EPSC Abstracts
Vol. 13, EPSC-DPS2019-179-3, 2019
EPSC-DPS Joint Meeting 2019

EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

Evolution of Major Sedimentary Mounds on Mars

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Abstract.

Most mapped sedimentary rocks on Mars are contained within mountains. These mounds - up to 8 km tall, with sub-horizontal layers - are found within craters (e.g. Mt. Sharp in Gale Crater, the target of the MSL rover); within canyons in Valles Marineris; and also free-standing on the plains. No similar mountains exist on Earth. In order to exploit the sedimentary record on Mars, we must understand mound evolution (e.g. [1-6]). The likely cause of the moats that define the mound shapes is terrain-influenced wind erosion (slope-wind erosion) [1, 7]. Surprisingly, geologic analysis and mesoscale atmospheric modeling indicates that terrain-influenced wind erosion was also active during the build-up of the mounds [2]. The net effect is that tall points get taller over time. The tall-points-get-taller hypothesis has recently received unanticipated support from the first gravity traverse on another planet [6]. Although we emphasize our own work here, our conclusions are mostly consistent with independent structural studies by other teams (e.g. [7-9, 20]). Because mound build-up involves aqueous cementation, whereas wind erosion requires dry conditions, we infer that mound stratigraphy records wet-dry alternations *during* Mars' more-habitable era.

1. Mound Build-Up: Slope-Wind Erosion Defines Moats Before Mounds "Top-Out"

In an initial study motivated by layer-orientation data (e.g. Fig. 1), we used a simple model of slope winds (checked by a mesoscale model) to show how sedimentary rock mounds can emerge from feedbacks between slope winds and erodible terrain [1]. Sediment initially accretes near the crater center far from crater-wall winds, until the increasing relief of the resulting mound generates mound-flank slope winds strong enough to erode the mound flanks. The counterintuitive result is that mountains grow taller over time (relative to the moat) by sediment accretion. This new idea opened a new research direction: morphodynamic feedbacks between wind and topography at 10-100km scale. We have since led a large effort to validate and extend the HiRISE-derived measurements of layer-orientation data for Mars mounds. The resulting synthesis [2] includes >½ (by volume) of Mars' mapped sedimentary rock mounds.

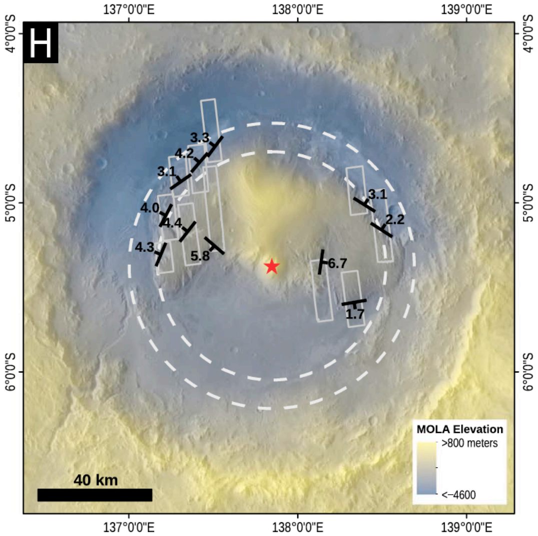

Fig. 1. Sedimentary layer orientations for Mount Sharp in Gale Crater. Light gray shows DTM outlines. Strike-dip symbols (dips in °) and labels indicate average orientations of all layers traced on the corresponding orthoimage/DTM. Range rings (white dashed lines) show distance of candidate peak ring from central peak (red star). From Kite et al. 2016.

The core idea of tall-points-grow-taller (a stratigraphic "Matthew effect") has been confirmed by stratigraphic surveys both at large scales [10] and at very high resolution [9], as well as by radar stratigraphy [8]. The model predicts only modest burial-heating of rocks currently in Gale's moat, consistent with data (e.g. [11-12]). We evaluated the differential compaction hypothesis for layer-orientation data at Gale [17], and found that it can only match data for geologically implausible overburden [5]. The differential compaction hypothesis also predicts low rock porosities along the MSL traverse, which is hard to reconcile with gravity traverse data [6]. Our data are not in conflict with rover results, which only pertain to the lowermost ~10% of the mound.

2. Mars Mound Grind-Down: Why Does Mt. Sharp Have a Bat-Wing Shape?

Using a mesoscale model, we have confirmed that wind erosion can form Mars mounds in large craters from initially-flat infill [4]. For the first time, our results provide a possible explanation for the "bat-wing" planform shape of Mt. Sharp (Fig. 2) – i.e., more erosion on the *downwind* side (relative to synoptic wind). We carried out a global survey of Mars erosion rates using small-crater counts, including many sedimentary-rock mounds [3]. Erosion rates are 10^2-10^3 nm/yr for sedimentary-rock mounds, much faster than planet-average but consistent with erosion rates estimated by other teams (e.g., [14]).

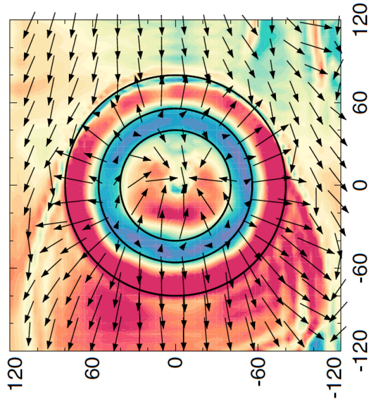

Fig. 2. Surface wind stress (shading) from a 2km-horizontal resolution simulation of a 160 km diameter, 3.5 km deep, mound-bearing crater. Arrows show the wind speed/direction, while the three black circles denote the locations of the crater rim and the bases of the crater and mound walls. Max. stress (red) is 1.5×10^{-2} Pa. See (e.g.) [13] for realistic-topography simulations.

3. What's Next?

So far most of our wind erosion mesoscale simulations have been carried out for <50 mbar atmospheric pressure. Early indications from higher-paleopressure work are that it is possible to form a moat at high paleoatmospheric pressure. We look forward to more structural geology tests (e.g. looking for layer pinch vs. swell in the Grand Canyon of Gale Crater), as well as MSL progress up Mt. Sharp. Rover ground truth will help to resolve whether the water source for aqueous cementation was groundwater upwelling [15] or top-down (e.g. snowmelt) [16]. Perhaps both were involved (Fig. 3) [18-20].

Acknowledgements. We thank M.P. Lamb, C. Borlina, B. Ehlmann, C. Newman, M.I. Richardson, A. Hore, O. Aharonson, A. Lucas, A. Howard, and J.C. Armstrong. Grants: NASA (NNX15AH998G). UChicago RCC.

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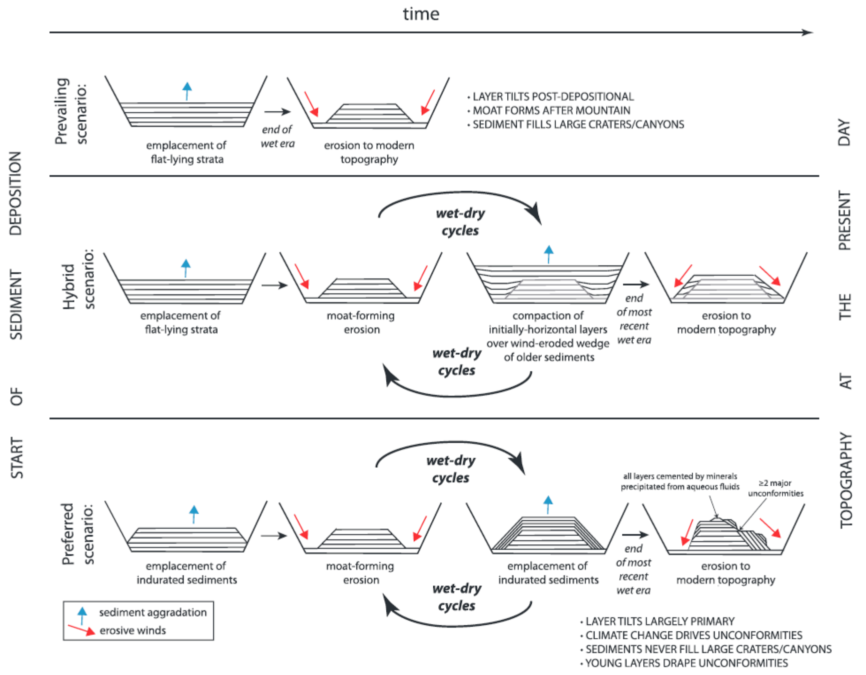

Fig. 3. (From Kite et al. 2016). Cartoon cross-sections of craters/canyons and evolving mounds, summarizing multiple working hypotheses for mound formation.