Agglomeratic olivine (AO) objects: melting of dust to create Type II chondrules

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SUMMARY

AO objects in ordinary chondrites are composed primarily of fine-grained (≤5-10 µm-diameter) ferrous (Fa_{12-35}) olivine, and troilite that is often concentrated towards the peripheries of objects. These objects also contain pyroxene, feldspathic material, relict magnesian olivine and pyroxene grains, relict chondrules and rare micro-CAIs. They are present as both chondrule-sized inclusions and as rims around other objects (chondrules, isolated grains). AO objects compose ~2% of ordinary chondrites overall [1] and may be chondrule precursors [1, 2, 3].

We studied AO objects and possibly related chondrules in three LL chondrites (NWA 4910-- LL3.1; NWA 3127-- LL3.1; Sahara 98175-- LL3.5) using OLM, SEM, EMPA and SIMS methods to evaluate the origin of AO objects, their relationship to chondrules, and implications for the origin of chondrules.

We conclude that:

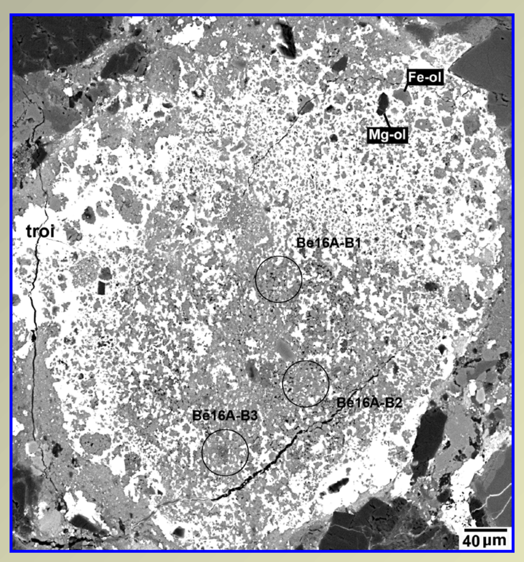
1) AO objects and Type II chondrules form a transitional sequence in texture and chemistry resulting from various degrees of thermal and chemical processing;
2) AO objects represent dust aggregates, which have quasi-chondritic composition on average, which were melted to produce Type II chondrules;
3) Both AO objects and Type II chondrules probably formed in similar locations within dense nebular dust clumps, in oxidizing environments generated by dust vaporization;
4) Both AO objects and chondrules formed as part of a recycling process that involved dust accretion, heating, evaporative melting, grain growth, mechanical disruption, and additional chemical processes including condensation, vaporization and reduction.

MODEL: DUST PROCESSING AND CHONDRULE FORMATION

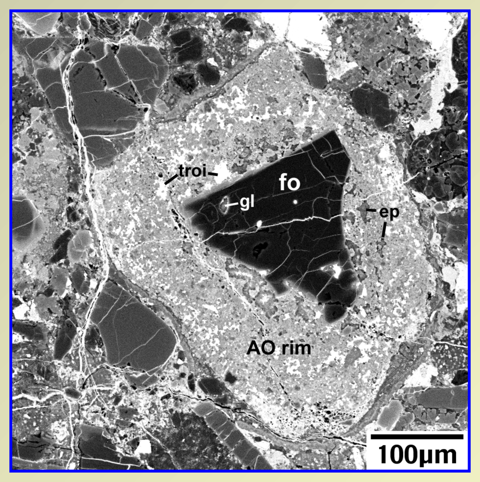
BSE images

AO-U: unmelted AO objects.

heating →



< AO-U inclusion contains mainly Fe-rich but also Mg-rich olivine in a network of troilite that increases in abundance towards the rim.

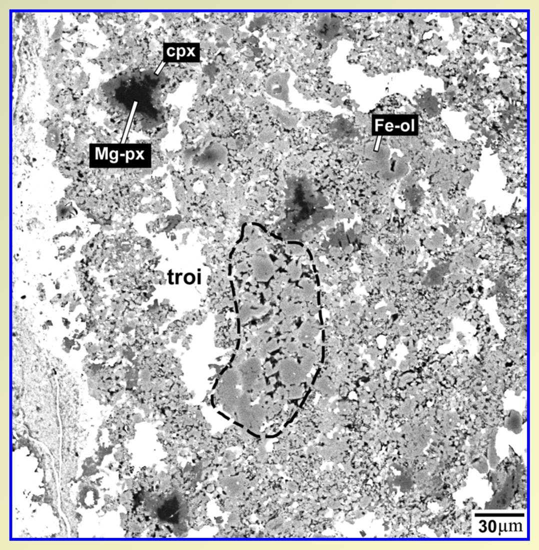


< AO-U rim surrounds a clast of coarse forsterite that contains glass inclusions, likely chondrule debris.

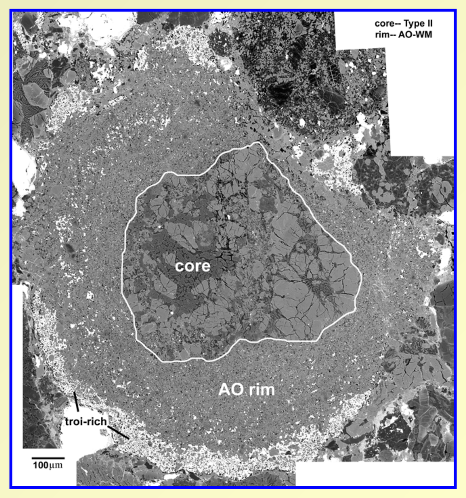
AO-U: Fine olivine (≤5 µm across) is anhedral; mostly lacks feldspathic (possibly glassy) areas.

AO-WM: weakly melted AO objects.

heating →



< AO-WM inclusion contains relict chondrule (dashed) & relict Mg-pyroxene surrounded by high-Ca pyroxene (cpx) coronas.

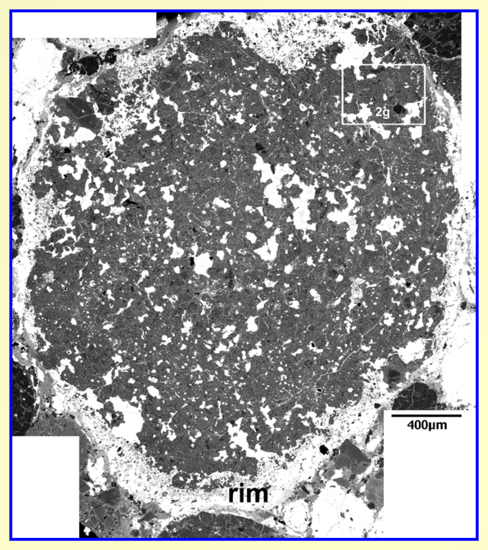


< AO-WM rim surrounds a coarse Type II chondrule core; troilite is concentrated at rim edge & in concentric bands.

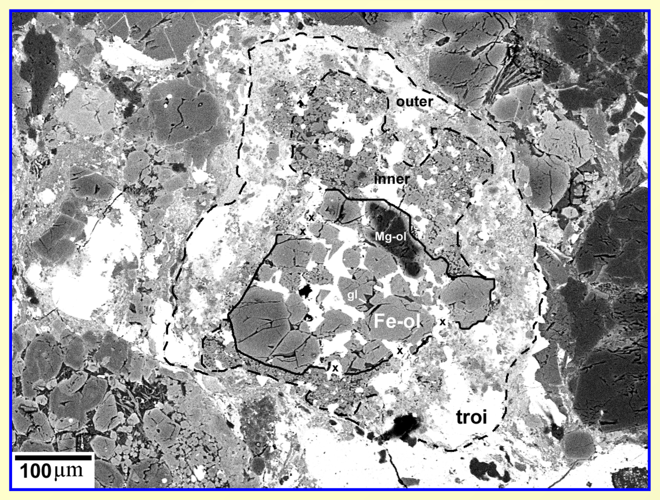
AO-WM: Fine olivine (≤5 µm across) is anhedral-subhedral; feldspathic patches (≤1-3 µm across) are common.

AO-M: melted AO objects.

heating →



< AO-M inclusion contains troilite & metal distributed throughout interior in globular masses & a troilite-rich rim.

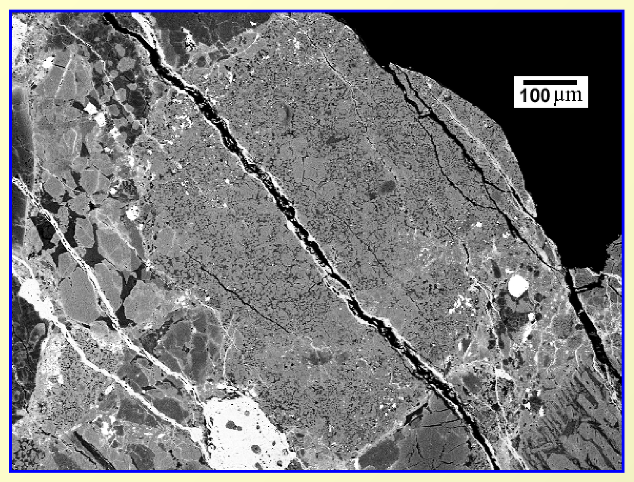


< AO-M inner rim & AO-U outer rim surrounds a small coarse Type II chondrule, whose mesostasis is largely replaced by troilite.

AO-M: Fine olivine (≤10 µm across) is subhedral-anhedral; glassy feldspathic patches (~2-12 µm across) are present.

Fine Type II chondrule.

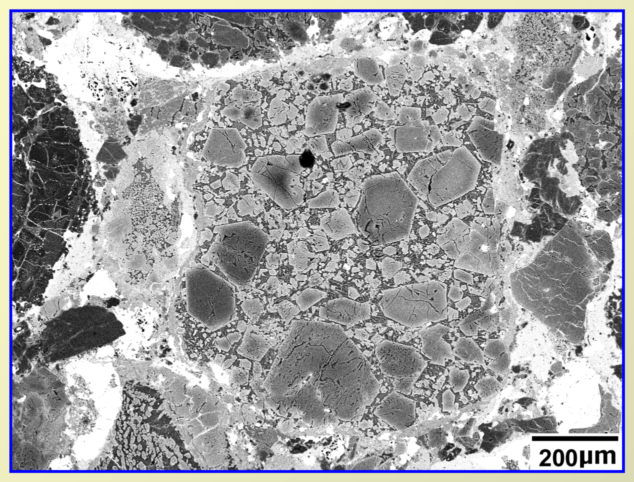
heating →



Fine Type II chondrule, microporphyritic texture, dominated by ferroan olivine.

Fine Type II: Euhedral-subhedral olivine grains (Fa_{12-38}, mainly ≤25 µm across) & glassy areas ≤2-15 µm across.

Coarse Type II chondrule.



Coarse Type II chondrule, microporphyritic texture, dominated by ferroan olivine but coarser grains are zoned.

Coarse Type II: Euhedral-subhedral olivine grains (mainly $Fa_{>10}$, up to 250 µm across) & glassy areas up to 50 µm across.

More melting, form chondrules

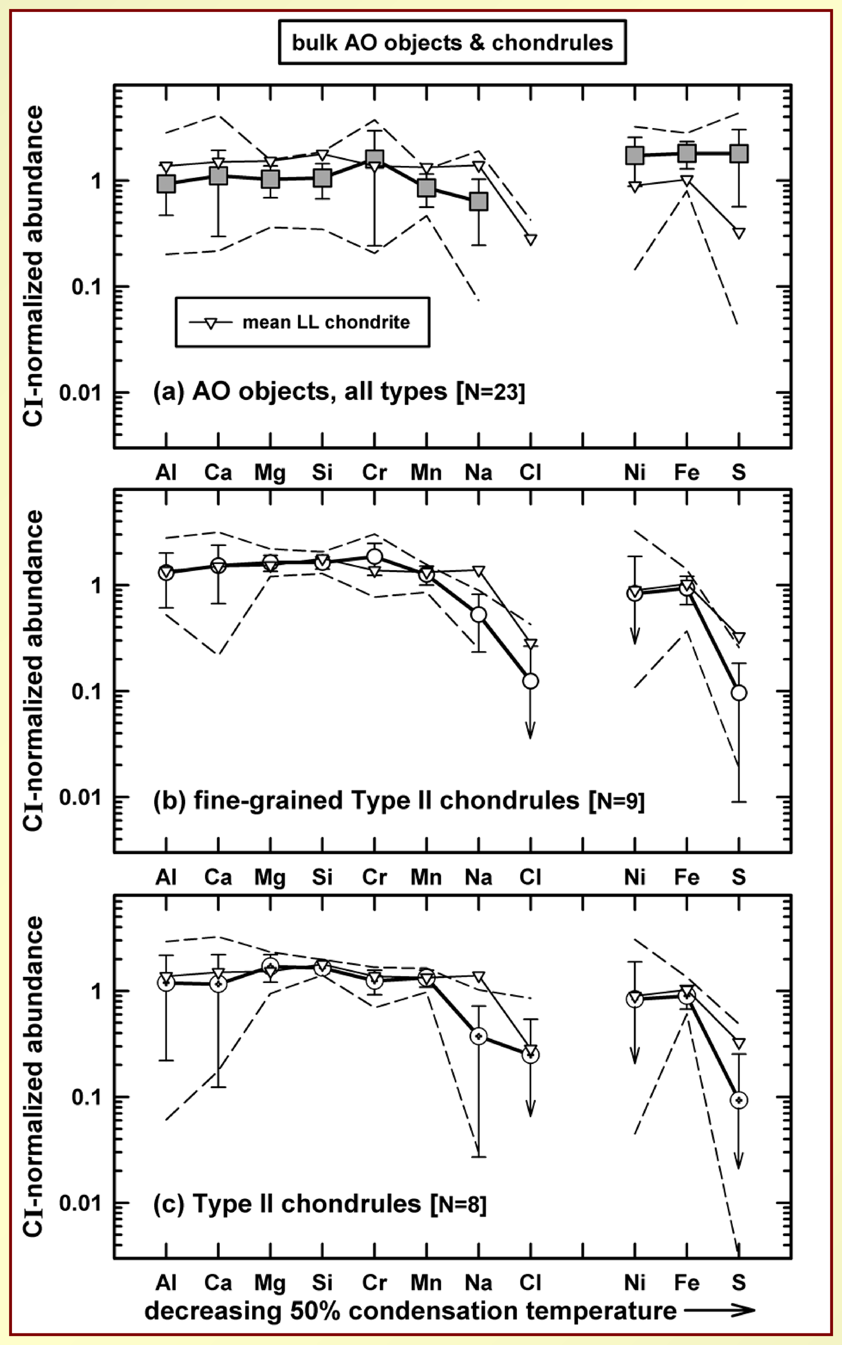
Evaporative melting drives S and Na into gas; some S condenses into AO objects

Incipient melting of dust aggregates, form AO objects

Evaporative melting drives S into gas, which recondenses on AO objects to form troilite-rich edges

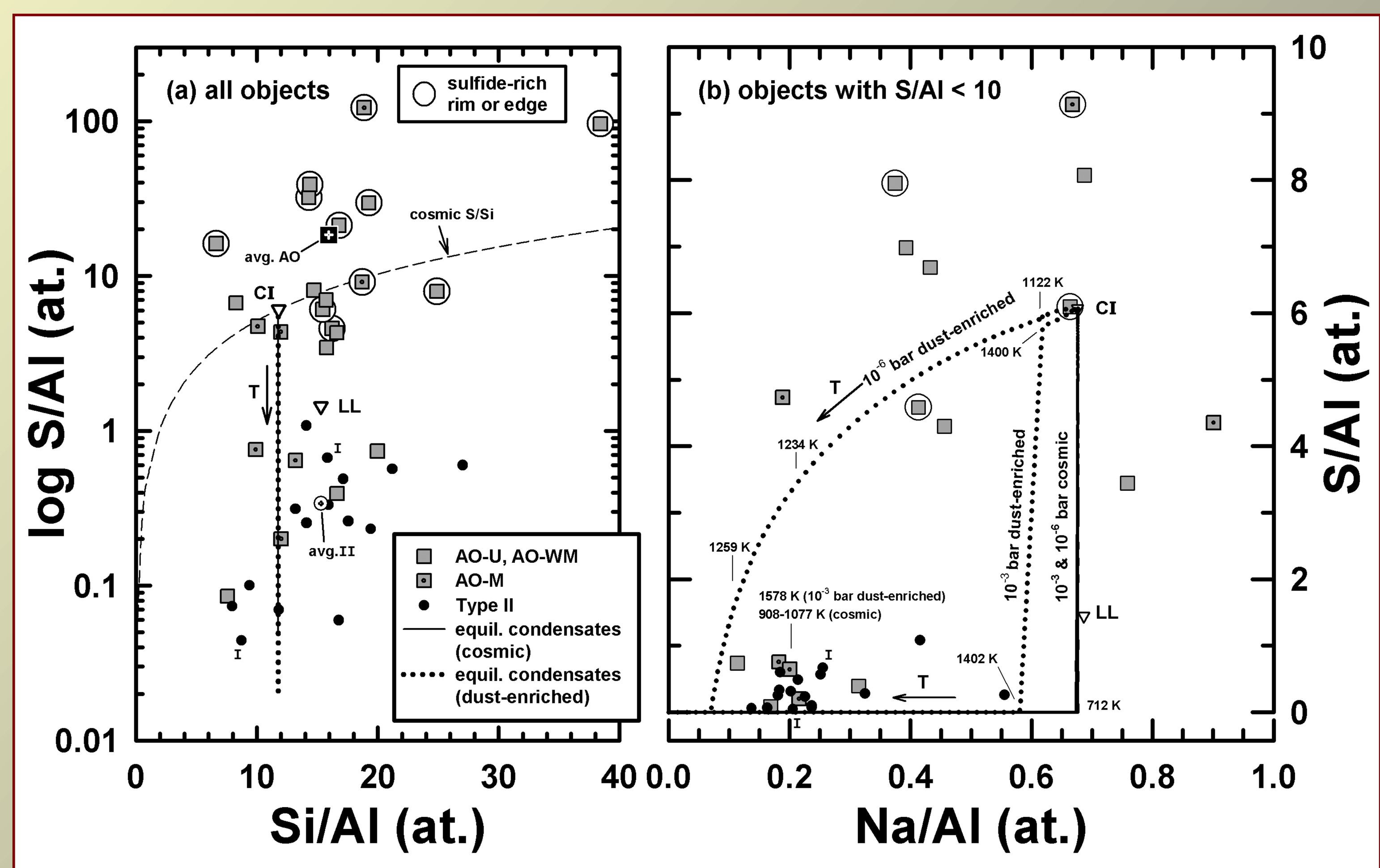
Mechanical disruption of chondrules, both Type I & II

Dust accretion, includes chondrule debris



< CI-chondrite-normalized abundances for (a) AO objects, (b) fine Type II chondrules, & (c) coarse Type II chondrules, based on defocused beam EMPA data. Dashed lines show ranges, points means, bars standard deviations. On average, AO objects have quasi-chondritic compositions with enrichments in S, Fe, and Ni; Type II chondrules are depleted in S and Na.

> Bulk compositions of AO objects & Type II chondrules compared to equilibrium condensates in systems with overall cosmic (D/G = 1) & dust-enriched (D/G = 10^4) compositions (using the CWPI code developed and made available by Mikhail Petaev). (a) all objects, (b) objects with S/Al < 10. T shows trend of increasing temperature. The compositions & textures of Type II chondrules imply high gas pressures (~10^{-3} bar), highly oxidizing gas (D/G >500-1000, possibly up to 10^4 - 10^5), and T of ~1410-1690 K.



References: [1] Weisberg M. & M. Prinz (1996). In *Chondrules and the Protoplanetary Disk* (eds. R. Hewins, R. Jones, E. Scott), pp. 119-127. [2] Hewins R.H. (1997) *Annu. Review Earth Planet. Sci.* **25**, 61-83. [3] Hewins R.H., Y. Yu, B. Zanda & M. Bourot-Denise (1997) *Antarct. Meteorite Res.* **10**, 275-298.

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