REFRACTORY INCLUSIONS AS PRECURSORS OF CHONDRULES: INITIAL RESULTS FROM MELTING EXPERIMENTS.

S. A. Whattam[1,2], R. H. Hewins[1,3] and B. Devouard[4], [1]Department of Earth & Planetary Sciences, Rutgers University, 610 Taylor Road, Piscataway, NJ 08854, USA (sawhatta@rci.rutgers.edu), [2]Hawaii Institute of Geophysics & Planetology, SOEST, University of Hawaii at Manoa, Honolulu, HI 96822, USA, [3]MNHN & CNRS UMR 7202, 61 rue Buffon, 75005 Paris, France, [4]Laboratoire Magmas & Volcans (UMR 6524), Université Blaise Pascal-CNRS, 5 rue Kessler, F-63000 Clermont-Ferrand, France

Introduction: Possible chondrule precursors include recycled chondrule debris, dust of CI composition, and high temperature condensates. Here we investigate the third possibility. Calcium-aluminum rich inclusions (CAI) and amoeboid olivine aggregates (AOA) occur as inclusions in some chondrules [1,2] and AOA containing discrete fine-grained CAI overlap in bulk composition with chondrules (Fig. 1). The apparent age difference and similarities in bulk composition between AOA and Type I chondrules suggest that some magnesian chondrules could have formed via (essentially complete) melting of precursor refractory assemblages of AOA and CAI [e.g., 3-8]. The thermal histories of CAI and AOA and their response to chondrule melting events are both of interest. Herein, we present initial results of sintering and melting experiments and focus on the melting response of precursor CAI+olivine mixtures. Experimental constraints on the thermal evolution (i,e,. duration and peak temperature) of precursor CAI and AOA from these and related experiments will be presented elsewhere.

Methods: For the isothermal runs, we first prepared CAI- and AOA-like starting materials (pellets), the compositions of which lie on an approximate mixing line from fine-grained CAI associated with AOA and Fo end members (Fig. 1). To prepare the starting CAI-like starting material, crystals of Miyakejima anorthite, Fianarantsoa diopside and Burmese (aluminous) spinel were separately crushed to <20 µm powders. Equal fractions of An+Di+Sp were then mixed and pressed into circa 200-300 mg cylindrical cores and suspended in Re baskets fastened to platinum sample holders. The cores were then sintered at IW-0.5 at 1200°C for 100 h with representative textures compared with those of natural CAI and AOA as shown in Fig. 2. Synthetic starting AOA materials materials comprise 35-40 mg pellets of crushed, Fo sol gel crystallized by heating at 1300°C for 40 h (Fa_0, typically finer than ~ 5 µm) and nuggets of the 1200°C-100 h synthetic CAI-cores further sieved to <43 µm. These materials were then mixed as 65:35 (Fo:CAI) and sintered at 1250°C for 200 h. Isothermal heating runs were carried out on 80:20 (olivine: synthetic CAI) mixtures of the starting 1200°C-100 h CAI-like material plus <20 µm San Carlos olivine (Fig. 2). Isothermal runs were conducted between 1250 and 1600°C for 1 h. All samples were run in a 1 atm, DelTech DT-31-VT-OS vertical furnace housed in the Department of Earth and Planetary Sciences at Rutgers University.

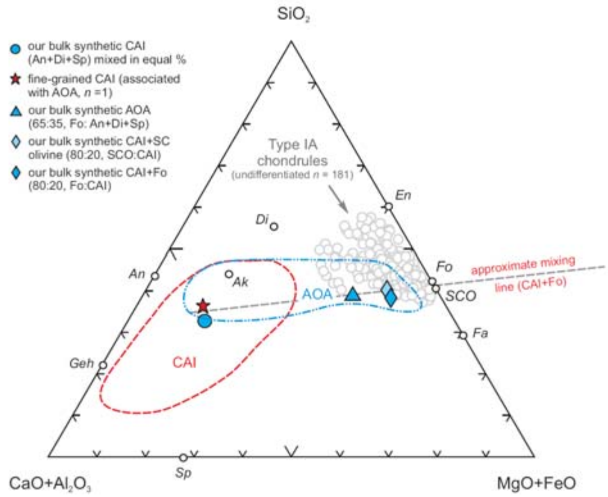

Figure 1 Comparison of bulk compositions of natural CAI, AOA and Type IA chondrules with our synthetic CAI, CAI + Fo, CAI + SC olivine and AOA mixtures.. Fields of Type IA chondrules, AOA and CAI are from [9, 10].

Results: *Starting material sintering runs*. The 1200°C-100 h sintered CAI-like material consists of ~ 10-20 µm, subhedral spinel grains set in a fine-grained groundmass of An+Di (Fig. 2a). The 1250°C-200 h sintered AOA-like material displays irregular, forsterite 'masses', commonly enclosing spinel (Fig. 2c). A fine-grained CAI from the Nangqiang carbonaceous chondrite [from 11] and an AOA from the ungrouped carbonaceous chondrite Acfer 094 [from 12] are shown for comparison in Figs. 2b and 2d respectively.

Isothermal runs. SEM images of the synthetic CAI+SC olivine isothermal heating runs are shown in Fig. 3. At low temperarature, CAI and olivine domains are demarcated by sharp contacts (Figs. 3a, b). Domains with either spinel or olivine crystals survive until 1550°C (Figs. 3c-e) with fractions of the former decreasing with increasing temperature. By 1600°C, there remains no evidence of a CAI precursor and the resulting texture is PO or POP (Fig. 3f) and very similar to 'classical' Type I porphyritic chondrules.

Discussion: Recent studies [e.g., 13-15] suggest that the vast majority of magnesian chondrule olivine is relict and that (low-Ca) pyroxene crystallized from melt enriched in nebular SiO during chondrule formation. The experiments of [16] illustrated that ‘porphyritic’ chondrule analogs could be produced from mixtures of (sintered) coarse-grained granoblastic olivine aggregates (GOA) and An+En subjected to high temperatures. Here we show that it is also possible to generate PO texture from mixtures of CAI-like precursors + olivine. The restricted compositional range of CAI (and AOA) would also require silica addition to explain the whole range of Type I compositions, as well as a change in oxygen isotopic composition [15] .

Even though CAI-derived melt eventually invaded the olivine regions in our charges, domains containing relict spinel persisted mixed with olivine-rich domains up to very high temperatures. Such objects with mixed chondrule and CAI phase assemblages e.g., some Al-rich chondrules from Acfer 094 [2] would have been homogenized if heated higher than 1600°C.

Conclusions: Charges comprised of CAI-like nuggets plus SC olivine heated for 1 h illustrate several textural features. (1) CAI and olivine domains retain sharp contacts at low temperature (1250-1350°C); (2) intermediate temperature runs (1400, 1450°C) illustrate encroachment of CAI melt into olivine domains with irregular, diffuse contacts; (3) the volume of CAI domains decreases as CAI melt migrates with increasing temperature; by 1600° there are no CAI domains and hence no evidence of derivation from CAI-like precursors; (4) resultant textures are PO or POP at 1600°C. CAI plus Fo or AOA may represent potential precursors of some magnesian chondrules but determining which would be difficult for those subjected to high degrees of melting.

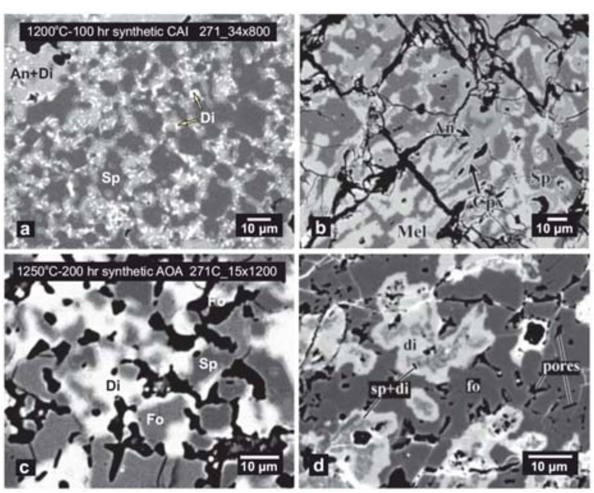

Figure 2 Comparison of SEM images of our synthetic, sintered (a) CAI- (spinel-rich region) and (c) AOA-like charges with a natural (b) CAI from the Ningqiang carbonaceous chondrite [11] and an (d) AOA from Acfer 094 [12].

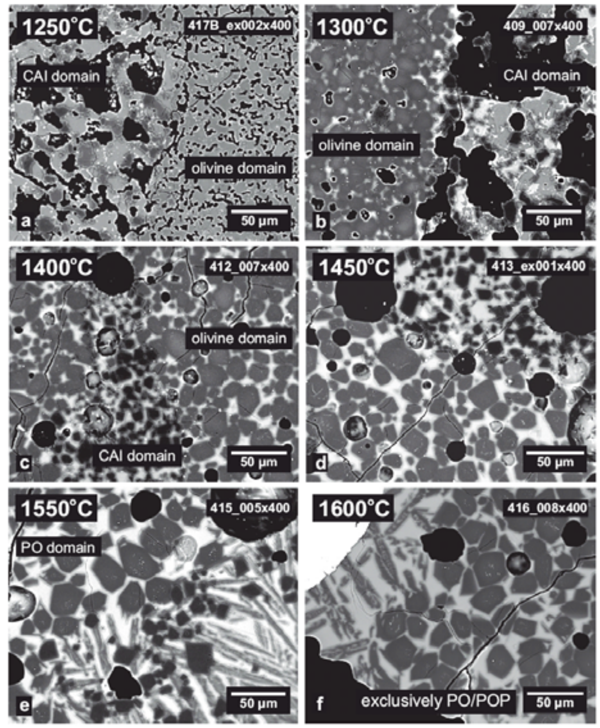

Figure 3 Textural evolution of 1 h synthetic CAI+SC olivine runs (representing AOA or separate condensates) as a function of temperature.

References: [1] Misawa, K. and Nakamura, N. (1996) Chondrules and the Protoplanetary Disk, 99-105. [2] Krot, A.N. et al. (2004a) *GCA 68*, 2167-2184. [3] MacPherson, G. J. and Huss, G. R. (2000) LPS, 31, Abstract # 1796. [4] Yurimoto H. and Wasson, J. (2002) *GCA 66*, 4355-4363. [5] Krot, A. N. et al. (2005) *Ap. J., 622*, 1333-1342. [6] Krot, A. N. et al. (2006) *Ap. J.*, *639*, 1227-1237. [7] Russell, S.S. et al. (2005), Chondrites and the Protoplanetary Disk, 317-360. [8] Nagahara, H. et al. (2008), *GCA 72*, 1442-1465. [9] McSween, H. Y. Jr. (1977) *GCA 41*, 1843-1860. [10] Mason, B. and Martin, P.M. (1977) *Smithsonian Contrib. Earth. Sci*., *19*, 84-9. [11] Lin, Y. et al. (2004) *Proc. Nat. Acad. Sci., 102,* 1306-1311. [12] Krot A.N. et al. (2004b), *GCA 68*, 1923-1941. [13] Libourel, G. et al. (2006) *EPSL, 251*, 232-240. [14] Libourel, G. and Krot. A.N. (2007), *EPSL, 254*, 1-8. [15] Chaussidon, M. et al. (2008) *GCA* 72, 1924-1938. [16] Whattam S. A. and Hewins R. H. (2009) *GCA 73*, 5460-5482.