EXAMINATION OF VISCOUS FLOW FEATURES ON THE SURFACE OF MARS.
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INTRODUCTION High-resolution images taken by the Mars Orbiter Camera (MOC) reveal the presence of a surface material that exhibits viscous flow features. This material is spatially associated with and shows characteristics similar to a mantle terrain, which was interpreted to be an ice-dust mixture on the order of 1- 10 m thick [1]. The process which forms the ice-dust mixture could be 1) similar to snowfall, in which ice and dust particles mix in the atmosphere and cover the surface uniformly, or 2) one in which ice fills the pore space between grain boundaries in dust deposits already present on the surface. For the second case, the volume fraction of ice would be equal to the porosity of the surface deposits, which is probably no greater than 40% [3]. For the "snowfall" process, it is assumed that $X_{ice} \gg X_{dust}$, where X is volume fraction. Under the present-day Martian climate, near surface ground ice is predicted to be unstable at low latitudes and is actively being removed from the mantle to create a "dissected" appearance [1]. Previous study of MOC images has shown that dissected areas of the mantle terrain exist in two distinct latitude bands (± 30° - 60°) on the surface of Mars [1,2]. Furthermore, the mantle terrain is estimated to be relatively young (~100,000 yrs) due to the absence of craters, which corresponds to the last period in which near-surface ground ice was stable at low latitudes and there existed an increase in the transport of volatiles (such as water) from polar to equatorial regions [3]. Of the 9,712 MOC images examined, 1,026 contain the dissected mantle terrain, and 72 were found to contain mantle material that shows signs of viscous flow. The goal of this study is to describe the flow features, their location, and assess whether an ice-rich mantle could flow under current or past martian conditions.

DESCRIPTION OF FLOW FEATURES Several morphologic characteristics were used to identify viscous flow features in MOC images. A number of images were noted to contain lobate features on steep slopes (see Fig. 1). Often found near the base of such lobes are parallel ridges, orthogonal to the slope, which we interpret to be pressure ridges formed by the downward movement of the mantle material. Another observation was the presence of valley fill that appears to be cratered and thus older than the 100,000 yr old mantle. This older material occurs on valley and crater floors, and perhaps represents an accumulation of the mantle material over several depositional cycles. The presence of one or more of these characteristics was used to determine whether or not a particular MOC image was one which exhibited flow features.

Some of the best examples of flow features are concentrated in several areas, including Reull Vallis, Dao Vallis, and the area near the crater Newton. Several of these regions also correspond to areas containing recent gullies as described by Malin and Edgett [4]. In some images the mantle material fills in the gullies and in other cases the gullies appear to cut through the mantle material. In general, the most prominent flow features occur in steep-walled valleys (both on the walls and valley floor) and in craters. Flow features are not typically observed on the slopes of isolated ridges. In almost all cases, images with flow features also contain areas of the dissected mantle terrain. The mantle typically covers the surface uniformly, independent of surface topography. This appearance is best explained by the "snowfall" formation process. Here we examine the plausibility that the viscous flow features represent an ice-dust mixture created in this manner. By studying stress-strain rate relationships, it is possible to determine if a mantle consisting of ice and dust could flow under various surface conditions.

ESTIMATING SHEAR STRESS Of the 72 images we identified with flow features, MOLA topographic profiles were constructed for those images containing mantle material on slopes in which the direction of flow was approximately parallel to the MOLA path (20 images). These topographic profiles were then used to determine the angle of the surface slope of the flowing material. In many cases the direction of flow was not exactly parallel to the MOLA path, and the measured slope angle was only an apparent slope. Using trigonometric relationships, these apparent slopes were converted to true slopes, typically increasing the slope angle by <2°. A total of 21 different slope angles were measured (two were from the same MOC image), with a minimum of 14°, maximum of 29°, and a mean of 21°. The estimated slope angles and the relationship,

$$\tau_{shear} = \rho g h \sin\theta$$

where ρ =density, g = gravity (3.7 m/s^2 for Mars), h = layer thickness (10 m here), and θ = surface slope angle, were then used to estimate the shear stress at the base of a 10 m thick mantle layer. For this model,

$$\rho = \rho_{ice} X_{ice} + \rho_{dust}(1-X_{ice})$$

where ρ_{ice} = 1.0 g/cm^3, and ρ_{dust} = 1.5 g/cm^3. For $0.2 \le X_{ice} \le 1.0$, and $\theta \ge 15°$, all estimated shear stress values are on the order of 10^{-2} MPa.

RESULTS Using an average shear stress of 10^{-2} MPa and the experimental results on ice deformation of Goldsby and Kohlstedt [5], strain rates for various creep mechanisms can be calculated as a function of temperature and grain size of ice. Sustained surface temperatures of ≥ 273 K are unlikely on Mars and an average daytime surface temperature for mid-latitude regions during the summer is expected to be in the range of 235 K - 260 K [6]. Though the actual grain size of ice particles in the mantle material is unknown, ice crystals formed in the Martian atmosphere are probably similar in size to those formed on earth (~ 1 mm or less). This study focuses on grain sizes in the range of 10-1000 μm. If creep is the main deformation mechanism, then for these grain sizes and average daytime temperatures, the resulting strain rates are on the order of 10^{-8} - 10^{-12} s^{-1} (Table 1). The rate-limiting creep mechanism under these conditions is grain boundary sliding (GBS), which follows a power law with a grain size exponent of -1.4 [5]. These estimated stresses and strain rates are similar to values obtained for terrestrial glaciers and ice sheets [5].

CONCLUSIONS Despite uncertainties in mantle composition, grain size (of ice and dust), thickness, and volume fraction of ice (the latter two determine the exact shear stress involved), we believe that the range of conditions and resulting strain rates presented here show that an ice-rich mantle composition is a plausible explanation for the viscous flow material. Since movement by basal sliding would require the presence of liquid water, which is not likely under present-day conditions on Mars, a slower process such as creep is probably the dominant mechanism. For our estimated strain rates of 10^{-8} - 10^{-12} s^{-1}, grain boundary sliding is the rate-limiting creep mechanism. The strain rate is highly dependent on surface temperature, which increases with obliquity, and grain size. Even for a low strain of 0.1 and our lowest strain rate of 10^{-12}, the time to form the observed flow features would only be ~3000 yrs, which is well within the estimated age of the mantle material and current period of high obliquity. Further deformation studies of mantle compositions with lower ice-to-dust ratios will provide greater insight to the possible formation of the observed flow features.

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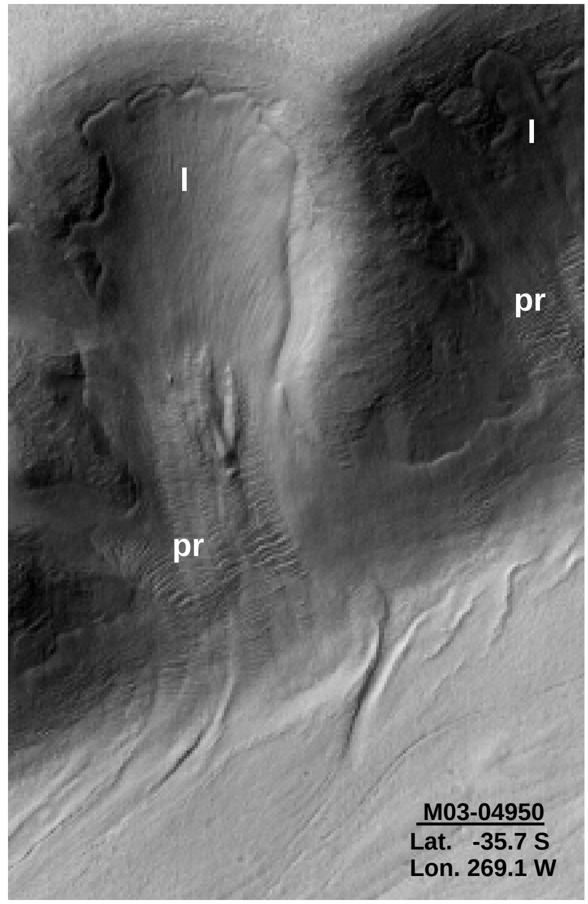

Fig. 1 An example of a MOC image with lobate features (l) and pressure ridges (pr).

	235 K	*240 K*	*245 K*	*250K*	*260 K*
10 μm	-10.1	-9.9	-9.7	-9.5	-8.9
20	-10.6	-10.4	-10.1	-9.9	-9.4
50	-11.0	-10.7	-10.6	-10.3	-9.8
80	-11.3	-11.0	-10.9	-10.6	-10.0
100	-11.3	-11.1	-10.9	-10.7	-10.2
200	-11.7	-11.5	-11.4	-11.1	-10.6
500	-12.3	-12.1	-11.8	-11.6	-11.1
800	-12.6	-12.4	-12.2	-12.0	-11.4
1000	-12.8	-12.5	-12.3	-12.1	-11.6

Table 1 Log of strain rate as a function of temperature and grain size. As temperature decreases, strain rate decreases; as grain size decreases, strain rate increases. All strain rates were calculated for a stress of 10^{-2} MPa.