AMOEBOID OLIVINE AGGREGATES RECORD NEBULAR METAL-SILICATE FRACTIONATION.
D. S. Ebel[1,2,3], M. K. Weisberg[1,3,4]. [1]Dept. of Earth & Planetary Sciences, American Museum of Natural History, New York, USA (debel@amnh.org); [2]Dept. of Earth & Environmental Sci., Columbia University, New York; [3]Graduate Center, City University of New York, NY; [4]Dept. of Physical Sciences, Kingsborough College, Brooklyn, NY 11235, USA.

Introduction: Metal/silicate abundance ratios vary among solar system bodies, from sub-solar in the L ordinary chondrites, to higher ratios in other primitive chondrites (e.g., E, CH, CB) and very high in planet Mercury. Amoeboid olivine aggregates (AOAs) are nodular accretions with discrete ^{16}O-rich, refractory Ca-, Al-, Ti-rich mineral assemblages (CAIs), with ^{26}Mg excesses revealing their very early Solar System ages, and often with separate Fe-metal alloy nodules, all surrounded by ^{16}O-rich, in some cases low-FeO, Mn-enriched (LIME) olivine rinds.

AOAs illustrate three of the principal components of variation among bulk chondrites: metal, Mg-olivine, and Ca-, Al-rich materials [1]. Many AOAs contain metal nodules surrounded by Mg-olivine, forsterite [2].

Methods: Polished thick and thin sections of chondrites were mapped on the AMNH SX100 electron probe micro-analyzer (EPMA) at 15kV and various beam currents and dwell times, for suites of 8 to 10 major and minor elements, at resolutions of 1 to 5 µm /pixel. EPMA spot analyses and field emission SEM cathodoluminescence (CL) imaging on a metal-rich Renazzo AOA were performed.

Results: The highly primitive chondrite Acfer 094 (C2 ungr, find) contains numerous isolated 100 µm scale nodules of metal and CAI material with olivine rims (Fig. 1). Similar isolated nodules are also present in other CCs (Fig. 2). These nodules resemble those of composite AOAs found in carbonaceous chondrites [3]. These isolated nodules in Acfer 094 (Fig. 2) and other CCs appear to be precursors for the large, more complex, composite AOAs ([4]; Fig. 2). The metal-olivine nodules are always on the outside of AOAs, with the CAI-olivine nodules interior, reflecting a temporal relationship.

Metal-rich Renazzo AOA: Mn diffusion into this AOA's fine-grained forsteritic olivine across broad fronts was observed using CL (Fig. 2E, inset). In this AOA, the olivine coatings on CAI and metal observed by secondary electron imaging are 2-5 µm euhedral aggregates forming triple junctions and are extremely difficult to polish without plucking (Fig. 3). In contrast, the CAI parts of the nodule appear tightly sintered and polish very effectively. Metal nodules in this AOA have Ni and Co significantly above the solar value, plotting along the cooling trajectories of a vapor of solar composition (Fig. 4).

Discussion: The classical condensation sequence from a vapor of solar composition [5] has metal condensing at higher temperature (T) than forsterite at total pressure (P^{tot}) > ~10^{-3} bar. However, the Mn-rich nature of olivine on the outer layers in some AOAs indicates formation at lower P^{tot} [6], where pure forsterite would condense at higher T than metal, given the presence of solid ultra-refractory grains for nucleation [7]. While the monomineralic portions of the nodules may have been sintered in transient heating events, there is little evidence of pervasive melting in these nodules.

The metal composition of the Renazzo AOA is consistent with equilibration with a vapor from which not all the Fe had condensed, but this metal not as Ni and Co enriched as many metal grains in Renazzo chondrule cores [9, their Fig. 7].

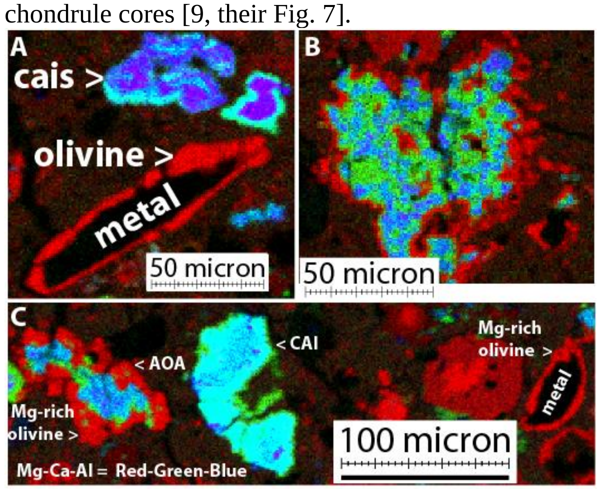

Fig. 1: Nodules of Mg-olivine-coated materials and uncoated CAIs in Acfer 094 (C2 ungr, find; Münster PTS). Composite mosaics are Mg, Ca and Al in color-balanced red, green, blue channels. These are isolated regions of interest in a very large x-ray map of one polished section [8, supplementary materials]. The regions in between the larger CAI, AOA, and chondrule above the scale bar are very fine-grained matrix.

These relationships suggest that high surface energy metal alloys formed larger grains, and that fine-grained olivine then coated those metal grains. All of this would occur after condensation of fine-grained

CAI aggregates, which are also often coated with forsteritic olivine. Single nodules of coated CAI material, like the AOA in Fig. 1, would then have aggregated into clumps, prior to accretion of the metal nodules exterior to olivine-coated CAI material. All of this suggests close spatial and temporal proximity for the formation of these independent and aggregated nodules.

The ubiquity of such primitive, nodular structures in carbonaceous chondrites hints that they were precursors of melted objects such as chondrules, as suggested by [2]. They appear to preserve superposition relationships implying a temporal order of condensation and aggregation. The separation of metal from silicate at this scale may have important implications for the dynamical environment of AOA formation.

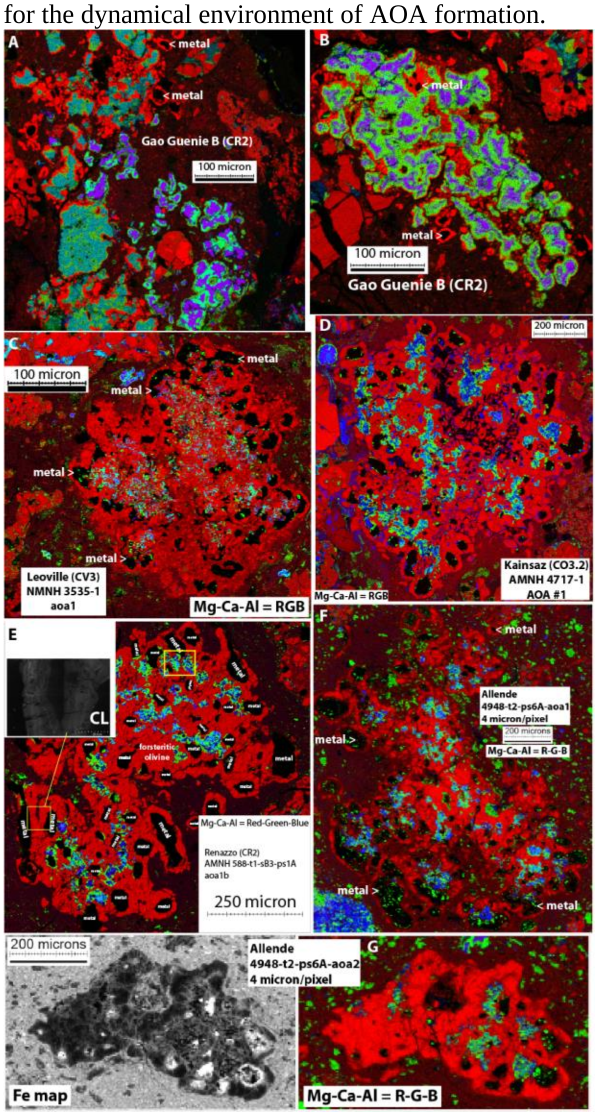

Fig. 2: Nodular refractory AOAs and CAIs. **A,B**: Gao Guenie (b) (CR2)s, **C**: Leoville (CV3), **D**: Kainsaz (CO3.2), **E**: Renazzo (CR2), **F, G**: Allende (CV3). Red Mg-olivine surrounds both blue and green Ca-, Al-rich mineral aggregates, and black metal grains.

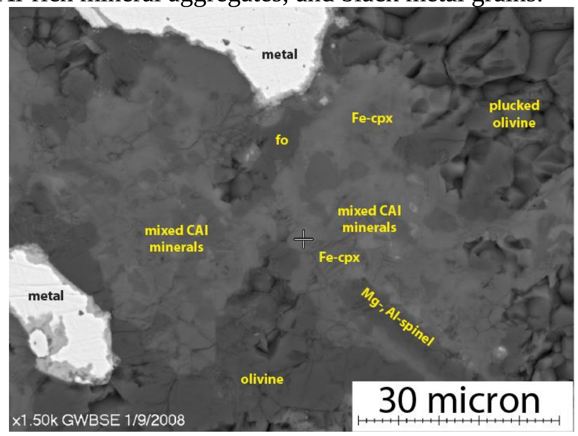

Fig. 3: Secondary electron image of CAI nodule with plucked olivine rim (area of yellow box near top of Fig. 2E).

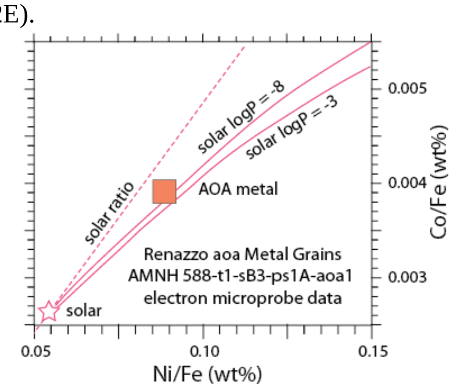

Fig. 4: Composition of metal in AOA of Fig. 2E, average of 15 points in 4 nodules. Curves show metal composition during condensation from solar composition vapor with decreasing temperature from upper right to solar composition (star) [5].

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Acknowledgments: This work is supported by NASA Emerging Worlds grants NNX6AD37G (DSE) and 80NSSC18K0589 (MKW).