RECONSTRUCTING RIVERS ON ANCIENT MARS: NEW TOOLS FOR FLUVIAL-RIDGE/INVERTED-CHANNEL PALEOHYDRAULICS. A. T. Hayden[1], M. P. Lamb[1], [1]California Institute of Technology, Pasadena, CA 91125. (ahayden@caltech.edu)

Introduction: Major uncertainties exist about the duration, extent, and quantities of liquid water on early Mars, with endmember hypotheses of a long-lived, warm and wet climate versus a cold and dry climate. The geometry and sedimentology of sinuous ridges may hold important information about ancient rivers on Mars [1-10], but understanding how ridges record river history is unclear. Sinuous ridges are often termed inverted channels for their resemblance to river channels in inverted relief [1-2] (Fig. 1); evidence for a fluvial origin has included their sinuous and branching nature that resembles fluvial networks, continuity with valley networks, and similar scaling between bend wavelengths and ridge widths [1-3]. Recent mapping observes ridges across a wide area, occurring in terrains as late as early Amazonian [4] and the landing ellipses for both the Mars 2020 and ExoMars rovers as well as other candidate sites for the missions. Ridges have been used to interpret a relatively warm-and-wet early Mars on the basis of wide geographic coverage, high stratigraphic density, position in putative oceanic deltas, and large dimensions [2-7].

However, interpretations of ancient rivers from sinuous ridges vary significantly, including in flow direction [5, 8], likely due to difficulty in discerning between two ridge formation pathways. In topographic inversion, ridges are exhumed channel casts, formed when channels fill with an erosion-resistant material and subsequent erosion removes the surrounding erodible material [9]. In this case, ridge dimensions approximate channel dimensions, ridge networks represent channel networks, and importantly the ridges preserve a fluvial landscape at a snapshot in time. In contrast, in deposit exhumation, ridges are exhumed channel belts, created by depositional rivers migrating laterally and aggrading vertically over significant time [5]. The key difference from topographic inversion is that channel belts are composed of sediments deposited during channel migration, rather than deposits that fill and preserve the channel. Channel belts are often significantly larger than their associated channels and on Earth often represent fluvial activity over millions of years. In addition, channel belts are often stratigraphically stacked within a depositional basin signifying even longer-lived fluvial activity.

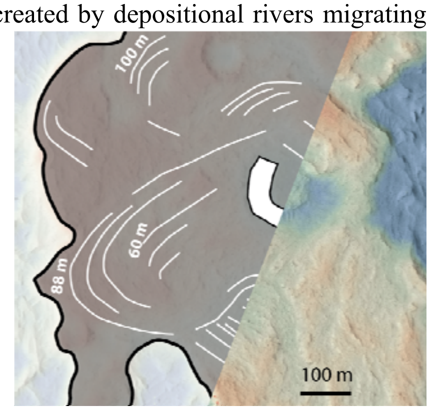

Fig. 1) Sinuous ridge in Aeolis Dorsa (CTX image & stereo-DEM; red is 15 m higher than blue). Outlines: ridge (black), lateral accretion sets (white; numbers are radius of curvature), oxbow (white fill).

Methods: We conducted fieldwork on terrestrial analog sites and compiled data on terrestrial channel belts. Field sites included a well-known Mars analog (Green River, Utah [10]), a location well-studied for its sedimentology but not ridges in the Ebro Basin, Spain [11], and a site without prior study near Ferron, Utah.

We measured grain sizes, bedding thicknesses and sedimentary structures in the field, and measured ridge geometry from digital elevation models and air photos. We focused on the ridge caprocks (indurated material at the top of each ridge), junctions between ridges, and locations where ridges intersect cliff exposures.

Process sedimentology allowed us to reconstruct paleochannel dimensions and discharge from median grainsize and height of dune and bar cross-sets [6]. Using terrestrial channel belts as a guide, we tested two methods for reconstructing paleochannel dimensions based on orbital measurements: 1) caprock thickness is 1.5 times larger than paleochannel depth due to amalgamation of channel deposits; 2) radius of curvature of lateral accretion sets is twice the paleochannel width.

We also created compilations of channel and channel-belt curvature, width and thickness to assess whether channels, channel-belts, and ridges have distinct curvature-width ratios.

To reconstruct original channel-belt widths, we developed a new model for caprock narrowing during ridge formation. The model assumes that as ridge relief increases due to differential erosion between the caprock and ridge flank, the caprock is undercut. Undercutting generates talus that serves as a negative feedback on erosion; scarp retreat slows as the ridge grows, potentially preserving it for long durations.

Results: Caprocks at all three locations comprise fluvial deposits (well-indurated sands and gravels with dune and bar cross-sets) atop floodplain deposits (mudstone with paleosols and sandstone sheets). Caprocks traced to ridge/cliff intersections indicate that the uneroded sandstone bodies are encased in mudstone, and are much wider than the ridge caprocks due to erosion. Many of the ridge intersections occur where caprock sandstone bodies cross at distinct stratigraphic levels. A few structures interpreted to represent laterally accreting channel margins were observed on the edge of eroded caprocks, indicating former paleochannel locations were laterally offset from the ridge. Together, these observations indicate that the ridges represent stacked fluvial channel belts—exhumed and eroded from within floodplain deposits—rather than inverted channel casts.

In the absence of detailed sedimentology, a common test for topographic inversion [1-3] is similarity of the ratio of radius of curvature or wavelength of the ridge centerline to ridge width because meandering river channels tend to have specific ratios around 7:1 and 2:1, respectively [12]. However, we found that channel belts also share these ratios (Fig. 2), and therefore they cannot be used to discern ridges that formed from channels from those that formed from channel belts.

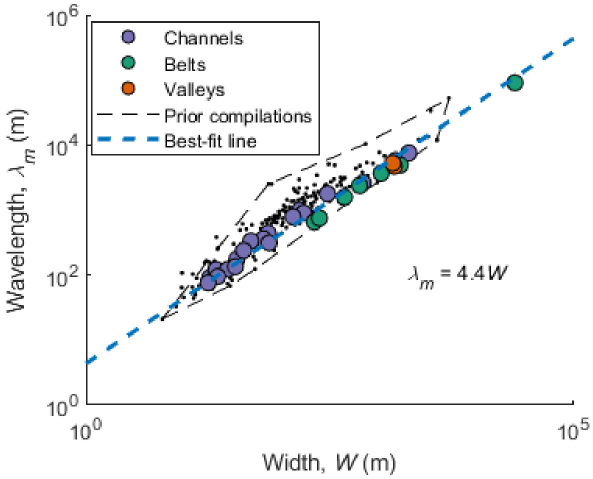

Fig. 2) Wavelength scales with width similarly for channels, channel bets, and valleys.

Paleochannel depths were determined to be 1-4 meters with widths 18-75 m using sedimentology. These dimensions are comparable to ridge breadths (5-60 m), smaller than caprock thicknesses (1-8 meters), and substantially smaller than reconstructed and observed uneroded channel-belt breadths (40-230 m), supporting that ridges are exhumed channel belts, not inverted channels. Our preferred methods to constrain channel dimensions from orbital data using caprock thickness as a proxy for river depth or curvature of lateral accretion sets as a proxy for channel curvature yield results similar to sedimentology reconstructions.

Example analysis for Mars: We demonstrate our methods to a ridge in Aeolis Dorsa region (Fig. 1). Applying the caprock thickness method to thickness measurements from HiRISE DEMs, we find that the paleochannels were ~4.7 meters deep and 84 meters wide. This is consistent with using radius of curvature of lateral accretion sets observed in HiRISE images, as well as radius of curvature and width of an abandoned oxbow (yields width = 37, 50, 50 meters, respectively). These values lead to reconstructions of bankfull discharge ranging from 220-1200 m^3/s. In comparison, if we had interpreted topographic inversion and calculated discharge from ridge width, reconstructed pre-erosion ridge width, or width calculated from radius of curvature of the ridge, we would have calculated discharge between 10^4-10^5 m^3/s (Fig. 3).

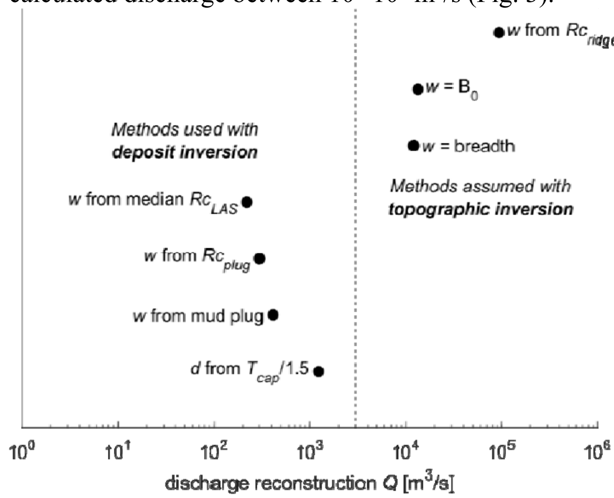

Fig. 3) Discharge reconstructions for a ridge in Aeolis Dorsa (Fig. 1), demonstrating the large differences in discharge reconstructed from different interpretations.

Conclusions: Our key finding is that the terrestrial ridges studied represent exhumed channel belts formed by long durations of fluvial activity. We showed that sinuous ridges at many locations on Earth represent exhumed channel belts rather than inverted channels. We furthermore showed that existing tests to discern formation pathways might be inaccurate and lead to overestimation of discharge by orders of magnitude.

Similar observations of stacking and layering of ridges on Mars and in our study areas suggest that some sinuous ridges on Mars also are exhumed channel belts, implying potentially millions of years of fluvial activity. Ridges record the slow migration of rivers across a floodplain and the stacking of multiple generations of channel belts within a depositional basin. In contrast, under the channel inversion model, ridges are interpreted as exhumed channel fills, with an undetermined duration of fluvial activity.

Works cited: [1] D. M. Burr, et al. *JGR: Planets* 115 (2010); [2] E. S. Kite, et al. *EPSL* 420, 55-65 (2015); [3] E. S. Kite et al. *Sci Adv* 5, (2019); [4] Dickson et al., *this conf.;* [5] R. A. DiBiase, et al. *JGR: Planets* 118, 1285-1302 (2013); [6] A. T. Hayden et al. *Icarus*, 92, 92-110 (2019); [7] Kite, E. S., et. al. *Icarus*. 225, 850-855 (2013); [8] Lefort, A., et. al. *Geomorph*. 240, 121-136 (2015); [9] C. F. Pain, et al. *Icarus* 190, 478-491 (2007); [10] Williams, R. M. E., et al. *Geomorph*. 107, 300-315 (2009); [11] D. Mohrig, et al. *GSA Bull.* 112, 1787-1803 (2000); [12] Williams, G. P., *J. Hydro.*, 88, 1 147-164 (1986)