SPATIALLY RESOLVED GLACIAL HISTORY ON GEMINA LINGULA FROM ANALYSIS OF TOPOGRAPHY BETWEEN TROUGHS. D.P. Winebrenner[1,2], M.R. Koutnik[2], E.D. Waddington[2], A.V. Pathare[3], S. Byrne[4], and B.C. Murray[5], [1]Applied Physics Laboratory, University of Washington, Box 355640, Seattle, WA 98195, dpw@apl.washington.edu [2]Dept. of Earth and Space Sciences, University of Washington, Box 351310, Seattle, WA 98195, [3]Planetary Science Institute, 1700 E. Fort Lowell Rd., Ste. 106, Tucson, AZ 85719; [4]Lunar and Planetary Laboratory, University of Arizona, Tucson AZ 85721, [5]Division of Geological and Planetary Sciences, Caltech,Pasadena, CA 91125.

Introduction: The shape of topography between troughs on Gemina Lingula (GL), over a broad area on its south side and tip, corresponds quantitatively to that of a flowing ice mass. More specifically, solution of an ice-flow inverse problem, with elevations as input (from the Mars Orbital Laser Altimeter, or MOLA), yields consistent estimates for ice-dynamical parameters, on 40 gradient paths defined by inter-trough topography (shown in Fig. 1) [1].

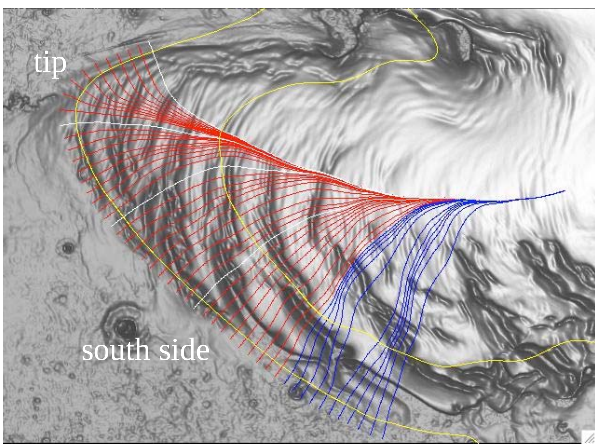

Figure 1. Gradient paths on a surface derived from topography between troughs on Gemina Lingula in the Martian North Polar Layered Deposits, superimposed on a shaded-relief presentation of MOLA topography. Only paths shown in red and white are used in this analysis. Two elevation contours on the surface defined by inter-trough topography are shown in yellow, at -4900 m and -3900 m. Solutions to inverse problems on the 40 paths shown in red and white all yield mutually consistent estimates of ice-dynamical parameters. Solutions on the paths shown in blue are not consistent, apparently due to ablation after inter-trough topography was formed. For details, see [1].

Based on this observation, we infer that inter-trough topography on GL was shaped by an approximate equilibrium between surface mass fluxes and ice flow at some time in the past, and that the formation of troughs occurred subsequently.

Here we show that additional information resides in spatial variations in the inverse-model solutions on GL. In particular, we find evidence that inter-trough topography near the tip of GL is lower in elevation than would be expected from solutions on the south side, by amounts on the order of 100 m. We suggest that the difference could be accounted for by differential ablation, and thus lowering, of inter-trough topography, subsequent to its formation.

A Diagnostic Flow-Number: A dimensionless number, F, that characterizes the flow-regime of an ice mass is given by the ratio of two characteristic time-scales [1]. The first of these is τ_b, the time-scale required for surface mass flux to emplace or remove a column of ice with characteristic thickness. The second is, τ_u, the time required for a parcel of ice to traverse the characteristic horizontal extent of the ice mass by means of ice flow. The flow-number is then given by $F = \tau_b/\tau_u$. Ice masses in which surface mass fluxes are equilibrated by ice flow are characterized by flow numbers on the order of 1, whereas flow-numbers much less than 1 or much greater than 1 indicate disequilibrium, with dominance of surface mass fluxes or ice flow, respectively.

Our solution of inverse problems in this case consists essentially of fitting an equilibrium ice-flow model to observed inter-trough topography [1]. That solution yields an estimate for the flow-number on each path, which serves as a consistency-check – inferred flow-numbers on the order of 1 are consistent with the assumption of equilibrium in the model, whereas inferred values very much larger or smaller generally are not.

Figure 2 shows a plot of inferred flow-numbers as a function of an index for flow-paths shown in Figure 1, with flow-path number 1 being the first flow-path on the tip on the side of GL bounding Chasma Boreale, and proceeding sequentially around the tip and on to the southern side of GL (paths shown in white in Figure 1 have index numbers 1, 11, 21 and 31, for ease of identification). Inferred flow numbers for a broad swath of paths on the south side of GL are in the range 2-3, which is highly consistent with formation of inter-trough topography there by an equilibrium between ice flow and surface mass fluxes. We therefore take these paths as standards for comparison, Inferred flow numbers for paths on the tip of GL, however, are only marginally consistent (F = 8-11) with an ice-flow-equilibrium origin for inter-trough topography there.

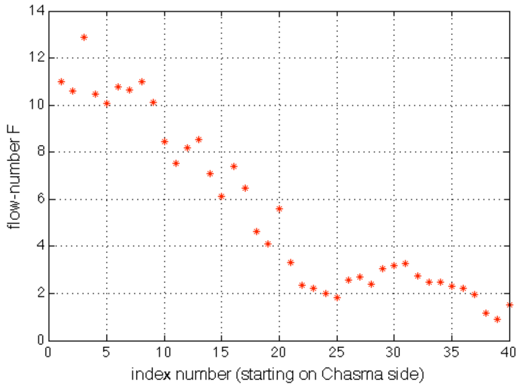

Figure 2. Flow-number, *F*, inferred from solutions to inverse problems on the 40 flow-paths in Figure 1 shown in red and white, as a function of the path index number .

Spatial Variation in Inter-Trough Topography: Inter-trough topography along flow-paths that traverse the tip of GL differs systematically from that on the south side. To compare topography on flow paths of differing lengths and elevations, it is helpful to normalize elevation by the maximum elevation on the path (which lies in each case on the central ridge of GL) and distance along the path by the total length of the path. Figure 3 shows a comparison of inter-trough topographies after such normalization, for two groups of flow paths – 5 paths on the south side in red, and 9 paths on the tip of GL in black.

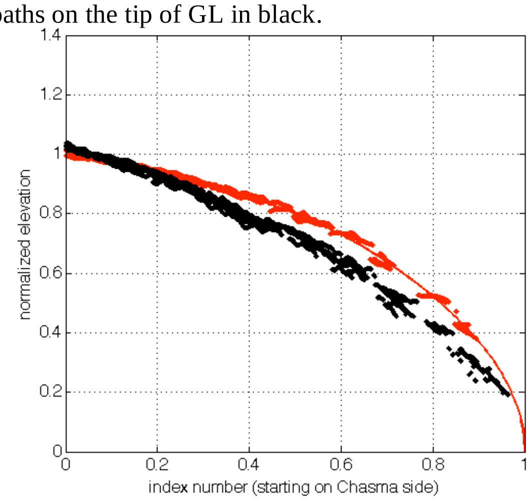

Figure 3. MOLA elevation data between troughs, normalized as discussed in the text, for two groups of flow paths from Figure 1. Data plotted in black are from the first 9 paths covering the tip of GL, on which inferred flow numbers range from 8-11. Data plotted in red are from 5 paths on the south side of GL and on which inferred flow-numbers are 2-3. The solid red line shows a representative model fit for the data plotted in red.

Inter-trough elevations on paths on the tip of GL fall consistently, and considerably, below those on paths from the south side (at corresponding horizontal distances along the paths). Similar differences, though smaller in magnitude and decreasing with increasing index number, also occur for paths 10-20, which traverse the south side of GL near the tip and for which inferred flow-numbers are intermediate.

Spatial variations in basal temperature or surface mass balance (at the time inter-trough topography formed) could have caused spatial variations in topography, but they would not necessarily cause the apparent departures (or near-departures) from equilibrium shown in Figure 2. An alternative explanation for the latter is ablation, and thus lowering of inter-trough topography after its formation.

The differences in normalized elevation data and the red standard curve in Figure 3 give, after accounting for individual normalizations on each path, an estimate of the deficit in actual elevation compared to elevation expected based on paths where $F = 2 - 3$. Figure 4 shows the apparent deficit in elevation on inter-trough topography, averaged over the length of the flow-path, for each path (with zero values on those paths that serve as standards).

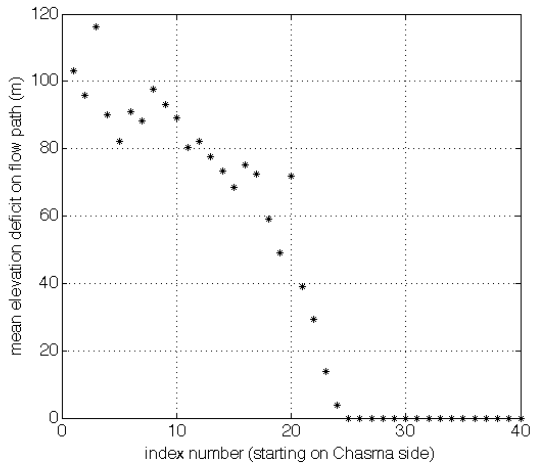

Figure 4. Apparent deficit in elevation on inter-trough topography where inferred flow-numbers are 4-11, based on expectations from paths where inferred flow-numbers are 2-3.

The inferred loss in elevation under this scenario is on the order of 100 m, is largest on the tip of GL, and decreases roughly monotonically with increasing (east) longitude, toward 0E (bottom right of Fig. 1). We will investigate surface mass balance scenarios capable of reproducing this pattern.

References: [1] Winebrenner, D.P. et al. (2008) *Icarus, 195*, 90-105.