VARIABLE, LOW-MAGNITUDE FLUVIAL EROSION ON EARLY MARS. R. P. Irwin III and J. C. Cawley, Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, 6th St. at Independence Ave. SW, MRC 315, Washington DC 20013, irwinr@si.edu, cawleyj@si.edu.

Introduction: The ancient valley networks and large sedimentary deposits are among the most striking features on the cratered highland landscape of Mars. Constraints on the paleohydrology of Late Noachian to Hesperian valley networks and paleolakes show an active fluvial regime that was comparable to cool semiarid regions on Earth [1–3]. These conditions must have been geologically short-lived, however, because the martian landscape never became densely dissected.

The epoch of valley network incision represents a small fraction of the epoch of impact crater degradation, possibly less than 1% [4,5]. The cumulative erosion over the rest of the Noachian Period was substantial, particularly in the form of crater degradation and basin infilling, but estimated erosion rates were slow by terrestrial standards [6,7]. Distinctive features of the relict Noachian landscape (the geomorphic surfaces into which the valley networks were incised) provide clues regarding the dominant paleoclimate and geomorphic regime over hundreds of millions of years. Here we describe features that are inconsistent with high-magnitude fluvial erosion during the Noachian Period, and we develop a concept for low-magnitude but somewhat variable fluvial erosion that explains the basic features of the landscape.

Noachian Geomorphic Surfaces: The dominant trend in Noachian geomorphology was the reduction of relief over a wide range of spatial scales, with a particularly effective loss of small landforms. Examples include a lack of fluvial dissection, a loss of small craters, and elimination of the rugged primary features of large craters. At broader spatial scales, infilling of craters and intercrater basins represented ongoing reductions of relief during the Noachian Period. Impact cratering was the major relief-forming process in most areas of the highlands.

This long-term reduction of relief created four major classes of Noachian geomorphic features, which we mapped in three highland study areas: debris-mantled escarpments, regolith pediments, sloping aggradational surfaces, and depositional plains. The study areas included parts of Noachis Terra, Terra Cimmeria, and Libya Montes (Fig. 1).

Debris-mantled escarpments. Martian escarpments generally represent linear retreat of steep slopes, with little dissection or embayment. The retreat of impact crater interior walls during crater degradation was radial but essentially the same thing. Degraded craters on Mars remained remarkably circular despite wall retreat estimated at 10–30% of the crater's initial diameter [6]. Moreover, crater walls remained steep during crater degradation, relaxing only from the initial 20–30° range to 10–20° while retreating by kilometers [8]. The linear retreat of steep escarpments strongly indicates that the products of weathering were readily removed from the escarpments and did not tend to accumulate. Moreover, the crater wall slopes allow only a minor role for creep by various processes that would tend to relax the slopes over hundreds of millions of years.

Regolith pediments. Large portions of the study areas were relatively stable surfaces that neither aggraded nor degraded significantly relative to fixed impact structures. These areas are equivalent to terrestrial pediments, although they are much more extensive on Mars, likely due to tectonic stability. They are underlain by impact ejecta and megabreccia rather than bedrock.

Sloping aggradational surfaces. Some topographically confined surfaces had no exposed degraded craters, indicating that they had aggraded during some interval of time, but they were gently to moderately sloping and became somewhat degraded during the Late Noachian to Hesperian erosion of valley networks. Some of these deposits appear to be ejecta of Noachian degraded craters overlying the crater fill of an adjacent basin. Others may be fluvial or aeolian deposits, based on their context.

Depositional plains. Most of the exclusively aggradational surfaces are confined to basin floors and have low gradients of 0–1° with no fluvial dissection. All of the Noachian degraded craters in these areas are degraded or embayed, indicating dominant aggradation.

Basin Overflow: The fluvial erosion and paleolake development around the Noachian/Hesperian boundary represented a fundamentally different paleoclimate and geomorphology relative to earlier Noachian conditions. Noachian impact craters and intercrater basins do not appear to have overflowed with water until this time [9]. Most integration of adjacent topographic basins during the Noachian Period required reduction of their shared topographic divide through retreat of opposing slopes, burial of the divide, or some combination; we do not find the kind of narrow breaches that result from overflow of water. This observation requires arid conditions throughout the Noachian Period, but it could not have been as hyperarid as modern Mars, or the observed crater degradation would not have taken place.

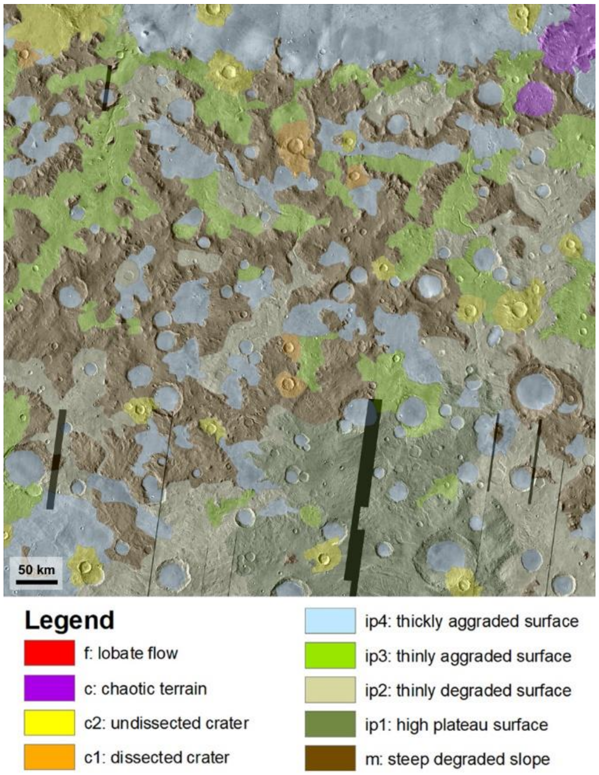

Figure 1. Geologic map of the Libya Montes study area, bounded by 5°N–7°S, 80–92°E.

Discussion: Landscape evolution on Noachian Mars involved significant slope retreat and lesser denudation of intercrater geomorphic surfaces. Sediments derived from these slopes and surfaces accumulated in basins, typically with sharp contacts separating the flat basin fill from the surrounding uplands. This observation shows either that the erosion process was gravity-driven or that the lithification process was mostly confined to basins, both of which are consistent with fluvial erosion. The landscape never became deeply dissected, however.

The lack of basin overflow indicates low precipitation relative to evaporation. Even around the Noachian/Hesperian boundary, Mars was not humid by terrestrial standards, or more basins would have overflowed. Although this observation shows that it did not rain or snow very much, there may also have been a limitation on precipitation intensity.

Strong precipitation events have a major effect on terrestrial watersheds, particularly in headwater areas. On Mars, we have found no indication of the kind of intense precipitation events that rain decimeters of water in a day and support dense dissection of slopes. If such event floods were common, then we would expect much more embayment of steep slopes and dissection of outlying surfaces.

Hypo-fluvial Erosion: Low-magnitude fluvial erosion could explain the major features that we observe in the highland landscape from before the Noachian/Hesperian boundary. It would provide an adequate water supply for weathering. Basalt chemically weathers to small particle sizes, so transport of its weathering products into basins would not require high-magnitude flows. The sharp break in slope at the base of crater walls strongly suggests a bimodal distribution of grain size between the crater wall (coarse) and floor (fine). The ability to remove the products of weathering from escarpments is an essential factor in scarp retreat. We have seen no evidence that Noachian streams transported much gravel, which would lead to more fluvial dissection and deposition of fans. Occasional flows into basins also provide a mechanism to distribute and cement finer-grained sediments on these surfaces. Wind may have played a supporting role in sediment transport. We emphasize that this kid of fluvial regime can explain the evolution of Noachian geomorphic surfaces over 10^8-year timescales, but the development of valley networks and paleolakes around the Noachian/Hesperian boundary requires both more water and more intense runoff production than was common previously [1–5].

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