MAGNETIC SUSCEPTIBILITY OF STONY METEORITES: EVALUATION OF ANISOTROPY AND FREQUENCY DEPENDENCE.

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Introduction: The characterization of meteorites provides insights into the evolution of the solar system**.** However, most widely used classification methods are destructive to the sample and time consuming. Coupled with the increasing backlog of meteorites worldwide, there is a need for a new non-destructive method of rapid and accurate classification. Magnetic properties have been demonstrated as a method of satisfying these requirements [1, 2].

We evaluate four parameters that show promise as classification tools and discriminants: bulk magnetic susceptibility and its frequency dependence (465, 825, 4650 and 19000 Hz), and the degree and shape of the anisotropy of magnetic susceptibility (AMS).

Magnetic susceptibility (MS) measurements were performed on 361 meteorite specimens. 145 of these 361 specimens, covering 14 classes of chondrites, primitive achondrites and achondrites, have been measured for AMS at a frequency of 19000 Hz [3]. Frequency dependence of bulk magnetic susceptibility (FDMS) was evaluated using frequencies of 465, 825, 4650 and 19000 Hz on 96 of the 361 specimens. An additional 222 specimens were also measured at 825 and 19000 Hz. We present the most comprehensive study of meteorite AMS and FDMS to date.

All specimens used in the study belong to the National Meteorite Collection of Canada of the Geological Survey of Canada (GSC), Natural Resources Canada. The collection contains about 2700 meteorites and thus provides an excellent opportunity for scientific research on multiple classes of meteorites and variation within meteorite classes.

Methods: Magnetic susceptibility (measured in mass units) was determined at 825 and 19000 Hz using the SI-2B instrument manufactured by Sapphire Instruments. The MS2 instrument manufactured by Bartington Instruments was used for measurements at 465 and 4650 Hz.

Measurements were performed by placing the meteorite into the applied magnetic field and recording the intensity of magnetization induced within the sample. All values were corrected using a sample standard of 19g MnO_2.

AMS was evaluated using a 6 orientation analysis with the parameters of A% for degree of anisotropy and B% for ellipsoid shape calculated [4]. A% ranges from 0 to 100 and B% ranges from -100 (oblate) to +100 (prolate).

A frequency dependence of bulk magnetic susceptibility, $\chi_{FD}\%$, was calculated using the equation:

$$\chi_{FD}\% = | 100[\chi_{825} - \chi_{19000}] / \chi_{19000} |,$$

where χ_{825} and χ_{19000} are the bulk mass magnetic susceptibility in SI units at 825 and 19000 Hz, respectively. This equation follows closely published formulations [5, 6]. It is, however, the higher frequency data which is used for normalization in the present study as they are the more precise.

Results: A clear trend can be seen in the chondrites as susceptibility increases from LL, L, H to E chondrites with increasing Fe-Ni metal and sulphide content. Achondrites display more variability in susceptibility values which reflects their more complex petrogenesis.

Degree of anisotropy range from 1 to 53% with both oblate and prolate ellipsoids present along with variation among meteorite classes [Figures 1, 2]. The aubrite class is the most distinct marked by a high degree of anisotropy, low bulk magnetic susceptibility and a prolate fabric.

A significant frequency dependence is observed when using the frequencies 465, 825, 4650 and 19000 Hz [Figures 3]. A common trend can be seen among classes where measured values at 825 Hz are consistently the highest. Furthermore, there is a correlation with instrument type, with the Sapphire Instruments data (825 and 19000 Hz) typically (but not always) larger than the Bartington data (465 and 4650 Hz). The interpretation of these patterns is currently being evaluated.

Individual meteorite specimen FDMS, evaluated using 825 and 19000 Hz, ranges from 1-34% with variations in strength among meteorites [Figure 4]. There is general consistency among specimens of the same meteorite. Exceptions, however, are present.

The C chondrites and SNC meteorites show subclass distinction using FDMS at 825 and 19000 Hz [Figures 4, 5]. The CM2 specimens occupy a distinct region marked by a higher frequency dependence than the CK4, CV3.0 and CO3.x specimens (NWA?, a CV3, is an exception).

The SNC meteorites show subclass variability with Nakhla having the lowest dependence, shergottites the highest and Chassigny falling in the middle.

Discussion and Conclusion: The presence of oblate and prolate fabrics of chondritic and achondritic origin suggests a complex-multiphase scenario for anisotropy formation [3].

The study of the frequency dependence of magnetic susceptibility is important for two reasons. Firstly, if a significant dependence is observed then a correction must be applied to the susceptibility measurements based on the frequency used. The relationship between magnetic susceptibility and changing frequency must be defined to determine the corrective factor. Secondly, if variability is displayed among classes then the frequency dependence of magnetic susceptibility provides another useful parameter of classification.

FDMS has been shown to exist for some paramagnetic and diamagnetic materials that readily conduct currents at frequencies > 500 Hz [7, 8]. Also, superparamagnetic behavior of grains has been observed at differing frequencies for grains with diameters between 0 and ~0.03 μm [5, 6].

The subclass distinctions of the C chondrites and SNC meteorites may be related to magnetite which has been shown to display a frequency dependence [5, 6].

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Acknowledgements: The authors thank Ann Hirt of the Institute of Geophysics, Zurich for information related to frequency dependence. The Bartington MS2 magnetic susceptibility meter was on loan from Defence R&D Canada-Suffield.

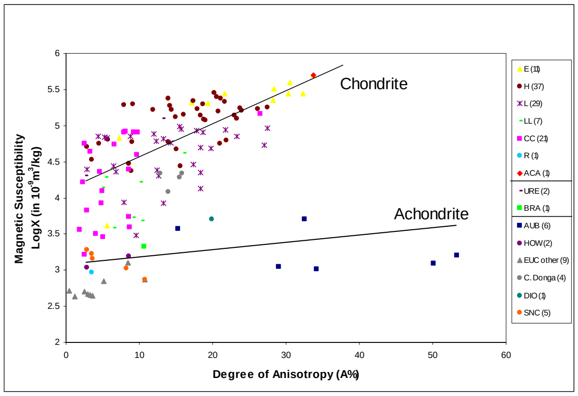

Figure 1. MS vs Degree of AMS (19000 Hz)

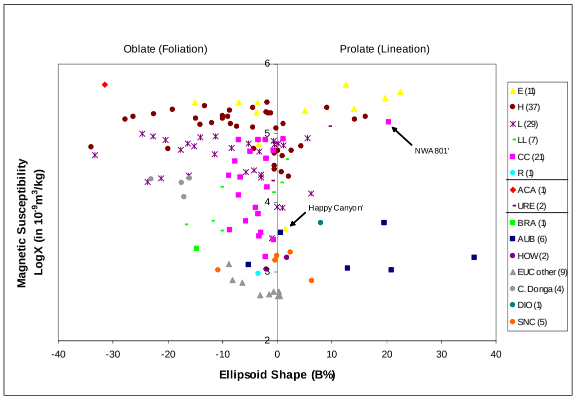

Figure 2. MS vs Ellipsoid Shape (19000 Hz)

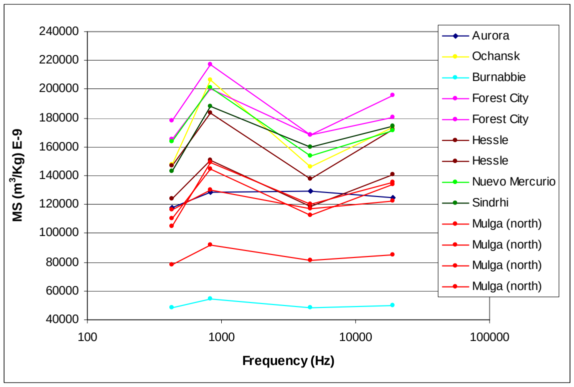

Figure 3. MS vs Frequency

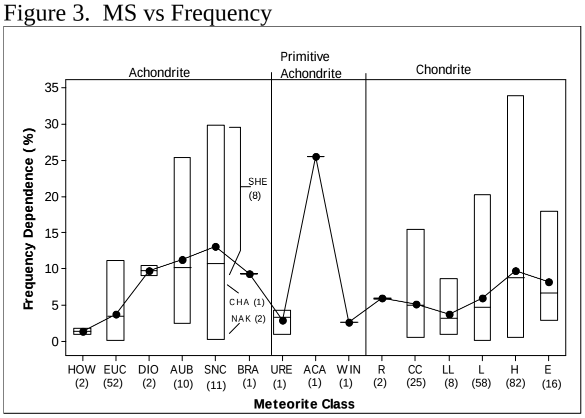

Figure 4. Meteorite Class vs FDMS. Parentheses indicate number of specimens used in the mean, Horizontal lines indicate min, median and max values, dot is average .

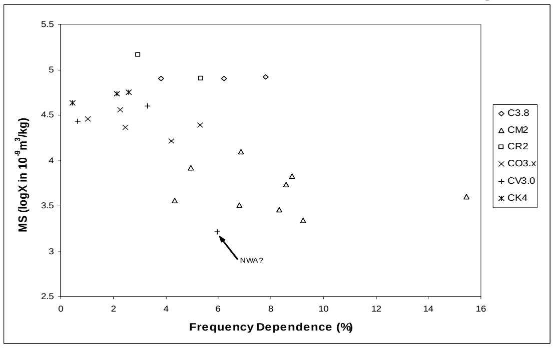

Figure 5. Subdivision of the C chondrites using FDMS