ORIGIN OF CHONDRULES BY DROPLET COALESCENCE: AN ALTERNATIVE TO THE DUST-BALL HYPOTHESIS. William R. Skinner, Department of Geology, Oberlin College, Oberlin, OH 44074

Chondrules are small (ca. 1 mm), primitive objects found in chondritic meteorites. They may be broadly classified into two categories: approximately spherical "drop-type" chondrules and irregularly shaped, angular "clast-type" chondrules which appear to be fragments of larger objects (1). Both types are generally regarded as being of igneous origin, and most have igneous textures, e.g., porphyritic olivine, radial pyroxene, etc.; the least altered ones retain a glassy mesostasis.

Experimental duplication of these textures and the compositional zoning found in phenocrysts suggest that cooling rates were in the range 100 to 2000 K per hour (2). This, together with the observation that chondrules in relatively unmetamorphosed chondrites are coated with layers of dust (3) and imbedded in interchondrular matrix of similar low temperature origin (4), has seemed to support a general view that transient heating events in the solar nebula produced chondrules by fusing precursor "dust-balls" of chondrule mass (5). An alternative to a transient heating event is passage of chondrule precursor material through a hot region in the nebula (6,7). In either case, partly fused dust-balls should have been included in the material that accreted to form meteorite parent bodies if dust-balls were the precursors. No such objects have been reported, but an alternative to this origin for chondrules is suggested by other textures in chondrites.

Compound chondrules, i.e., two or more chondrules that are stuck together, have been reported by many observers (8,9) who note that these objects usually consist of partners with similar textures. Compound chondrules in chondrites of petrologic type 3 share a dust-rim coating that does not occur along the interface between partners, i.e., the dusty rims were acquired after the sticking event. Some partners are of similar size, some are of quite different sizes, and the smaller one generally molds against the larger one (10), suggesting that the smaller object was still liquid when it adhered to the larger, already solidified chondrule. Such relationships are difficult to explain if the heating event was a single, transient phenomenon. Transit through a heated region of the nebula may be more accommodating of such textures, especially if supercooling of small droplets occurs as is observed in terrestrial rainclouds (11). Other chondrules display rims of agglomerated droplets acquired prior to coating by dust rims, suggesting that chondrule formation took place in a region of the nebula populated by small droplets. Thus there is textural evidence that chondrule formation could have occurred by coalescence of droplets, but evidence for this process would not survive if the droplets were sufficiently fluid. This has been pointed out in a paper that convincingly proposes that droplet capture and coalescence contributed to formation of type B CAIs (12). Although evidence for coalescence is scarce in chondrule textures, it is far more abundant than evidence that chondrules formed by melting of dust-balls having chondrule mass.

If chondrules formed by droplet coalescence and agglomeration, what was the origin of these droplets? They may have been formed by condensation (if local nebular pressures were sufficiently high) or by melting of dust grains or small dust aggregates to yield partially or completely melted droplets. Complete melting, partial melting, vaporization, and condensation may all have played a role before and during coalescence, and with differing intensities in different regions and at different times. One problem in understanding growth of nebular materials to chondrule size is "solved" by droplet coalescence, because the "sticking factor" is very high for liquids, and coalescence would proceed rapidly once a few larger droplets formed and began sweeping up smaller ones as they "fell" through the nebula (or otherwise moved at a velocity different from smaller droplets). This process is fairly well understood in meteorology and accounts for the rapid growth of raindrops in terrestrial rainclouds (11).

The variety of chondrule textures and compositions observed in individual chondrites might result from incomplete vaporization and/or condensation of nebular dust if this varied in degree with position in the chondrule-forming region. Subsequent transport to low-temperature regions where chondrules from various sources accumulated with local dust into parent bodies might explain the variety of chondrules seen within individual chondrites. The terrestrial analogy is the mixing of sand grains derived from several sources into one depositional basin. Such sand grains may display a variety of compositions reflecting the complexity of sources; they also display a size-sorting produced by the transportation/deposition history. Chondrules within individual chondrites also have restricted size ranges (10) which may reflect transportation/deposition histories in the solar nebula.

Certainly, formation of a majority of chondrules by coalescence is not proven by these observations. My argument is that this mechanism should be seriously considered as an alternative to the hypothesis that chondrules formed by melting of solid aggregates having chondrule mass. For example, coalescence of partly crystallized droplets with different bulk compositions could contribute to an unequilibrated assemblage of phenocrysts in porphyritic chondrules. Detailed analyses of phenocrysts in unequilibrated chondrites would help to evaluate this hypothesis.

Barred olivine chondrules with coarse rims of olivine in optical continuity with the barred core may also have formed in an environment populated with small droplets. Analogous clear ice rims on some terrestrial hailstones are thought to be formed as droplets of supercooled water are captured and wet the surface of the hailstone, the heat of crystallization helping to maintain a fluid state in the coating during the wetting event (11). Barred olivine "chondrules" with rims have been produced in the laboratory by fusing dust to a crystallized core, but such rims do not have the magnesian compositions observed in natural barred olivine rims (13). Obviously, it is important to know which (if either!) mechanism was operative in nature because there are very different implications for the environment of formation in the nebula.

There is probably much in terrestrial meteorology and general atmospheric physics that may offer new approaches to problems in meteoritics.

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