POSSIBLE COMPOSITION OF MARTIAN POLAR CAPS AND CONTROLS ON ICE-CAP BEHAVIOR. J. S. Kargel, U.S. Geological Survey, 2255 North Gemini Drive, Flagstaff AZ 86001, USA.

David Fisher [1] asked *"If martian polar caps flow"*? Are martian polar caps akin to Earth's polar glacial ice sheets, or are they immobile? Though certain dynamical differences are obvious, it is unknown whether similarities in ice tectonics may also exist. The question bears not only on modern martian polar processes, but perhaps on hypothesized glacial processes elsewhere on Mars in the geologic past. The rheological properties and tectonics of martian polar caps also pertain to the possibility that liquids may have existed beneath the polar caps in the past, or even now [2], and prospects for life in possible lakes beneath the ice caps. The cold martian polar surface temperatures and the lower martian gravity compared to Earth's suggests a reduced propensity of martian polar ice deposits to deform under their own weight. The greater accumulation timescales of the martian polar caps [3] compared to Earth's also means that more time has been available for accumulated deformation, possibly offsetting the effects of colder temperatures and lower gravity on Mars. Further complicating our understanding is that the martian polar caps may not be made purely of ordinary water ice — CO_2 is another possible major constituent; the rheological and melting behavior may be very different from what we are accustomed to dealing with on Earth.

Global Survey's laser altimeter (MOLA) data for the northern polar region have imposed new constraints on physical models of the northern polar cap — chiefly that the ice thickness reaches a maximum of ~3 km (http://ltpwww.gsfc.nasa.gov/tharsis/mola.html). These new data are reassuringly similar to rougher knowledge of topography given by Viking-era data [3]. MOLA data have not been acquired over the southern polar cap, but Viking-era data suggest a comparable ice thickness. These results are used as inputs to thermal models of the martian polar caps. Four compositions are modeled, including pure H_2O, pure CO_2, carbon dioxide clathrate hydrate ("hydrate"), and interlayered water-ice and hydrate. Hydrate is considered a likely cap-forming substance because, as widely pointed out at least for the current-epoch south polar cap [4–11], hydrate is more thermodynamically stable than water ice plus "dry ice" at prevailing south polar temperatures [12]. In the fourth (newest) model, the layering is produced by climatic oscillations due to orbital precession and cyclic variations in inclination [3,13,14]. The disparate thermal conductivities of ice and hydrate produce huge differences in the models' thermal gradients and basal temperatures [15]. These differences as well as the differing rheologies of hydrate and water ice [16] might produce distinctive tendencies for or styles of deformation. Chief new results of the models and possible tendencies (not yet modeled in detail) are:

(a) If made mainly of water-ice, the polar caps are far below the pressure-melting curve of H2O even at their bases. Their rheological stiffness might make them unlikely to have undergone significant plastic deformation, unless they are billions of years old, i.e., older than thought. If composed of water-ice, the polar caps probably are static, mass-limited condensate piles subject only to sublimation and wind erosion.

(b) If made of CO_2 hydrate, extensive solid-state deformation is possible, and basal dissociation with local formation of two immiscible liquid phases is probable. In areas where basal melting occurs (generally where cap thickness is >2 to 2.5 km), regions of zero basal shear stress and almost no surface relief are expected. A state near glacial equilibrium (a balance at each point on the ice cap between accumulation and losses due to horizontal flow, basal melting and expulsion of liquid, and surface sublimation) is possible. However, the actual ice sheets, like most glaciers on Earth, may oscillate widely around equilibrium due to episodic perturbations (such as episodic liquid outflow or solid-state surge events, and changes in accumulation or sublimation).

(c) If made of interlayered CO_2 hydrate and water ice (for which I have a weak preference for both polar caps), a state at or approaching the melting point of water ice is expected near the base of the polar cap. Gravitationally driven solid-state deformation conceivably might occur in two greatly differing styles (or not at all) —

either glacier-like transport or salt dome-type diapirism; however, the somewhat stiffer rheology of hydrate compared to water ice could hinder deformation in favor of more extensive basal melting.

(d) If made primarily of CO_2 ice (least favored for both polar caps), widespread basal melting is assured in areas where thickness >1 km. But the polar caps probably could not sustain the observed relief and thickness near the edges of the polar caps.

Global Surveyor images of the polar regions soon may offer new clues as to polar processes and ice composition. Possible future observations and inferences may include:

- If no imaging evidence for either deformation or fluid outflow-- favors model "a."
- If large expanses of virtually no surface relief-- basal lakes, models "b" or "c."
- If evidence for explosive fluid outflows-- models "b" or "c."
- If evidence for solid-state diapirism, tectonic doming-- model "c" or possibly "b."
- If evidence for extensive horizontal ice flow-- model "b" or possibly "c."

Existing MOLA and Viking-era topographic data show polar caps 3 km thick, arguing against model "d," since a thick polar cap of dry ice would most likely have to contain a very deep and probably physically unstable lake of liquid carbon dioxide; however, a possibility is that the hydraulic conductivity of the substrate allows basal flow at a rate sufficient to remove all the liquid. In any event, any liquids beneath the martian polar caps are almost certainly CO_2 rich; if aqueous, they would be solutions of carbonic acid. This possibility has implications for rock weathering (probably extensive) and biological potential. The possible periodic expulsion of basal liquids could produce eskers (glacier-deposited ridges of sand and gravel); either episodic expulsion or steady basal flow of aqueous acid solutions could have formed and transferred copious quantities of salts from polar cap areas to adjacent zones, possibly resulting in surface deposits observable by Global Surveyor. Solid-state deformation could have physically eroded rocks and deposited moraines. However, if the bases of the ice caps are not anywhere at the melting point, regardless of or because of solid-state deformation, moraines, eskers, and salt deposits would be unexpected.

Other mechanisms of volatile trapping have been considered, including occlusion of martian air and trapping of cometary/asteroidal volatiles. Both are expected to produce geochemically distinctive and scientifically valuable polar materials, but these volatiles should not be of sufficient abundance to affect the rheology and deformation of the polar caps.

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