ANATOMY OF AN ANCIENT AEOLIAN SANDSTONE ON MARS: THE STIMSON FORMATION IN GALE CRATER.

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Introduction: Aeolian systems are widely documented across the solar system, however aeolian strata, the preserved expression of migrating dune fields, have only been documented on Earth and Mars. The Stimson formation, Gale crater, represents one of a few documented examples of a thick aeolian succession which has been ground-truthed beyond the earth [1].

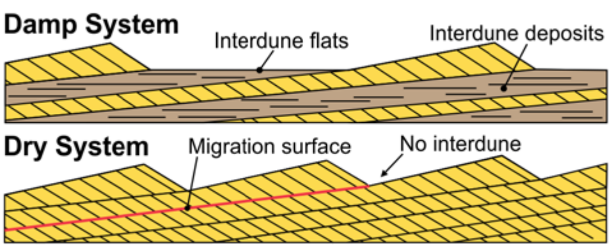

Figure 1: Damp and dry aeolian system architecture

The accumulation of aeolian strata depends on many factors, including: sediment supply; wind direction and intensity; and the generation of accommodation space, however the role of water is commonly overlooked. Water can play a significant role in accumulation of aeolian successions, allowing sediment undersaturated wind to generate strata, were aeolian deposits would otherwise not accumulate.

Dry aeolian systems, where water plays no role in sediment accumulation, relies purely on aerodynamic variations in sediment transport rate, such that sediment influx is greater than outflux. This requires dunes to grow until the depositional surface is covered, and dunes start to climb over the stoss slope of the preceding dune. Formation of interdune areas in dry systems represents an area of sediment bypass on the depositional surface, where there is no mechanism for sediment preservation. Fine-grained sediments (mud to fine sands) rarely accumulate in significant thicknesses in these systems, as there is no mechanism to prevent wind-winnowing from occurring.

Damp and wet aeolian systems are controlled by the relative position of the water table and its capillary fringe to the depositional surface. Sediment transported across a moist depositional surface can adhere, and over time cause accumulation of strata. Critically, this allows dunefield accumulation from a sediment undersaturated wind, and for the accumulation of fine grain particles which would otherwise be wind-winnowed. Where the interdune becomes wet, interdune deposits may be characterized by fluvial facies, evaporites, microtopography, and deformation structures associated with dune migration.

Using models developed from terrestrial aeolian successions, we aim to characterize the Stimson formation, and reconstruct the original dune field from the stratigraphic succession represented as the Stimson formation.

Geological setting: Gale is a 155 km diameter impact crater located ~5°S of the Martian equator, that contains a ~5 km high mountain (Aeolis Mons) of layered rock at its center [2]. Since August 2012, the lower-most 200 m of stratigraphy has been explored using the rover *Curiosity*, yielding a host of sedimentary environments. The Bradbury group and lower Murray formation represent the first ~100 m of succession, represent interfingered fluvial, deltaic, and lacustrine sediments, with minor aeolian interbeds. The Murray formation represents the next 100°m, characterized by interbedded lacustrine mudstone and lake-margin sandstones. The Stimson formation unconformably overlaid ~75 m of Murray formation, consisting of blocky and grey meter-scale cross-bedded sandstones which were juxtaposed against the smooth-surfaced, tan-colored and horizontally laminated Murray mudstones.

Methods: To document sedimentological features within the Stimson formation, Curiosity's suit of engineering and scientific cameras were used: outcrop-scale images were recorded using Navcams and Mastcams, recording the sedimentary architecture, and facies relationships, while grain-scale textures were recorded using the Mars Hand Lens Imager (MAHLI). Architecture was analyzed by mapping bounding surfaces associated to determine geometric relationships of depositional elements. These relations, combined with facies analysis were used to determine style of deposition, and sediment accumulation to reconstruct the dunefield.

Architectural observations: Stimson outcrops are typically characterized by cross-bedded sandstones with sets of cross-beds between 40-80 cm thick (Fig. 2). Within the sets, cross-strata comprise repetitive laminations that are a few millimeters thick and typically sub-parallel. Cross-laminations downlap onto the underlying bounding surface with an asymptotic profile and are truncated at their top by an overlying bounding surface. Based on set thickness, texture and three-dimensional geometries of laminations, these sets of cross-beds are interpreted to represent the preserved basal section of sinuous-crested aeolian dunes. Cross-laminations were formed by sediment accumulation on the lee-side of a dune, leading to incremental dune advance in a down wind direction. We interpret the cross-laminations to comprise mainly wind-ripple stratification due to the uniformity of lamination thickness and their highly parallel character. Distinct grain-flow strata have not been observed. Palaeocurrent analysis based on measurements of 139 foreset azimuths indicate a wind regime that drove dune migration towards the northeast. Cross sets are separated by erosional bounding surfaces which appear sub-horizontal and largely sub-parallel at outcrop-scale, but upon closer inspection, undulate through the stratigraphy by several tens of centimeters, resulting in the lateral pinch-out of sets (Fig. 2). Bounding surfaces can be traced over distances of up to 40 m, before they are truncated by younger bounding surfaces. These erosional surfaces are interpreted to have been scoured by migrating dunes as they climbed over the stoss slope of the preceding dune, eroding its stoss and upper part of the lee slope. Minor erosional bounding surfaces can be observed within some cross-bed sets, which typically cut across the set obliquely the top to the base, and truncate underlying laminations, while superseding laminations are parallel to the bounding surface. These bounding surfaces are interpreted to represent reactivations surfaces, which signify changes in wind direction, wind reversals, or a hiatus in dune migration and degradation of the lee slope.

Reconstruction of the Stimson dunefield: From analysis of the sedimentary architecture, and comparison with terrestrial aeolian strata, we interpret the Stimson formation to represent strata deposited in a dry-aeolian dune system. This interpretation is based on the absence of horizontally-bedded fine-grained interdune deposits, and other sedimentary features characteristic of wet systems, such as: wavy or crinkly laminations; mottled facies [3]; microtopography; deformational structures caused by dunes migrating over wet substrates [4]; evaporite deposits; [5] or facies of certain fluvial origin. Dune-field morphology can be reconstructed from set thicknesses, and the spatial extent of the Stimson formation mapped on orbital images using empirical relationships derived by observations of terrestrial aeolian systems. We interpret that cross-sets of 40-80 cm thickness would have been deposited by dunes between 8–11 m high [6], with an estimated wavelength between dune-crests of up to half a kilometer [7] (assuming preserved sets represent main dunes within the dune-field). The presence of common reactivation surfaces suggest a complex wind regime, where wind direction frequently changed direction, reversed, or abated. The absence of interdune deposits preserved between cross-sets indicates that dunes had grown to occupy all available space on the depositional surface, allowing a positive angle of climb, and accumulation of sediment which was preserved in the stratigraphic record. Sinuous crested dunes migrated towards the northeast, oblique to the regional dip of the deflationary unconformity that cuts across the underlying Murray formation.

The accumulation of dry aeolian system strata on a deflationary unconformity is significant in that it signifies an environment devoid of liquid water at the surface, and in the shallow subsurface, suggesting that Gale crater was an arid environment at time of deposition of the Stimson formation.

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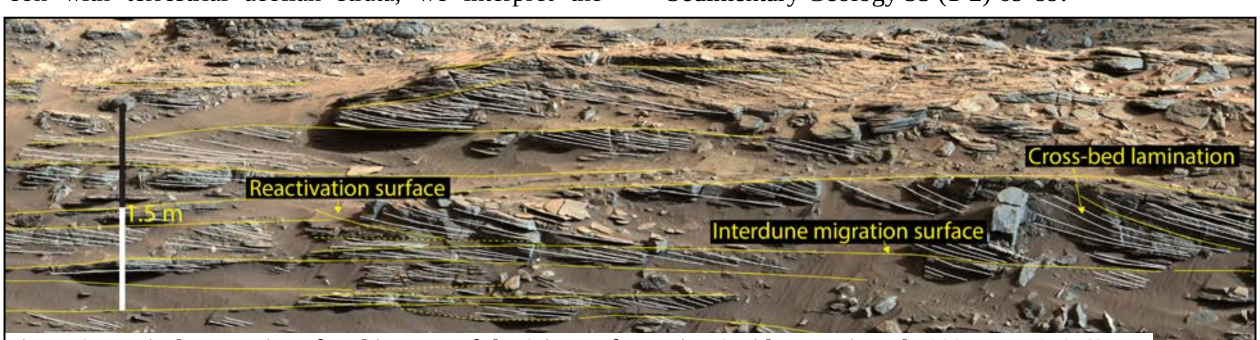

Figure 2: Typical expression of architecture of the Stimson formation (Bridger Basin, sol 1099, mcam04872)