NON-DESTRUCTIVE DETERMINATION OF THE PHYSICAL PROPERTIES OF ANTARCTIC METEORITES: IMPORTANCE FOR THE METEORITE – ASTEROID CONNECTION. T. A. Harvey[1], J. L. MacArthur[1], K. H. Joy[1] and R. H. Jones[1], [1]Department of Earth and Environmental Sciences, University of Manchester, Manchester, M13 9PL. (thomas.harvey-2@manchester.ac.uk)

Introduction: Physical properties of extra-terrestrial materials, such as density, porosity, magnetic susceptibility and electrical conductivity, tell us about the formation and evolution of planetary bodies [1-3]. Bulk density measurements are used to interpret the composition and internal structure of asteroids [5-7]. For example, such measurements have been used to aid interpretation of data from missions to asteroids such as the NASA Dawn mission to Vesta and Ceres, where comparison of Dawn data with HED meteorite bulk density data was used to refine the theoretical internal structure of the asteroid [4]. Moreover, bulk density is a key factor in understanding asteroid survivability during collisions, as well as meteorite survivability during Earth atmospheric entry [8-10]. Bulk density is determined by dividing sample mass by bulk volume defined by the sample exterior (including internal voids). Porosity is intrinsically linked to sample density and can vary greatly in some groups of meteorites [2]. Sample porosity informs us about the physical history of parent bodies with respect to processes such as asteroid lithification, break-up, and re-assembly [2].

Magnetic susceptibility is a measure of the extent that a material can be magnetized in an applied magnetic field, related to the proportion of magnetic minerals in a sample [1,2]. Simultaneous measurement of electrical conductivity allows differentiation of samples with high concentrations of magnetic, conductive Fe,Ni metal and those with magnetic, non-conductive oxides or sulfides [15,16]. Different meteorite groups contain a range of proportions of magnetic minerals, reflecting the formation conditions and secondary processes that control their mineralogy [2,16].

Because of the importance of understanding density and porosity, we have developed a method to measure sample volume (and hence derived density) using a non-destructive photogrammetry method. Here, we assess the efficacy of our method for determining sample bulk density and discuss how data derived from our workflow can be used to inform the discussion of meteorite – asteroid comparisons, focusing on the mesosiderite meteorite – parent body connection.

Samples: We studied the physical properties of selected meteorites (ranging in mass from 0.81 to 2460 g) returned by the UK-led 'Lost Meteorites of Antarctica' project [18-20]: 13 ordinary chondrites (1=LL, 6=L, 6=H), 2 mesosiderites, 1 carbonaceous chondrite, an aubrite, and a eucrite [20,21].

Method: 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, a three-dimensional (3-D) model of the meteorite can be generated [12-14], from which the volume and density can be computed. To achieve this, photographs of the meteorites were collected in a lightbox set-up inside the Class 1000 clean labs at the University of Manchester. Suites of photographs were processed using Agisoft Metashape to produce high-fidelity 3-D models of each meteorite [13]. Models were imported into 3DSmax and scaled according to a measured sample dimension. Bulk density was computed using measured mass and a volume value exported from 3DSmax [14]. We made 3-D models of two wooden cuboids of known size (5 × 5 × 10 cm and 2.5 × 2.5 × 10 cm) to access the measurement error. Computed volume values from these calibration models were within 2 % of their known value.

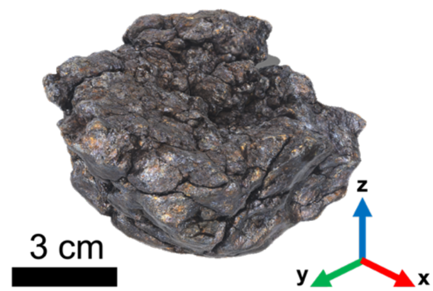

Figure 1: Screenshot of a 3-D photogrammetry model of the second stone of mesosiderite OUT 18014 (233.46 g).

We used the AMetMet, a non-destructive, combined magnetic susceptibility-electrical conductivity field probe, developed by colleagues at CEREGE, to determine the magnetic susceptibility and electrical conductivity values of the meteorites [15]. Each reported value reflects an average of six measurements, with reported errors of 2 standard deviations.

Results: *Meteorite densities:* Bulk density values for the 18 samples were determined using the photogrammetry method. Bulk densities range from 3.13 ± 0.06 to 4.47 ± 0.09 g/cm^3 with a range of intermediate values comparable to known meteorite groups (Fig. 2).

Magnetic susceptibility and electrical conductivity: We measured magnetic susceptibility and electrical conductivity for 16 meteorites as two samples (both <2 g) did not give reproducible results. Magnetic susceptibility measurements ranged from Logχ values 3.42 ± 0.46 to 5.47 ± 0.07 (χ has units 10^{-9} m^3/kg). Electrical conductivity (C) values range from 0 ± 1.01 to 4.87 ± 0.15 (a unitless value).

Discussion: *Assessment of photogrammetry method for determining meteorite bulk density:* There are several techniques for determining the sample volume of a rock. These include the Archimedean bead method, laser-scanning, X-ray computed tomography and photogrammetry, each of which has positives and negatives in terms of data accuracy, accessibility and potential risk to sample integrity [2,8,22]. Our photogrammetry-derived bulk density values for samples >10 g are mostly within the range of previously reported values (Fig. 2) [22]. For samples <10 g (highlighted in Fig. 2), comparison with literature meteorite data suggests that the photogrammetry workflow under-estimates sample volume, and thus overestimates bulk density. The range of reported bulk density values for individual meteorite groups (mostly attributable to variable porosity) makes the extent of this effect difficult to quantify.

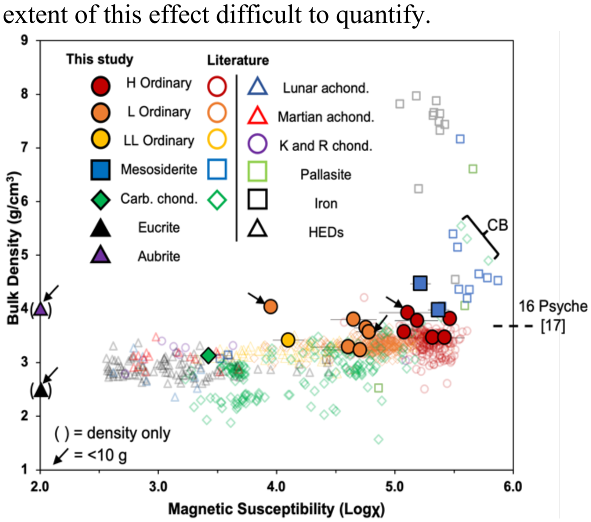

Figure 2: Photogrammetry-derived bulk density vs. magnetic susceptibility (χ has units 10^{-9} m^3/kg) for 18 Antarctic meteorites (solid symbols). Y-axis error bars are derived from ± 2 % relative error in the volume measurement but are smaller than the symbols. X-axis error bars represent 2σ on 6 measurements. Literature data (open symbols) are from [22].

Meteorite classification: Figure 2 shows that magnetic susceptibility and bulk density correlate weakly, and that most of our values are similar to previously determined values for meteorites in the same group [22]. Combination of magnetic susceptibility with bulk density, which is linked to the proportion of dense mineral phases within a sample, provides a useful tool for distinguishing between the meteorite groups, although overlaps between ranges for bulk density and magnetic susceptibility mean that specific meteorite groups cannot be definitively inferred [2,22,23].

Interpretation of mesosiderite physical properties and link to parent bodies: We measured two mesosiderites, both of which are petrologic type A and textural type 3, with ~30 vol% metal, and might be paired, [20].

Bulk density values of mesosiderite OUT 18014 and OUT 18018 are 3.98 ± 0.08 g/cm^3 and 4.47 ± 0.09 g/cm^3 respectively, and magnetic susceptibility (Log*χ)* values are 5.37 ± 0.09 and 5.22 ± 0.09 respectively. These values lie within the ranges of mesosiderite samples from literature (densities 3.08 to 7.17 g/cm^3; magnetic susceptibilities 3.52 – 5.87: Fig. 2 [22]), and are comparable to the majority of data for type A mesosiderites. The difference between the two stones, as well as the range of bulk density and magnetic susceptibility measurements for mesosiderites, may be attributable to variability in the proportion of Fe,Ni-metal, which ranges from 17 to 90 vol. % between different meteorites, or variable weathering of metal [16,22,24].

In preparation for the NASA Psyche mission, remote estimates of physical properties for asteroid 16 Psyche have been compared with measured meteorite properties to estimate the composition of the asteroid [17]. Mesosiderites and CB (Bencubbin-like) chondrites have been identified as potential material from 16 Psyche [17]. Our mesosiderite bulk densities, and those from other studies [22], are comparable with recent estimates for asteroid 16 Psyche (3.78 ± 0.34 g/cm^3) [17]. Bulk density values for CB chondrites (4.90 – 5.55 g/cm^3: Fig. 2 [21]) are high relative to this estimate, but within the range established for 16 Psyche by different authors [17,25]. For such comparisons, it would be advantageous to expand the number of measurements of bulk density for meteorites of all classifications.

Conclusions: Our combined approach is a low-cost, effective method to make physical property measurements that improve our understanding of the link between meteorites and their parent bodies.

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