THE AEOLIAN ENVIRONMENT OF GLEN TORRIDON, MARS, OBSERVED BY THE MSL ROVER.
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Introduction: An important goal of the Mars Science Laboratory (MSL) mission at 155 km-diameter Gale crater is evaluation of sedimentary strata exposed on the lower slopes of the 5 km-high mountain (informally designated as "Mt. Sharp") that rises from the center of the crater floor [1]. Orbital analyses of these rock units reveal clay-bearing materials and other indications of ancient aqueous processes during the first half of the planet's history, before planet-wide surface conditions became more consistently arid [2].

Clay-bearing materials are exposed at "Glen Torridon," the floor of a shallow trough that extends across the lower slope of Mt. Sharp [2]. Trough shape is irregular, but is about 400 m wide where the MSL rover has been exploring. Downslope, the Glen Torridon floor materials are bounded by the erosion-resistant, hematite-bearing Vera Rubin Ridge that stands above the trough floor with up to 7 m of local relief. Upslope, the trough boundary is marked by the Greenheugh Pediment scarp that rises locally ~15 m above the floor of Glen Torridon. Between the Vera Rubin Ridge and the Greenheugh Pediment, the intervening trough forms a natural conduit for wind-driven sand to periodically collect within and/or migrate through. Probably for this reason, the MSL rover has encountered a diversity of aeolian bedforms on the trough floor at Glen Torridon that seem to encompass a broad range of relative ages. This presentation summarizes the characteristics of aeolian bedforms and other aeolian features encountered by MSL at Glen Torridon, including features different from elsewhere along the MSL traverse and whose formative mechanisms are uncertain.

Active Dark Sand Ripples: Orbital views show patches of dark sands scattered across the trough floor, particularly along the base of the Vera Rubin Ridge, with ripple wavelengths ~2 m in some locations. MSL observations confirm these large bedforms, as well as the presence of superposing smaller ripples in intricate associations (Fig. 1A). The largest dark sand ripples, lacking continuous mantles of very coarse grains at crests, are uniquely martian and similar to examples encountered at Gusev crater and in several other places at Gale [5-9]. Origins of these large ripples are controversial: as formed either by fluid drag, analogous to subaqueous ripples on Earth [6, 10]; or by conventional impact splash, in which larger maximum ripple sizes (of all grain sortings, including megaripples) are enabled on Mars by lower wind dynamic pressures that limit maximum ripple heights less effectively than in terrestrial conditions [11]. At Glen Torridon, ripple troughs typically are finer-grained and more reddish than ripple crests, similar to grain size-related color trends noted on large ripples elsewhere at Gale attributed to more abundant ferric materials for grain sizes <150 µm [12,7,13]. In some locations at Glen Torridon seen closely by MSL, color properties of large dark sand ripples differ from examples elsewhere at Gale by having more extensive surface cover dominated by >150 µm grains (particularly at crests, but extending further down into trough areas than is typical at other ripple locations). MAHLI views of a large ripple in Glen Torridon revealed well-rounded 250-350 µm grains dominating the crest, but with additional coarser grains up to 2 mm scattered across the bedform surface. Nevertheless, rover wheel track disturbances among these ripples reveal subsurface sand to be volumetrically dominated by grains <150 µm, as found elsewhere at Gale, and also within many other types of aeolian bedforms investigated by rovers at Gusev crater and Meridiani Planum e.g., 5, 14-15]. One possibility that might apply only to Glen Torridon locations with bedforms having less abundant <150 µm surface grains is that net deflation is occurring as these ripples migrate.

Coarsely-Surfaced Bedforms: In other areas, particularly along the base of Vera Rubin Ridge wherever dark sand deposits are absent, large bedforms typically 10-20 m long with ~2 m widths are covered with pebbles most commonly 2-4 mm (but with finer and considerably coarser material also present) (Fig. 1B). Rover wheel tracks over these bedforms show high-fidelity molding from wheel surfaces, indicating a component of very fine material is present, probably reducing porosity. Low track shadow indicates cohesion, therefore induration and greater age than the dark sand ripples. Greater age is also indicated in instances where bedform surfaces have acquired and retained perched impact ejecta blocks that subsequently have partly decayed in place, creating trails of weathered debris extending downslope. Some of these bedforms have vertical profiles with unusually low aspect ratios of ~0.03.

On Earth, potential analog bedforms having crests mantled with pebbles are known by a variety of terms—e.g., megaripples, coarse-grained ripples, aeolian ridges, granule ripples—in part because of the diversity these bedforms exhibit depending on the grain size-
frequency of the local available sediment supply, formative winds, and other factors [e.g., 16-19]. In all cases the coarsest grains do not saltate, but can only be mobilized in creep-like movements by the effects of high-speed impacts from finer saltating sand. Depending on sediment supply, the coarsest, creep-limited grains might be present only at surface crest areas (and mostly absent from interiors), or might drape the entire bedform surface and be abundant within the interior, mixed with finer grains. At Glen Torridon, wheel-scuffing revealed internal pebbles embedded in the scuff wall. On the basis of these characteristics, the closest terrestrial analogs to the Glen Torridon large, pebble-covered bedforms are megaripples in Wright Valley, Antarctica, which have relatively low aspect ratios, surfaces completely covered with pebbles (somewhat coarser than the Glen Torridon bedforms), and pebble-rich interiors [20].

Wind Regime Changes at Glen Torridon: Contrasting characteristics between the currently active dark sand ripples, and the inactive megaripples, indicate changes over time in sediment supply and/or formative winds. The dark, mafic sands of the extensive Bagnold dune field approach within 2 km of Glen Torridon, and changes in the Bagnold dunes revealed from orbital monitoring indicate formative winds currently blowing approximately SW [3,4], a direction closely aligned with the NE-SW orientation of the trough containing the Glen Torridon materials explored by MSL. This suggests the trough currently functions as an active conduit for dark sand driven by prevailing local winds blowing to the SW. MSL observations at Glen Torridon consistent with this include drifts of dark sand extending SW behind numerous isolated rocks scattered across the trough floor, and dark sand drifts in what seem to be protected areas against the SW flanks of many of the older, inactive megaripples (Fig. 1B). Migration directions of the older megaripples are uncertain; several of these bedforms have shallow crescent shapes suggesting migration to the NE at some point in the past, but others do not, and might have been affected by alternating formative winds from opposing directions. Terrestrial megaripples can show similar effects due to relative longevity and slow reaction times [18]). More decisively, coarser pebbles completely cover the older, megaripples, compared with the coarsest grains scattered more thinly at crests of the active ripples, indicating currently less energetic saltation flux conditions—finer saltating grains, lighter formative winds, lower atmospheric pressure, or some combination—than in the past when the megaripples were active.

Acknowledgements: This work was supported by the MSL project. We are grateful to mission staff at JPL, Malin Space Science Systems, and elsewhere for their continuous dedication and creativity exercised during flight operations.


Figure 1. (A) Active dark sand ripples of various sizes observed sol 2364 (false-color mcam12417). (B) Inactive pebble-covered megaripples observed sol 2334 (false-color mcam12417). Darker zone to left is drift of mafic sand (somewhat dustier than active ripple fields elsewhere at Glen Torridon) against megaripple, consistent with drifts of similar material extending also to the left from behind isolated rocks in the background (arrows).