MAGNETIZATION OF CV METEORITES IN THE ABSENCE OF A PARENT BODY CORE DYNAMO

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Introduction: Magnetizations held by meteorites can provide important clues to the origin and nature of parent bodies [e.g., 1-2]. However, the seemingly strong magnetization held by Allende, and the interpretation that it records a core dynamo [3], has been controversial because meteorites which might reasonably represent other differentiated portions of the parent body are not known from the meteorite collection. In addition, recent studies indicate that ^{26}Al was not present in sufficient concentrations to produce sufficient melting of CV parent body [4]. The principal factor useful for the discrimination of core dynamo fields from external fields is absolute field intensity. Fields 10's of µT in strength favor core dynamos, whereas much weaker fields can be the result of external processes (e.g. solar wind, impacts). Prior paleointensity estimates for Allende cover an extraordinary range, from less than 1 µT to 1600 µT (0.02 to 32 times the typical strength of Earth's surface field). This is arguably the first sign that Allende's magnetic properties are highly complex. We have recently investigated the fundamental requirements for paleointensity recording in the Allende meteorite: the presence of single domain non-interacting magnetic grains [5-6]. First order reversal curve data reveal strong magnetic interactions, typical of interactions seen in terrestrial pyrrhotite. Magnetic interactions are also suggested by paleomagnetic investigations of remanence and electron microscopy. Thus, these data indicate that Allende fails basic paleomagnetic recording requirements. Here, we extend these studies, investigate alternatives to the magnetization of CV meteorites and consider implications for the origin of the parent body.

Methods: New rock magnetic and paleomagnetic data were collected on small (1-2 mm) samples of the Allende meteorite, > 1.0 cm from the fusion crust. All measurements were conducted at the University of Rochester (UR) and at Michigan Technological University (MTU). Magnetic susceptibility measurements were conducting using AGICO Kappabridges (UR, MTU). Natural remanent magnetization measurements were collected using a 2G 3-component DC SQUID magnetometer with high resolution sensing coils (UR). The UR magnetometer is housed in a magnetically shielded room (ambient field <200 nT). Heating was accomplished using a Synrad v20 CO_2 laser [7]. Use of a laser is crucial because it affords heating on minute time scales, avoiding thermally-induced alteration that accompanies heating with ovens (typically hour time scales). In addition, a new chamber allowing CO_2 heating in a controlled atmosphere (e.g., Ar, N) was employed (Figure 1). Scanning electron microscope and energy dispersive spectroscopy data were collected using a Zeiss-Auriga scanning electron microscope.

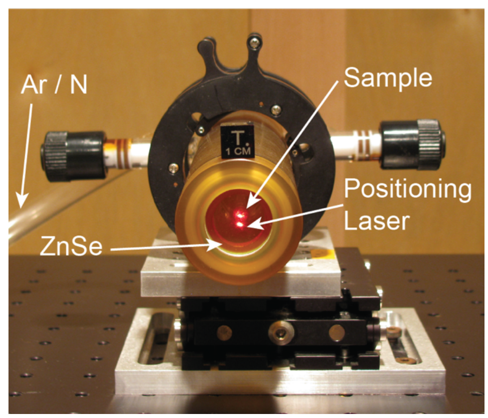

Figure 1. Chamber for CO_2 laser heating in a controlled atmosphere in the UR Paleomagnetic Shielded Room. Red shows positioning laser; ZnSe is CO_2 transparent window.

Findings: Allende demonstrates several extraordinary rock magnetic and directional characteristics. The first is a decoupling of magnetic phases that dominate magnetic susceptibility versus those that control remanence (i.e., directions, intensity). The latter is controlled by a pyrrhotite-like ($Fe_{x-1}S_x$) carrier, whereas the former is controlled by magnetite (Fe_3O_4) and awaruite (Ni_3Fe), having high Curie temperatures (~580 and 620 ^oC, respectively). This decoupling is important because it suggests that during the acquisition of remanence, FeS grains in Allende would have experienced an internal field related to induced magnetic components in the high magnetic susceptibility magnetite and awaruite. We find that during magnetic cycling at low temperatures (less than 292 °C, Figure 2), the remanence carrying ability of Allende appears to grow. These characteristics are similar to those that characterize the lambda transition in hexagonal pyrrhotite. Electron microscopy shows the presence of adjacent NiFe and FeS grains, highlighting interactions.

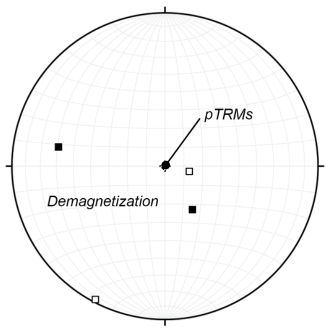

Figure 2. Directional results of field cycling experiment. A sample is progressively given partial thermal remanent magnetizations (pTRM) at 292 °C (in Ar) and subsequently demagnetized (squares). As predicted the demagnetized points show no preferred position, and the pTRMs are along the applied (vertical) axis. But during the course of this cycling, the pTRM intensity progressively increased.

While fascinating, the rock magnetic and paleomagnetic characteristics of Allende indicate that it is inappropriate as a paleointensity recorder; continued attempts to exclude early solar system processes based on a paleointensity value of 20 μT attributed to Allende are unwarranted [8]. That is, the presence of magnetic interactions negates the prior paleointensity values.

Discussion: The failure of Allende to meet paleointensity recording requirements naturally raises the question of what, if any, magnetic data from CV meteorites can be used to contribute information about the parent body. We note that work on the CV meteorite Kaba suggests that its magnetization might be dominated by magnetite [9]. Unfortunately, the magnetization of Kaba reported to date is dominated by secondary viscous remanence magnetization (VRM), presumably of terrestrial origin. Data that best show removal of this VRM suggest a paleointensity of approximately 1 μT. While this could be an overestimate due to cooling effects, unrecognized interactions and unremoved VRM, we explore whether this value can be explained by external solar wind sources. The parent body can be expected to be bathed in the solar wind of the young Sun. A minimum estimate of the field associated with this wind can be expressed as:

$$B_0=\mu_0 H_0=B_s(\Omega_s/\Omega_{sun})(R_s/R_{sun})^2(V_w d)^{-1}$$

where V_w is solar wind velocity, d is distance in the stellar equatorial plane, and B_s, R_s, Ω_s are the surface magnetic field, radius, and angular speed of the Sun, respectively. Using solar values leads to a lower limit of the external field of approximately 250 nT at the time of the metasomatic event at 1AU, less than 5 million years after the formation of the solar system [10], that is hypothesized to have heated CV meteorites and imparted a magnetization (by thermal remanent magnetization, chemical remanent magnetization, or both). An upper limit for the field accounts for the conversion of kinetic energy of the solar wind flow into magnetic energy; this yields 2.2 μT, with additional enhancements possible due to giant stellar flares. We find that these field conditions, bounded by our lower and upper estimates, are satisfied within 1 AU of the current asteroid belt. In addition to the field from the young stellar stellar wind, there may be magnetic fields in any surviving protoplanetary disk that arise from some combination of in situ MHD turbulent amplification and/or flux advection of the ambient molecular cloud field. These fields warrant further investigation.

Conclusions: Magnetization of the CV meteorites by solar seed fields in the absence of a core dynamo is consistent with available magnetic and meteorite evidence. The magnetization conditions are most compatible with an origin close to the present-day asteroid belt, rather than transport from far reaches of the solar system as suggested in some dynamical models [11].

References: [1] Nagata T. and Funaki M. (1983) *Mem. Natl. Inst. Polar Res. Spec. Issue*, *30*, 403-434. [2] Sugiura N. and Strangway D. W. (1985) *Proc. Fifteenth LPSC* (AGU, Washington DC), C729-C738. [3] Carporzen L. et al. (2011), *PNAS*, *108*, 6386-6389. [4] Nagashima K. et al. (2016), *Geochem. Cosmochim. Acta,* in press. [5] Tarduno J. A. et al. (2016) *LPS XLVII,* Abstract #2609. [6] O'Brien T. M. et al. (2016) *LPS XLVII,* Abstract #2913. [7] Tarduno, J. A. et al. (2007) *Nature*, *446*, 657-660. [8] Oran R. and Weiss B. (2016), *AGU Fall Meeting,* Abstract #GP23C-1352. [9] Gattacceca J. et al. (2016), *Earth Planet. Sci. Lett.*, *455*, 166-175. [10] Doyle P. et al., (2015), *Nature Comm.*, 6:7444. [11] Walsh K. et al., (2011), *Nature, 475*, 206-209.