

Two Generations of Sodic Metasomatism in an Allende Type B CAI. D. K. Ross^{1,2}, J. I. Simon², S. B. Simon³ and L. Grossman³, ¹Jacobs Technology-JETS, 2224 Bay Area Blvd. Houston TX, 77058. daniel.ross@nasa.gov, ²NASA-ARES, JSC, Houston TX 77058, ³Univ. of Chicago, Dept. of Geophys. Sci., Chicago IL, 60637.

Introduction: Calcium-Aluminum rich inclusions (CAI) in Allende, along with other chondritic components, experienced variable amounts and types of alteration of their mineralogy and chemistry [1-3]. In CAIs, one of the principal types of alteration led to the deposition of nepheline and sodalite. Here we extend initial observations of alteration in an Allende CAI [4], focusing on occurrences of nepheline and a nepheline-like phase with unusually high Ca (referred to as “calcic nepheline” in this abstract). Detailed petrographic and microchemical observations of alteration phases in an Allende Type B CAI (TS4) show that two separate generations of “nepheline”, with very distinct compositions, crystallized around the margins and in the interior of this CAI.

We use observations of micro-faults as potential temporal markers, in order to place constraints on the timing of alteration events in Allende. These observations of micro-faulting that truncate and offset one generation of “nepheline” indicate that some “nepheline” crystallized before incorporation of the CAI into the Allende parent-body. Some of the sodic metasomatism in some Allende CAIs occurred prior to Allende parent-body assembly. The earlier generation of “calcic-nepheline” has a very distinctive, calcium-rich composition, and the second generation is low in calcium, and matches the compositions of nephelines found in nearby altered chondrules, and in the Allende matrix.

Nepheline Compositions: Fully quantitative FEG-SEM measurements of nepheline compositions were obtained on the JEOL 7600F SEM at NASA-JSC. This instrument is equipped with a Faraday cup, and standards were used to calibrate x-ray yields. X-ray spectra were collected with a ThermoFisher SDD-EDS system. Data were collected at 15 kV and 3 nA. The ability to achieve high-resolution observation of target phases, and to carefully control the placement of the electron beam, enabled avoidance of mineral inclusions and ensured high-quality measurements. Using EDS data collection allowed us to limit beam exposure times, integrate peak intensities, and minimize Na-migration issues.

There are two separate generations of “nepheline” growth based on their very distinct compositions, differing sites of occurrence, and relationships to micro-faulting. Based on relationships to faults, the two generations of nepheline are pre-faulting (first generation) and post-faulting (second generation). The first generation of “nepheline” growth occurs immediately beneath, or in close proximity to the base of the Work-

Lovering (W-L) rim of the CAI. The second generation of nepheline is commonly intergrown with sodalite, can occur in the interior of the CAI, or near the

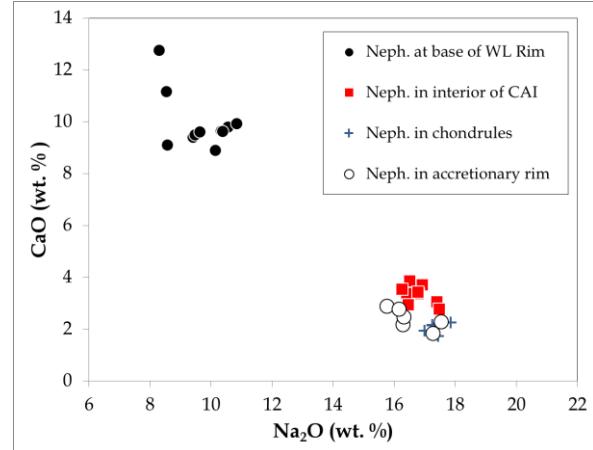


Figure 1. CaO versus Na₂O in “nepheline” in various settings in the Allende meteorite. The unusual, highly calcic composition of nephelines at the base of the Work-Lovering (WL) rim is apparent. Low-calcium, high-sodium nephelines occur in chondrules, in Allende matrix, in the accretionary rim of this CAI, and associated with sodalite in the interior of the CAI.

rim, and is similar in composition to nepheline in chondrules, in the accretionary rim of the CAI, and in Allende matrix. First-generation “calcic-nepheline” is unusually calcic, and relatively poor in sodium and potassium. Second generation nepheline is relatively poor in calcium, and rich in sodium and potassium (see Figs. 1 and 2). The “calcic nepheline” contains more Ca than any reported nephelines that we have found in the literature. We have no direct observation of the crystallography of this phase, but infer that it is nepheline based on its stoichiometry. Ca substitution in nepheline can be charge-balanced by an Al substitution for Si, or by a vacancy on the Na site, and our data indicate the latter type of substitution occurs in both generations of nephelines described here. In view of the correspondence of compositions of 2nd generation nepheline with that found outside the CAI, in chondrules, in Allende matrix, and in the accretionary rim of the CAI, we infer that this 2nd generation nepheline grew during Allende parent-body alteration.

Micro-faulting and Temporal Constraints: The margins of the CAI, including the Wark-Lovering rim and extending into the interior, are cut by four normal faults. These faults do not offset the boundary between the fine-grained (accretionary) rim of the CAI and Al-

lende matrix. One example is visible in Fig. 3. This faulting resulted in the breakout and detachment of a fragment of the CAI (noted on Figure 3 as “interrupted WL rim and missing CAI fragment”). The detachment and departure of a fragment of the CAI requires that the faulting preceded incorporation of the CAI into the Allende parent-body. Draping and infill of basins in the CAI margin and thickening of the accretionary rim adjacent to the fault supports formation of the accretionary rim during nebular transport. The size of the missing CAI fragment, and the presence of draped accretionary rim within the basin produced when a CAI fragment was detached indicates that the fault must have preceded incorporation in the parent-body. The fault shown in Fig. 3 and 4 also truncates and offsets the “calcic nepheline” that occurs immediately below the W-L rim (see Fig. 4 “truncated calcic nepheline”). These relationships indicate that the “calcic nepheline” grew prior to incorporation in the parent body. The “calcic nepheline” could have been formed when the CAI was free-floating in the protosolar nebula, or during its residence in a previous generation, icy, small parent body^[5]. The large difference in composition between the two generations of “nephelines” argues that the fluids or gases that led to their crystallization were very distinct.

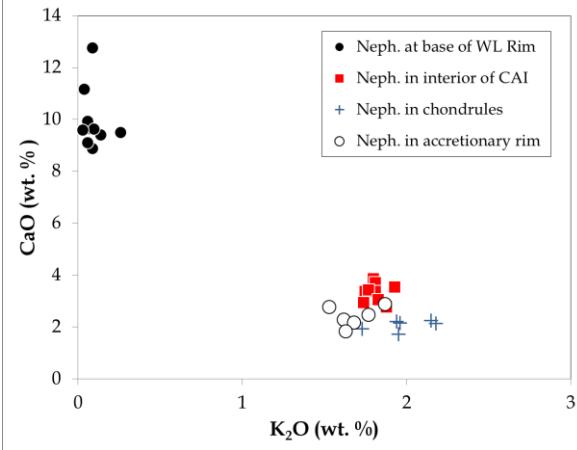


Figure 2. CaO versus K₂O in “nepheline” in the Allende CAI, chondrules and matrix. These data reinforce the presence of two very distinctive compositions of “nepheline”, one calcium-rich and poor in K and Na, the second Ca-poor and K-rich.

Summary: The relationships between fault formation, accretionary rim formation and secondary alteration in this CAI supports the idea that some metasomatism of some Allende CAIs must have pre-dated incorporation in the Allende parent body. While we recognize that parent body alteration has occurred, it seems clear from the data shown here that earlier phases of alteration and metasomatism are a reality.

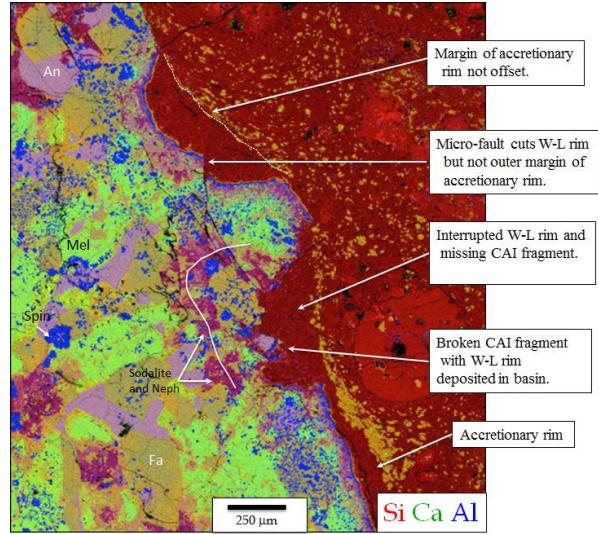


Figure 3. X-ray map of margin of CAI, with microfault that resulted in breakout and detachment of a portion of the CAI. The absence of an offset in the accretionary rim margin, and the detachment and departure of the broken CAI fragment indicate the fault predated incorporation in the parent-body. The fault offsets the W-L rim, showing that it formed after formation of the W-L rim.

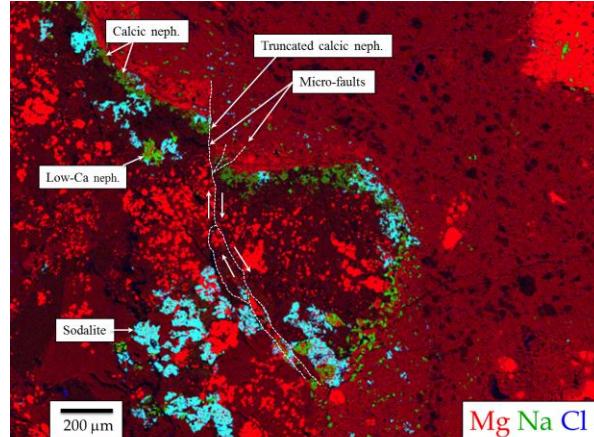


Figure 4. X-ray map showing a closeup view of the same faulted margin shown in Fig. 3. This map highlights secondary nepheline and sodalite. Fault traces are shown by dashed lines. The distinction between “calcic nepheline” and second generation, relatively Na- and K-rich nepheline is visible in this image. Intergrowth of sodalite and low-Ca nepheline is also shown. Truncated and offset “calcic nepheline” is visible along the fault trace.

References: [1] Brearley, A.J. (2003) *Treatise on Geochem.*, v.1, 247. [2] Brearley, A.J. and Jones, R.H. (1998) *Rev. in Mineral.*, 36, Ch. 3. [3] Krot, A.N. et al. (1995) *Meteorit.*, 30,748. [4] DK Ross et al. (2012) *LPSC XLV*, abstract # 2466. [5] Grossman (2010) *MAPS*, 45,7-20.