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Present-day flow rates of mid-latitude glaciers on Mars

M.M. Sori, S. Byrne, and A.M. Bramson
University of Arizona, Tucson, USA (sori@lpl.arizona.edu)

1. Introduction

Water ice is abundant on Mars. A combination of radar data and image analysis has shown that a large volume of that ice (on the order of 10^5 km^3) exists in the form of mid-latitude glacial landforms [1]. These glaciers are important to characterize and understand because they hold promise for elucidating Martian paleoclimate and may be important in landscape evolution.

To better understand mid-latitude glacial evolution on Mars, we estimate flow rates of viscously deforming icy features. We select a flow feature that has fine-scale topographic data available from a HiRISE-derived digital elevation model (DEM). We estimate the geometry of the feature and use it as input into a finite element method (FEM) numerical flow model to estimate deformation rates under current and past Martian conditions. We discuss the implications of our results for glacial history and the prospects of observing active flow.

2. Image Analysis

The HiRISE camera [2] aboard the Mars Reconnaissance Orbiter has obtained image coverage of ~3% of the Martian surface at resolutions of ~25 cm/pxl. Stereo images allow for construction of DEMs with vertical precision of ~1 m. Previous work [e.g., 3] that estimated stresses and strain rates associated with mid-latitude flow features was limited by Mars Orbiter Laser Altimeter (MOLA) resolution and coverage. HiRISE-derived DEMs allow superior measurement of relevant physical parameters, such as surface slope and flow thickness.

Here, we analyze a viscous flow feature in the Deuteronilus Mensae region on Mars (Fig. 1), which has an associated HiRISE-derived DEM. The feature contains downslope lineations characteristic of flow and superposes lineated valley fill (LVF), which are thought to represent glacial deposits [e.g., 4]. By extracting topographic profiles from the DEM, we find that this flow feature has an approximately poleward-facing surface slope of ~2° and a thickness of <100 m.

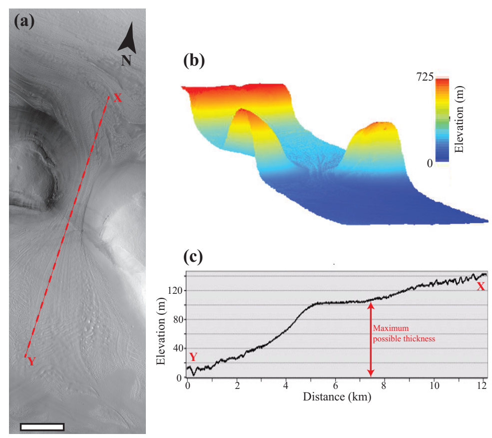

Figure 1. (a) HiRISE image PSP_007795_2175 of a flow feature at 37°N, 25°E. (b) Projected DEM of the image in (a) with 5× vertical exaggeration, constructed using another HiRISE image, PSP_009588_2175, as a stereo pair. (c) Topographic profile of the flow feature parallel to its downslope direction, represented by a red dashed line in (a).

3. Flow Model

We use the FEM software Elmer/Ice [5] to solve the Stokes equations for conservation of mass and momentum and estimate flow velocities. We approximate the flow feature (Fig. 1) as a 2D mass under Martian gravity, with a free surface boundary condition at the top of the feature and no sliding at the base (i.e., cold-based glaciation). We use a rheology that separates strain rate into various deformation mechanisms [6] and considers the effects of intermixed dust or debris [7]. The rheology is grain-size dependent; we choose a nominal grain size of 1 mm. We have previously applied this methodology to quantify viscous flow of icy material at Mars' north pole [8] and on Ceres [9].

Ice rheology is highly sensitive to temperature. We estimate temperature in mid-latitude Martian ice using a 1D semi-implicit thermal model [10] that simulates energy balance at the surface between direct insolation, blackbody radiation, and thermal conduction into the subsurface. We assume the feature is pure ice of thermal inertia ~2100 J m^{-2} $s^{-0.5}$ K^{-1} superposed by 1-m-thick regolith with albedo 0.25 and thermal inertia ~250 J m^{-2} $s^{-0.5}$ K^{-1}. With these parameters, and under current orbital conditions, the annual-average temperature of our feature is 215.3 K.

For this feature, we find relatively low velocities. Under current conditions, we show that the feature is expected to viscously deform at rates of order 10^{-4} m/yr (Fig. 2). We nominally assume that the feature is pure ice; although radar analysis has not been conducted for this particular feature, it has confirmed such an interpretation for other similar features [11, 12]. However, we also ran cases of non-zero dust contents.

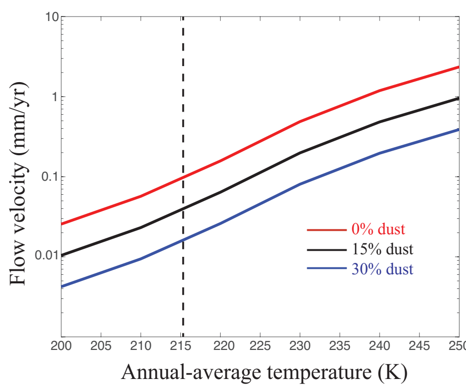

Figure 2. Flow model results for the feature in Figure 1 for various dust contents. Dashed vertical line represents the annual-average temperature in current conditions from our thermal model.

4. Conclusions

The viscous flow feature contained within this HiRISE DEM is insufficiently thick or steep to undergo significant deformation on timescales less than Myrs under current conditions. It has previously been hypothesized [e.g., 8] that active viscous flow may be possible to observe in HiRISE images over the lifetime of the instrument. However, our results show viscous flow features similar to this one are not good candidates to conduct such searches, because they require ~kyrs to flow a distance comparable to a HiRISE pixel.

We will report on the application of our methodology to other viscous flow features at the mid-latitudes of Mars in order to understand how representative the results presented here are of other glacial landforms. Additional areas of study include flow features superposing lobate debris aprons and concentric crater fill. We expect simulations of other viscous flow features will result in significantly higher velocities due to greater surface slopes [3]. We are also refining our methodology to conduct 3D flow simulations.

References

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