FLOW DIRECTION ASSESSED FROM 3D GEOMETRY RECONSTRUCTION OF KODIAK BUTTE IN JEZERO CRATER (MARS). G. Caravaca[1, *], G. Dromart[2], N. Mangold[3], S. Gupta[4], S. Le Mouélic[3], O. Gasnault[1], L.C. Kah[5], S. Maurice[1], R.C. Wiens[6]. [1]Institut de Recherche en Astrophysique et Planétologie, Université de Toulouse, CNRS, CNES, France, [2]LGL-TPE, Univ. Lyon, France, [3]LPG, Univ. Nantes, France, [4]Imperial College, London, UK, [5]Univ. Tennessee, Knoxville, TN, [6]LANL, Los Alamos, NM. *gwenael.caravaca@irap.omp.eu

Introduction: Upon landing in February 2020, the rover *Perseverance* of the Mars2020 mission has been exploring Jezero crater on Mars, seeking traces of ancient life. This crater was notably first selected because of the presence of a well-developed fan-shaped sedimentary body in its western part, at the mouth of Neretva Vallis (Fig. 1, e.g., [1]). At the time of the landing, one of the main goals was to assess whether this feature was of fluvial(-deltaic) or alluvial origin. Thanks to long-distance remote observations performed from on-ground by the *Perseverance* rover, this question has been answered by the identification of structures characteristic of a Gilbert-type delta, confirming the fluvio-deltaic origin of the western fan sedimentary system [1]. Here, we focus on Kodiak butte (Fig. 1), a remnant of a former extension of the Jezero western delta [1]. We used SuperCam's Remote Micro-Imager (RMI) to obtain long-distance mosaics of Kodiak in order to compute a Digital Outcrop Model (DOM) of the butte. We use the resulting 3D model to characterize the 3-dimensional architecture and stratal patterns within the butte, and to identify variations in flow direction and regime during the late stages of delta deposition.

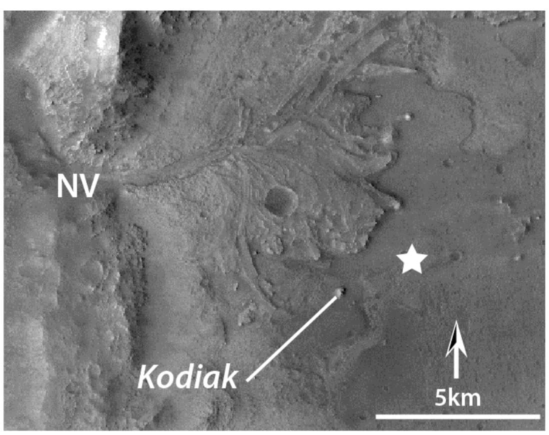

Fig. 1 Orbital view of the western fan in Jezero crater (CTX basemap), and position of the Kodiak butte, relative to the Octavia E. Butler landing site (white star). NV: Neretva Vallis.

Data and methods: To obtain a detailed 3D view of the Kodiak butte, we conducted a multi-sol imaging experiment using the RMI subsystem of the SuperCam instrument. With a focal length of about 563 mm [2], this camera can image at a couple of cm per pixel from 2 km distance, i.e., it offers the possibility of distinguishing decimetric details at this long distance. These images are useful to assess the properties of remote outcrops not yet visited by the rover. The experiment consisted in applying a photogrammetric treatment to a series of long-distance observations provided by SuperCam's RMI. A similar experiment has recently been conducted in Gale crater [3], where ChemCam's RMI frames were used to reconstruct the 3D shape of remote outcrops up to ~750 meters away from the *Curiosity* rover. Here, we follow the method described in [3], applied to 15 images of the Kodiak butte captured by SuperCam during sols 63 and 248 (Fig. 2a). The mosaics were acquired from two points of view, situated ~2 to ~2.5 km-away from Kodiak (Fig. 2b), separated by a virtual baseline of ~800m (red dashed line in Fig. 2b). This virtual baseline is needed to obtain a stereo pair of the imaged area with a sufficient overlap to perform the photogrammetric treatment.

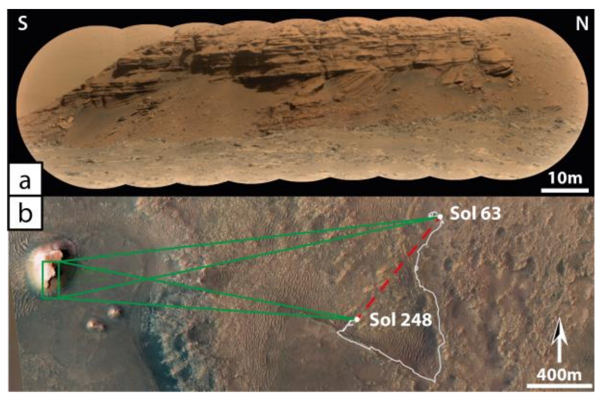

Fig. 2: a) RMI mosaic of the southern part of Kodiak butte. b) Imaged area on the Kodiak butte cliff-face (green box) and successive positions of the *Perseverance* rover during sols 63 and 248 where the RMI mosaics were acquired. The "virtual baseline" (red dashed line) is ~800m.

Digital outcrop Model: The resulting 3D DOM, presented in Fig. 3 reproduces about 2100m² of the Kodiak cliff-face. Its scaling is achieved using the original RMIs, controlled with Mastcam-Z mosaics and HiRISE orbital imagery. To improve the visualization of the structures, this model has also been integrated within a Virtual Reality environment, allowing investigation of the geomorphic features of Kodiak at true 1:1 scale. This DOM can be seen online (in VR) on the Sketchfab web platform at: https://skfb.ly/o89yU .

Spatial variations in the stratal pattern of Kodiak: The 3D mesh reveals in detail the relief and architecture of the Kodiak butte surface and its stratigraphy. From bottom to top, the Gilbert-like succession indicated by [1] can clearly be observed, namely bottomsets, south-dipping foresets and topsets, plus a layer containing boulders (Fig. 3a). Each layer or block can be assessed individually and orthogonally to get a reliable thickness measurement for the layers, and the same technique to measure the long axes of individual blocks.

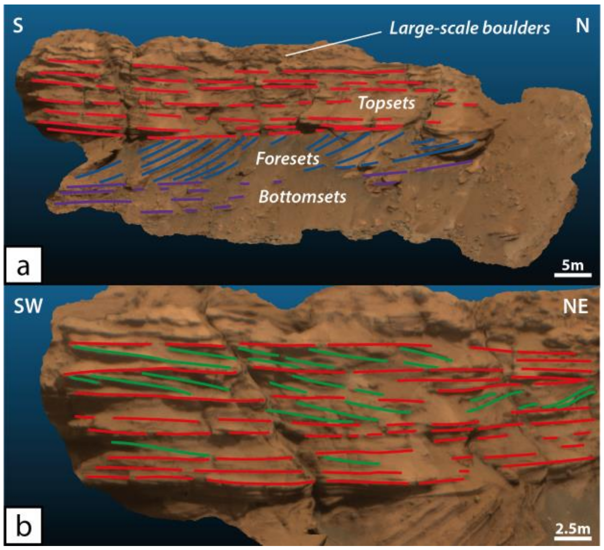

Fig. 3: a) View of the 3D DOM of the Kodiak butte. Red, blue and purple lines highlight top-, fore- and bottomsets, respectively, showing a southward flow direction. b) Detail perspective view of the topset part displaying several sets of thinner oblique stratifications (green lines), indicating probable episodic variation of the flow direction toward the east. DOM can be viewed online at https://skfb.ly/o89yU.

Measurements give average bed thicknesses of approximately 15 cm, 17 cm and 19 cm for bottom-, fore- and topsets, respectively. This upward increase in thickness is in agreement with the local apparent regression pattern recorded by a deltaic sequence. Within the topset package, at least 3 sets of oblique stratifications (green lines, Fig. 3b) can be observed in-between planar sub-horizontal topsets (red lines, Fig. 3b). These beds have a smaller average bed thickness compared to surrounding planar bed of topsets (approx. 13.5 cm). Also, there are indicating a different bed inclination direction to the east, when most of the butte's record points to a southward direction.

Finally, the average long axis size of the boulders at the top of the butte is approx. 52 cm, with individual block measurements ranging from 22 cm to 104 cm. This clast-supported unit seems to unconformably lie upon topsets, possibly within an eroded channel at the top of the sedimentary body.

Discussion: The observed succession is in general agreement with other analyses on the Kodiak butte and main delta front in Jezero crater [1, 4, 5], and the 3D model furthermore distinguishes localized variation in the depositional regime during the late-stage history of the delta at Kodiak. The sets of oblique stratifications show conspicuously different but recurring changes in transport direction toward the East, and are associated with reduced bed thicknesses. This pattern is compatible with the onset of either meandering beds or curved braided bars during the deposition of the topset sequence. Similarly, the presence of large-scale boulders, which lay unconformably on top of the delta topsets, also points to a decoupling in history after deposition of the delta [1]. This highlights a complex history of the delta area, and notably raises the question of the temporal extension of these events, with a possible cyclicity as illustrated by alternating oblique and planar topsets.

Summary: Using remote observations acquired by SuperCam's RMI, we compute a high-resolution 3D Digital Outcrop Model of the Kodiak butte. This model helps us to assess the 3D shape, architecture and stratal pattern of this sedimentary body from a distance of about 2 km, giving us insight into the stratigraphic history of the delta even before reaching it with the rover. On the one hand we confirm the delta architecture evidenced by [1] and on the other hand we observe major changes in flow direction and regime that occurred during the late stages of delta formation, with a clear eastward flow by at least 3 times among the overall southward topsets, associated with reduced bed thicknesses. This points at the onset of meandering or curved braided channels, not dissimilar to observations on the main delta top. We characterize marked but recurrent changes of fluvial activity, with implications to the overall timescale of the Jezero delta system.

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References: [1] Mangold et al. (2021) *Science, 374*, 6568. [2] Gasnault et al. (2021) *LPSC LII*,#2248. [3] Caravaca et al. (2021) *Remote Sensing, 13*, 4068. [4] Mangold et al. (2022) *LPSC LIII* (this conf.). [5] Gupta et al. (2022) *LPSC LIII* (this conf.).