Ice Lens Formation and Implications for Habitability of the Phoenix Landing Site

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Is This Segregated Ground Ice ?

Nearly pure (99-98%) ice was excavated in the Dodo/Goldilocks trench by Phoenix.

Excess ice cannot be cold trapped from the atmosphere. It implies either precipitation, or *in situ* segregation.

Least unlikely is formation by *in situ* segregation, (Mellon *et al.*, 2009).

In situ segregation occurs via the same thin films of unfrozen H_2O that psychrophiles depend upon.

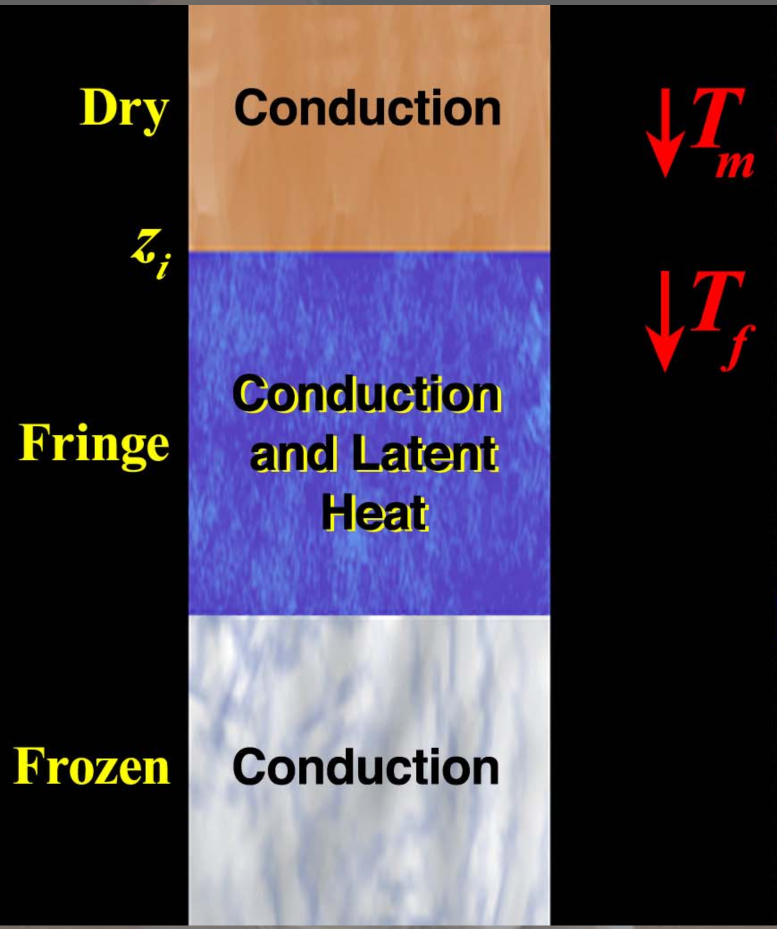
Could ice lenses form at the Phoenix site? What might be the implications for habitability?

Approach:
Premelting physics soil model

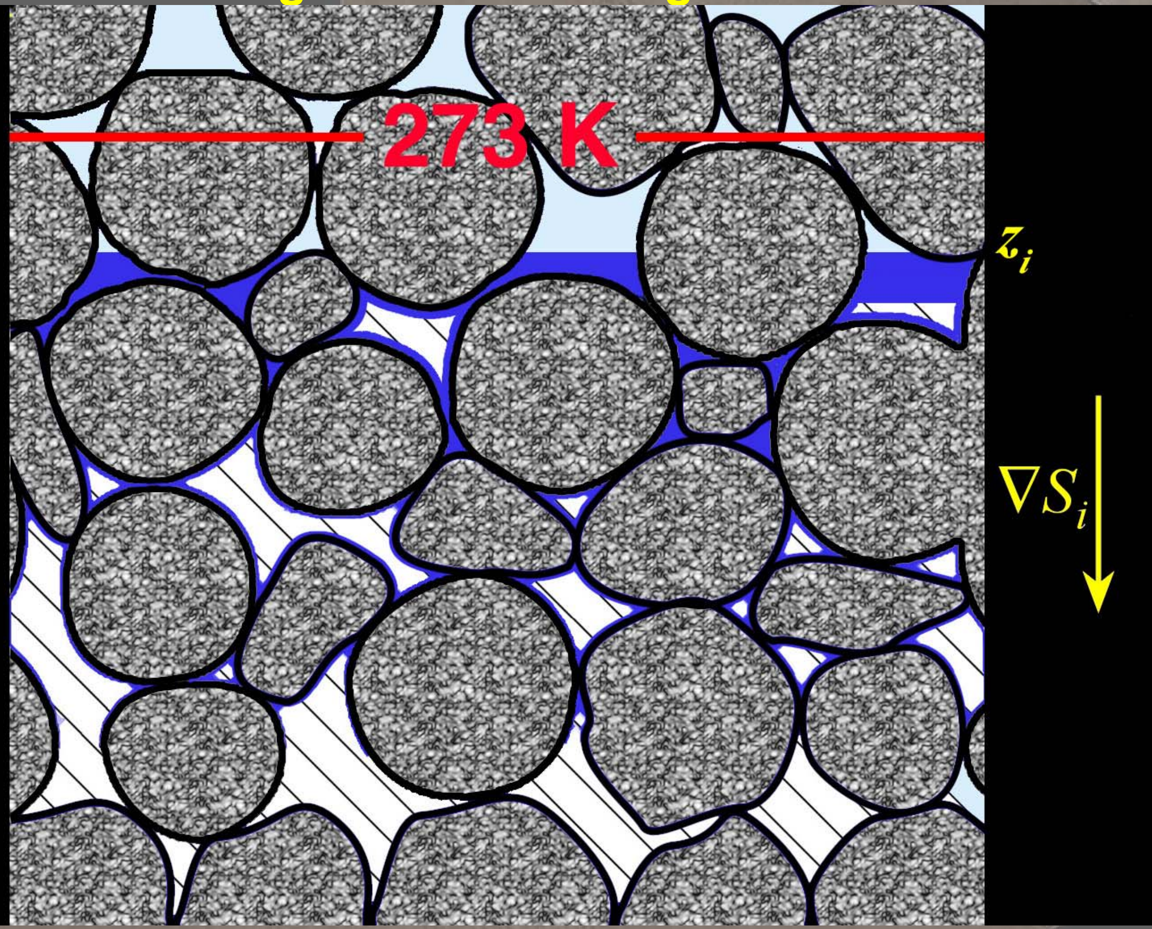
Address:
Unfrozen Water abundance
Warming and Cooling Rates
Frequency and Duration

Model – T_s – $H_2O_{s,\ell}$ - F_x

Model Column



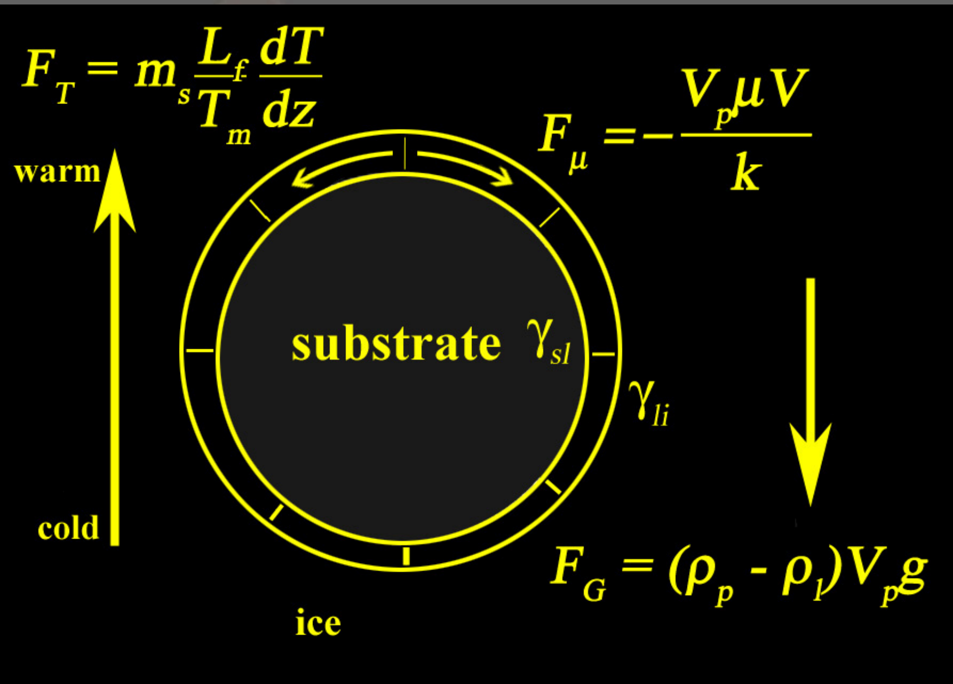
Warming front advancing into soil



Model provided with z_i and $T_0(t)$

The warmest temperature at which ice can exist is T_f < 273K; the pore fraction filled with ice is $S_i(T)$; both are fixed by the soil.

Frost Heave & Ice Lenses



F_T -Thermomolecular Force

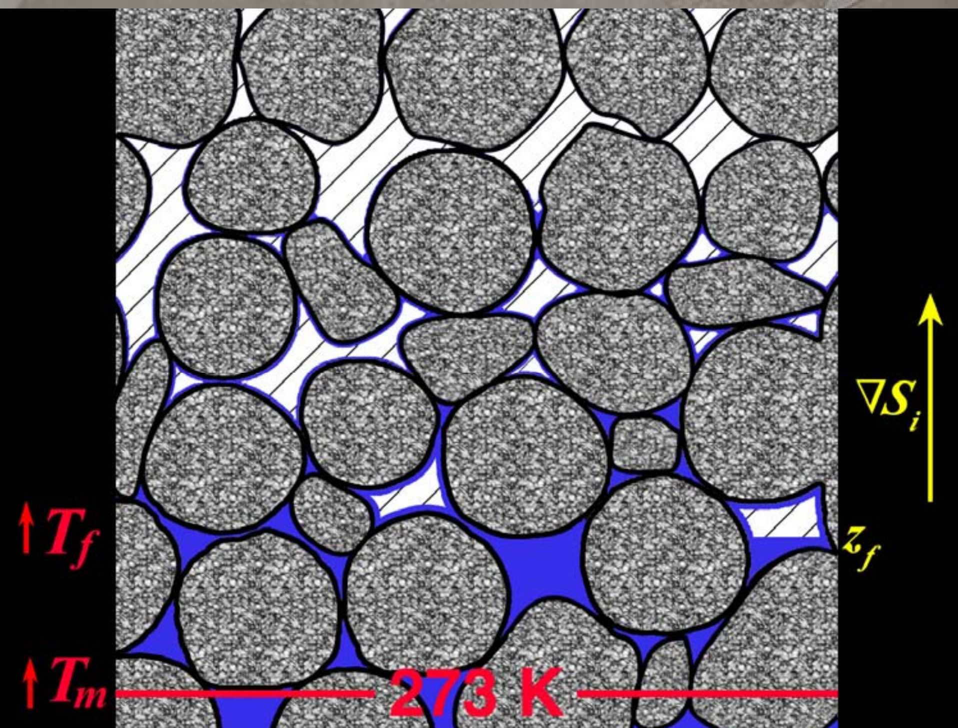
Films minimize interfacial free energy
Proportional to mass of displaced ice
Stronger for thinner films

F_μ -Viscous Force

Resistance to flow in films

F_G -Gravitational Force

Includes buoyancy



$$\frac{\partial p_p}{\partial z} = -(1-\phi)(\rho_p - \rho)g - \rho L_f \frac{T_m - T}{T_m} \frac{\partial(\phi S_i)}{\partial z}$$

In freezing soil, F_T and F_G are balanced by forces transmitted between particles.

Integrate inter-particle pressure (P_p) from surface to z_f. If $P_p(z) < 0$, grains unload, and lens can initiate

Complete melting is not required; process can work at $T < T_f < T_m$

Defining the Soil

Soils are defined by four parameters, all of which can be measured on terrestrial analogs

T_m-T_f: Freezing point depression; $\theta = (T_m - T)/(T_m - T_f)$: Undercooling

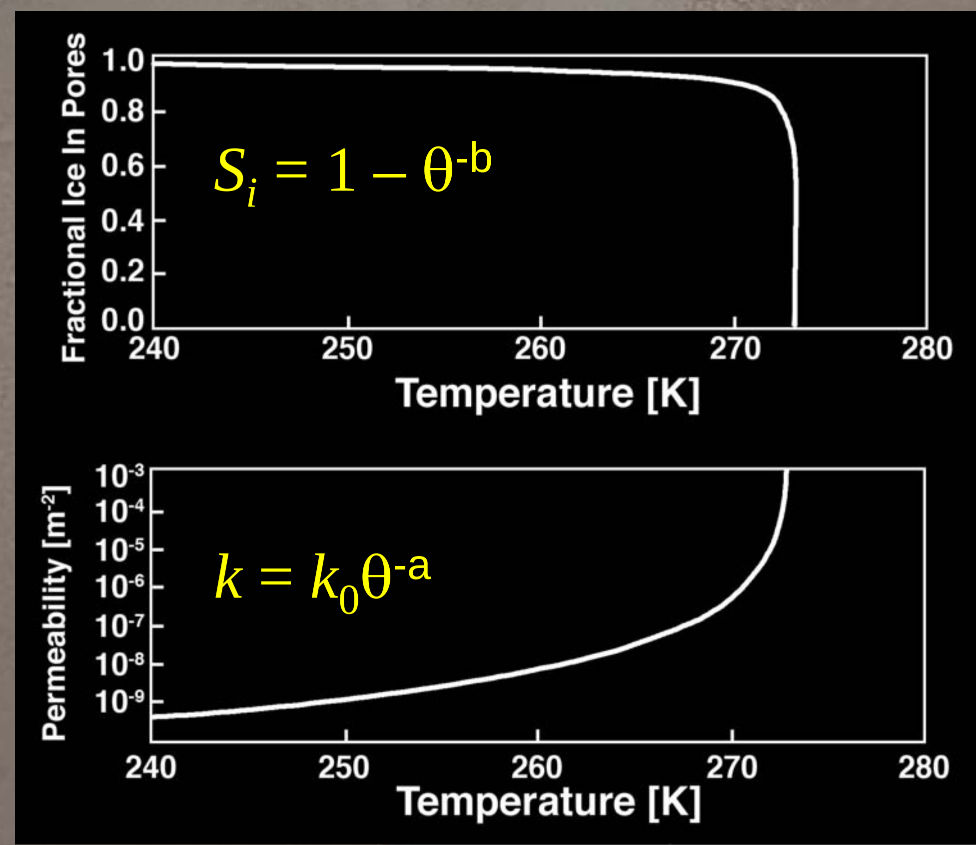
k_0: Permeability

β: Describes Ice Saturation with *T*

α: Describes Permeability with *T*

Parameters for many soils compiled in Andersland and Ladanyi, (2004). We use two soils: Chena Silt, and Inuvik Clay

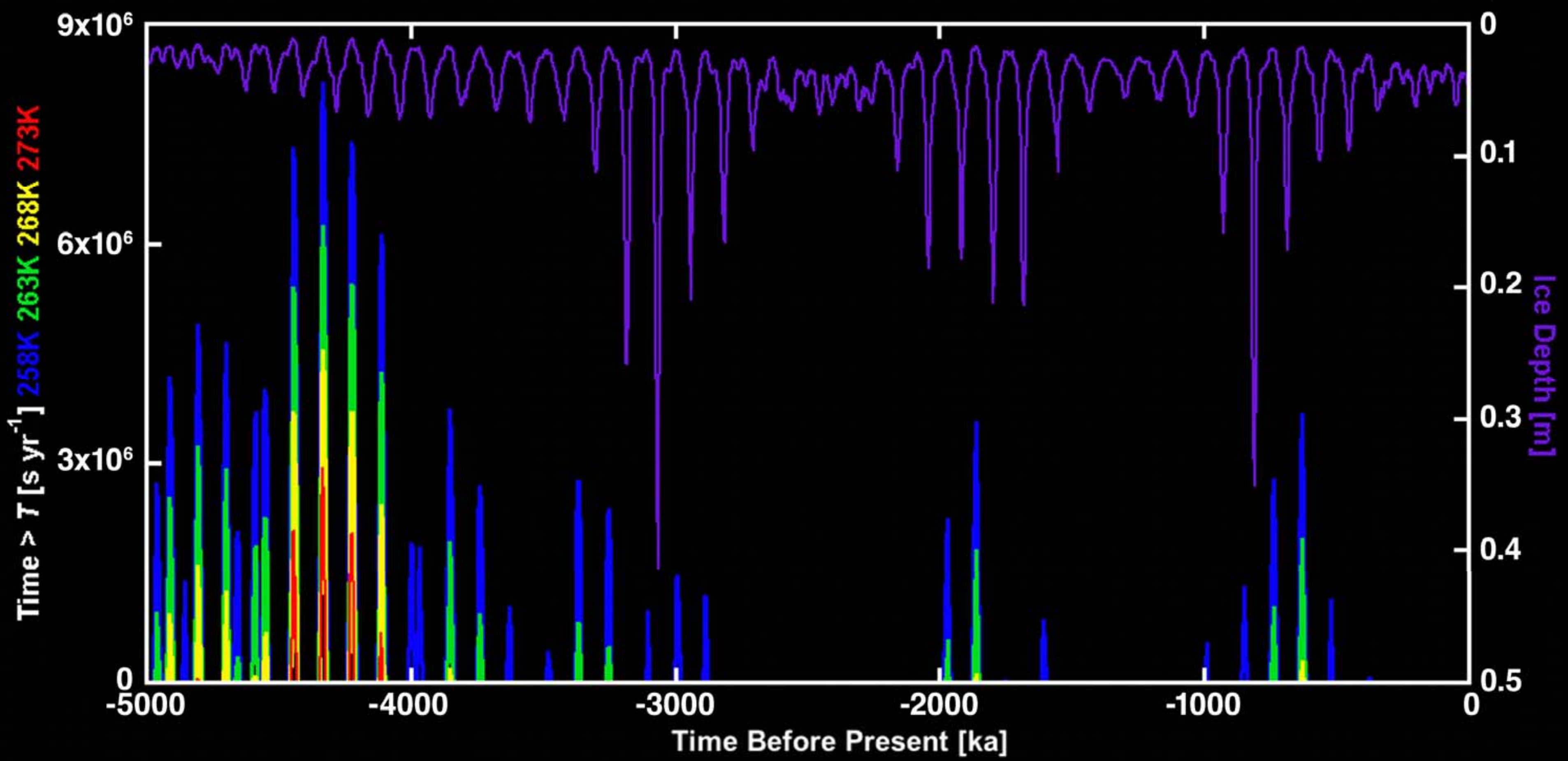
Are these valid extrapolations to martian temperatures?



Defining The Environment

Mars climate model (Zent, 2008), based on Laskar *et al.* orbits, defines z_i and T_0 at PHX site for 10 Ma bp

***Very* sensitive to assumptions about polar cap, particularly at high θ.**



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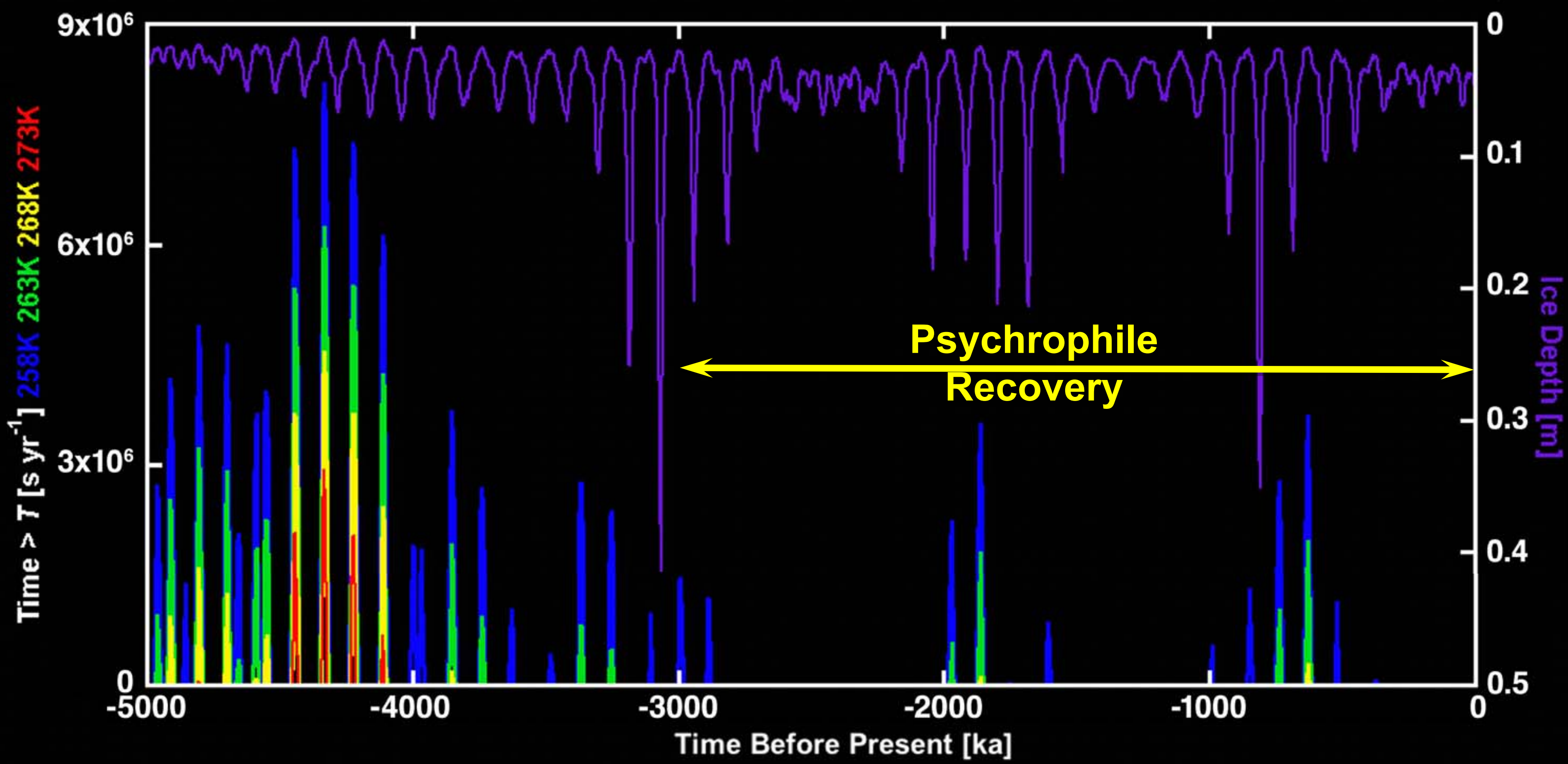


Possible Limits

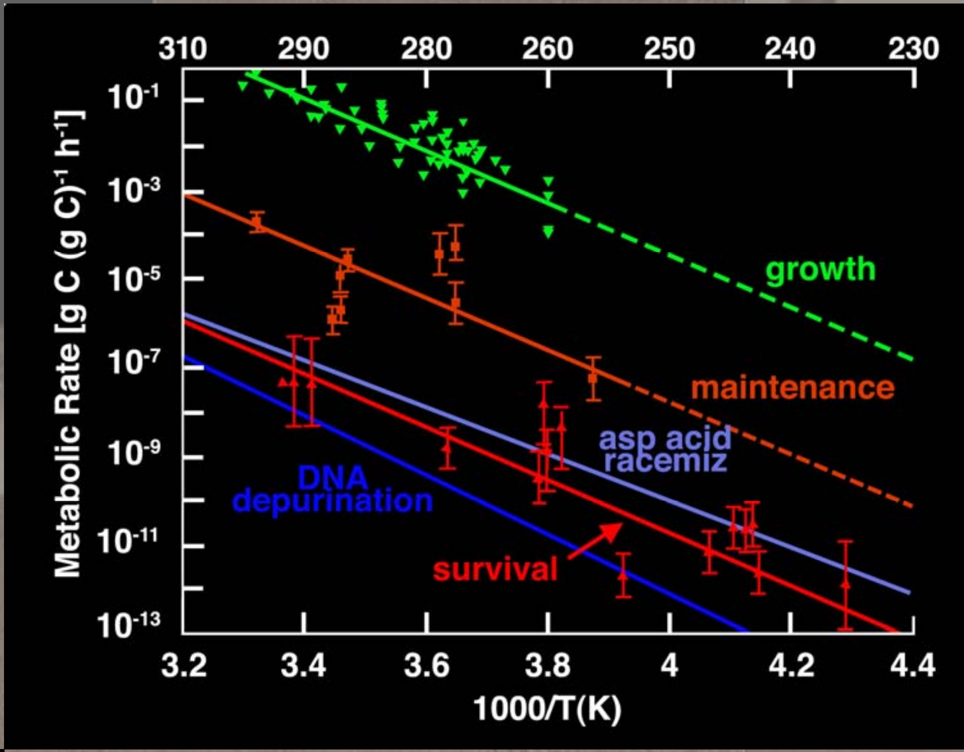
Temperature

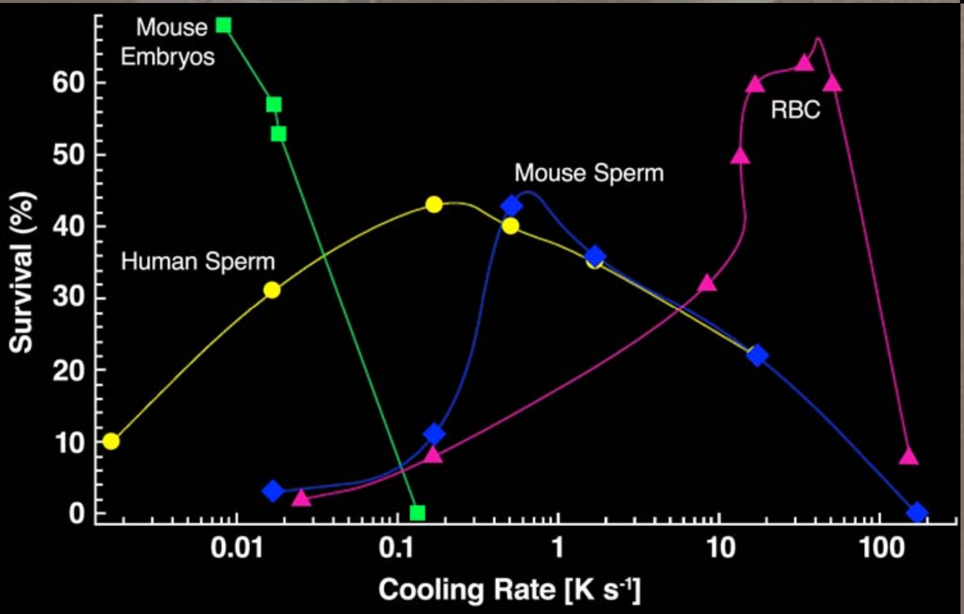
Primary limitation is loss of diffusional exchange due to collapse of unfrozen H_2O channels in ambient.

Growth: $T \leq 258$ K (?)

DNA & membrane repair: $T \leq 250$ K (?)

No survival limit as endospores





Temperature Change

Survival described by inverted U plot.

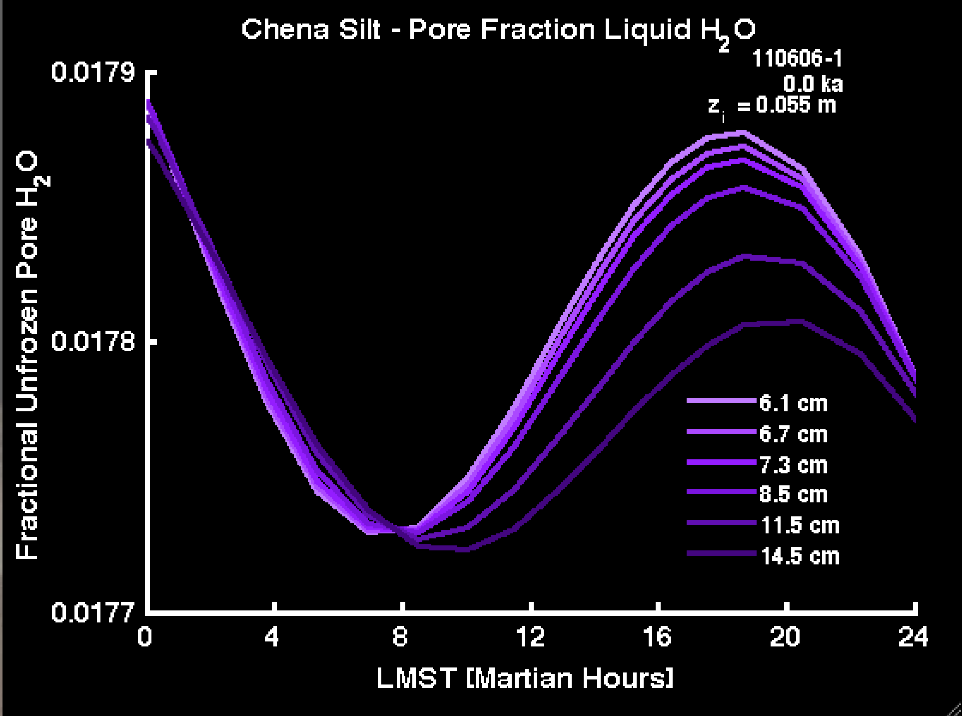
d*T*/dt too fast: Intracellular ice damage.

d*T*/dt too slow: Solution effects damage

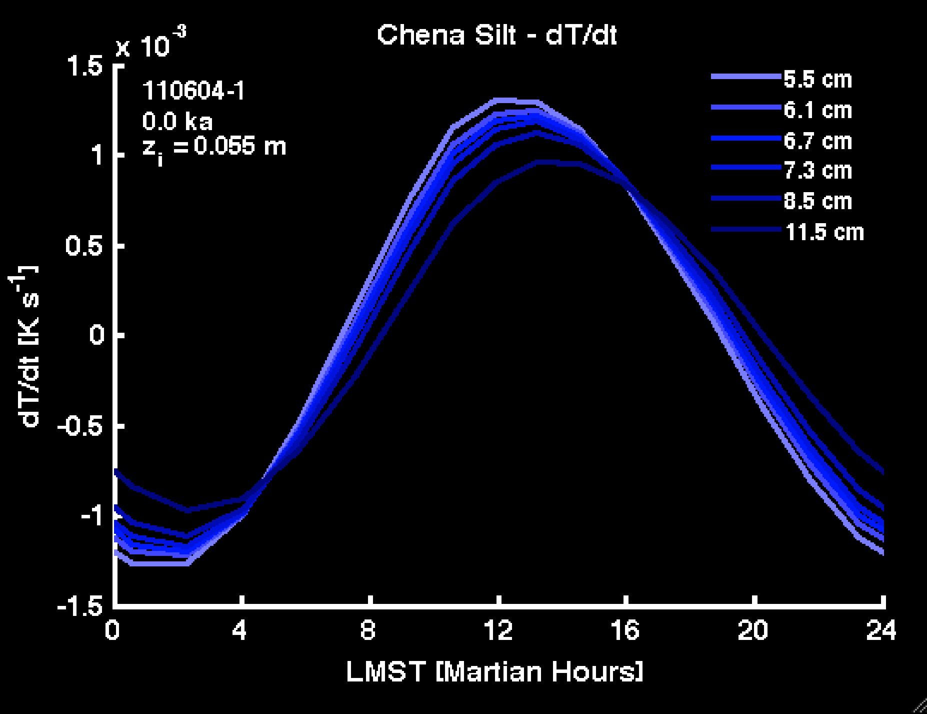
Optimal d*T*/dt varies over 4 orders of magnitude

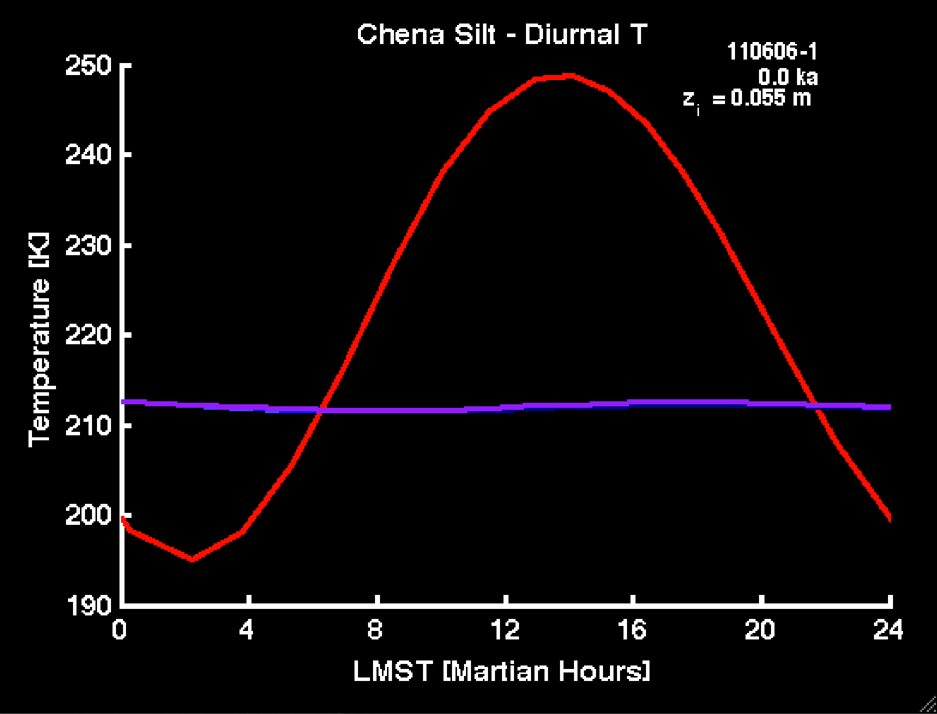
Current Orbit

Too cold for maintenance
Damage accumulating
Perhaps 5x10⁵ years?



Chena Silt; z_i ~ 5.5 cm





Sub-Freezing

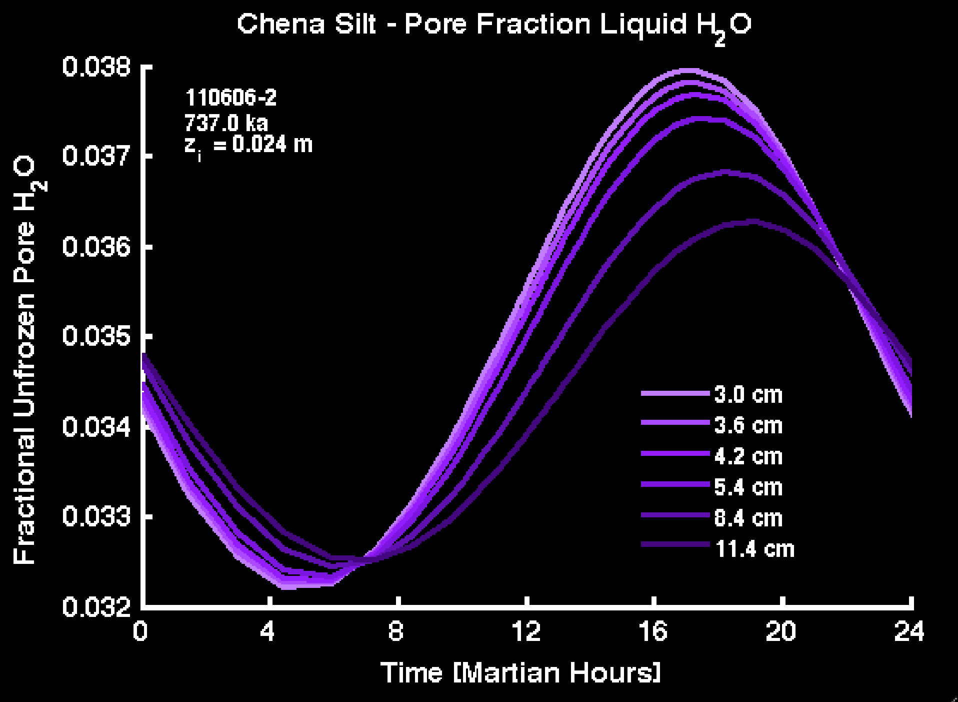
Repair, metabolism and some growth possible.

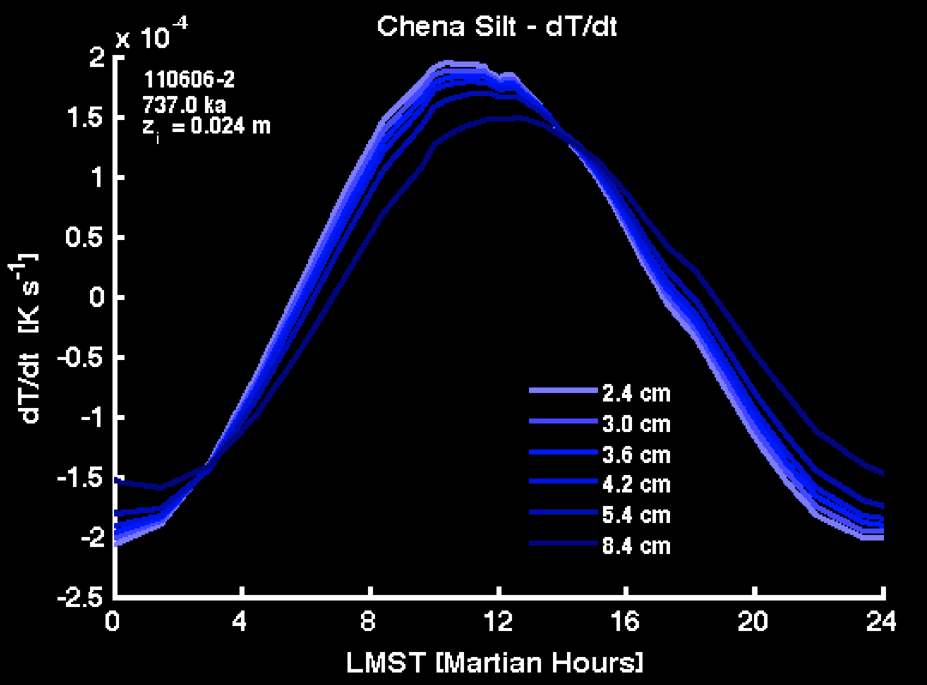
Periodically last 4-5 Ma

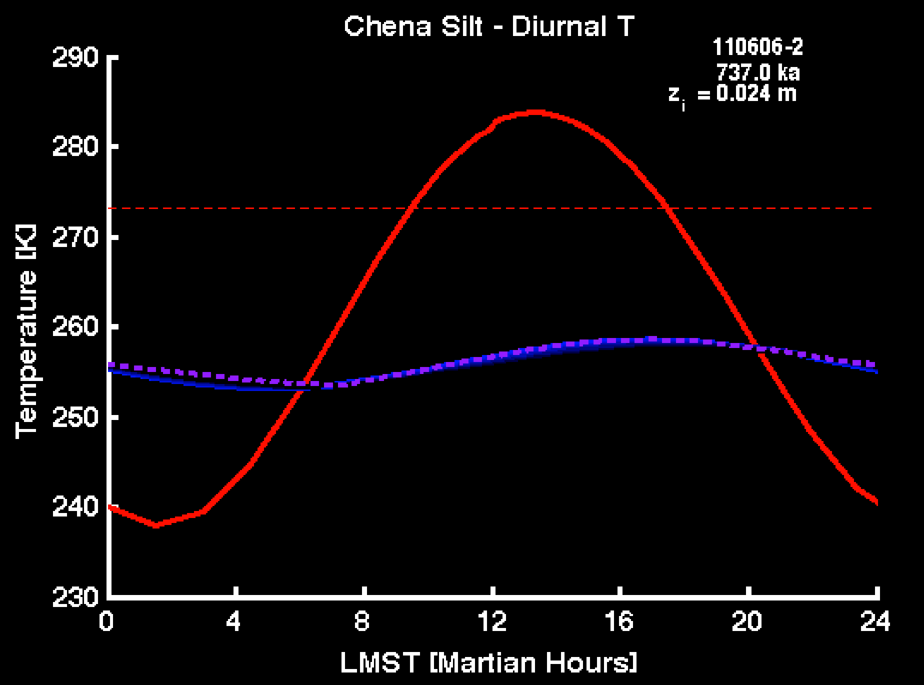
Every 10^5 years, > 3 Ma bp

Frequency of crossing 250 K threshold?

737 ka bp; Chena Silt; z_i ~ 2.4 cm







Survival

Low metabolic activity and anabiosis?

Limitation due to ionizing radiation

Low *T* limit for repair?

Can both strategies be employed?

Membrane adaptations & synthesis of new lipids can begin within 30 seconds

Endospore development requires hours to complete, but in some bacteria follows a daily cycle, at some cost.