**ACCRETION AND MELTING OF DUST TO FORM FERROAN CHONDRULES IN ORDINARY CHONDRITES.** A. Ruzicka[1], C. Floss[2] and M. Hutson[1] [1]Cascadia Meteorite Laboratory, Dept. of Geology, Portland State University, 1721 SW Broadway, Portland, OR 97207 U.S.A., email:ruzickaa@pdx.edu. [2]Laboratory for Space Sciences and Physics Dept., Washington University, St. Louis, MO 63130 U.S.A. email: floss@wustl.edu

**Introduction:** To better understand the origin of chondrules, it would be helpful to know the identity of chondrule precursors. Agglomeratic olivine inclusions (AOIs), which consist chiefly of fine-grained olivine with variable amounts of troilite and rare refractory minerals, comprise a small (~2%) proportion of type 3 ordinary chondrites, and were interpreted to be candidates for little-melted chondrule precursors [1-4]. We studied textures and chemically analyzed (via EMPA and SIMS) minerals and bulk constituents of AOIs in three LL chondrites, NWA 3127 (LL3.1), Sahara 98175 (LL3.5), and newly-classified NWA 4910 (LL3.1, also known as "Begaa"), to determine the origin of these objects and their relationship to typical chondrules. Based on our data, we suggest that AOIs include both unmelted and melted types, that they are indeed aggregational in origin, and that they likely were precursors to some ferroan (Type II) chondrules in ordinary chondrites.

**Physical characteristics and aggregational origin:** AOIs range in size from ~0.2-2.8 mm across. Due to their fine grain sizes (typically <5-10 µm across) and an abundance of troilite, they appear opaque or nearly opaque in transmitted light. Some objects show no textural evidence for melting, whereas others have fine-grained igneous-textured matrices and could be termed fine-grained Type IIA chondrules (Fig. 1a). Some objects are texturally zoned, with coarser-grained igneous cores and rims that show no evidence for melting (Fig. 1b). An aggregational origin for AOIs is implied both by disequilibrium textures and mineral chemistry, including (1) diverse olivine and pyroxene compositions (e.g., olivine in AOIs spans $Fo_{65-99}$ and has corresponding large variations in trace-element composition), with many relict grains (Fig. 1a,b); (2) the frequent presence of coarser mineral clusters that appear to be relict chondrules (Fig. 1a,b); (3) common layering structures that suggest progressive radial accretion of material (Fig. 1b), often with late addition of troilite; and (4) the presence of rare CAIs, including one with a grossite ($CaAl_4O_7$) core.

**Trace-element compositions:** SIMS data for bulk constituents were obtained in fine-grained areas of the AOIs using a broad (~45-µm-diameter) beam. These data suggest that most AOIs have relatively unfractionated (chondritic) trace-element compositions. This is true both for unmelted and melted types. Lithophile element abundances are typically ~1.3 to 2 x CI chondrites, similar to the bulk composition of ordinary chondrites [5] and some Type II chondrules [6].

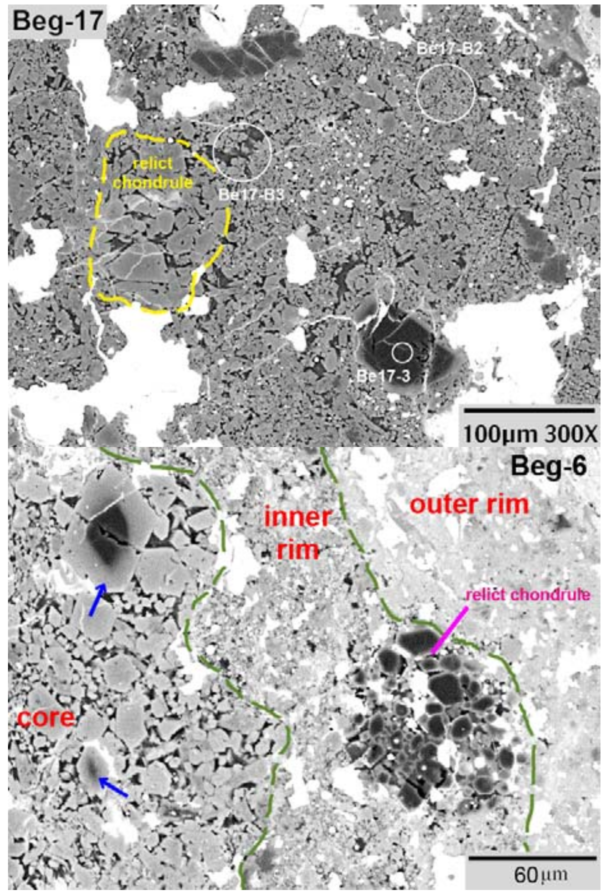


*Fig. 1. BSE images of (a) Beg-17 and (b) Beg-6 in NWA 4910. Both objects contain relict olivine grains (e.g., blue arrows) and relict chondrules. The inner and outer rim for Beg-6 shows no textural evidence for melting; some entire AOIs have textures similar to this inner rim. SIMS analysis spots labeled in (a) include relict forsterite (Be17-3, $Fo_{99.3}$), typical fine-grained mesostasis (Be17-B2), and a glass-rich pocket (Be17-B3). Bright areas are mainly troilite although metal is also present in Beg-17.*

For example, Fig. 2 shows data for two AOIs in NWA 4910, one of which (Beg-16A) is unmelted, and the other of which (Beg-17—Fig. 1a) was partially melted. In the unmelted object, an average of three SIMS analyses (Be16A-B1, -B2, -B3) shows a remarkably unfractionated composition for both lithophile and siderophile elements (Fig. 2). In the partly melted object, an analysis of a typical fine-grained area (Be17-B2) also shows a nearly unfractionated composition, except for a depletion in P, Fe, Co, Ni and Eu, and a small enrichment in the alkalis (Fig. 2). A similar composition is measured for a relict chondrule in the object (Fig. 2). In contrast, a glassy region of the AOI is enriched in incompatible elements, and relict forsterite is strongly fractionated (Fig. 2). Beg-17 could have formed by melting of material similar to Beg-16A, after an admixture of forsterite and other mineral and chondrule debris. Similar abundance patterns for P, the alkalis and the REE for all components in Beg-17 (Fig. 2) suggest that all of these components were derived from a common batch of material or that they were processed in similar ways. The low P content may indicate that this element was partitioned into metal during melting.

**Implications for Chondrule Formation:** The data for AOIs are consistent with previous suggestions [1-4] that some objects in ordinary chondrites have relatively unfractionated compositions and that these objects could be the precursors to chondrules. The compositions of the AOIs are what one would expect for nebular dust that condensed at relatively low temperatures, below the troilite condensation temperature. It is unclear whether troilite actually condensed in these objects, although textures are consistent with this possibility. The bulk compositions of AOIs are similar to the more volatile-rich ferroan (Type II) chondrules, and their textures resemble fine-grained variants of these objects, implying that AOIs could have been precursors to Type II chondrules. However, as most AOIs contain chondrule debris, including more magnesian grains and relict chondrules, many must have formed after earlier chondrule-forming episodes. Thus, the data are consistent with a recycling process, in which the products of chondrules were often mechanically and chemically recycled to begin another episode of chondrule formation [6-8]. The AOIs appear to reflect one aspect of this process. In particular, they appear to record evidence for accretion of chondritic and chondrule materials and for the incipient melting of these materials. As AOIs were not extensively melted, they better preserve evidence for the transformations that occurred during chondrule formation. Thus, their importance extends far beyond what one might expect based on their relatively low volumetric proportions.

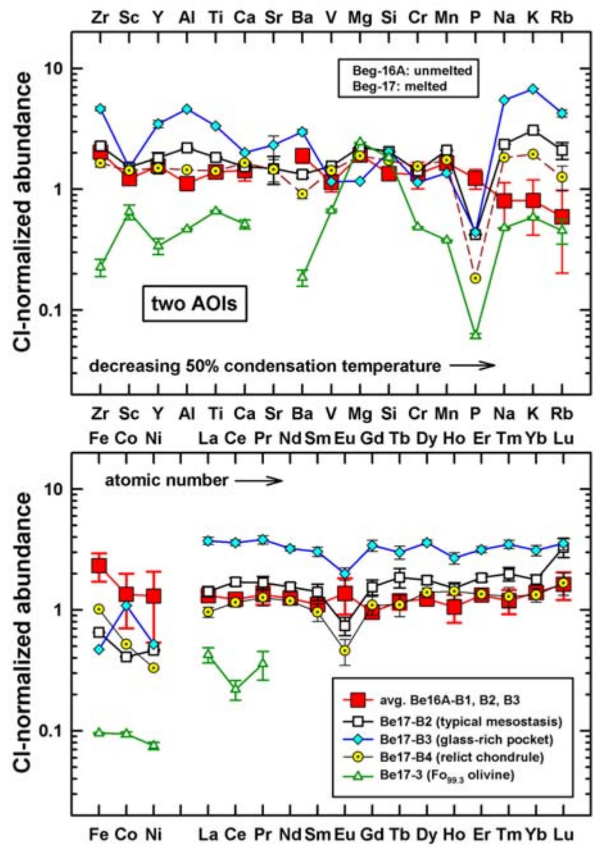


*Fig. 2. CI chondrite-normalized abundances for selected analyses in two AOIs, Beg-16A and Beg-17. Beg-16A and a typical mesostasis analysis for Beg-17 (Be17-B2) have relatively unfractionated compositions. A relict chondrule in Beg-17 (Be17-B4) has a similar composition, whereas a glass-rich pocket (Be17-B3) is enriched in incompatible elements, and relict forsterite (Be17-3) has a strongly fractionated-composition.*

**References:** [1] Weisberg M. and Prinz M. (1994) *LPS XXV*, 1481-1482. [2] Weisberg M. and Prinz M. (1996) In *Chondrules and the Protoplanetary Disk*, Ch. 13, pp. 119-127. [3] Hewins R.H. (1997) *Annu. Rev. Earth Planet. Sci.* **25**, 61-83. [4] Hewins R.H. et al. (1997) *Antarct. Meteorit. Res.* **10**, 275-298. [5] Wasson J.T. and Kallemeyn G.W. (1988) *Phil. Trans. Roy. Soc. London* **A325**, 535-544. [6] Jones R.H. et al. (2005) In *Chondrites & the Protoplanetary Disk*, pp. 251-285. [7] Ruzicka A. et al. (2008) *GCA* **72**, 5530-5557. [8] Ruzicka A. et al. (2007) *EPSL* **257**, 274-289.