IMPACT OF LOW THERMAL CONDUCTIVITY LAYERS ON THE BULK CONDUCTIVITY OF A MARTIAN CRUSTAL COLUMN. M. L. Urquhart, William B. Hanson Center for Space Sciences, University of Texas at Dallas (Mail Station FN 33, P.O. Box 830688, Richardson, TX 75083-0688, urquhart@utdallas.edu).

Introduction: Estimates of the thermal conductivity of the Martian crust are important in theoretical calculations of the depth to melting of the Martian cryosphere. The thermal conductivity of real layers in the subsurface is not well constrained. Thermal modelers typically use 1-d models, and treat the crust as a single homogeneous layer. Variation in thermal conductivity with depth is generally treated through the adoption of a column-averaged value. Choosing an average thermal conductivity for the crust of Mars may be too simple an approach to make accurate predictions on the depth to melting for water ice, especially if low thermal conductivity layers are present.

The effect of a low thermal conductivity layer on the thermal gradient and depth to melting was demonstrated by Mellon and Phillips in the context of a possible explanation for young gulley landforms on Mars [1]. The implications of low thermal conductivity layers on theoretical calculations of the depth to melting for water ice on Mars were also briefly discussed in Urquhart and Gulick [2]. Here we show why the consideration of the presence of low conductivity layers is important in calculations of the potential depth of a Martian water table.

Thermal Conductivity and the Geothermal Gradient: Geothermal gradients resulting from geothermal heating are calculated using Fourier's law of heat conduction,

$$\frac{\partial T}{\partial z} = \frac{-Q}{k} \qquad (1)$$

where T is the subsurface temperature at depth d, Q is the geothermal heat flow out of the Martian interior and k is the thermal conductivity. Equation 1 assumes a homogenous layer of crustal material in terms of thermal conductivity. For the crust of Mars, like that of the Earth, vertical homogeneity is certainly more realistic than a single idealized homogenous layer. The usual way modelers have approached this problem in the past (including the author) is through the adoption of a value for the thermal conductivity of the Martian crust that is consistent with basaltic rock and ice cemented soil of 2.0 W/m-K to 2.8 W/m-K [2,3,4], with 2.0 W/m-K. In this case, Equation 1 becomes:

$$\frac{\partial T}{\partial z} = \frac{-Q}{k_{ca}} \qquad (2)$$

where k_{ca} is column averaged thermal conductivity. This approach works reasonably well for a series of layers with similar thermal conductivities, but not when low thermal conductivity layers are present. If the variation in thermal conductivity is known or can be approximated using a simple function then Equation 1 integrates as:

$$T = Ts\int_{o}^{z} \frac{-Q}{k(z)}dz \qquad (3)$$

where T is the temperature at a given depth, Ts is the average surface temperature. Equation 3 is useful in the case of thermal conductivity variation due to compaction with depth, for example. In many cases, however, a simple function may not be appropriate. Another approach is to treat the subsurface as a series of homogenous layers of varying thermal conductivity and calculate the effective thermal conductivity of the crustal column based on the values of individual layers. The thermal gradient for each layer may then be treated independently, or a column averaged thermal conductivity may be used.

Impact on the Thermal Gradient of Adding Thermal Conductors in Series: For a series of homogeneous layers, each with different layers of thermal conductivity, the bulk thermal conductivity will differ from the average value. Each of these conductors is acting in series. In a manner analogous to an electrical conductivities, the total thermal conductivity of these layers, k_{total} add as:

$$\frac{1}{k_{total}} = \left(\frac{1}{k_1} + \frac{1}{k_2} + \frac{1}{k_3} + \ldots \frac{1}{k_n}\right) \qquad (4)$$

As layers (thermal resistors) are added, k_{total} increases. In the calculation of a column averaged value to be included in Equation 2, the thickness of each layer must also be taken into consideration. Using Equation 4, it is clear the lowest thermal conductivity layers will dominate the total conductance of a crustal column. Just as in an electrical series circuit, if one high resistance (low conductivity) component is present, the total resistance will be significantly raised. When variation over individual layers is considered over the column in the calculation of column averaged thermal conductivity, the low thermal conductivity layers will also tend to dominate.

The possible values for the thermal conductivity of typical crustal materials in the thin Martian atmosphere varies over two orders of magnitude [5], with dry dust and soil on one end of the scale and ice-cemented soil and solid rock on the other. Mellon and Phillips used a value for a 100 m thick dry soil layer of 0.045 W/m-K [1], which is consistent with laboratory measurements of thermal conductivity of particulate materials made under Martian conditions [5]. Let us assume that such a layer is present in a column of crust 1 km m thick, with the remainder of layers having a thermal conductivity equal to a typically adopted value of 2.0 W/m-K. If we were to simply average the thermal conductivity over the length of the column, the value would be $k_{ca} = 1.8$ W/m-K. However, if we treat our layers as conductors in series, $k_{ca} = 0.37$ W/m-K. If the low thermal conductivity layer is thinned to a mere 10 m (1/100th of the total column thickness), the effective thermal conductivity for 1 km column is still significantly affected, with $k_{ca} = 1.4$ W/m-K.

Of course, layers of dense rock or saturated ice-cemented soils are also likely to be present in the subsurface. However, these layers will have less of an impact on k_{ca} than will their high k counter parts. Adding a layer of k = 2.8 W/m-K yields has no noticeable impact when the layer represents 1/100th of the column thickness, and only raises k_{ca} by a mere 0.06 W/m-K for a layer 1/10th of the column thickness. Including both high and low thermal conductivity layers, each equal to 1/10th of the total column thickness, raises k_{ca} by less than 0.01 W/m-k over the case with only the low thermal conductivity layer.

The impact of low thermal conductivity layers can be seen in Figure 1. Here a moderate heat flow value of Q = 30 mW/m^2 and a surface temperature of 200 K are used for the purposes of illustrating the effect of different values of thermal conductivity on the depth to melting. (The vertical dotted line marks a temperature of 273 K.) As can be seen in Equation 1, higher thermal conductivities result in lower thermal gradients.

Discussion: When low thermal conductivity layers are present in a crustal column, they can easily dominate the column averaged thermal conductivity and the resulting column averaged thermal gradient. The model presented here is itself an extremely simplistic 1-d approach, and is intended only to illustrate the dramatic effect low thermal conductivity layers can have on subsurface temperatures. Low thermal conductivity layers can be expected to occur at the surface in equatorial low latitude regions. In such cases, these layers will also affect the upper thermal boundary condition. Here we have considered only the impact of variation in thermal conductivity with depth on the column averaged thermal conductivity and the thermal gradient assuming a fixed surface temperature.

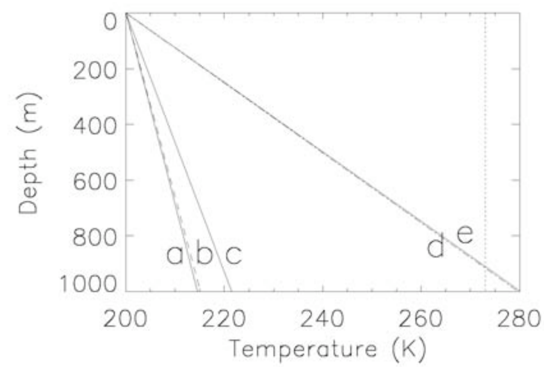

Figure 1: *A comparison of the depth to melting at the equator for values of column averaged thermal conductivity. The dashed line b represents the thermal gradient for a typically adopted value of 2.0 W/m-K. Line a represents a slightly higher value for k_{ca} when a 100m layer of k = 2.8 W/m-K is included. Line c is for the case where a very thin (10 m) low k layer is present, resulting in k_{ca} = 1.4 W/m-K. Line e represents the thermal gradient when a 100 m thick layer of k = 0.045 W/m-K resulting in k_{ca} = 0.37 W/m-K, and is almost indistinguishable from line d, which includes both high and low thermal conductivity layers.*

References [1] Mellon M. T. and Phillips R. J. (2001) *JGR, 106,* 23165-23179. [2] Urquhart M. L. and Gulick V. C. (2003) *GRL. 30*. CiteID 1622. [3] Clifford (1993) *JGR, 98,* 10973-11016. [4] Schubert *et al*., (1992) in *Mars*. [5] Presley, M. A. and P. R. Christensen (1997), *JGR, 92*, 6551-6566.

Acknowledgements: The author thanks Michael Mellon for his helpful discussions, suggestions and his critical review of a past paper that inspired this work.