COLLISIONAL-DISRUPTION EXPERIMENTS: ANALYSIS OF IDENTICAL IMPACTS; Scott W. Rubin,[1*] Mark J. Cintala,[2] and Friedrich Hörz[2]. [1] Lunar and Planetary Institute, 3303 NASA Road 1; [2] NASA Johnson Space Center, all in Houston, TX 77058. *LPI Summer Intern, 1990.

In analyses of impact-fragmentation experiments, the ratio M_R/M_O (where M_R is the largest fragment remaining after the impact and M_O is the original mass of the target) is often used as a scaling parameter.[1,2,3] This quantity is typically plotted as a function of the specific impact energy (impact energy per unit mass of target, E_T/M_O); almost inevitably, such plots exhibit severe scatter that remains intractable even to sophisticated scaling efforts.[4] Because such experiments are currently the only, tangible link to naturally occurring disruptive collisions, it is important to determine the cause of the large variances resulting from such experiments. This study attempts to determine a possible cause of this scatter by analyzing the results of identical impacts into identical targets.

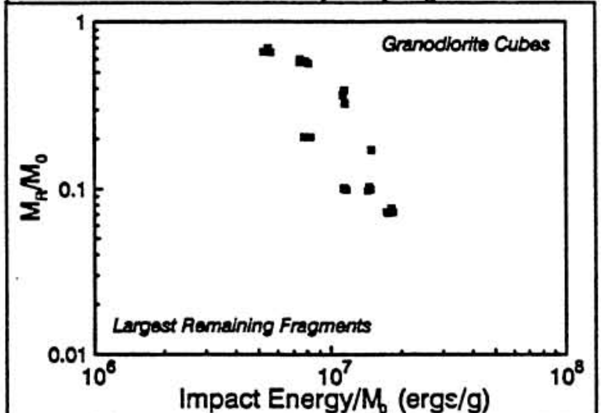

Figure 1. Mass of the largest remaining fragment in units of the original target mass plotted against the specific impact energy for five sets of essentially identical impact experiments. Note the scatter that approaches half of an order of magnitude in places.

Experimental Conditions: Uniform, coherent granodiorite (2.631±0.018 g/cm^3) slabs were cut on a wafering saw and subsequently abraded with a polishing disk to yield cubes 7.066±0.046 cm on a side. Five sets of five cubes were fabricated, with intraset masses varying by no more than 0.10%. Material with visible cracks or other imperfections were excluded from this study, as were those that were dropped or otherwise traumatized. We assured that these targets were, for all practical purposes, identical in size, mass, and homogeneity. Stainless-steel 440 spheres (7.86 g/cm^3) were launched at average velocities of 1.00, 1.20, 1.45, 1.64, and 1.83 km/s, yielding kinetic energies of 7.34×10^8 to 1.71×10^9 ergs. The velocities varied by no more than 4.7% and by as little as 0.03% over each set of five impacts. The targets were suspended by a thin wire loop to minimize artificial reflections of stress waves, and impacts were normal to and in the center of the uppermost horizontal face of each cube. The resulting fragmentation products were dry sieved and weighed, with target recovery typically greater than 99.5%.

The Data: When plotted against E_T/M_O (Fig. 1), M_R/M_O exhibits the same trend observed previously. The scatter in the data is apparent, and is essentially typical of such experiments. At velocities of 1.20 and 1.45 km/s, the masses of the largest remaining fragments differ by as much as a factor of four within a given set; the masses of the largest fragments remain relatively constant at the highest velocities. While in some cases the mass of the largest piece is much greater than the rest of the debris, in most instances the largest remaining fragment is barely that, being comparable to several other fragments in mass. In the latter cases, even the least massive of the largest pieces is much larger than any of the remaining fragments. Figure 2 illustrates the masses of the largest eight fragments relative to the initial target mass in a typical example from each of the five sets of impacts. Within the two lower-energy sets, collisions resulting in one large remaining fragment and collisions yielding several large pieces both occur. In those cases with several large fragments, the combined mass of the largest few pieces is comparable to the mass of the largest remaining fragment in the collisions with only one large remaining piece. The scatter in a plot using this recombined mass (M_A/M_O) is substantially less than that in Fig.1. Note, however, that the variation at the higher energies is actually greater than that in the initial case of Fig. 1. It is apparent that the largest permissible fragment at the lower specific energies sometimes disaggregates into a few smaller pieces. This tendency is not observed at the higher specific energies, implying that it is not a result of high energy densities.

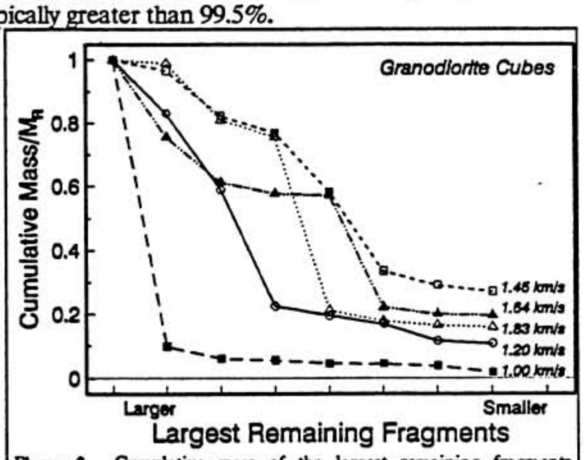

Figure 2. Cumulative mass of the largest remaining fragments expressed as a fraction of their total mass. Note the distinct break in slope for each distribution

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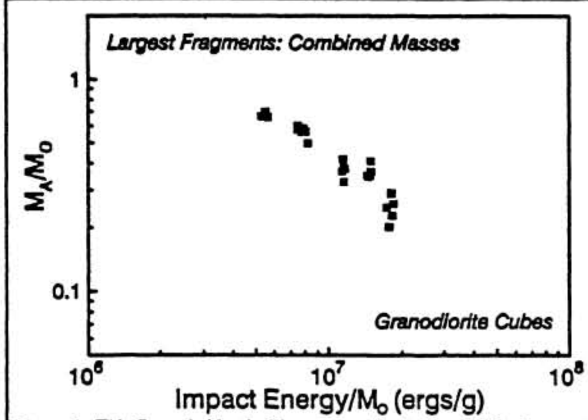

Figure 3. This figure is identical in construction to that of Fig. 1, except that the combined mass of the largest few remaining fragments is plotted instead of the largest single piece. Note the reduced scatter at the low energies, but the increased variance at the higher energies compared to the data in Fig. 1.

Discussion: Since the target and projectile materials were the same for each experiment, the lowest-energy impacts in these experiments were also those generating the lowest shock stresses. The variability in Fig. 1 at the lower velocities (or stresses) implies that undetected imperfections in the targets yield spurious results when parameters such as M_R/M_O are used to describe the data. Microcracks or larger but otherwise invisible cracks would provide ready zones of weakness, encouraging disruption by relatively low-amplitude stress waves.[5] High-velocity impacts, with associated stresses strong enough to rupture the rock irrespective of flaws, produce more regular distribution of M_R/M_O as a function of E_T/M_O.[1,2,3]

To emphasize further the random nature of this effect, Fig. 4 compares the size distributions of debris from two experiments: one at 1.2 km/s, the other at 1.8 km/s. Their shapes are remarkably similar at the finer grain sizes, which are those subjected to the highest stresses and stress gradients. The trends lose their distinction at the larger sizes, where stresses were the lowest. It is well known that, because they contain much greater surface areas, a unit mass of the finer materials requires much more energy to generate than do coarser fragments. The scatter in Fig. 4 as the larger fragments are considered likely requires a small expenditure of energy. Indeed, the surface area contained in the smallest calculated size bin (63 μm) typically contained on the order of 10^6-10^7 times more surface area than the largest bin. Assuming that the work required to form a unit of surface area is proportional to the surface area itself, the energy necessary to form the largest fragments represents a trivial fraction of the total expended in comminution. Thus, M_R/M_O represents minor variations in total comminution energy, and as such, can be influenced very easily by undetectable imperfections in target materials.

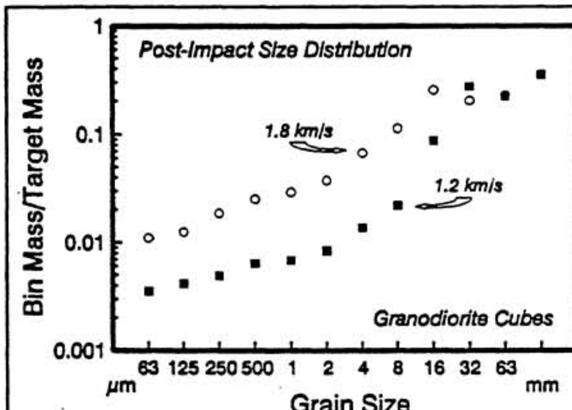

Figure 4. Size distributions for experiments at the lowest and highest velocities employed in this study. Note the similarities in the distributions until the largest sizes are considered.

Concluding Remarks: Scatter in distributions of the largest remaining fragment with increasing specific impact energy is real and can be very pronounced. The variations evident in Fig. 1 cannot be described as being entirely random, since some fragments cluster near a "maximum" largest remaining fragment for a given specific energy. It is clear, however, that the normalized mass of the largest remaining piece is not particularly diagnostic for use as a scaling parameter over a range including the lower energies. It appears likely, on the other hand, that a definite but as yet undetermined specific energy exists, beyond which this ratio could be used effectively. At the lower velocities, the cumulative mass of a particular number of largest fragments might be more useful, but an objective means of evaluating the largest few fragments would be the more informative. Grain-size distributions and surface-area calculations suggest that the variation in the largest remaining fragments is due to random weaknesses within each target, indicating an uncontrollable factor when M_R/M_O is used as a descriptive parameter. As described previously,[3] it appears that the specific surface-area created per unit of impact energy remains the least ambiguous descriptor of collisional-disruption events.

References: 1 Gault, D.E. and Wedekind, J.A. (1969) *JGR 74*, 6780. 2 Fujiwara, A. *et al.* (1977) *Icarus 31*, 277. 3 Cintala, M.J. and Hörz (1984) *LPS 15*, 158. 4 Housen, K.R. and Holsapple, K.A. (1990) *Icarus 84*, 226. 5 Fujiwara, A. (1980) *Icarus 41*, 356.