

NEAR-SURFACE LIQUID WATER ON MARS. D. A. Paige¹, ¹Dept. of Earth and Space Sciences, UCLA, Los Angeles, CA 90095. (dap@mars.ucla.edu)

Introduction: The discovery of evidence for recent liquid water seepage and runoff features on Mars [1] has generated considerable interest in understanding their origin. The explanations that have been proposed thus far can be divided into two basic categories based on the dominant heating source: geothermal [1,2] and solar [2-3]. Analyses of the distribution of these features indicates that they are found in a range of geologic settings, including rocky alcoves, sloping soil surfaces and dunes [1,3]. They tend to be most abundant poleward of 30° latitude, and have a distinct preference for poleward facing slopes [1,3]. While not all seepage and runoff features may have formed in the same manner, their preference for poleward facing slopes suggests very strongly that solar heating plays a significant, if not dominant role in their formation. To date, efforts to use the results thermal models to explain the origin and distribution of these features have yielded mixed results due to two major problems.

The first problem is that while it is clear that at high obliquity, poleward facing slopes can become warm enough to permit temperatures in excess of 273K throughout the day during the warmest days of summer [3], creating situation in which a significant quantity of ground ice might be expected to be present in these warm areas presents serious difficulties. To first order, ice will migrate away from warm regions and become trapped in cold regions, so in general, ice should not be expected to be found when and where it “needs to be” to form these features [2].

The second problem is that during periods of high obliquity, the distribution of peak solar heating is strongly biased towards higher latitudes. If solar radiation is the dominant heating source for these features, then they would be expected to be found in much more commonly at higher latitudes. The observations only partially support this trend, in that while the features are generally not observed equatorward of 30° latitude [1], they are not observed with increasing frequency at higher latitudes. Clearly, the distribution of these features must be due to more than simply the distribution of isolation.

Model Description: In an effort to better understand the origin and distribution of the Martian seepage and runoff features, a detailed model has been developed that includes all the major processes responsible for determining surface and subsurface temperatures, as well as the distribution and phase of water. The atmosphere is treated using a ten-layer diurnal and sea-

sonal 1-dimensional radiative-convective model which included anisotropic, non-conservative scattering by atmospheric aerosols and absorption by CO₂ gas at solar wavelengths; anisotropic, non-conservative scattering and emission by atmospheric aerosols at infrared wavelengths; emission and absorption at infrared wavelengths by CO₂ and H₂O gas; conductive and convective heat transport between surface and atmosphere; surface carbon-dioxide ice condensation and sublimation. The model also includes the effects of direct and indirect solar and infrared radiation on sloped surfaces and shadowing an indirect heating in alcoves. The time-varying depth to the top of a ground ice or partially liquid layer is determined by accounting for the diffusion of water vapor to and from the atmosphere through overlying layers. Subsurface heat conduction is treated using time-varying thermal properties to account for significant thermal effects of the presence of ground ice itself [4]. Latent heat effects due to subsurface ice condensation, sublimation, as well as ice freezing and melting where appropriate, are included as well.

Results: In general, the model results suggest that seepage and runoff features can be explained by the melting of near-surface ground ice during periods of high obliquity in virtually all the locations and settings that they have been observed. However, special circumstances are generally required to produce liquid running water, and this provides an explanation of sorts, for why these features are not more widespread than they apparently are.

During Mars' present orbital configuration, nighttime temperatures everywhere on the planet are always well below 273K, which effectively prevents subsurface temperatures from reaching the melting point for sustained periods. However, when Mars' obliquity approaches 45°, its eccentricity approaches 0.11, and summer solstice in one of Mars' hemispheres coincides with perihelion, the model results show that middle and high-latitude surface temperatures during summer can in fact remain well above the melting temperature throughout the day. During summers at high-obliquity, poleward-facing slopes at middle latitudes are warmer at night than flat surfaces or equator-ward facing slopes because they receive direct sunlight at more favorable angles during the late evening and early morning hours. Increased atmospheric dust opacity decreases direct isolation at high solar zenith angles, which results in lower surface and subsurface temperatures. The model results show that visible dust optical depths of

less than 0.2 produce the best conditions for high surface and subsurface temperatures on sloped surfaces.

Poleward-sloping rocky outcrops and alcoves provide particularly favorable locations for the melting of ice during the warmest days of the year during periods of high obliquity. The high thermal inertia of rock results in higher daily averaged temperatures, as well as higher nighttime temperatures than low thermal inertia dust or soil. In alcoves, the indirect radiation provided by adjacent rock walls further also elevates nighttime temperatures. The model results show that most poleward-facing rock faces would be expected to sustain subsurface temperatures in excess of 273K for more than 30 days every year during periods of high obliquity. This is significant in and of itself from an astrobiological standpoint. However, to generate enough liquid water to result in an observable flow feature, the outcrop must have enough permeability to allow water vapor to diffuse into the rock to form ice during the fall and winter seasons, and enough impermeability to act as a diffusive barrier to sublimating and evaporating water within the rock during summer. In this context, an outcrop of a semipermeable sedimentary rock layer would be a more ideal location for the source of a flow feature than an outcrop of a relatively impermeable extrusive or intrusive volcanic layer.

Poleward sloping soil, dust and sand surfaces are also favorable locations for the melting of liquid water, but a somewhat different mechanism is required. As shown in previous studies, ice is not expected to be stable to evaporation on sloping surfaces that experience high enough surface temperatures to produce liquid water [2]. However, in the case where the surface has been recently eroded by downslope movement or wind, an exposed, or thinly mantled deposit of ice-rich soil can indeed melt if the overlying dust mantle and/or sublimation lag deposit provides enough of a diffusive barrier to water sublimation and evaporation. The high thermal inertia of the ice-saturated subsurface soil significantly enhances its thermal stability. The results suggest that the most favorable locations for seepage and runoff features on sloping soil, dust and sand surfaces will be in locations that are subjected to active erosion, which is consistent with available observations.

While the results of these model simulations cannot tell us what is true, they can tell us what is possible, and in total, they suggest that liquid water conditions, and liquid water runoff are physically plausible on Mars during periods of high obliquity, and may be the dominant explanation for the water seepage and runoff features that have been observed in the recent MOC observations.

References: [1] Malin, M. C. and K. E. Edgett, *Science* 288, 2330 (2000). [2] Mellon, M. T. and R. J. Phillips, *JGR* 106, 23165 (2001), [3] Costard, F. *et al.*, *Science Express*, 2001. [4] Paige, D. A. *Nature* 356, 43 (1992).