A PHYSICAL MODEL FOR THE DEPTH PROFILE OF THERMAL CONDUCTIVITY IN THE MEGAREGOLITH OF AIRLESS BODIES: IMPLICATIONS FOR INTERIOR THERMAL STRUCTURE AND EVOLUTION.

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A key determinant for the interior structure and thermal evolution of planetary bodies is the thermal conductivity, $k_{th}(z)$, of the "megaregolith" (porous outer layer of accumulated ejecta and impact-fractured material [1, 2]. Most studies of planetary interiors or topographic relaxation rates assume a thermal conductivity appropriate for solid rock or ice applies all the way up to the surface, whereas the surface thermal inertia values measured for most satellites and asteroids indicate a conductivity 10^3-10^4 less.

We know from remote measurements of thermal inertia on icy satellites that the surface value of k_{th} is very low, typically 0.001 Wm^{-1}K^{-1} [e.g. 3,4]. And from studies of lunar regolith we know k_{th} can be 10 times greater just a few cm deeper due to a decrease in porosity from 60-70% at the surface to typical values (30-40%) for random close-packed particles [5]. But 0.01 Wm^{-1}K^{-1} is still less than 1% of the conductivity of solid ice, and any further increase due to compaction may require lithostatic pressure >1 MPa [6,7].

The main obstacle to better estimates of megaregolith thermal effects is the paucity of information about its structure and composition. But one mitigating feature of cold airless regolith is that k_{th} is largely independent of particle size at any depth where mechanical forces dominate van der Waals forces, *i.e.* for z>10m on Callisto [W14a]. The size dependence of k_{th} for regolith on the Moon and Mars is due to the radiative and/or gas components of conduction, but these are negligible in the upper 10 km of most outer solar system bodies. The thickness of megaregolith is another important unknown, with estimates ranging from 100m to 10km [2,8,9]. But we note that even a 100m-thick layer can create a significant ΔT (**Fig. 1 and Fig. 2**).

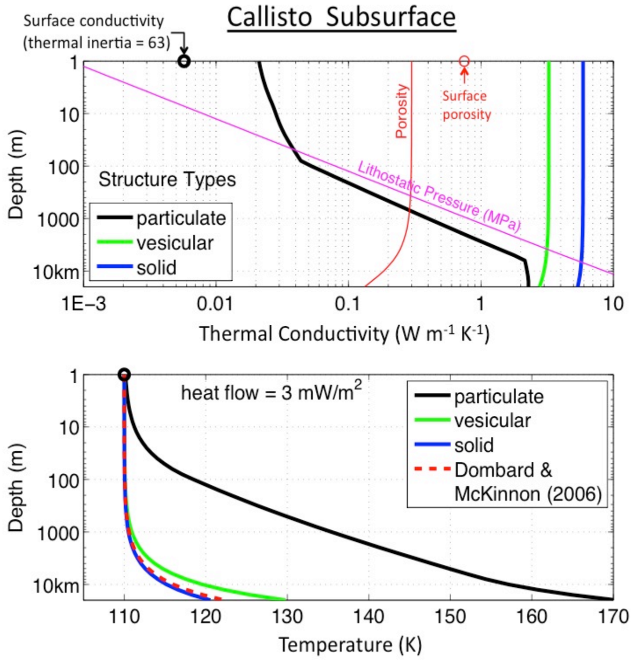

Figure 1 – Example model calculations for Callisto.

(Top) Model-calculated profiles of thermal conductivity, $k_{th}(z)$, in the upper 10 km using the MaxRTC Model [Wood, 2013, W13] for cases representing the wide range of possible physical structures: a nonporous solid (*blue line),* a vesicular solid – *i.e.* isolated pores – (*green line*), and uncemented particles – *i.e.* nearly isolated particles (*black line)*. Both the particulate and vesicular cases use the same porosity profile, $\Phi(z)$ (*red line*), illustrating that the continuity of the solid material is much more important than its porosity [10]. All cases include a T-dependent solid conductivity.

Calculated surface conductivity is 0.006 W/m/K for a 20 μm particles and Φ=60% (surface values are indicated by circles on the top axis), yielding a thermal inertia of 63 J m^{-2} s$^{-1/2}$ K^{-1} – in line with observed values [3]. Particle size increases linearly with depth, but results are not sensitive to this assumption (see text). We assume Φ=30% at z=1m and calculate the decrease with depth based on data for hydrostatic compaction of granular ice [6,15].

(Bottom) Temperature profiles corresponding to the conductivity profiles above for a heat flow of 3 mW/m^2 [11] and an average surface temperature of 110 K. For comparison, a profile used to model crater topography relaxation [12] is also shown (*dashed red line*).

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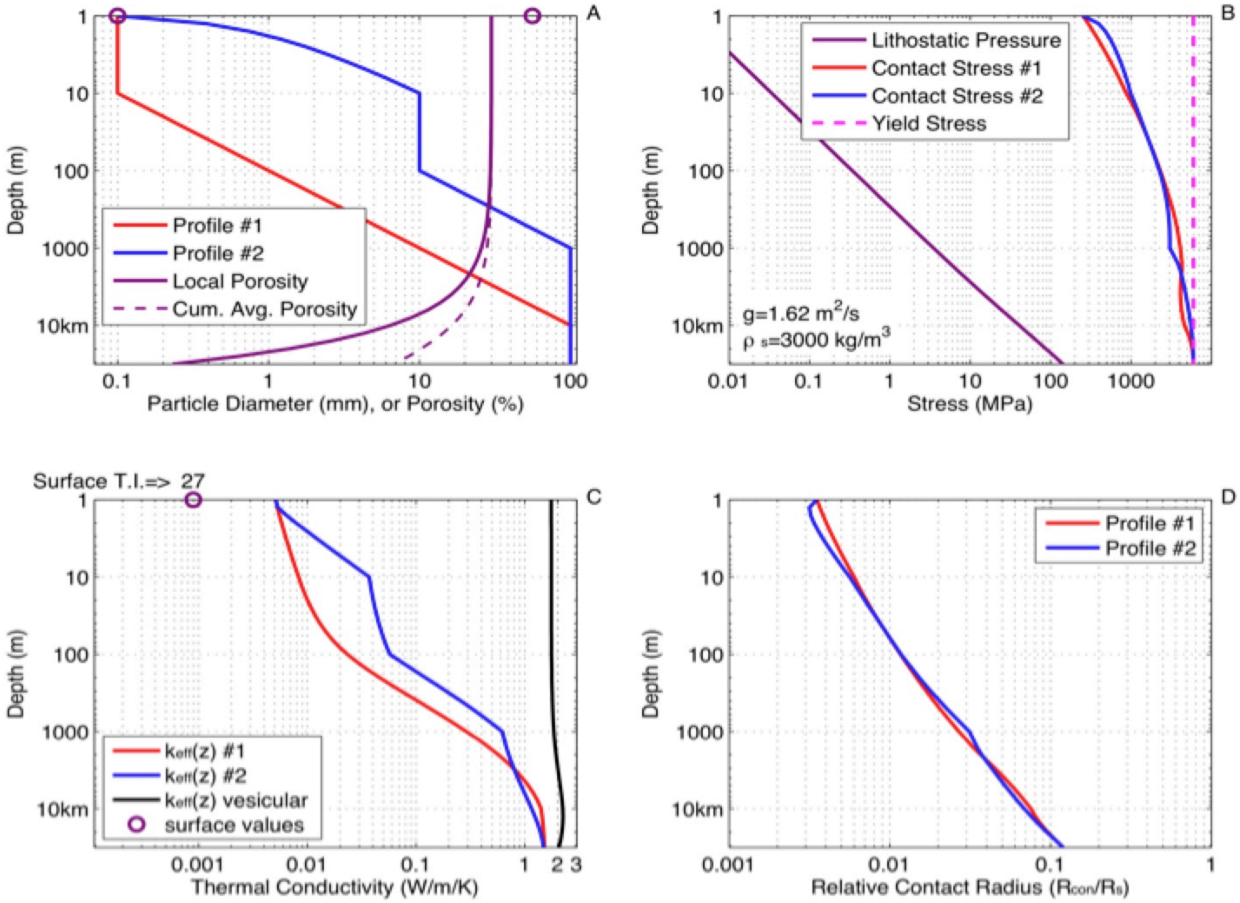
[W14] Wood, S.E. (2014), in prep. [15] Holsapple, K. A. and K. R. Housen, *personal communication*. [16] Wieczorek *et al*. (2013), *Science 339*, 671. [17] Vasavada *et al*. (2012), *JGR 117*, E00H18

Lunar Subsurface



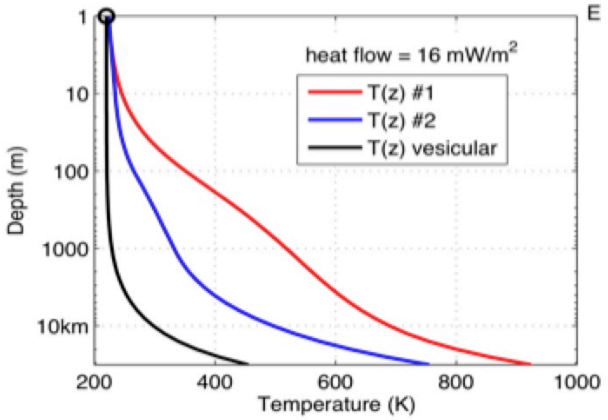


Fig. 2. Left & Above: MaxRTC model calculations of $k_{th}(z)$ (*plot C*) and T(z) (*plot E*) for assumed profiles of particle size and porosity (*plot A*) and using material properties of basalt. Porosity is consistent with recent GRAIL results [16]. Black lines in plots C and E are for vesicular basalt with the same porosity as the particulate cases (#1 and #2), but assuming a continuous solid (f_{sc}=1). Surface k_{th} and thermal inertia ("T.I.") are calculated using the same model but with higher porosity (56%) for uppermost 2 cm; these values are consistent with LRO Diviner observations [17]