GEOMORPHIC SURFACES IN THE NOACHIAN HIGHLANDS OF MARS. J. C. Cawley and R. P. Irwin III, Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, 6th St. at Independence Ave. SW, MRC 315, Washington DC 20013, cawleyj@si.edu, irwinr@si.edu.

Introduction: The relatively stable tectonics and slow landscape evolution during the Noachian Period on Mars resulted in distinct and mappable escarpments, regolith pediments, sloping aggradational surfaces, and depositional plains, which together make up intercrater plains. These features developed under arid conditions over extensive periods of time. In contrast to the much more dynamic geomorphology due to plate tectonics on Earth, these martian features a) retained indications of their formative geomorphic processes, and b) can be used to place constraints on the Noachian environment of Mars.

The intercrater plains can be readily subdivided into mappable aggradational and degradational units. The primarily degradational features include high-standing debris-mantled escarpments and regolith pediments. Aggradational features include some sloping plains and flat depositional plains.

Material weathered in place on these quasi-stable, long-lived surfaces and was transported preferentially down-slope from regolith pediments toward alluvial plains and basin floors.

Weathering and erosion relied on slow, gravity-driven erosion by running water. Wind likely also played an important role.

We mapped three study areas. Noachis Terra is a heavily cratered region with little fluvial dissection and better-preserved intercrater surfaces. Terra Cimmeria has a rolling landscape with more fluvial erosion. Libya Montes is a high-relief, rugged landscape next to the Early to Middle Noachian Isidis impact basin.

The mapped geomorphic surfaces have limited valley incision throughout and limited denudation except on escarpments, suggesting that any fluvial erosion was mostly below thresholds for transport of coarse-grained sediment. Apparently, most of the erosion occurred under "hypo-fluvial" conditions that limited channeling and the grain sizes being eroded on the landscape.

Debris-mantled Escarpments: By definition, escarpments are steep, laterally extensive slopes that are girded above and below by more gently sloping surfaces. With time, material from the escarpment is preferentially removed down and across the lower flat or sloping surface, and the escarpment retreats into the highland surface above. Escarpments exhibit discrete patterns of retreat depending on the levels and frequency of the eroding process. If precipitation is high, then a threshold is reached where the escarpment face is channeled and retreat is more rapid and non-uniform. Wind also may remove sand-sized and finer grains to slowly modify escarpments.

Escarpments in our study areas have retreated slowly and uniformly, forming sloping interior walls from the original slump terraces of complex impact craters. Highland escarpments developed mostly in impact ejecta or megabreccia, have debris-mantled surfaces, and lie in most cases below the angle of repose. The interior walls of Noachian impact craters have declined in slope from an initial ~20–30° to ~10–20°.

Regolith Pediments: Pediments are gently sloping erosional surfaces that develop on long-term stable bedrock or earlier deposits [1]. They act as long-exposed weathering surfaces, as well as slow conveyor belts for downslope erosion of materials. Weathering occurs on a combination of materials that were derived in place or sourced from the highlands above, all of which is then transported across the pediment surface. In general terms, pediments remain geomorphically stable over long periods of time, and they tend to be only lightly incised by fluvial channels [2]. They may be interrupted by rounded inselbergs of bedrock, or (more commonly the case) knobs of the underlying coherent regolith or megabreccia.

Regolith pediments on the cratered highlands of Mars appear to have evolved in a geomorphic regime that was at or below thresholds for fluvial and aeolian erosion most of the time. Sheetwash, infiltration, dissolution, recrystallization, and chemical weathering would be physically plausible in this setting.

Sloping Aggradational Surfaces: Gently sloping plains are mappable in some lower-lying areas of the landscape. These surfaces appear to be either ejecta blankets from degraded craters or thicker sequences of sediment derived largely from upgradient surfaces. These areas are aggradational based on a lack of degraded craters. Possible alluvial plains occur where drainages were more integrated and stream flow may have been more significant. Such units are marked by deposition of mainly fine-grained materials, buried or eradicated small craters, and variable late-stage channeling. These features may suggest limits to the energy available for geomorphic work over long timescales.

Depositional Plains: Flat depositional plains occur in pre-existing basins or swales, and as crater floors where sharp breaks in slope separate them from the steeper crater walls [3]. These depositional floors seldom contain alluvial fans or, indeed, positive relief terminal deposits in general [4].

Many of these floor deposits are on the order of a kilometer thick [5], such that even large craters of tens of kilometers in diameter became buried or embayed there. The material that comprises these smooth plains is likely to be fine-grained, and it is dispersed over laterally extensive, nearly flat surfaces. In most cases, aeolian dunes or other large-scale wind transport features are absent. Some plains may be volcanic.

Weathering and Erosion Thresholds: In long-term arid fluvial regimes, several thresholds might be expected to leave tell-tale clues in the stable landscape. These thresholds are described here in terms of their general forms:

1. Adequate surface water to chemically weather basalt. Somewhat above the weathering threshold, water may infiltrate a surface and subsequently evaporate, allowing dissolution, recrystallization, and ice fracturing in addition to chemical weathering. Desert varnish, opal, hyaline silica, or duricrusts may form at interfaces with fog, fine and intermittent rain, or condensation [6].

2. A small water supply that is not fully retained in a vadose zone, such that it does not generate overland flow. Duricrusts, interstitial phyllosilicates, hydrated silica, and other secondary materials can form in these settings [7]. A water supply level near the first two thresholds would be consistent with a hyperarid desert.

3. A water supply that exceeds the infiltration capacity during occasional events, generating sheet flow and perhaps some channelized flow, but no long-distance flow. Runoff moves finer-grained sediments and soluble materials downslope over time.

4. A water supply that would exceed the infiltration capacity by enough to transport sediment and incise channels. Recurring flow encourages weathering of the substrate and further channel incision. A water supply near thresholds 3 and 4 is common in many terrestrial deserts.

5. A water supply of sufficient event magnitude and frequency to maintain small perennial lakes against evaporation and incise long channels or valleys. This threshold is exceeded in semi-arid climates and apparently around the N/H boundary on Mars.

6. A water supply that exceeds potential evaporation, such that basins overflow, and the surface has fully integrated drainage. Mars does not appear to have ever exceeded this threshold.

Depositional Process: Deposition across flat-lying basins depends on a fine-grained sediment supply which must be widely dispersed, must not subsequently be removed by wind, and which may have been wetted or cemented in place.

A range of processes may be involved, including wetting by rain or fog, followed by recrystallization of salts or hydration of other minerals to form duricrusts [8]. Hyaline silica, opal, or calcedony may be the result of direct recrystallization or sol-gel reactions, or it might be mediated by alkali silica or acid silica reactions in wetted materials [9].

Sedimentary basins may be preferential sites where sediments are wet by surface water or groundwater. Flat and very gentle slopes may reflect gradients at which rainsplash or sheetwash would rework surface materials before and as they became cemented and surface-sealed by clays [10].

It is probable in this setting that sedimentary mechanisms selecting for flat-floored morphology may also be synergistic with lags of coarser-grained clasts (fluvially transported or airfall materials) or concretions (e.g., at Meridiani Planum). Such relict clasts or concretionary grains (as in terrestrial analogues) are left behind as aeolean deflation occurs. In turn, a thin veneer of such clasts, sometimes only one clast thick, then serves to armor and protect the fine-grained deposits beneath them [11].

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