Is There Groundwater on Mars Today?

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Exploring Mars Habitability

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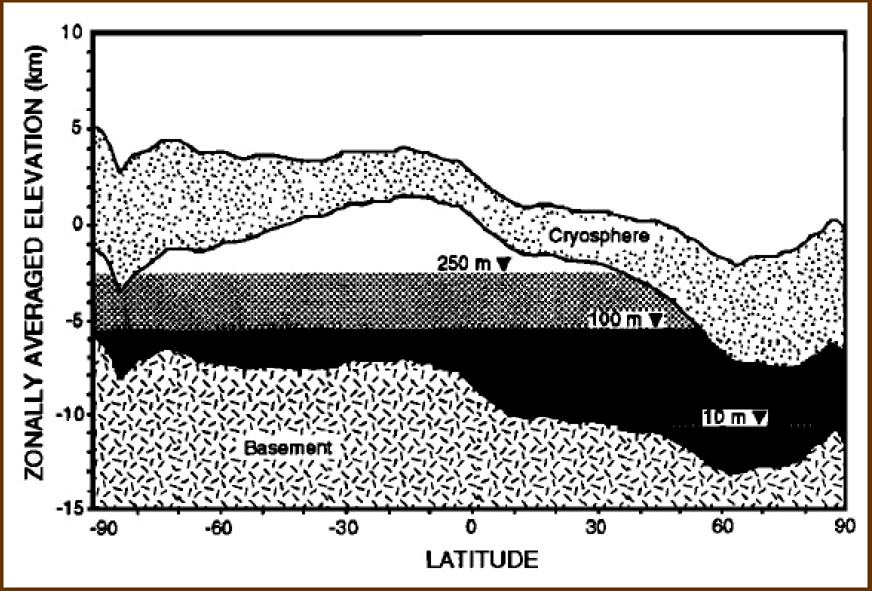
Global Groundwater and Hydrological Cycle?



Clifford, *JGR*, 1993

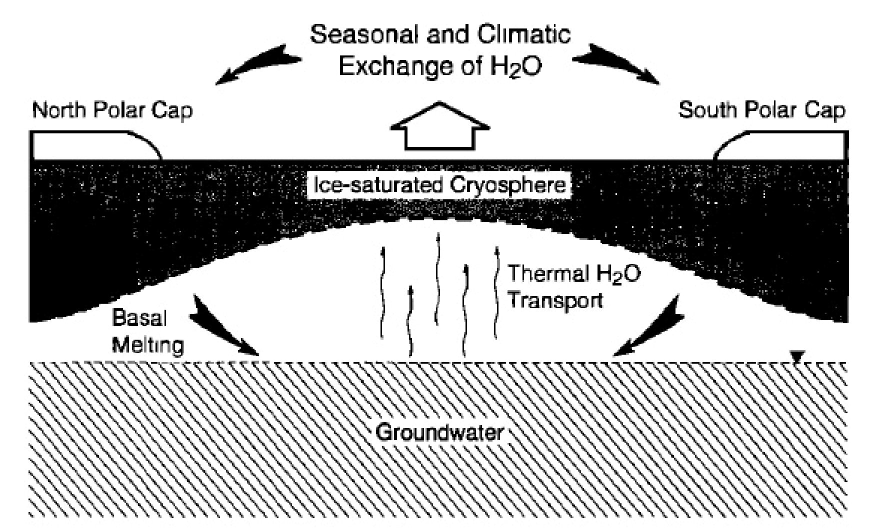


Fig. 33. A model of the climatic behavior of water on Mars.

- Groundwater results from initial H_2O in excess of storage capacity of cryosphere.
- Recharge via basal melting under thick polar caps.
- Incomplete secular loss of ground ice at low latitudes retards loss of deeper H_2O.

MarsFlo: A Comprehensive Multiphase Groundwater Model

- Three-phase model (liquid, solid, vapor) of migration of H_2O in a porous medium with a single auxiliary species (CO_2) as gas and dissolved in liquid (Painter and Grimm, 2007; 2009; Painter, 2009).
- Conservation of mass, momentum, and energy.
- Constitutive relationships for
  - Equilibrium phases (equations of state)
  - Capillary pressure, relative permeability, and thermal conductivity vs. phase saturations.
  - Gas-diffusion coefficients (Clifford and Hillel, 1983; Millington and Quirk, 1961).
- Validated against laboratory experiments

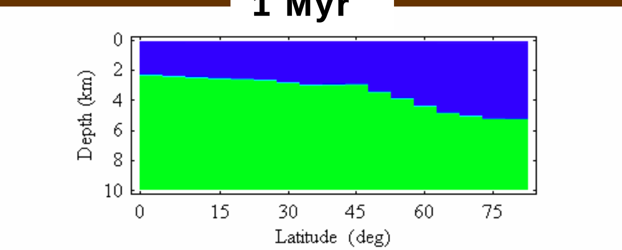
Boundary Conditions

Grimm and Painter, 2009

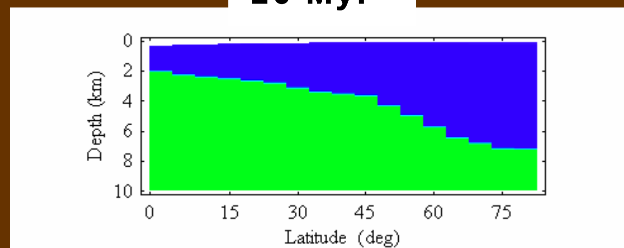
- Surface
  - Sudden imposition of present atmospheric pressure and temperature approximates Hesperian climate change.
  - Obliquity variations interpolated from sampling distribution of Laskar et al. (2004) at 10-Myr intervals: neglects long-term trends.
  - Open top boundary.
- Base
  - Two heat flow models span “early” (3.0 Ga) or “late” (1.1 Ga) climate change
    - $q = 54$ mW/m^2 $e^{-t/1.72 \text{ b.y.}}$ reaches chondritic after 1.1 b.y.
    - $q = 100$ mW/m^2 $e^{-t/2.46 \text{ b.y.}}$ reaches chondritic after 3.0 b.y.

Reference 2D Model:
150 m GEL, Late Climate Change (1.1 Ga)

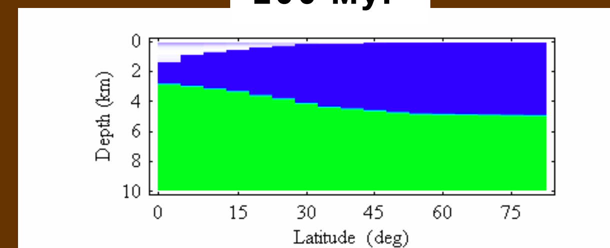
1 Myr



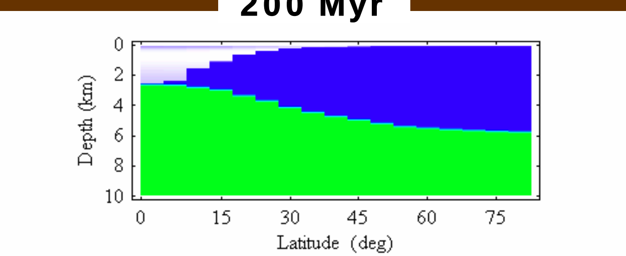
10 Myr



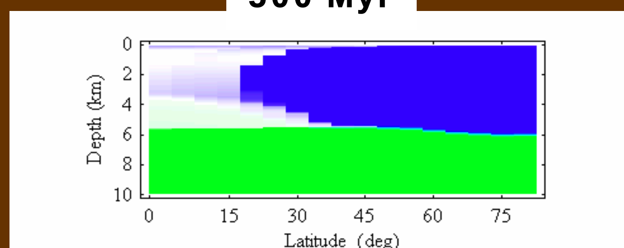
100 Myr



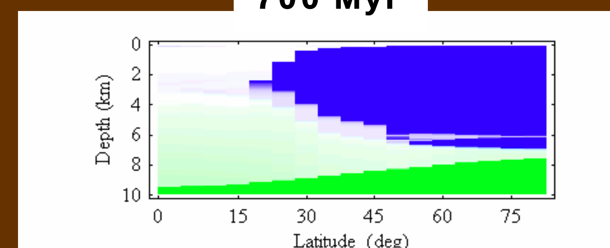
200 Myr



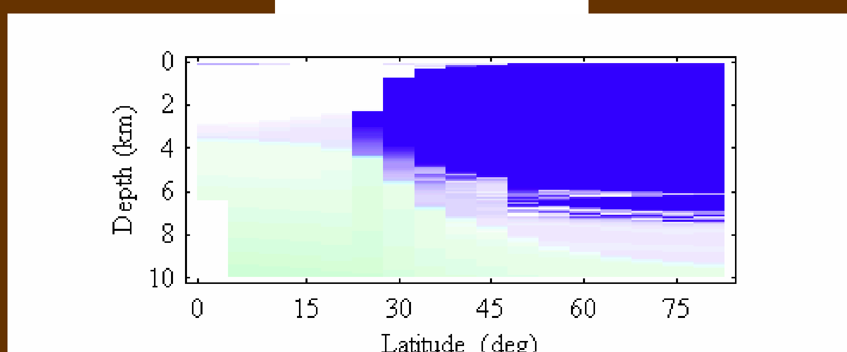
500 Myr

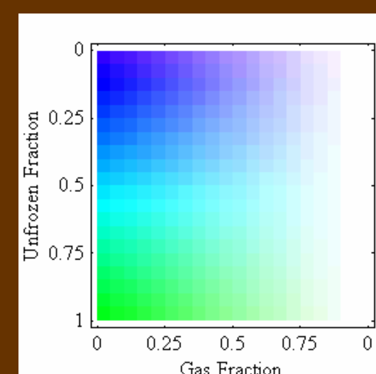


700 Myr



1000 Myr



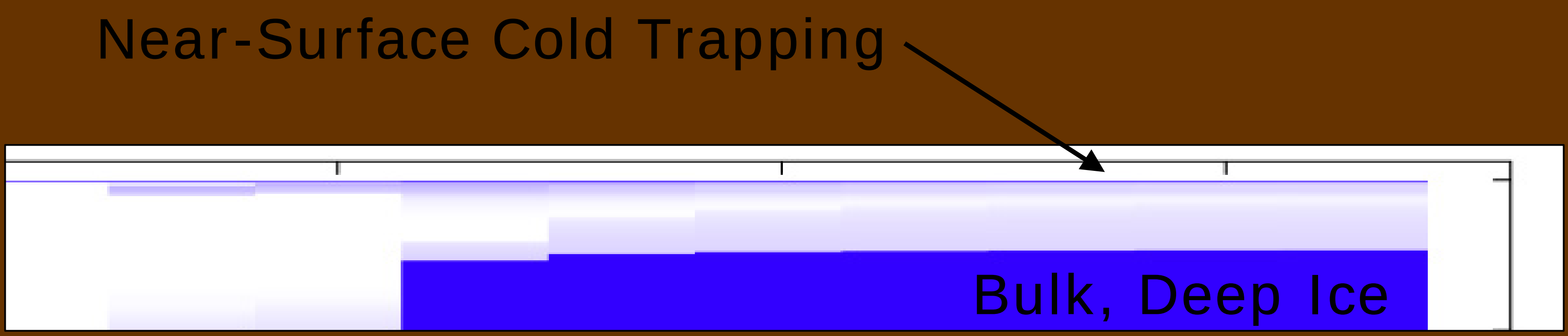


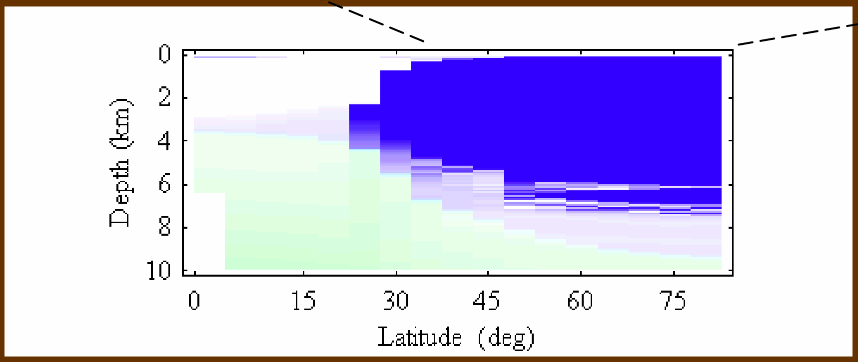
Low-Latitude Sublimation Rates

- Few km of ice completely sublimed in a few hundred million years.
  - Consistent with Mellon et al. (1997) loss of 80 m GEL in 19 m.y.
    - Same 10-μm eff. pore size and chondritic heating.
    - Reasonable number for sed. rock or megaregolith.
  - Consistent with Clifford and Hillel (1983) 10-μm pore size.
    - Long retention by favoring 1-μm pores (clay!) in order to match specific surface area of surficial drift derived by Viking: inappropriate for bulk subsurface.

Distribution of Ice

- Near-surface ice at midlatitudes and higher, tracks classical predictions & orbital observations.

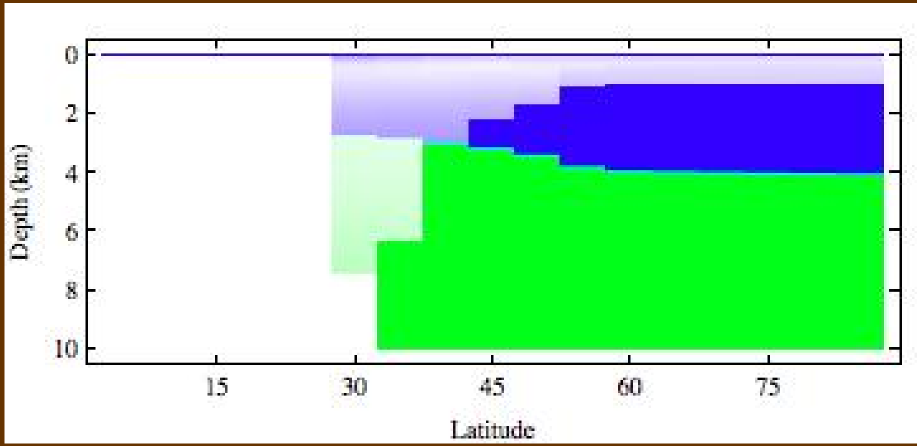




- Bulk ice at mid-hi lat., depths of several hundred meters.

1D Model (Vertical Transport Only)

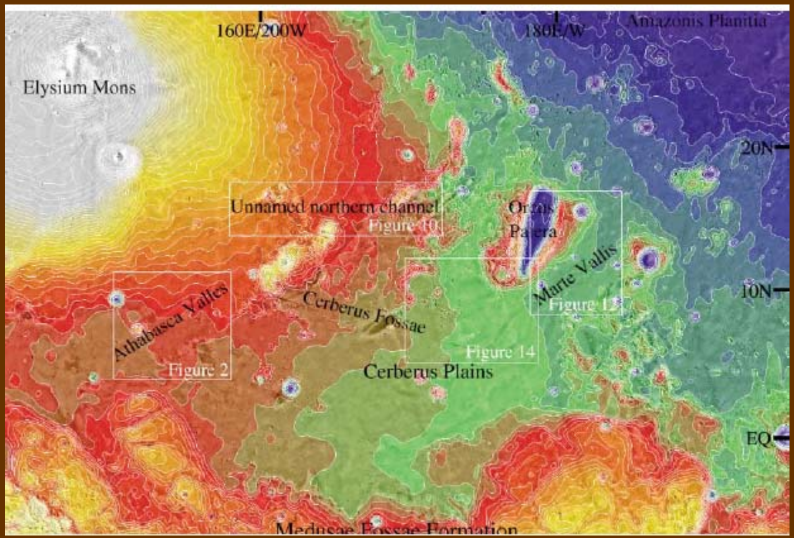
- With lateral transport disallowed, groundwater can be retained under mid/high-latitude subsurface ice.



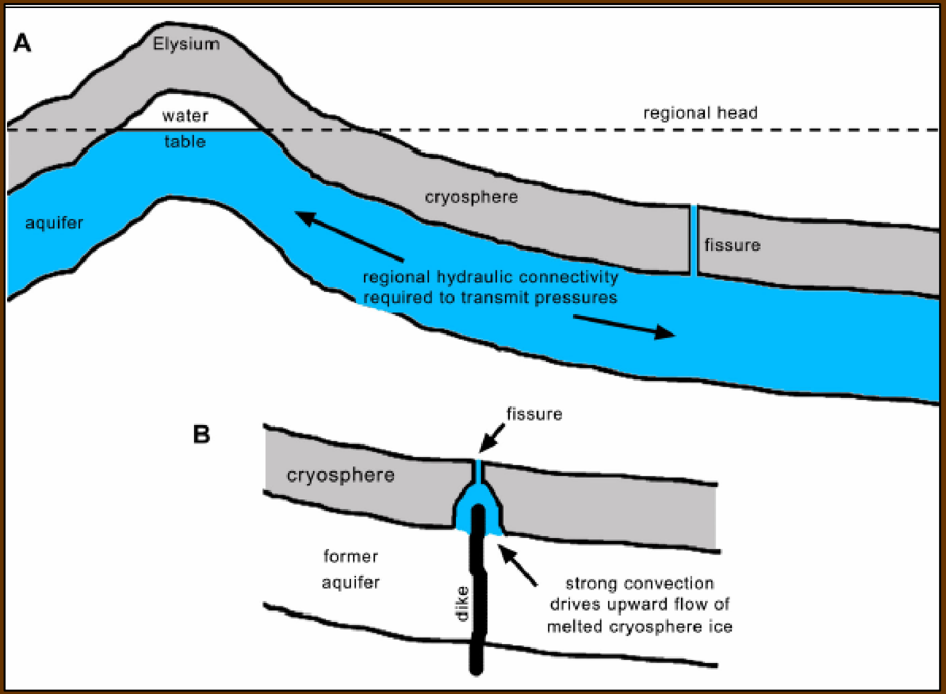
150 m GEL, max storage 300 m, 100 Myr

- We know lateral pressurization is at least partially inhibited, else groundwater head would have caused outflows at locations (Amazonis) other than observed (Chryse) Harrison and Grimm, 2009.
  - Solid planets are naturally heterogeneous.
  - Ice is self-sealing: better than rock.

Young Outflow Channels



Burr et al., 2002



- Arguments hinge on two, very young systems: Athabasca-Marte and Echus-Kasei Valles are very young.
- Both are show intimate assocations with recent volcanism

- A – Static aquifer emplaced after Elysium formed
- B – Dike drives local melting of ice.
- C – Juvenile water
  - can produce 1-2 orders of magnitude more water than needed to carve channels

Lobate-Ejecta Craters

- Secular retention and lateral continuity of tropical, buried ice is key to maintaining underlying groundwater.
- Putative cratering into ground ice represented by lobate-ejecta craters (see discussion in Carr, 1996).
  - Decrease in onset diameter with latitude taken to indicate shallower ice table.
  - Trial age-dating of individual craters by Reiss et al. (2006) shows deficiency in Amazonian and increase of onset diameter with age: current ice table deep or “nonexistent.”

Methane

- Zahnle et al., 2011 dispute presence of methane on both observational and theoretical grounds.
  - Ground-based observations are tellurically contaminated.
  - Current spacecraft-based observations have insufficient resolution and signals are too weak.
  - Reported rates of change far exceed natural capabilities unless a large, unknown oxidant is present.

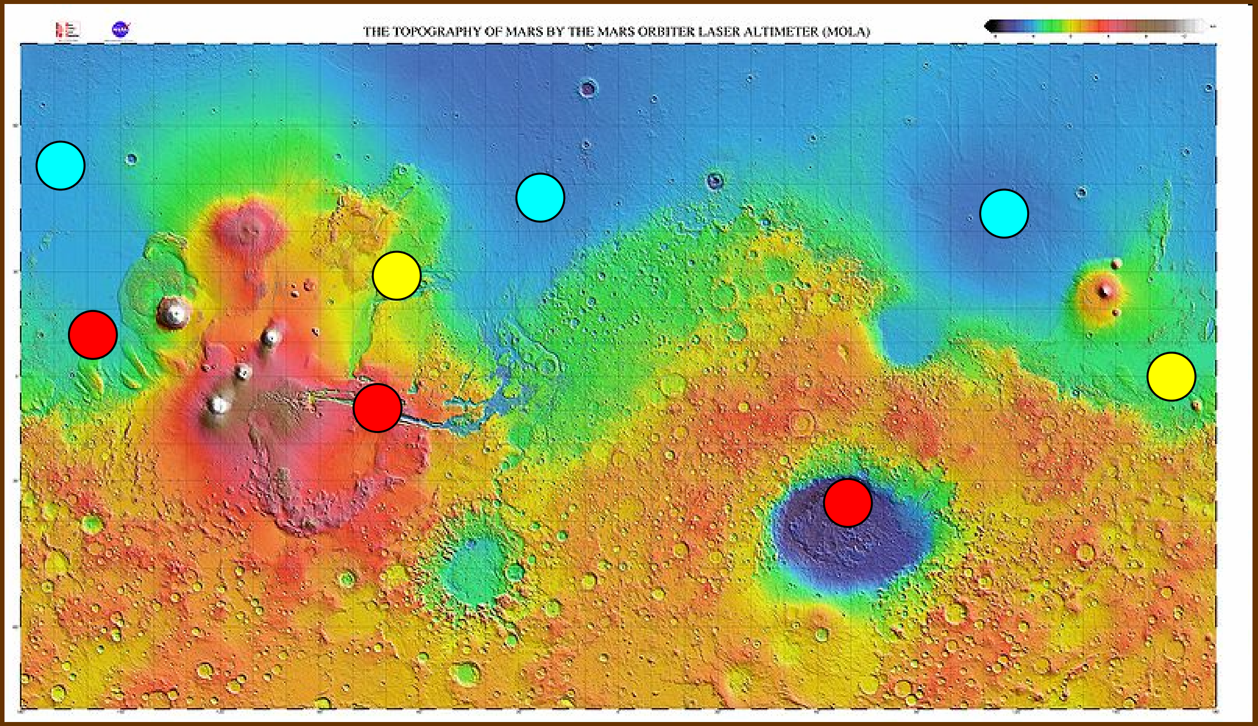
?

Effects of Assumptions/Parameters

- Initial water inventory – insensitive.
- Gradual transition – delay.
- Heat flow – lower?
- Crustal permeability – lower?
- Long-term obliquity – cold-biased state?
- Expelled H_2O – recycle?
  - Luhmann et al. (1992): 50 m GEL loss from sputtering.
  - Jakosky (pers. comm): “order of magnitude uncertainty.”

Implications

- 2D flow: may only have adsorbed water remaining. Not habitable.



- 1D flow: groundwater confined by ice to mid-high latitudes.

- Sites preferred for groundwater by
  - Blue: Confining mid-latitude ice (after Grimm and Painter, 2009)
  - Red: Low elevation near equator (Clifford & Parker, 2001)
  - Yellow: Young outflows

Conclusion

- Subsurface ice in the tropics may completely sublimate, driven by excursions to low obliquity.
  - "On a global scale, it appears unlikely that a fossil ground ice layer has been preserved throughout Martian history" (Clifford and Hillel, 1983).
- Where not laterally confined, groundwater will flow toward the tropics and evaporate.
  - Not a global phenomenon: groundwater flow was compartmented in Hesperian.
- Inhibition of atmospheric loss and crustal recycling of H2O may have maintained groundwater.
  - Calls for Amazonian recharge at poles or elsewhere.
- In situ geophysical exploration is necessary
  - Low-frequency electromagnetic sounding optimal for detecting deep water.

It’s Only A Model