DARK MANTLES AROUND CM CHONDRULES ARE NOT ACCRETIONARY RIMS. John T. Wasson, Josep M. Trigo-Rodriguez and Alan E. Rubin, Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA 90095-1567, USA.

Petrographic relationships between fine-grained materials and chondrules--Metzler et al. [1] described fine-grained serpentine- and tochilinite-rich dark mantles surrounding chondrules and other entities in CM chondrites. They interpreted these mantles to have formed by the accretion of dust onto individual chondrules, inclusions and mineral grains in the solar nebula. However, the dark mantles have properties inconsistent with a nebular origin, including porosities much lower than those that could have been produced by nebular mechanical processes (i.e., processes that did not involve melting).

We therefore instituted a petrographic study of thin sections of several CM chondrites that display a wide range in the degree of aqueous alteration: Murchison, QUE 93005, QUE 97990, QUE 99355 and Yamato 791198 (Y-791198). We prepared a detailed mosaic back-scattered electron (BSE) image of each thin section using the LEO 1430 scanning electron microscope at UCLA; we also used the JEOL electron microprobe at UCLA to identify and characterize phases. In this abstract we will discuss Y-791198, which Metzler et al. described as a "primary accretionary rock."

There are numerous petrographic features that appear inconsistent with the Metzler et al. model. These include cases (a) where the dark material mantles more than one object, (b) where dark materials mantle no sizable object, and (c) where mantling materials are highly asymmetric. We suggest instead that the low porosities and the structures of the dark mantles are the result of impact compaction on the parent asteroid.

In CM chondrites, aqueous alteration has converted different amounts of metallic Fe-Ni, primary sulfide phases and mafic silicates to the secondary FeO-rich phases tochilinite, cronstedite and montmorillonite [2] that can be grouped together as PCP (poorly characterized phases). A large fraction of these secondary phases has been deposited in voids causing these sites to appear bright on BSE images. As a result, brightness variations can provide petrographic details about the history of CM regoliths.

Absence of compaction processes in the solar nebula—Modeling [3] and laboratory simulations [4,5] of grain coagulation in the solar nebula show that slow-moving (1-10-m/s) micrometer-size grains stick to surfaces at the point where they first touch. Fragmentation of these small assemblages occurs at velocities ≥10 m/s [4]. The first generation of structures have enormous porosities, on the order of 90% [5]. Two-dimensional modeling shows that collisions between loose assemblages of fines yield some compaction [3], but porosities still remain high, >50% [5], even when such assemblages are compressed under static pressures up to 10^6 Pa. Thus, there is no basis for expecting low-porosity structures to form in the solar nebula.

The Metzler et al. [1] model--Figure 1 is a modified version of a sketch showing the Metzler et al. [1] picture of the process that created the mantled objects in the nebula and how the mantled objects accreted into "primary accretionary" CM rocks. Metzler et al. proposed that the compaction of the dark mantles occurred in the solar nebula and that these nebular objects then became tightly packed in the asteroid forming "primary accretionary rocks." Subsequent crushing and fragmentation of these materials on the CM asteroid produced the more common, brecciated members of the CM group, but with fragments of the "primary accretionary rocks" still recognizable in most CM chondrites.

Petrographic studies—The five CM chondrites in our set span the range from moderately (QUE 97990) to extremely (QUE 93005) aqueously altered. Y-791198 exhibits an intermediate degree of aqueous alteration. All five CM chondrites are brecciated and show evidence of shear.

Figure 2a shows an example of the mantled structures in Y-791198 discussed by Metzler et al. It consists of a severely altered refractory inclusion with a somewhat asymmetric dark mantle. The interior of the mantle has a fine, matte texture; the exterior regions have white flecks of PCP. But, in contrast to the Metzler et al. sketch (Fig. 1), there is no sharp outer border. Instead, the outer parts of the dark mantle are adjacent to PCP-rich clasts and small chondrule fragments.

There are two very different assemblages in Fig. 2b of Y-791198. In the upper portion there is an irregular fragment of a low-FeO mafic chondrule containing an ellipsoidal patch of sulfide. The dark mantle around the chondrule fragment is relatively symmetric. Again, the inner part of the mantle is finer grained and matte; the outer part is darker except where speckled with PCP. As in the last example, there is no sharp outer mantle border, and just to the right of a hole (black patch) at the bottom of the mantle is an embedded clast that seems unrelated to the main chondrule fragment. Scanning right to left across the bottom of Fig. 2b, we see fine, dark material (outlined by brighter PCP-rich material) that passes around an angular fragment and continues across the image without enveloping any other object larger than 10 μm.

The impression that one gets from Fig. 2c is of flow. On the bottom right a highly altered, shattered, low-FeO chondrule that is largely surrounded by an irregular dark mantle. At the upper left, a high-FeO porphyritic olivine chondrule containing low-FeO olivine relict grains seems to have fragmented; an irregularly thick mantle passes near the base, but the lower border is mainly determined by a parallel "flow" of PCP. Near the center, a fragment of a low-FeO olivine chondrule has almost no associated mantle, but to its left, an angular mass of fine material has no included object.

These samples pose numerous problems for the Metzler et al. [1] picture of mantle formation and accretion around individual chondrules and inclusions. We propose the following model that seems consistent with our understanding of mechanical processes occurring during agglomeration and accretion.

A model for the formation of the structures formed by fine materials in the CM chondrites—Chondrules and nebular fines are closely related. The high temperatures that melted chondrules resulted in the evaporation of fines in the heated region, with immediate recondensation when the heat dissipated. Because chondrules record multiple melting events, both chondrules and fines are transient objects until agglomeration occurs.

As discussed above, theoretical and laboratory studies [3-5] show that fine materials can stick together in the nebula to form low-porosity structures. When turbulence levels fell and the solid/gas ratio increased in the midplane, chondrules became loosely trapped in the porous structures formed from fines.

Planetesimals and eventually asteroids formed. Impacts on asteroid-size bodies led to compaction. Some portion of the compacted material formed rocks tough enough to survive and eventually fall as meteorites. Fine materials adjacent to the incompressible chondrules and refractory inclusions experienced greater degrees of compaction.

Because the compact mantles have lower abundances of PCP than interchondrule matrix regions, we infer that the initial compaction occurred before the onset of extensive aqueous alteration. After (or during) the compaction, fragmentation occurred. Because of their strength, most chondrules survived. In part because they were more compact, and in part because they were protected by the chondrules, fine materials adjacent to chondrules tended to remain intact. Some rounding of the chondrule mantle assemblages may have been produced by rolling in the regolith. The porosity of the interchondrule material was much higher than that of the mantling materials.

Episodes of aqueous alteration produced PCP that filled voids in the interchondrule matrix. This process completed the formation of the "primary accretionary rocks" discussed by Metzler et al. [1]. Additional impact brecciation occurred, producing the more common CM structures. In some cases, these occurred in a regolith setting, and the small grains in the regolith were irradiated by the solar wind and solar-flare protons producing track-rich [6] and gas-rich CM materials [7].

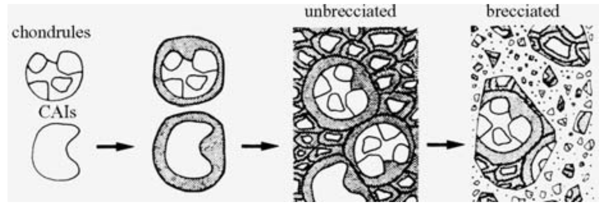

Fig. 1. Modified cartoon from Metzler et al. [1] showing the formation of dark mantles and "primary accretionary rocks" as envisioned by these authors. Note that the compaction of the mantles occurred in the nebula, and that the chondrule/mantle structures were not appreciably altered during the formation of the parent asteroid.

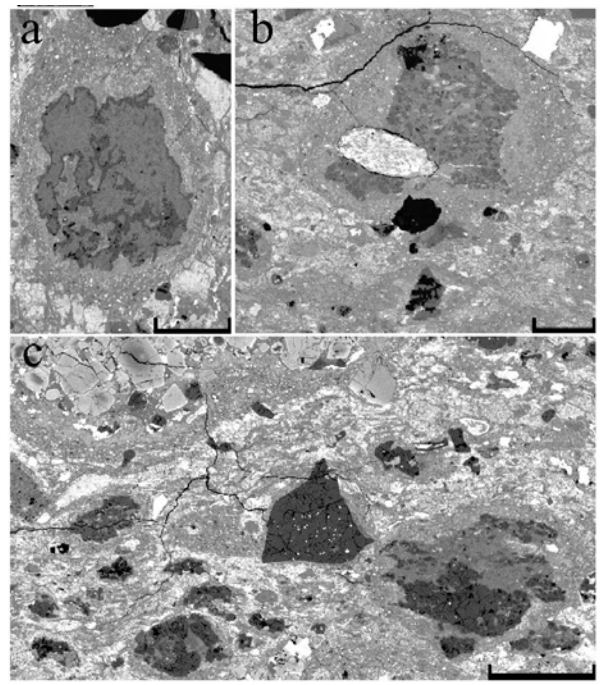

Fig. 2. Fine dark materials in Yamato 791198. a) An inclusion is surrounded by an inner fine-grained mantle and an outer mantle speckled with PCP. The mantle border appears sharp only where it is fixed by the presence of a clast. b) Two different structures are shown. The upper is a low-FeO chondrule fragment surrounded by a relatively symmetric mantle having diffuse borders, especially on the left, and an embedded clast just right of the dark hole. Across the bottom of the image, irregularly wide dark material stretches from side to side, passing around an angular clast but otherwise enclosing no object larger than 10 μm. c) The structures in this region seem to be dominated by flow (or possibly compression). The dark clast in the middle has no mantle; a dark-mantle region to its left encloses no coarse objects. At the upper left, dark mantle material seems to be flowing next to a fragmental high-FeO porphyritic olivine chondrule; the lower border of the fine-grained flow is fixed by a parallel PCP flow. Even the reasonably symmetric structure in the lower right merges with the adjacent matrix on the lower left.

References:

[1] Metzler K., Bischoff A. and Stöffler D. (1992) *Geochim. Cosmochim. Acta* 56, 2873-2897. [2] Zolensky M. and McSween H.Y. (1988) In *Meteorites and the Early Solar System* (ed. J.F. Kerridge and M.S. Matthews), pp. 114-143, Univ. Arizona Press. [3] Dominik C. and Tielens A.G.G.M. (1997) *Astrophys. J.* **480**, 647-673. [4] Blum J. and Wurm G. (2000) *Icarus* **143**, 138-146. [5] Blum J. and Schräpler R. (2004) *Phys. Rev. Lett.* **93**, 115503-1-115503-4. [6] MacDougall J.D. and Phinney D. (1977) *Proc. Lunar Planet. Sci. Conf.* **8th**, 293-311. [7] Metzler K. (2004) *Meteorit. Planet. Sci.* **39**, 1307-1319.