USING ORBITAL AND ROVER IMAGERY TO RECONSTRUCT THE HISTORY OF JEZERO CRATER LAKE FROM 3D DIGITAL TOPOGRAPHY. M. K. Kanine[1], B. L. Ehlmann[1], C. Tate[2], S. Gupta[3], J. Grotzinger[1], J.N. Reahl[1], G. Paar[4], T. Ortner[5], L.C. Kah[6], S.F.Sholes[7], J. F. Bell[8], [1] California Institute of Technology Division of Geological and Planetary Sciences, [2]Cornell University, [3]Imperial College London, UK, [4]JOANNEUM RESEARCH, Graz, Austria, Institute for Information and Communication Technologies, [5]VRVis Zentrum für Virtual Reality und Visualisierung Forschungs-GmbH, [6]University of Tennessee, Knoxville, [7]JPL/Caltech, [8]Arizona State University

Introduction: One of the main goals of the Perseverance rover mission is to sample facies at Jezero Crater that have high biosignature preservation potential, such as mudstone in deltaic bottomsets and lake bed strata [1]. Predicting where this mudstone occurs requires a thorough understanding of the fluvio-deltaic deposits. Previous studies (e.g., [2, 3]) have argued that sigmoidal geometries observed in Jezero's western fan and Kodiak butte are evidence that these strata are deltaic in origin. However, sigmoidal geometries can be preserved in both fluvial (e.g. barforms, which have lower biosignature preservation potential) and deltaic (progradational sequences of topsets, foresets, and fine-grained bottomsets) deposits, and are thus not unique indicators of deltaic origin [e.g., 3]. To understand the 3D structure of the Jezero deposit and differentiate between fluvial and deltaic strata, we: 1) calculate and analyze bed orientations in 13 outcrops on the delta scarp and remnants using orbital data, extending the work of [2], and 2) use ongoing on-the-ground stereo imaging by the Mastcam-Z and SuperCam instruments to create high-resolution digital outcrop models (DOMs) to integrate with our orbital measurements and build on the initial findings of [3, 4].

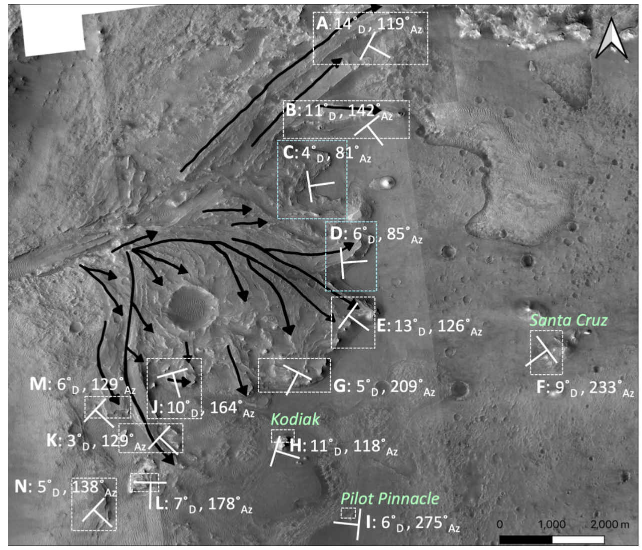

Figure 1. Summary of bedding orientations from HiRISE, calculated with methodology of [8, 9]. Outcrops studied (labeled A-N) are boxed in dotted lines. Average bed orientations for each outcrop are reported as *dip angle°D, dip azimuth°Az*. Paleoflow directions (black arrows) are adapted from [12]. Outcrops C, D, M,and N appear in *Fig 4*. Bedding orientations on the scarp broadly agree with the inferred paleo-transport directions, as expected for a deltaic origin.

Methodology:

Orbital Data Analysis: We use mosaicked HiRISE (High Resolution Imaging Science Experiment [5]) visual imagery [6] with resolution ~25 cm/px and mosaicked digital elevation models (DEMs) [6] at ~1m/px. Exposed beds (locations boxed in *Fig. 1*) were traced in QGIS [7] at 1:1000 scale using the Terrain Profile QGIS plugin. The trace coordinates were then resampled and densified using a variance-limited approach [8] to create a modified input data matrix in preparation for plane fitting using the *Attitude* module. *Attitude* [9] performs a principal component analysis (PCA) regression on input coordinates to fit a plane through the two directions of most variance in the data. The variance along the axis normal to the nominal plane is used to calculate the error in the plane's strike and dip. Bed orientations are then visualized in dip angle-dip azimuth space (as in *Fig. 2*).

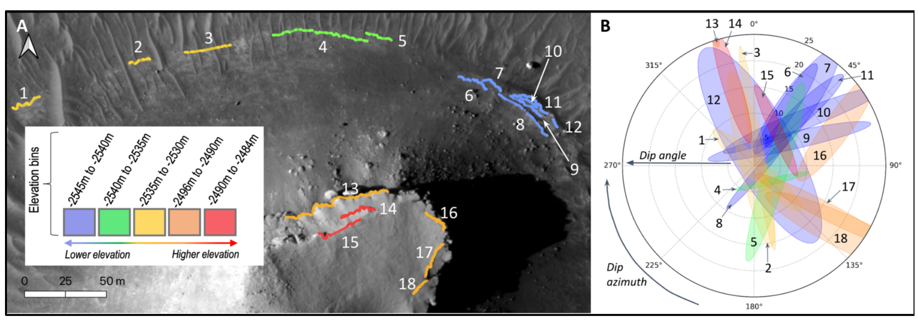

Figure 2. Application of methodology [8,9] on Kodiak butte. **A:** Traces are color-coded by elevation bin. **B**: Bed orientations plotted on dip angle-dip azimuth diagram; colors correspond to elevation bin.

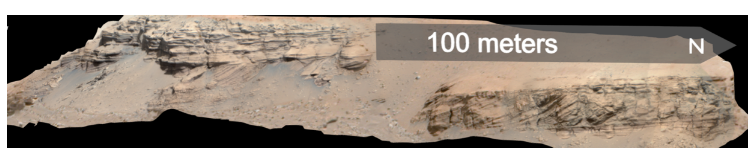

Figure 3: Kodiak butte digital outcrop model(DOM) produced from SfM.

Rover Data Analysis: Structure-from-Motion (SfM) [10] from long-baseline Mastcam-Z and SuperCam stereo [11] images were used to produce a ~0.2 m^2/triangle and ~4 cm/pixel DOM of delta remnant Kodiak [3] (*Fig. 3*). The Mastcam-Z and SuperCam images are draped over the DOM to show pixel-level detail. The DOM is roughly globally oriented; rigorous registration to a Mars-geographic reference frame is in progress.

Results and interpretations: Over 200 bedding traces were performed on orbital data at 10 bedding exposures on the delta scarp and on 3 delta remnants. Mean dip azimuths (dip directions) of the outcrops (*Fig. 1*) reflect paleoflow directions inferred from inverted channel-filling deposits [12]. In contrast, for exhumed fluvial point bars, the steepest beds would generally dip perpendicular to flow direction. Remnant outcrops Pilot Pinnacle and Santa Cruz contain distorted and folded layers visible in HiRISE and Mastcam-Z images that may represent post-depositional slumping or avalanching delta front sediment, and are unlikely to reflect original paleo-transport directions.

A cross section of prograding sigmoidal geometries is expected to show layers that steepen upward (in deltas, the transition from flat bottomsets to inclined foresets) then return to shallow angle dips (fluvially-deposited topsets). Outcrops B, C*, D, G, H, J, M* and N* (*in *Fig 4*) display this trend in whole or in part; data at other outcrops is insufficient to determine a trend from orbit, though the orbital measurements may be used in the future in concert with rover observations. We compare the scale of the geometries we see in outcrop to those expected for bar strata given the predicted flow depths of 7m and 2m for meandering and distributary channels, respectively [12]. The sequences observed on the delta scarp and remnants in this study surpass this thickness, (*Fig 4*), reaching up to ~90m on the delta scarp. Rover imagery and DEMs [3, 10-12] also reveal clinoforms spanning ~10m [3, 4] on a face of Kodiak not visible from orbit, again exceeding channel-scale thicknesses [12], consistent with interpretations of the strata as deltaic progradational sequences [3, 4].

Conclusions: Understanding delta architecture can allow identification of locations of fine-grained deposits that are most likely to preserve biogenic material, e.g. bottomsets at <2° slope at the base of the sequence (below ~-2510m) at outcrops C and D (*Fig 4*). Applied across the delta scarp, our PCA-based method [9] for bedding orientation determination identifies evidence for a deltaic origin for most of the vertical extent of the strata exposed in outcrops along the Jezero scarp and remnants, including 1) dip azimuths that broadly agree with inferred sediment transport directions [12] and 2) stratigraphic sequence thicknesses and dip angle trends consistent with prograding delta deposits. We also present a 3D model of the Kodiak butte, illustrating that rover data provides perspective and resolution not available from orbit. Future studies that couple orbital HiRISE observations with surface Mastcam-Z imagery will enable more detailed observations of landform structure and grain size relationships within the units (i.e., between underlying flat beds and overlying inclined or shallowly-dipping layers), which will help differentiate between a fluvial or deltaic origin for the deposits at Jezero Crater.

Acknowledgments: Thanks to the Mastcam-Z team and especially the DEM group for data collection and discussion. All data used for geomorphic mapping are available in the NASA Planetary Data System (PDS) and via public sites like JMARS. **References:** [1] Ehlmann, B. L. et al. (2008) *Nat. Geosci., 1*, 355-358. [2] Goudge, T. A. et al. (2017) *EPSL, 458,* 357–365 [3] Mangold, N. et al. (2021) *Science, 374, 6568*, 711-717. . [4] Gupta, S. et al. (2022), this conf. [5] McEwen, A.S. et al. (2007) *JGR: Planets, 112*, E05S04. [6] Fergason, R. L. et al. (2020) *LPSC 51,* Abstract #2020. [7] QGIS Association (2021) QGIS.org. [8] Stein, N. T. et al. (2020) *JGR: Planets*, *125*, e2019JE006298. [9] Quinn, D. P. and Ehlmann, B. L. (2019). *Earth and Space Sci., 6*, 1378–1408. [10] Tate, C et al. (2022), this conf.. [11] Caravaca, G et al. (2021) *Remote Sens, 13*, 4068. [12] Goudge, T. A. et al. (2018) *Icarus, 301,* 58-75.

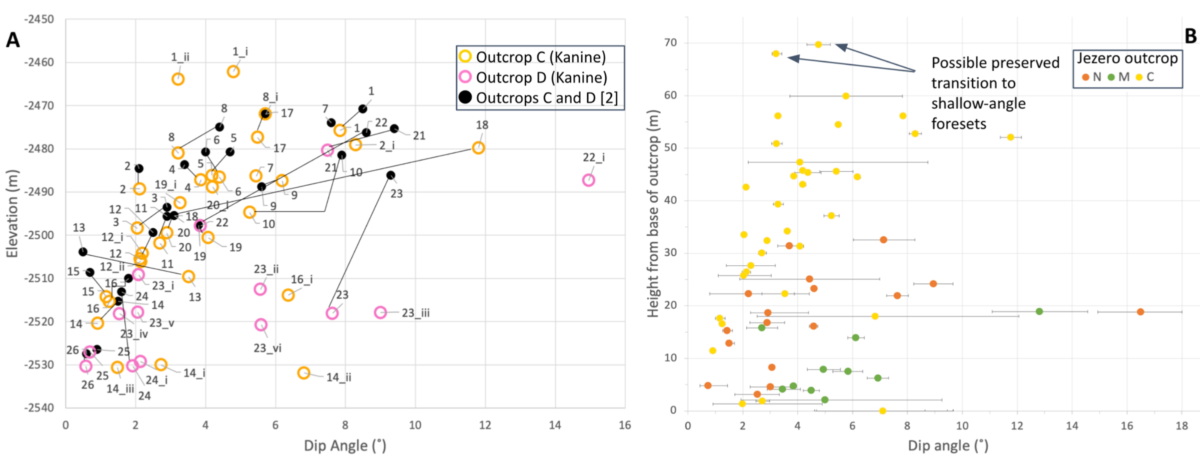

Figure 4: Erosional remnants of sigmoidal strata in height-scale vs. dip angle space. **A**: Outcrops C and D measured in [2] and this study. Traces denoted with only a number are the same beds measured by [2]; those labeled #_ *Roman numeral* are layers proximal to those studied in [2]. **B:** Outcrops C, M, and N have sequences thicker than expected fluvial deposits [12], indicating deltaic origin.