DRIVING STRESSES IN MARS POLAR ICE CAPS AND CONDITIONS FOR ICE FLOW. H. Jay Zwally and Jack L. Saba, Code 971, NASA Goddard Space Flight Center, Greenbelt, MD 20771 (jay.zwally@gsfc.nasa.gov).

Measurements of the topography of the North polar ice cap by the MOLA laser altimeter show that the ice cap is 2950 ± 200 meters thick [1]. The volume of the cap is about 1.2 x 10^6 km^3 covering an area of 1.04 x 10^6 km^2, which is about 40% of the Greenland ice sheet in volume and 62% in area. The composition of the Northern cap was previously concluded to be predominately H_2O, rather than CO_2 ice, based on thermodynamic considerations of the in-sustainablity of CO_2 during summer [2][3].

Principal questions about the cap are: does the ice move and at what rate, is the cap currently growing or depleting in volume, and how and when was the cap formed? The presence of steep slopes at the edge of the cap and the darker spiral troughs in the cap suggest that ablation processes are depleting the ice cap at the margins. In contrast, the central portions of the cap remain bright throughout the Martian year, suggesting that there is a net accumulation of mass in the central part. If the ice cap were stagnant (i.e. no ice flow), it would be growing steeper due to a transfer of mass from the margins to the center through the atmosphere.

Previous analyses of the characteristics of the ice cap included modeling of the ice flow [4], ablation features and mass transfer [5], and deductions about basal freezing or melting [6]. Those analyses were based on estimates of elevations, surface slopes, ice thicknesses, and ice temperatures that had large uncertainties, but the previous estimates were of sufficient quality so that the essential features of their analyses remain valid. An important remaining uncertainty is the ice temperature near the base, which is a principal parameter affecting the ice rheology and rate of ice flow in the cap [7].

The force of gravity acting on the ice causes it to move in the downhill direction, if the shear stress in the ice exceeds the yield stress or is sufficient to cause appreciable strain deformation. The shear stress is defined as

$$\tau_b = \rho g h \sin(\alpha)$$

where ρ is the density, g is the acceleration of gravity, h is the ice thickness and α is the surface slope (e.g. [7]). For the small basal slopes typical of ice sheets, the additional effect of a sloping base is negligible. The shear stress, usually called the driving stress, is balanced at the base of the ice by the basal drag. Because very small scale undulations in the surface and the underlying bedrock base do not significantly affect the ice flow, the derivation of the above equation implicitly assumes that the surface slope is averaged over several ice thicknesses.

The distribution of slopes of the North polar cap is shown in figure 1. The peak of the slope distribution lies at 0.11°, which is very close to the peak for all of Greenland. The high slope tail of the distribution, dropping to about 10% at 0.5° and 3% at 1.0°, is very close to the distribution derived for Greenland. Therefore, even though the annual mass accumulation rates for the Martian ice cap and the Greenland ice sheet may differ by orders of magnitude, the

Figure 1. Martian North Pole slope

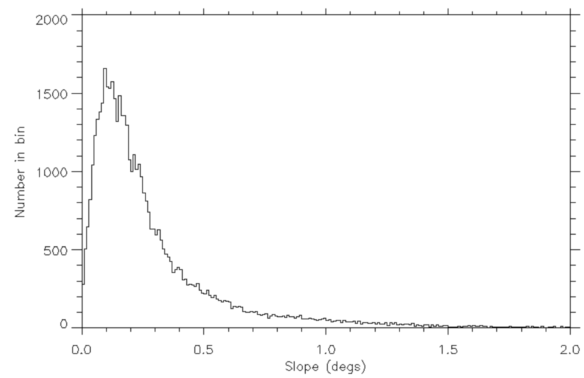


Figure 2. Martian North Pole Driving Stress

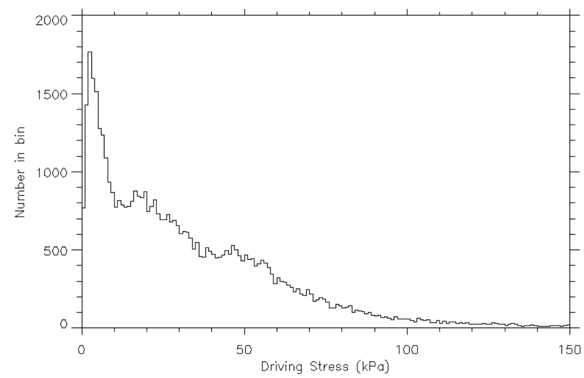
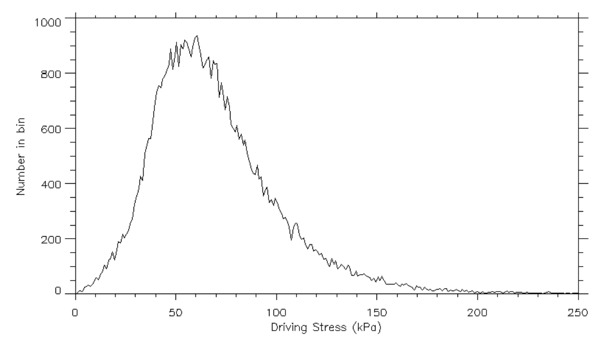


Figure 3. Greenland Driving Stress



ice masses have obtained surface shapes that are essentially the same.

Shear driving stresses near the base of the cap, as calculated from observed surface slopes and the gravitational forcing, are shown in figure 2. Only values for which the ice thickness exceeds 400 m are included in order to exclude areas of clearly stagnant ice outside the main cap. The corresponding distribution for Greenland is shown in figure 3.

The density used in both calculations is 0.92 appropriate for pure solid ice. Since the Mars ice cap is believed to contain some undetermined amount of dust, the Martian values should be increased by, for example maybe 40%, corresponding to a 20% dust mixture in the ice. The Greenland distribution peaks at 55 kPA, which is only about ½ of the 100 kPA value commonly used for the yield stress of ice. Only about 15% of the values lie above 100 kPa.. The Martian distribution appears to be a combination of three distributions. The lowest one peaking at about 5 kPa is probably indicative of areas of thinner and flatter ice that would have negligible deformation. The second one peaking at about 20 kPa has a large number of the values from the arm of the cap that extends away from the pole at 0° longitude. The third peak at about 50 kPa, has a predominance of values from the central part of the cap centered at the pole. Depending on the amount and composition of the dust mixture in the ice, both the second and the third peaks have characteristic values similar to those in the Greenland ice sheet.

The rate of flow for particular values of the shear stress depends on the ice rheology. However, recent research on terrestial ice sheets indicates that rates of ice deformation at the low stress values characteristic of ice sheets are significantly higher than the rates given by the classic viscous-plastic flow laws commonly used. One mechanism is the anisotropic alignment of ice crystals, which occurs under strain over long periods, that significantly enhances the shear strain rate [8]. The similarity of the driving stress distribution in the Martian cap to the terrestrial Greenland ice sheet, may suggest a similarity in the flow properties of the ice masses that is not accounted for in conventional ice flow laws.

References: [1] Zuber M. T. et al. (1998) *Science*, 282, 2053-2060. [2] Keiffer H. H. et al. (1976) *Science*, 194, 1341-1344. [3] Farmer C. B. et al. (1976) *Science*, 194, 1339-1341. [4] Budd, W. F. et al. (1986) *Polarforschung*, 56, 43-63. [5] Fisher D. (1993) *Icarus*, 105, 501-511. [6] Clifford S. M. (1987) J Geogphys Res, 80, (B9), 9135-9152. [7] Paterson W. S. B. (*1994) The Physics Of Glaciers* (Pergamon Press). [8] Li Jun et al. (1996) *Ann Glacio*l, 23, 247-252.