# NON-DESTRUCTIVE DETERMINATION OF THE PHYSICAL PROPERTIES OF ANTARCTIC METEORITES.

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**Introduction:** The fundamental physical properties (such as density, porosity, magnetic susceptibility and electrical conductivity) of extra-terrestrial materials provide insight into the processes that controlled the formation and evolution of the parent bodies from which they are derived [1]. For example, meteorite densities are used to make inferences about the composition and internal structure of asteroids [1,2], and to understand parent body thermal history [3]. Porosity can be used to understand the physical history of meteorite parent bodies, in terms of processes such as asteroid compaction, lithification, break-up and re-assembly [1]. It is also a key parameter in understanding both meteorite survivability during Earth atmospheric entry and asteroid survivability during impacts [4,5].

Magnetic susceptibility is the measure of the extent to which a material will be magnetized when a magnetic field is applied [1]. As such, it is a useful measurement of the proportion of magnetic minerals inside a sample [6]. Understanding whether or not these magnetic minerals can conduct electricity allows for differentiation between magnetic Fe,Ni metal and magnetic oxides or sulphides [1,6,7]. Different groups of meteorites contain varied proportions of metal and other magnetic minerals as a result of differing formation or parent body processes. Therefore, magnetic susceptibility and electrical conductivity measurements can be used to interpret sample mineralogy and aid the classification of recovered meteorites [6,8].

We are investigating the physical properties of a suite of meteorites returned by the UK-led 'Lost Meteorites of Antarctica' project [9,10] using a combined, non-destructive approach that includes measurements of magnetic susceptibility and electrical conductivity. In addition, we are developing the use of photogrammetry to determine density.

Photogrammetry uses two-dimensional images to determine accurate information about the surface of an object [11]. Using a suite of overlapping images depicting a meteorite in a range of orientations, it is possible to generate a three-dimensional (3-D) model of the meteorite [12]. The 3-D models are used to compute sample volume, which is used to determine sample density. The technique is non-contaminating and can be scaled dependent on the optical resolution of the contributing image suite.

**Method:** *Photogrammetry:* To date, image suites for 20 samples, ranging in mass from ~1 g to ~2500 g, have been acquired in the Class 1000 clean labs at the University of Manchester.

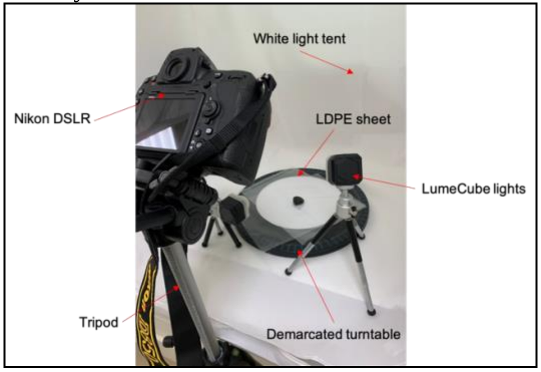

*Figure 1: Lightbox set-up showing camera, turntable, low-density polyethylene (LDPE) sheet and portable lights within light tent.*

Each sample is placed on a turntable in a controlled light environment to minimize shadows and reflections. (Fig. 1). Photographs are captured using a 45-megapixel DSLR camera at 5° rotational intervals. These images are taken in RAW format, processed to ensure accurate color, and unsuitable images are removed. We use vernier calipers (± 0.005 mm) to measure between two points along the sample's width. We use professional photogrammetry software, Agisoft Metashape [13], to create a high-fidelity three-dimensional model of each meteorite [14]. Models are imported into professional CAD software, 3DS Max [15], and scaled to true size according to the known dimension measured by the calipers. A value for the volume of the sample is computed using one of the standard measurement tools in the software toolbox.

We use the AMetMet, a magnetic susceptibility-electrical conductivity field probe developed by colleagues at CEREGE, to determine magnetic susceptibility and electrical conductivity values for the samples [6,7].

**Results:** We have successfully produced high-quality 3-D models of a suite of meteorites returned from Antarctica that include a range of mass and sample size, and a diverse range of simple to complex sample morphologies (Fig. 2).

To understand the uncertainty in measurements derived by photogrammetry, we also produced 3-D models of two wooden cuboids of known size (~5 × 5 × 10 cm and ~2.5 × 2.5 × 10 cm). Computed volume measurements were within ~2 % of their known value.

To date, we have calculated bulk density for ten meteorites. Densities range from 3.1 – 3.9 g/cm$^3$. For the same meteorites, magnetic susceptibility ranges from Log χ values 3.4 – 5.5. Figure 3 shows these parameters, which appear to be weakly correlated.

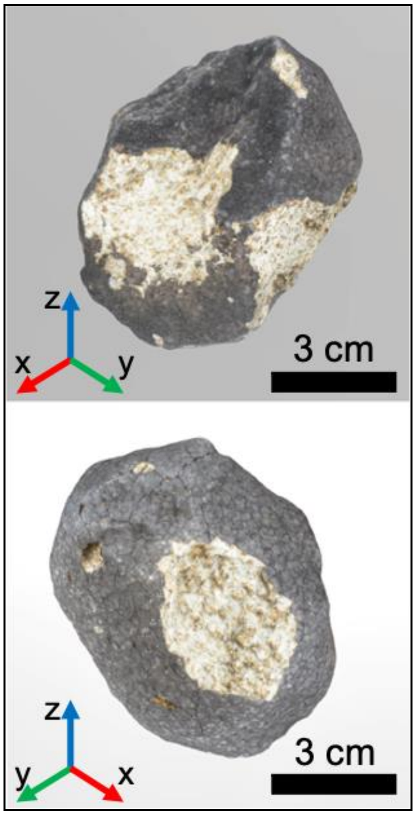

*Figure 2: Screenshots of a finalized model of one of our Antarctic meteorites.*

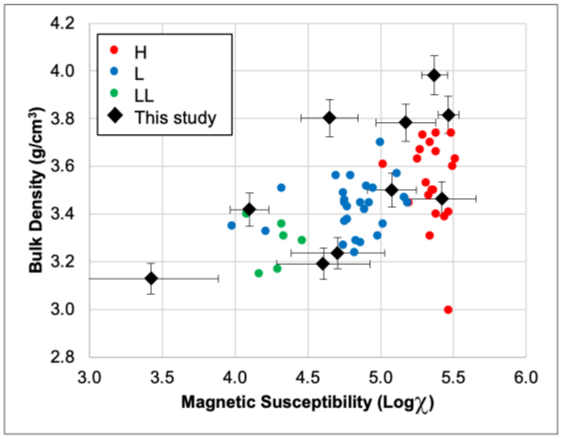

*Figure 3: Plot of bulk density computed from photogrammetry vs. magnetic susceptibility (presented as Log χ where χ has units $10^{-9}$ $m^3$/kg) for ten Antarctic meteorites. Y-axis error bars on bulk density represent ± 2 % relative error in the volume measurement, translated into the density uncertainty. X-axis error bars represent 2 standard deviations on the 5 magnetic susceptibility measurements that were averaged together. Ordinary chondrite data from [18].*

**Discussion:** Magnetic susceptibility distinguishes between broader meteorite groups (e.g. between ordinary and carbonaceous chondrites) as they are characterized partly by their metallic iron content [15]. However, overlapping magnetic susceptibility ranges (e.g. between H and L ordinary chondrites: Figure 3) mean that the meteorite group cannot be definitively inferred [1]. Combination of magnetic susceptibility with density, which is linked to the proportion of dense mineral phases within a sample, provides a more robust tool for distinguishing between the meteorite groups [17,18]. Consolmagno et al. [18] showed that using grain density rather than bulk density provides a better separation between ordinary chondrite groups; this is due to variable sample porosity. However, bulk density may be useful for distinguishing a broader range of meteorite groups.

Most of the density and magnetic susceptibility values we determined are similar to the ordinary chondrite data of [18], although our range is slightly greater. Consolmagno et al. [18] studied a range of lower sample masses (3 – 128 g) than our study. The meteorites are currently being classified.

**Future Work:** Once the meteorites have been formally classified, we will compare densities obtained by our method to literature data, to assess the value of the photogrammetry method for determining density. We will combine our data with computed tomography studies of the same meteorites to take into account the effects of porosity and compare the accuracy of each method for measuring density, as well as examining the range of grain and bulk density values. We will also investigate how electrical conductivity measurements relate to varied metal volume and / or metal connectivity.

**References:** [1] Consolmagno G. et al. (2008) *Chem. Erde*, 68, 1. [2] Britt D.T. & Consolmagno G.J. (2000) *Icarus* 146. [3] Akridge G. et al. (1998) *Icarus*, 132. [4] Advellidou C. et al. (2016) *Mon. Notices Royal Astron. Soc.* 456, 3. [5] Flynn G.J. (2014) *Asteroids, Comets, Meteors*, 183. [6] Gattacceca J. et al. (2004) *Geophys. J. Int.* 158. [7] Folco L. et al. (2006) *Meteorit. Planet. Sci.* 41, 3. [8] Debaille V. et al. (2017) *The 8th Symposium on Polar Science*. [9] Joy K.H. et al. (2019) *50th LPSC*, 2132. [10] www.ukantarcticmeteorites.com [11] Yilmaz H.M. (2010) *Exp. Tech.* 3. [12] www.ares.jsc.nasa.gov/astromaterials3d [13] www.agisoft.com [14] Harvey T.A. et al. (2020) *51st LPSC*, 2103. [15] www.autodesk.co.uk [16] Rochette P. et al (2003) *Meteorit. Planet. Sci.* 38, 2. [17] Terho M. et al. (1991) *Proc. NIPR Symp. Antarct. Meteorites*, 6. [18] Consolmagno G.J. et al. (2006) *Meteorit. Planet. Sci.* 41, 3.