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Chondrites as samples of differentiated planetesimals

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Chondritic meteorites are unmelted, variably metamorphosed samples of the earliest solids of the solar system. A recent paleomagnetic study of CV chondrites suggests that their parent body was internally differentiated and produced a core magnetic dynamo (Carporzen et al., submitted, and this session). Here we show that a parent body that accreted to >250 km in radius by ∼1.7 Ma after the formation of CAIs could retain a solid undifferentiated crust overlying a differentiated interior, and would be consistent with formational and evolutionary constraints on the CV parent body. Further, this body could have produced a magnetic field lasting more than 10 Ma.

CV chondritic meteorites contain the oldest known solids: calcium-aluminum-rich inclusions (CAIs). The variety of metamorphic textures in ordinary chondrites motivated the "onion shell" model in which chondrites originated at varying depths within a parent body heated primarily by the short-lived radioisotope 26Al, with the highest metamorphic grade originating nearest the center.

The large abundances and sizes of CAIs in CV chondrites have long suggested an early parent body accretion age. New Pb-Pb and Al-Mg ages of chondrules in CVs are consistent with the CV parent body having largely completed accretion by the youngest chondrule age of ∼1.7-3 Ma. The CV chondrite parent body likely reached peak metamorphic temperatures around 7 to 10 Ma after CAIs, based on I-Xe chronometry for Allende and Mn-Cr chronometry for Mokoia.

Bodies that accreted to more than >∼20 km radius before ∼1.3 to 3 Ma after the formation of CAIs likely contained sufficient 26Al to melt internally from the insulated cumulative effects of radiogenic heating. These early-accreting bodies will melt from the interior out, sometimes forming an interior magma ocean under a solid, conductive, undifferentiated shell. This shell would consist of the same chondritic material that made up the bulk accreting body before melting began. The presence of talc and the absence of serpentine indicate peak temperatures of ∼300-350°C.

Subsequent to the analysis of natural remanent magnetization in angrites, Carporzen et al. (2009, submitted, and this conference) have described how unidirectional magnetization in Allende is consistent with a long-lived internally generated field. The metamorphic, magnetic, and exposure age data collectively indicate a new model for the CV chondrite parent body in which interior melting is incomplete and the magma ocean remains capped by an undifferentiated chondritic shell. This conductive lid insulates the internal magma ocean, slowing its cooling and solidification by orders of magnitude while still allowing sufficient heat flux out of the core to produce a dynamo with intensities consistent with magnetization in Allende. Materials in the undifferentiated lid experienced varying metamorphic conditions.

Bodies that are internally differentiated in the manner described here may well exist undetected in the asteroid belt. The shapes and masses of the two largest asteroids, 1 Ceres and 2 Pallas, can be consistent with differentiated interiors, conceivably with small iron cores with hydrated silicate or ice-silicate mantles. Other asteroids may have lost their hydrostatic shapes through later impacts, and their surfaces may never have been covered with erupted basalt; surfaces of these bodies may have remained chondritic throughout this process. Such surfaces will therefore be irregular, space-weathered primitive material, perhaps with highly altered or even differentiated material at the bottoms of the largest craters and in crater ejecta. This scenario can explain the mismatch between the enormous diversity (> 130) of parent bodies represented by achondrites and the paucity (< 10) of basaltic asteroids.