The size-velocity distribution of crater ejecta has implications for a number of processes important in planetary science, such as the accretion of planets, the collisional evolution of asteroid populations, and the origin of certain meteorites. Definitive data on size-velocity distributions for large-scale cratering events do not exist yet. A number of investigators (1-4) have performed small-scale cratering experiments with projectile masses on the order of a few tens of grams and impact velocities of less than a few kilometers per second. As demonstrated by recent work on crater scaling (5), it is unlikely that the results of such experiments can be meaningfully extrapolated to large-scale events. Some data exist for natural (volcanic), nuclear, and chemical explosions (6-8), but explosions are not perfect analogs of cratering events. Some theoretical models exist, but none so far can describe completely enough to predict size-velocity distributions of all the ejecta. House et al. (9) can predict ejection velocities as a function of place of origin within the crater, but cannot predict sizes. Fragmentation models (10,11) can be used to predict size, but not velocity distributions. The Melosh spallation model (12) predicts the size-velocity distribution of spills, but these comprise only a small fraction of the total mass of ejecta. Because of the importance of the size-velocity distributions of large primary events on a number of planetary processes and the paucity of definitive data concerning it, an empirical study of the distribution of secondary craters associated with three large impact structures was undertaken.

The craters studied were the lunar craters Copernicus (d=93 km) and Aristillus (d=55 km) and the Martian crater Dv (d=26 km). These craters were chosen because they are relatively fresh and on young terrane, so that their secondaries are not easily confused with small primaries or with secondaries from other nearby craters. The diameter and distance from the primary (range) were measured for approximately 1000 secondaries around each of the lunar craters; because of the poorer resolution of the Viking photograph, however, only 115 secondaries were measurable around the Martian crater. The ejection velocity was determined from range, using the ballistic equation for a spherical planet (13):

\[ \phi = \tan^{-1}\left(\frac{v^2 \sin \theta \cos \phi}{(Rg-v^2 \cos^2 \phi)}\right) \]

Here, \( \phi \) is half the angular distance of travel, \( \theta \) is the ejection angle, \( R \) is the radius of the planet, \( g \) is local surface gravity, and \( v \) is the ejection velocity. It was assumed that \( \theta = 45 \). This velocity and the secondary crater diameter were then used in the Schmidt-Holsapple scaling law for dry sand (14) to estimate the size of the ejecta fragment whose impact produced the secondary crater.

The results are shown in Figures 1-3. That the data appear to lie along discrete curves is an artifact of the measurement technique: Crater diameters were measured only to the nearest tenth millimeter (Copernicus and Aristillus) or quarter-millimeter (Dv). The maximum size at a given velocity decreases with velocity, consistent with the concept that higher shock levels produce smaller fragments ejected at higher velocities.

In each case, there is an abrupt cutoff in the size-velocity curve at velocities of ca. 600-800 m/sec; any fragments accelerated to velocities greater than the cutoff velocity were too small to have produced detectable secondary craters. For Copernicus, no fragments larger than ca. 10 m had velocities greater than 935 m/sec; for Aristillus, the corresponding numbers are 18 m and 850 m/sec; and for crater Dv, they are 38 m and 735 m/sec. The larger size cutoff for the Martian crater almost certainly is the result of the much poorer resolution of the Viking photos compared to the Lunar Orbiter IV photos. The "true" cutoff velocity may be somewhat higher and the cutoff size lower. The existence of an abrupt discontinuity in the data from three different size craters on two different planets, all at <1 km/sec, indicates the discontinuity is real, and is not simply a result of the lack of finer resolution in the available photos. This implies that it is nearly impossible to accelerate large (>10 m) ejecta fragments to velocities much in excess of 1 km/sec. This is not inconsistent with a lunar origin for ALHA 81005, since it only had to have been a few centimeters in diameter when launched from the Moon. It becomes extremely difficult, however, to support the hypothesis that the SNC meteorites originated as >15 m pieces of ejecta launched from Mars at >5 km/sec.

References: (1) Gault, D.E. et al. (1963) NASA Publ. TND-1767; (2)
SIZE-VELOCITY DISTRIBUTION

Vickery, A. M.


Figure 1

Figure 2

Figure 3