DOES THE MAGNETIZATION OF CV METEORITES RECORD A PARENT BODY CORE DYNAMO?

J.A. Tarduno[1,2], T.M. O'Brien[1] and A.V. Smirnov[3,4] [1]Department of Earth & Environmental Science, University of Rochester, Rochester, NY 14627 (john.tarduno@rochester.edu), [2]Department of Physics & Astronomy, University of Rochester, Rochester, NY 14627, [3]Department of Geological and Mining Engineering and Sciences, Michigan Technological University, Houghton, MI 49931, [4]Physics Department, Michigan Technological University, Houghton, MI 49931.

Introduction: While it has been recognized for decades that the Allende meteorite (CV_{OxA}) holds a magnetization [1-3], the origin of this magnetization remains uncertain. Recent interpretations of magnetic data from Allende as a record of a core dynamo [4] are central to the hypothesis that the CV parent body was differentiated [5]. A key part of the dynamo interpretation is that Allende was magnetized 9-10 million years after the formation of the solar system, following an interval when magnetizations related to the young active Sun might otherwise have imparted strong magnetizations [4]. Allende is hypothesized to have been magnetized during a parent body metasomatic event lasting several millions of years. The magnetization is thought to be carried by pyrrhotite ($Fe_{x-1}S_x$) [4] which is observed to completely unblock (i.e. demagnetize) at laboratory temperatures of ~290 ^oC. Other magnetic minerals in Allende, such as magnetite (Fe_3O_4) and awaruite (Ni_3Fe), have high Curie temperatures (~580 and 620 ^oC, respectively) but have been reported to carry no magnetization. Thus, the dynamo interpretation implies that the metasomatic event reached temperatures no higher than ~290 ^oC.

However, this maximum reheating temperature defined by the magnetization, and core dynamo interpretation, are at odds with other data and magnetic theory. Several studies suggest Allende experienced metamorphic temperatures of 500-600 ^oC [6-8]; if so, other phases in Allende should hold magnetizations if a core dynamo had been present. Moreover, fundamental magnetic recording properties predict that magnetite in Allende should be magnetized in the presence of a core dynamo, even if metamorphic temperatures did not exceed 290 ^oC. Specifically, theory [9-10] suggests the thermal relaxation time can be related to rock magnetic parameters as follows [11]:

$$\frac{1}{\tau} = \frac{1}{\tau_o}\exp\left[-\frac{\mu_o V M_s H_K}{2kT}\left(1-\frac{|H_0|}{H_K}\right)^2\right] \quad (1)$$

where τ_o (10^{-9} s) is the interval between thermal excitations, μ_o is the permeability of free space, V is grain volume, M_s is spontaneous magnetization, H_K is the microscopic coercive force, k is Boltzman's constant, T is temperature, and H_0 is the applied field. This formulation was used by Pullaiah et al. [12] to determine time-temperature relationships that can be in turn be used to predict how secondary magnetizations might be acquired:

$$\frac{T_A \ln(\tau_A/\tau_0)}{M_S(T_A)H_K(T_A)} = \frac{T_B \ln(\tau_B/\tau_0)}{M_S(TB)H_K(T_B)} \quad (2)$$

where the two relaxation times (τ_A, τ_B) correspond to temperatures (T_A, T_B) respectively, and $H_K >> H_0$. Equation 2 describes the tendency for the maximum metamorphic temperature to leak to a higher unblocking temperature range [13-14]. If samples from Allende had been reheated to 290 ^oC for 1 million years in the presence of a core dynamo, the resulting remanence should have unblocking temperatures between 400 and 450 ^oC (i.e. within the unblocking temperatures of magnetite). The apparent lack of a magnetization held by magnetite suggests the metasomatism took place in a null field.

The considerations above indicate that the magnetization of Allende is mineralogically-controlled rather than a record of a core dynamo. Below we investigate how an intrinsic magnetization might arise in Allende and, by association, other CV meteorites.

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. Magnetic hysteresis measurements were collected using a Princeton Measurements Corporation Alternating Gradient Force Magnetometer. Natural remanent magnetization measurements were collected using a 2G 3-component DC SQUID magnetometer with high resolution sensing coils. The magnetometer is housed in a magnetically shielded room (ambient field <200 nT). Heating was accomplished using a Synrad v20 CO_2 laser [15]. Scanning electron microscope and energy dispersive spectroscopy data were collected using a Zeiss-Auriga scanning electron microscope.

A preliminary series of heating experiments were conducted to investigate the behavior of high unblocking temperature (magnetite and awaruite) versus low unblocking temperature (iron-sulfide) magnetic carriers. We illustrate this with the following 4-step experiment (Figure 1): *i*. the specimen's natural remanent magnetization (NRM) was recorded. *ii*. the specimen was thermally demagnetized to 625 °C, and then exposed to a 12 µT field during cooling until 500 °C. Thereafter, the applied magnetic field was shutoff, imparting a partial thermal remanent magnetization (this targets magnetization to magnetite and awaruite). *iii.* Next, the sample was heated to 290 °C in zero field and measured. *iv*. Finally, the sample was heated to 350 °C in zero field and measured. The latter steps target sulfide magnetizations (i.e., pyrrhotite [4] or the anomalous pentlandite discussed by Funaki and Wasilewski [16]).

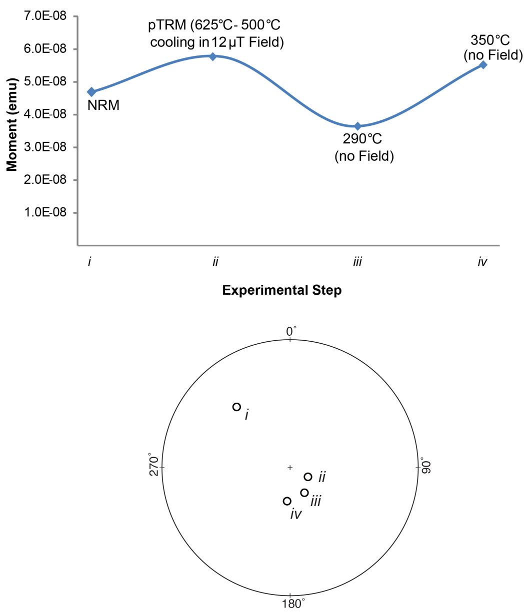

Figure 1. Top: Magnetic remanence (intensity) characteristics of a specimen of the Allende meteorite (see Methods). Bottom: Equal area plot of magnetic directions.

Findings: The specimen acquired a weak but detectable remanence after heating in the presence of a field between 625 and 500 °C, suggesting that magnetite and/or awaruite are viable magnetic recorders in the Allende meteorite (Figure 1). After heating in a null field at 350 °C, the remanence *increased* relative to the remanence after heating in a null field at 290 °C. This pattern is completely unexpected for a thermal remanent magnetization. We note that the remanence after the acquisition of the partial thermoremanent magnetization, and after the last step, were similar, arguing against alteration as the cause of the anomalous increase in remanent intensity. Instead these preliminary remanence data, coupled with SEM and EDS analyses, and magnetic hysteresis data [17] highlight the role that magnetic interactions may play in creating an intrinsic magnetization for the Allende meteorite.

Discussion: The magnetic unblocking temperatures of the Allende meteorite (~290 °C) appear inconsistent with estimates of metamorphic temperatures [6-8]. They are inconsistent with theory [9-13] that predicts the Allende meteorite should have a magnetization at higher unblocking temperatures if it underwent metasomatism in the presence of a core dynamo magnetic field. Instead the magnetization of Allende may be an intrinsic magnetism carried by sulfides that interacted with other magnetic minerals during metamorphism. Some of these minerals may have carried weak magnetizations imparted early in the parent body history by the young Sun, or by impacts [18], providing seed fields for the later magnetization of the sulfides. Ultimately, these results may indicate that for asteroids, only highly differentiated bodies, such as the pallasite parent body [19-21], once hosted core dynamos.

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