ORIGIN OF LINEAR RIDGES IN THE CLAY-BEARING UNIT OF MOUNT SHARP, GALE CRATER, MARS.

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Introduction: This study focuses on a series of linear ridges that occur within the Fe/Mg smectite clay-bearing unit of Aeolis Mons (informally Mount Sharp) within Gale crater (Fig. 1), the field site for the Mars Science Laboratory Curiosity rover. The clay-bearing unit of Mount Sharp has been one of the highest priority exploration targets for the Curiosity rover because the smectite spectral signature detected using data from the Compact Reconnaissance Imaging Spectrometer for Mars suggests habitable aqueous conditions [1-4]. The analysis of clay-bearing unit ridges presented here provides insight into the origin of these features as well as implications for the depositional context and erosional history of this critical interval of the Mount Sharp stratigraphy.

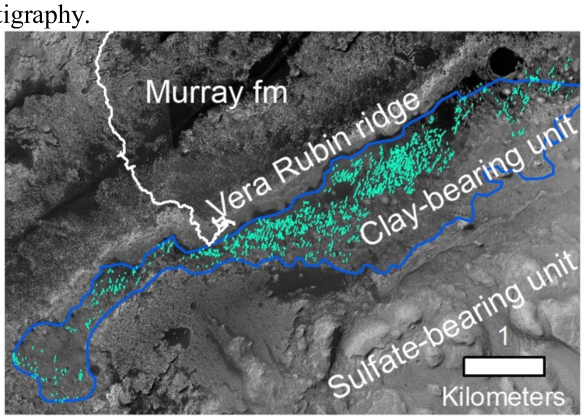

Figure 1. Distribution of 1189 ridges (teal) mapped on a HiRISE mosaic within the clay-bearing interval of Mount Sharp (outlined in blue based on [5]'s alteration spectral parameter map). The rover's traverse as of Sol 2166 is shown in white.

Previous work: The ridges within the clay-bearing unit of Mount Sharp were first described by [1], who noted similarities between the morphology of the ridges and eolian bedforms. However, [1] observed that the ridges are lithified and proposed two possible origins: lithified eolian bedforms or soft sedimentary rock eroding in an undulating pattern.

The interpretation of these ridges as lithified eolian bedforms was also supported by [6], who suggested that the ridges may represent remnants of eroded dunes that had been reworked during flooding and burial. Alternatively, the ridges in the clay-bearing unit could be due to partial coverage of underlying bedform topography by incompletely eroded fine-grained, clay-bearing material.

Thus, two origins were proposed to explain the ridges of the clay-bearing unit: (1) lithified primary eolian bedforms or (2) erosional forms, both with important implications for the primary depositional origin of the clay-bearing strata.

Methods: The ridges were mapped and characterized using gray-scale and color visual and topographic basemaps constructed from 25 cm/pixel stereo pairs from the High Resolution Imaging Science Experiment (HiRISE) that were processed, georeferenced, and projected via the methods of [7]. Ground-based observations of the linear ridges come from the Curiosity rover's Mast Cameras (Mastcams), which acquired color mosaics from fixed-focal-lengths of 34 and 100 mm.

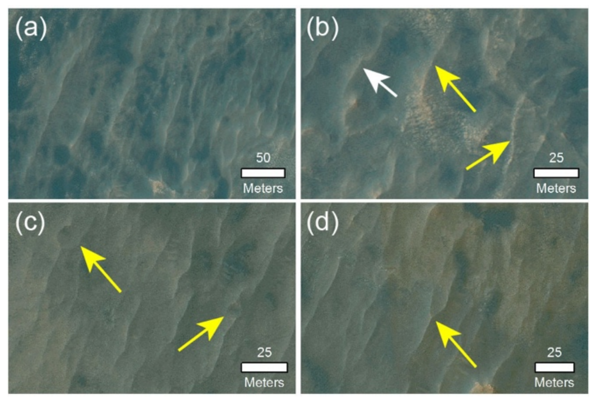

Figure 2. Ridges in the clay-bearing unit as viewed in color HiRISE images. North is up in all images: (a) typical linear ridges within the smooth subunit of the clay-bearing unit, (b) ridge within the smooth subunit (white arrow) near ridges (yellow arrows) within the fractured subunit of the clay-bearing unit, (c) craters (yellow arrows) disrupting ridgelines, (d) a bifurcating ridge (yellow arrow).

Observations: *Orbiter imagesl.* Ridges were identified in HiRISE images by their relatively linear ridge crests, which typically appear bright on the sun-facing sides and darker on the sides tilted away from the sun (Fig. 2). They are also relatively bright compared to modern eolian sand. The majority of the 1189 ridges we mapped in HiRISE occur in the smooth sub-unit of the clay-bearing unit [4,8], although several are observed in the lighter-toned fractured sub-unit (Fig. 2b) [4,8]. The ridges overwhelmingly trend NE-SW with an average trend of 17.8º/197.8º, which is highly discordant to stratal orientation or to traces of sedimentary layers. These features range in measured length from 3 to ~200 m, averaging ~30 m. The ridge wavelength is between ~5 and

30 m. Small impact craters locally disrupt ridgelines (Fig. 2c), and several occurrences of ridge bifurcation are observed (Fig. 2d). Not all ridges are resolvable within the digital terrain model, but of those that are, they typically measure no more than ~1 m in height. NW-facing slopes of the ridges are observed to be generally steeper than the east-facing slopes.

Rover images. Linear ridges within the clay-bearing unit have been observed on the ground by the Curiosity rover at distances of ~100-150 m in several Mastcam mosaics taken from the southern edge of Vera Rubin ridge. Although views have been oblique, ridges are readily identifiable within the mosaics as low-lying, elongate hills. In contrast to local highs within the clay-bearing unit that appear to be composed of well-lithified, platy bedrock (likely sandstone), the ridges are observed on the ground to occur predominantly in low-lying, recessively eroded, poorly consolidated outcrops overlain by loose fines (sand and/or dust). Faint, but distinct, traces of bedding with apparent dips to the west-southwest are exposed within several of the ridges (Fig. 3).

Discussion. The presence of craters disrupting ridgelines and the occurrence of ridges within the fractured clay-bearing sub-unit support the interpretation that these features are inactive, and possibly lithified, rather than active eolian bedforms, i.e., [9]. If these ridges represent lithified linear dunes, they would be consistent with the predominantly northerly winds predicted from an inventory of long time-scale eolian features such as yardangs and transverse aeolian ridges (TARs) observed elsewhere in Gale crater [10]. If these features represent fossil TARs themselves, there is an ~90º offset in trend relative to other TARs in Gale crater. While the wavelength, height, and presence of forked ridges in the clay-bearing unit is generally consistent with TARs, the asymmetry observed in the clay ridges is not.

Present data from orbiter or rover images cannot be used to fully confirm or eliminate an origin as fossil bedforms, but several lines of evidence support an origin for the ridges as erosional features. The ridges do not show the streamlined or tapered morphology of yardangs, but share similarities with periodic bedrock ridges (PBRs) eroded into cohesive sedimentary bedrock; examples occur both on Earth and Mars [11,12]. Ridges in the clay-bearing unit appear continuous with, and exhibit similar characteristics as, inter-ridge bedrock. This is particularly apparent for those ridges observed within the bedrock of the fractured sub-unit. Bedding is also observed to cut through the ridges observed in Mastcam mosaics, though views from additional angles are likely needed to confirm whether bedding is consistent with that expected for dune-scale sedimentary bedforms. The ridges are also most prevalent in what appears to be very fine-grained, easily erodible bedrock, rather than the better-lithified platy sandstones that occur intermittently throughout the clay-bearing unit. Periodic bedrock ridges are thought to form perpendicular to the prevailing wind direction [11], so if the clay ridges are such landforms, then they would be most consistent with an easterly or westerly wind direction. This would match easterly winds inferred from modern eolian dunes and sand shadows formed on relatively short time-scales in Gale crater [10]. Most importantly, if the clay ridges are erosional in origin, there would be no direct connection to a primary eolian depositional interpretation for this unit.

Future work will involve incorporation of additional ground-based observations of the ridges when Curiosity begins, in 2019, its in-situ exploration of the clay-bearing unit with the aim of distinguishing between primary and erosional formation mechanisms.

References: [1] Anderson and Bell (2010) *Mars, 5*, [2] Milliken et al. (2010) *GRL*, *37*, [3] Grotzinger et al. (2014) *Science, 343*. [4] Fox, V. et al. (2018), *LPS XLIX*, Abstract #1728, [5] Fraeman et al. (2016), *JGR-Planets, 121*, [6] Milliken et al. (2014) *GRL, 41*. [7] Calef et al. (2013) *LPS XLIV,* Abstract #2511, [8] Cofield et al. (2017), *LPS XLVIII*, Abstract #2531, [9] Edgett and Malin (2000), *JGR-Planets, 105,* [10] Day, M. and Kocurek, G. (2016), *Icarus, 280*, [11] Montgomery, D. et al. (2012) *JGR-Planets, 117*, [12] Hugenholtz et al. (2015), *Aeolian Research, 18*.

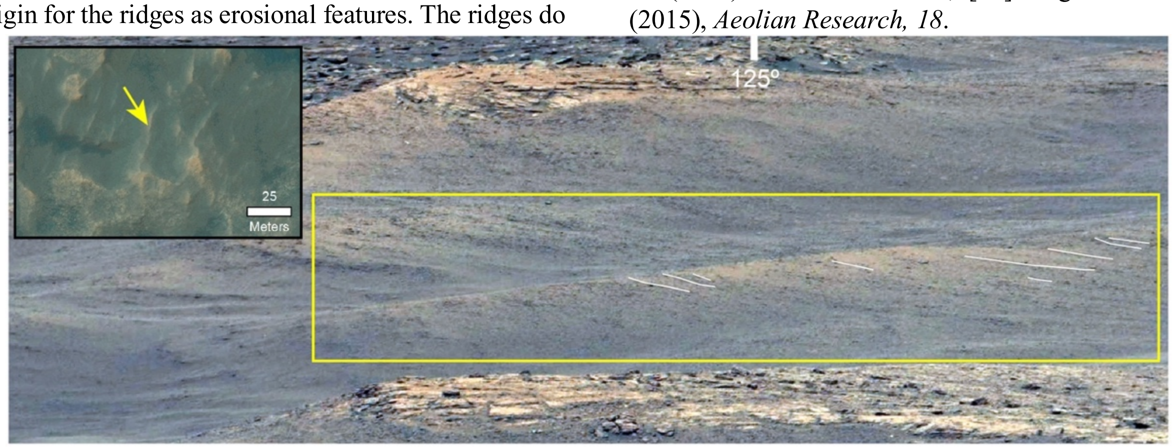

Figure 3. Mastcam M-100 view to the southeast of a ridge (yellow box) within the smooth clay-bearing unit localized to HiRISE (inset image, yellow arrow). Possible southwest-dipping beds within the ridge is annotated with white lines.