THE APPARENT THERMAL INERTIA OF LAYERED SURFACES ON MARS. M. T. Mellon[1] and N. E. Putzig[2], [1]Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO, [2]Department of Earth and Planetary Sciences, Washington University, St. Louis, MO.

Introduction: Thermal inertia is the key surface property that controls the temperature response of the martian surface to solar heating. It is defined as square root of the product of the thermal conductivity, density and heat capacity. Visible and infrared spectroscopy senses the material composition of the upper microns to tens of microns of the surface. Visible imaging exposes the physical structure of the surface and subsurface at typically meter to kilometer scales, at comparable vertical and horizontal scales. Thermal inertia provides a window into the physical and compositional structure of the surface at an intermediate depth scale of few centimeters to a few decimeters.

The thermal inertia of the martian surface has been derived over the last several decades from numerous remote sensing observations of the instantaneous surface temperature [e.g. Kieffer et al., 1977; Mellon et al., 2000]. Inherent in the various methods employed for deriving thermal inertia from these observations is the assumption that the subsurface (the upper centimeters to meters) consists of homogeneous soil. Real surface soils are rarely homogeneous, exhibiting of structural and compositional layers or complex three dimensional clastic matrices. However, in the absence of *a priori* knowledge of the subsurface structure, the homogeneous assumption has been employed and an apparent thermal inertia derived.

In this work we examine the effects of layering in the martian subsurface on the diurnal and seasonal surface temperatures, and on the apparent thermal inertia as has been derived assuming homogeneity. By understanding the thermal signature of layered surfaces we can ultimately determine their distribution on Mars, improve our ability to interpret thermal inertia data, and better understand the structure of the martian surface and shallow subsurface.

Geologic settings for martian surfaces: We examine several example types of natural layering that may exist on Mars based on terrestrial analogs, or do occur on the surface of Mars based on landed observations [e.g., Mutch et al., 1977; Binder et al., 1977; Ward et al., 1999; Squyres et al., 2004a; 2004b]. Differences in composition or physical makeup of the different layers can result in large thermal inertia contrasts by nearly two orders of magnitude (see Table 1). These thermal inertia contrasts will result in distinct temperature and apparent thermal inertia behaviors.

Many areas of the surface of Mars are dominated by low thermal inertia dust. Lander observations have revealed that dust settling from the atmosphere is ubiquitous. Atmospheric dust coats solar panels and other spacecraft components. Dust has been observed to coat surface rocks, particularly on top of rocks, as well as coarser soils.

Ice rich permafrost is believed to be common at high latitudes on Mars in both hemispheres [Leighton and Murray 1966; Boynton et al. 2002]. Models of subsurface-ice stability have long suggested shallow ground ice will persist in the current martian climate beneath a veneer of dry, ice-free soil, perhaps as shallow as centimeters below the surface [Mellon et al., 2004]. Indeed, observations of neutron and gamma ray flux support this view of a layered permafrost with ice just centimeters below the surface in some locations. Ice-cemented soil exhibits a thermal inertia comparable to that of rock.

Duricrusts, weakly salt-cemented soils, are also observed at every landing site. These crusts are typically observed in shallow excavations, and exhibit a layered character with crusted soils overlying unconsolidated soils. A cemented layer in an otherwise homogeneous soil will exhibit dramatically different thermal properties, even if the cementing agent is low in abundance.

Desert pavements are another example of a layered surface material, where larger particles accumulate at the surface due to aeolian deflation (and frost heave in cold climates). Pavements are common in terrestrial polar and non-polar desert regions forming an armor of interlocking cobbles or layers of coarse soil grains over an otherwise fine grained soil matrix. Similar particle size sorting and layering has been observed at some landing sites [e.g. Arvidson et al., 2004].

These geologic settings provide examples of thermophysical characteristics of lower-thermal-inertia material overlaying higher-thermal-inertia material (dust coatings and permafrost layers), or conversely higher-thermal-inertia material over lower-thermal-inertia material (duricrust and desert pavement). In practice, a wide range of geologic configurations can be envisioned and represented by these examples.

Table 1. Layer Material Examples.

Martian Material	Thermal Inertia*
Dust	<75
Average soil	250
Rock	2000-3000
Ice-cemented soil	2290
Nominal Duricrust	1300

* Units of $J\ m^{-2}\ K^{-1}\ s^{-1/2}$.

Modeling layered surfaces: Previously, Jakosky [1979] and Ditteon [1982] considered the thermal behavior of layered surfaces on Mars, primarily to examine the cause of the afternoon cooling effect observed in Viking IRTM temperature observations. More recently Titus et al. [2006] extracted the layered thermal properties of high latitude permafrost in the areas of possible Phoenix landing sites. No comprehensive examination of layering for a wide range of geologic settings and the contrasting thermal signature have yet been conducted.

To investigate the thermal signature of a layered martian surface we employed a standard Mars thermal model similar to that used for years to predict surface and subsurface temperatures, derive thermal inertia from remotely sensed surface temperatures, and to examine the behavior of subsurface volatiles [Kieffer et al., 1977; Mellon and Jakosky, 1993]. This numerical model has been additionally adapted to account for a wide range of subsurface layer compositions and structures [Mellon et al., 2004].

The diurnal and seasonal surface temperature behavior of a layered martian surface differs from that of a homogeneous surface because of the relative balance and phase of heat conduction and storage in the different layers throughout the day. As an example, when low-thermal-inertia martial overlies high-thermal-inertia material, as in dust on rock, the upper layer insulates the lower layer from the extremes in surface temperature. Likewise the lower layer wicks heat away from the upper layer and stores it more effectively, thus shifting the peak daytime temperature to later in the afternoon and raising the nighttime temperature as stored heat is slowly returned to the surface.

Next we used a numerical interpolation algorithm to derive the apparent thermal inertia of an equivalent homogeneous-soil surface from the predicted surface temperatures of a layered soil. In doing so we find that the apparent thermal inertia varies slightly throughout the day and year. The signature of these variations differs from one another depending on the layering configuration and structure as a result of the phase delays in heat storage cause by the different thermal inertias of each layer.

Results: In general, layered surfaces show significant diurnal and seasonal variations in their apparent thermal inertia. While the apparent thermal inertia typically falls in between the minimum and maximum of the individual layers, short excursions outside this range can also occur due to the interplay between and phase lag of heat storage in the individual layers.

Surprisingly, very little dust is required to mask large rocks and bedrock. The diurnal temperature signature of bedrock is substantially affected by even a thin (few hundred micron) coating of dust and the rock is completely masked by about one diurnal skin depth of dust (a centimeter), see Figure 1. As little as a couple hundred microns of dust can reduce the apparent thermal inertia to half that of the underlying bedrock.

A substantial difference occurs in the seasonal behavior of low-thermal-inertia material overlying high-thermal-inertia material, relative to the reverse of this layering. This difference and others unique signatures can be quite valuable in distinguishing the nature of layers in the subsurface in actual thermal inertia derived from remotely sensed temperatures. Details of our analysis will be discussed.

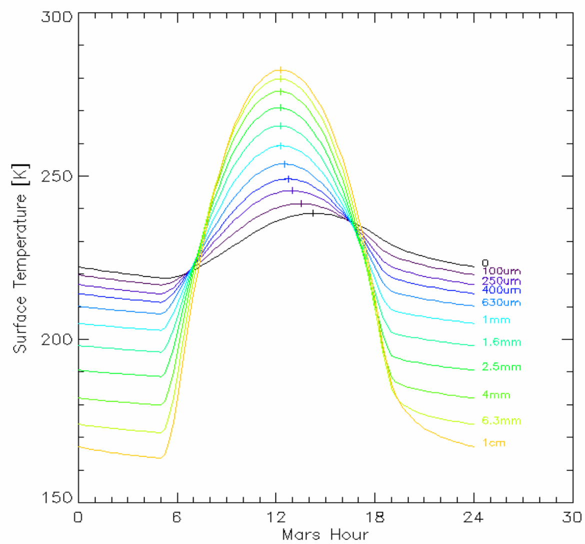

Figure 1. Diurnal temperature behavior for a rock surface (thermal inertia 2250) coated with a layer of dust (thermal inertia of 75). Dust coating depths are shown up to about 1 diurnal skin depth of dust.

References: Arvidson, R. E., et al., Science, 306, 1730-1733, 2004; Binder, A. B., et al., J. Geophys. Res. 82, 4439–4451, 1977; Boynton, W.V., et al., Science 297, 81–85, 2002; Ditteon, R., J. Geophys. Res. 87, 10,197–10,214, 1982; Jakosky, B. M., J. Geophys. Res. 84, 8252–8262, 1979; Kieffer, H. H., et al., J. Geophys. Res. 82, 4249–4291, 1977; Leighton, R. B., and B. C. Murray, Science 153, 136–144, 1966; Mellon, M. T. and B. M. Jakosky, J. Geophys. Res., 98, 3345-3364, 1993; Mellon, M. T, et al., Icarus, 169, 324-340, 2004; Mutch, T. A., et al., J. Geophys. Res. 82, 4452–4467, 1977; Squyres, S. W., et al., Science, 305, 794-799, 2004a; Squyres, S. W., et al., Science, 306, 1698-1703, 2004b; Titus, T. N., et al., 37th Lunar and Planet. Sci. Conf., Houston, 2006; Ward, A. W., et al., J. Geophys. Res. 104, 8555-8571, 1999.