A COMPARISON OF CURRENT ASTEROIDAL-REGOLITH MODELS.

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To date, several models concerning the evolution of asteroid surfaces have been constructed. The early efforts provided crude estimates of regolith properties. Recently, two models (1,2) have emerged which are considerably more detailed than their predecessors. However, numerical estimates of regolith depth appear to differ by a factor of a few. The purpose of this abstract is to compare the two recent models in order to understand the source of disparity.

Housen *et al*. (1) constructed a regolith model to describe that portion of an asteroid's surface (called the "typical region") which is saturated with the effects of small craters. At time *t* only craters smaller than some diameter $D_s(t)$ saturate the surface and hence are contained in the typical region. These craters deplete the regolith because some ejecta is lost to space. On small asteroids, where ejecta from a crater are widespread and hence "saturate" the surface, all of the large craters excluded from the typical region contribute to regolith buildup. On bigger asteroids, where ejecta are not widespread, only craters smaller than some diameter $D'_s(t)$ have ejecta deposits which saturate. Ejecta from larger craters are excluded from the typical region.

Saturation of craters was defined to occur when they occupied a given fraction of the total surface area. To facilitate a definition of ejecta saturation, annuli were drawn around craters; saturation occurred when the annuli occupied a given fraction of the surface. Two types of annuli were considered. The width (i.e. outer radius - inner radius) of a Type 1 annulus is a constant a_1 as suggested by some theoretical considerations of ejecta velocities. The width of a Type 2 annulus is a constant a_2 times the crater diameter, *D*, as suggested by some studies of ejecta blanket profiles. The constants were chosen so that an annulus incorporated 90% of a crater's ejecta.

The size-frequency distribution of craters was found by combining estimates of the mass flux of debris in the asteroid belt with relationships (crater scaling laws) between impact energy and *D*. Two types of cratering laws were used: strength scaling, where *D* is determined by target strength and gravity scaling, where gravitational effects determine *D*.

Housen *et al*. considered ejecta on rocky asteroids $\leq$ 300 km in diameter to be widespread. Roughly 3.5 km of regolith accumulated on a 300 km body before catastrophic fragmentation occurred. Even though larger asteroids retain more ejecta, they develop less regolith because the ejecta of craters bigger than $D'_s(t)$ are excluded from the typical region. For example, a depth of ~1.2 km was computed for both a 500 km and a 1000 km asteroid.

Langevin and Maurette (2) (denoted by L-M) have also developed a regolith model. They considered the regolith depth at a point on the surface but in essence excluded the effects of large craters until saturation had occurred and so effectively modeled a "typical region" similar to Housen *et al*. Saturation of ejecta was defined to occur at a time when circles, drawn around the craters, became sufficiently numerous to meet their

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mathematical criterion. The radius R_c of a circle was determined from estimates of ejecta velocity distributions. For gravity scaled craters, they set $R_c = D$. For strength scaled craters, they used R_c = constant, depending on gravity and target strength. A projectile mass flux for asteroids was estimated as 30 times the 1-AU flux, which was found by using crater scaling laws to "invert" the lunar crater distribution. Scaling laws were then applied to yield a crater distribution for asteroids. Regolith depths at fragmentation were found to be 800 m, 500 m and 250 m for rocky bodies of diameter 300 km, 500 km and 1000 km.

Why are these depths smaller than those of Housen *et al.*? For the 300 km body, the difference is primarily due to the Housen *et al.* assumption of globally distributed ejecta. This assumption was justified by computing the radial distance (~410 km) which encompassed 90% of the ejecta. Thus 90% of the ejecta is spread over 95% of the surface. However, the ballistic range for the 50th percentile of ejecta is ~45 km, which corresponds to only ~2% of the area. Although choosing between the 50th or 90th percentile, in deciding how widespread ejecta blankets are, cannot be rigorously justified, the fact that 50% covers only 2% of the surface implies the Housen *et al.* assumption is not correct for this body. If ejecta is considered to be localized, according to the L-M ejecta velocity model described below, then the depth decreases to ~1.5 km because some ejecta from large craters are now excluded from the typical region. The assumption of globally distributed ejecta should be reasonable for the modeled asteroids smaller than 300 km.

We now consider three reasons for discrepency in calsulations for bodies > 300km, for which both Housen *et al.* and L-M considered ejecta to be localized.

(1) *Differences in definitions of saturation*. The "saturation criterion" used by L-M effectively determines expressions for $D_s(t)$ and $D_s'(t)$. The functional form differs slightly between the two models (3). By substituting their expressions into the Housen *et al.* evolution equations one finds that, depending on asteroid size, the L-M criterion produces regoliths ~10%-100% deeper than the Housen *et al.* criterion. Clearly this does not explain the lower depths found by L-M.

(2) *Differences in crater flux*. The crater-size distributions are apparently similar in shape except for a relative x10 depletion in the L-M flux at D~1km. The exact flux used is not stated by L-M, so the effect of the differing fluxes is hard to determine; however, the effect should be minor because the craters which affect regolith depth the most are considerably larger than 1 km.

(3) *Velocity of crater ejecta*. The ejecta model of L-M is similar to the Housen *et al.* annuli. L-M assumed the fraction of ejecta with velocity $>v$ to be (v_c/v), where v_c is the ejecta velocity at a crater rim. For gravity scaled craters they used $v_c=\sqrt{gD}/12$, where g is gravity. If the ballistic-range equation is used, it is easy to show that 90% of ejecta lie within a distance $R_c=D$. This corresponds to the Type 2 model of Housen *et al.* with a_1=0.5. For strength scaled craters the L-M value of v_c depends on target strength but is independent of D. In this case R_c is a weak function of D but, for values of D appropriate to strength

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scaling, R_c and hence the width of a Housen et al. annulus, are roughly constant. Thus, strength scaling corresponds to a Type 1 annulus.

Although the strength and gravity scaling cases of L-M are equivalent to Type 1 and 2 annuli, the assumed sizes for ejecta deposits differ. For example, for the 500 km body, where gravity scaling applies, the L-M model implies a_2=0.5, but Housen et al. used a_2=1.4. The reason for this discrepency is that Housen et al. annuli widths were ultimately derived from ejecta velocity data that pertained to strength scaling (where velocities are high) rather than gravity scaling. Their regolith depths are larger because the more widespread ejecta is incorporated into the typical region faster than in the L-M model.

The lower ejecta velocities of L-M also means that more ejecta is retained on asteroids. Moreover, the fraction of escaping ejecta for gravity scaled craters is dependent on crater size (Housen et al. assumed the fraction was constant).

By repeating the Housen et al. calculations, with a_2=0.5 and a diameter-dependent fraction of escaping ejecta for gravity scaled craters, a regolith depth of ~ 900 m was calculated for both a 500 km and a 1000 km asteroid.

Summary. The main difference between the two regolith models is in the assumed velocity distribution of ejecta. Housen et al. somewhat overestimated regolith depths by overestimating ejecta velocities. The difference in crater flux is not expected to play a major role. In any event the uncertainties involved in estimating the flux preclude judging one flux model as better than the other and instead indicate some of the uncertianties involved in regolith depth calculations. The Housen et al. saturation criterion results in thinner regoliths than L-M. Again, neither model is more "correct" than the other because the "degree of saturation" required to produce a nearly uniform debris layer in the typical region (so that the average value meaningfully characterizes the actual distribution of regolith depths) is itself ill-defined. However, the Housen et al. model does seem preferable because the exact portion of the surface modeled is clearly defined. The Housen et al. model (with the same ejecta velocities as L-M) still gives deeper regoliths than L-M. This may be due to factors not considered above, e.g. the fragmentation lifetimes of asteroids (and the dependence on asteroid size) differ between the two models. The method used by L-M in computing lifetimes has not yet been published, so a comparison cannot be made at this time.

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Refs: (1) Housen, K.R., Wilkening, L.L., Chapman, C.R., and Greenberg, R. (1979). Icarus 39, 317-351 and Asteroids (T. Gehrels, ed.), 601-627. (2) Langevin, Y. and Maurette, M. (1980). Lunar and Planet. Sci. XI, 602-604. (3) Housen, K.R. (1981). Ph.D. Dissertation, Univ. of Ariz.

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