THE SIZE DISTRIBUTIONS OF FRAGMENTS EJECTED AT A GIVEN VELOCITY FROM IMPACT CRATERS; J. D. O'Keefe and Thomas J. Ahrens, Seismological Laboratory 252-21, California Institute of Technology, Pasadena, CA 91125

Meteorites come from collisions on objects varying in size from asteroidal to terrestrial. Massive extinctions on the earth may have resulted from large impacts. The origin of meteorites is dependent on the maximum-size fragment that can be ejected at velocities exceeding the planetary escape velocity, whereas the biological consequence of large impacts is dependent on the number and mass of fine particles (diameters $\lesssim 10^{-6}$ m) that are ejected high into the atmosphere.

Using a model [1] developed to calculate the mass distributions of fragments ejected at a given velocity during impact events, we extend our previous work and have found additional results that strengthens these conclusions.

By definition, the cumulative amount of mass M_c of fragments ejected at all velocities of mass greater than m is given by

$$M_c \equiv \int_{V_{min}}^{V} \frac{\partial M_{cv}}{\partial V} f(m, m_{bv}(V)) dV \tag{1}$$

where $\frac{\partial M_{cv}}{\partial V}$ is the amount of mass ejected at velocities between V and V+dV, and $f(m, m_{bv}(V))$ is the unknown distribution of fragments ejected at V. The expression for the amount of mass ejected at a given velocity, M_{cv}, can be determined from the fits to the cumulative amount of mass ejected at velocities greater than v obtained either from theoretical calculations [1] or data [e.g. 2-3].

$$\frac{\partial M_{cv}}{\partial V} = \frac{\xi M_T}{V_{min}} \left[\frac{V}{V_{min}}\right]^{-(\xi+1)} \tag{2}$$

where M_T is the total amount of mass ejected. The exponent is related to the crater volume scaling parameter $\overline{\alpha}$ [3] by $\xi = 6\overline{\alpha}/(\overline{\alpha}-3)$

The key assumption in the theory is that the functional form of the distribution of fragments ejected at a given velocity is the same as the distribution function of the fragments in the ejecta blanket. For explosive events Jaeger et al. [4] have found that this is the case. With this assumption the cumulative fraction of mass fragments of mass greater than m is given by

$$f(m, m_{bv}(V)) = \left[1 - \left(m/m_{bv}\right)^{\frac{\beta}{3}}\right] \tag{3}$$

In addition, we assume that the mass of the largest fragment ejected at a given velocity is a function of the velocity of ejection and is given by

$$\frac{m_{bv}(V)}{m_b} = \left(V/V_{min}\right)^{-\delta} \tag{4}$$

where δ is an unknown parameter to be determined. From both explosion cratering data [5] and planetary cratering observational analysis [6], $\delta = 3$ is a reasonable fit to the data (see Figure 1). In addition, if the theory of Grady and Kipp [7] is used to relate the mass of the largest fragment to the strain-rate, it can be shown from a knowledge of the surface velocity field ($V \propto (r/R_c)^{-3/\xi}$) [3] that the exponent $\delta \equiv \frac{(\xi+3)m}{m+3}$, where $m \simeq 8$ [7]. For a variety of materials, δ ranges from 3 to 3.6. Now eq. 1 can be integrated to give

$$\frac{M_c}{M_T} = \left[1 - \left(\frac{m}{m_b}\right)^{+\frac{\xi}{\delta}}\right] + \left(1 - \frac{\delta\beta}{3\xi}\right)^{-1} \left[\left(\frac{m}{m_b}\right)^{+\frac{\xi}{\delta}} - \left(\frac{m}{m_b}\right)^{\frac{\beta}{3}}\right] \tag{5}$$

This in turn can be compared to fits to experimental data [2,8,9] given by

$$M_c/M_T = [1-(m/m_b)^{\alpha/3}] \tag{6}$$

where $m_b = 0.2M_T^{0.8}$ [2]. The data can be fit with $\beta \simeq 0.5$ (see Figure 2). Note that this has the same value as the cumulative mass distribution exponent α (Eq. 6). This means that the distribution of fragments ejected at a given velocity is polydispersed and that in the flow and ejection process, grinding and crushing has occurred, since fracture processes are more monodispersed [7,10].

The following is an expression for the cumulative mass of fragments of mass greater than m, that are ejected with velocities less than V

$$M_{cv} = M_T \left[1 - \left(\frac{V}{V_{min}}\right)^{-\xi}\right] \left[1 - \left(\frac{m}{m_b}\right)^{\frac{\alpha}{3}} \left(\frac{V}{V_{min}}\right)^{\frac{\delta\alpha}{3}}\right] \tag{7}$$

where M_T is the total mass ejected from a crater and V_{min} is the minimum velocity of ejection.

References

[1] O'Keefe, J. D., and Ahrens, T. J. (1985), *Icarus*, **62**, 328-338. [2] Gault, D. E., Shoemaker, E. M., and Moore, H. J. (1963), *NASA Publication TND-1767, p. 39.* [3] Housen, K. R., Schmidt, R. M., and Holsapple, K. A. (1983), *J. Geophys. Res.*, **88**, 2485-2499. [4] Jaeger, Z., Englman, R., and Slotky, D., to be published. [5] Schoutens, J. E. (1979), *Nuclear Geophysics Sourcebook, IV-Part II,* Rep. DNA 65 01H-4-2, Defense Nuclear Agency, Washington, D.C. [6] Vickery, A. M. (1984), abstract, *Lunar Planet Sci. XV,* 880-881. [7] Grady, D. E. and Kipp, E. (1980), *Int. J. Rock Mech. Min. Sci. & Geomech. Abstr.*, **17**, 147-157. [8] Lange, M. A. and Ahrens, T. J. (1981), *Proc. Lunar & Planet. Sci. Conf. 12th,* Pergamon Press, New York, pp. 1667-1687. [9] Fujiwara, A., Kamimoto, G., and Tsukamoto, A. (1977), *Icarus,* **31**, 277-288. [10] Hartmann, W. K. (1969), *Icarus,* **10**, 201-203.

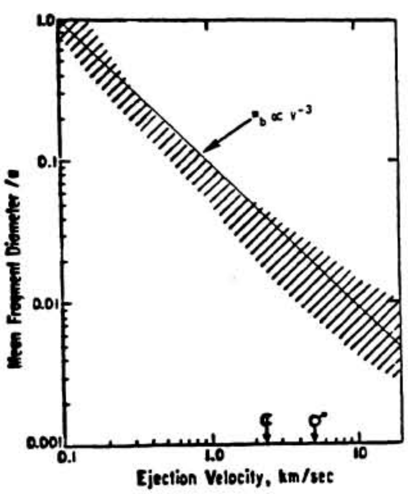

Fig. 1. Envelopes of largest fragments versus ejection velocity from selected Lunar and Martian craters (Vickery, [6]) mass of fragments correlates with $\delta = 3$.

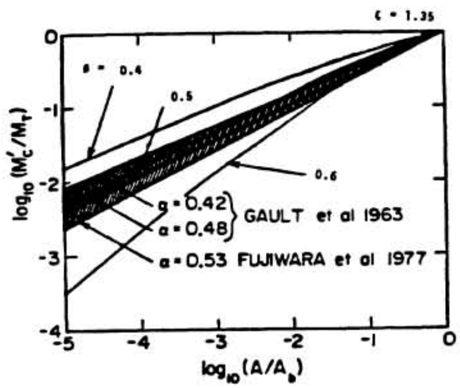

Fig. 2. Cumulative mass M_c' (ejected at velocity V) normalized by the total mass M_T (ejected at velocity V) versus fragment size normalized to the largest fragment ejected at velocity V. Data is for a value of $\xi = 1.35$ as indicated and theoretical curves are present for $\beta = 0.4$, 0.5, and 0.6.