AGGLOMERATIC OLIVINE (AO) OBJECTS: MELTING OF DUST TO CREATE TYPE II CHONDRULES. A. M. Ruzicka[1] and M. L. Hutson[1,2], [1]Cascadia Meteorite Laboratory, Portland State University, Department of Geology, 17 Cramer Hall, 1721 SW Broadway, Portland OR 97207-0751 (ruzickaa@pdx.edu), [2]Portland Community College, SYL ST 312, P.O. Box 19000, Portland OR 97280-0990 (mhutson@pcc.edu).

Introduction: Ordinary chondrites contain inclusions comprised primarily of fine-grained ferrous olivine [1, 2]. These inclusions have been termed agglomeratic chondrules [1-4] and have sizes similar to typical chondrules but differ in being finer-grained and displaying more evidence for accretion than melting [2, 3, 5]. Similar material of obvious accretional origin is also present partially or completely rimming typical chondrules and chondrule fragments [6]. Thus, we refer to this material as agglomeratic olivine objects (AO objects) [6]. AO objects and possibly related Type II chondrules were studied in three ordinary chondrites (NWA 4910 [LL3.1] "Beg", NWA 3127 [LL3.1] "NWA", Sahara 98175 [LL3.5] "Sah98").

Results: AO objects are rich in fine-grained (≤5-10 µm across) ferrous olivine (Fa_{12-35}) and troilite (Fig. 1a). The troilite fills spaces between silicates, and is often concentrated on object peripheries (Fig. 1c, 2a). In areas of high troilite content, the troilite forms an apparently continuous "network" between silicates. Although dominantly fine-grained, AO objects contain clumps of coarser material that are likely relict chondrules or microchondrules (Fig. 1a, 2b) as well as coarse magnesian olivine and pyroxene grains that are likely relict grains from Type 1 chondrules (Fig. 1c, 2a). A layered micro-CAI was also found in one AO object (Fig. 2a). Although bulk compositions are variable, that of an average AO object resembles ordinary chondrites, except for being enriched in Fe, Ni, and S [6]. Trace-element abundances of fine-grained areas are mainly similar to ordinary chondrites [6].

AO objects can be subdivided into three transitional stages: unmelted (AO-U), weakly melted (AO-WM), and melted (AO-M). AO-U objects are comprised mainly of anhedral olivine (≤5 µm across) and mostly lack feldspathic areas. AO-WM objects differ from AO-U objects by having anhedral-subhedral olivine grains with a substantial proportion of feldspathic domains that may contain glass (≤1-5 µm wide). AO-M objects are slightly coarser than AO-U and AO-WM (olivine grains ≤10 µm across) and show clear textural evidence for melting, with feldspathic glassy regions up to ~2-12 µm wide occurring interstitial to euhedral-subhedral olivine and low-Ca pyroxene grains. Troilite in AO-M objects tends to form more compact masses than the more distributed networks in AO-U objects. Additionally, AO-M objects contain drop-formed masses of metal and troilite consistent with melting.

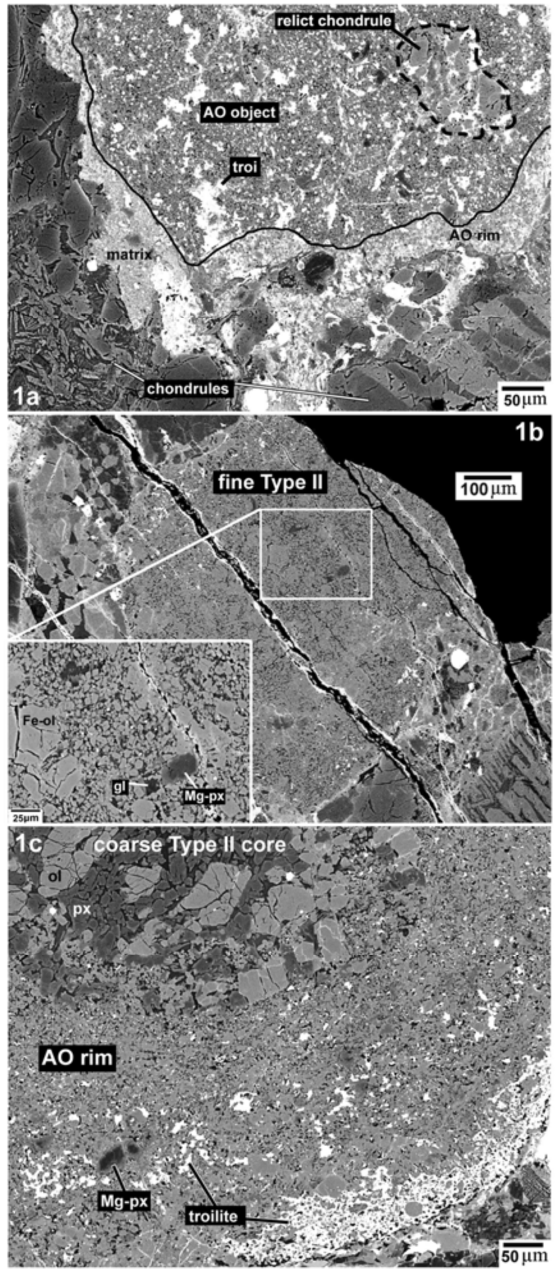

Fig.1a-c. BSE images of (1a) AO-WM object Beg-2, showing its fine-grained, ferrous olivine- and troilite (troi)-rich character, and textural contrast with chondrules and chondrite matrix; a relict chondrule is indicated by the dashed line; (1b) fine Type II chondrule Sah98-5 contains ferrous olivine (Fe-ol), some relict Mg-pyroxene (Mg-px) grains and glass (gl) pockets, and has much less troilite and better developed microporphyritic texture compared to AO objects; (1c) Sah98-13 consists of a coarse Type II chondrule core surrounded by a layered AO rim, with troilite concentrated on the rim edge and also forming a partial internal concentric band.

AO objects of all subtypes are present as partial to complete rims surrounding cores of Type II chondrules and coarse isolated grains (Fig. 1c, 2b, 2c). Although typically surrounding ferroan core objects, AO rims sometimes mantle magnesian cores, including Type I chondrules, transitional Type I-II chondrules, and individual forsterite grains. No examples were found of AO material surrounding core objects more ferroan than the rims. Contacts between the rims and core objects are relatively sharp in most cases.

Type II chondrules have microporphyritic textures and can be subdivided into fine Type II (olivine mostly <25 μm across) and coarse Type II (olivine 10-250 μm across) (Fig. 1b, 1c, 2b). All of the Type II chondrules studied contain significantly less troilite than AO objects and are depleted in S and Na [6], but otherwise resemble them in being dominated by ferroan olivine and containing relict magnesian olivine and low-Ca pyroxene grains (Fig. 1b, 2b).

Discussion: The properties of AO objects are interpreted to reflect progressive heating of dust of quasi-chondritic composition, accompanied by grain coarsening during melting (in the sequence AO-U, AO-WM-AO-M, fine Type II and coarse Type II), partial loss of the most volatile elements (chiefly S, also Na) during evaporative melting to form Type II chondrules, and back-reaction with gas, to form troilite-rimmed AO objects. AO object dust often accreted onto chondrules. Data-model comparisons suggest that progressive heating of dust to form AO objects and Type II chondrules could have occurred in a dusty environment to yield a transient, oxidizing gas of high pressure (~10^{-3} bar), with gas derived from vaporized dust being much (>500-1000x or even up to 10^4-10^5 x) more abundant than ambient solar composition gas. AO objects are protochondrules, but are themselves composed of chondrule debris (relict chondrules, relict grains) of different types (both magnesian and ferroan), suggesting that they represent one step of a chondrule recycling process that also included chondrule disaggregation and additional chemical processing. Our data appear to be compatible with the nebular shock wave model of chondrule formation. We suggest that shock waves traversing large dust clumps could have created both ferroan AO objects and Type II chondrules in clump interiors, whereas magnesian Type I chondrules could have formed on the perimeters of the clumps where conditions were more reducing, and heating effects were stronger.

References: [1] Weisberg M.K. and Prinz M. (1994) *LPS XXV,* 1481–1482. [2] Weisberg M.K. and Prinz M. (1996) In *Chondrules and the Protoplanetary Disk*, 119-127. [3] Van Schmus W.R. (1969) *Earth Sci. Rev., 56*, 405-421. [4] Connolly H.C., Jr. and Love S.G. (1998) *Science, 280*, 62-67. [5] Hewins R.H. et al. (1997) *Antarct. Met. Res., 10*, 275-298. [6] Ruzicka A. et al. (2011) *Geochim. Cosmochim. Acta*., in press..

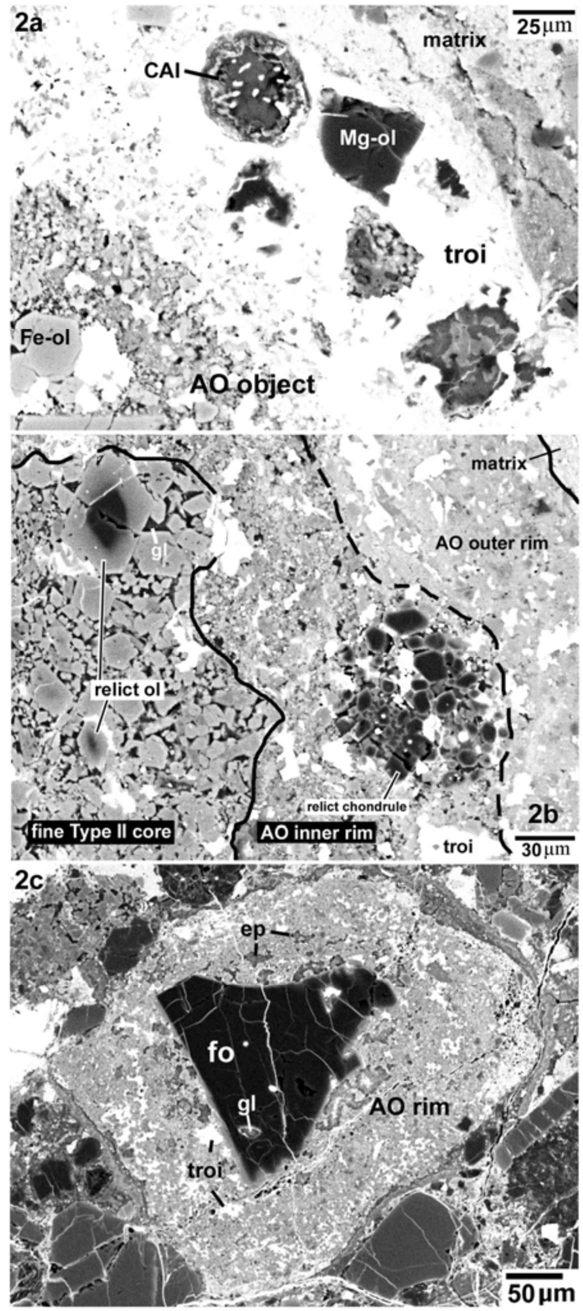

Fig. 2a-c. BSE images of (2a) AO-U object Beg-3, showing a micro-CAI, a magnesian olivine (Mg-ol) clast, and other fragments in a troilite-rich periphery; (2b) Beg-6 contains a fine Type II chondrule core surrounded by concentric AO-U rims of two types (coarser inner, finer outer); a relict chondrule is embedded in the inner rim; (2c) NWA-11C contains a fragment of coarse forsterite ('fo', $Fo_{99.3-99.4}$) grain with glass inclusions, surrounded by an AO-U rim; ep = epoxy.