

A SOLAR-FURNACE STUDY OF THE FORMATION OF REFRACTORY RESIDUES BY EVAPORATION. MacPherson, G. J.¹, Kawabe, I.¹, Grossman, L.^{1,2}, King, E. A.³ ¹Department of Geophysical Sciences, University of Chicago, Chicago, IL 60637; ²also Enrico Fermi Institute; ³Department of Geology, University of Houston, Houston, TX 77004

The refractory Ca-Al-rich inclusions (CAI) in C2 and C3 meteorites have been proposed as the earliest solid material to have formed in the solar nebula [1]. An alternative proposal is that such objects are residues formed after high temperature heating and evaporation of some unknown solid parent material in the solar nebula [2,3]. Previous experiments to test the latter hypothesis have failed to adequately characterize the mineralogy and textures of the run products [3,4]. We have initiated experiments to study the mineralogy, textures, and chemistry of residues produced by evaporating samples of a Columbia Plateau basalt, bulk Murchison and bulk Allende meteorites in a solar furnace. Our goal is that the results of these experiments will help to constrain models for the origin of CAI. Samples were heated in vacuum and atmospheres of air and H₂; details of the experimental procedures are given in [5]. Run products were examined with optical and scanning electron microscopes, and the constituent phases were analyzed by electron microprobe. Aliquots of selected samples were analyzed by INAA. We have thus been able to thoroughly characterize the mineralogy, textures and chemistry of our run products. We report here some initial results.

The run products have shapes ranging from large (1 cm) hemispherical "buttons" to small (several mm dia.) pancakes; in all cases the rounded or irregular surface (top) was the part being directly heated while the flat part (bottom) was in contact with the water-cooled crucible floor. The large temperature gradient caused extreme chemical and mineralogical stratification in all the runs observed so far. In one case a sample consists of silicates and silica-rich glass near the bottom but is composed entirely of calcium-aluminate phases at the top. Such extreme zonations have never been observed in natural Ca-Al-rich inclusions from Allende or Murchison. Nonetheless the textures and mineralogy of individual zones can be compared with the properties of CAI.

The most refractory, Ca-Al-rich residues produced so far are from the basalt rather than the meteorites, due at least in part to the higher initial contents of Ca and Al in the basalt. Three of the runs we have studied, produced under three different atmospheres, all contain CaAl₄O₇ and MgAl₂O₄ as major phases, with CaAl₂O₄ as an additional phase in two of them. One of these, run under vacuum, is a 1.8 mm thick disc with a remarkable structure: the bottom 70 μm is clear yellow glass (47% SiO₂, 9.8% FeO) with anorthite crystals projecting perpendicularly to the base of the disc; above this is a 140 μm-thick zone of tan glass (35% SiO₂, 0% FeO) containing spherulites and skeletal euhedral crystals of colorless spinel and some melilite (Ak 2); above this is dense black glass with a graphic intergrowth of skeletal CaAl₄O₇ and CaAl₂O₄, which grades upwards to a clear zone of skeletal and fibrous CaAl₄O₇ crystals. This is the only run we have thusfar found to contain melilite. The top portion of this sample is enriched in refractory elements relative to the starting material (Dy 9x, Eu 5x, Al 5x, Ca 4x, Ti 2x) but depleted in volatile elements (Mg 0.6x, Mn 0.009x, V 0.05x, Na < 0.003x).

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The bottom of the sample is slightly poorer in Dy, Eu, Al and Ca than the top and richer in Ti, Mg, Mn and Na, but both top and bottom are depleted in Mn, V and Na relative to the starting material. We also obtained some condensates from the walls of the vessel during this run: the material is amorphous, is depleted in refractory elements by 0.2-0.8x relative to the starting material, and has approximately the original content of volatile elements. Another sample, run under H₂, also shows a layered structure and has CaAl₄O₇ as its major phase; it differs in having abundant spherules of Fe metal. The non-metallic portion of the sample is 3-6x enriched in refractory elements, 1.6x enriched in V, and depleted in volatile elements by 0.0015 to 0.5x. The metal is depleted in refractory lithophile elements (<0.001-0.35x) but strongly enriched (9x) in V. The textures of these refractory residues are suggestive of very rapid crystallization: skeletal and elongate crystals, commonly in spherulitic arrangement. Such textures have not been reported in natural refractory inclusions from carbonaceous chondrites. If textures in the experimental and natural samples can be directly compared in spite of somewhat differing mineralogies, the cooling and crystallization rates of the natural inclusions may have been much slower than those of the experiments.

The experimental runs using bulk Allende and Murchison as starting materials have thusfar only produced residues in which the major phases are olivine and magnetite, with lesser glass, Fe metal in some cases, and clinopyroxene. Typically the products consist of bladed olivines having a spinifex-like texture, with interstitial magnetite and glass. One sample contains olivine (Fo 80-84) and interstitial magnetite near the bottom but has forsteritic olivine (Fo 98) and Fe metal near the top, indicating severe disequilibrium in the internal oxidation conditions. These samples are 1-3.5x enriched relative to the starting material in refractory elements throughout, but depleted by <0.01-0.04x in Na. V is depleted by 0.3-0.5x except where Fe metal is present in which case V is enriched by 2x.

A major difference between the refractory residues produced experimentally and natural CAI is the mineralogy. CAI commonly contain hibonite and melilite, but CaAl₄O₇ and CaAl₂O₄ have not been reported. In the experiments by ourselves and others [3,4], however, melilite is rare and hibonite has not been reported, and CaAl₄O₇ and CaAl₂O₄ are common. If CAI are evaporation residues, we do not understand why no inclusions were ever formed that contain CaAl₄O₇ or CaAl₂O₄. Rather, we would expect a wide range of bulk compositions and mineralogy as a result of varying degrees of volatilization. We recognize that our experimental technique produces extreme temperature gradients and higher temperatures than probably existed in the solar nebula. Metastable phases in our run products and differing volatilization patterns from those that might have occurred in the solar nebula can not therefore be ruled out. Nevertheless these preliminary experiments may provide some evidence against an evaporation residue origin for CAI.

References: [1] Marvin, U. V. *et al.* (1970) EPSL 7, 346-350. [2] Kurat, G. *et al.* (1975) EPSL 26, 140-144. [3] Hasimoto, A. *et al.* (1979) EPSL 43, 13-21. [4] Notsu, K. *et al.* (1978) GCA 42, 903-907. [5] King, E. A. *et al.* (1982) This volume.