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PATTERNS OF GLACIAL DEFORMATION IN A LOBATE DEBRIS APRON: IMPLICATIONS FOR GLACIAL GEOLOGY, INTERNAL STRUCTURE, AND REGIONAL CLIMATE HISTORY. A. Grau Galofre^{1,2}, J.K. Serla², P. Becerra³, A. Noblet¹, S.J. Conway¹, ¹Laboratoire de Planétologie et Géosciences/CNRS UMR 6112 (anna.graugalofre@univ-nantes.fr), ²School of Earth and Space Exploration, Arizona State University, ³Micro-cameras & Space Exploration, Rue du Puits Godet 10A, 2000, Neuchatel, Switzerland.

Introduction: The flow and deformation of ice-rich material is one of the main agents of Amazonian landscape modification in the Martian mid-latitudes [1,2,3]. Their stratigraphy records the history of ice mass balance, their deformation structures reflect the changing equilibrium of stresses, and their presence opens the door to future human in-situ resource utilization (ISRU) [4,5]. Characterizing the origin and evolution of such features through their morphology is therefore key to understand the glacial, geological, and climate history of Amazonian Mars.

Our objective is to characterize the deformation patterns of a Lobate Debris Apron (LDA) located in the eastern Hellas region (Figure 1), and interpret them in terms of the deposit's internal structure and evolution. To make progress, we characterize the LDA with three length scales [6,7]: distance between flow fronts (Δx), spacing between deformation lobes (λ), and width of arcuate bands (γ) (Figure 2).

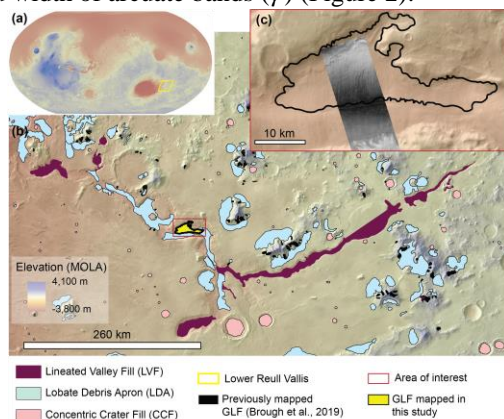


Figure 1. Context and setting of the LDA under study within Reull Vallis. (a): global topography (MOLA) highlighting the eastern Hellas region. (b): THEMIS overlain with MOLA showing the location of ice-rich deposits within and around Reull Vallis. The LDA under study is shown in yellow. (c) THEMIS overlain with MOLA data showing the CaSSIS image and LDA outline.

We discuss contrasting hypotheses for the origin of these distinct deformation length scales. Our results provide a guide to interpret glacial deformation patterns in martian ice-rich deposits in the light of internal structure, balance of stresses, regional climate history, and underlying topography.

Datasets. Our work serves as a case study for the use and integration of data from the Colour and Stereo Surface Imaging System (CaSSIS) with existing datasets.

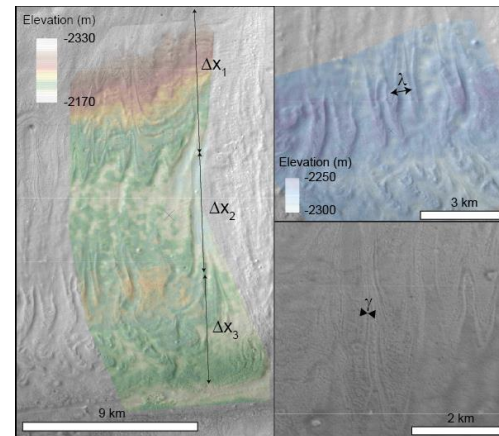


Figure 2: Deformation structures within the LDA. Left and top right: CTX DEM overlying CTX image K06_055540_1384_XN_41S258W showing the terrace distribution (left) and regular lobes (right). Bottom, right: CaSSIS image showing the arcuate bands and spacing.

We make use of CaSSIS' BLU and PAN color bands (499.9 nm and 675 nm) and a Color Band Ratio Composite (CBRC) [8], topography from the Mars Orbiter Laser Altimeter (MOLA) [9] and stereo-derived topography from CTX [10], images from the High Resolution Imaging Experiment (HiRISE) [11], and subsurface structure from the SHallow RADar (SHARAD) [12].

Observations: We use CaSSIS image MY34_005511_224 to describe the morphometry and deformation patterns of the LDA at a resolution of 4.6 m/pixel. We find three main deformation structures in the LDA. Three flow fronts, structured like terraces separated by a distance Δx , are visible in the southern wall of Reull Vallis, terminating in an inner trough that marks the midline of the Vallis cross-section (Figure 2, left). Within each terrace, laterally continuous, regularly spaced lobes are visible with a characteristic wavelength λ (Figure 2, top right). Nested arcuate bands appear within each lobe, convex in the direction of ice paleo-flow (Figure 2, bottom right), correlated with the flow fronts at each terrace. The main axes of deformation indicate the deposit paleo-surface slopes.

Stereo-derived topography from CTX pair N05_064204_1384_XI_41S258W and K06_055540_1384_XN_41S258W shows that the current topography is not aligned with the direction of paleo deformation (Figure 2), indicating that deformation occurred prior to deposit deflation. Elevation data also shows that terraces are correlated with topographic

highs, implying selective deposition of ice-rich material and/or presence of complex underlying topography, and suggesting a stress distribution alike that of icefalls [7].

Spectral density estimation of CaSSIS CRBC image, (CRBC = (1BLU-4PAN)/ (4PAN/BLU) ([13] changing NIR with PAN)), allows for the quantification of the dominant wavelengths for λ and γ . The results are shown in Figure 3. We obtain $\lambda \sim 180 - 350$ m and $\gamma \sim 25 - 33$ m for inter-lobe spacing length and arcuate band width, respectively. We measure inter-terrace distance to be $\Delta x_1 = 5800$ m; $\Delta x_2 = 3100$ m, and $\Delta x_3 = 2300$ m with $\sigma = 400$ m. Whereas the axis of deformation is straight in terraces 1 and 2, it curves significantly in terrace 3 (Figure 2), suggesting a complex strain history in response to a combination of stresses, possibly including tension followed by compression.

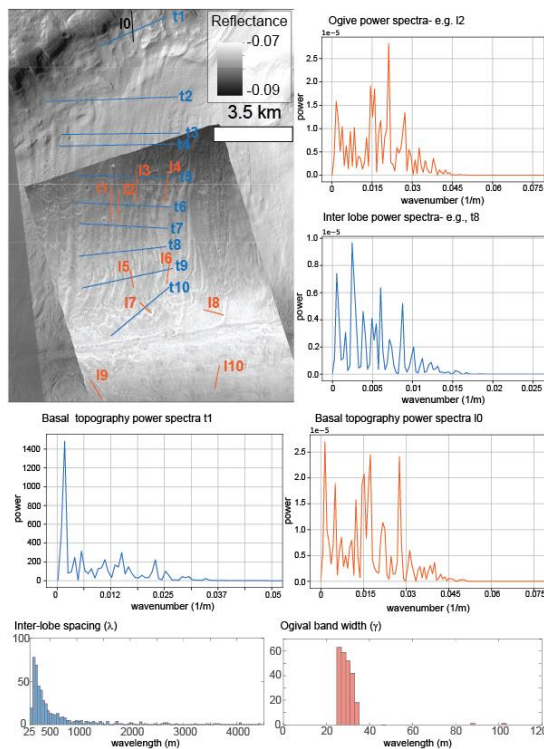


Figure 3. Spectral analysis of lobe spacing (blue transects) and arcuate band width (orange transects). Top left shows CaSSIS overlying CTX with the sites of transect (reflectance vs. distance) extraction. Bottom panels show a histogram of acquired wavelength peaks. The other panels are example spectras, as indicated.

Discussion: The presence of significant deformation in this LDA requires episodes of ice fluidization, when viscosity would have decreased and allowed for deformation. These episodes were likely driven by regional warm spells, given the high effective viscosity and exceedingly slow deformation rates of ice and ice-rich material in today's surface

temperature conditions, and the exponential dependence of ice softness with temperature [7]. Our observations also show no fracture patterns (crevasses), meaning that the tensile stresses experienced were always below the fracture point [7], and therefore that strain rates (and stresses) were low. Our interpretations of the surface structures are:

- **Terraces:** We interpret terraces to be local points of accumulation of icy material, likely controlled and enhanced by the presence of steps in the basal topography. The elevation drop (Figure 2) makes the stress distribution alike that of an icefall [6,7].

- **Lobes:** We interpret lobes to result from laterally-varying deposit thickness in the alcove. This is supported by λ matching the alcove topography (Figure 3, upper left).

- **Arcuate bands:** We interpret arcuate bands to be possible ogives, which on Earth extend across the surface of glaciers with alternating reflectance patterns convex in the direction of flow. When associated with icefalls, ogives result from variations in ice deformation and mass balance [6,7]. If the bands are indeed ogives, λ corresponds to the distance ice moved in a Martian year, placing constraints on ice viscosity and mass balance [7]. More work, in particular numerical modeling of the deformation of this LDA, is necessary to rule out other possible interpretations.

Conclusions: The morphology of the LDA under study, and likely that of other mid-latitude ice deposits, record the changes in ice temperature and viscosity, the evolution of stresses, and possibly variations in mass-balance, making them valuable time capsules of the recent mid-latitude climate record.

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References: [1] Head J.W. et al. (2006) *GRL*, 33(8). [2] Dickson, J.L. et al. (2012) *Icarus*, 219(2) 723-732. [3] Levy J.S. et al. (2016) *Icarus*, 264 213-219. [4] Hauber E. et al. (2008) *JGR: Planets* 113(E2). [5] Smith I.B. et al. (2020) *PSS* 184 104841. [6] Goodsell B. et al. (2002) *J Glaciol.* 48(161) 287-300. [7] Cuffey K.M. and Paterson W.S.B. (2010) *Elsevier, Academic Press, 4th edition*. [8] Thomas N. et al. (2017) *Space Sci.* 212(3) 1897-1944. [9] Zuber M.T. et al. (1992) *JGR : Planets* 97(E5) 7781-7797. [10] Malin M.C. et al (2007) *JGR : Planets* 112(E5). [11] McEwen A.S. et al. (2007) *JGR : Planets* 112(E5). [12] Seu R. et al. (2007) *JGR : Planets* 112(E5). [13] Tornabene L.L. et al. (2018) *Space Sci.* 214(1) 1-61.