MARS SUBSURFACE WARMING DUE TO ATMOSPHERIC COLLAPSE AT LOW OBLIQUITY. Stephen E. Wood[1] and Stephen D. Griffiths[2], [1]Dept. of Earth and Space Sciences, Univ. of Washington, Box 351310, Seattle, WA, 98195-1310, sewood@ess.washington.edu, [2]Dept. of Applied Mathematics, Univ. of Leeds, Leeds, LS2 9JT, UK.

Introduction: We present a modeling study of a mechanism that has not previously been considered but is likely to have generated significant subsurface warming during the periodic intervals when Mars' obliquity was lower than 25°. Orbital dynamics calculations show that Mars' obliquity, which is currently 25°, oscillates between 10° and 45° - with a dominant periodicity of ~120,000 years and a modulation period of ~1.3 million years - due to long-term perturbations by the other planets [1]. The present Martian atmosphere is 95% CO_2 with a mean surface pressure of 700 Pa, but model calculations [2] show that it could drop to as low as 30 Pa at low obliquity because the global surface pressure would be controlled by the annual-average temperature of the perennial CO_2 ice at the poles [3]. At such low pressures, the thermal conductivity (k_{th}) of a porous regolith can be significantly reduced as the mean free path of gas molecules approaches the size of pore spaces [4]. This drop in k_{th} leads to an increase in subsurface temperatures as the upwelling planetary heat flux (q_p) becomes effectively trapped beneath an insulating upper layer. Our modeling shows that for an estimated present-day value of q_p = 30 mW/m^2 [5] the magnitude of the warming can exceed 40 K at latitudes and depths where ground ice may still be present. This effect provides a potential mechanism to periodically generate warm, wet conditions throughout Martian history, including several times within the past 1 Myr. It might also help explain some of the recent geomorphological features attributed to liquid water or flowing ice.

Modeling. We have implemented a 1-D finite-difference thermal model for the time evolution of Mars' subsurface temperatures over the past 10 Myr to study the effects of varying obliquity and atmospheric pressure. Results for one simulation at 40 N latitude are shown in **Fig. 1** and **Fig. 2A**. At this latitude, near-surface ground ice is not expected to be thermally stable [6], and is not observed in MGS GRS data [7]. However, studies of the onset diameter of rampart craters as a function of latitude suggest an ice rich layer may be present at depths of ~100 m [8]. The subsurface structure in this case was assumed to consist of a 40m-thick layer of fine sand over a coarser-grained, partially consolidated "breccia" layer extending to a depth of 2 km, and below that a non-porous "bedrock"

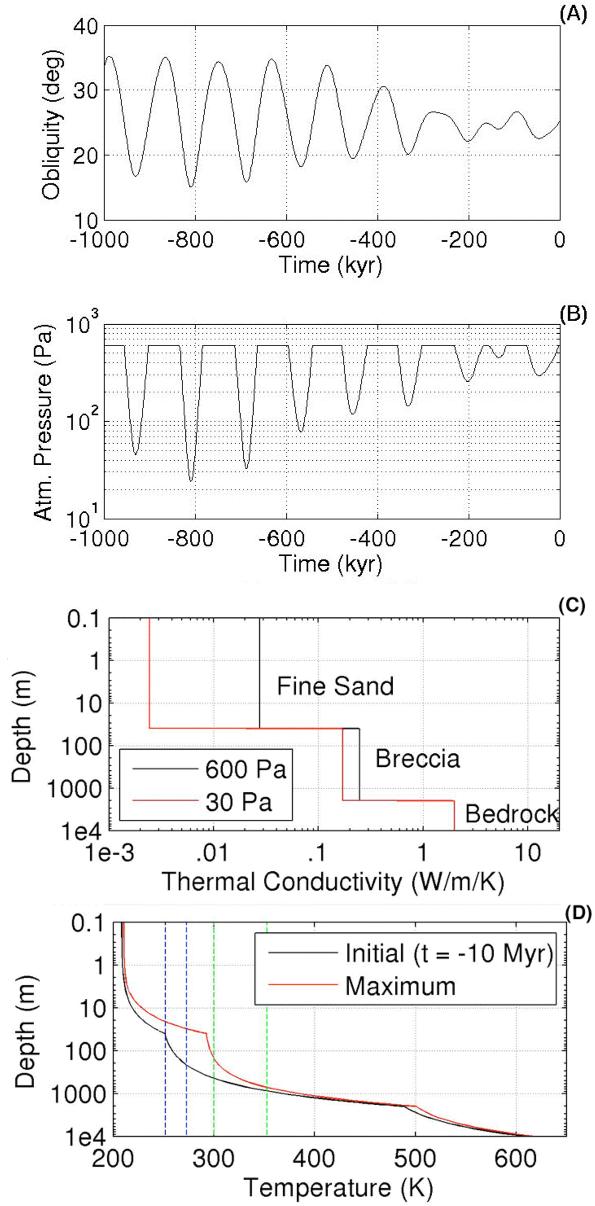

Figure 1. **(A)** Variation in the tilt angle of Mars' spin axis (obliquity) over the past million years [1]. **(B)** Variation in Mars atmospheric surface pressure due to the formation of perennial CO_2 ice polar deposits during periods of low obliquity [2]. **(C)** Subsurface profiles of thermal conductivity at present-day atmospheric pressure (black line) and at low pressure (red line). **(D)** Initial model temperature profile (at 10 Myr before present) along with the maximum temperature reached at each depth over a 10 Myr run.

down to 10 km. The thermal properties of the model breccia layer may also be representative of icy regolith.

Following atmospheric collapse, the thermal conductivity of the sand layer drops by a factor of 10 in less than a year, but the temperature gradient away from the interface responds much more slowly, so the heat flux through this layer quickly decreases to 3 mW/m^2. In the breccia layer below, k_{th} only decreases by 30% so the heat flux there drops to 20 mW/m^2. This creates a flux divergence of 17 mW/m^2 at the sand-breccia interface which causes temperatures there to start increasing. The warming continues throughout the 30 kyr period of low atmospheric pressures.

For a given heat flow and duration of atmospheric collapse, the magnitude of the warming depends on thickness and thermal properties of regolith layers. A second major influence is the thickness of each layer-relative to its 30 kyr thermal skin depth, z_{30}. In the case described above, the thickness of the fine sand layer was close its z_{30} value of 38 m. Increasing its thickness to 100m produces a slightly greater warming, but increasing it further has little effect. Figure 2B illustrates another important case (also at 40 N) in which there are multiple layers of low conductivity material; and shows that as long as the intervening layers are thin relative to their z_{30}, then the cumulative warming effect is comparable to that of a single layer with an equivalent thickness (compare to Fig. 2A). Figure 2C shows model-calculated profiles of the maximum temperature changes at different latitudes for the case of a 100 m layer of coarse sand over breccia. The near-surface temperature changes reflect the variations in annual average insolation due to the obliquity variations, but note that the maximum subsurface warming is largely independent of latitude.

Table 1

	Particle Diameter μm	$p_{surf} = 30$ Pa: k_{th} ($Wm^{-1}K^{-1}$)	$p_{surf} = 30$ Pa: Thermal Skin Depth (30 kyr) (m)	$p_{surf} = 600$ Pa: k_{th} ($Wm^{-1}K^{-1}$)	$p_{surf} = 600$ Pa: Thermal Inertia ($Jm^{-2}s^{-1/2}K^{-1}$)
dust	3	7.2 E-4	29	2.8 E-3	47
fine sand	100	2.4 E-3	38	2.8 E-2	212
coarse sand	500	8.6 E-3	71	4.6 E-2	274
breccia	1 E4	0.17	264	0.25	754
bedrock	-	2.00	836	2.00	2323

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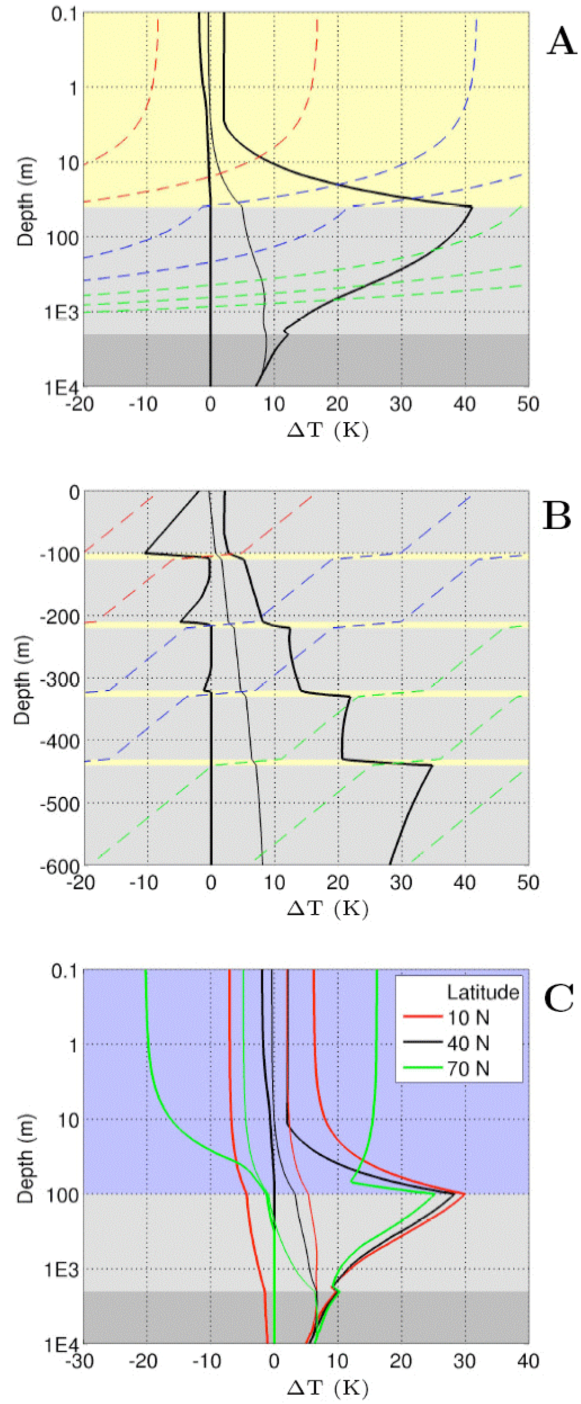

Figure 2. Thick solid lines indicate the model-calculated maximum temperature deviations (relative to the initial temperature profile) over the past 10 Myr for various assumptions regarding the composition and thickness of subsurface layers. The color of each layer corresponds to those listed in **Table 1**. Thin solid lines indicate the temperature profile at the end of 10 million years (present day). In **2A** and **2B**, the dashed red lines indicate the 200K and 225K isotherms; the dashed blue lines indicate 250K and 273K isotherms (the range of liquid brine formation); and the dashed green lines indicate the 300K, 325K, and 350K isotherms (range of sulfate dehydration).