CLAY AND SULFATE-CEMENTED SANDSTONES IN GALE CRATER: EVIDENCE FROM ORBITAL DATA.
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Introduction: The ~5-km tall Mt. Sharp in Gale crater preserves an extensive stratigraphic record of ancient surface conditions and processes on Mars, with the potential to inform us of habitability on early Mars. Strata in Mt. Sharp appear to be sedimentary in origin [1-3], but the depositional environments recorded by these rocks are still debated. Hypotheses have included lacustrine deposition, volcanic ash, eolian deposition, ancient polar deposits, and precipitation as giant spring deposits [1-7]. The key to predicting which portions of the mound may best preserve organic material, if it were ever present, lies in detailed mineralogical and sedimentological anlaysis of the strata. Here we describe a range of morphologic features consistent with some of the Mt. Sharp strata having been deposited as sandstones. Orbital spectral data suggests these sandstones are cemented by sulfate and possibly clays, which may record fluctuations in the height of the groundwater table and/or the relative contributions of groundwater and surface runoff.

Methods: This study utilized visible imagery acquired by HiRISE (~25 cm/pixel) and CTX (~5 m/pixel) and visible-near infrared reflectance spectra acquired by the CRISM instrument (~18-36 m/pixel), all of which are onboard the Mars Reconnaissance Orbiter (MRO). Where available, HiRISE digital terrain models were also examined to help assess stratal geometries and stratigraphic relationships. Predictions that result from analysis of these data are being tested with *in situ* observations by the Curiosity rover, including data from Mastcam, CheMin, and ChemCam; this is an ongoing process and will continue as the rover drives toward and ascends Mt. Sharp.

Results: Spectral data indicate that the Lower fm. of Mt. Sharp contains sulfate salts, clay minerals and, in some localities, red hematite [3]. These phases are often mixed with pyroxene. Mg/Fe-bearing clay minerals are also detected on the crater floor adjacent to Mt. Sharp. In these locations the clay-bearing units are not the stratigraphically highest unit; they are exposed in erosional windows. It is unclear from current data if these units onlap (and thus post-date) the Lower fm. or if they are part of the Lower fm. itself, occurring as preserved strata that underlie the part of the Lower fm. exposed in Mt. Sharp, which is believed to have been more laterally exensive in the past. The exact timing of the deposition of these clay-bearing units is thus poorly constrained, but the Lower fm. is believed to date to the Noachian-Hesperian boundary [7].

HiRISE images of the NW exposures of the Lower fm. reveal planar stratification in cross-section that is laterally continuous over hundreds of meters and that are separated by inclined stratification on the order of tens of meters. Foresets truncated by upper bounding surfaces and bottomsets that downlap onto lower bounding surfaces are also observed (Fig. 1). Similar features are also observed in the exposed wall of a large canyon on the west side of Mt. Sharp. CRISM spectra of this canyon and of equivalent strata are consistent with the presence of sulfate salts, possibly Mg-varieties.

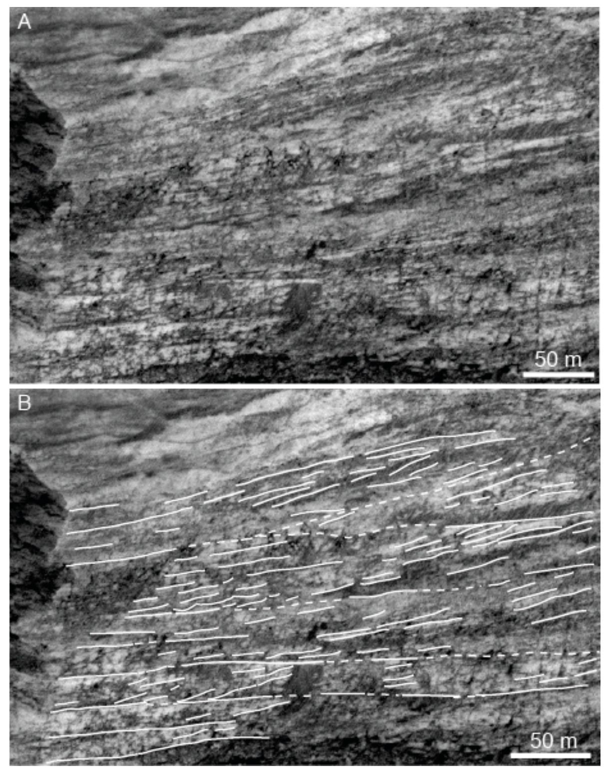

Figure 1. Cross-sectional view of NW portion of Mt. Sharp. Low-angle foresets are truncated by upper bounding surfaces; beds downlap onto lower bounding surfaces, consistent with eolian stratification and deflation to capillary fringe of groundwater table. North is down.

HiRISE/CTX images also reveal numerous occurrences of preserved bedforms, including dune crests, troughs, and crestline bifurcations. The presence of craters, through-going fractures, and exposure by erosion of overlying units indicate that these bedforms must be lithified and that they are, in some cases, part of the stratigraphy of Mt. Sharp. Stratified units with decameter wide, parallel flat-topped segments separated by troughs are present throughout the terrain surrounding Mt. Sharp. This 'washboard' morphology occurs in the 'mound skirting unit' of [8]; MRO and *Curiosity* observations show it contains filled fractures consistent with post-depositional fluid flow and mineralization.

Several spectacular examples of preserved bedforms are present along the southern margin of Mt. Sharp, and in at least two locations it is observed that the preserved bedforms transition into washboard morphology, suggesting a genetic link between these two features (Fig. 2). At least some locations indicate the washboard morphology is the result of preferential erosion of the dune crests and preservation of materials between the crests. One example of bedforms has been exposed by erosion of overlying fan deposits that result from deposition of material generated by fluvial incision of the Lower fm. At least three examples of partially degraded bedorms are associated with clay mineral signatures in CRISM data.

Discussion & Conclusions: The presence of inclined beds separated by planar bounding surfaces is consistent with eolian deposition and deflation to the capillary fringe of the groundwater table, as is common in terrestrial dune environments and as has been interpreted at Meridiani Planum [9]. In contrast, such exquisite preservation of dune topography/bedforms in the rock record is extremely rare on Earth and indicates unique depositional conditions [10]. Specifically, stabilization (cementation) and rapid burial promote this type of preservation, often associated with rapid transgression in terrestrial settings. The exact mechanism for preservation on Mars is unknown, but at a minimum it requires cementation of the dunes (in some cases up to the crests); in Gale, the examples of bedforms overlain by fan deposits are consistent with rapid burial, possibly by fine-grained material in a relatively quiescent setting. In some locations, the transition of bedforms to washboard morphology suggests interdune sediments, possibly cemented by or precipitated from rising groundwater, are preserved at the expense of the dune crests, which apparently have a lowe degree of cementation. Together, these observations suggest variations in groundwater height and possibly the presence of lacustrine episodes in Gale Crater.

Sulfates and clays associated with these deposits suggest they may occur as cementing agents within pyroxene-rich sands. Exhaustive studies have shown that authigenic pore-lining/filling clays are ubiquitous in terrestrial sandstones [11]. If the clays associated with these Martian sandstones are also pore-filling cements, then they too may be authigenic and thus record details of local aqueous geochemistry in Gale Crater. The payload of Curiosity will be able to test these hypotheses as it traverses the washboard morphology and the lower reaches of Mt. Sharp.

References: [1] Cabrol N. et al. (1999) Icarus, 139, 235–245; [2] Malin M. and K. Edgett (2000) Science, 290, 1927–1937; [3] Milliken, R., et al. (2010) GRL, 37, L04201; [4] Scott, D. and M. Carr (1978) USGS Map, I-1083; [5] Schultz, P. and A. Lutz (1988) Icarus, 73, 91-141; [6] Rossi, A., et al. (2008) JGR, 113, E08016; [7] Thomson, B. et al. (2011) Icarus, 214, 413-432; [8] Anderson, R. and J. Bell III (2010) Mars, 5, 76-128; [9] Grotzinger, J. et al. (2005) EPSL, 240, 11-72; [10] Eschner, T. and G. Kocurek (1988) AAPG Bull., 72, 932-943; [11] Wilson, M. and E. Pittman (1977), J. Sed. Pet., 47, 3-31.

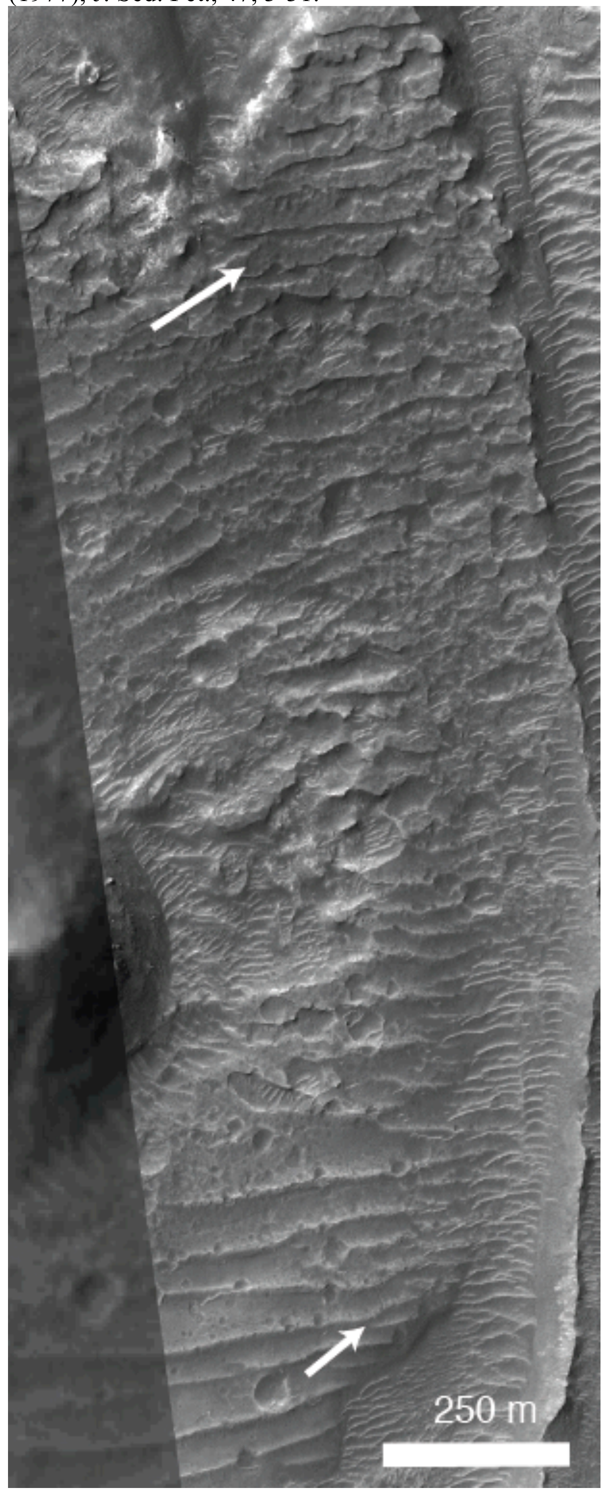

Figure 2. Example of preserved bedforms w/ bifurcation (lower arrow) transitioning to 'washboard' morphology (upper arrow), consistent with preservation of interdune sediments. Image is from S boundary of Mt. Sharp.