

PHYLLOSILICATES IN TWO COARSE-GRAINED ALLENDE CAIs: EVIDENCE FOR ADVANCED HYDRATION Rena Ford and Adrian J. Brearley, Dept. of Earth and Planetary Sciences, MSC03-2040, University of New Mexico, Albuquerque, NM 87131 (rford@unm.edu).

Introduction: Calcium, -Aluminum rich inclusions (CAIs) from the Allende meteorite have been the subject of extensive research and debate for the past 30 years [1-4]. These objects retain a remarkable record of the highest temperature processes in the solar nebula and have placed important constraints on condensation processes. CAIs in Allende also show evidence of significant secondary alteration that in most cases involves the formation of a range of anhydrous phases. Rarely, phyllosilicates have been documented in some Allende CAIs [3], but they are only present as very minor phases. The origin of these hydrous minerals is the subject of considerable debate and both nebular and parent body scenarios for their formation have been proposed [1,3].

As part of a larger study of secondary alteration effects in CAI in Allende, we have found two CAIs in the same thin section which show evidence of extensive alteration. The most notable characteristic of these two CAIs is that they appear to contain a much higher abundance of hydrous phases, probably calcic micas, than has been reported previously. We have studied these objects and the surrounding matrix in detail using SEM, electron microprobe and TEM to gain insights into the alteration reactions and the conditions and environment of alteration. TEM work was carried out on selected regions of one of the inclusions (CAI 1) that were extracted using focus ion-beam (FIB) techniques.

Samples:

CAI 1: CAI1 is a coarse-grained, type A inclusion that measures ~300 μm across, and ~800 μm long with a shape reminiscent of a crescent moon. Primary mineralogy of CAI1 includes melilite, spinel, Ti,-Al rich pyroxene, platinum group nuggets, and perovskite. Primary melilite crystals have been extensively replaced by secondary phases and have a heavily corroded appearance, but the relict portions of these crystals poikilitically enclose rounded spinel grains. The melilite crystals are universally rimmed by a layer of secondary melilite that is distinguishable from the primary melilite by both its texture and

composition, and is ~15 μm wide. Spinel grains also make a discontinuous rim around CAI1. Spinel inclusions within melilite have a lower FeO content than those around the rim of CAI1. Ti, -Al rich pyroxenes have a spongy, porous appearance suggesting that they may have undergone partial alteration. Alteration products comprise at least half of CAI1 and occur in a variety of different textural settings. As noted above, secondary melilite occurs as a rim of irregular thickness around primary melilite grains. The boundary between rim and the core melilite is highly irregular with multiple embayments indicative of replacement of the primary melilite. The secondary melilite is compositionally distinct with increased Fe and Na. Alteration of primary melilite is enhanced along grain boundaries and fractures. The rim of secondary melilite appears itself to have been replaced by a porous intergrowth of fine-grained nepheline and sodalite which constitute the dominant alteration products in this inclusion

Within the regions of porous nepheline and sodalite, distinct pockets of a phase that often has a platy morphology are present (Figure 1) Sometimes these platy grains appear to radiate outwards from the center of the pocket and are ~15 μm long and ~1-2 μm thick. Electron microprobe data for this phase show that it contains elevated concentrations of CaO and Al_2O_3 and has low totals (~95 wt%) indicative of a hydrated phase, possibly a mica. The data are suggestive of the calcic mica, margarite, but the analyses are clearly not stoichiometric margarite. TEM analysis of FIB extracted samples of regions containing this phase reveal a complex picture. These areas consist of a coarse, well-crystallized phyllosilicate phase embedded in a matrix of ultrafine-grained phyllosilicates. The coarse-grained phyllosilicates appear to be a disordered intergrowth of phases with basal spacings of 0.7 nm, 1.0 nm and 1.4 nm. The identity of these phases is not yet known, but may be mixture of mica, aluminous chlorite and possibly kaolinite. We are currently investigating

these complex phases in more detail using HRTEM, electron diffraction and EDS analysis.

A third texture arises from the alteration product of Ti,-Al rich pyroxene. In these regions the alteration products contain pore space, nepheline, sodalite, pyroxene, and an unidentified phase. It is possible that the precursor material of these regions was a combination of melilite and Ti,-Al rich pyroxene, but the primary material has been entirely replaced.

CAI 2: CAI2 is a compact type A measuring ~300 μm across, nearly 800 μm long, and is roughly oblong in shape. CAI2 contains melilite, spinel, hibonite, and perovskite. Melilite crystals are coarse grained and poikilitically enclose spinel and perovskite crystals. Hibonite crystals are acicular and are mostly altered to spinel as evidenced by the pseudomorphs of spinel. Spinel occurs as a phase within the melilite crystals, as a rim around CAI2, and, as mentioned before, a pseudomorph after hibonite. Perovskite is found within the melilite crystals, but also as an unaltered phase within some of the altered regions leading to the conclusion that at least some of the alteration material is a product of melilite alteration.

Approximately two thirds of CAI2 has been altered into a porous intergrowth of fine-grained (>5 μm) alteration products. Embedded within these alteration products are perovskite grains and spinel pseudomorphs after hibonite. Some of the alteration phases are platy and have a similar morphology and composition to those in CAI1 and are probably a mica. Detailed TEM work is required to characterize this phase fully.

In comparison with CAI1, CAI2 contains very little sodalite and there is no evidence of a rim of secondary melilite around the primary melilite crystals. This difference may be a reflection of the different primary mineralogies of the two inclusions. In particular, CAI2 has less sodalite and nepheline and more hibonite than CAI1

Discussion: Although tentative, our findings indicate that these two inclusions show evidence of significantly more extensive hydrous alteration than has been reported previously in Allende CAIs. Phyllosilicates, were present in Allende CAIs, are usually very rare and poorly developed. Most workers have argued that formation of hydrous phases in CAIs occurred in the solar nebula due to interaction with a water-bearing gas,

an explanation which is consistent with the rare and very limited degree of hydration observed in most CAIs.[3]. However, it seems more problematic to ascribe the extensive development of hydrous phases in these two CAIs to nebular processes. Significant interaction with an aqueous fluid is implied and is consistent with other evidence that suggests that Allende may have been affected quite extensively by aqueous fluids on an asteroidal parent body. One problem with the parent body scenario is that the effect of hydration on CAIs is clearly quite heterogeneous. Most CAIs do not contain evidence of hydrated phases and examples such as the ones described here are apparently rare. However, one possible explanation for such heterogeneity is that channelized fluid flow provided higher local fluid fluxes, such that some inclusions interacted more extensively with hydrous fluids.

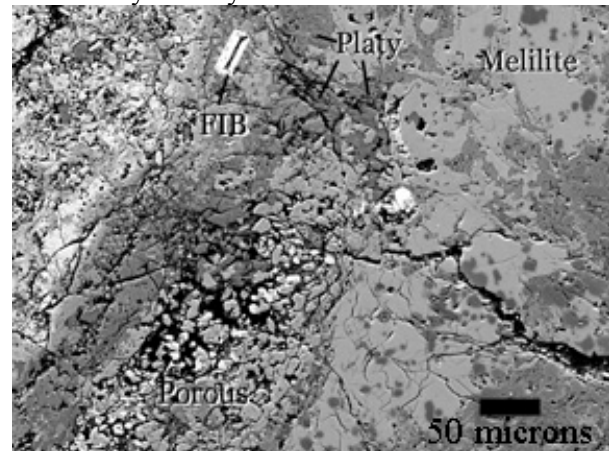


Figure 1. Back scattered electron image of CAI 1. A porous alteration region is seen in the lower left hand corner of the CAI, with coarse grained melilite crystals to the right of the porous alteration region. In the upper left is one of the FIB sections made for this study.

References [1] Meeker, G.P., Wasserburg, G.J., Armstrong, J.T., 1983, *Geochim. Cosmochim. Acta*. Vol 47, pp. 707-721. [2] Krot, A.N., Scott, E.R.D., Zolensky, M.E., 1995, *Meteoritics*, vol 30, pp. 748-775. [3] Keller, L.P., Buseck, P.R., 1991, *Science*, vol 425, pp. 946-948 [4] MacPherson, G.J., Simon, S.B., Davis, A.M., Grossman, L., and Krot, A.N., 2005, *ASP Conference Series*, Vol 341, pp 225-250. **Acknowledgements:** This work was funded by NASA Cosmochemistry grant NNG06GG37G to A.J. Brearley