THERMOPHYSICAL PROPERTIES OF THE MARTIAN SOUTH POLAR REGION. N. E. Putzig[1], M. T. Mellon[1], and R. E. Arvidson[2], [1]Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO 80309, [2]McDonnell Center for the Space Sciences, Department of Earth and Planetary Sciences, Washington University, St. Louis, MO 63130. E-mail contact: putzig@colorado.edu.

Introduction: Previous analysis of thermal inertia and albedo data from the Mars Global Surveyor (MGS) Thermal Emission Spectrometer (TES) delineated three major surface thermophysical units [1, 2, 3]. A fourth unit of low thermal inertia and low-to-intermediate albedo was found to dominate the region poleward of 65ºS [1]. We consider end-member geological explanations for this unit and conclude that reduced density in a relatively course-grained or indurated mantle is favored over theories invoking dark, unconsolidated dust. A mechanism for reducing bulk density by ablation of near-surface ground ice is suggested by results from the Mars Odyssey Neutron Spectrometer [4] and is supported by other theoretical [5] and TES spectral studies [6].

Background: Thermal inertia is the key surface property controlling diurnal temperature variations and is dependent on particle size, degree of induration, rock abundance, and exposure of bedrock within the top few centimeters of the subsurface (i.e., the thermal skin depth). It is a measure of the subsurface's ability to store heat during the day and to re-radiate it during the night. Thermal inertia is defined as the combination of bulk thermal conductivity k, bulk density ρ, and heat capacity C of the surface layer such that:

$$I \equiv \sqrt{k\rho C} \; . \qquad (1)$$

For granular materials under Mars surface conditions, k dominates and is driven by the conductivity of gas in pore spaces, but it also depends on ρ [5]. Thus, a large change in bulk density may effect a significant change in thermal inertia.

In general, unconsolidated fines (i.e., dust) will have low values of thermal inertia, indurated dust (duricrust) and sand-sized particles will have intermediate values, and rocks and exposed bedrock will have high values. In the context of MGS observations, the thermal inertia of any given location on the Martian surface is generally controlled by a variable mixture of such materials on the scale of the TES observations (approximately 3 x 6 km). By considering thermal inertia together with other observed surface properties, one can gain insight into the physical characteristics of the surface and the geological processes which have affected it.

Methodology: We used global maps of thermal inertia and albedo from [2], MOLA elevation, MOC images, and Viking MDIM 2.0 and color data in our analysis. The thermal inertia map was derived from nighttime (approximately 2 AM local time) thermal bolometer observations of surface temperature gathered during TES orbits 1583-11254, covering over one Mars year (L_s 103º to 360º + 0º to 152º) [2,3]. The mapping process employed filters to eliminate observations from periods of high water-ice-cloud and atmospheric-dust opacity and completely excludes orbits 4199-5410, due to the 1999 global dust storms. Map overlays and two-dimensional histograms between the various datasets were used to delineate areas with common features and to assign mapping units.

Thermophysical Unit Definition: Previous analyses [2, 3] of MGS-TES derived thermal inertia identified three regions of distinct albedo and thermal inertia. These have been interpreted as surfaces dominated by (A) unconsolidated fines; (B) courser-grained sediments, rocks, bedrock exposures, and some duricrust; and (C) duricrust with some rocks and/or bedrock exposures. In Figure 1, we show unit boundaries revised from those defined in [1], wherein the thermal inertia-albedo parameter space was further subdivided into regions of (D) low thermal inertia and low-to-intermediate albedo; (E) very low albedo; (F) very high thermal inertia; and (G) very high albedo.

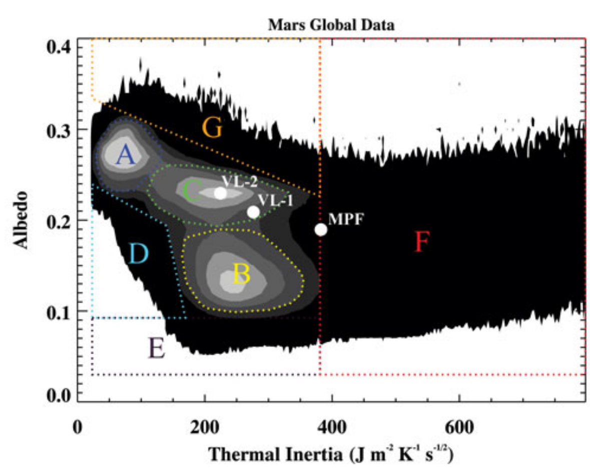

Figure 1: Global correlation between thermal inertia and albedo. Unit letters correspond to those in Figure 2.

Figure 2 provides an orthographic map of these units centered on the South Pole, showing their areal distribution in the southern hemisphere. Unit D (light blue) exhibits distinct low-thermal-inertia boundaries (compare Figure 3), making it unique from surrounding

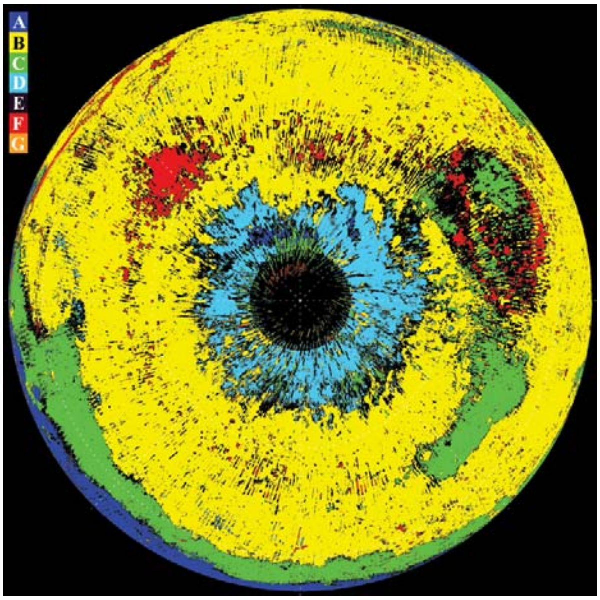

Figure 2: Thermal inertia-albedo unit map of the southern hemisphere of Mars (filled from equator to 80ºS). Unit letters correspond to those in Figure 1.

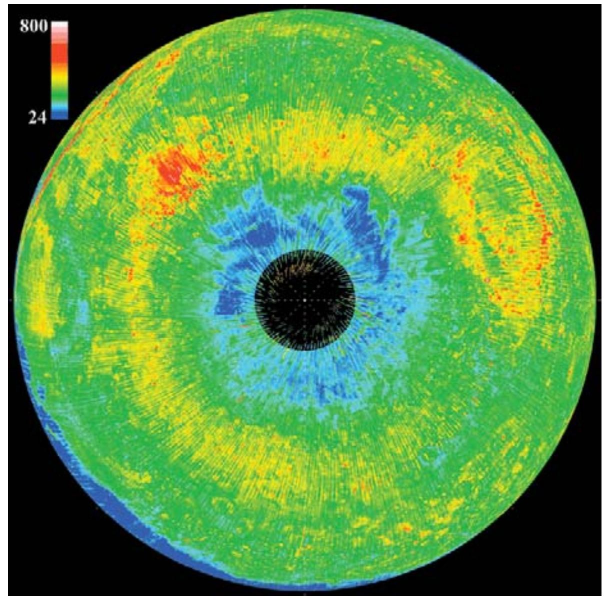

Figure 3: Thermal inertia map of the southern hemisphere of Mars (filled from equator to 80S). After Mellon et al (2002). Compare polar low thermal inertia region to Unit D in Figure 2.

higher thermal inertia Units B (yellow) and C (green). Unit D dominates the region south of about 65ºS.

End-member Hypotheses: The low thermal inertia values of Unit D, which are similar to those of Unit A, are normally considered to be indicative of fine-grained, unconsolidated materials. However, the albedo of Unit D, which is comparable to that of Unit B, is much lower than that of Unit A. These observations lead to two end-member scenarios. The first involves a reduction in thermal inertia in a material that is otherwise similar to that in Unit B, which can be achieved by lowering bulk conductivity. The second involves a reduction of albedo in a material that is otherwise similar to that in Unit A, either through a compositional difference or a darker coating on individual grains.

Thermal Inertia Reduction: Unit D may represent a surface of either indurated fines or courser grained materials in which the bulk thermal conductivity has been lowered. Laboratory data (Figure 4) show a linear dependence of thermal conductivity on density with a slope of about 0.0225 W m^2 kg^{-1} K^{-1} [5]. Using Equation (1) and assuming a constant heat capacity, we calculate that the observed 2-fold reduction in thermal inertia from Unit B to Unit D would require about a 2.5-fold reduction in density. Recent estimates of ground ice in the top meter of the Martian surface based on data from the Mars Odyssey Neutron Spectrometer [4] predict ice content up to 75% by volume in the polar regions. In the upper few centimeters (the TES sensing depth), ice is seasonally unstable and is expected to ablate. It is conceivable that such an ablation zone may produce a near surface with greatly expanded pore volume and reduced bulk density.

A regional analysis of thermal inertia-albedo correlation provides additional support for this thermal inertia reduction scenario. We generated a series of a 2D histogram of thermal inertia and albedo restricted to various southern latitudes, and found a single broad peak spanning the region between Units B and D (see Figure 5). This peak migrates from Unit B to Unit D with increasing southerly restriction of latitudes. Additionally, we examined MOC images from each Unit as well as some which extend across the Unit boundary and found a mantled appearance in both regions. Images over Unit D showed more polygonal and cracked surfaces, whereas those over Unit B were generally smoother. However, we have found no abrupt morphological changes over the Unit boundaries. Taken together, these results suggest that the two units may be compositionally related.

Albedo Reduction: Alternatively, Unit D may represent a surface of fine-grained, unconsolidated materials of a composition which is either distinct from that in Unit A (implying a distinct source material for dust), or the same as that in Unit A but altered by a darkening process. In the first case, the darker material might be either a layer which is thermally thin (but optically thick; ~few µm) overlying a bright dust similar to that in Unit A, or a thicker dark layer with similar thermal properties to that in Unit A. In the second

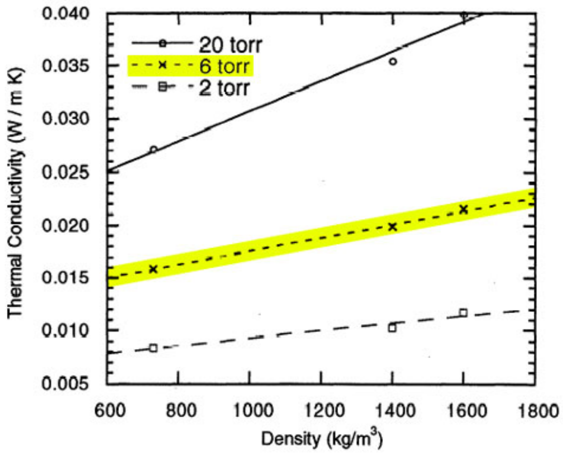

Figure 4: Thermal conductivity versus bulk density for 25-30 µm particles at three atmospheric pressures. That corresponding to Mars surface conditions is highlighted. From Presley and Christensen [5].

case, the individual grains of an initially bright dust may be coated by a darker material (presumably by some chemical process which is restricted to the south polar zone).

A major problem with these dark dust theories is the fact that global dust storms on Mars are expect to homogenize unconsolidated fines over years to decades [7]. It is therefore difficult to maintain a large region covered with a darker dust over extended periods. However, Viking results [8] show a similar pattern of low thermal inertia in this region, so it is unlikely that this is a transient phenomenon. Also, a dust cover index map [6] produced from TES spectra indicates that there is little or no unconsolidated dust in the region shown as Unit D in Figure 2.

Summary: We have identified an unsual region of low thermal inertia and low albedo which dominates the south polar region of Mars. While its thermal inertia is consistent with lower resolution data from Viking [8], this region differs from the classic low thermal inertia regions at mid-latitudes in that the latter are characterize by high albedo. We considered hypotheses to explain this observation, involving either a reduction of thermal inertia in Unit B material or a reduction of albedo in Unit A material. Several independent lines of evidence support a reduction in thermal inertia obtained by a reduction in bulk density, whereas albedo reduction theories encounter problems with the homogenization of fines expected to occur due to global dust storms.

The density reduction theory favored here fails to explains the lack of a similar phenomenon in the north polar region. The latest Odyssey neutron data [9]

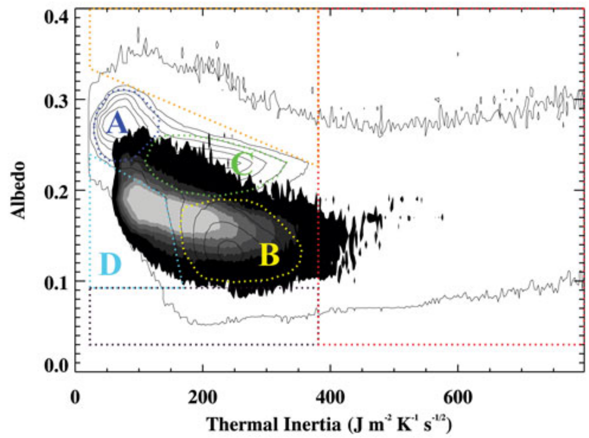

Figure 5: Correlation between thermal inertia and albedo for the globe (unfilled contours) and 60ºS to 80ºS (filled contours). Unit letters as in Figures 1 and 2.

show even more extensive ground ice in the north than in the south, so one might expect a similar process to occur there. While the current thermal inertia map actually shows a zone of high thermal inertia at most longitudes northward of 70ºN, this is not in keeping with Viking results [10], and these high values are believed to be caused by a model or observational artifact and not reflective of the actual surface [2]. Nevertheless, we see no indication of a regional reduction of thermal inertia in the north in those regions where the data appear to be more reliable. Further effort to correct this problem and to fully characterize the north polar region may help resolve this issue.

The concepts discussed here represent end-members and it is possible that the true cause of this phenomenon may have multiple sources. Furthermore, intermediate explanations are not currently distinguishable. For example, smaller reductions in both albedo and thermal inertia in Unit C material might serve to produce all or part of the results observed in Unit D.

References: [1] Putzig *et al* (2003) *LPSC XXXIV.* [2] Mellon *et al* (2002) *LPSC XXXIII*. [3] Mellon *et al* (2000) *Icarus* 148. [4] Boynton *et al* (2002) *Science* 297. [5] Presley & Christensen (1997) *JGR* 102 E4. [6] Ruff & Christensen (2002) *JGR* 107 E12. [7] Kahn *et al* (1992) in *Mars*, Kieffer et al, eds., U. of Az. [8] Paige & Keegan (1994) *JGR* 99 E12. [9] Boynton (2003) Verdanasky-Brown Microsymposium 37. [10] Paige *et al* (1994) *JGR* 99 E12.