RECENT GULLIES ON MARS AND THE SOURCE OF LIQUID WATER. M. T. Mellon[1] and R. J. Phillips[2], [1]Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO, 80309, mellon@argyre.colorado.edu, [2]McDonnell Center for the Space Sciences and Department of Earth and Planetary Sciences, Washington University, St Louis, MO 63130.

Introduction: Reported observations of gully-like landforms on the Mars and their apparent young age suggest that liquid water has recently flowed on the surface. However, the present day surface temperatures are too low for the source of liquid water to occur at or near the surface. Where this water comes from, and what these features tell us about Mars, remain open questions. We tested several mechanisms for the origin of liquid water at the surface. We found that nominal geothermal heat combined with a low-thermal-conductivity regolith can allow subsurface temperatures to exceed freezing at relatively shallow depths. Partial freezing of an aquifer at this depth can generate pressures adequate to force water to the surface.

Gullies On Mars: Malin and Edgett [2000] reported geologic features resembling terrestrial water-carved gullies in the mid and high latitudes of Mars. They occur poleward of 30º latitude primarily in the southern hemisphere. More often they are reported on poleward facing slopes than equatorward facing slopes, though they occur on all orientations of slopes.

The morphology of the gullies varies but typically consists of a source region "alcove" of order 100 m wide, v-shaped channels of order 10 m wide leading from the alcove, and a depositional fan (see Figure 1).

The source regions appear to originate a few hundred meters or less from the top of the local slope and are frequently associated with exposed strata of material that appear to exhibit significant cohesive strength. Erosion is best explained by a fluid of some sort and water is considered the most likely candidate. These features are believed to be geologically young by their superposition atop dunes and permafrost polygons; how young is difficult to determine, though a range of older than 20 yr to younger than 1 Myrs is suggested.

Permafrost on Mars: Our general understanding of the current martian climate has been that the planet is globally covered with permafrost – a region of the regolith where surface temperatures remain below the freezing point of water. Permafrost consisting of porous soil in diffusive contact with the atmosphere is expected to be ice-rich at mid and high latitudes due to condensation of atmospheric water. Mars also undergoes orbital oscillations that can significantly alter the climate. As a result the permafrost can become periodically ice rich at all latitudes at moderately high obliquities, though permanent ground ice is only expected poleward of 30° to 40°.

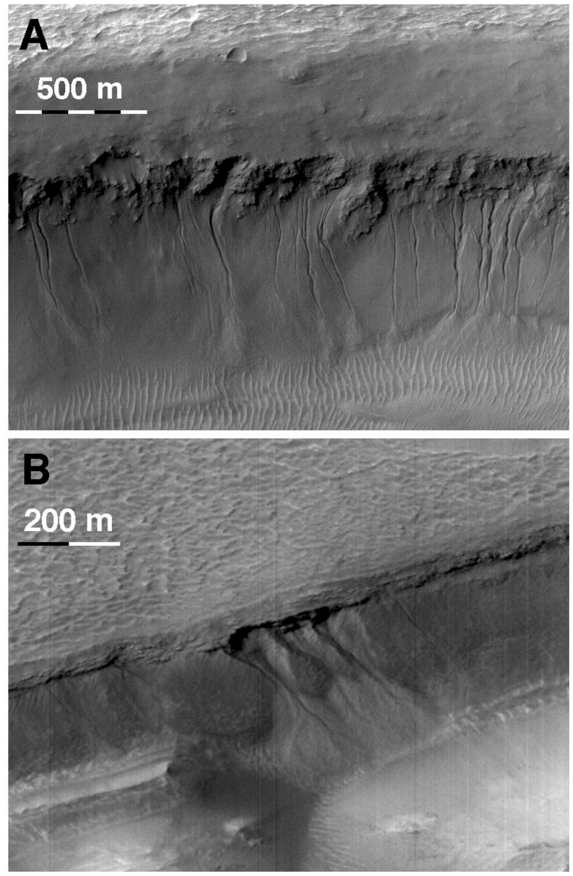

Figure 1: Examples of gullies on Mars. Source water appears to flow from a zone of cohesive strata.

In regions where ground ice is stable, densely ice-cemented soil will occur below a few tens of cm of dry soil. Below this, the soil will become ice-cemented to the depth of the seasonal thermal wave, a few m. Deeper still, ground ice could exist if a ground water supply allowed water-ice to collect, by upward diffusion of vapor. In the absence of available ground water, however, the soil below a few m would remain ice-free.

The distribution of gully features coincides with the expected distribution of near-surface ground ice suggesting a possible relationship. But low ground temperatures at the latitudes at which the gullies are found presents a contradiction to the presence of liquid water.

Modeling Approach: Can reasonable conditions can occur for geothermal heat to adequately warm the subsurface, such that pockets of liquid water may exist at depths shallower than previously considered?

To address this question, we modeled the subsurface temperature gradient under the influence of geothermal heat flow *q*, through a subsurface material with a thermal conductivity *k*:

$$\partial T/\partial Z = q/k.$$

We assumed a nominal geothermal heat flow of 30 mW/m^2, which is consistent with numerous global-average estimates. This value is not consistent with localized volcanic activity, evidence for which is not observed in proximity to the gullies.

The thermal conductivity *k* can vary by orders of magnitude depending on the subsurface material, which is largely unknown. One possibility is that the subsurface is ice saturated. Ice-cemented soil would have a thermal conductivity of about 2.4 W/m K. A similar value to dense rock. A weakly cemented sandstone would contain significant void space. A representative thermal conductivity would be about 0.9 W/m K.

In contrast, ice-free loose soil would have a much lower thermal conductivity. Indeed, temperature observations were used to derive the surface thermal inertia, with a global average value of 250 J/m^2 s$^{1/2}$ K, which translates to a thermal conductivity of 0.045 W/m K. While this measurement is sensitive to only the top few cm of the surface, it is possible that, in places, the surface layer may be representative of the subsurface.

Combining the subsurface temperature profile with subsurface pressure from lithostatic loading, Figure 2 shows the geothermal profile superimposed on the phase diagram of water for each of these three thermal conductivities. It is clear that for ice-cemented soil, dense rock, and sandstone-like materials, the depth to the base of the permafrost is several km. However, for ice-free, loose soil, this depth is only 100 to 200 m, consistent with the source depth of the water which apparently formed the gullies.

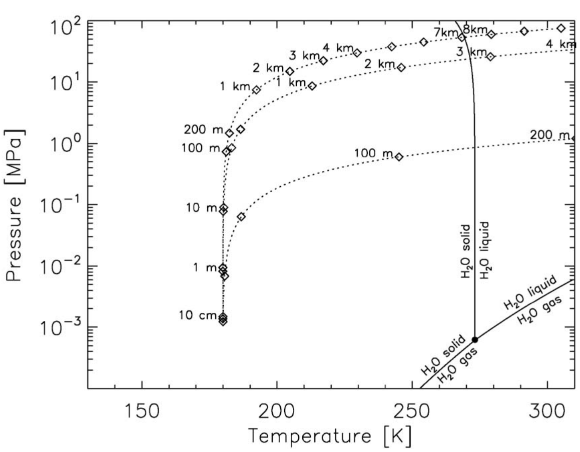

Figure 2: Example geothermal profiles, for ice-cemented soil (top curve), weakly cemented sandstone (middle) and loose, dry soil (bottom curve).

Is an ice-free loose soil a reasonable material for depth scales of 100 meters? If ground water is present, it will diffuse upward, driven by the geothermal gradient, and if unobstructed, will populate the regolith with ground ice, raising the thermal conductivity. The presence of gullies implies the presence of such ground water. However, the presence of cohesive strata in the upper hundreds of meters of regolith, can act as an aquitard, preventing the upward migration of ground water and maintaining a low conductivity dry soil.

Taking this model one step further, in some locations water could become trapped between strata, creating a confined aquifer. Orbital oscillations, which produce oscillations in the surface temperature will easily induce temperature oscillations at these shallow depths.

Partial freezing the confined aquifer will generate pressure *P*,

$$P = (0.09Ef) / (3f(1-2v)+EK(1-f)),$$

where *E* is Young's modulus of ice, *K* is the compressibility of liquid water, and *f* is the fraction of water frozen. Pressures can reach as high as 800 MPa for near-complete freezing. For moderate 1% freezing of the aquifer a pressure of 1.8 MPa would be generated, which is still adequate to fracture frozen soil.

We propose a conceptual model, Figure 3, which illustrates an ideal situation. Cohesive, impermeable strata confine an aquifer. Dry, low-conductivity soil above the aquifer provides a blanketing effect to allow geothermal heat to maintain liquid water. Near-surface ground ice stability allows a ground-ice plug to prevent the aquifer from sublimating directly to the atmosphere over time (left). Periodic freezing builds fluid pressure and causes failure of the frozen soil under tension.

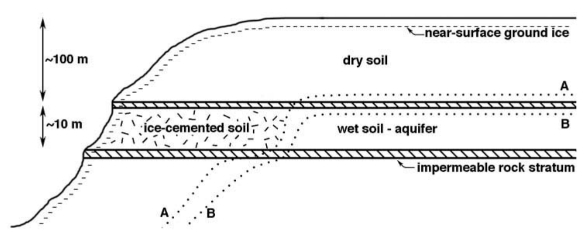

Figure 3: Conceptual model of trapping and freezing ground water. Orbitally-driven cycles in surface temperature cause the 273K isotherm to move from A to B resulting in partial freezing and increased pressure.

This model demonstrates that liquid water can occur on Mars at relatively shallow depths consistent with observed gully geometry. In addition, adequate pressures can be generated by orbitally induced partial freezing, to cause failure and escape of liquid water to the surface. Details of this model will be discussed.