THREE DISTINCT PHASES OF FLUVIAL EROSION ON MARS. R. P. Irwin III[1], R. A. Craddock[1], J. A. Grant[1], A. D. Howard[2], J. M. Moore[3], A. M. Morgan[2], R. M. Ramirez[4], and S. A. Wilson[1]. [1]Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, PO Box 37012, MRC 315, Washington, DC 20013-7012, irwinr@si.edu, craddockb@si.edu, grantj@si.edu, purdys@si.edu. [2]Planetary Science Institute, 1700 East Fort Lowell, Suite 106, Tucson, AZ 85719-2395, ahoward@psi.edu, amorgan@psi.edu. [3]NASA Ames Research Center, Space Science Division, Moffett Field, CA 94035, Jeffrey.M.Moore@nasa.gov. [4]Department of Physics, Physical Sciences Building 106, University of Central Florida, Orlando, FL 32816-2385, Ramses.Ramirez@ucf.edu.

Introduction: High-resolution orbital imaging and increasingly precise topography have reinforced Viking-based interpretations [1,2] that fluvial landforms developed in phases on Mars. The degradation of impact craters and incision of valley networks were concentrated during the first billion years of Mars geologic history, indicating a climatic change from warmer, wetter conditions during that time to the cold, dry desert that Mars is today [3]. In the first phase, crater degradation and planation of cratered surfaces occurred throughout the Noachian Period [2,4]. The second phase included formation of most valley networks during a relatively brief period of semiarid conditions around the Noachian-Hesperian boundary [5–8]. Finally, the third phase included modification of some post-Noachian impact craters and widespread deposition of young alluvial fans [9], the largest of which are concentrated in parts of the 15–30ºS latitude band [10].

Here we differentiate between these three phases of erosion on Mars, where distinct suites of landforms and processes prevailed at different times. As an explanation for the Mars geologic record, the inadequacy of a single abrupt decline in the climate has long been recognized [2,11], and the three-phase concept described here does not exclude the possibility of a more complex history of fluvial erosion and climate change.

Noachian Period: The ubiquitous degradation and destruction of impact craters relative to airless bodies is the most distinctive characteristic of Noachian erosion. Crater degradation proceeded mainly through retreat of the interior wall escarpment and deposition of the resulting debris on flat to gently inward-sloping plains on the floor, burying the central peak structure [12]. Ejecta blankets were smoothed, losing their primary roughness while retaining much of their original mass, to form gently to moderately sloping intercrater plains [13,14]. As crater degradation proceeded, the relief from rim to floor declined through wall retreat and infilling. Wall escarpments remained steep, with sharp breaks in slope separating the wall from the interior floor plains and the exterior intercrater plains [12]. Crater walls did not become deeply dissected (or subsequent back-wasting has erased evidence thereof), and craters retained their circular planform during overall degradation [13,14].

Intercrater basins were degraded similarly. Deeply buried or embayed craters are concentrated on basin floors, and small craters on intercrater plains were degraded without significant denudation or aggradation around the impact structure [14]. Some adjacent Noachian basins became connected through burial of the original topographic divide, but narrow incision of basin divides was rare [15].

Noachian interpretation. The ubiquitous loss of small roughness elements (including all Noachian craters <4 km in diameter [16]) and aggradation of basin floors indicate (1) weathering of bedrock outcrops, (2) a gravity-driven transport or sedimentation process, and (3) a scale-inefficient transport process that did not dissect the landscape. These requirements suggest the presence of water for weathering, downslope sediment transport, and cementation, but without the scale-efficient fluvial erosion that characterizes Earth [14]. Basins generally did not overflow with water, there being no apparent way to heal the resulting water gaps.

Noachian-Hesperian Boundary: The widespread incision of valley networks was a radical departure from the evolution of the geomorphic surfaces into which they are incised. The valleys indicate spatially extensive water sources, including at locally high elevations, both characteristics that are unique to precipitation [17]. Over 200 basins filled with water and overflowed [18], indicating a water supply that exceeded losses to evaporation and infiltration [7].

Most valley networks do not fully dissect their watersheds, leaving undissected surfaces between tributaries and drainage densities below unity [19]. Undissected headwater areas are common on all but the steepest slopes [5]. The highland landscape is still mostly endorheic, with valley lengths controlled by the length of slopes related to early to pre-Noachian relief features [15]. Remarkably, Noachian valleys generally debouch to basin floors with no terminal deposits observed in positive relief [6,20], and the same is true for crater wall gullies that formed at this time [17].

Noachian-Hesperian interpretation. The incision of valley networks and overflow of basins requires a decline in aridity, such that long-distance flow was possible and input to some lakes exceeded losses [7,8].

The lack of dense dissection and relict gravel deposits along escarpments suggest that Mars did not experience the intense meteorological storms that characterize Earth. Low to moderate runoff events may have depended on the sealing of intercrater planation surfaces by the chemical and physical products of basalt weathering [14], reducing the originally high infiltration capacity of impact ejecta [21].

Hesperian-Amazonian Boundary: Some valley networks were active before and after discrete geologic events, such as large post-Noachian impacts [22,23] or the origin of the crustal dichotomy boundary escarpment [6]. These superposition and cross-cutting relationships support crater-counting studies of alluvial fans that revealed a late phase of fluvial erosion around the Hesperian-Amazonian boundary [24,25]. An important difference between this last major phase of fluvial erosion on Mars and the previous two phases is the occurrence of alluvial fans (Fig. 1).

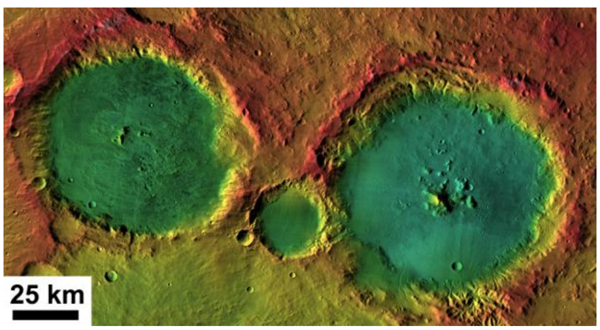

Fig. 1. Example of a Hesperian degraded crater with alluvial fans (98 km Murray crater, right) and a similarly sized Noachian degraded crater with no alluvial fans (left). Thermal Emission Imaging System daytime infrared mosaic colored with Mars Orbiter Laser Altimeter 128 pixel/degree topography to show relative elevation, centered at 23.1°S, 27.1°E in Noachis Terra.

Hesperian-Amazonian interpretation. Alluvial fans or dissected alcoves from which they are commonly sourced are not evident in Noachian crater degradation [10]. The third phase of fluvial erosion included supply of and transport capacity for gravel sediment under local conditions of high relief and slope.

Discussion: These changes in martian landforms and processes require global-scale changes in aridity, perhaps related to the release of water from surface or subsurface reservoirs along with atmospheric evolution, and local-scale capacity to transport gravel sediment in the last phase.

The slow crater degradation of the Noachian Period indicates prolonged chemical weathering of basalt to transportable particle sizes and concentration of those weathering products in topographic lows [14]. By contrast, the development of valley networks and basin overflow around the Noachian-Hesperian boundary require lower aridity [7,8] but potentially low to moderate runoff production that primarily transported sand or finer grain sizes in valley networks. Finally, the development of alluvial fans around and perhaps after the Hesperian-Amazonian boundary may indicate frost weathering and snowmelt that could generate and transport gravel on relatively high, steep slopes [26].

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