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The Prow outcrop: an “open catalog” of multiscale 3D fluvial sedimentary structures in the lower sulfate unit of Gale crater (Mars)

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The *Curiosity* rover of the Mars Science Laboratory has been exploring since mid-2021 the lower sulfate unit of Mount Sharp in the Gale crater. This unit, first described from orbital observations as showing spectral signatures of hydrated sulfate minerals [1], has recently been revealed to record a major paleoenvironmental and climatic transition during the Hesperian-Noachian transition, with the onset of alternating wet and dry conditions before a complete aridification of Martian conditions [2]. Before the current campaign, this unit was mainly studied using remote observations (e.g., [2, 3]), but *Curiosity* has now entered this major interval allowing to precisely study the rock record leading to this major climatic event.

Since the rover left the Glen Torridon area (aka the clay-bearing unit, Fig. 1), the *Curiosity* rover entered the sulfate-bearing unit (~Sol 3100, mid-2021; Fig. 1) and traversed sedimentary series mainly composed of fine to coarse sandstones. While no clear facies change or sharp contact has been observed when entering the sulfate-bearing unit, these levels differ from the previously observed terrains in Gale by an increased occurrence of nodular features with a strong sulfate geochemical signature [4, 5], polygonal ridges [4], or even halite detections [6]. Otherwise, the sedimentary structures and grain-size are continuous across the upper members of the Carolyn Shoemaker formation and into the overlying Mirador formation, indicating a likely continuity in the continental settings for most of these deposits.

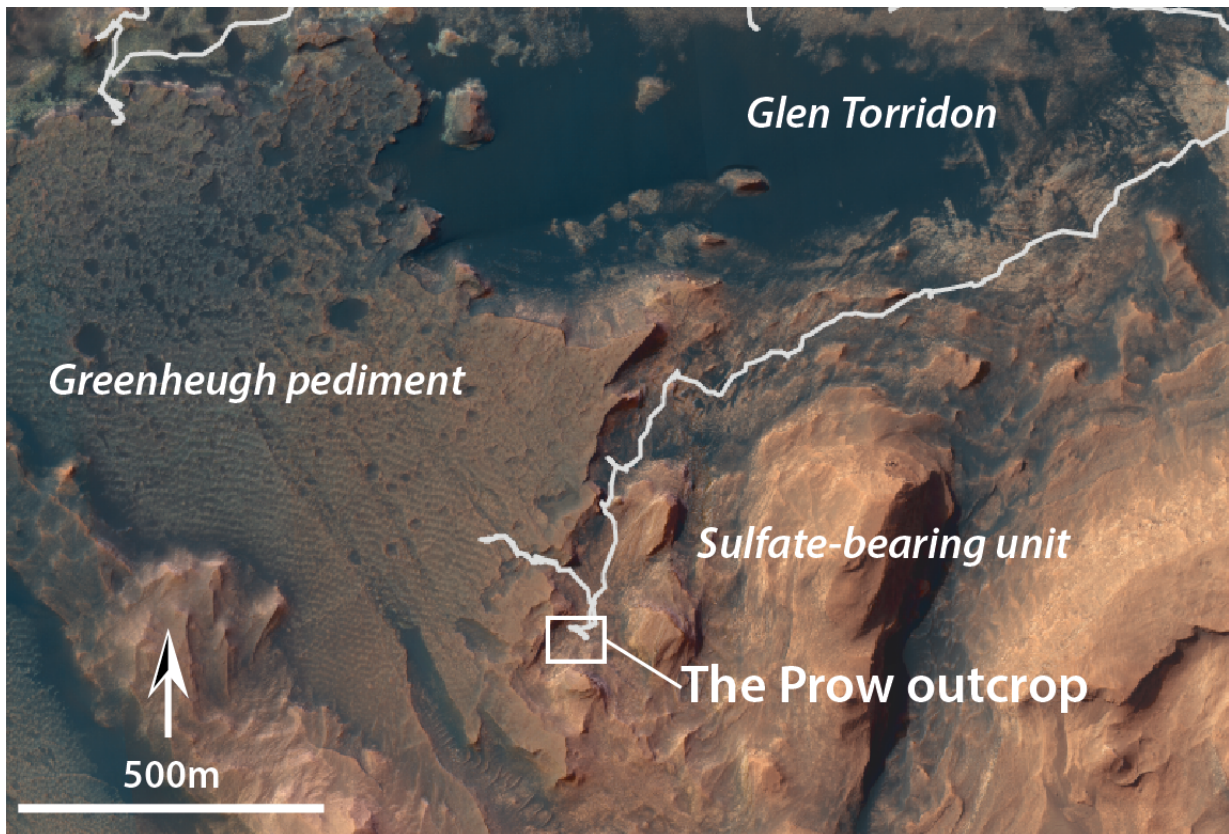


Figure 1: Localization of the Prow outcrop in the sulfate-bearing unit of Gale crater

Such structures are notably well visible at the Prow locality, a major outcrop situated in the Contigo member of the Mirador formation, just below the Greenheugh pediment (Fig. 1). This outcrop has been reached and studied in January and February 2022, between sols 3349 and 3379. Using ~3200 mid- and close-range images from the Navigation and Mast cameras (Navcam, Mastcam), we used structure-from-motion photogrammetry to reconstruct a Digital Outcrop Model (following the method described in [7]) of the Prow locality and its vicinity (Fig. 2). This DOM covers an area of about 1000m². Two small excerpts of this DOM are explorable online on the Sketchfab platform at <https://skfb.ly/o8DJZ> and <https://skfb.ly/otpLW>. The DOM allows us to visualize and characterize several sets of meter- to centimeter-scale sedimentary structures, over about 30 meters of lateral continuity, either using on-screen visualization, or integrated within a Virtual Reality environment.

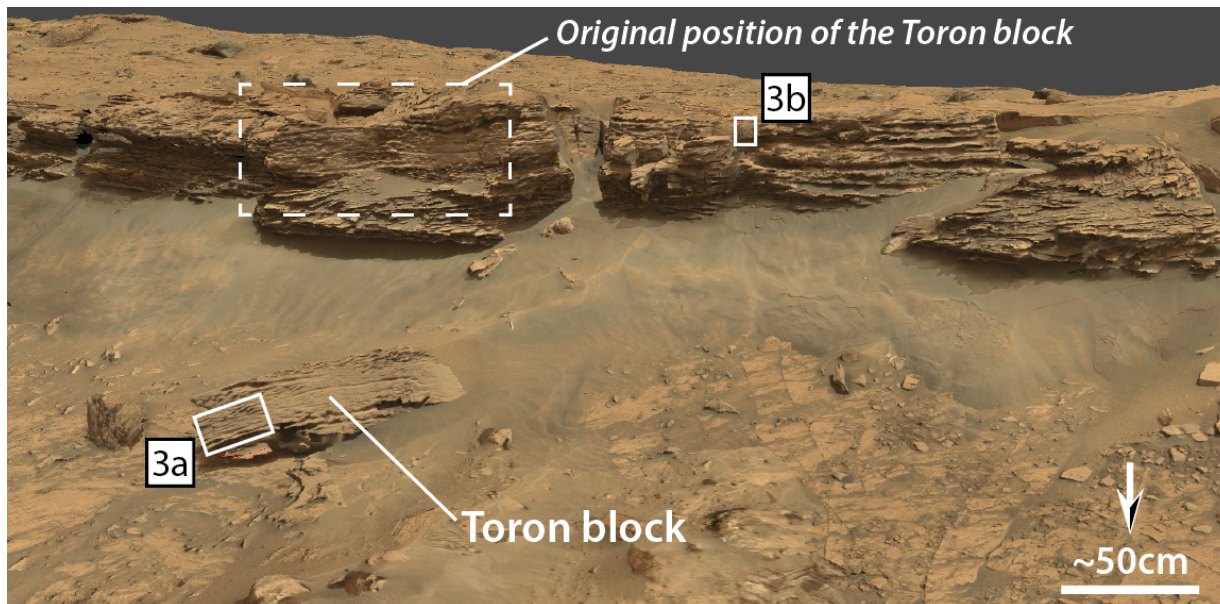


Figure 2: General view of the 3D DOM of the Prow outcrop, and position of the ChemCam’s RMI targets illustrated in Fig. 3. The Toron block was identified as a block “fallen” from the main cliff-face using the 3D reconstruction, allowing close-range inspection of its layers

The DOM reconstruction has been helpful in determining the targets of interest during the Prow exploration by *Curiosity*. One particular benefit has been to identify the Toron block (Fig. 2) as a fallen piece of the main outcrop, allowing us to perform very close-range observations of the outcrop’s cliff-face (e.g., Fig. 3a) without actually putting the rover too close to the actual rock-face. The interest of using such 3D reconstruction notably lies in the ability to characterize the spatial distribution of the multi-scale structures observed at the Prow, but also to study the spatial distribution (and potential variations) of the geochemical composition of these layered sandstones as seen by the ChemCam instrument. We also take advantage of the high-resolution micro-images provided by the Remote Micro-Imager subsystem of the ChemCam instrument (with a field of view of 20 mrad per frame, resolving grains under the silt at close range) to study the facies (grain-size, micro-structures) of the different sandstone beds cropping out at this locality (Fig. 3).

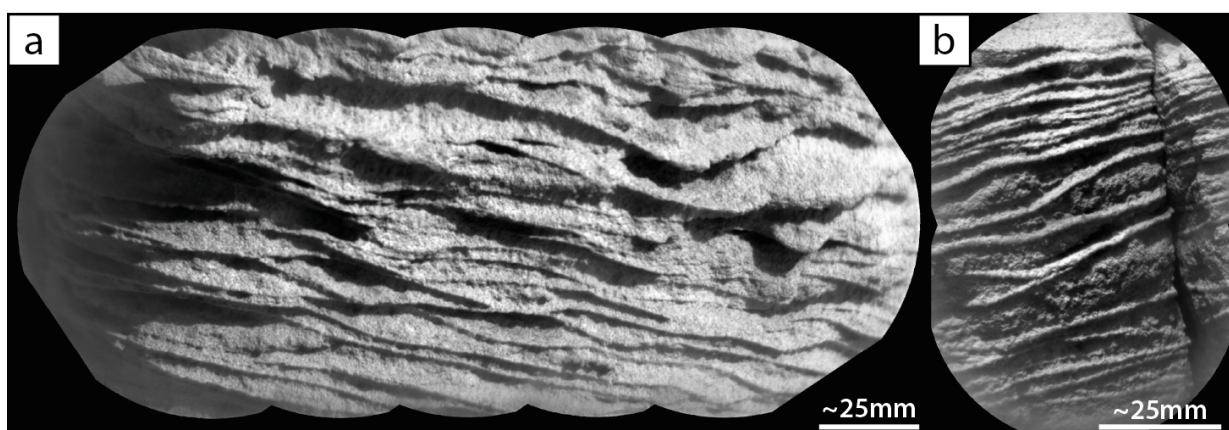


Figure 3: Examples of RMI mosaics used to characterize the texture and micro-scale sedimentary structures at the Prow outcrop. a) RMI mosaic of the target Paikwa showing possible climbing ripples, observed on the fallen Toron block. b) RMI mosaic of the target Roraimita showing draping on the cross-laminae

At the Prow, we characterize several sets of sedimentary structures such as (but not limited to) meter-scale cross-stratifications, cm-scale symmetric ripples but also probable climbing ripples (Fig. 3a). These structures, mostly indicating a direction of transport toward the NW (similar to what is observed in underlying Glen Torridon area), denotes sustained aqueous conditions compatible with a fluvial setting. We also observe in some place at the Prow, and notably in the upper layers, mm-scale fine-grained draping (Fig. 3b) deposited at the surface of (cross-)stratifications, reminiscent of flaser bedding on Earth. These fine muddy levels indicate recurrent intervals of low-energy deposition in-between higher-energy periods. Put together, these elements help us to characterize sustained aqueous conditions in a dynamic setting of combined flow and wave action at the time the sediments were deposited (e.g., [8]), helping us to determine probable mixed fluvio-aeolian settings around the critical climatic transition observed within this sulfate-bearing unit characterized by alternating wet and dry conditions.

References: [1] Miliken *et al.*, 2010, *Geophys. Res. Lett.* **37**, L04201; [2] Rapin *et al.*, 2021, *Geology* **49**; [3] Caravaca *et al.*, 2021, *Remote Sensing*, **13**(20), 4068; [4] Rapin *et al.*, 2022, *EPSC, this meeting*; [5] Schieber *et al.*, 2022, *LPSC*, Abstract #1304; [6] Meslin *et al.*, 2022, *LPSC*, Abstract #2492; [7] Caravaca *et al.*, 2020, *Planet. Space Science* **182**, 104808 ; [8] Gupta *et al.*, 2022, *ESPC, this meeting*.