THE STIMSON FORMATION: DETERMINING THE MORPHOLOGY OF A DRY AEOLIAN DUNE SYSTEM AND ITS CLIMATIC SIGNIFICANCE IN GALE CRATER, MARS

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Introduction: Although terrestrial aeolian systems are generally considered to be dry and devoid of water, the presence of water can play a significant role in controlling sediment accumulation and dune-field sedimentary architecture. Aeolian systems can be classified broadly as dry, damp or wet, depending on the degree to which liquid water controls depositional processes.

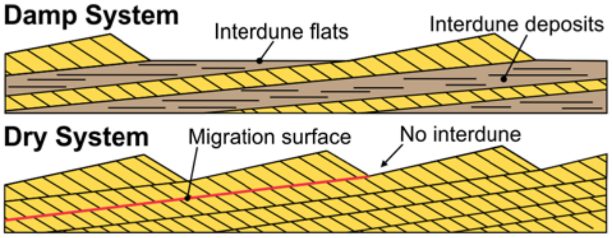

Figure 1: Damp and dry aeolian system architecture

Dry aeolian systems are where water plays no role in sediment accumulation, instead, accumulation occurs aerodynamically by spatial or temporal decrease in transport rate such that sediment influx is greater than outflux. Dunes are required to grow and cover the entire depositional surface before sediment accumulation takes place. This leads to the absence of interdune deposits from the stratigraphic record in these cases. Sediment accumulation in *damp and wet aeolian systems* is controlled by the relative position of the water table or capillary fringe to the depositional surface, trapping sediment by adhesion and allowing dune-field construction to occur with sediment-undersaturated wind. Critically, this results in the accumulation of interdune deposits because dunes do not occupy the whole depositional surface and moisture on the interdune surface can capture sand and dust particles that are otherwise wind-winnowed from dry aeolian systems. Where wet aeolian systems exist, interdune deposits may be characterized by fluvial facies, evaporites, crinkly laminations and deformation of wet sediment associated with advancing dunes.

Whilst terrestrial aeolian strata are relatively well documented and understood, there exists only two documented examples of aeolian strata preserved on extra-terrestrial planet: The Burns and Stimson formations, both on Mars. To better understand these strata from the restricted perspective of a remote mobile robotic platform (rover), terrestrial depositional models can be used to support observing strategy and interpretation.

The Stimson formation, Gale crater, is considered to represent the depositional remnants of an ancient aeolian dune-field preserved on the basal flank of Aeolis Mons (informally called Mount Sharp) [1]. Here, we use observations from Mars Science Laboratory (MSL) rover *Curiosity* to describe sedimentary facies and key bounding surfaces in order to reconstruct the palaeoenvironmental context of the Stimson formation, the controls on its accumulation, and potential for habitability at the time of deposition.

Geological setting: Gale is a 155 km diameter impact crater near the Martian equator which contains a 5 km high mountain of stratified rock at its centre [2]. Since August 2012, using the Curiosity rover, we explored a portion of the lowermost exposed 200 m of this stratigraphy; the first ~100 m (Bradbury group and lower Murray formation through Pahrump Hills outcrop) were interfingered fluvial, deltaic, and lacustrine sediments (conglomerates, sandstones, mudstones) with minor aeolian interbeds; the next ~100 m (all Murray formation) are largely mudstones with minor [interfingered?] sandstones. About ~75 m of the Murray formation strata we explored are unconformably overlain by the Stimson formation. The Stimson formation consists of distinctive meter-scale cross-bedded sandstone, which typically has a blocky grey-toned expression. The underlying Murray formation is a mudstone that is typically characterized by mm-scale horizontal laminations, although cross-bedded facies are also observed.

Methods: To document outcrop-scale features in the Stimson, we targeted and examined images and stereopair products acquired by the rover's two Mastcams and its engineering cameras (Navcams and Hazcams). Mars Hand Lens Imager (MAHLI) images were obtained to observe grain-scale textures.

The sedimentary architecture of the Stimson formation was analyzed by mapping of bounding surfaces and associated stratal units to determine their geometric relationships. These relationships, combined with analysis of the facies were used to determine depositional processes, the style of sediment accumulation, and to reconstruct the dune-field morphology.

Architecture of the Stimson: 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 grainflow strata have not been observed. Palaeocurrent analysis based on measurements of 117 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.

Reconstruction of the Stimson Environment: 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]; 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 approximately half a kilometer [7] (assuming preserved sets represent main dunes within the dune-field). 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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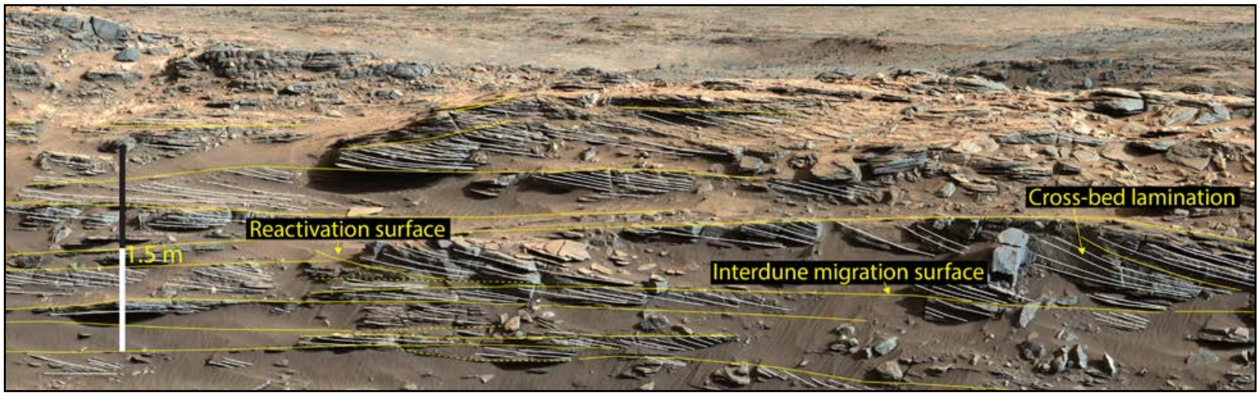

Figure 2: Typical architectural expression of the Stimson formation. Example: Bridger Basin (Sol 1099, mcam04872)