A MODEL FOR THE REMOVAL AND SUBSURFACE STORAGE OF A PRIMITIVE MARTIAN ICE SHEET.* S.M. Clifford, Dept. of Physics and Astronomy, University of Massachusetts, Amherst, MA 01003

In the martian northern plains and near the south polar cap, examination of Viking orbiter imagery has revealed a number of features which bear a strong resemblance to Iceland's table mountains (Allen, 1979; Hodges and Moore, 1979). Since table mountains are formed by subglacial volcanic eruptions, the discovery of possible analogs on Mars has led to the suggestion that an ice-rich unit once covered a significant fraction of the planet's surface; from an examination of the height of these landforms Allen (1979) has determined that the thickness of this unit may have ranged from 100 to 1200 m. In response, Arvidson et al. (1980) have argued that, in the absence of any obvious volatile sinks of sufficient size, the problems associated with the removal and storage of such a massive ice sheet make it difficult to support a subglacial origin of the martian 'table mountains'. However, a number of these problems can be surmounted by the hydrologic model discussed by Clifford et al. (1979) and Clifford and Huguenin (1980a). This model is based on the existence of a global interconnected groundwater system underlying the martian permafrost. Even a fairly conservative estimate of the storage potential of such a groundwater system still provides sufficient volume to readily accommodate a mass of H$_2$O equivalent to that which may have been stored in an extensive primitive ice sheet.

A groundwater system is necessarily subject to certain geologic constraints - the most obvious being that there must exist a suitably porous and permeable layer in which the groundwater can reside. The existence of such a layer on Mars is expected for a number of reasons, most of which are summarized by Carr (1979) and Fanale (1976). Figure 1 is a simplified physical description of this crustal layer. For the purposes of this abstract we will assume that lithostatic pressure leads to self-compaction of fracture

![Figure 1. An idealized stratigraphic column of the martian crust. The levels illustrated are: a) the weathered surface layer, or martian "soil", a fine particulate material which is thought to have an average depth of from one to several hundred meters (est. mean porosity: 30 - 50%) (Pollack et al., 1979; Hillel, 1971); b) the rubble layer, consisting of a mantle of crater ejecta interbedded with volcanic flows (est. mean depth: several kilometers or more; est. porosity: 10 - 50%) (Fanale, 1976; Carr, 1979); c) the fractured zone, basement material fractured in situ by impact generated shock waves and tectonic stress (depth to self-compaction: 10 - 20 km; est. mean total intergranular and fracture porosity: 5 - 20%) (Carr, 1979; Davis and De Wiist, 1966; Wise, 1980; Notts, 1980).](image-url)
Storage of a Primitive Martian Ice Sheet
Clifford, S.M.

Figure 2. A pole-to-pole cross section of the martian crust illustrating the relationship between topography, permafrost and the proposed groundwater system. Surface elevations are averaged as a function of latitude after Mutch et al. (1976). Permafrost thicknesses are taken from Fanale (1976). The self-compaction depth is assumed to be a uniform 10 km.

Figure 3. Retreat of a primitive martian ice sheet in response to a climatic shift in the frost point latitude. Low and mid-latitude surface temperatures rise above the frost point temperature resulting in the poleward redistribution of H_2O. Eventually the polar ice cap exceeds the thickness required for the onset of basal melting. Given the geothermal heat flux estimate of Fanale (1976), a 500 m thick ice sheet that once covered 40% of the planet could be introduced into the proposed global groundwater system in as little as ten million martian years. (Diagram is not to scale.)
Storage of a Primitive Martian Ice Sheet
Clifford, S.M.

and intergranular pore space at a uniform depth of 10 km below the martian surface and that the mean value of crustal porosity, down to this depth, is ~5% (Clifford and Huguenin, 1980b). These are probably conservative figures (Carr, 1979; Wise, 1980) but they serve to make the following point: Consider the amount of water contained in a hypothetical ice sheet 500 m thick and covering 40% of the martian surface. If we could somehow transform this ice into a liquid and use it to fill the available pore space in our model crust we would find that the groundwater system so formed would underly over 95% of the martian surface at a depth approximately 4 km below the planet's mean elevation (see Figure 2). Thus, even conservative choices for the depth of self-compaction and overall porosity yield a crust with a sizable groundwater storage capacity.

Given that the crust has sufficient capacity to store a primitive ice sheet as groundwater there still remains the question as to how this transformation can be physically accomplished. Figure 3 illustrates one possible approach. Ice will remain stable on the martian surface only at latitudes where the mean annual temperature remains below the frost point. Should the mean temperature rise above the frost point the ice sheet will begin to ablate and the \( \text{H}_2\text{O} \) redistributed poleward. What the sheet loses in areal extent it gains in thickness at the pole. Each additional layer of ice deposited causes a readjustment of the local thermal gradient. Eventually a thickness is reached where basal melting will occur (Clifford, 1980). If the area involved in basal melting is equal to the present size of the permanent north polar cap, and if we assume the geothermal heat flux of 22 cal cm\(^{-2}\) yr\(^{-1}\) calculated by Fanale (1976), then the entire mass of the hypothetical ice sheet described earlier could be introduced into a global groundwater system in as little as 8 million martian years.

In conclusion, we see that the hydrologic model presented by Clifford et al. (1979) and Clifford and Huguenin (1980a) can resolve both of the major problems cited by Arvidson et al. for the subglacial birth of the martian 'table mountains'. Unfortunately, a true test for the existence of a global groundwater system, such as the one discussed here, must wait for some future program of seismic exploration on Mars (Tittmann, 1979).