THE LIGHT-TONED YARDANG UNIT, MOUNT SHARP, GALE CRATER, MARS SPOTTED BY THE LONG DISTANCE REMOTE MICRO-IMAGER OF CHEMCAM (MSL MISSION).

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Introduction: The landforms referred to as yardangs are defined according to their erosion patterns, i.e. elongated, asymmetric sharp-edged spurs sculpted by abrasion and deflation processes [1]. The Light-Toned Unit (LTYu), also referred to as Coarse yardangs unit (Cyu) [2], is one of the five geological units that compose the central Mount Sharp, and was emplaced at the E.-L. Hesperian transition [2]. From orbit (Fig. 1) the LTYu displays a general lens-shape. The LTYu lies between -3900 and -2200 m in elevation, in clear unconformity on the Syu (Small yardangs unit) which is composed of dark-toned, nearly flat-lying layers. The CRISM spectral signatures of LTYu are those of the ubiquitous Martian dust, and the composition of the bedrock is unknown [3]. That contrasts with the spectra of sulfates observed over the Syu, for which ferric oxide (hematite) has also been noticed. The LTY in Gale definitely resembles the FLDs (friable layered deposits) of the regional Medusae Fossae Fm which has been related to ash and air fall deposits [4].

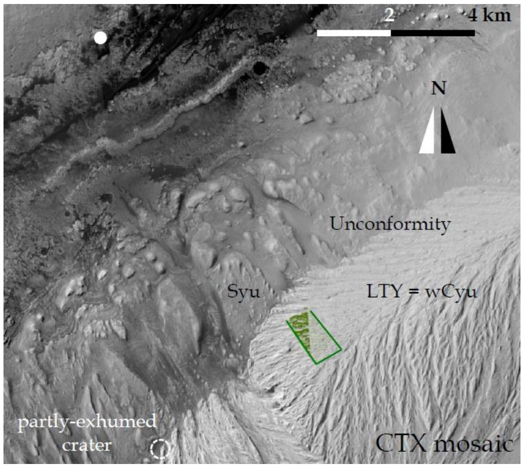

Fig. 1: CTX image of the Light-Toned Yardangs. The LTYu unconformably overlies the Syu (Small yardangs unit) made up of dark-toned, 10-30 m thick, flat-lying layers evenly interbedded with thin strata. The unconformity geometry shows a maximal elevation difference of about 1.6 km with a surface dipping to 10°W region [6]. The green-colored area is the viewshed from the LD RMI (Fig. 2) taken from the white spot located in the upper left of the image.

A long distance mosaic towards Mt Sharp was assembled from a double series of RMI images taken on sols 1183 and 1241 of the MSL mission. The final mosaic was the object of a preliminary description that revealed the presence of fine-scale horizontal layers, and possibly angular beds [5]. We report here the result of a re-inspection of this LD RMI mosaic and discuss environments and mechanisms that favored the deposition and preservation of the LTYu.

The Long Distance Remote Micro-Imager: The LD RMI images were captured by ChemCam, a remote sensing instrument currently operating onboard the NASA Mars Science Laboratory (MSL) rover, which determines at distance, the morphological type and composition of rocks and soils [7]. The ChemCam suite incorporates the Remote Micro-Imager (RMI) which provides several types of context imaging [8]. ChemCam's RMI offers the finest pixel scale on the rover mast with 19.6 µrad/pixel (1024x1024 grayscale CCD detector). The smallest distinguishable features are of the order of 0.1 mm at 3 m [8, 9], 4.1 cm at 1 km, and 0.5 m at 12 km (referred to as "Long Distance") in the best focus conditions. These images are a useful complement to MastCam color or multi-filter images (e.g. [10]). The small depth-of-field and field-of-view of the RMI have made it challenging to obtain an optimal focus on long distance targets, but a new autofocus algorithm based on an onboard repeated analysis of the RMI images gives accurate results [11].

Depositional architectures: LD RMI images show that the LYTu is made up of a stack of several meters-thick, light-toned, resistant, clearly-dipping (i.e. apparent dip up to 12°SW) layers that mimic giant clinoforms, separated by recessive horizons dipping the same way. Closer observation reveals that the resistant, first-order layers are internally composed of counter-dipping to sub-horizontal, evenly- to cross-stratified minor beds fading down into the recessive horizons.

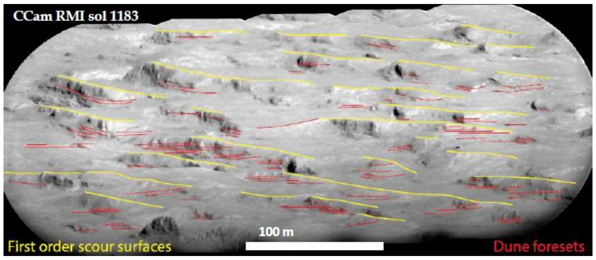

Fig. 2: Mosaic of a five LD RMI images taken on sol 1183. Light-toned, resistant, subparallel layers show an apparent dip of [4-12]°SW. These layers are bounded by the first-order surfaces (yellow lines) that are erosive surfaces which truncate the gently counter-dipping, even and fine beds which generally prograde to the left hand side of the image, i.e. foresets (red lines). Strike section of orthogonally-directed trough cross-beds can be noticed as well.

Analog: The stratal architecture of the LTYu (cross-bedding pattern, thickness) compares remarkably well to that of the eolian Jurassic Navaro Sandstones exposed in the Zion National Park, UT (Fig. 3).

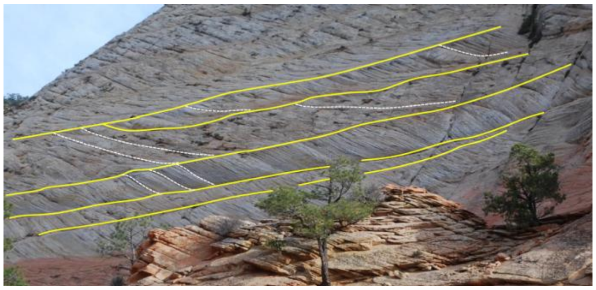

Fig. 3: Exposure of Jurassic Navaro Sandstones in Zion National Park, UT (Zion Mt Carmel Highway) illustrating the stratigraphic record of an eolian dune field. Three orders of cyclic cross-beds are recorded. Updipping, several meters thick individual cross-bed sets are bounded by first-order, ramping up, scour surfaces (underlined in yellow). Foresets display oblique to tangential, i.e. prograding transverse dunes to barchanoid ridges. The steeply-dipping foresets were built out by grainflow and grainfall processes. Individual foresets and groups of foresets (underlined in white) represent annual and decadal (30 & 60 yrs) cycles respectively [12]. Upper parts of foresets and windward side of dunes have been stripped away and only the lee sides of the dunes have been preserved. Erosion surfaces produced by reversals of the normal-to-bedform component of flow tend to be best developed on the lee slope and to become non-erosional hiatal surfaces downward. Rocks are variably lithified according to the development of calcite and iron oxide cements.

Deposition and preservation: We refer to the theoretical model of figure 4 to understand the way eolian dunes of the LTYu climbed and were partly preserved.

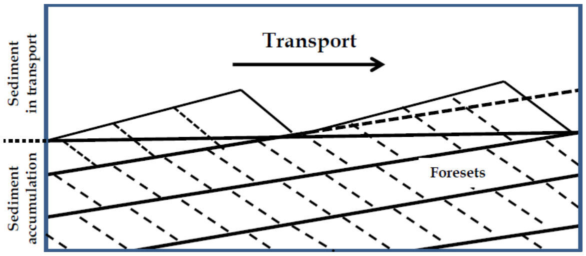

Fig. 4: Theoretical diagram for the generation of sets of cross-strata by migrating and climbing dunes [13]. Where bedforms climb at angles lower than their windward slopes, the underlying and preceding bedforms are eroded. This leads to the formation of prominent bounding surfaces, i.e. first-order surfaces, that define sets of cross-strata.

As to the formation of the dunes of the LTYu, it is inferred that traction process prevailed over gravity-driven processes on lee-sides given the very gently to flat-lying counter-dipping foresets (Fig. 2). The visible dual cyclic cross-bedding has been produced by periodic fluctuations in wind flow direction/flow velocity. The dominant transport was by north-northeasterly winds. It can be thought that accumulations occurred in dry eolian systems because of the absence of interdune-flat accumulations. The hardly visible basal portions of sets however may represent accumulation in wet, interdune depressions.

The contact geometry between LTYu and Syu (truncation of underlying strata, declivity) is suggestive of eolian control of the surface of erosion. The similar dip for the basal unconformity and the first-order climbing surfaces of the LTYu suggests that these two features are genetically-related, i.e. generation related in time/space. In central Gale, the passage of the negative sediment budget -associated with the formation of the unconformity- to the positive sediment budget -associated with the deposition of the LTYu- is believed to reflect the general deceleration of the wind flows -case of a dry eolian system- and/ or a rise of the water table [11]. A water table development through-up the LTYu is consistent with the fact that the LTYu elevation, i.e. ranging from -3900 m to -2200 m, is below the present-day lowest elevation of the crater rim, i.e. -2000 m [14].

Conclusion: Several lines of conclusions can be drawn: 1) from the structures and cyclic cross-bedding of the layers, it can be stated that the Mount Sharp LTYu is composed of giant eolian climbing dunes pushed up by N-NE winds, and not of pyroclastic (*flow*) deposits, but it could be reworked pyroclastics; 2) the generation of the unconformity together with the deposition of the LTYu in Gale are likely to have marked the onset of prevailing subaerial and dry environments in central Gale at the Early-Late Hesperian transition, even if some ground moisture percolating from the crater rim must have persisted; 3) the dominant north-northeasterly winds at Gale might be gravity (katabatic) winds blowing down from the southern highlands to the northern lowlands.

References: [1] McCauley et al. (1979) *JGR*, *84*, 8222-8232. [2] Le Deit et al. (2013) *JGR, 118*, 2439-2473. [3] Milliken et al. (2010) *GRL, 37*, L04201. [4] Hyneck et al. (2003) *JGR 108*. [5] Anderson et al. (2016) *LPS XLVII, Abstract* #1770. [6] Thomson & Bridges (2008) S^{nd} *MSL Landing Site Meeting*. [7] Maurice et al. (2012) *Space Sci. Rev., 170*, 95-166. [8] Le Mouélic et al. (2015) *Icarus, 249*, 93-107. [9] Langevin et al. (2013) *LPS XLIV, Abstract #1227*. [10] Bell et al. (2013) *LPS XLIV*, Abstract #1417. [11] Gasnault et al. (2016) *LPS XLVII, Abstract #2329.* [12] Chan & Archer (2000) Utah Geol. Ass. Pub. 28. [13] Kocurek (1986) Sedimentary Environments. *Blackwell Science*, 125-153. [14] Calef et al. (2016) LPS XLVII, *Abstract* #2822.