SIMULATING LONG-TERM NOACHIAN MARS LANDFORM EVOLUTION AND PALEOCLIMATE.

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Introduction: It is evident from numerous fluvial features (e.g., alluvial fans, deltaic deposits, and valley networks) that Mars was episodically warm enough to support an active hydrological cycle [1-5]. Valley networks and paleolakes were active around the Noachian/Hesperian (N/H) transition [6, 7], and most studies of early Martian geomorphology have focused on this relatively short time span. However, the prevailing environmental conditions over the rest of the Noachian Period are not well known. Longer-term conditions are more relevant to biological evolutionary timescales than are shorter-term climatic excursions.

Some of the best insights into long-term conditions come from studies of Noachian crater degradation and the interaction of cratering with other processes [8, 9]. Unlike Earth, where landforms are constantly being altered by tectonic, fluvial, mass wasting, and other processes, older geomorphic surfaces are generally well preserved on Mars due to greatly reduced erosion rates since Noachian Period. We are using the degree of degradation of craters on the Martian equatorial highlands to reconstruct the sequence of impacts, starting shortly after the last major basin-scale impacts. These degraded craters and relict intercrater surfaces are then used to model the geomorphic processes that shaped the Noachian landscape from the onset of the visible cratering record (~4.0 Ga) up through the time of valley incision (~3.7 Ga). Through landscape evolution modeling of the representative study areas on the Martian highlands, we constrain the possible long-term Noachian environment.

Landform Evolution Model: The MARSSIM landscape evolution model simulates geomorphic processes and impact cratering on planetary surfaces, and it has been applied to study various planetary bodies including Mars and icy satellites of Jupiter and Saturn [10-12]. The model is versatile, and the components of the model can be turned on and off to include only the processes that are of interest to the study.

For this study, the relative importance of fluvial processes, aeolian mantling, and rock weathering rate were explored by changing the discharge exponent (α in $Q=kA^{\alpha}$), evaporation scaling ($X=(E-P)/RP$), cratering order, and rock erodibility. Q is discharge, A is contributing area, E is evaporation, and P is precipitation (see Table 1 and the appendix for parameter definitions and effects, respectively).

The model was run using the initial topography created by deleting all craters >5 km from the MOLA DEM and the impact crater sequence derived based on the study by [13]. The model continues to run iteratively until the weathering equivalent of 6 million years under arid conditions on Earth is has elapsed.

Table 1. List of parameters tested in the MARSSIM model.

Discharge exponent (α)	Dependence of runoff on contributing area. Values used: 0.3, 0.5, 0.7, 1.
Evaporation Scaling (X)	Water balance at crater basins. Determines which lakes are overflowing. X = -1 - 19
Bedrock erodibility	Changes erodibility of the bedrock relative to regolith.
Aeolian Mantling	Introduces set amount of sediment into the study site.
Crater resistance	Sets crater rim material more resistant than the surrounding intercrater plains.

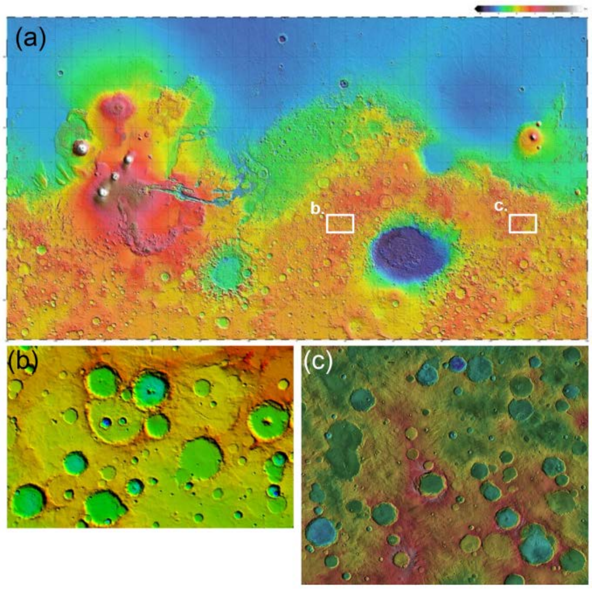


Fig. 1. (a) MOLA global topography with locations of two study sites indicated by white boxes. MOLA or THEMIS Day IR with MOLA data overlaid for the two study sites: Noachis Terra (b) and Terra Cimmeria (c).

Study Sites: Two sites that were selected for the study are *Noachis Terra* (25°S, 28°E) and *Terra Cimmeria* (21.5°S, 138.25°E) (Fig 1a), both of which are located on the southern highlands. Due to the computational limitation, study sites were limited to about 500 x 500 km. The two sites presented here are similar in terms of apparent dominant processes that had shaped the region. Neither site shows strong fluvial dissection, and many of the old craters maintain their rim structures (Fig 1b,c).

Results: Our model results for Noachis Terra indicate that the rate and pattern of Noachian erosion might have been limited by the weathering rate of the bedrock. When the bedrock was set as readily erodible as regolith, crater rims retreated rapidly, causing the resulting surface topography to be largely obliterated over the model timescale. The runoff production that best replicated present-day topography was similar to that of terrestrial arid to semiarid climates (α=0.3–0.5). The evaporation scaling did not play a big role in this region. When the condition was set to more humid conditions ($X < 4$), many of the craters hosted lakes and formed terraces that are not evident in the images. Hence the parameter values that best replicate Noachis Terra are small α ($\alpha < 0.5$) and X larger than 4, with a low rock weathering rate (Fig. 2).

Simulation was conducted for the Cimmeria region using the parameter values that best fit the Noachis Terra region to test if the climatic conditions at Noachis Terra were regional or global in scale. Our preliminary results show that the same set of parameter values used for the Noachis Terra region were able to replicate the Cimmeria region as well, although some small adjustments on crater sequencing and initial topography are necessary (Fig. 3).

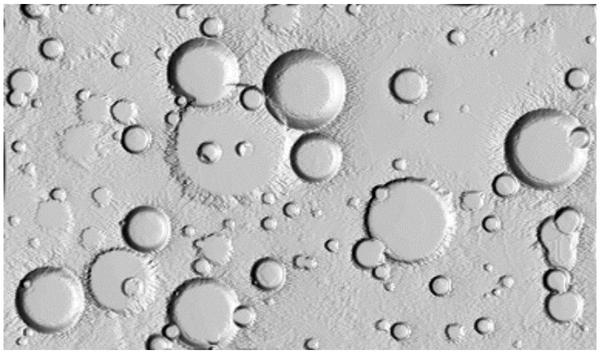


Fig. 2. Simulation that best matched the observed topography at Noachis Terra (compare to Fig. 1b).

Conclusion: Qualitatively, the MARSSIM can replicate the long-term evolution of both study sites well. Aeolian deposition and a resistant crater rims had minor effects on the simulation results. The set of parameters that best fit the observed landforms at the two regions was similar, which suggests that this climatic condition was more global/larger-scale rather than a local condition. However, simulations should be done at more locations throughout the southern highlands to be conclusive.

References: [1] Burr D. M. et al. (2009) *Icarus*, 200, 52-76. [2] Hynek B. M. and Phillips R. J. (2003) *Geology*, *31*(9), 757-760. [3] Irwin R. P. III et al. (2005) *Geology*, *33*(6), 489-492. [4] Moore J. M. and Howard A. D. (2005) *JGR*, *110*. [5] Moore J. M. et al. (2003) *GRL*, *30*(24). [6] Howard A. D. et al. (2005) *JGR*, *110*. [7] Fassett C. I. and Head J. W. III (2008) *Icarus*, *195*, 61-89. [8] Irwin R. P. III and Howard A. D. (2002) *JGR*, *107*(E7). [9] Howard A. D. (2007) *Geomorphology*, *91*, 332-363. [10] Luo W. and Howard A. D. (2008) *JGR*, *113*. [11] Barnhart C. J. et al. (2009) *JGR*, *114*. [12] Howard A. D. and Moore J. M. (2008) *GRL*, *35*. [13] Forsberg-Taylor N. K. et al. (2004) *JGR*, *109*.

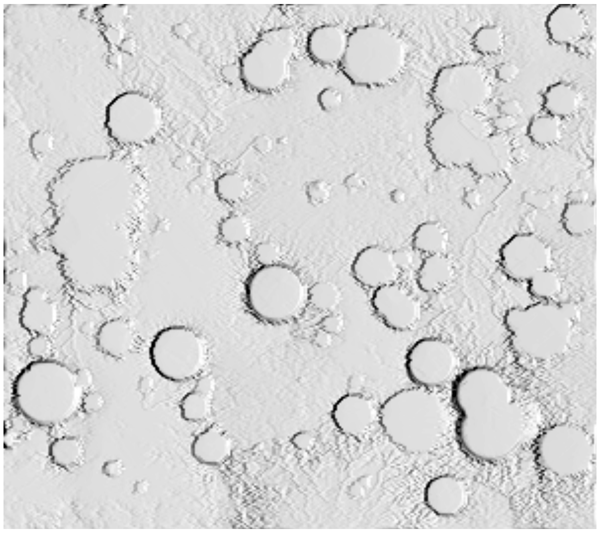
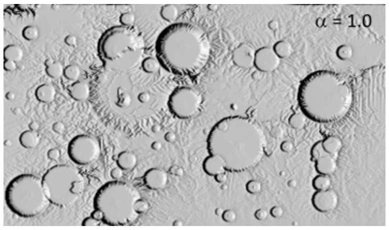


Fig. 3. Simulation for Cimmeria region using the same parameters as for Noachis Terra. Degree of crater degradation and amount of fluvial incision are well replicated (compare to Fig. 1c).

Appendix: Simulation results below show how some of the parameters effect the outcome.



When dependency of runoff on contributing area is high ($\alpha \sim 1$), crater rims and intercrater plains are heavily dissected (Left).

More humid conditions (small X) create lakes and terraces within the craters (below left) and when the rock erodibility is too low, crater rims remain well-defined (below right).