SIMPLE NON-FLUVIAL MODELS OF PLANETARY SURFACE MODIFICATION, WITH APPLICATION TO MARS.

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Introduction: Simple models of geomorphic modification of planetary surfaces by erosion or deposition are reported here. These processes are linear and non-linear creep, uniform accrescence and decrescence, and non-linear airfall deposition. They do not include models of flow whose depth is of the same order of magnitude as the landform, such as glacial flow or relaxation of crater forms in planetary ices. The models are applied to a simulated saturation cratered surface whose dimensions are 25.6 x 25.6 km and represented on a 256 x 256 grid, using crater statistics from [1] (Fig. 1).

Creep: Creep is the lateral transport of surface materials under the influence of gravity. A model of creep with theoretical, experimental, and terrestrial observational evidence has been proposed by [2]. The creep flux, q, is given by:

$$q = S \Big/ \left[1 - \left(S/S_c \right)^2 \right], \qquad (1)$$

where S is the slope gradient. The denominator provides for accelerated creep as gradients approach a critical gradient, S_c (for cohesionless materials this is the angle of repose). If gradients are low the rate law for surface modification is simply linear diffusion. Creep produces a surface resembling an out-of-focus photograph (Fig. 2). In advanced stages of surface modification when gradients are small the denominator term is unimportant. Few large planetary surfaces resemble Figure 2, because the efficiency of creep diminishes as the inverse square of the distances over which it must transport material.

Uniform Accrescence and Decrescence: Uniform surface erosion (decrescence) or deposition (accrescence) on a planetary surface produces distinctive landforms. Erosion or deposition occurs normal to the exposed surface, so that the rate of vertical elevation change, dz/dt, is a function of the slope angle, θ:

$$dz/dt = \left(1/Cos\theta \right) dn/dt\ , \qquad (2)$$

where dn/dt is the normally-directed rate of erosion or deposition (which is assumed to be spatially and temporally constant). Without the cosine term, the surface shape would be unchanged by erosion or deposition.

Decrescence. Uniform decrescence has been applied to the lateral erosion of scarps in layered rocks [3], and the process produces scarp planforms that are characterized by broad reentrants and sharp points. The pattern of scarps in the Martian "Swiss cheese" terrain exemplifies this morphology (Fig. 4). When applied to erosion of a cratered surface, decrescence (2) steepens and backwastes the inner crater rim of larger craters, eroding into the inter-crater uplands and adjacent smaller craters, while smoothing the crater floor and smaller craters (Fig. 3). Details of the simulation (such as the "ghosts" of the original location of the inner edge of inner crater wall and the differential effect on large versus small craters) are suspect because a 3x3 grid is used to calculate the slope angle.

Accrescence: Uniform build-up of a scarp or surface produces broadly-rounded projections and sharp inward-pointed reentrants (a "cumulate" planform). Chemical precipitation in water-filled terrestrial caves produces such patterns. When applied to a cratered surface (2) produces broadly-rounded crater rims and, if sufficient deposition occurs, negative conical crater interiors, producing an overall "doughnut" appearance (Fig. 5).

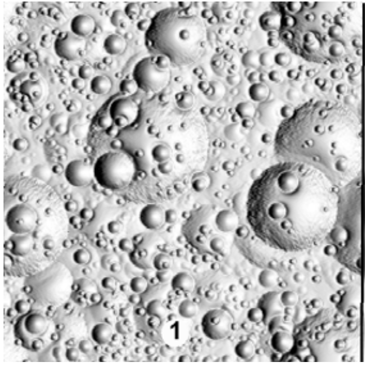
A mantling blanket has been deposited over much of the mid latitudes of Mars [4,5]. Pre-existing crater rims and fluvial valley walls often have the rounded nature characteristic of accrescence (Fig. 6).

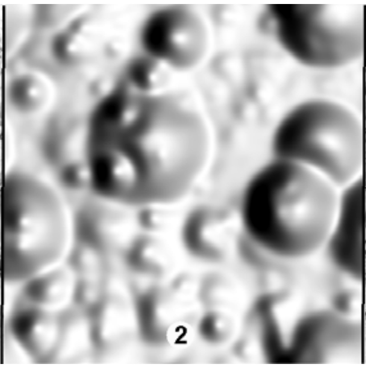
Only certain types of deposition can produce uniform accrescence. Vertical sedimentation from a quiescent fluid (e.g., settling atmospheric dust or suspended sediment in lakes) does **not** produce this pattern, because the capture cross section is proportional to the cosine of the slope angle, cancelling the cosine in (2). Chemical sedimentation can produce such a surface. For the mid-latitude debris blanket, a possible mechanism is multiple episodes of uniform accumulation of an ice cover precipitated on the surface from the atmosphere, with incorporated dust remaining on the surface as the ice sublimates. If the original morphology of the crater rim or scarp edge can be estimated, the degree of rounding during accrescence can be used to estimate the thickness of the deposit.

Eolian Sedimentation: Airfall and eolian degradation is modeled by a heuristic set of rules that model deposition and erosion as a nonlinear function of the degree of exposure of a given location. Locations on or near ridges or isolated peaks (e.g., crater rims) are either eroded by eolian stripping and abrasion or receive diminished rates of sedimentation relative to relatively sheltered locations, such as crater floors and lower walls, which undergo net aggradation. Details of the model are reported in [6]. Application of this model to a cratered surface produces sedimented crater floors with general parabolic form while the rims remain exposed (Fig. 7). Smaller craters within larger craters or depressions are eradicated. Similar filled craters are abundant in the equatorial highlands (Fig. 8).

Discussion: These simple models will rarely completely describe erosional or depositional processes on planetary surfaces. However, they can be the starting point for more comprehensive models. For example, models of decrescence can include effects of gradient, layering, secondary radiation, and accumulated dust on ablation rates [7,8,9].

References: [1] Garvin, J. B. et al. (2003) *Mars 6 Conf.*, Abstr. 3277. [2] Roering, J. J. et al. (1999) *Water Resour. Res., 35*, 853-870. [3] Howard, A. D. (1996) *Geomorph.*, *12*, 187-214. [4] Soderblom, L. A. et al. (1973) *JGR*, *78*, 4117-22. [5] Mustard, J. F. et al., (2001) *Nature*, *412*, 4111-4. [6] Howard, A. D., *LPS XXIX*, 1323-4. [7] Howard, A. D. (1978) *Icarus*, *34*, 581-599. [8] Byrne, S. and Ingersoll, A. P. (2003) *Science*, *299*, 1051-3. [9] McClune, K. L. et al. (2003) *JGR 108*, DOI:10.1029/2002JE001878.





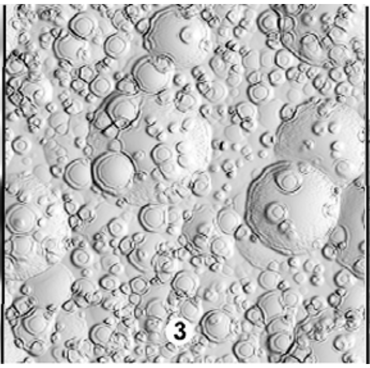
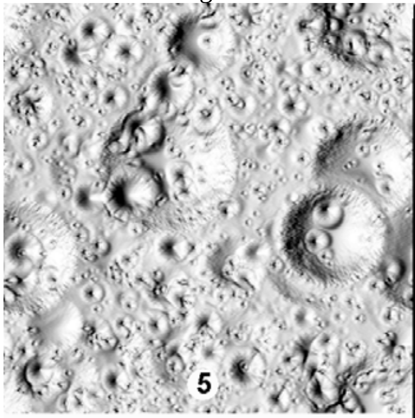
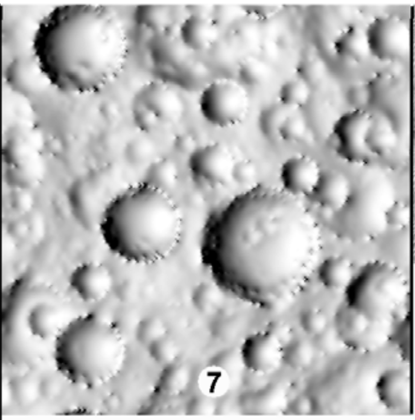


Figure 1. Simulated cratered surface; **Figure 2.** Cratered surface after simulated non-linear creep; **Figure 3.** Cratered surface after simulated uniform decrescence; **Figure 4.** Martian south polar mesas. MGS MOC Image release 2-497. Image width 3 km. Located at 87°S, 343°W.





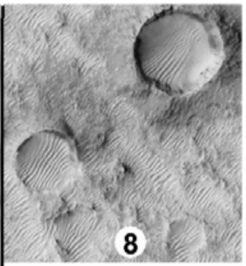


Figure 5. Cratered surface after uniform accrescence; **Figure 6.** Sedimented Martian surface with doughnut crater rims and rounded valley walls. THEMIS VIS image release 20031126a. Image width about 13 km. Location at 42°S, 91°W; **Figure 7.** Cratered surface after simulated eolian deposition; **Figure 8.** Craters filled with eolian deposits, with exposed rims and intercrater highs; MGS MOC Image release 2-524. Image width about 2.2 km. Located at 20°S, 307° W.