AEOLIAN GEOMORPHOLOGY WITH MER *OPPORTUNITY* AT MERIDIANI PLANUM, MARS.

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Introduction: Wind/surface interactions are responsible for most geomorphologic characteristics of the landscape investigated by *Opportunity*, including many larger-scale features seen from orbit. Here we summarize this unusual weathering/erosion system for insights into: (1) the greater stability of lagged ripple surfaces compared with friable bedrock exposures (the inverse of normal expectation); (2) the flatness of the plain defined by the underlying bedrock; (3) the dependence of aeolian ripple size on local regolith particle size-frequency variations; (4) potential acceleration of sulfate-enriched bedrock chemical weathering rates from interactions with shifting deposits of active (unlagged) basaltic sand; (5) the origin of bright halo impact crater rims and dark crater interiors (seen from orbit); and (6) the origin of the broad, outcrop-free annulus surrounding Victoria crater (seen from orbit).

Fundamental Components: The landscape at Meridiani Planum explored by *Opportunity* is dominated by level expanses of dark-toned regolith, <1 m thick, worked into ripples of various sizes by the wind. Exposures of underlying light-toned, sulfate-enriched bedrock occur near or at the rims of a small population of impact craters, and other places where regolith is absent. Regolith is a slightly cohesive mixture of (1) basaltic ~100 micron sand, (2) some air fall dust, and (3) coarse sand-, gravel-, and pebble-sized components consisting of hematite concretions, meteorite fragments, and other, unidentified, clasts.[1,2] Wheel trenches reveal the coarser regolith components are concentrated in a surface lag. Wheel trench walls and other measurements attest to cohesion binding these components together.[4]

…And Mobile, Abrading Basaltic Sand: However, a minor population of loose or very loosely bound basaltic sand grains is sparsely distributed across the plains, mobilized periodically by wind. This mobile portion of the sand population becomes concentrated within traps such as pits, troughs, and impact crater floors, collecting into transient deposits substantial enough to be recognized. Ripples in these deposits are misaligned with the hematite-lagged ripples outside the traps, but are more closely aligned with current-era strong wind events implied by wind streak directions.[5] This material is responsible for the dark floors of some craters as seen from orbit.

Unusual Abrasion/Resistance Hierarchy: Free basaltic sand at Meridiani is an effective abrader of weaker, sulfate-enriched bedrock. Free basaltic sand in turn seems less resistant than hematite concretions contributed to the regolith from the sulfate-enriched bedrock (Microscopic Imager views of embedded concretions with associated wind-eroded “rock tails” show no obvious erosional asymmetries). In this unusual system, hematite-lagged aeolian ripples are more stable than rock: Ejecta blocks of sulfate-enriched rock erode to conform to the rippled surface they have landed upon before the ripples have changed their positions. The ripples, lagged with highly-resistant coarse 1-2 mm hematite-enriched particles, thus appear to have been stable for relatively long periods of time.

Flatness of the Landscape: In view of the vulnerability of the bedrock to abrasion by windblown regolith, it is likely that saltation across expanses of sulfate-enriched rock contributed significantly to the low relief of the underlying bedrock/regolith interface. The same process is implicated for the absence of perched ejecta boulders on and around the rims of the larger impact craters, as well as the conforming block surfaces found in many smooth slopes (e.g., inside and outside impact craters) responsible for a “flagstone” appearance of block surfaces on these slopes.

Influence on Chemical Weathering Rates: Repeated accumulation and removal by wind of free basaltic sand might also locally affect the rate of chemical weathering of sulfate-enriched rock within traps where accumulations of free sand are expected to fluctuate and form transient, renewable, thin porous regolith sheaths. In these places (only), color variations of rock correlating with height above local regolith grade are found together with some unusual rock morphologies that preserve rock exteriors as free-standing walls at the expense of lower, flatter, more eroded rock interiors (where fine particles are likely to accumulate). Informed by comparisons between brushed and unbrushed rock surface colors, color correlations indicate cleaner, less dusty (less red) rock surfaces are more removed from local regolith grade. Lower down, closer to where basalt sand seems to have been deposited and then removed (conceivably many times), rock surfaces are more red, as well as more eroded, suggesting that weathering has been enhanced by burial beneath a thin, porous covering of basaltic sand, thin enough to allow thermal communication between the atmosphere and underlying rock. Contrasting thermal inertias between the bedrock and the thin basaltic sand cover could result in thermal profile inversions on diurnal timescales, enhancing mobility of ultra-thin salt-carrying layers of condensed water vapor along grain boundaries and enhancing weathering effects compared with settings elsewhere.

Controls On Ripple Development/Size: Outside the traps containing deposits of free basaltic sand, regolith has been worked into ripples covered with ~1-2 mm hematite-enriched grains.[1,2,3,5,6] (Wheel trenches show the hematite grains form only thin exterior coatings and ripple interiors are much finer-grained.) Ripple size and morphology vary considerably, according to position along *Opportunity*'s traverse:

Plains Near Eagle and Endurance craters. Ripples near Eagle and Endurance craters are small, with cross-sections typically 1 cm high, 10 cm wide. Flat or slightly concave troughs have scatterings of relatively large (several-mm) hematite-enriched concretions that are absent from adjacent ripple surfaces. One of these large concretions was revealed at the base of a ripple cross-section created by a wheel trench, evidence that large concretions are too massive to participate in ripple formation/migration and are "run over." Ripple size in the Eagle-Endurance plains area is remarkably uniform, but larger versions of these ripples, up to several cm high, occur along the rims of depressions that can function as traps for free basaltic sand. The "rim ripples" probably form when occasional extreme wind events clear out transient accumulations of free basalt sand from these traps, briefly driving larger particles in creep out of the depression to form ripples that stall upon exit once they stray into the break-in-slope lees just beyond depression rims. Bright halos around crater rims seen from orbit are due to very thin deposits of dust lingering in the lees provided by these larger-than-normal "rim ripples." Light-toned bedrock outcrop is *not* responsible for the bright halos, as shown at Eagle crater where outcrop extends only half way around the rim interior.

Large Ripples Encountered Further South. As Opportunity ventured south, the nature of the plains and their ubiquitous ripples changed. Views northward from the sol 366 wheel trench show mostly flat terrain with low ripples, while views south show mostly a system of much larger ripples and troughs that seem to have originated as coalesced blowouts/rim ripples, evolving into a system of ripples up to 40 cm high divided by wide troughs with well-defined concave-up profiles. These ripples are large enough to channel near-surface winds, controlling movement of particles along trough axes. Profiles and images indicate secondary debris deposits are commonly banked along the E sides of troughs. W sides of troughs show evidence of much thinner deposits, and where these have been stripped, closer to ripple crests, banding is observed consistent with past ripple migration to the W. Hints of "cross-sections" revealed in occasional pits (probably impact craters) against ripples suggest banding dips to the W, also consistent with ripple migration W. Large ripples are seen immediately adjacent E of Victoria crater, but not immediately to the W, again consistent with past W migration. However, large ripples of bimodal or mixed grain sizes on Earth generally are relatively long-lived bedforms of limited mobility, therefore subject to preserving wind reversals that can complicate interior structure.[7] The same could easily be true for the large ripples at Meridiani Planum.

Influence of Particle Size-Frequency. It has long been known from terrestrial work that non-erodible surface roughness can retard saltation flux and soil erosion.[e.g., 8] MI sampling indicates smaller hematite concretions S of Endurance crater.[2] At Meridiani, smaller ripples to the N are found on relatively flat regolith surfaces densely littered with the largest sizes of hematite concretions. Larger ripples to the S prevail where these largest hematite concretions are less abundant or absent. Unfortunately, it was not practical to verify this control on ripple size with enough observations and areal coverage of MI imagery along the traverse S. Instead, Pancam images with depressions >60 deg were examined. These images supported the hypothesis, revealing decreased maximum concretion sizes where ripples were larger, but the assessment is complicated by highly variable populations of other large clasts that are not obviously round hematite concretions.

Origin of the Victoria Crater Annulus. More support for the hypothesis was provided when Opportunity first rolled on to the broad, outcrop-free annulus surrounding Victoria crater, and found plains similar to near Eagle and Endurance craters with low ripples once again correlated with abundant large hematite concretions littering the surface. The annulus owes its origin to impact ejecta sourcing buried bedrock containing abundant large hematite concretions (like bedrock at the surface near Eagle and Endurance craters, but unlike bedrock at the surface at Victoria), which weathered out from encasing ejecta blocks abraded by saltating particles, leaving a relatively dense, protective lag of these particles on the surface in the configuration of the original ejecta distribution.

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