WHAT DO METEORITE FALLS TELL US ABOUT THE STRENGTH OF ASTEROID BOULDERS?

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Introduction: One of the questions raised by the proposed Asteroid Retrieval Mission (ARM) is "what is the strength of a boulder on an asteroid's surface?" One possible source of data is the meteorite collection and the observations of meteorite falls. Since highly fractured boulders should breakup in the atmosphere and arrive as meteorite showers, the relative ratio of boulders to showers can provide insight into boulder strength.

Fall Data: Since about 85-95% of the mass of a meteoroid is lost during atmospheric entry [1], we have chosen to investigate only those falls with a final recovered mass of at least 10 kg. This corresponds to a minimum pre-atmospheric mass of 100-200 kg and roughly 25 centimeter minimum diameter. Using the Catalogue of Meteorites and the Meteoritical Bulletins published from July 2004 through April 2012 [2,3], we compiled a list of observed meteorite falls with a total recovered mass greater than or equal to 10 kg. We found a total of 269 meteorites that met these criteria, of which 263 entries reported or estimated the number of fragments associated with their falls. The total mass of each of the observed falls ranged from 10 kg to 27,000 kg over a set of 268 falls (one fall was reported in the cited literature as being unknown in terms of its total mass but was claimed to be on the order of "many metric tons"). The largest individual mass within each of the observed falls ranged from 1.7 kg to 1,770 kg over a set of 241 falls (in twenty-eight cases, the largest individual masses were not reported). The mean and standard deviation for the total masses of the falls were 192.64 ± 1669.37 kg, while those for the largest individual mass in each fall were 56.77 ± 152.33 kg. In determining which of the multiple stone falls were to be classified as a "boulder" and which were to be classified as a "shower", a demarcation line of 10 stones was employed as the maximum number for "boulder" compared to "shower". The overall percentage of observed showers was found to be around 28.1% leaving the remaining 71.9% to be described as boulders by our criteria, based on the set of 263 meteorites whose number of fragments were reported or estimated in the cited literature. The ratio of boulders to showers was determined to be around 2.55:1, with 189 boulders and 74 showers as classified. Comparing the percentages of showers within the meteorite types showed a trend in strength with irons (4.3% showers) only very rarely exhibiting reported showers, stony-irons (25%), ordinary chondrites (28%), achondrites (35.7%), and carbonaceous chondrites (70%) predominantly showers.

Single Stone Falls: Single-stone falls represent a total of 41.3% of the reported meteoritic falls with a total recovered mass that was greater than or equal to 10 kg. The mass of each of the single-stone falls ranged from 10 kg to 600 kg over a set of 111 falls. The mean and standard deviation for the masses were 46.72 ± 70.44 kg. In comparing the different subtypes of single-stone falls, the iron and stony-iron meteorites showed the highest mean masses while the iron (73.9%), stony-iron (50%), and enstatites (71.4%) showed the highest percentages of falls as single stones. Ordinary chondrites and achondrites were quite similar in their percentages of single stone falls with 38.2% and 35.7% respectively. Carbonaceous chondrites had by far the lowest percentage of single stone falls at 10% and these were all CO3 chondrites. These findings roughly reflect the data from unpaired Antarctic finds [4], with irons having a higher mean mass and a higher percentage of falls as single stones than the stony meteorites.

Conclusions: The meteorite fall data primarily sample the "boulder" population of meteoroids roughly 0.25 meters to a few meters in their pre-atmospheric diameter because of the 85-95% atmospheric loss. The relative rarity of showers seems to indicate that most meteoroids that survive to produce meteorites in this size range are fairly strong and coherent. Not surprisingly, irons and stony-irons are the strongest classes, which is consistent with the overwhelmingly high production of Earth's smallest impact craters by iron meteorites [5]. Carbonaceous chondrites are by far the weakest and most fracture-prone meteorite class with 70% of the falls being showers and single stone falls being very rare.

References: [1] Brown P. et al. (2016) Orbital and Physical Characteristics of Meter-scale Impactors from Airburst Observations. Icarus 266, 96-111. [2] Grady, M. M, and A. L Graham. (2000) Catalogue of Meteorites. Cambridge: Cambridge University Press. [3] Meteoritical Bulletins, Nos. 88-99, Meteoritics & Planetary Science (2004-2012). [4] Kring D.A. and T. Swindle (2016) Personal Communication. [5] Kring D.A. (2007) Guidebook to the Geology of Barringer Meteorite Crater, Arizona (aka Meteor Crater), Lunar and Planetary Institute (Contribution No. 1355), Houston, 150 pp.