Stability and Diffusion Time Scales of Water Ice in the Martian Regolith; Michael T. Mellon *t and Bruce M. Jakosky **, * Laboratory for Atmospheric and Space Physics, † Department of Astrophysical, Planetary, and Atmospheric Sciences, ‡ Department of Geological Sciences, University of Colorado, Boulder, CO 80309

Introduction: There exists a wealth of geologic evidence suggesting water ice has played an important role in the formation of Martian landforms. We investigate the stability of subsurface ice and the time scales for diffusion of atmospheric water vapor into the regolith. The geographic extent of subsurface water ice is compared with the locations of observed geologic features.

Squyres and Carr mapped the global distribution of ice-related morphology. Their study showed regional variations, in both longitude and latitude, in the distribution of debris aprons, concentric fill craters, and "softened" crater profiles. They found large regions in the northern and southern mid-latitudes with an abundance of these geologic features, while other mid-latitude and equatorial regions lacked any significant ice-related geomorphology. Farver and Doms estimated the latitudinal extent of ice stability based on subsurface temperatures for a "typical" regolith and concluded ice would be stable poleward of about 40 degrees. Their results provide an explanation for the latitudinal variation in the geomorphic features mapped by Squyres and Carr, but do not provide an explanation for the longitudinal dependence.

A comparison of the map of Squyres and Carr with maps of thermal inertia and albedo, from Palluconi and Kieffer, reveal a correlation between low thermal inertia/high albedo regions and regions of ice-related surface morphology. This correlation suggests that thermal inertia and albedo play an important role in determining water-ice stability in conjunction with latitude. By allowing for regional variability of the thermophysical properties of the regolith, we show that mid-latitude regions of low thermal inertia have colder mean annual surface and subsurface temperatures and act as preferential sinks of atmospheric water vapor by diffusion into the regolith and condensation in the cold subsurface pores.

Present Work: To study the regional stability of ice we modeled the thermal behavior of the subsurface and the thermally driven diffusion of water vapor within the regolith. We used a standard thermal model, which consists of a finite difference solution to the thermal diffusion equation with the appropriate boundary conditions. In this model we allowed each latitude and longitude to determine the thermal inertia and albedo, as derived from Viking IRTM thermal emission data, and insolation, controlled by latitude and orbital parameters. We then computed the evolution of subsurface temperature throughout the Martian year. We assumed the thermal inertia observed at the surface is representative of the top few meters of regolith and that atmospheric infrared radiation is 2% of the maximum daily insolation (the "2% approximation").

With the temperatures from the thermal model, we used a standard molecular diffusion model to compute the thermally driven diffusion of water vapor within the regolith and in exchange with the atmosphere. The regolith was assumed initially devoid of water. As vapor diffused into the regolith, it was allowed to partition between three phases: vapor, ice, and adsorbate. The temperatures controlled the vapor density over ice or adsorbate and the diffusion coefficient as described by kinetic theory. The diffusion coefficient also varied with ice content as condensing ice choked off the pore space. The regolith was assumed to consist of basalt with a density of 1.68g cm$^{-3}$ and a porosity of 40%, typical for an average thermal inertia of 6.5 (10$^{-3}$cal cm$^{-2}$s$^{-1/2}$K$^{-1}$).
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Results and Conclusions: The following conclusions were arrived at based on the results of numerical simulations of thermal and diffusive behavior as described above.

- Water will diffuse from the atmosphere into the soil to form adsorbate and ice. Ice will form and be stable where the mean soil temperature is less than the mean atmospheric saturation temperature. For $10 \, \text{pr} \, \mu \text{m}$ well mixed with $\text{CO}_2$ this occurs at about $196 \text{K}$.
- The latitude north of which ice is stable varies by as much as 20-30 degrees from one longitude to another, depending on atmospheric water content (see figure 1).
- Subsurface ice will begin to form in as few as 1000 years. 30-40% of the available pore space will accumulate ice in $10^5$ years (same as orbital time scales).
- The amount of ice and the time scale for accumulation depends on the thermal and diffusive properties of the regolith.
- Atmospheric water alone can supply the regolith with ice to a depth where the annual thermal oscillations give way to the geothermal gradient, typically 2-5 meters.
- At high obliquity ice is stable globally. At low obliquity ice is restricted to the polar regions.
- Areas of non-correlation between 'ice morphology' and ice stability suggest the need for a more complex explanation, such as orbital evolution and changes in thermal properties due to modification of surface deposits.
- To fully understand and estimate depth, spatial extent, and quantity of stable regolith ice will require the incorporation of orbital cycles into a time dependent model.

![Fig. 1. Mean annual surface and subsurface temperatures for the current epoch. For an atmospheric water column of $10 \, \text{pr} \, \mu \text{m}$, ice will be stable poleward of $196 \text{K}$. The time required to populate this region with ice from atmospheric water is longer than the time scales for orbital evolution.](image-url)