BALLISTIC DIFFUSION ON PLANETARY SATELLITES. S.W. Squyres, NASA Ames Research Center, Moffett Field, CA 94035, and C. Sagan, Cornell University, Ithaca, NY 14853.

A number of models have been formulated to describe regolith evolution on airless bodies (1,2). Because the principal bodies of interest in these models have been the Moon and asteroids, the effects of variation of the impact flux across the body have been quite properly neglected. For satellites in synchronous rotation around large outer solar system planets, however, the variation in impact flux can be substantial. For example, the calculated cratering rate at the apex of orbital motion on Mimas, Saturn's innermost major satellite, is more than 18 times the cratering rate at the antapex (3). The flux gradient across the satellite is a simple result of the very high orbital velocity. We find that the flux gradient can result in appreciable erosion on the leading hemisphere and deposition on the trailing hemisphere, especially for small, low-gravity satellites. Particles on the leading hemisphere have a relatively high probability of being ejected and landing on the trailing hemisphere, but, because of the lower impact flux on the trailing hemisphere, a smaller probability of being returned by subsequent impacts to the leading hemisphere. The net result is diffusion of surface material from the apex toward the antapex in response to the impact flux gradient.

Consider a point on a synchronously rotating satellite with latitude Θ and longitude Φ. Let J be a function that gives the mass flux of meteoritic material striking the surface at any point. J will be largest at the apex of orbital motion and smallest at the antapex. Call f the ratio of the mass of ejecta generated during an impact event to the mass of the projectile. The rate of removal of material from a surface element at (Θ,Φ) by impact ejection is therefore $fJ(\Theta,\Phi)$. Now, call α the angular distance along the surface from an impact point. There is a function $F(\alpha)$ that describes the mass distribution of ejecta produced by an impact. It is greatest immediately adjacent to the point of impact (where α is close to zero), and decreases with increasing angular distance away from the impact point (i.e., with increasing α). The net erosion or deposition rate at any point on the satellite's surface may then be calculated by summing the removal rate due to ejection with the rate at which material is deposited from impacts on all other parts of the satellite:

$$dM/dt(\Theta,\Phi) = -fJ(\Theta,\Phi) + fR^2\int_0^{\pi}\int_0^{2\pi}F(\alpha)J(\alpha,\xi)\sin\alpha d\xi d\alpha$$

In this expression, R is the radius of the satellite and ξ is the azimuth from the point under consideration. If $J(\Theta,\Phi)$ and $F(\alpha)$ are known, then the erosion and deposition rates can be calculated as a function of position on any object.

To simplify the calculation, we have assumed the flux distribution $J(\Theta,\Phi)$ to be radially symmetric about the apex-antapex axis, and to be given by:

$$J = J_{max} - (J_{max}-J_{min})\,\frac{1-\cos\psi}{2}$$

where ψ is the angular distance across the surface from the apex.

BALLISTIC DIFFUSION

Squyres, S.W., and Sagan, C.

Calculation of the ejecta distribution function $F(\alpha)$ requires knowledge of the ejection angle and velocity distribution of the ejecta, and the size and mass of the satellite. For our model we use the ejection angle and velocity distribution functions measured by Gault and Heitowit (4) for hypervelocity impacts into basalt. We then introduce a velocity scaling factor q which may be varied to account for the lower ejecta velocities that result from impacts into less cohesive material. With the model distribution functions established, we then determine $F(\alpha)$ by calculating the angular distances at which the orbits of all ejecta perticles reintersect the surface of the satellite. Ejecta particles which are put on escape trajectories are considered to be permanently lost.

In order to investigate the process, we have considered an arbitrary satellite with a radius of 500 km, a density of 2.0 g cm^{-3}, an apex meteoritic mass flux $J_{max} = 10^{-9}$ g cm^{-2} yr^{-1}, and an antapex mass flux $J_{min} = 10^{-10}$ g cm^{-2} yr^{-1}. We have then varied each of the major parameters individually: density, radius, velocity scaling factor q, and flux differential J_{max}/J_{min}. The net amount of regolith transport by ballistic diffusion is inversely proportional to the satellite density. The dependence on satellite radius is more complex. For very large satellites the effect is small, because the large gravity results in most ejecta traveling only small angular distances from the impact point. With decreasing radius, the effect becomes much more pronounced. For very small satellites ($R < 25$ km), however, there is a net erosion over the entire body, as significant quantities of ejecta reach escape velocity. As expected, the amount of transport decreases with decreasing velocity scaling factor and flux differential.

We have done preliminary calculations of ballistic diffusion for some outer planet satellites. For the smaller satellites the effect may be quite pronounced. For example, our calculations suggest that there may have been several tens of meters of erosion on the leading hemisphere of Mimas over the age of the solar system. Iapetus, which probably experiences a very strong flux gradient due to head-on impacts with retrograde debris from Phoebe, may have undergone several meters of erosion on its leading hemisphere. Ballistic diffusion may be related to the leading hemisphere/trailing hemisphere albedo asymmetries observed on some satellites, particularly the pronounced one on Iapetus.

Acknowledgments- We are grateful to Brian Hirano for assistance in performing the calculations, and to Don Gault for helpful discussions.

References

(1) Shoemaker, E.M., et al. (1970) Proc. Apollo 11 Lunar Sci. Conf., p. 2399-2412.
(2) Housen, K.R., et al. (1979) Icarus 39, 317-351.
(3) Smith, B.A., et al. (1981) Science 212, 163-191.
(4) Gault, D.E., and Heitowit, E.D. (1963) Proc. Sixth Hypervelocity Impact Symp., 419-456.