SIMULATED EROSION OF MARTIAN HEAVILY CRATERED TERRAIN; Alan D. Howard, Department of Environmental Sciences, University of Virginia, Charlottesville, VA 22903.

Introduction. The Noachian valley systems of Mars remain an enigma. Numerous valley networks formed contemporaneously with late stages of heavy bombardment. Various evidence has suggested that the atmosphere of Mars at that time was unlikely to have been dense and warm with widespread precipitation [1]; therefore, scenarios have been proposed for seepage erosion of valley networks involving localized mobilization of frozen regolith water due to impacts or volcanism [2]. The apparently spotty distribution of valley networks favors localized sources [3]. On the other hand, considerable erosion and redistribution of regolith materials have been involved in degradation of the heavily cratered terrain [4] and that amounts of water required to excavate the valley networks and create observed sedimentary fills is greater than can be accounted for by one-time dewatering of surrounding regolith [5].

The scenario to be investigated here is that most of the valley networks resulted from weathering and runoff processes that were arrested at an early stage by a deteriorating environment. Some high relief areas of the cratered uplands have been dissected sufficiently that graded slopes and well-defined drainage divides have formed, such as a zone about 30-70 km wide centered along the Loire Valley channel (615A4S). Our knowledge of terrestrial erosional processes has matured to the point that computer simulation models of landform evolution have become feasible [6]. Such models reproduce the salient features of slopes and channels in natural drainage basins. A simulation approach is being used to model early stages of dissection of heavily cratered terrains.

Initial conditions. Cratering produces a constructional surface that is characterized by numerous enclosed basins (craters and inter-crater basins), locally steep topography (crater rims), a richly textured surface of ejecta, and considerable variability of composition and erosional susceptibility of material. It is likely that large spatial variations in drainage density and degree of dissection, as well as a fragmented drainage network would result during early stages of dissection of a cratered landscape. Unfortunately, Martian heavily-cratered terrains have not been well characterized in topography. The Moon is the only cratered body with acceptable topographic mapping. Accordingly, lunar topographic contour maps of heavily cratered terrain at two scales (1:2,750,000 and 1:250,000) have been digitized for use as initial conditions. The Martian atmosphere and gravity will have created significant differences in crater form (e.g. depth/width ratios) and size-frequency characteristics from the lunar case, and later modeling will utilize empirical corrections or simulated cratered terrain to evaluate these effects.

Initial modeling efforts focus on initial stages of crater modification by slope and fluvial processes similar to those in arid landscapes on Earth. Areally distributed rainfall or snowmelt are assumed to feed surface and near-surface runoff as well as degradation of surficial materials by weathering. Thus the modeling will assume a relatively clement surface environment. The simulation modeling allows evaluation of the sufficiency of surficial weathering and erosion to produce observed cratered terrain degradation.

Process Assumptions. Modeling is progressing from simple to more comprehensive process modeling. The various processes and simple models are outlined below.

Slope erosion processes. The simplest models assume shallow redistribution of surficial materials by creep-like processes. The depth of creep motion is assumed to be thin compared to the typical relief scale of the cratered terrain (this contrasts with deep-seated creep involved in crater relaxation, glacial flow, and formation of lobate debris aprons and “terrain softening” [7]). Creep is assumed to be limited to surface soil layers, and thus independent of total soil depth. The potential creep flux \( q \) is a function of the slope gradient, \( S \): \( q = K_s S^\alpha / (1 - K_t S^\epsilon) \), where \( K_s \) is a rate constant, \( \alpha \) and \( \epsilon \) are constant exponents, and a constant \( K_t > 0 \) allows for threshold limiting slopes (bold type indicates vector quantities). The potential rate of erosion due to creep, \( E_q \), equals the divergence of creep, \( \nabla \cdot q \). However, the actual erosion rate by creep may be less than the potential erosion rate if the creep is capable of eroding more weathered regolith than can be replaced by new weathering during the same time interval, \( W \).

Case 1: Weathering and creep erosion are assumed to be the sole processes acting upon the landscape. Furthermore, the maximum rate of creep erosion is less than the weathering rate and \( K_t = 0 \). Under these circumstances the resulting landscape evolution is analogous to the decay of initial temperature differences on a flat plate due to thermal conduction, that is, crater bottoms are filled and rims lowered until a level topography is created. Small craters are eradicated faster than larger, and regional slopes decline only slowly. This model
Simulated Erosion: Howard A. D.

is unrealistic when compared to Martian cratered terrain because crater rims rapidly become rounded.

Case 2: This is similar to Case 1 except that the weathering rate is low enough to restrict erosion rates on divides and steep slopes (where potential creep erosion is greatest). In this model during each iteration the creep erosion rate is examined to determine if it is greater than $W$. If it is, then the erosion rate equals $W$ (which may be assumed to depend upon slope angle and/or slope position), and the downslope mass-wasting contribution is limited to the weathering rate. This case improves the similitude to degraded Martian craters in that rims persist longer. Obviously, this model is lacks development of valley networks and sedimentary basins.

Channel processes. Channel processes involve bed erosion and sediment transport/deposition. Channels may either be bedrock or alluvial, the former being underloaded with respect to bedload and limited in erosion rate to the scouring potential of the channel [8].

Bedrock channels. Steep headwater channels and rills on Earth are generally bedrock- or regolith-floored. Channel erosion rate, $E_c$, is assumed to depend upon overland flow shear stress, $r$: $E_c = K_c (r - r_c)^\beta$, where $r_c$ is a critical shear stress and $\beta$ is a constant exponent. Simple hydraulic geometry arguments permit quantification of $r$ as a function of contributing drainage area, $A$, and local gradient, $S$: $r = K_o A^{7/3} S^{2/3}$ [9]. The assumption of bedrock-floored channels means that explicit sediment routing in channels is not required.

Case 3: It is assumed that maximum creep erosion rates are less than the potential weathering rate. The total erosion at any location, $E_t$, equals $E_s + \eta E_c$ unless $E_s > 0$ and $E_c < 0$, where $E_t = E_s + \eta E_c$. The parameter $\eta$ models erosion of weathered regolith than unweathered regolith (bedrock). Drainage density is determined by the values of the model constants that determine the relative importance of mass wasting and channel erosion processes. Simulations with values $K_t = 0$ and values of $K_s$, $K_c$, and $K_o$ giving a moderate drainage density produce strongly-rounded crater rims. Relatively low values of $K_s$ coupled with $K_t = 0$ (a maximum stable slope angle) and $\beta = 2$ give steep-sided incised valleys.

Case 4: If $W$ is small enough that bedrock becomes exposed on slopes, the sediment deposition in channels is less than $E_s$ and bedrock erosion rates are less restricted by creep deposition on steeper portions of the landscape. Simulated landscapes are similar to Case 2 except for the addition of channels.

Alluvial channels. For a given sediment, $Q_s$, and water, $Q$, loading from upstream and for particular channel dimensions there is a minimum channel gradient, $S_m = K_v Q^\nu Q_s^{-\eta}$, that can occur without sediment deposition. In low and depressed portions of a landscape original gradients are less than $S_m$, so that bedload is deposited forming an alluvial channel. Sediment deposition has a maximum rate, $D_m$, dependent upon sediment supply from slope and channel erosion upstream less upstream deposition. Deposition in low areas tends to create fan-like infillings.

Runoff hydrology. On terrestrial landscapes runoff, $Q$, can usually be modeled to be a simple function of contributing drainage area, $A$, e.g., $Q = K_w A^{\nu}$. On cratered landscapes there are innumerable enclosed depressions which trap runoff. Two endcases are relatively easy to examine: A) All water entering depressions infiltrates; and B) water entering depressions creates a lake with overflow and no net loss of water to infiltration or evaporation. In the more realistic intermediate case the occurrence of overflow depends upon depression volume and surface area relative to inflow rate.

Results of simulations will be presented for the four cases presented above. Future simulations will address scale effects, fluvial sediment deposition, and various runoff scenarios, including groundwater flow and seepage.