# SINUOUS RIDGES AS TOOLS TO INVESTIGATE POST-FLOW MODIFICATION IN THE AEOLIS–ZEPHYRIA PLANA, WESTERN MEDUSAE FOSSAE FORMATION, MARS

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**Introduction:** Because water seeks the lowest equipotential level, profiles of fluvial features are a useful medium for detecting post-formation deformation of aqueous features. For example, on Earth, (paleo-)river profiles that show pronounced convexities or local topographic maxima have been used to infer tectonic uplift during or after fluvial flow [e.g.1, 2]. The topographic profiles of paleo-river channels in inverted relief – formed through preferential induration of the channel beds and regional erosion of the surrounding landscape – are no longer susceptible to modification by infilling processes and therefore are likely to provide information on post-flow modification such as tectonic uplift or sediment compaction. Topographic analyses of sinuous ridges (SRs, [3]), interpreted as inverted fluvial features [3, 4] in the region of Aeolis-Zephyria Plana (AZP), suggest that the current slopes of the inverted fluvial features have been significantly modified since the time of formation. Using several datasets, we investigate the topography of a sample of SRs in the AZP and the amplitude and origin of the SR undulations.

**MFF:** The AZP region, centered at 1.5°S, 152°E coincides with the western Medusa Fossae Formation (MFF [5,6,7]), an extensive light-toned deposit located along the dichotomy boundary [e.g. 8], dated to the Hesperian/Amazonian epochs [e.g. 3] and inferred as a primary volcaniclastic deposit [7, 9].

**Sinuous ridges:** The SRs of the AZP are mostly interpreted as inverted paleochannels or inverted floodplains, formed by precipitation, indurated by chemical cementation of the fluvial sediments, buried then exhumed following aoelian abrasion of the surrounding terrain [3, 4, 10]. A single SR was tentatively interpreted as an esker, based on its rounded morphology and undulatory profile [e.g. 3]. Their location within the MFF implies that they are the youngest such population yet discovered on Mars. A previous study [3] documented about 150 SRs in the AZP and identified 5 main morphological types, although on-going work with more recent data [11] has mapped almost 900 SRs using a simplified classification scheme.

**Data and Methodology*:*** Images and topographic data were used in our investigation of SR undulations. The THEMIS 512 ppd IR day mosaic was used as a basemap. HiRISE and CTX images were radiometrically corrected and projected using the Integrated Software for Imagers and Spectrometers (ISIS; [12, 13, 14]). Three different and independent types of topographic data were used in these investigations: 1) individual MOLA data points (~150-m-footprint and ~300-m-along-track spacing), 2) digital terrain models (DTMs) created from Context Camera (CTX) [15] stereo pair images (6 m/pixel) using the Ames Stereo Pipeline [16] and 3) DTMs created from High Resolution Imaging Science Experiment (HiRISE) [17] stereo pair images, using Socet Set. All dataset were imported and co-registered in ArcGIS. Longitudinal profiles of ~ 2 dozen SRs were derived in ArcGIS by selecting MOLA data points located on top of the SRs. Longitudinal and cross-sectional profiles of the same SRs were also created in ArcGIS from the HiRISE and CTX DTMs. The SR profiles were then analyzed comparatively with the morphology of the SRs as shown by the CTX and HiRISE images. **Results:** Surprisingly, the derived fluvial SR profiles do not decrease monotonically in a single direction as would be expected of a river channel, but exhibit undulations with amplitudes from 10 m up to 200 m (e.g. Fig.1). Shorter wavelength undulations (λ ~100 m) have amplitudes of a few tens of meters, and low points along the profiles correspond to degraded SR reaches. Longer wavelength undulations (λ ~2000 m) have amplitudes greater than 50 meters (i.e., greater than SR relief) and are not associated with degraded SR reaches. We interpret these long-wavelength undulations as the result of post-formation deformation of the SRs.

**Hypotheses:** After ruling out the possibility that the observed undulations may be data artifacts, **w**e hypothesize four mechanisms for slope undulations.

*Esker formation.* Although the long-wavelength undulatory slopes could indicate subglacial flow [18], the densely networked pattern and SR morphologies are very dissimilar to the patterns and morphologies of terrestrial eskers [19]. Observations of twin ridges and putative tributaries along the SR previously interpreted as an esker [4, 5, 11] suggest that this SR may actually have a fluvial origin [20].

*Multi-generational SRs.* Because of the complex stratigraphy of the MFF, even in circumstances where superposition is not obvious and SRs may appear co-linear, multiple distinct generations of SR formation may have occurred separated in time. If those SRs are located at different stratigraphic levels, this co-linear superposition could result in (apparent) undulations in the SR topographic profile that in fact are derived from exhumation of two SRs of different generations.

*Differential erosion* consitutes the localized removal of the capping layer along SR segments, exposing and causing erosional stripping of the underlying, less resistant substrate. The erosional features are closely spaced, so this mechanism is consistent with short wavelengths undulations (~5-100 m), and they must have relief less than the SR relief for the SR to remain visible, so this mechanism would be confined to the undulations that are lower in amplitude than the SR relief. Therefore, differential erosion is hypothesized for locations where the SR appears less distinct (reduction of its width and/or height), and where undulation amplitude is less than SR relief.

*Differential settling* results from the compaction of porous MFF material under a (now eroded) overlaying mass, or from removal of material at depth. Thus, differential settling is hypothesized for locations where the upper surface of the SR is still distinct (preserved surficial SR morphology). This process could account for those undulations that are greater in amplitude that the relief of the sinuous ridges, since the drop in elevation is produced in the subsurface.

*Tectonic features* such as blind thrust faults, deep-seated normal faulting or igneous intrusions, may create folds or undulations in the overlying land surface. Thus, the topographic undulations in the SRs may be caused by crustal tectonism within the basement material inferred to underlie the MFF [21; 22]. Such tectonism might originate from processes associated with the formation of the dichotomy boundary or related to the wrinkle ridges from the Cerberus plains.

**Implications:** Although further work is needed to precisely determine the origin of the undulations, several of them are consistent with differential settling or tectonic deformations of the western MFF subsequent to SR formation. This study demonstrates that neither the surface topography nor the topography of strata within the MFF can be assumed to be original, and thus are additional evidence of the complex history of the MFF. If the differential settling hypothesis is verified, then determining the amount and locations of differential settling would help in estimating the degree and distribution of porosity in the MFF and would provide information on the emplacement mechanism of the MFF. Further study on SR erosion patterns may also provide more information on the type of material of the western MFF. These results also suggest that slopes in the MFF can neither reliably be used as input into fluvial models, nor can they be used to discriminate features such as eskers from inverted fluvial channels. This finding may also apply to other light-toned martian deposits.

**Acknowledgements:** We thank Becky Williams for helpful discussion and Edwin Kite for providing a HiRISE DTM.

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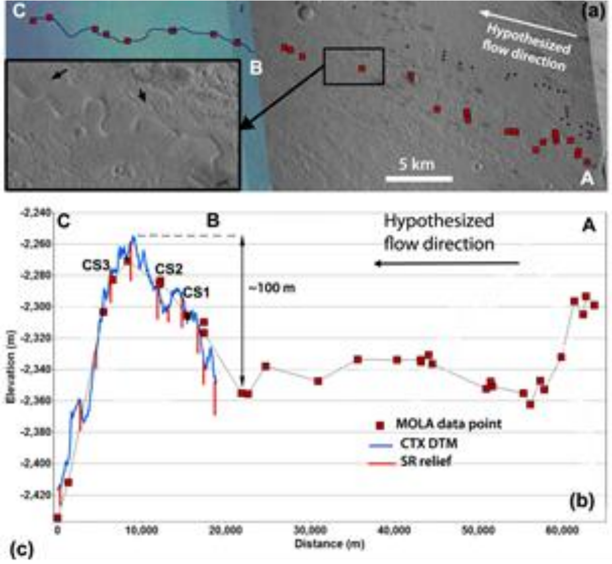

Fig. 1. Low relief SRs (~ 25m) with undulating topographic profiles (up to 100 m amplitude) (a) CTX image (P01_001395_1742_XN_05S205W, grayscale) and CTX DTM (B20_017548_1739_XI_06S206W G02_019104_1740_XI_06S206W, color). Topographic profile with MOLA points (A to C) and CTX DTM (line, B to C) (b) Longitudinal profile with CTX DTM (blue line) and MOLA data points (red squares). Vertical red lines: relief of the SR at different locations.