# ORIGIN OF SPINEL FRAMBOIDS IN CALCIUM-ALUMINUM-RICH INCLUSIONS.

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**Introduction:** Calcium-aluminum-rich inclusions (CAIs) are the oldest solar system solids [e.g., 1] and the key for the understanding of high-temperature processes occurred in the early solar system. Spinel is one of the most ubiquitous phases either in unmelted CAIs or melted CAIs. In some type A and type B CAIs, spinel occurs as 'palisade bodies' or 'framboids' [e.g., 2-4]. Palisade bodies are spheroidal shells of spinel enclosing typical CAI minerals such as melilite, spinel, Al-Ti-diopside (fassaite) and anorthite. They are known to have formed in situ in their host inclusions as a result of crystallization of spinel around the vapor-melt interfaces of vesicles [2]. On the other hand, framboids are tightly packed spheroidal clusters of spinel enclosed within phases such as melilite, fassaite and anorthite, and their origin is still controversial. El Goresy et al. [3] suggested that framboids are direct condensates from the vapor phase formed around pre-existing phases. In contrast, Simon et al. [2] interpreted framboids as polar sections of palisade bodies and there is no genetic distinction between these objects. Furnace experimental study [4] showed that framboids likely formed by near-solidus processes (annealing) rather than liquid crystallization. To test these scenarios, we conducted petrological, mineralogical and O-isotopic studies of the least-altered, ultrarefractory phase bearing CAI R3C-01-u1 [5] in a compound type A CAI R3C-01 from the reduced type CV chondrite Roberts Massif (RBT) 04143 [6].

**Sample and Analytical Methods:** Petrology and mineralogy of the CAI in a thin section of RBT 04143 were studied using FE-SEM at Tohoku University. Quantitative X-ray microanalyses of CAI minerals and X-ray elemental mapping were performed at Tohoku University with FE-EPMA using WDS detectors. Grain boundaries of minerals and crystal orientations were determined using EBSD system equipped with the FE-SEM. Oxygen isotopic compositions of individual minerals and quantitative oxygen isotope images (isotopographs) in the CAI were obtained with the isotope microscope system at Hokkaido University, consisting of the Cameca ims-1270 and SCAPS ion imager. Analytical conditions are similar to those in [5] and [7].

**Results and Discussion:** In the irregularly-shaped, compound CAI R3C-01 that composed of five petrologically distinct units, framboids occur only in one unit (R3C-01-u1) and none of such framboids were identified in other units. In addition, palisade bodies are apparently absent in this inclusion.

Fifteen spinel framboids are identified in R3C-01-u1. All framboids are surrounded by relatively coarse (>10 µm), reversely-zoned melilite (typically $Åk_{15\text{-}20}$ in the core and $Åk_5$ at the rim) and unzoned melilite (typically $Åk_5$) grains. Every framboid encloses fine-grained melilite (<10 µm), whose grain size seems to be inconsistent with a melt origin. Combined with a lack of fine-grained melilite outside of the framboids suggests that tiny melilite grains enclosed in framboid predate the spinel, which is consistent with equilibrium condensation sequences [e.g., 8]. In most framboids, spinel grains are associated with tiny (<5 µm) fassaite, though tiny perovskite and tiny fassaite occur adjacent to spinel in one framboid. Vanadium oxide content in a single framboid is constant within ±0.1 wt% but variable among different framboids ranging from 0.2 to 0.8 wt%. Variations in $V_2O_3$ contents in spinel and Ca, Ti-rich phases associated with spinel might reflect difference in formation conditions of each spinel framboid.

Isotopographs of oxygen isotopes show that spinel is uniformly $^{16}$O-rich and melilite enclosed in framboid is $^{16}$O-poor. Melilite grains surrounding framboids show diverse oxygen isotopic compositions: reversely-zoned melilite is depleted in $^{16}$O whereas unzoned melilite is enriched in $^{16}$O.

Mineralogy, petrology and O-isotopic composition of the CAI suggest that (1) framboids formed prior to aggregation of $^{16}$O-rich and $^{16}$O-poor melilite surrounding the framboids; (2) spinel and melilite enclosed in framboids would have condensed in different isotopic reservoirs, or both phases have condensed from a $^{16}$O-rich gas and melilite experienced oxygen isotope exchange during nebular reheating [e.g., 9]; and (3) each framboid formed separately as small CAI and subsequently aggregated to form the inclusion. We argue that framboids in this inclusion are nebular condensates that predate their host inclusion, as suggested by El Goresy et al. [3].

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