MAGNETIC SUSCEPTIBILITY OF STONY METEORITES FROM THE NATIONAL METEORITE COLLECTION OF CANADA.

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Introduction: There has been recent interest in using magnetic susceptiblity to characterize and classify meteorites [1,2]. Measurements of magnetic susceptibility represent a fast, non-destructive and systematic way to categorize the rapidly expanding inventory of stony meteorites being discovered on Earth. Previous studies [1,2] have demonstrated that although magnetic susceptibility varies over 4 orders of magnitude, there is consistency between different fragments of the same meteorite and also between different meteorites in the same class. Application of the magnetic susceptibility technique has also been used to identify misclassified meteorites [1,2].

The National Meteorite Collection of Canada is hosted at the Geological Survey of Canada (GSC), which is part of Natural Resources Canada. This collection contains 2700 meteorite specimens belonging to 1100 different meteorites. Among these are 730 different stony meteorites. The Canadian collection thus represents an opportunity to apply and expand the magnetic susceptibility approach initiated by Rochette and co-workers [1,2].

In this paper we report initial results from the Canadian collection. We present magnetic susceptibility data for 194 specimens from 108 different stony meteorites. For 11 meteorites we analyzed multiple specimens (for a total of 97).

In addition, our equipment and measurement protocol allowed us to investigate two additional parameters, which were not part of previous meteorite studies [1,2], frequency dependence and anisotropy. We evaluated the frequency dependence by measuring specimens at two frequencies, 19000 and 825 Hz. Our method for approximating anistoropy is discussed below.

Methods: The magnetic susceptibilities (measured in mass units) were determined at two different frequencies (825 Hz, and 19,000 Hz) on a SI-2B instrument manufactured by Sapphire Instruments. The first coil (4.5 cm diameter) is an internal coil operating at 19000 Hz; the second coil (5.1 cm diameter) is an external coil at (825 Hz). The internal coil is more sensitive, but the external coil was necessary for larger samples. Coil saturation at 19000 Hz was reached for several samples, but in such cases, values were still obtainable on the less sensitive and larger 825 Hz coil. Also, several samples were too long/large for the smaller coil and for these the magnetic susceptibility values were only obtained using the larger coil.

We also attempted to obtain a rough measure of magnetic anisotropy. Since it was difficult to orient and fit irregularly shaped specimens into the coil for all the orientations that would be required for a full AMS analysis, we have assessed magnetic anisotropy using a proxy method as follows. Two sets of measurement were made. One set of 5 repeat measurements was performed with the sample in a specific but randomly chosen orientation (this we termed the 'static' measurement). A second set of measurement was done, but this time the sample was randomly reoriented for each of the 5 repeat measurements (this we termed the 'random' measurement). The standard deviation of the 'static' measurements on a sample will only reflect instrumental measurement uncertainty, while the standard deviation of the 'random' measurements will reflect the anisotropy as well as instrument uncertainty. Thus a comparison of the standard deviations of the 'static' and 'random' measurements for the same sample will provide a relative measure of anisotropy. This approach is most reliable the 19,000 Hz measurements for which instrumental uncertainty is lowest.

The SI-2B instrument is temperature sensitive; therefore all measurements were taken at room temperature. Measurements on a standard sample composed of fine-grained MnO_2 was also used to correct for the variation in temperature during analysis. Data for the two frequencies was also normalized to the same MnO_2 value, on the assumption that MnO_2 has no frequency dependence, an assumption that remains to be tested.

Results:

Mean values: Mean magnetic susceptiblity values (log K_m in 10^{-9} m^3/Kg) for each group (Fig. 1A) are 3.67 and 3.69 for the aubrites (19000 Hz and 825 Hz respectively), 2.98 and 3.09 for the eucrites, 5.19 and 5.24 for H-chondrites, 4.74 and 4.76 for L-chondrites, 4.16 and 4.18 for LL-chondrites, 5.36 and 5.48 for enstatite chondrites, 4.04 and 4.08 for carbonaceous chondrites, 3.19 and 3.20 for howardites, and 2.99 and 3.02 for SNCs. Due to its size the mesosiderite was only measured at 825 Hz yielding a logKm value of 6.13.

Analysis of data dispersion: For 11 meteorites multiple specimens were available, and of these, 6 had 3 or more specimens. The coefficient of variation for these is, Camel Donga 4.5%, La Criolla 1.3%, Millbillillie 2.3%, Mulga1.8%, Nuevo Mercurio 5.6% and Wiluna 1.5%. These low values indicate a high consistency among specimens from each meteorite.

We next considered the spread in data from each meteorite type (Fig. 1B). The aubrites had the highest coefficient of variation at 24% followed closely by the eucrites at 22%. The three aubrite meteorites measured show considerable range. The large spread in eucrite data is due to the systematic difference in susceptibility between the Camel Donga (Km= 4.31) and Millbillillie (Km=2.66) meteorites. The other meteorite types showed much tighter groupings.

Frequency Dependence: A graph (not shown) of Km(825 Hz) and Km(19000) for all the data gives a consistent slope of 1.01 consistent with a minor frequency dependence for the dataset as a whole. (A slope of 1 would imply no frequency dependence.)

The frequency dependence for each meteorite type is shown in Figure 1C Deviations from 0 represent increasing frequency dependence. The H- and carbonaceous chondrites, along with the SNCs have the greatest frequency dependence, while the aubrites and howardites have the lowest.

Anisotropy of magnetic susceptibility: Comparison of 'static' and 'random' sets of measurements provides a rough estimate of magnetic susceptiblity anisotropy (Figure 1D). The aubrites, enstatite chondrites and SNCs have the largest inferred anisotropies, while the LL-chondrites and carbonaceous chondrites have the lowest.

Discussion:

Low susceptibility values for achondrites (aubrite, eucrite, howardites, and SNC) are consistent with the lack of visible metal in these classes of meteorites. A steady progression of decreasing susceptibility from enstatite chondrites through H and L to LL chondrites corresponds to a decrease in visible metal content. As expected based on high metal content, the mesosiderite has the largest susceptibility.

Both the frequency dependence and the inferred magnetic anisotropy values cut across the achondrite/chondrite division. Some chondrites (H and carbonaceous) have a similar frequency dependence to that exhibited by the SNCs. Low values of anisotropy are exhibited by some chondrites (LL and carbonaceous) and also achondrites (howardite).

Our work suggests that integrating the frequency dependence and anisotropy data with the bulk susceptibility measurements will provide a more robust characterization of meteorite specimens than that based on bulk susceptibility alone. Our next step involves attempting to classify meteorites that are of unknown or uncertain type.

References: [1] Rochette et al. (2001). *Quaderni di Geofisica*, 18: 30 p. [2] Rochette et al. (2002) Meteor.. Planet. Sci. 2002, in press

Figure 1: Magnetic susceptibility patterns in stony meteorites based on this study.