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BREAKUP OF METEOROIDS IN THE VENUSIAN ATMOSPHERE AND ITS EFFECTS ON CRATER FORMATION

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Introduction. Early results of the Magellan mission to Venus show that almost all of the observed impact craters appear to be unaffected by erosion, burial, and tectonic deformation (1). Therefore it is reasonable to assume that the observed paucity of small craters in the cumulative size-frequency distribution (SFD) relative to the simple power laws observed on airless planets is most likely due to atmospheric effects on the incoming meteoroids. Furthermore, many of the impact events appear to be formed by multiple fragments, indicating breakup of the initial meteoroid in transit through the atmosphere.

Simple models (2,3) have been used to predict a minimum crater diameter and certain features of the SFD using data from the Venera mission. However, these models did not include the effects of gravity on the meteoroid's trajectory and they did not model meteoroid breakup. Passey and Melosh (4) developed a model for travel and breakup of a meteoroid in an atmosphere, but their model was never used to estimate a SFD. Our study attempts to match the cumulative SFD and the number and size distribution of multiple-floored craters and crater fields using the Passey and Melosh model.

Procedure. Passey and Melosh give a set of five coupled first order differential equations that describe passage of a meteoroid through the atmosphere using a drag force equal to $C_d \rho_a A V^2$ where C_d is the drag coefficient, ρ_a is atmospheric density, A is cross-sectional area of the meteoroid, and V is meteoroid speed. Although ablation is included in the calculations, it has a negligible effect on the size of meteors considered here. Atmospheric density is assumed to be as in (2) and all other parameters are as in (4) unless otherwise specified. Breakup of the incoming meteoroid occurs when the pressure differential between its front and back becomes greater than the yield strength. A yield strength of 10 MPa was assumed. It was also assumed that the meteoroid breaks into four fragments 1/2, 1/4, 1/8, and 1/16 of the initial mass with the remaining mass (1/16) discarded.

To generate a SFD one must know the size, velocity, density and angular dependence of the incoming meteoroids and then have a way to convert this information into crater diameters. We assumed a size distribution proportional to $R^{-\alpha}$ (R is radius, α constant), a velocity distribution evenly spaced from 10 to 25 km/s, angular dependence proportional to $\sin\theta\cos\theta$ (θ is angle with respect to the planetary surface), and initially a meteoroid density of 3000 kg m^{-3} (corresponding to "stony" asteroids). We used a diameter scaling function based on crater gun work (5) with an adjustment factor of 2.6 to a) bring this function in line with those derived from pi-scaling (6) and explosion craters (7) and b) account for rebound and slumping of the transient crater. The initial meteoroid and its corresponding four fragments were integrated down to the surface, and a downrange distance and crater diameter were calculated for each. The final crater diameter was calculated as the greater of the following: a) the diameter D produced by an unbroken meteoroid or b) $0.5(D1 + D2) + dx$, where $D1$ and $D2$ are the diameters produced by the largest and smallest fragments that reach the surface, and dx is their separation. If dx is $>0.5D$, then the crater is assumed to be multiple floored or a crater field is formed. It was assumed that any objects that strike the surface below a critical velocity V_{cr} do not form craters.

The three parameters that were allowed to vary to match the observed SFD were C_d, V_{cr}, and α. The parameter α primarily controls the overall slope of the resulting SFD with larger values giving steeper slopes. Increasing either C_d or V_{cr} has the general effect of increasing the minimum size crater formed.

Results and Discussion. The best fit to the observed data was obtained using $C_d = 1.5$, $V_{cr} = 3$ km/s, and $\alpha = -2.5$. The cumulative and incremental ($\sqrt{2}$ binning) size-frequency distributions are shown in Figures 1 and 2 for the observed data, the modeled data, and the data modeled in the absence of an atmosphere. The model data fits the observed data reasonably well, with three main discrepancies:

1. The model could not reproduce the flatness of the incremental SFD for craters 10–30 km in diameter. This flatness produces the gentle roll-off in the observed cumulative SFD.
2. In order to match the roll-off in the cumulative SFD for large diameters, C_d and V_{cr} had to have large values; this produced no craters below ~6 km in diameter, as compared to the observed 3-km cutoff (1).
3. Large values of C_d and V_{cr} also prevented all but a few multiple-floored craters from forming in the model data.

The values required for C_d and V_{cr} are plausible, but seem rather high. This may indicate that either meteoroid breakup or cross-sectional area is being modeled incorrectly. At least some of the discrepancy between data and model can be alleviated by including a small percentage of iron meteoroids. Assuming that only the density is different for iron meteoroids (8000 kg m^{-3}), they will have a lower diameter cutoff and produce more multi-floored craters. Combined with stony meteoroids, iron meteoroids will lead to a smoother roll-off in the cumulative SFD.

Future work. It is important to note that the unique shape of the size-frequency distribution, the lack of erosional effects on this distribution, the cutoff in crater diameter, and the distribution of multiple-floored craters make this problem well constrained. Further evaluation is required of the physical model and its input assumptions, and the effects of varying different parameters needs to be explored further.

References. (1) Phillips, R. J., *et al.*, 1991, *Science,* in press. (2) Ivanov, B. A., *et al.*, 1986, *JGR, 91,* D413–D430. (3) Ivanov, B. A., 1991, *EM & P, 50,* in press. (4) Passey, Q. R. and H. J. Melosh, 1980, *Icarus, 42,* 211–233. (5) Gault, D. E., 1974, *A primer in lunar geology*, NASA Ames, 137–175. (6) Holsapple, K. A. and R. M. Schmidt, 1982, *JGR, 92,* 1849–1870. (7) Nordyke, M. D., 1962, *JGR, 67,* 1965–1974.

Figure 1: Cumulative Size-Frequency Distribution

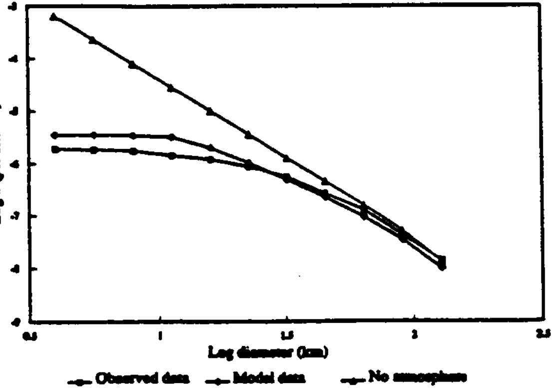

Figure 2: Incremental Size-Frequency Distribution