

COLLOIDAL DISPERSIONS IN THE EARLY SOLAR SYSTEM. K. M. Cannon¹ and D. T. Britt¹,
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Introduction: Carbonaceous chondrite parent bodies accreted with sufficient ice and ²⁶Al-laden dust to undergo significant aqueous alteration [1]. Typically, this alteration has been modeled as water flowing through a fixed (i.e., lithified) silicate matrix in either an open [2] or closed [3] system. However, Bland et al. [4] recently challenged the canonical model, finding no reason to assume these bodies were well lithified, and instead suggested they evolved to form “giant convecting mud balls”. The authors describe the mud as a mixture of fines and water [4]. Matrix grain sizes are commonly ~100-1000 nm in the most primitive carbonaceous chondrites [5], which matches telescopic observations of interstellar dust [e.g., 6]. Therefore, when dispersed in water the resulting materials would actually be colloidal dispersions rather than suspensions that usually characterize terrestrial muds (Fig. 1).

Colloids have many unique properties compared to suspensions and solutions, particularly in terms of electrokinetic interactions between particles (moderated by surfactants) and in terms of their rheology. Extremely high surface area to volume ratios would also enhance both alteration rates, and catalytic potential with respect to organic molecules. These features of colloidal dispersions may have significantly influenced the early evolution of chondritic parent bodies. To our knowledge, no previous efforts have applied concepts from the field of colloid science to understanding planetary processes, nor attempted to re-create such materials. Here, we describe a formation scenario for colloidal dispersions, and lay out an experimental plan to study these materials.

Formation of planetary colloidal dispersions:

Fig. 2 illustrates a schematic model for how colloidal dispersions could form. Initially, fluffy aggregates of silicates (here, taken to include metals/sulfides/oxides),

ices and organics accrete, probably in the vicinity of the (migrating?) snowline ~2-4 Ma after CAIs [7-9]. Volumetric heating from mostly ²⁶Al causes water ice to melt, wetting the surfaces of the weakly bound silicate grains and allowing them to disperse. The colloidal dispersion may stabilize or flocculate depending on the electrokinetic potentials of the various grains and the influence of external forces including gravity and convective motions. Rapid aqueous alteration of mafic silicates may change the dispersion characteristics due to the unique surface/edge charges on phyllosilicate grains. Organic molecules and gases released by serpentinization may also influence the colloid behavior.

Because carbonaceous parent bodies are likely formed with subequal amounts of water and rock, any colloidal dispersions would have been highly concentrated; their physical properties would depend on the specific water:rock (W:R) ratio of accreted material. Initial W:R ratios have been estimated for various chondrite groups using oxygen isotopes [9] and disk condensation models [10]. These give W:R estimates of 1.2 for CI chondrites, ~0.4 for CMs, 0.1-0.4 for CRs, 0.1-0.2 for CVs, and 0.01-0.1 for COs. We converted these values into a volume fraction of solid grains ϕ in the dispersion assuming a density of 1.0 g/cm³ for water and 3.5 g/cm³ for silicates. This results in $\phi=0.19$ for CIs, 0.42 for CMs, 0.42-0.74 for CRs, 0.59-0.74 for CVs, and 0.74 to 0.97 for COs. Thus, in terms of physical properties, colloidal dispersions in CIs should have behaved as mostly Newtonian fluids, while those in CMs and more hydrated CRs should have behaved as pseudoplastic gels [11]. CV and CO materials probably exceeded the solid volume fraction limit for flow, and may not have had enough water to saturate pore spaces between solid grains.

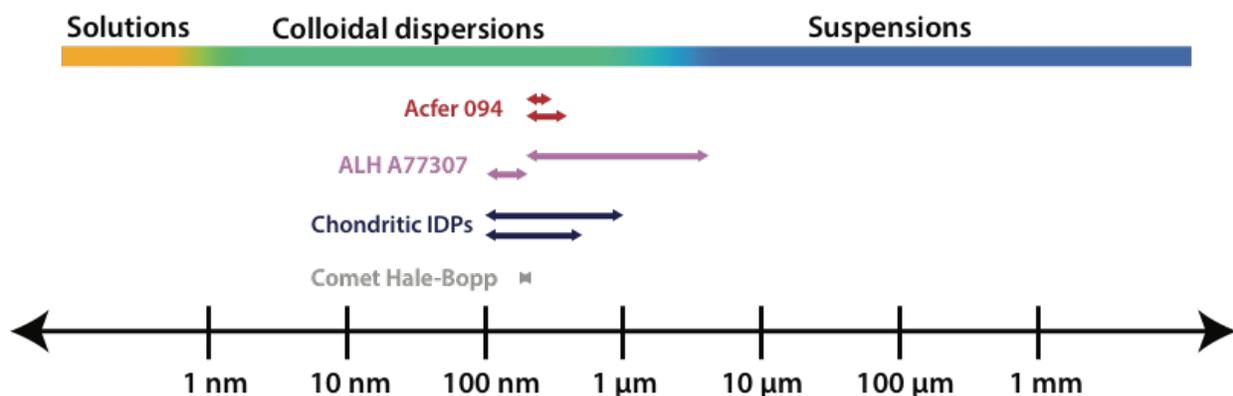


Figure 1. Grain sizes of matrix silicates in primitive chondrites, chondritic IDPs, and comet Hale-Bopp. Data from [5].

Experimental plan: We are beginning a series of experiments to study (1) the conditions under which colloidal dispersions could form upon heating of primordial chondritic material, (2) the physical nature of these dispersions, and (3) their mineralogical evolution during aqueous alteration.

The first step is to grind relevant materials to sub-micron particle sizes. We are using a Retsch PM100 planetary ball mill with a ZrO_2 grinding jar and media to achieve grain diameters in the 100-1000 nm range. The materials include forsteritic olivine and enstatite to begin, with plans to evaluate amorphous silicates, metals and sulfides in the future.

Melting and wetting experiments. A key question is whether stable colloidal dispersions would naturally form in chondritic parent bodies upon heating. Fine-grained ice particles will be prepared by spraying finely dispersed water into LN₂. When physically mixed with the ground silicates, the silicate-ice mixtures can be warmed to re-create natural chondritic melting, albeit on a condensed timescale. Using WETSEM® capsules on an SEM, we hope to image this process in real time, including grain interactions.

Basic physical properties. Mixing the ground silicates with water in specific W:R ratios will allow us to measure the physical nature, stability, and temperature-dependent viscosity of relevant colloidal dispersions. Including a population of larger grains to represent chondrules will provide more realistic scenarios like those modeled by [4].

Water-rock reactions. We will heat the olivine and pyroxene dispersions to modest (<150 °C) temperatures to study the rate and nature of aqueous alteration of colloid-sized grains. Of particular interest is any changes in physical properties and stability due to the formation of serpentine/smectite.

Organics. Parent body processing of organic molecules during melting and aqueous alteration is poorly understood. We plan to study this process experimentally by adding both simple and complex organic molecules in a separate set of melting and alteration experiments, and evaluating breakdown and/or polymerization products formed.

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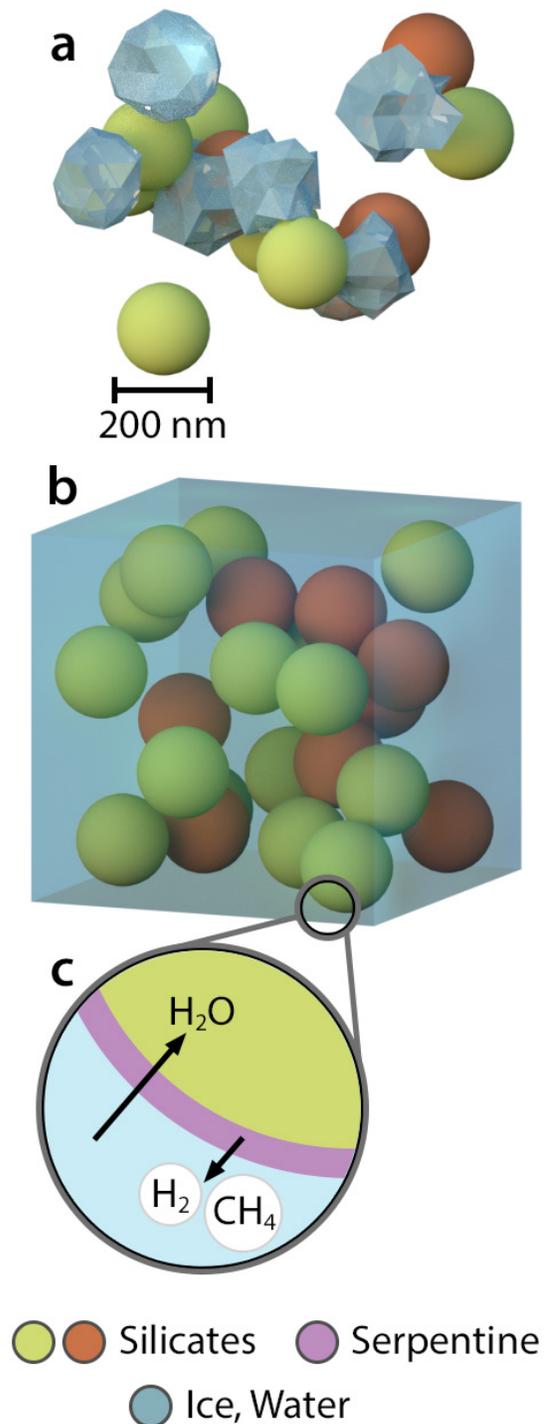


Figure 2. Schematic model of colloid formation. a) Fluffy aggregates of icy and rocky grains accrete in the solar nebula. b) After the ice melts, a condensed colloidal dispersion forms, as shown to scale for a solid volume fraction of 0.19 appropriate for CI-chondrites. c) Inset shows alteration of an olivine grain to serpentine, with concomitant gas release.