STRATIGRAPHIC RECONSTRUCTION AND ANALYSIS OF THE DELTA REMNANT KODIAK IN JEZERO CRATER, MARS. C. D. Tate[1*], A. H. Hayes[1], O. A. Kanine[2], S. Gupta[3], G. Caravaca[4], G. Paar[5]. [1]Cornell University, Department of Astronomy, Ithaca, USA; [2]California Institute of Technology Division of Geological and Planetary Sciences, Pasadena, USA; [3]Imperial College London, UK; [4]Institut de Recherche en Astrophysique et Planétologie, Université de Toulouse, CNRS, CNES, France; [5]Joanneum Research, Graz, Austria; [*]corresponding author cdt59@cornell.edu.

Introduction: Kodiak is an erosional remnant of the larger Western fan of Jezero that is continuously visible to the Perseverance rover throughout the first two years of the Mars 2020 mission. This 80 m tall and 250 m wide butte supports the hypothesis that an ancient lake once existed in this crater [1]. The clarity of its exposed layers rivals even the Western Delta of Jezero which stands less than a kilometer North of which Kodiak is a remnant once attached before erosion resculpted the landscape. Herein, we discuss the digital modeling process that reconstructs the three-dimensional shape of Kodiak and the stratigraphic analyses enabled therewith.

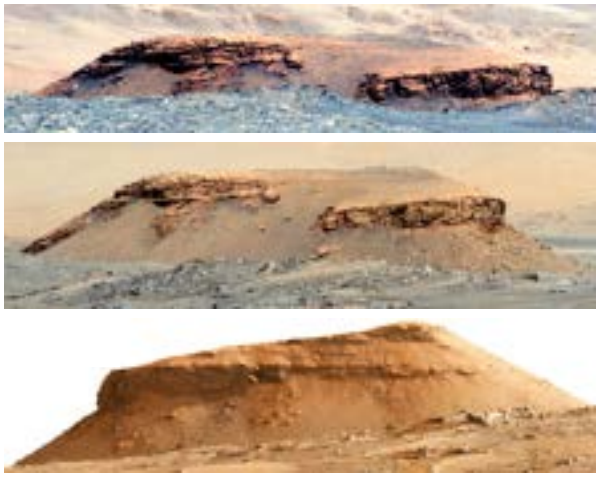

Figure 1: Mastcam-Z mosaics of Kodiak from sol 275 (top), sol 83 (middle), and sol 414 (bottom) of the Mars 2020 mission. In all images, Séítah terrain is in the foreground, and the rim of Jezero Crater is in the background.

Data: This analysis uses images from two science instruments on the Perseverance rover: Mastcam-Z [2] and SuperCam's Micro-Imager (RMI) [3]. The reconstruction shown in Figure 2 includes over 200 Mastcam-Z images taken from 10 locations along the Perseverance traverse and six RMI mosaics from six locations. For the first 388 sols of the mission, the rover saw Kodiak's eastern face from azimuths +65° to +100° from a 2-2.6 km distance. Images from sols 400 to 580 view Kodiak's northern face from -22° to +18° azimuth at a minimum distance of 500 m. Together, these images document about two-thirds of Kodiak.

This range covers most of Kodiak's exposed outcrops above its wide skirt of scree and talus.

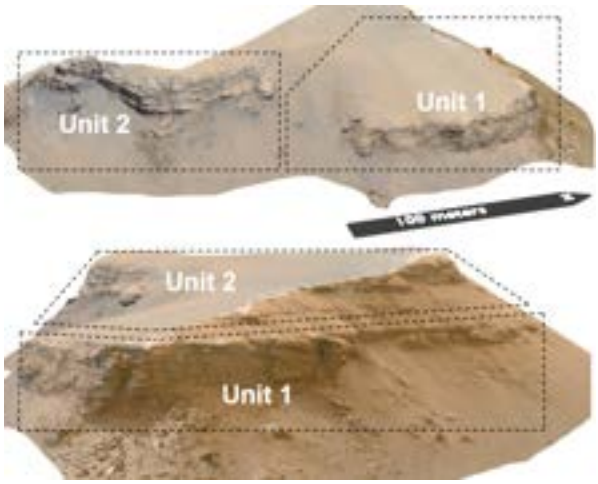

Figure 2: Rendered images of Kodiak's eastern (top) and northeastern (bottom) faces. The black bar is 100m long and points North relative to the top image.

Methods: We process these images to reconstruct a high-resolution digital terrain model (DTM) shown in Figure 2 and available online here. We use the Agisoft Metashape structure-from-motion photogrammetry application, which applies a semi-global multi-view stereo technique (similar to long-baseline stereo techniques used on previous missions [7] [8]). At a high level, this process compares tie points in each image to all other images and solves for the depth maps of each image. These depth maps are combined into an optimized 3D model composed of irregularly spaced triangles. The images are then projected onto this model and blended into a coherent texture map of the best resolution at each location.

Mastcam-Z's resolution on Kodiak's outcrops is ~4 cm on the east side and ~1 cm on the north side. The mesh resolution is about 8 cm for the major outcrops. RMI images more than double the textural detail on most outcrops. Several locations have stereo RMI coverage, improving the DTM's triangle density.

We use PRo3D [8] for layer tracing and a PCA-based plane-fitting algorithm [9] to calculate layer orientation and error in the layer's fit.

Analysis: This DTM provides an unprecedented opportunity to measure the geometry of the exposed layers and expand upon existing geological interpretations [e.g., 4,5,6]. We divide the stratigraphy of Kodiak into two units, each containing beds dipping roughly to the south (see Figures 2 and 3). Although

the precise contact between these units is obscured by the talus and scree surrounding the butte, the clinoforms we assume to be delta front foresets following [refs] are well exposed. Both units outcrop in the eastern and northern faces of Kodiak. The clinoforms of the younger unit 2 are best exposed in the south of Kodiak over a distance of 120 m, while the older and more complex unit 1 extends over twice that distance on both sides of Kodiak. The western edge of unit 1 even dips opposite the rest of the outcrop, leading [4,6] to propose that it has a distinct formation history.

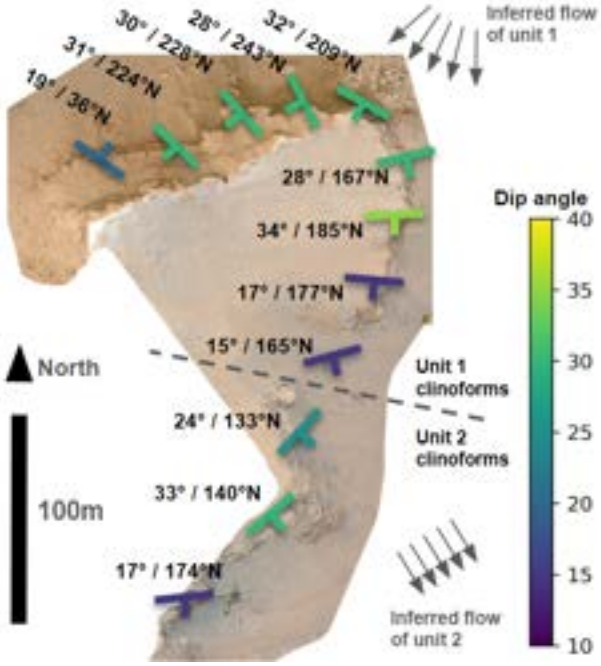

Figure 3: Orthomosaic of Kodiak showing the variation in dip (color) and azimuth directions for the steepest clinoforms around the butte.

The top unit (unit 2) is well exposed on a face ~perpendicular to its dominant dip direction. This reveals a cross-section of a clinoform package dipping at 10-40° sandwiched between packages that dip 2-12 degrees in the same direction (azimuth 130-170° from North). We interpret this unit as consistent with that of a typical Gilbert-style delta with topsets, foresets, and bottomsets forming a succession of deltaic deposits in Jezero Crater's ancient lake. The lake level at the time of unit 2deposition is preserved at the foreset-topset contact at elevation -2493. The height of the inferred foresets indicate a lake depth immediately in front of the ancient delta between 4 and 6 meters. The sharp contact between the topsets and foresets indicates a falling lake level as the delta evolved.

The strike azimuths of the unit 1 foresets change systematically by 75° along the outcrop, with unit 1 beds dipping southwest for ~50 m on the northeastern face of Kodiak and to the south for ~50 m on the eastern face. We interpret his divergence as sediment in a delta lobe spreading out from a confined source with the average flow approximately to the southwest. The lake depth for unit 1 is estimated between 7 and 8.5 m indicating in front of the delta.

We infer local flow directions are preserved in the foreset dip directions (Figure 3). We interpret the southeast flow direction of unit 2 as flow in a delta lobe prograding radially from the lake's inlet river, Neretva Valis. The southwest flow direction of unit 1 is roughly 80° from the direction radiating from the river mouth. From this, we propose that complex interactions between two deltaic lobes built the geometries visible in Kodiak.

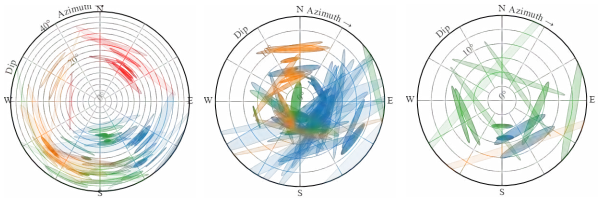

Figure 4: Stereonet [9] of the foresets (left), topsets (middle), and bottomsets (right) dip angles and azimuths. The colors show unit 2 foresets (blue) and unit 1 foresets on the eastern (green), northern (orange), and northwestern (red) faces of Kodiak.

Conclusions: We present a detailed model of the Kodiak butte from a combined over 500 sols of imaging from Perseverance. Stratigraphic analysis of the resulting DTM expands upon previous interpretations of Kodiak as deposits from a Gilbert-style delta with quantitative measurements. These depositional environments may have been linked to that of the larger Western fan, so the investigation of Kodiak can advance our understanding of Jezero's other deltaic structures.

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References: [1] Mangold N. et al. (2021) Science 374.6568 711-717, [2] Bell J. et al. (2021) Space Sci. Rev., [3] Maurice et al. (2021) Space Sci. Rev., [4] Kanine O. A et al. (2023) LPSC LIV abstract (this conf.). [5] Caravaca G. et al. (2022) LPSC LIII abstract. [6] Caravaca G. et al. (2023) LPSC LIV abstract (this conf.). [7] Hayes A. et al. (2011) Earth and Space Science., [8] Barnes R. et al. (2018) Earth and Space Science., [9] Quinn D. and Elaman B. (2019), Earth and Space Science, 6, 1378–1408.