QUANTIFIED IDENTIFICATION OF PALEO-TERRACES ALONG A PROPOSED MARTIAN OCEAN CONTACT. S.F. Sholes[1,2], D.C. Catling[1,2], and D.R. Montgomery[1], [1]Dept. of Earth and Space Sciences, Box 351310, Univ. of Washington, Seattle, WA, [2]Univ. of Washington Astrobiology Program, Seattle, WA (sfsholes@uw.edu).

Introduction: Some of the most disparate conclusions about past Mars concern whether the climate and water inventory could or did sustain an ocean. Given the absence of geochemical evidence of marine sediments, much of the work in favor of past martian oceans comes from the recognition that the large outflow channels along the N-S topographic dichotomy empty into the northern lowlands, coupled with proposed shoreline contacts that were originally hand-drawn on low-resolution Viking images [1, 2].

Whether oceans were present is crucial for understanding both the evolution of water as well as the potential astrobiological implications. Large oceans up to the "Arabia" shoreline contact would imply a greater amount of water in the past than currently thought [11] as well as liquid water on the surface for longer timescales that may be more conducive the formation and proliferation of life.

Despite great advances in data product resolutions and availability, relatively little research has been done to apply quantitative methods and re-examine proposed shorelines with these new data to understand their genetic origins. Such high-resolution data products are necessary to identify many coastal geomorphological features (e.g. strandlines, narrow marine terraces, beach ridges) [3].

Some previous analysis suggests that many hypothesized shoreline features are much more consistent with other geomorphological features and processes (e.g. glaciers and periglacial terrain, volcanic flows, mass wasting, and diffuse albedo contrasts across lithologic units) [3]. Most of the prior work studying these hypothesized paleoshorelines has focused on photo interpretation studies.

Here, we adopt a quantitative and validated method for characterizing subtle paleoshorelines on Earth using topographic signal processing techniques [4-5] and apply it to hypothesized paleoshorelines on Mars for the first time. This provides a key tool for ensuring putative features meet the topographic criteria necessary for paleoshorelines.

Methods: We apply this method to a site in Cydonia Mensae that has proposed paleoshorelines along the southern rim of an eroded crater exposed to the northern plains. The area is noted for 4-12 subtle arcuate ridges that parallel the dissected margin of the highlands and have been interpreted as marine terraces [6].

We previously developed a high-resolution (1 m/px) digital elevation model (DEM) of this "best-case" region [3] using the Ames Stereo Pipeline [7] with stereo pair High Resolution Imaging Science Experiment (HiRISE) data (Fig. 1a).

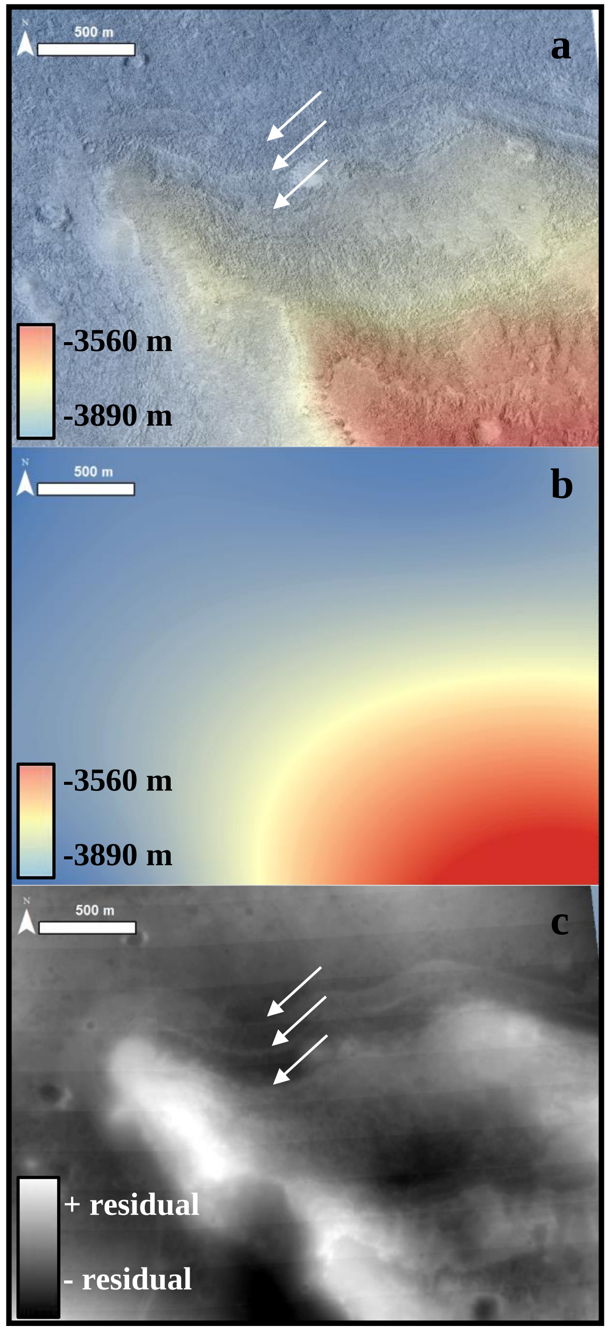

Fig. 1: *a)* DEM atop HiRISE (PSP_001414_2165) image of sample site. *b)* 4th order polynomial trend fit to the DEM. *c)* Residual topography (*a* - *b*). Arrows indicate putative shoreline features.

Topographic expression analysis evaluates the residual topography between the high-resolution DEM and an "idealized" topography created by fitting a polynomial surface to the elevation data (Fig. 1). The data are then smoothed using a boxcar moving average filter to increase the signal-to-noise ratio for processing.

The residual topography highlights the deviations from the overall slope that are characteristic of shoreline platforms and has been successful in identifying subtle terrestrial paleoshorelines [4], including the difficult-to-identify intermediate paleo-Lake Bonneville shorelines [5], with similar spatial sampling.

Identification of Shoreline Features. In the residual topography raster data, features that significantly deviate from the idealized slope readily stand out as alternating dark and light bands (Fig. 1c). This is useful for quickly assessing the presence or absence of any possible shoreline features. Given that the residual topography raster displays deviations from the slope, follow up analyses of the topographic profiles across the DEM are done to identify whether the features are consistent with terraces or other landforms (e.g. ridges).

Paleoshorelines can be identified quantitatively by a set of four consecutive extrema within the slope and curvature of the residual topography: the riser inflection (RI; highest slope between terraces), riser crest (RC; highest convex curvature demarking the beginning of the terrace), bench top (BT; flattest part of the terrace), and knickpoint (KP; highest concave curvature at basal slope).

Using this method, we can also quantify the bench width (defined as the distance from the riser crest to the knickpoint), the wave-cut slope (angle of deviation from overall slope trend), and whether the features follows an equipotential surface.

Results: Our preliminary results find 3-4 benches in the sample site that are all ~10-20 m wide. Each bench is characterized by the necessary consecutive residual extrema (Fig. 2) required for paelo-shoreline terraces and follow an equipotential surface. Additionally, these benches spatially correspond with the proposed marine-carved benches along the "arcuate ridges" (Fig. 1a).

Discussion: *Possibility of Oceans?* In our example, both the crater and surrounding terrain are part of the Early Hesperian transition unit [8] but the benches fall on the older (Noachian) "Arabia" shoreline contact. Since this site is located within an eroded crater that is only partially exposed to the northern plains, these may not represent marine processes but rather lacustrine ones. Nevertheless, it seems likely that the crater pooled water, as a lake or ocean-inlet, at one time given these bench features, the nearby incised valley networks, and the large number of other identified paleo-crater lakes on Mars [9].

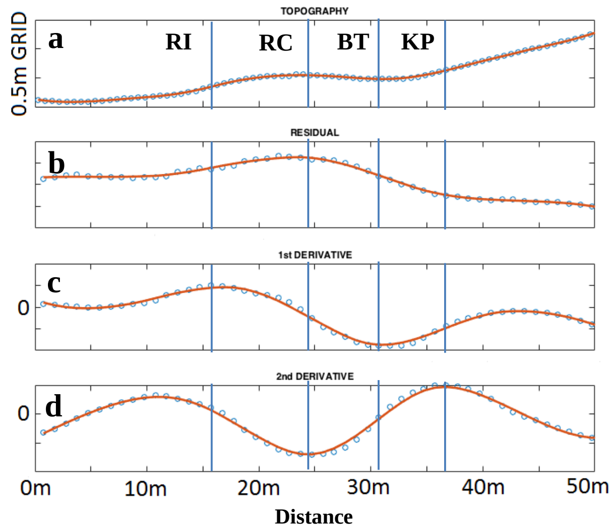

Fig. 2: Topographic expression analyses across the northernmost putative shoreline feature in Fig. 1. *a)* Topographic profile, *b)* Residual topography, *c)* Slope of the residual, *d)* Curvature of the residual. Red lines show filtered smoothed data, vertical lines demark the RI, RC, BT, and KP (see text for def.).

Structural terraces will presumably form similar patterns in the residual topography, so this method may only determine the presence of necessary characteristic features for terraces/benches and not their genetic origins. Further analyses looking for other hallmark littoral landforms and spectroscopic features are required. However, given the age of the terrain, erosional features such as terraces are more likely to survive than depositional ones.

This work illustrates a straight forward, and soon-to-be automatable, application of terrestrial topographic expression analysis for paleoshorelines to other planetary surfaces. Ongoing work uses this methodology to assess 30+ proposed paleoshorelines across the northern plains of Mars [3], combining the results with spectroscopic, thermal inertia, and photo-geomorphological analyses. This will provide a comprehensive overview on the state of these putative contacts. Additionally, this methodology can be used to assess generalized terrace features, including paleo-crater lakes explored by landed missions [10].

References: [1] Parker et al., *JGR:Planets* 98, 1993. [2] Parker et al., *Icarus* 82, 1989. [3] Carr and Head, *GRL.* 42, 2015. [4] Sholes et al., *8th Intern. Conf. on Mars* #1014, 2014. [5] Hare et al., *JGR: Solid Earth* 106, 2001. [6] Jewell, *Geomorph.* 253, 2016. [7] Clifford and Parker, *Icarus* 154, 2001. [8] Moratto et al., *LPSC XLI* #2364, 2010. [9] Tanaka et al., *Planet. Space Sci.* 95, 2014. [10] Goudge et al., *Icarus* 260, 2015. [11] Parker and Bills, *8th Intern. Conf. on Mars* #1791, 2014.