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ABLATION OF MARTIAN GLACIERS

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Glacier-like landforms are observed in the fretted terrain of Mars in the latitude belts near ± 42° (1). It was suggested that sublimation or accumulation-ablation rates could be estimated for these glaciers if their shapes were known (2). To this end, we have obtained photoclinometric profiles (e.g. 3) of a number of these landforms (e.g. fig. 1). On the basis of our analyses of these profiles, we conclude that ice is chiefly ablating from these landforms that either are inactive rock-glaciers or have materials within them that are moving exceedingly slowly at this time. These conclusions are consistent with other geologic information.

For our analyses, we use a two-dimensional model of an isothermal glacier. The flow of material through a unit width of the glacier is assumed to obey the following flow law (4):

$$\bar{V} = A\tau^3 \, (h/5)$$

where: $\bar{V}$ is the average velocity of the material through a unit width of a section perpendicular to the bed of the glacier, h is the thickness of the material measured at right angles to the bed, τ is the stress on the bed, and A is the flow-law parameter.

The volume flow rate through a unit width, Q, is given by:

$$Q = \bar{V} h$$

The stress on the bed of a section of the glacier is estimated from the profiles (assuming an equilibrium condition) by using:

$$\tau = \rho g \bar{h} \, [(\Delta h / \Delta b) + \sin \theta]$$

where: ρ is the density of the material, g is the acceleration of gravity (3.72 m/s^2), $\bar{h}$ is the mean thickness of a section above the bed, Δh is the difference in thickness of each end of the section, Δb is the length of the section along the bed, and θ is the slope angle of the bed.

There are a number of problems with the glacier-like forms: 1. Their compositions are unknown. They may be chiefly ice, or they may contain large amounts of rock detritus (rock-glaciers). 2. If they are rock-glaciers, the flow laws are unknown. We assume flow like water-ice. 3. The flow-law parameter for water-ice is a strong function of temperature (4). We use 3.18 x 10^{-28} Pa^{-3} s^{-1} (ice at 210 K). 4. Densities are unknown and may range between 1,000 kg/m^3 (water-ice) and 1,800 kg/m^3 (rock-glaciers) or more. For the calculations below we use a density of 1,800 kg/m^3 (e.g., 5), but stresses for ice would be 1/1.8 times smaller than those of rock-glaciers and velocities and flow rates would be 1/5.8 times smaller. 5. The slopes of the glacier beds are inclined beneath at least part of the glaciers. 6. The undulatory form of the profile gives rise to variable stresses, average velocities, and volume flow rates. 7. Ice-glaciers are ephemeral, but rock-glaciers are not. Rock-glaciers contain ice and detritus; nearly complete ablation of the ice results in an inactive residue of detritus.

For the profile in figure 1, stresses on an assumed horizontal bed of the rock-glacier range from 70 to 23 kPa; near the tip, stresses decline from 36 kPa to zero (eg. table 1). Average velocities range from 135 to 3 μm/y; near the tip, velocities decline from 10 μm/y to zero. Volume flow rates peak at 15,400 cm^3/m y, but are smaller in the tip and head. If there is a bed sloping 1.7° beneath the rock-glacier (fig. 1), stresses on the bed range between 35 and 18 kPa and average velocities are between 1 and 9 μm/y. Volume flow rates peak at 1,000 cm^3/m y, but are smaller in the tip and head.

The changes in volume flow rates imply ablation or losses over the length of the glacier; because of the undulatory surface, however, calculated volume flow rates vary and do not yield a uniform ablation rate. For the rock-glacier with the horizontal bed, the maximum local ablation rate for a length increment of 592 m is 26 μm/m^2y. Assuming uniform loss along the length, the ablation rate is 4.3 μm/m^2y. For the rock-glacier with the inclined bed, the corresponding ablation rates are 1.4 and 0.2 μm/m^2y, respectively.

The value of the flow-law parameter has a profound effect on the magnitudes of the calculated velocities, flow rates, and ablation rates. If the value for ice at 190 K is used, instead of 210 K, the velocities and rates would be about one one-hundreth of those in table 1; at 230 K, they would be about 40 times larger. In the isothermal case, such changes would not alter the qualitative conclusions, however.

Profile expectations for a rock-glacier that has a constant volume flow rate through all sections and those for an ice-glacier that is fed at the head and loses volume uniformly along its length (fig. 1) are much thicker near the tip than the actual one. Similar but smaller bulbous tips would be expected for a glacier having a sloping bed. The lack of a bulbous tip suggests that the glacier is no longer fed. Basal stresses for active rock-glaciers on Earth are greater than about 75 kPa (5), but those computed from the profile are less (see also 6). This finding suggests that, if the glacier is a rock-glacier, it is inactive.

Other information also suggests net ablation. Many of the lobate forms exhibit decreases in slope and slope reversals near their heads; some appear to be isolated mounds. Profiles across tongue-like forms undulate and inferred thicknesses are locally zero. Finally, some landforms suggest the former presence of lobate landforms that have been reduced or removed by ablation.

Net ablation of these glaciers requires sinks for the deposition of the ablated ice. Such sinks probably occur in the colder polar regions north and south of the glacier-like landforms (see also 7).

REFERENCES CITED

(1) Squyres, Steven W., 1978, Martian fretted terrain: flow of erosional debris: Icarus, v.34, p. 600-613.

(2) Moore, Henry, 1985, Sublimation rates required for steady-state glaciers on Mars, in Clifford, S. ed., Workshop on Water on Mars, LPI Tech. Rept. 85-03, Lunar and Planetary Institute, Houston, TX., p. 59-61.

(3) Davis, Philip A. and Soderblom, Laurence A., 1984, Modeling crater topography and albedo from monoscopic Viking Orbiter images: 1. Methodology: J. Geophys. Res., v. 89, no. B11, p. 9449-9457.

(4) Paterson, W.S.B., 1981, The Physics of Glaciers, 2nd ed., Pergamon Press, Oxford, England, 380 p.

(5) Wahrhaftig, Clyde and Cox, Allan, 1959, Rock glaciers in the Alaskan Range: Bull. Geol. Soc. Amer., v. 70, p. 383-436.

(6) Lucchitta, Baerbel K., 1984, Ice and debris in the fretted terrain, Mars: J. Geophys. Res., v. 89, Supplement, p. B409-B418.

(7) Squyres, S. W. and Carr, M. H., 1986, Geomorphic evidence for the distribution of ground ice on Mars: Science, v. 231, no. 4735, p. 249-252.

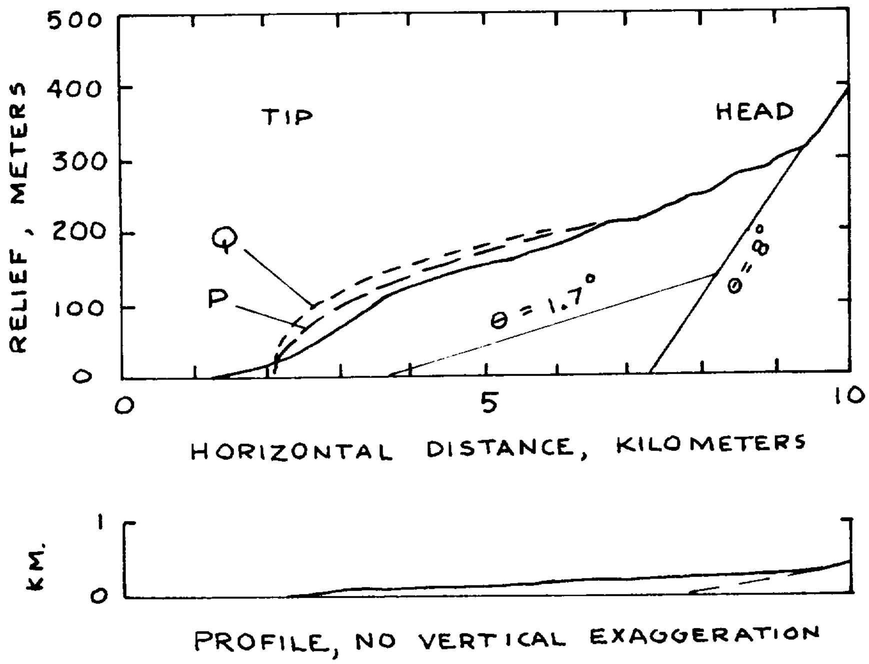

Figure 1. Photoclinometric profile of martian glacier (heavy-solid line). Assumed horizontal base extends to 7.2 km. Assumed sloping base indicated by θ = 1.7°. Slope of mountain is 8°. Short-dashed line (Q) is form of an isothermal glacier that has a constant volume flow rate through all sections. Long-dashed line (P) is form of an isothermal glacier that is fed from its head and ablates uniformly along its length. Both Q and P have horizontal bases that extend to 7.2 km. Note that actual tip of glacier does not have a convex bulbous tip and that its surface undulates.

Table 1. Selected values of calculated mean thicknesses ($\bar{h}$), assumed slope of beds (θ), basal stresses (τ), average velocities ($\bar{V}$), and volume flow rates (Q) for sections having midpoints (D) for two models of martian glacier (fig. 1). Horizontal widths of sections are 592 m. A flow-law parameter for ice at 210 K was used in the calculations.

	Horizontal Base					Inclined Base				
D (km)	$\bar{h}$ (m)	θ (deg)	τ (kPa)	$\bar{V}$ (μm/y)	Q (cm^3/m y)	$\bar{h}$ (m)	θ (deg)	τ (kPa)	$\bar{V}$ (μm/y)	Q (cm^3/m y)
2650	48	0	18	0.6	0.3	48	0	18	0.6	0.3
3834	114	0	28	5.2	593	105	1.7	26	3.8	396
5018	152	0	26	5.2	782	107	1.7	18	1.3	139
6201	189	0	60	81.7	15,400	110	1.7	35	9.2	1,010
7977	138	8	38	15.5	2,140	118	1.7	33	8.8	1,040
8569	81	8	24	2.3	190	81	8	24	2.3	190