MAGNETIC FIELDS OF THE EARLY SOLAR SYSTEM RECORDED IN CHONDRULES AND METEORITES: INSIGHTS FROM MAGNETIC REMANENCE AND FIRST-ORDER REVERSAL CURVE (FORC) MEASUREMENTS.

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Introduction: The magnetic fields of the proto-sun and the winds and jets that it produced are expected to have played an important role in the evolution of the Solar System. Placing accurate limits on the magnitudes of these magnetic fields has proven difficult because conventional absolute paleointensity methods used by paleomagnetists, i.e., the Thellier-Thellier method and its derivative methods, require that samples be heated multiple times to temperatures that span the magnetic blocking temperatures of the remanence carrying minerals (~200-700°C). Unfortunately, the magnetic minerals common in meteorites generally alter even at low temperatures (<200°C) and, so far, no valid Thellier-Thellier paleointensity determination has been obtained. Instead, absolute paleointensities have been estimated using remanence ratios (REM, REM′, and REMc), which rely on ratios of the natural remanent magnetization (NRM) to the isothermal remanent magnetization (IRM) before and/or after alternating field (AF) demagnetization along with experimental calibration of these ratios in known laboratory magnetic fields (e.g. [1], [2], [3], [4], and [5]).

Although remanence ratios are currently the accepted means for estimating the paleointensities of meteorites, serious concerns exist as to their validity. To better understand how remanence ratios may be biased and to assess the magnetic histories of several meteorites, we conducted a series of non-destructive magnetic measurements on chondrules from Bjurbole, Karoonda, and Allende meteorites and on small chips of bulk meteorite from Murchison and Acfer-139 meteorites. Our measurements include (1) the NRM, (2) the anhysteretic remanent magnetization (ARM), (3) the IRM, (4) hysteresis properties, (5) coercivities of remanence, (6) IRM acquisition curves, (7) first-order reversal curves (FORCs), which map the coercivity distributions and magnetic interactions in a sample, and (8) magnetic susceptibility. In addition, many of the chondrules have been imaged in 3D using x-ray synchrotron tomography [6].

Results: Many of the observations referred to in this abstract are outlined in detail in [5].

First, a significant proportion of the coercivity distribution for nearly all samples measured so far is very low, falling below about 8 mT (e.g. Figs. 1, 2). This would indicate that most meteorite samples are

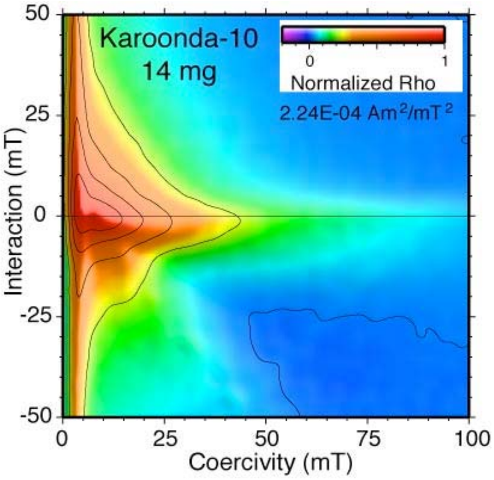

Figure 1. FORC diagram showing the coercivity distribution and interactions for a chondrule from the Karoonda meteorite.

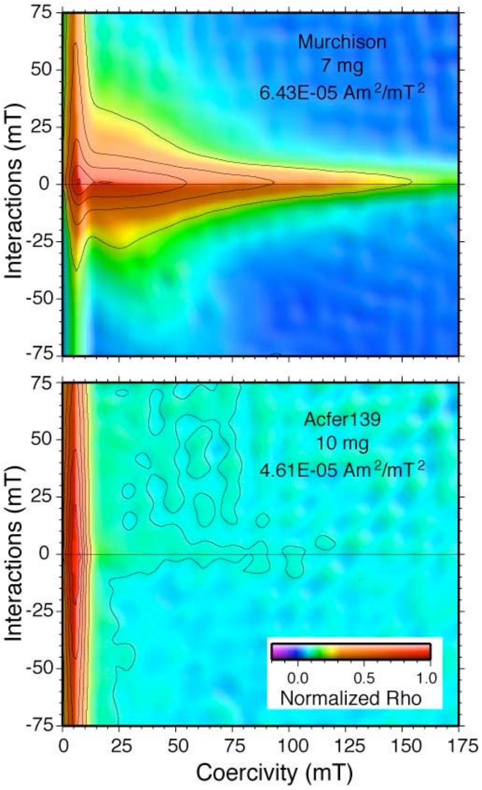

Figure 2. FORC diagrams for bulk meteorite chips of the Murchison and Acfer-139 meteorites.

susceptible to low-coercivity overprints. This is true even for those samples with populations of magnetic grains that have moderate to high coercivity because these samples also typically have a population of grains with very low coercivity.

Second, distinctly different distributions and interactions exist for the different meteorites. The coercivity distributions are mainly log-normal shaped, with Bjurbole distributions being bimodal or trimodal. Allende FORC distributions have coercivities that extend out to about 250-350 mT, with little or no interaction above 10 mT (Fig. 3). Karoonda FORC distributions are triangular shaped with high interactions at low coercivity and progressively lower interactions out to the peak coercivity of about 130 mT (Fig. 1). The Acfer-139 meteorite chip, which is matrix material only, has a very large low-coercivity mode that is highly interactive, with only a hint of a moderate coercivity component (Fig. 2). The Murchison meteorite chip has a coercivity distribution (Fig. 2) most like that of the Allende samples, but with higher interactions below 50 mT than in most of the Allende samples. In the Bjurbole chondrules, a high coercivity mode (400-700 mT) arising from tetrataenite interacts strongly with one or more lower coercivity modes in a manner unlike that seen in terrestrial rocks. Such strong interactions have the potential to bias paleointensity estimates.

Third, vector demagnetization diagrams of the NRM illustrate that low-coercivity overprinting is common (Fig. 3).

Fourth, because low-coercivity overprinting commonly occurs, paleointensities based on REM values, where REM = NRM/IRM with no magnetic cleaning, will probably be biased. The paleointensity bias is about an order of magnitude for most chondrules with low-coercivity overprints analyzed in this study.

Fifth, paleointensity estimates based on a method we call REMc, which uses NRM/IRM ratios after magnetic cleaning, avoid this overprinting bias and indicate that the paleofields recorded by the chondrules are roughly a third to a tenth of the geomagnetic field. Allende chondrules, which are the most pristine and possibly record the paleofield of the early Solar System, have a weighted mean paleointensity of 10.4 ± 1.0 μT. Karoonda and Bjurbole chondrules, both of which have experienced some thermal alteration, were magnetized or possibly remagnetized in paleofields of 4.6 ± 1.0 and 3.2 ± 0.2 μT, respectively.

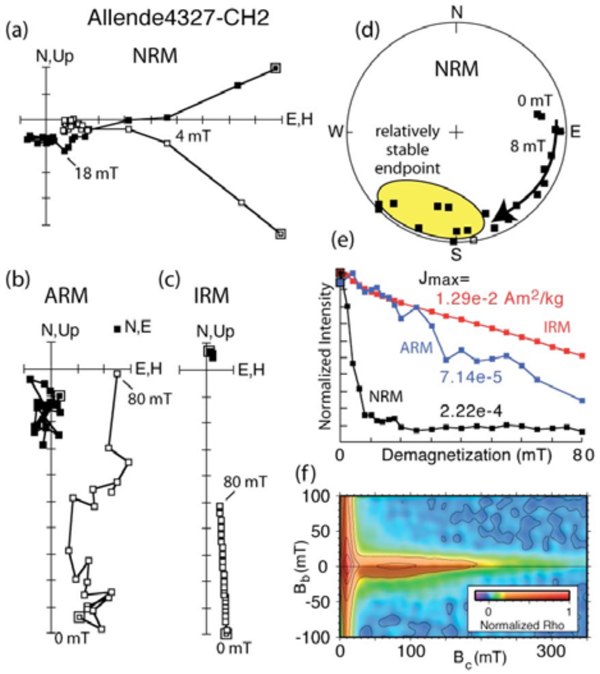

Figure 3. Representative orthogonal demagnetization plots for the a) NRM, b) ARM, and c) IRM of an Allende chondrule; d) the NRM directions plotted on a stereographic projection, which illustrates the progressive removal of a lower coercivity overprint; e) the decay of the normalized NRM, ARM, and IRM and (f) the FORC distribution [5].

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Additional Information: Example FORC diagrams, data sets, and FORC software are available from http://paleomag.ucdavis.edu.