MORE MUDBALLS: SIMULATING PRIMORDIAL PLANETESIMALS AS UNCONSOLIDATED MIXTURES OF MUD AND CHONDRULES.

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Introduction: Models of the hydrothermal evolution of primitive asteroids typically posit open- or closed-systems with respect to fluid flow. Well-supported model constraints, data, and observations, are not converging on one scenario. The initial state for these models involves anhydrous coherent rock reacting with water. We tested the effect of removing that assumption. There is no *a priori* reason why nebular fines, ice, and chondrules would be lithified before aqueous alteration. If primordial asteroids began as unlithified aggregates, then on melting, chondrules would become a suspended load in a viscous mud, and concepts of open or closed-system alteration would no longer apply.

Model: We explore this concept with the MAGHNUM numerical simulator, previously used to model thermal evolution of CC parent bodies [1-3]. New features include particle transport using Stokes settling, minimum porosity from packing models, and mud viscosity. We vary chondrule packing density, mud:chondrule ratio, W/R ratio, asteroid radii, and accretion time, and mixtures of different chondrule sizes.

Results and Discussion: In our initial study [4] we showed that, on melting, chondrules settle rapidly to form a chondrule-rich core, and mud ocean mantle. Convection moderates internal temperature. These results have implications for meteorite chemistry (as the system is thoroughly mixed, alteration is necessarily isochemical), and oxygen isotopes (heterogeneity in secondary phases over short lengthscales (e.g. in carbonate [5,6]) is expected, as grains forming at different times and temperatures are brought together only at the end of convection).

In this expanded study we see that convection is not restricted to the mud mantle, but extends into the core. Plumes in the mud ocean are driven partly by plumes in the core that exit to the ocean bottom, as well as cold downwellings dropping off the ice shell. Large scale convection not only moderates internal temperature, it reduces variation in temperature throughout the interior. Exploring the effects of varying a number of input parameters we see that higher W/R ratios and later accretion times both result in a thicker ice shell, lower peak T, and reduced convection. In cases where convection is relatively strong we observe effective size sorting of chondrules fractions: coarse particles settle rapidly and dominate the inner core; fine particles the outer core.

We also designed simulations to target specific cases. A Ceres-like scenario with accretion at 2Myr after CAI produces an ice crust, mud mantle, and rocky chondrule-rich core. Peak T is ~200C. Convection is dominated by equatorial plumes with downwelling at the poles. In a CV-like scenario accreting at 3Myr after CAI, with W/R of 0.1, we see peak T similar to Allende, and circulation throughout the object. The model asteroid is not an onion shell: high T plumes extend close to the surface.

References: [1] Travis B.J. and Schubert G. 2005. *EPSL* 240: 234-250. [2] Palguta J. et al. 2010. *EPSL* 296: 235-243. [3] Travis B.J. et al. 2012. *Icarus* 218: 1006-1019. [4] Bland P.A. and Travis B.J. 2013. Abstract #1447. 44th LPSC. [5] Young E.D. et al. 1999. *Science* 286: 1331-1335. [6] Jenniskens P. et al. 2012. *Science* 338: 1583-1587.