What do Meteorite Falls tell us about the Strength of Asteroid Boulders?

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Abstract. 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 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.

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. 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. In determining whether multiple-stone falls were to be classified as a "boulder" or a "shower", a demarcation line of 10 stones was employed. Observed showers represented around 28.1% of the total reported falls, yielding a ratio of boulders to showers of around 2.55:1. Comparison of these showers by meteoritic subtype showed a trend in strength, as irons exhibited showers in only 4.3% of falls, while shower falls of stony-irons (25%), ordinary chondrites (28%), achondrites (35.7%), and carbonaceous chondrites (70%) were more common. Single-stone falls represented around 41.3% of the total reported falls. Examination of these single-stone falls by subtype showed irons and stony-irons to have the highest mean masses while irons (73.9%), stony-irons (50%), and enstatites (71.4%) had the highest percentages of single-stone falls. Ordinary chondrites (38.2%) and achondrites (35.7%) had similar percentages of single-stone falls, while carbonaceous chondrites had by far the lowest percentage (10%). These findings roughly reflect data from the unpaired Antarctic finds[4], with irons having a higher mean mass and percentage of single-stone falls than the stony meteorites.

The meteorite fall data primarily sample the "boulder" population of meteoroids roughly 25 centimeters to a few meters in pre-atmospheric diameter. 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 stronger classes, which is consistent with the high production of Earth's smallest impact craters by iron meteorites[5]. Carbonaceous chondrites are by far the weakest and most fracture-prone class with 70% of the falls being showers and single-stone falls being rare.

[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.