CHARACTERIZATION OF SMALL SEDIMENTARY STRUCTURES IN ROCKS OF THE GLEN TORRIDON REGION (GALE CRATER, MARS) USING PHOTOGRAMMETRY. G. Caravaca[1*], N. Mangold[1], S. Le Mouélic[1], L. Le Deit[1], O. Gasnault[2], F. Rivera-Hernandez[3], C. M. Fedo[4], K.S. Edgett[5], R.C. Wiens[6] [1]UMR CNRS 6112 LPG, Université de Nantes, France, [2]IRAP, Toulouse, France, [3]Dartmouth College, Hanover, NH, [4]Dept Earth & Planetary Sciences, University of Tennessee, Knoxville, TN. [5]Malin Space Science Systems, San Diego, California, USA, [6]LANL, Los Alamos, USA. *gwenael.caravaca@univ-nantes.fr.

Introduction: The Glen Torridon (GT) region in Gale crater, Mars, has been explored by the Mars Science Laboratory *Curiosity* rover since ~Sol 2300 (Feb. '19), seeking traces of the clay-bearing minerals initially detected from orbiter data [1]. The lowermost locations of the GT trough are dominated by the Jura member mudstones, and fine-grained sandstones of the Knockfarril Hill member above it. The latter exhibit multi-scale laminations and cross-bedding. The precise characterization of these sedimentary structures is critical for understanding the stratigraphic relationships between the GT members, but also the hydrodynamical conditions that prevailed during deposition of these sediments. Some of the smallest structures encountered by *Curiosity* were observed using the Mars Hand Lens Imager (MAHLI) instrument which can resolve coarse silt (62.5 μm) at a distances of ~2 to 4 cm. In this study, we use MAHLI images and Structure-from-Motion (SfM) photogrammetry to reconstruct 3D micro Digital Outcrop Models (DOM) of GT rocks for interpreting small-scale 3D sedimentary structures.

Micro-DOM Reconstruction using Structure-from-Motion Photogrammetry: To image outcrops and/or individual rocks from a closer perspective, we can use MAHLI, a color micro-imager on the rover's robotic arm [2]. MAHLI images are critical to characterize grain size distribution and sub-mm- to cm-scale sedimentary structures in rocks. However, 2D photo mosaics are sometimes tricky to interpret and can lead to difficulties in discriminating 3D structures from mosaicking artifacts. To overcome this issue, a 3D representation of the outcrops encountered by *Curiosity* can be useful. We thus use SfM photogrammetry to reconstruct high-resolution 3D micro-DOMs of rock outcrops imaged by MAHLI (e.g. Fig. 1) when the images allow it [3]. Using these 3D outcrop models can help us determine 1) whether specific structures appearing on the 2D mosaics are real or not (e.g. due to parallax) and 2) whether the surficial shapes of outcrops are a product of erosion or original sedimentary structures that can be used to interpret depositional conditions. Three-dimensional models also enable us to observe the outcrop from varying points of view. Line-drawing of the 3D geometry of the strata (e.g., laminae) in an outcrop also helps us to identify and characterize structures that would be difficult to distinguish in planar images (Figs. 1b-c, 2b). This is especially important in the GT area due to the very fine-grained nature of the observed sandstones, with cm-scale variations in the sedimentary architecture potentially indicative of rapid shifts in laterally evolving depositional settings.

Characterization of 3D Small-scale Sedimentary Structures: The Stack_Of_Glencoul target (Sol 2444) is part of the Teal Ridge outcrop, a ~1.5 meter-high outcrop consisting of cross-laminated sandstones. The outcropping conditions of the Stack_Of_Glencoul target and its complex 3D shape makes it difficult to assess whether the cross-stratifications observed in the 2D mosaic are original structures or due to differential erosion. The 3D micro-DOM of this target (Fig. 1a) helps us confirm the original nature of these cross-stratifications (Fig. 1b). Line-drawing of these mm-scale laminations (blue lines, Fig. 1c) show the presence of at least four sets of low angle (<15°) cm-scale cross-stratifications, separated by sharp truncation surfaces (red lines, Fig. 1c). These truncations and multiple/alternating directions of propagation in 3D (Fig. 1c) suggest that these sediments were deposited in a dynamic setting such as a fluvial environment. This target also records a complex post-depositional history indicated by a network of diagenetic veins (Fig. 1), identified by ChemCam as calcium sulfate veins (these have been identified throughout the Murray formation) [4]. Some of the veins cross-cut the laminations, while others occur in-between layers.

The Strathdon target (Sol 2462) shows sub-cm-scale undulating laminations, highlighted by differential erosion of the outcrop (Fig. 2). These undulations could be ripple marks but burial can also create similar structures [e.g. 5]. Nevertheless, these laminations are characterized by cm-scale cross-stratifications with varying directions of propagation (green lines on figs. 2b-c), suggesting that these sediments were deposited in an energetic fluvial setting. In the lower part of the outcrop, undulated laminations (possibly ripples) are emplaced unconformably above a more massive bed as highlighted by the red line on Fig. 2c. This contact hints at potentially rapid variations of the hydrodynamical regime between quieter and more energetic settings. This target also records a complex post-depositional history and shows a similar network of calcium sulfate veins as those observed in the Stack_Of_Glencoul target.

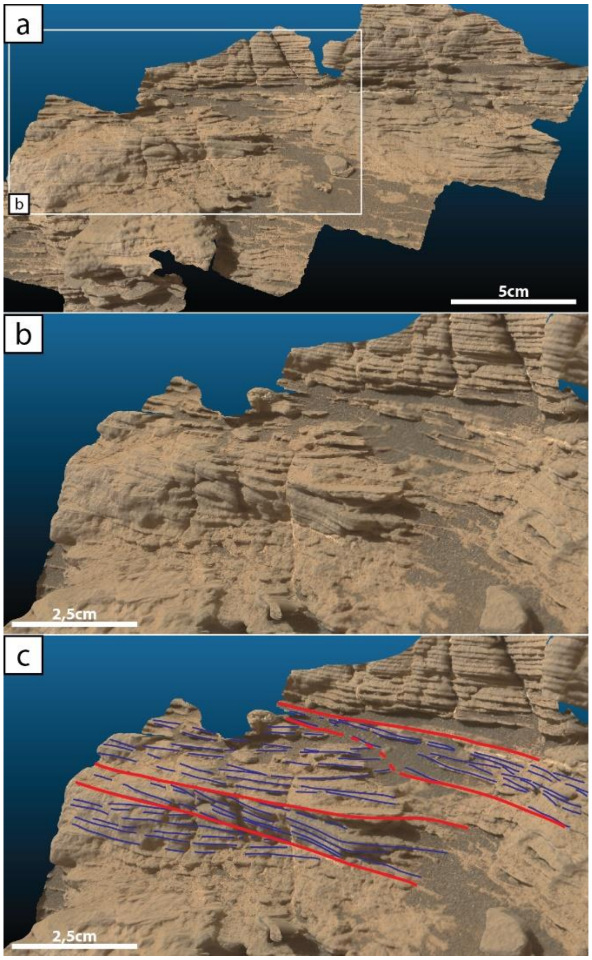

Fig. 1 a) 3D micro-DOM of the Stack_of_Glencoul target (Sol 2444) reconstructed using 15 MAHLI images (https://skfb.ly/6P7zS). b) Close-up view of cross-stratification structures from a different point of view. c) Interpretation of the same view as (b); blue lines: cross-stratifications; red lines: truncations.

Summary and conclusions: High-resolution photogrammetric 3D micro-models reconstructed using MAHLI images are useful for accurately identifying and characterizing sedimentary structures on Martian outcrops. Analyses of these 3D structures are important to understand the lateral and vertical variations of the paleoenvironments in the GT region. While the lowermost part of the GT area contains mudstones deposited in a quiet lacustrine environment, the Knockfarril Hill member shows a progressive shift toward a more dynamic depositional setting as evidenced by its sedimentary structures. Further additional work will be carried out to integrate composition data from the ChemCam instrument in order to assess potential geochemical variations in line with observed variations of the sedimentary structures. These sedimentary facies changes (through time and space) might have critical implications regarding the deposition and/or *in situ* formation of the clay-bearing minerals observed in the GT region.

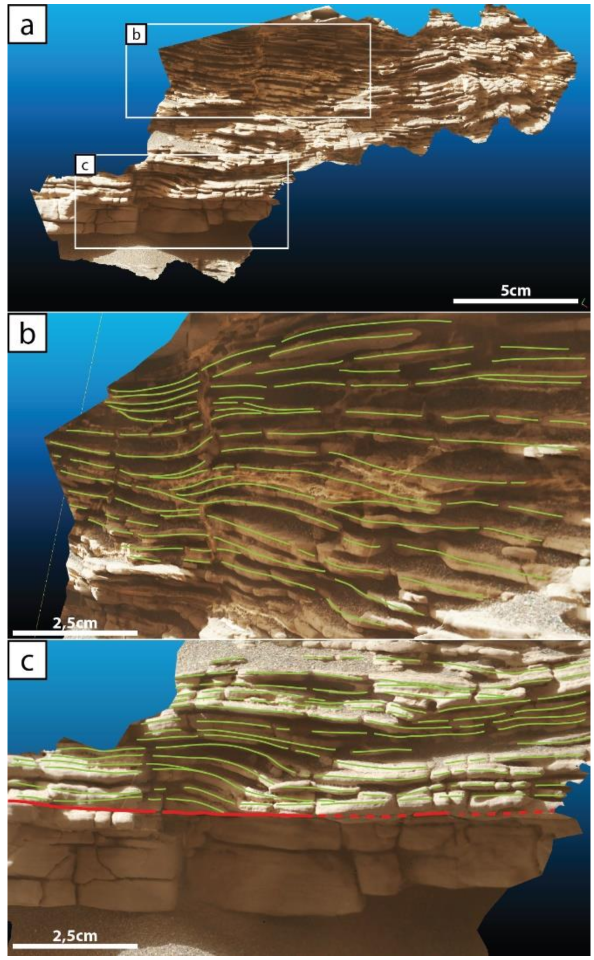

Fig. 2 a) 3D micro-DOM of the Stathdon target (Sol 2462) reconstructed using 18 MAHLI images (https://skfb.ly/6P7tz). b) and c) Close-up views of different sets of cross-stratifications from varying points of view. Green lines: cross-stratifications; red line: unconformable contact (dashed lines denotes parts of the contact hidden under an overlying lamination).

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