of low-Ca pyroxene are reasonably matched by condensation of a nebular gas depleted in H2 and He by ~10× that has cooled at a constant rate of 50K/h at a total pressure of 10⁻⁴ bar. The presence of both UR minerals and silica in the same AOA implies an effective isolation of condensates during formation of the Y-793261 refractory object [10]. Our observation provides the first direct evidence for gas-solid condensation of 16O-rich silica coincident with formation of refractory inclusions in the solar nebula.