CRATER EJECTA VELOCITIES FOR IMPACTS ON ROCKY BODIES


Small rocky bodies should have negligibly thin debris deposits on their surfaces, according to regolith evolution models (1,2,3,4). In fact most regolith calculations suggest that rocky bodies with diameters below several tens of km should have at most thin dusty coatings. On the other hand, the generally subdued surface features observed in the recent (10/91) image of 951 Gaspra, while not conclusive, at least suggest a much thicker debris layer.

Small rocky asteroids were thought to be essentially barren because the high ejecta velocities associated with cratering in rock exceed the escape velocity. Virtually all estimates of ejecta velocities for rock have been derived from the impacts into basalt reported by Gault et al. (5). All ejecta measured by Gault et al. had velocities greater than 45 m/s, which is well above the escape velocity of a Gaspra-sized body (8.5 m/s).

However, the targets used in the experiments of Gault et al. are probably not representative of rock at the kilometer size scales of interest. Large masses of rock naturally contain cracks and joints with spacings large enough that they are not incorporated into the small samples used in the lab. These cracks could form either during the cooling of a differentiated body, or during subsequent noncatastrophic impacts. The presence of cracks serves to weaken the target, thereby lowering ejecta velocities. Therefore, the appropriate simulant of a rocky asteroid is probably not pristine crack-free rock, but rather a material which contains fractures and joints at a representative size scale.

The purpose of this abstract is to summarize the results of ejecta velocity measurements for impacts into targets fabricated from a material developed for simulations of large scale cratering in jointed rock. The material consists of, by weight, 50% basalt fragments (2.5 mm mean diameter), 20% iron grit (0.4 mm diameter), 24% fly ash and 6% water. The fly ash, which bonds the basalt fragments together, consists of two types whose relative proportions can be varied to achieve a desired strength.

Two impact experiments are reported here, which were identical except that one used a low-strength target and the other used a relatively stronger one. The initial conditions are listed in Table 1. The impacts were conducted at 1G, 1 atm pressure, and were filmed with a Fastax camera. As an aid in measuring ejecta velocities, a slotted aluminum plate was placed above the target surface to filter out all debris except those traveling in a plane perpendicular to the camera line of sight. A mirror adjacent to the target positioned at 45° to the line of sight verified the debris were in a common plane. Using the films, the positions and sizes of roughly 100 fragments were digitized as a function of time. Ballistic equations were used in a regression to find the initial launch conditions for each fragment. Ejecta velocity distributions were constructed by summing the masses of fragments with a given velocity or greater. These values were then divided by the fraction of the crater area exposed by the slotted plate to estimate the total mass from the crater which exceeded the given velocity.

The fraction of mass having velocity greater than v is shown in Figure 1. As expected, the low strength target used in shot 986 resulted in smaller ejection velocities than in shot 987. For comparison, the Gault et al. distribution for pristine basalt is also shown in Figure 1. The median ejection velocities for the present tests are about an order of magnitude lower than the Gault et al. data.

The large variation in strength for the targets shown in Figure 1 provides a test of ejecta scaling relationships. For example, Housen et al. (6) used a point source approximation for the impactor to show that, for strength dominated impacts,

\[ f(v) = F\left(v\sqrt{\rho / Y}\right) \tag{1} \]

where \( f \) is the fraction of debris faster than velocity \( v \), and \( \rho \) and \( Y \) are the target density and strength. Figure 2 shows the results in this form using the tensile strengths from Table 1 and a value of \( 1.4 \times 10^8 \) dyn/cm\(^2\) for the basalt impacts (7). The good correlation of the data in Figure 2 suggests that it can be used to determine velocity distributions for a wide range of target strengths.

The slope of the results in Figure 2 can be used as another scaling test. In the point source approximation, the impactor radius \( a \) and velocity \( U \) are replaced by a single parameter \( C = a U^\mu \). The scaling exponent \( \mu \) has been determined to be about 0.55 for the material used here (8). Housen et al. (6) demonstrated that for sufficiently large \( v \) the function in eq. (1) must be a power-law with an exponent of \(-3\mu\). Figure 2 shows that such a line, with \( \mu = 0.55 \), agrees reasonably well with the data.
The velocity distribution for pristine rock, which is typically used to model impacts on rocky asteroids, implies that virtually no ejecta should be retained on a small, Gaspra-sized body. However, it is unlikely that pristine samples of rock are good analogues of rocky asteroids. More likely, for large scale cratering of these bodies, the effective strength will be smaller than that of laboratory samples, perhaps as low as the rock simulant used here. In this case, Gaspra, as well as other small rocky asteroids could retain a significant fraction (50-70%) of their crater ejecta and thereby develop substantial regoliths.

Table 1

<table>
<thead>
<tr>
<th>Shot</th>
<th>Impactor mass (gm)</th>
<th>Target Strength (g/s)</th>
<th>Camera speed (fps)</th>
<th>Crater Dimensions (g/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>vel (km/s)</td>
<td>tensile</td>
<td>compress</td>
<td>volume</td>
</tr>
<tr>
<td>986</td>
<td>0.532</td>
<td>9.0x10^5 (13)</td>
<td>6.8x10^5 (99)</td>
<td>18.0</td>
</tr>
<tr>
<td>987</td>
<td>0.537</td>
<td>4.5x10^6 (66)</td>
<td>1.0x10^5 (1500)</td>
<td>4.79</td>
</tr>
</tbody>
</table>

Notes: (a) Impactors were 1/4" dia aluminum, density=2.7. (b) Strengths are quasistatic. Values in parentheses are p.s.i. Tensile strength is an estimate based on the compressive value and a relationship between the two values reported in Table 1 of ref (8). Note, the target density was 2.6 gm/cm^3. (c) Due to the presence of the plate above the target surface, crater dimensions were measured after inverting the sample to remove the debris within the crater.