

SCALING OF FRAGMENTATION EXPERIMENTS CONDUCTED AT ELEVATED PRESSURE.

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The goal of most impact fragmentation experiments has been to discover the effects which collisions have had on asteroids and planetary satellites. A difficult hurdle in this task is to understand the differences between the disruption of an asteroid sized object and the much smaller bodies which can be studied in the lab. For example, Davis *et al.*¹ first suggested that the threshold energy per unit target mass, Q^* , required to fragment a large gravity-dominated asteroid may be much larger than that measured for small targets, because the self compression in large objects enhances their strength. Housen and Holsapple² show a similar trend for large bodies but additionally have shown that in the strength dominated regime strain rate effects can cause Q^* to decrease as target size increases. Therefore as target size increases from those used in experiments to those of asteroids, Q^* is expected to first decrease, level off, and then increase when the target size is large enough that gravity effects dominate over those of material strength.

The dependence on target size makes it difficult to estimate Q^* for large gravity-dominated objects. Most estimates are based on models which consider Q^* to be a function of the sum of a strength term and the gravitational compressive stress. However differences in model assumptions have resulted in order of magnitude discrepancies in estimates for the gravity regime (ref 2).

This situation is analogous to that in impact cratering where, given experimental data in a strength dominated regime, one needs to predict crater size in the gravity regime. To overcome the scaling uncertainties, experiments are required in which the lithostatic stresses are larger than the governing material strength measure. The Boeing centrifuge has been used successfully in the cratering problem to obtain data directly in the gravity regime. Unfortunately, centrifuge methods are not as useful for fragmentation studies because the geometry of an asteroid's gravity field cannot be directly simulated and because the requisite gravity levels cannot currently be attained.

The purpose of this study is to explore another simulation method which can give insights into large scale fragmentation events. Spheres of diameter 10-15 cm were explosively fragmented under a high pressure ambient atmosphere. The overpressure provides a compressive stress of the same magnitude as the gravitational compression in large asteroids. The details of the experiments are given by Schmidt and Housen³. Here we consider a scaling relation which correlates the results for various pressures and which can be applied to fragmentation at large scales.

Consider the mass, M_L of the largest remnant from an explosive fragmentation event and its dependence on the overpressure P , the target mass, M , density ρ , and tensile strength Y , the explosive mass m , specific energy q and density δ . For simplicity, we consider the strength Y to be rate and size independent here because the experiments involved only small variations in the strain rate. The details of scaling for a rate dependent strength can be found in ref. 2. A useful scaling relation can be obtained by adopting a point source approximation for the explosive. Additionally fracture of the target is assumed to occur only if the shock induced stress exceeds the sum of the material strength and the ambient pressure P . Omitting the algebra, one finds for a fixed target density and explosive density,

$$M_L / M = F \{ Q [Y + P]^{-3\mu/2} q^{(3\mu-2)/2} \}. \quad (1)$$

F is an unspecified function, $Q = mqM$, and μ is a scaling exponent, nominally 0.5 to 0.55 (ref 4).

Fig. 1 shows our results for weakly cemented basalt, without adding P to Y . As expected, the low pressure results are consistently below those for high pressure, illustrating the enhanced strength of the targets for large P . Figure 2 shows the same data set using the pressure scaling shown in eq. (1). All data now lie on a common curve, suggesting (1) is a valid scaling form for these data.

The results can be applied to the disruption of large bodies. For a homogeneous sphere, the volume averaged stress in a body of radius R and density ρ is $\sigma(R) = 4\pi\rho^2GR^2/15 = 3.8 \times 10^{-7} R^2$ (cgs) for $\rho=2.6$. Equating the gravitational stress σ to P allows the overpressure used in the experiments to be related to R . For example, our test fixture can accommodate pressures up to 6000 psi, which corresponds to a body of radius 330 km, comparable to that of the largest asteroid.

The threshold conditions for catastrophic fragmentation can be determined from Figure 2. The value of the abscissa for $M_L/M=0.5$ is 1.7. Replacing P by σ gives the fragmentation threshold:

$$Q^* = 1.7[Y + 3.8 \times 10^{-7} R^2]^{3\mu/2} q^{-(3\mu-2)/2}. \quad (2)$$

Figure 3 shows Q^* as a function of R . The tensile strength of 1.2×10^6 dyn/cm² measured for our weakly cemented basalt was used for Y . Note, however, that while the adopted value of Y affects the value of R at which the strength/"gravity" transition occurs, it does not affect the position of the curve for large R . For comparison, two representative tests are shown which had values of M_L/M near 0.5.

Figure 3 also shows the specific energies which Fujiwara⁵ estimated for three Hirayama families. Traditionally, the curve based on the elevated pressure tests passes rather close to the families. Traditionally, fragmentation models have predicted that if an asteroid experienced a collision having a specific energy as large as that estimated for the families, the target would be pulverized, leaving only very small fragments. Partial reaccumulation of the debris has been invoked to explain the size of the largest family member, but reaccumulation to form other large members in the family is difficult to justify. This led Davis *et al.*¹ to the suggestion of the enhanced strength of large gravity dominated asteroids. The results here suggest that the strength of large bodies may even be larger than estimated by Davis *et al.* or Housen and Holsapple². If this is true, reaccumulation to form large family members may not be required.

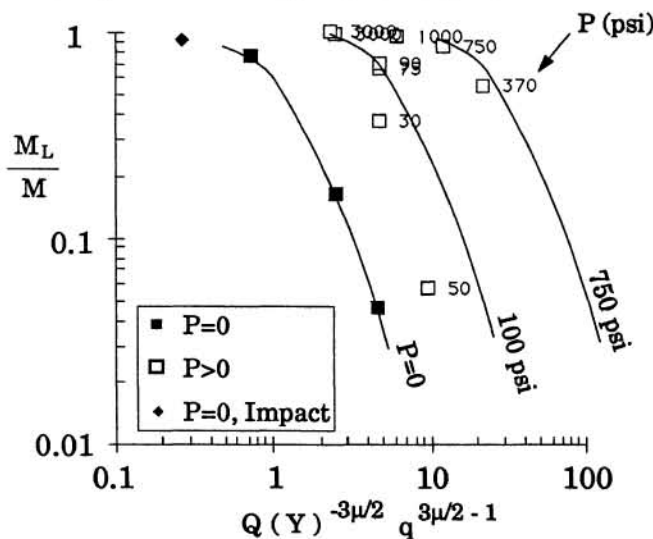


Fig 1. Explosive fragmentation results for various ambient pressures. For a given collisional specific energy Q , the mass of the largest remnant fragment increases at pressure increases, because pressure enhances the effective strength of the target.

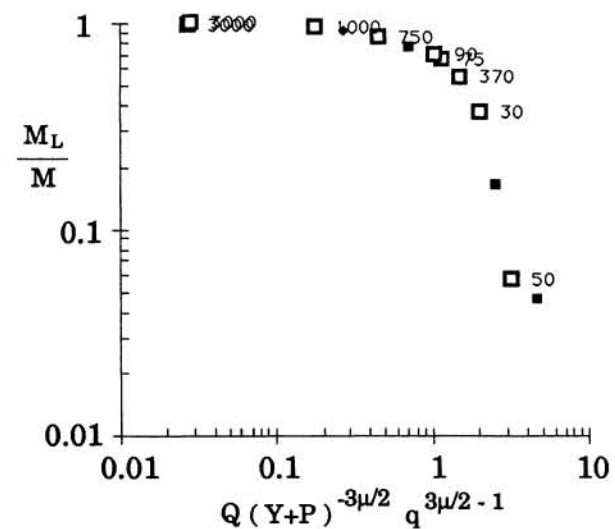


Fig 2. The same results as shown in Fig 1, except pressure is included in the scaling relation. The results for all pressures are correlated well.

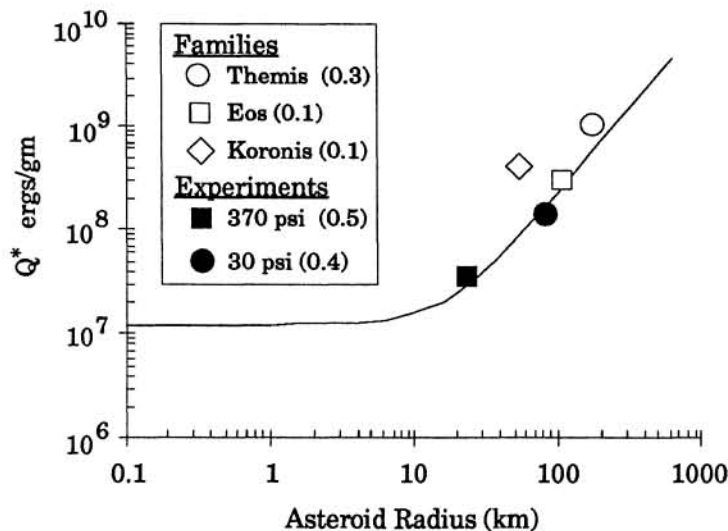


Fig 3. The curve represents the specific energy such that the largest remnant is 1/2 the mass of the original target as predicted by our elevated pressure experiments. Two data points are shown along with the three classical Hirayama families. The values of M_L/M are shown in parentheses.

Refs: (1) Davis *et al.* 1985, *ICARUS*, 62, 30-53. (2) Housen and Holsapple, 1990, *ICARUS*, 84, 226-253. (3) Schmidt and Housen, 1991, this volume. (4) Holsapple and Choe, 1991, this volume. (5) Fujiwara, 1982, *ICARUS*, 52, 434-443.