A PARTIALLY DIFFERENTIATED PARENT BODY FOR CV CHONDRITES? B. P. Weiss[1], L. Carporzen[1], L. T. Elkins-Tanton[1], D. L. Shuster[2], D. S. Ebel[3], J. Gattacceca[4], M. T. Zuber[2], J. H. Chen[5], D. A. Papanastassiou[5], R. P. Binzel[1], D. Rumble[6], and A. J. Irving[7], [1]Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, 54-814, 77 Massachusetts Avenue, Cambridge, MA 02139, USA, [2] Berkeley Geochronology Center, Berkeley, CA 94709, USA, [3]Department of Earth Planetary Sciences, American Museum of Natural History, Central Park West at 79th St., New York, NY 10024, USA. [4]CEREGE, CNRS/Université Aix-Marseille 3, France, [5]Science Division, M/S 183-601, Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA 91109, USA, [6]Geophysical Laboratory, Carnegie Institution, Washington, DC 20015, USA, [7]Department of Earth and Space Sciences, University of Washington, Seattle, WA 98195, USA

Introduction: We have recently discovered that large (> ~100 km radius), differentiated planetesimals that formed within a few million years (Ma) of calcium aluminum inclusions (CAIs) were likely capable of generating transient, core dynamo magnetic fields [1, 2]. A core dynamo could explain the ancient natural remanet magnetization of angrites [2] and possibly many other achondrites [1].

The Allende meteorite, a carbonaceous chondrite from the CV group, also contains a stable magnetization blocked up to 290°C [3]. This "middle temperature" (MT) component has traditionally been ascribed to externally generated magnetic field sources like the T Tauri sun and the protoplanetary disk [3]. However, the MT component's unidirectional orientation in Allende indicates that it postdates accretion of the CV parent planetesimal. In particular, magnetic, petrographic and I/Xe thermochronometry measurements indicate it was acquired at ≥8 Ma after CAIs over a period of millions of years [4, 5]. This is after the expected lifetime of the T Tauri sun and disk. These field sources could also not produce a unidirectional magnetization on the moving, spinning CV body.

Therefore, we recently concluded that the most likely source of Allende's MT component is an internal core dynamo [5, 6]. This would imply that the CV planetesimal was partially differentiated, with a metallic core, melted mantle, and relict chondritic crust. Here we present new data to test this hypothesis.

New magnetic data: Allende is one of the best paleomagnetically studied rocks in history, with nearly two dozen studies by ~9 different groups (see ref. [1]). However, a number of mysteries have remained:

Origin of the NRM: It has been previously unclear how Allende was magnetized (e.g., [3]). Therefore, we compared its NRM to a variety of laboratory-induced magnetizations: partial thermoremanence (pTRM) (analog for parent body metamorphism in the presence of a core dynamo field), isothermal remanent magnetization (IRM) (analog for nebular lightning or magnets), viscous remanence (analog for exposure to Earth's field), and shock remanent magnetization (analog for meteoroid impacts). The results (Fig. 1) indicate that Allende's NRM was acquired as a pTRM

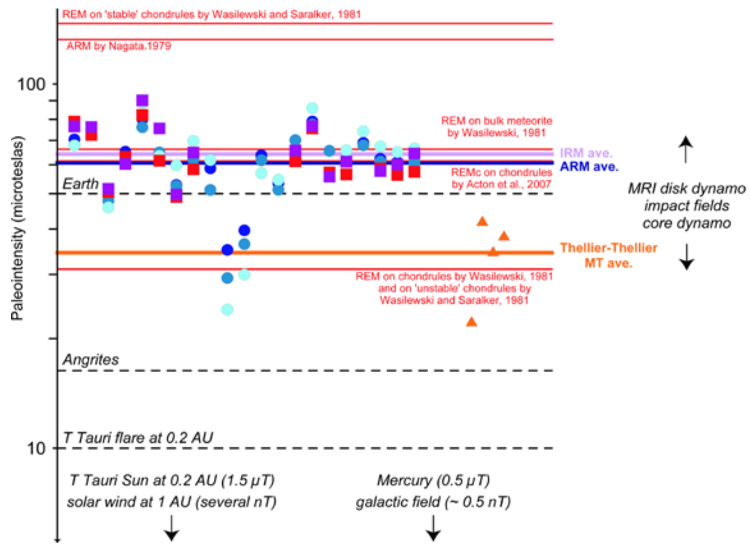

Fig. 1. Summary of paleointensities obtained for Allende. Each vertical cluster of points is derived from a single subsample in our study: circles = thermally calibrated ARM paleointensities, squares = thermally calibrated IRM paleointensities, triangles = Thellier-Thellier paleointensities on the MT component. Colors correspond to ARM bias fields of 50 μT (light blue), 200 μT (mid-blue) and 600 μT (dark blue) and IRM (red) and REM' (purple) methods. Mean paleointensities from our ARM, IRM, and Thellier-Thellier experiments are given by blue, light purple lines and orange lines, respectively. Red lines show means of previously measured paleointensities using the REM, REMc, ARM methods (see ref. [5]) calibrated using our pTRM measurements. Dashed lines show surface field of the Earth, the solar wind field at 1 AU from the sun, the galactic field, the inferred paleofields of T Tauri short lived flares at 0.2 AU, and surface fields inferred for the angrite parent body [2].

during cooling from peak metamorphic temperatures of 290°C or possibly higher [5].

Paleointensity of the field: We have conducted more than 90 paleointensity experiments using isothermal [IRM and anhysteretic remanent magnetization (ARM)] [2] and IZZI-variant Thellier-Thellier techniques [7]. The isothermal techniques were thermally calibrated using measurements of IRM/pTRM

Fig. 2. The Eagle Station pallasite has an O, Cr, and possibly Mo isotopic composition indistinguishable from CV chondrites [8-10]. Image width is ~3 cm.

and ARM/pTRM. The uncertainties for the Thellier-Theller values were quantified with repeat experiments on laboratory pTRMs. Our results (Fig. 2) strongly indicate that the intensity of the field which produced the MT component was of order 30 μT [5]. Such strong fields are consistent with a core dynamo [1, 2]. We are currently studying other CV chondrites to further test this conclusion.

Achondrites and metamorphosed chondrites from the CV parent body: The partial differentiation hypothesis predicts that there might be extant samples of the metamorphosed and/or melted interior of the CV body. To test this idea, we are studying several achondrites and metamorphosed chondrites like NWA 3133 with affinities to CV chondrites [8].

We have focused on the Eagle Station pallasite (Fig. 2), which has been previously tied to the CV parent body via O, Cr and Mo isotopes [9-11]. This suggests that it could be a sample of the core-mantle boundary of the CV body. We are currently testing this hypothesis by remeasuring these and other isotopes known to be heterogeneous amongst bulk solar system bodies [12, 13]. We are also comparing trace element abundances in Eagle Station to CV chondrites.

Search for partially differentiated asteroids: Another key test of the partial differentiation hypothesis is that there should perhaps be extant asteroids with differentiated interiors and chondritic crusts. We have been testing this idea using geophysical modeling of existing asteroid shape data and spectroscopic observations of possible CV parent bodies.

Geophysical constraints on Ceres and Pallas: We consider the simple case of a rotating, hydrostatic body composed of a core and mantle, each of uniform density. For such a body it is possible to relate shape, gravitational moments and internal structure [14]. Using recent observational data [15], results for 2 Pallas are shown in Fig. 3, which plots contours of core density (ρ_c) as a function of fractional core radius (r_c/R, where r_c and R are the core and asteroid radii, respectively) and mantle density (ρ_m). An assumed iron core with ρ_c ~ 7800 kg m^{-3} constrains the core radius to $0.3 < r_c/R < 0.6$ and constrains the mantle density to $1000 < \rho_m < 2400$ kg m^{-3}. The range of allowable core size contains values large enough to produce a magnetic field from a core dynamo [1, 2], and the corresponding range of mantle density permits a silicate composition [6]. Similar conclusions were found for Ceres, although a ice-rich or porous mantle is required [6].

Connection with Eos family: Fragments of a partially differentiated asteroid? Spectroscopic observations suggest that the Eos dynamical family of asteroids could be the remnants of the CV chondrite parent body [16]. Many members of the spectrally diverse Eos family also resemble achondrites, which has been used to argue that the pre-breakup Eos asteroid was a partially differentiated object [17, 18]. We are testing this hypothesis with new observations of family members with possibly achondrite-like spectral properties.

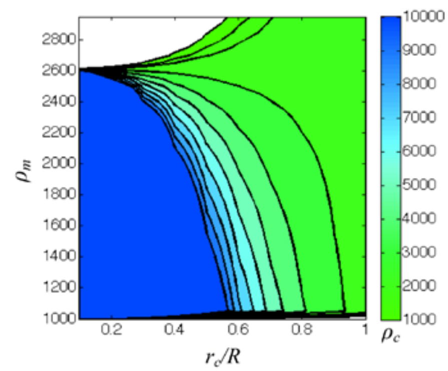

Fig. 3. Contours of core density (ρ_c) for core radius/planetary radius (r_c/R) and mantle density (ρ_m) for asteroid 2 Pallas. Densities are in units of kg m^{-3}.

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