Testing the preservation of river channel properties in Earth analogs to martian fluvial sinuous ridges. B. T. Cardenas[1], T. A. Goudge[1], C. M. Hughes[1], D. Mohrig[1], J. Mason[1], T. Swanson[2], and J. S. Levy[3], [1]Jackson School of Geosciences, UT Austin, [2]Department of Earth Science, Rice University, [3]Department of Geology, Colgate University. Contact: benjamin.cardenas@utexas.edu

Introduction: River channel-filling deposits are exhumed and exposed at multiple regions across the surface of Mars[1-5]. The geometry of these exhumed fluvial deposits, often termed sinuous ridges, records quantitative information about formative conditions of the ancient surface environment. However, it is incorrect to assume that measurements commonly used to parameterize modern river channels, such as channel width, depth, slope, and sinuosity, will be accurately represented by the geometry of a preserved sedimentary deposit. Indeed, a disconnection between channel-form and deposit-form is expected due to the time integration of depositional processes, as well as erosional processes working during exhumation. The effect of these processes on sinuous ridge measurements have been largely unexplored and, considering that one of three potential landing site for the Mars 2020 mission contains sinuous ridges[3], such an examination is more necessary than ever.

Here, we examine analog sinuous ridges on Earth formed from exhumation of channel-belts, the time-integrated deposits of in-channel fluvial sedimentation, of the Cretaceous Cedar Mountain Formation[6] of central Utah, USA. Geologic mapping and measurements of sedimentary structures and significant erosional surfaces were acquired at the outcrop scale. These datasets are used to understand how time is integrated into ridge geometry, and how this should be considered when remote measurements of martian fluvial sinuous ridges are used to estimate formative river channel conditions, ridge construction times, and the duration of wet intervals in martian history. UAV data from the North Loup River, NE, USA, supplement the outcrop interpretations.

Methods: UAV photosurveys were used to create high-resolution photo mosaics and digital elevation models of two Cedar Mountain Fm. ridges using Agisoft Photoscan Pro. These mosaics were then used in the field to record the locations and dimensions of deposits interpreted as bar accretion strata and dune trough cross-strata. Measurements of dip direction and grain size were taken from each interpreted structure. The dip direction of dune trough cross-strata define the local paleo-transport direction. Dip direction for bar-accretion strata preserve the local bar growth direction, which does not necessarily reflect paleo-transport direction. Ridge centerlines were calculated in a GIS, and defined as a downstream-ordered series of points with an azimuth direction pointing towards the next point. Measured dip directions were detrended using the azimuth direction of the nearest centerline point. Each detrended value is termed a paleotransport anomaly (Fig. 1). For comparison, centerline-detrended transport directions were also calculated for dunes observed in UAV photosurveys of the North Loup River bed.

Results: Sinuous ridges contain multiple stacked sandstone/conglomerate channel-belts separated by ridge-scale erosional surfaces and associated mudstones. The deposits of multiple channel-belts are exposed on both ridge tops due to spatially varying degrees of erosion. Paleotransport anomalies for deposits exposed on the upper surfaces of the two ridges have mean values of 6° and -8° with σ = 35° and 29° (Fig. 1). Maps of cross-strata show sandstone and conglomerate sets located mid-ridge and at ridge edges.

Discussion: The local prominence of bar accretion strata perpendicular to dune paleo-transport direction indicates the preservation of point bar accretion strata (Fig. 1, inset). These surfaces record the lateral migration of a point bar surface over time, which act to widen the channel-belt relative to the formative channel. Additionally, the presence of dune trough cross-strata composed of sandstones and conglomerates at the edges of the ridges define the occurrence of channel thalweg rather than channel-margin deposits at these positions. These missing marginal portions of paleo-channel deposits represent the incomplete preservation of paleo-width, and are consistent with the noted lack of preserved channel levee wings[10].

The paleotransport anomalies are compared to modern transport anomalies. In the North Loup River, steering around mid-channel bar topography creates a dataset with a similar mean and standard deviation to that of the ancient (mean = -12°, σ = 33°). A laterally-amalgated channel-belt many individual channel widths in dimension is expected to have a straighter centerline than that of the formative river , resulting in a significantly higher σ than for a single river channel. Since σ of the Cedar Mountain Fm. belts is not higher than a modern analog, the ridge centerlines are interpreted to be generally representative of formative river centerlines in spite of the time-integrating character of the ridge-producing deposits. Maps showing the intensity of the anomaly reveal a spatial link between high anomaly values and sections of channel-belt shaped by lateral migration (Fig. 1). Even so, the error associated with using centerline position of the ridge as a proxy for centerline position of the formative paleo-channel is within the natural variability of modern transport anomalies for all but a few locations (Fig. 1).

The upper ridge surfaces are composed of deposits from three channel-belts. Channel-belts are separated vertically by ridge-scale erosional surfaces associated with mudstones, interpreted as floodplain style sedimentation within a channel during extended periods of channel inactivity following avulsion, an architecture associated with net-aggrading settings[7-9]. The modern undulatory ridge tops are the product of differential erosion of these stacked channel-belts, and their surface slopes do not represent the paleo-slopes of formative channel beds. High surface slope surfaces rapidly transitioning to low-slope benches are often associated with stacked channel-belt contacts. Similar observations have been used to show stacking in martian ridges[2, 3].

Conclusion: Both depositional and erosional processes act to produce dimensions for a sinuous ridge that can be quite different from those of the formative river channel(s). Careful observations informed by analog work and an understanding of the geology composing sinuous ridges is an important step toward defining the uncertainty in using measurements from sinuous ridges to estimate properties such as paleodischarge[10-11], and is vital to accurate interpretations of depositional setting (e.g., identifying and understanding the implications of channel-belt stacking [2-3]). This study finds that centerlines were least sensitive to modification by time integrating processes, a significant conclusion for workers measuring sinuosity, radius of curvature, and paleotransport-related asymmetry[2]. Careful observations can reveal channel-belt stacking patterns at remote-sensing scales. Further study of these analogs will benefit hypothesis testing and paleoenvironmental interpretations of the martian rock record from orbit.

References: [1] Burr D.M. et al. (2009) *Icarus, 200,* 52-76. [2] Cardenas B.T. et al. (2017) *GSA Bull.*. [3] Goudge T.A. et al. (2018) *Icarus, 301,* 58-75. [4] Jacobsen R.E. and Burr D.M. (2017) *Geosphere, 13(6),* 2154-2168. [5] Kite E.S. et al. (2015) *Icarus, 253,* 55-65. [6] Williams R.M.E. et al. (2011) *GSA Spec. Pap., 483,* 483-505. [7] Mohrig D. et al. (2000) *GSA Bull., 112(12),* 1787-1803. [8] Cuevas Martinez J.L. et al. (2010) *Sedimentology, 57(1),* 162-189. [9] Chamberlin E.P. and Hajek E.A. (2015) *JSR, 85(2),* 82-94. [10] Hayden A.T. et al. (2017) *LPS XLVII,* abstract #2488. [11] Jacobsen R.E. and Burr D.M. (2018) *Icarus, 302,* 407-417.

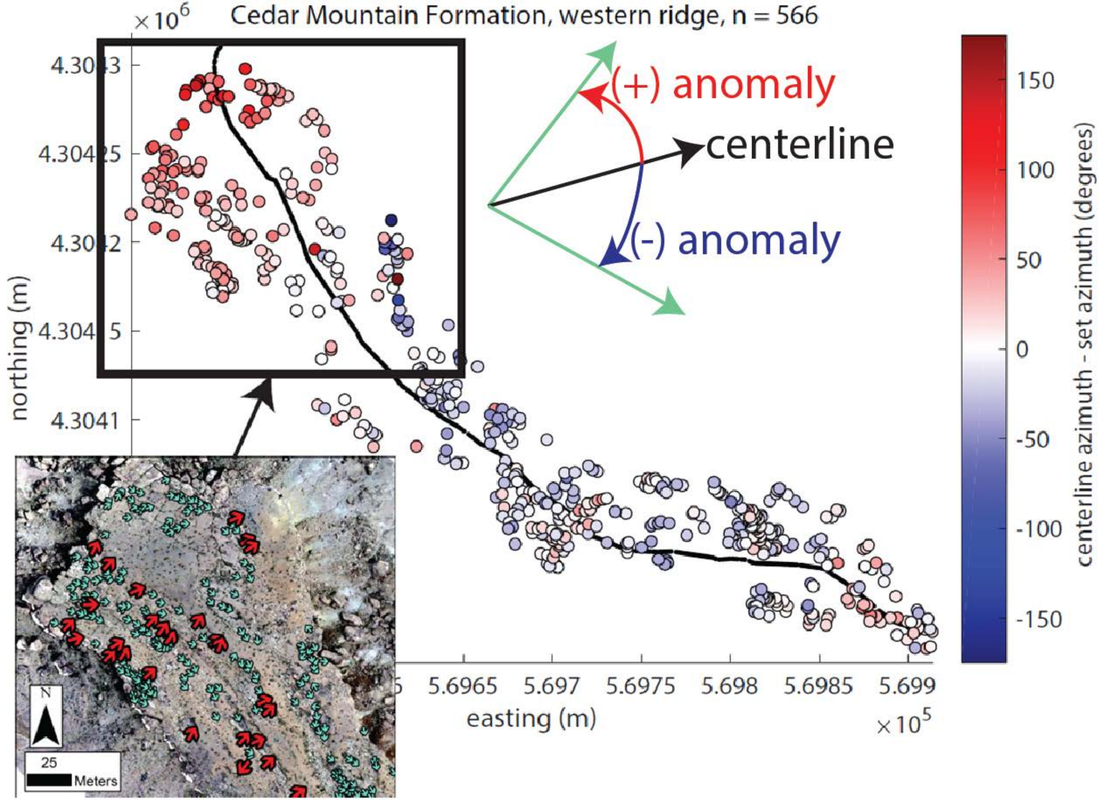

Figure 1 – Paleotransport anomaly map for one Cedar Mountain Fm. ridge. Circles show locations of paleotransport measurements from trough cross-strata exposed at the ridge surface, and are color-coded by their paleotransport anomaly (line diagram). The ridge centerline is shown in black. Paleotransport anomalies are highest where point bar lateral-accretion surfaces are dominant sedimentary structures (inset). In the inset, teal arrows show paleotransport direction measurements, and large red arrows show the dip directions of point bar lateral accretion surfaces.