Chris McKay
NASA Ames Research Center

Dr. Christopher P. McKay, Planetary Scientist with the Space Science Division of NASA Ames. Chris received his Ph.D. in AstroGeophysics from the University of Colorado in 1982 and has been a research scientist with the NASA Ames Research Center since that time. His current research focuses on the evolution of the solar system and the origin of life. He is also actively involved in planning for future Mars missions including human exploration. Chris been involved in research in Mars-like environments on Earth, traveling to the Antarctic dry valleys, Siberia, the Canadian Arctic, and the Atacama desert to study life in these Mars-like environments. His was a co-I on the Titan Huygen's probe in 2005, the Mars Phoenix lander misson for 2007, and the Mars Science Lander mission for 2009.

Life on Mars: Past, present, and future

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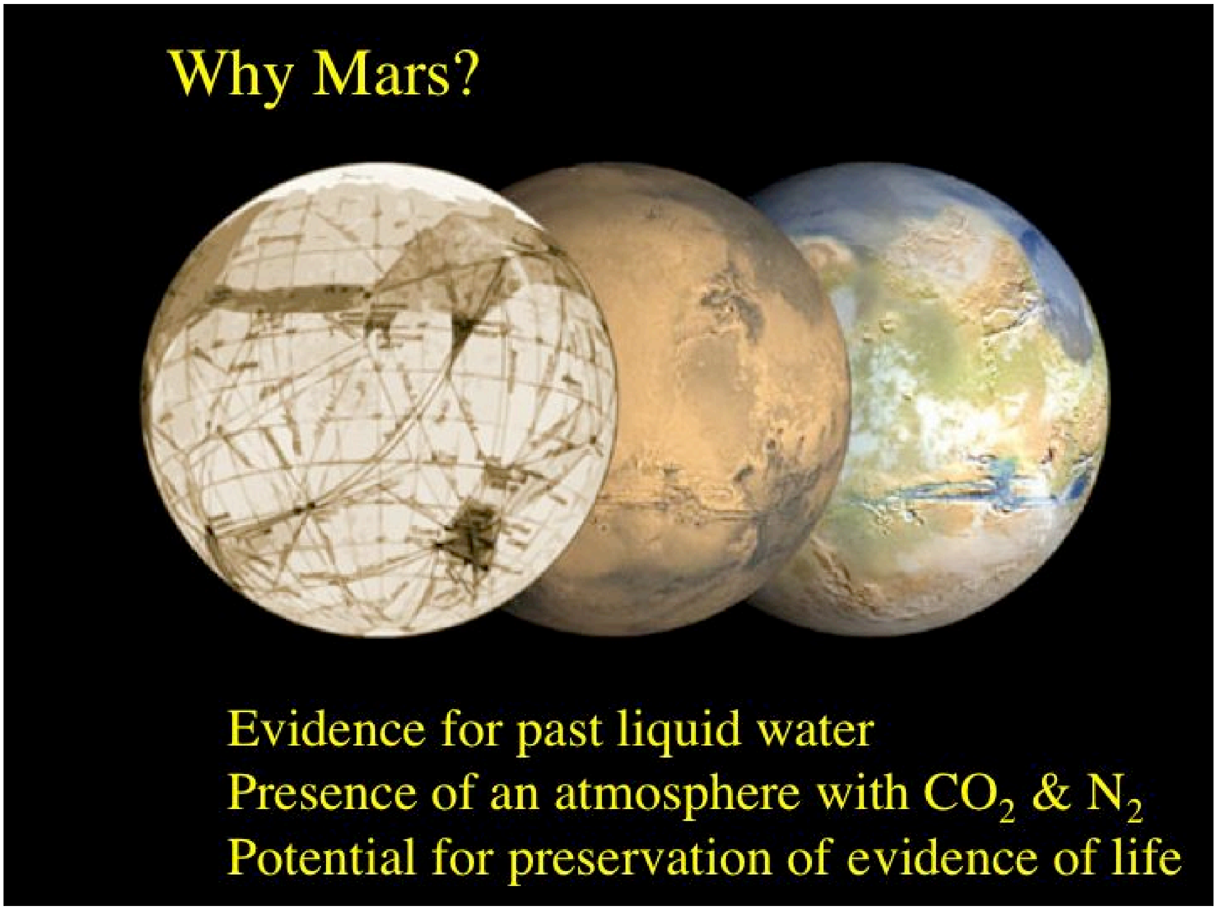
This talk is a compilation based on the work of many colleagues over many years. My thanks and acknowledgements to all of them

Why is Life on other Worlds Interesting?

- The possibility of a second genesis of life:
  ⇒ comparative biochemistry
  ⇒ life is common in the universe (yeah!)

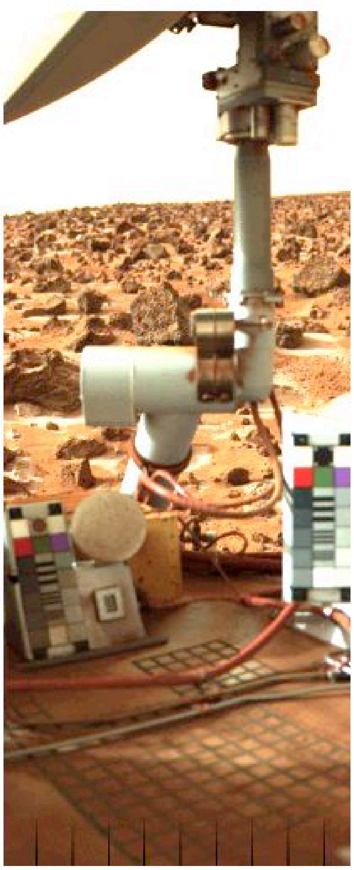
- Information about the early planetary environment
- Relevant to the origin of life on Earth

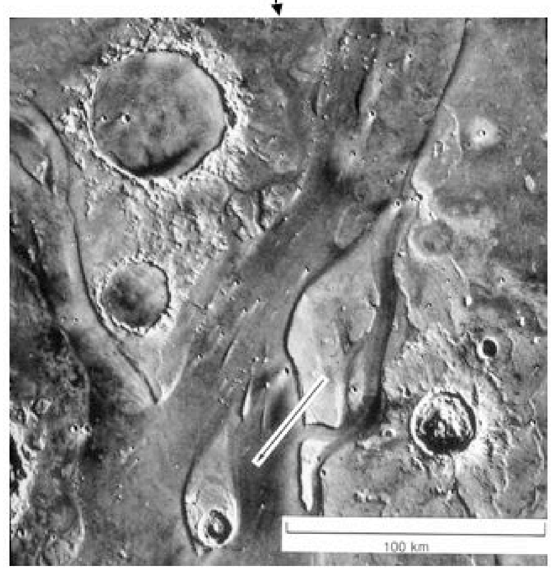


Viking:

water frost on Mars

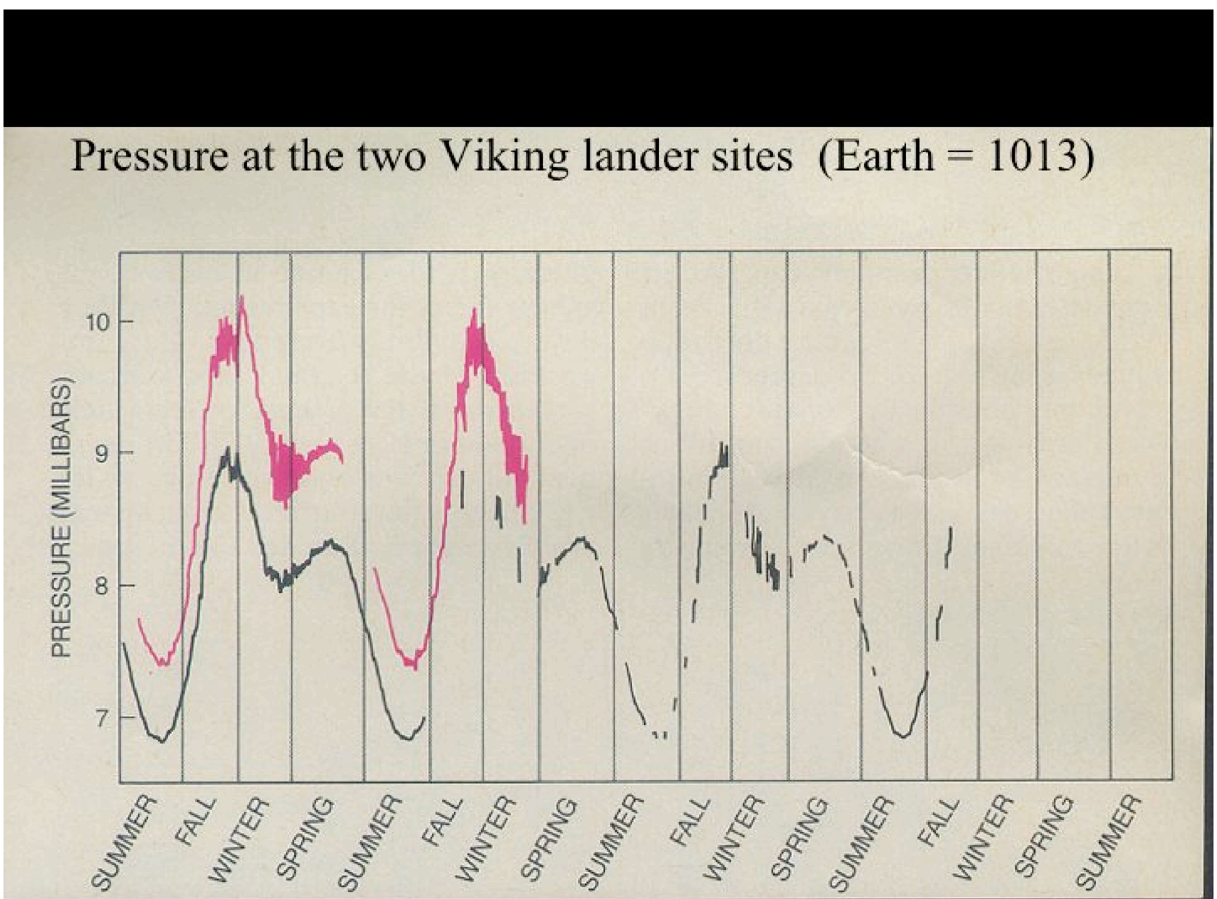
water flowed on the surface





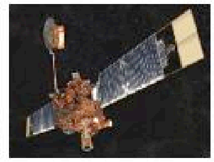
Composition of the Martian Atmosphere

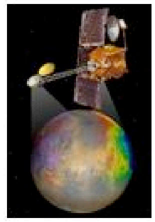
- Carbon Dioxide (CO_2) 95.3%
- Nitrogen (N_2) 2.7%
- Argon (Ar) 1.6%
- Water Vapor (H_2O) 0.03% - 0.1% (saturated in places)
- Oxygen (O_2) 0.13%
- Carbon Monoxide (CO) 0.07%



Current Mars Missions

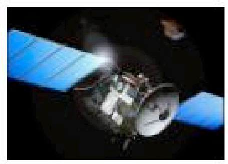
- Mars Global Surveyor



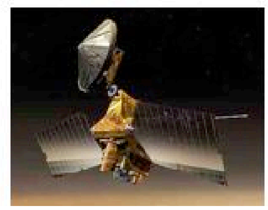


- Mars Odyssey

- Mars Exploration Rovers



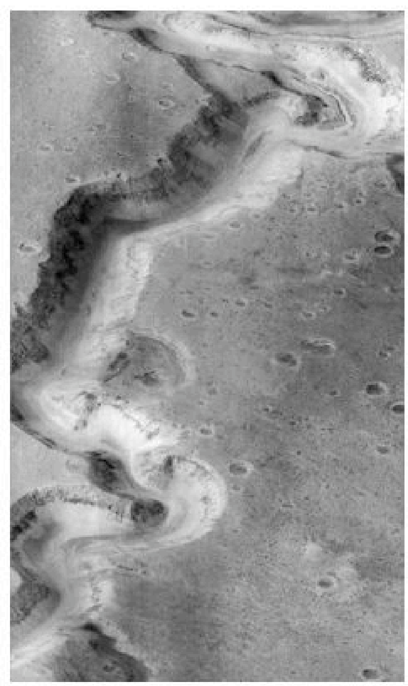
- Mars Express



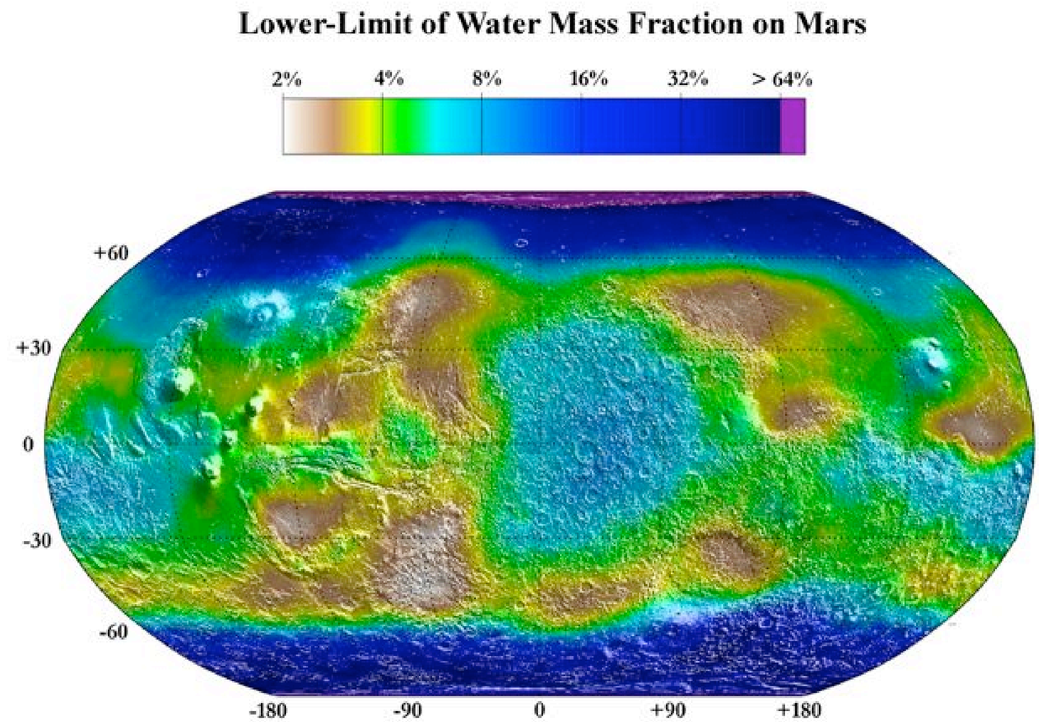
- Mars Reconnaissance Orbiter

Mars Global Surveyor
&
Mars Express

Evidence for water flow on Mars

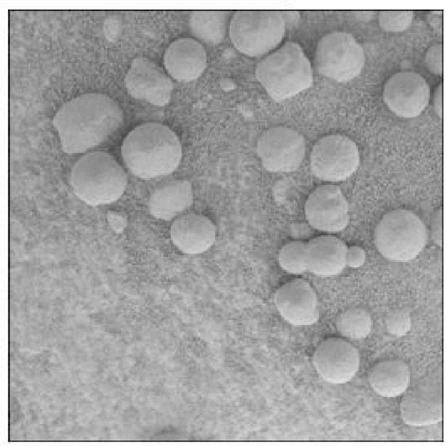


Nanedi

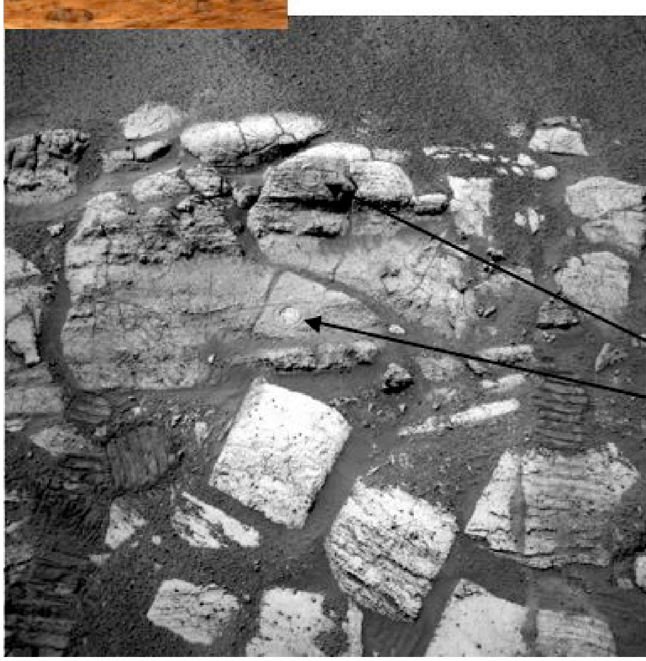


Minimum estimated water mass fraction in the top 1 meter of the martian surface from GRS on Mars Odyssey. http://grs.lpl.arizona.edu/

Evidence for Water at Meridiani Planum

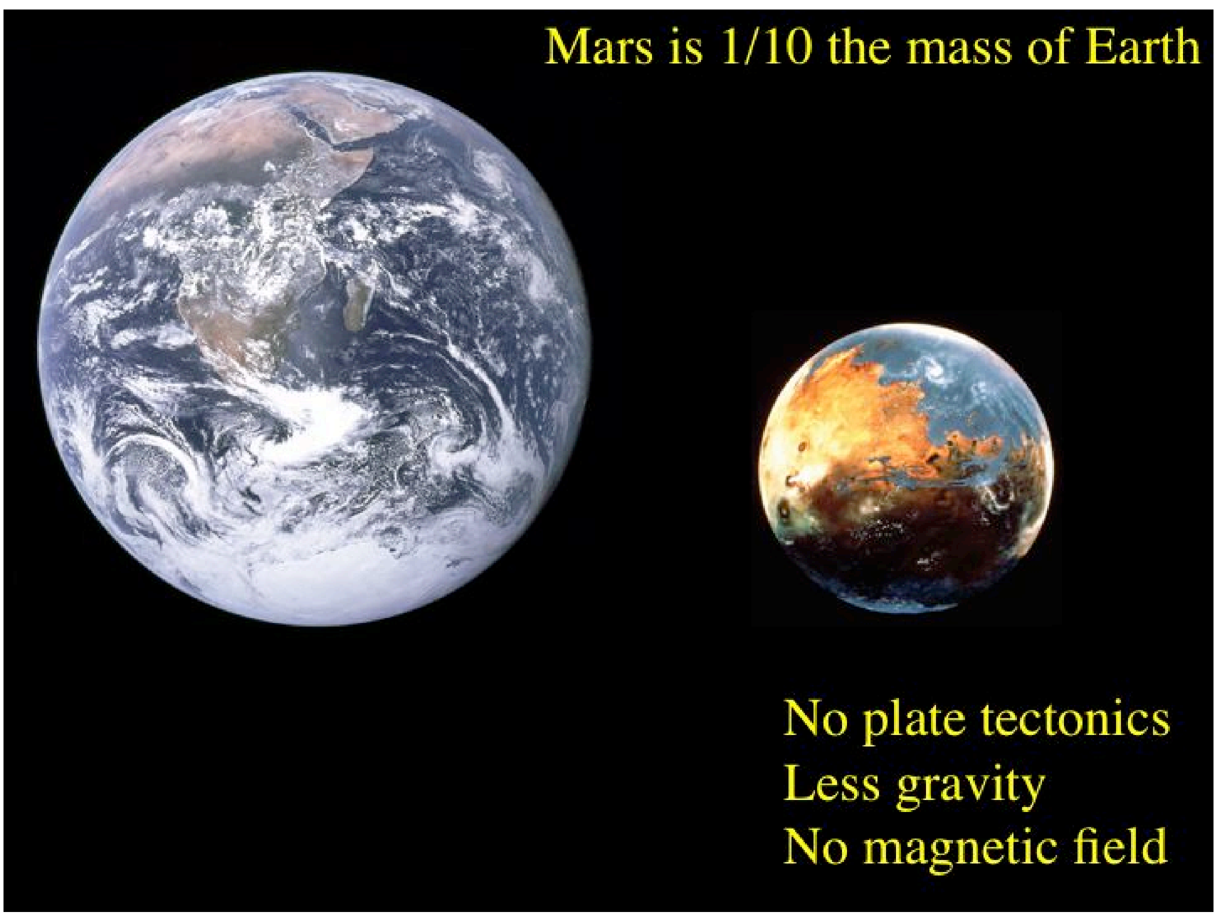


'Blueberries' are hemitite concretions

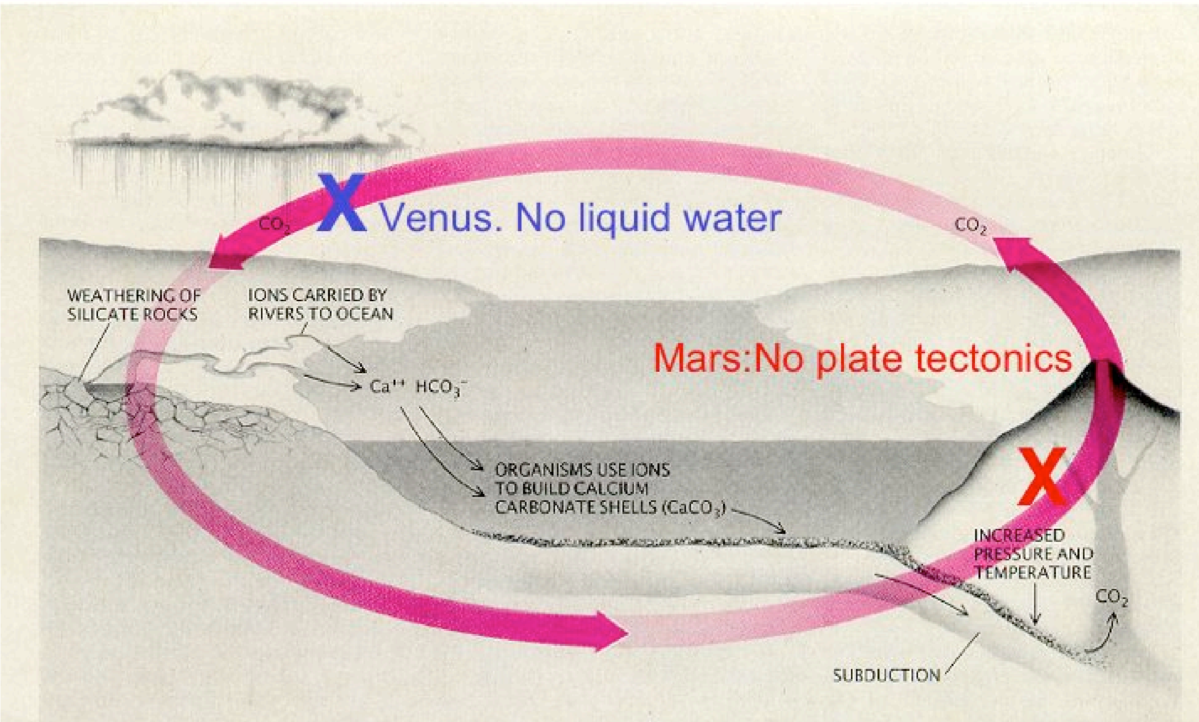


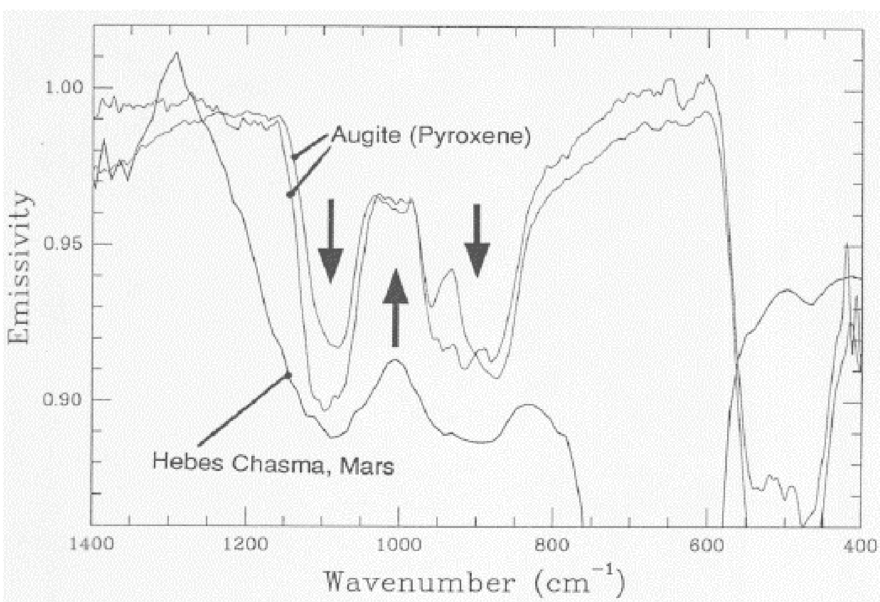
More salt
Less salt

Layering consistent with water.


Mars is 1/10 the mass of Earth
No plate tectonics
Less gravity
No magnetic field

Venus and Mars lack the complete cycle





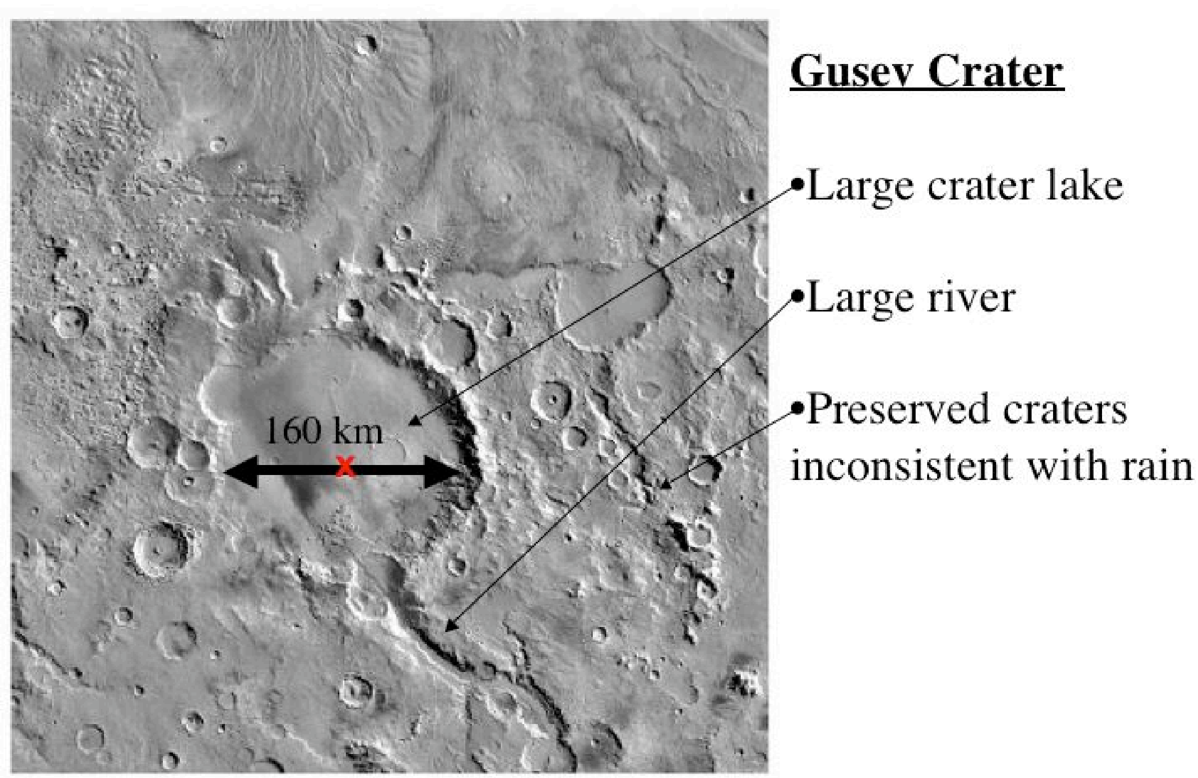
Thermal Emission Spectrometer

indicates a dry cold world.

From the *TES top 25 Science* results:
Unweathered volcanic minerals (pyroxene, feldspar, and minor olivine) dominate the spectral properties of martian dark regions. Conversely, no evidence has been found for weathering products above the TES detection limit. This lack of evidence for chemical weathering of the martian surface indicates a geologic history dominated by a cold, dry climate in which mechanical weathering was the dominant form of erosion.

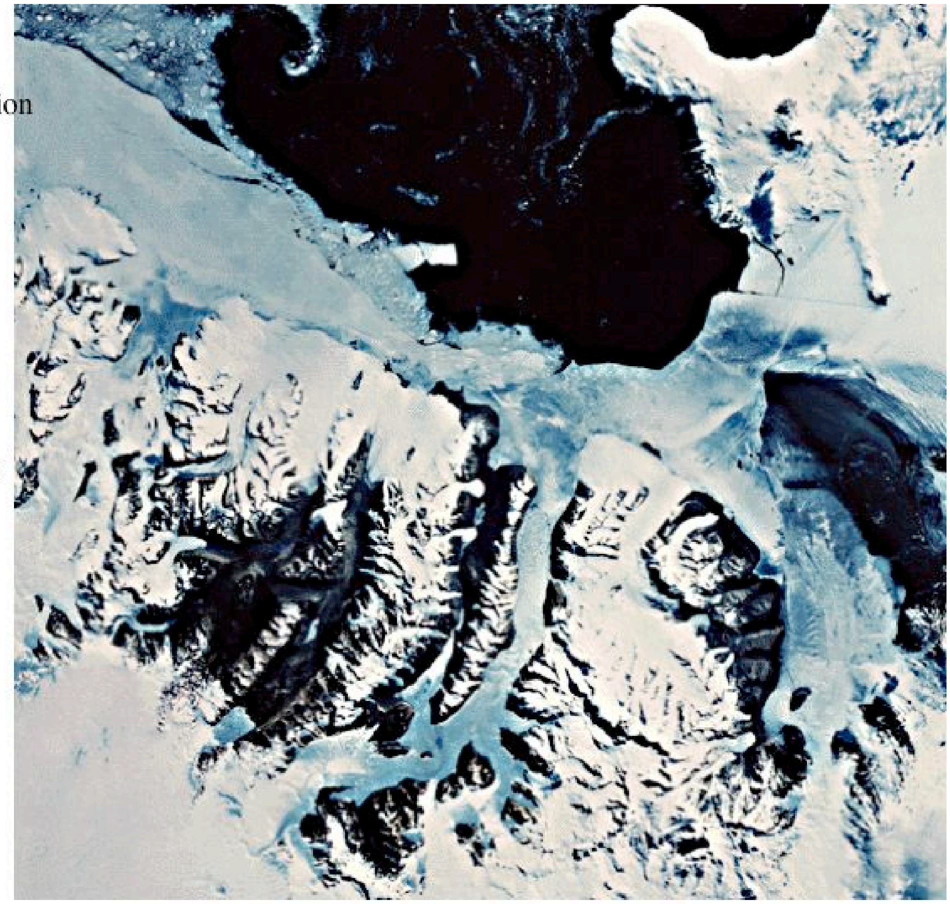
When Mars was wet it was cold

- Evidence of very low erosion:
  < 10^{-9} m/yr, compare to dry valleys 10^{-6} m/yr
- Sporadic distribution of valley features
- Unweathered basaltic surface minerals
- Climate modelers have difficulty getting surface temperatures above 0°C.
- No massive surface carbonates detectable by remote sensing.

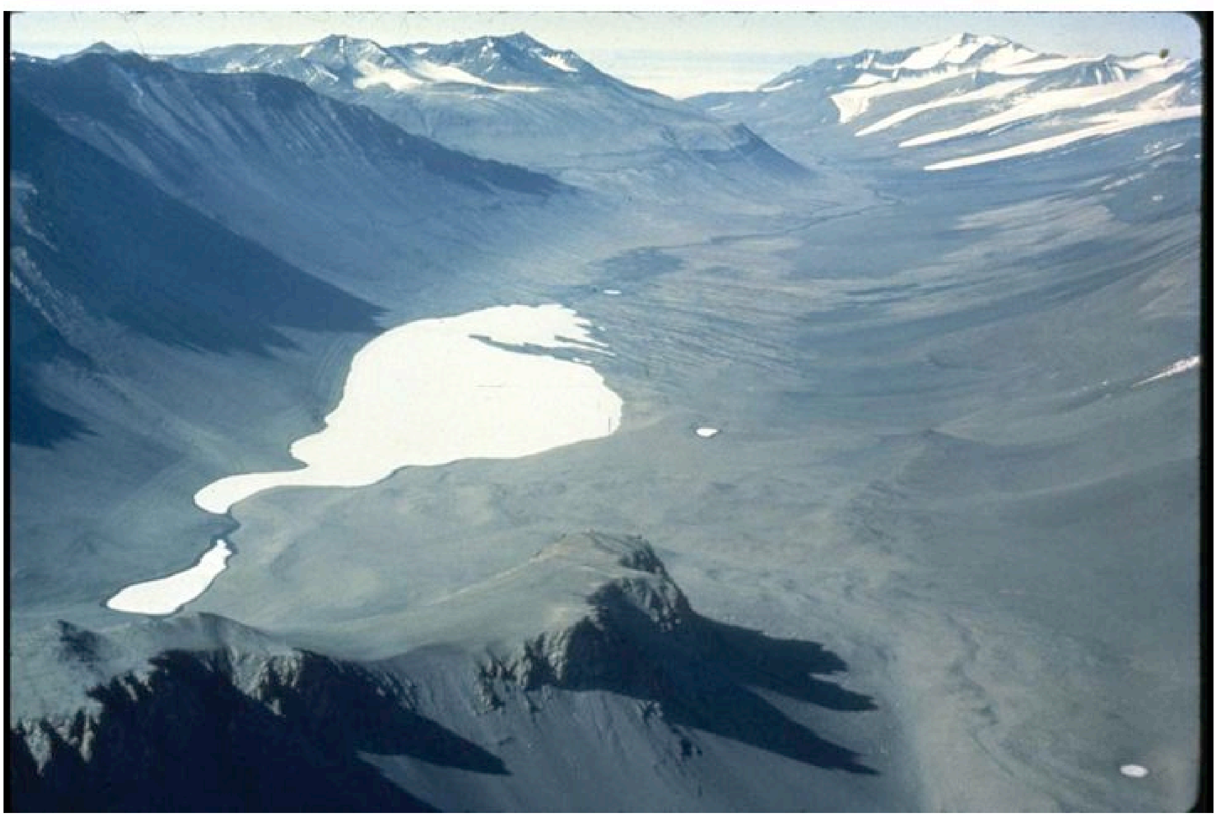


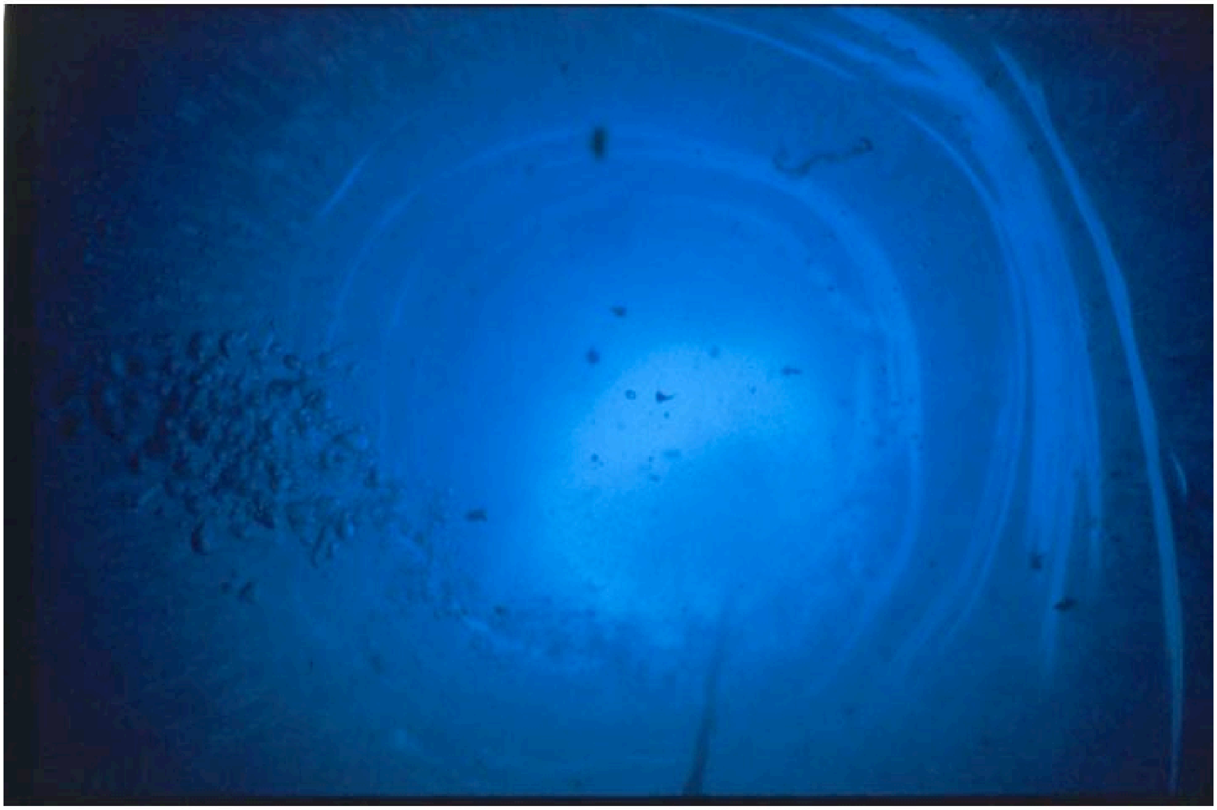
The Dry Valleys

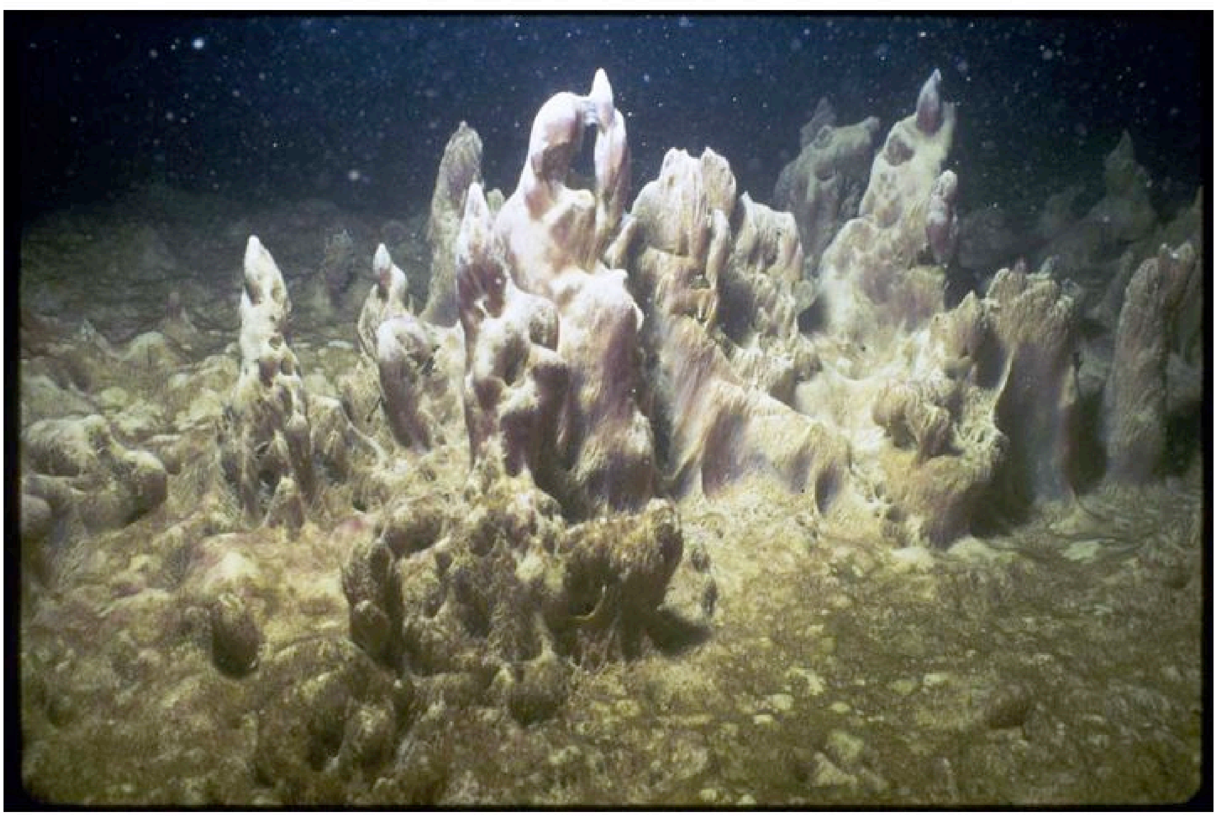
- Largest ice-free region in Antarctica
- Temperatures:
  -20°C average
  +10°C maximum
- 1-2 cm equivalent H_2O as snow
- Pressure well above triple point of H_2O



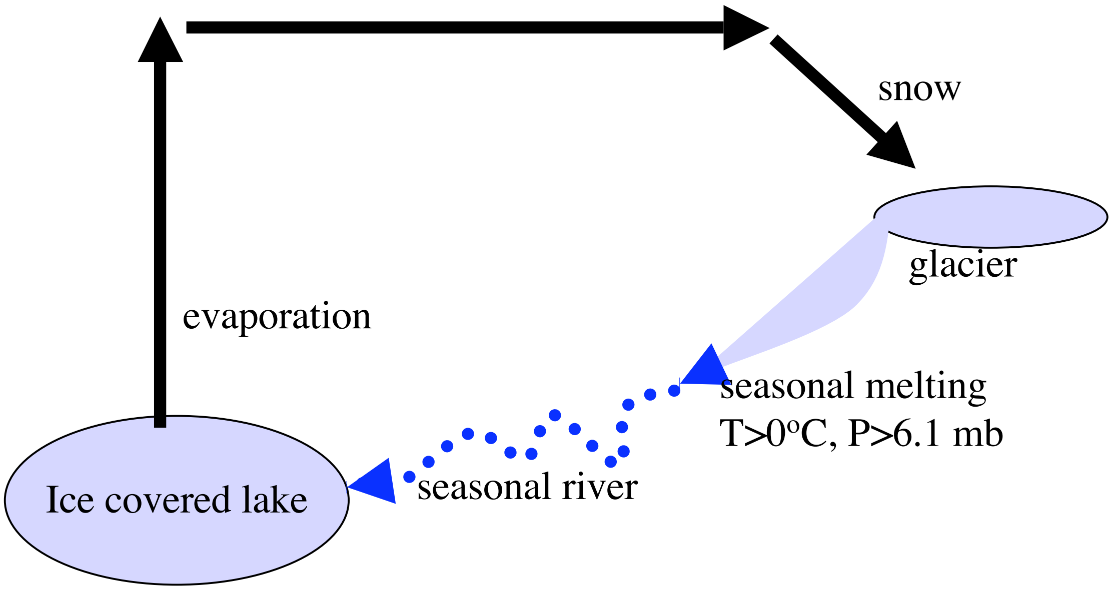
Lake Vanda and the Onyx River in the Antarctic dry valleys

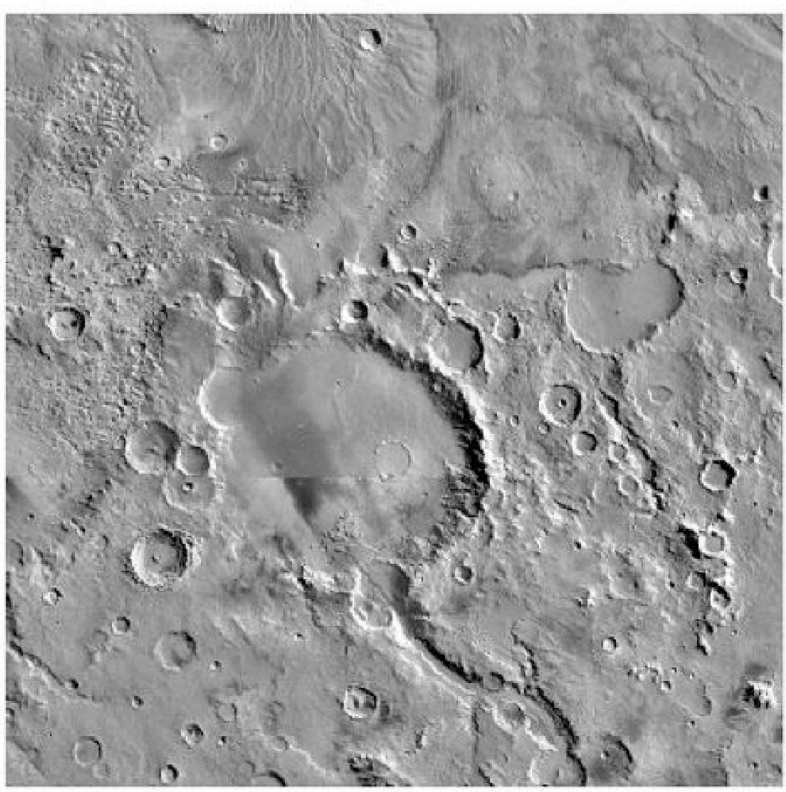






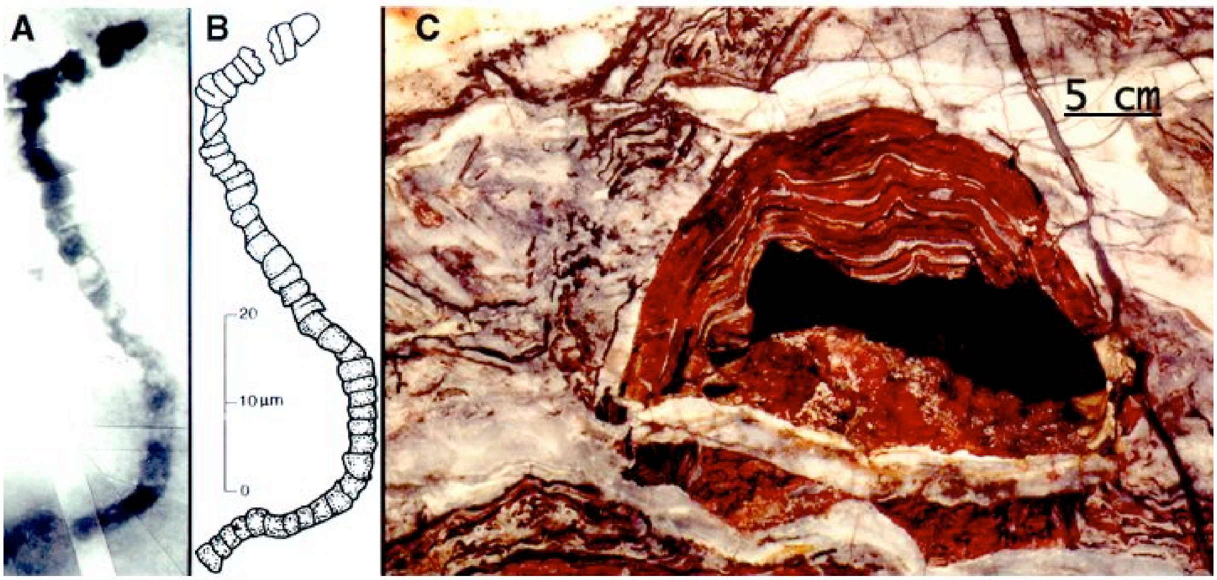
Snow-based hydrological cycle





Oldest (probable) fossil on Earth: 3.5 Gyr old

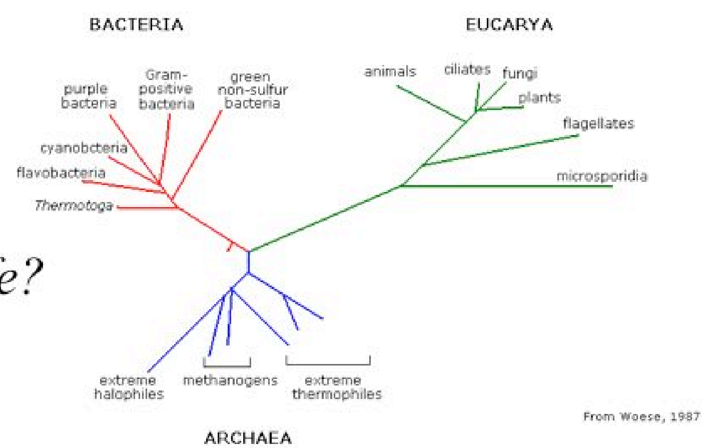
courtesy of J.W. Schopf



Fossils are not enough

- Fossils tell us that there was life on Mars
- But not the nature of that life or its relationship, if any, to life on Earth

Is martian life on the tree of life?



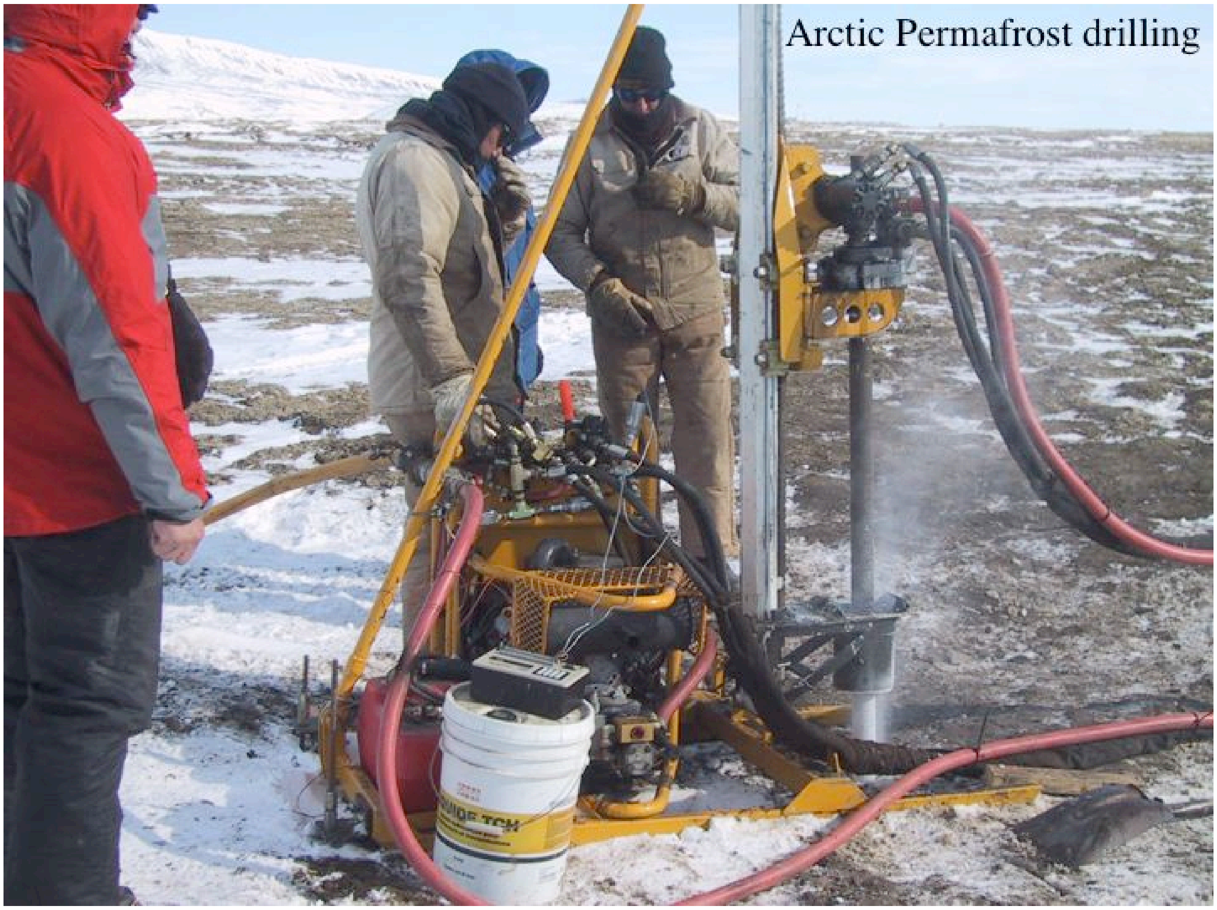
Fossils are not enough for a forensic investigation.

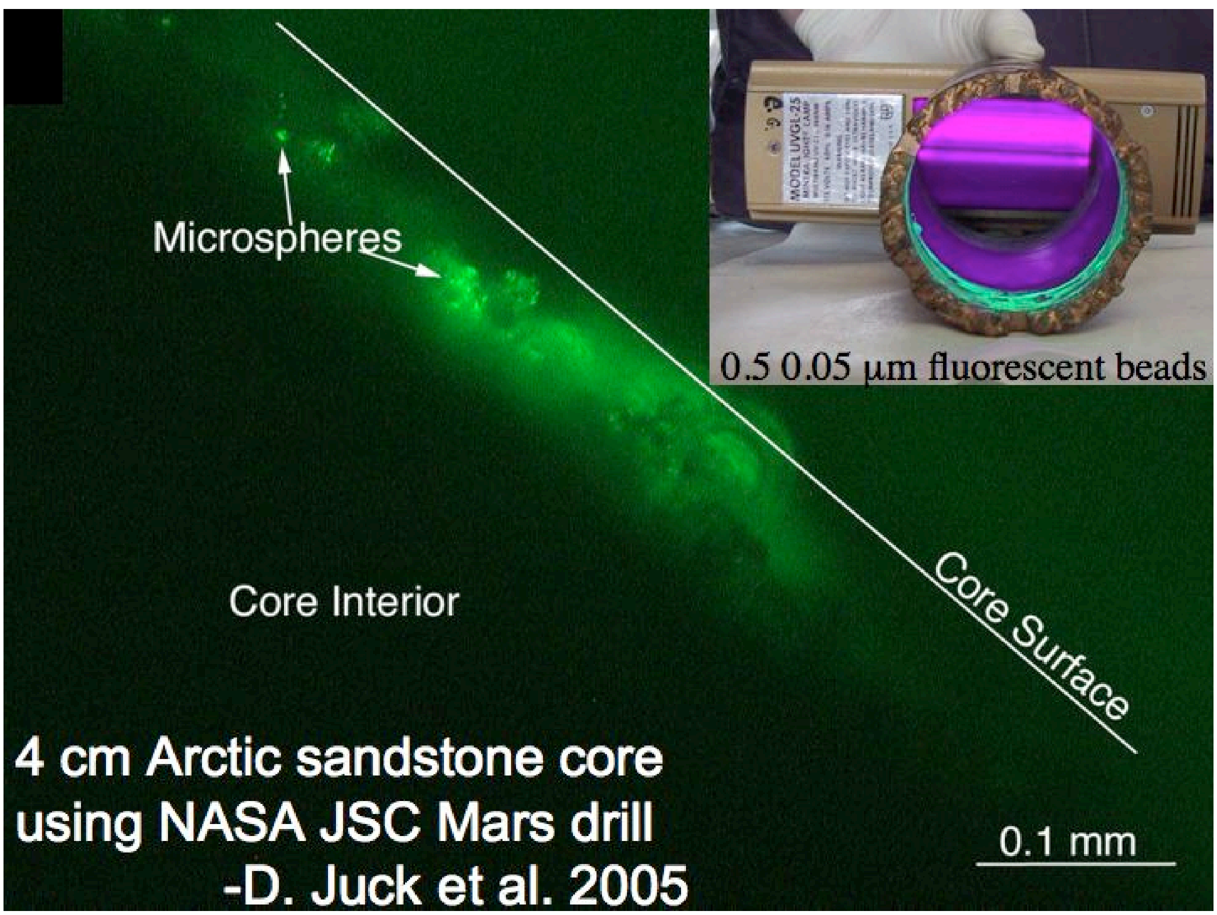
Possible Sources:

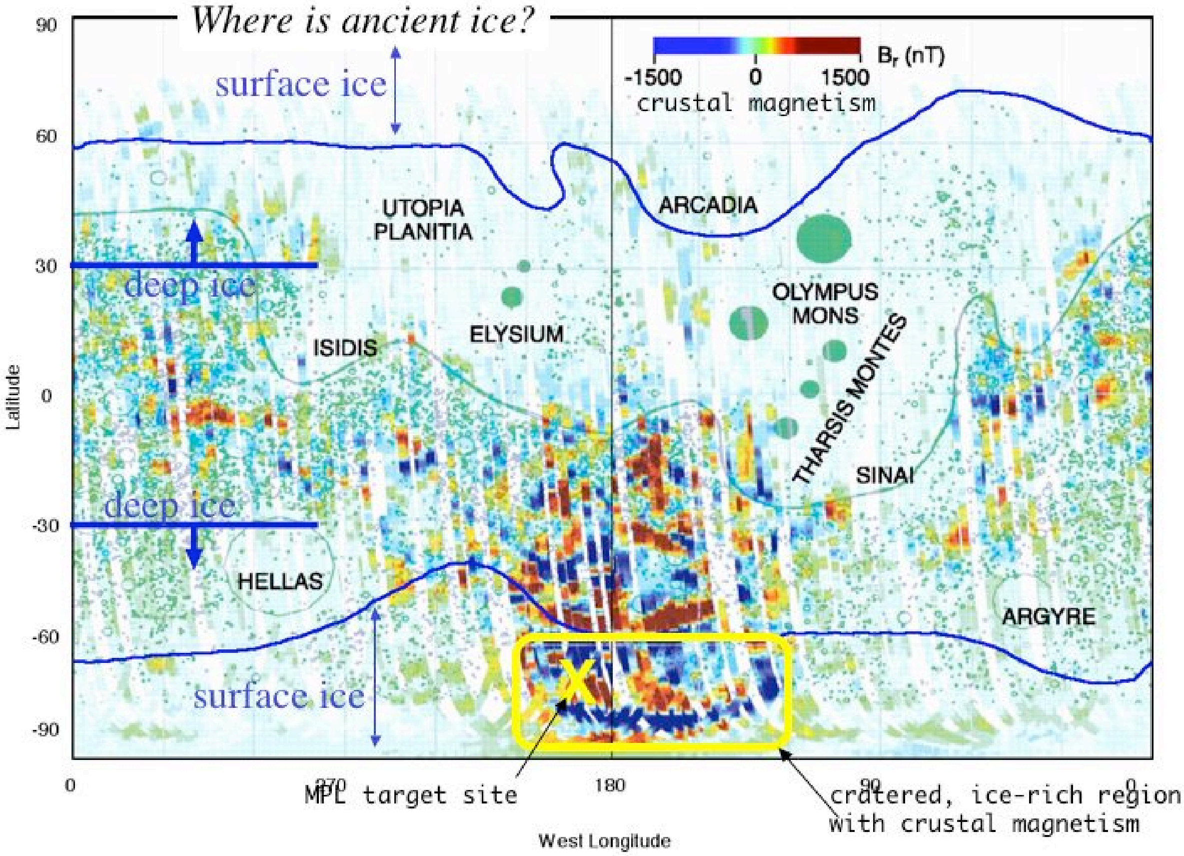
- Viable spores in the soil
- Extant subsurface life
- Organisms preserved in amber or salt
- **Organisms preserved in permafrost** ←

Permafrost in Siberia: 3.5 Myr old and contains viable bacteria

Beacon Valley, Antarctica: Here there may be 8 Myr old ice; -25°C
This ice contains viable bacteria and may be the oldest ice on Earth.


Arctic Permafrost drilling


Microspheres
0.5 0.05 μm fluorescent beads
Core Interior
Core Surface
4 cm Arctic sandstone core
using NASA JSC Mars drill
-D. Juck et al. 2005
0.1 mm



From:Smith & McKay, PSS 2005; data from Acuna et al, 1999; Barlow, 1997, Squyres and Carr, 1986

Limits on long term dormancy

- kT: Thermal decay: ~$e^{-\Delta E/kT}$
  racemization of amino acids
  degradation of organic material
  not important on Mars, -70°C
- eV: Radiation from crustal U,Th, K ~0.2rad/yr
  lethal dose for *Deinococcus radiodurans* in 100 Myr
  on Mars hundreds of lethal dose over 3.5 Gyr
- Its dead, Jim

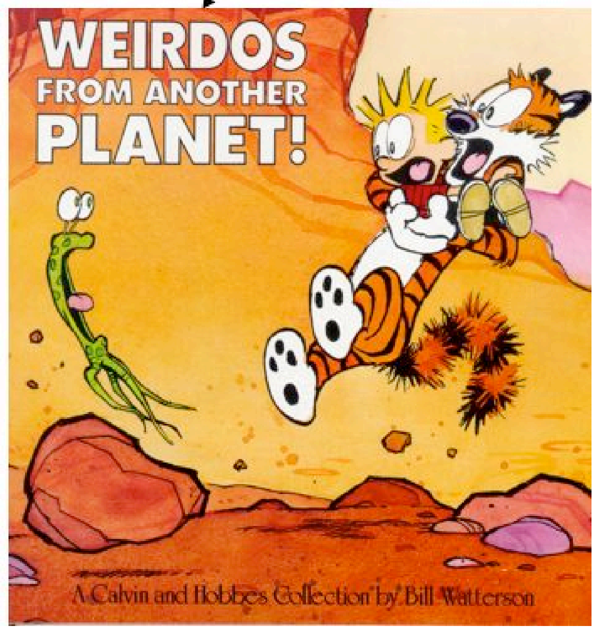
If we find organic material on Mars (or Europa) how can we tell if it was ever alive?

If its like us then easy, less interesting
If its alien then hard, but interesting

How do we recognize alien life?

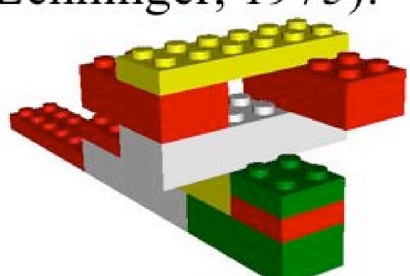
use a tricorder!

we'll know it when we see it!



The Lego® Principle

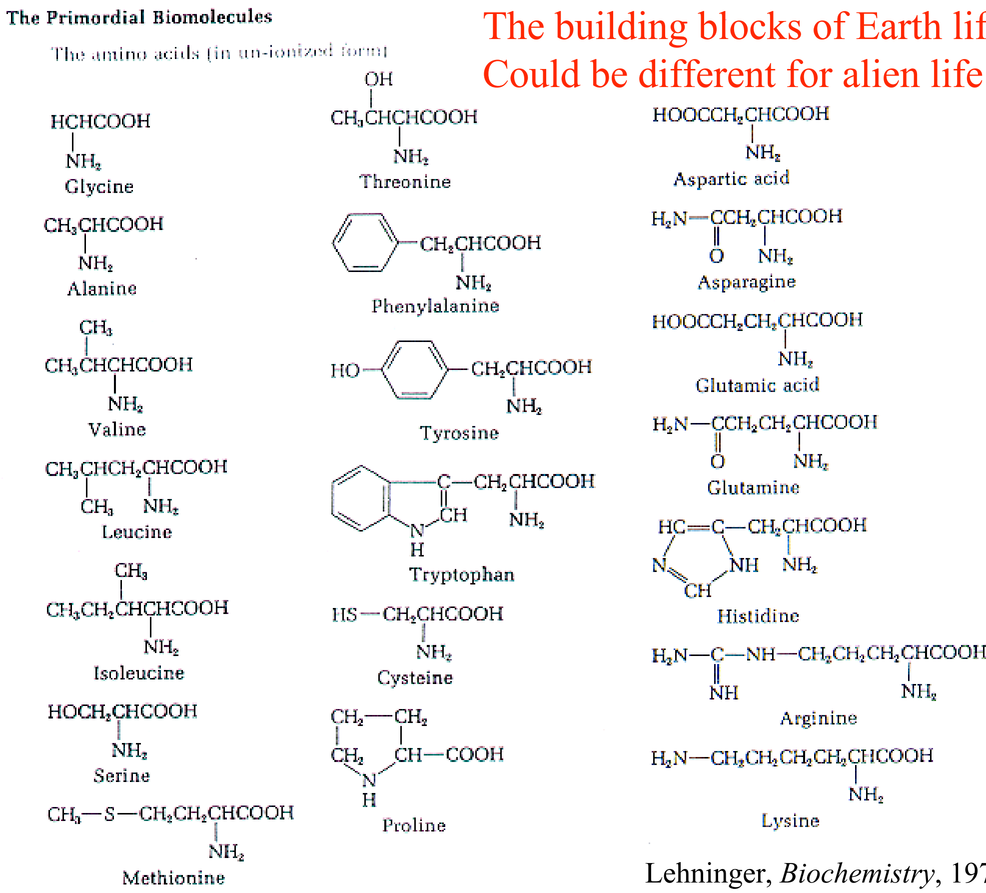
•Biology is largely built from on a small number of components (Lehninger, 1975):
-20 L amino acids
-5 nucleotide bases
-few D sugars, etc.



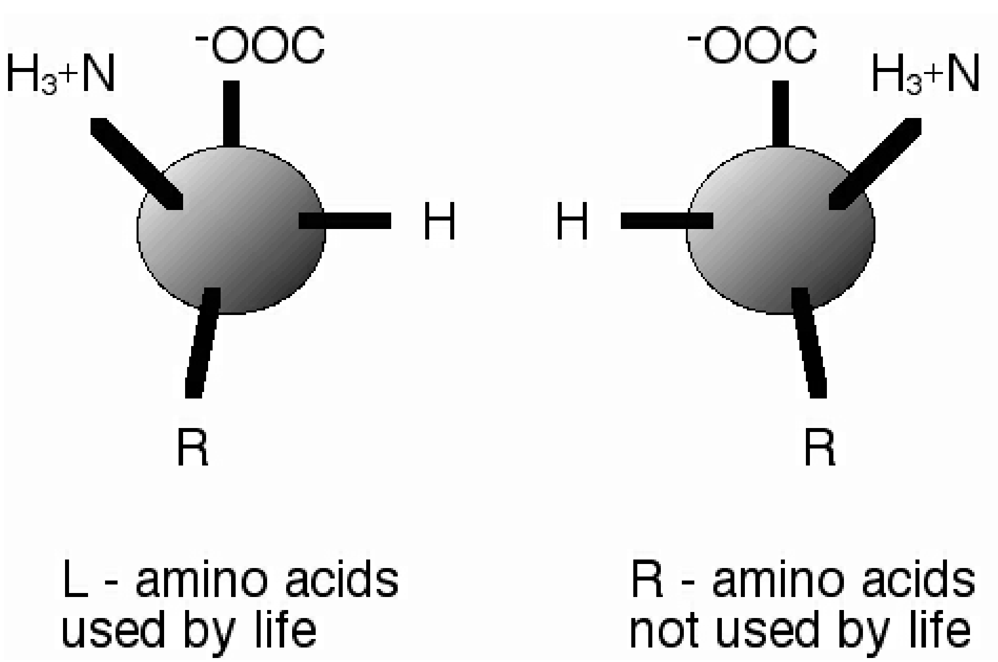
•Likely a common property of biology (and mass-produced children's toys) throughout the universe.

McKay 2004 *PLoS Biol* 2(9)1260-12623

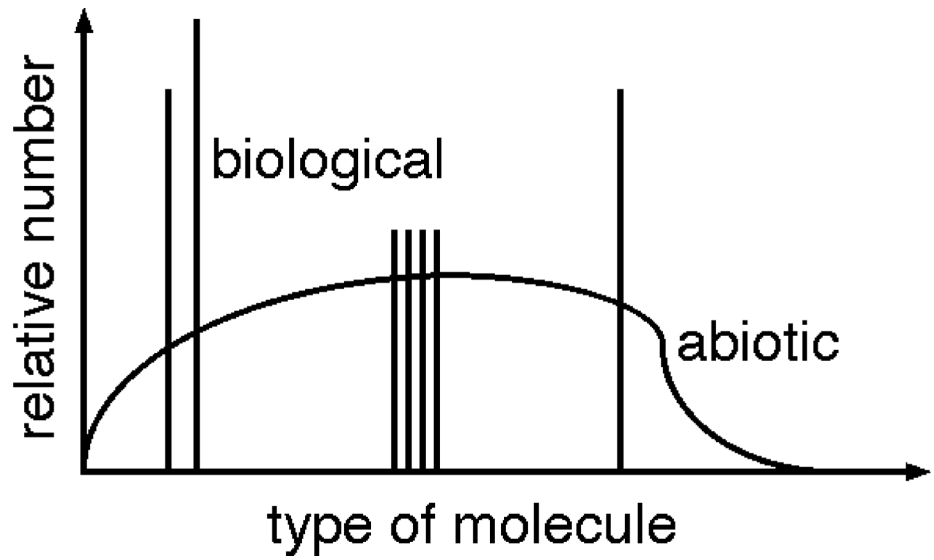
The building blocks of Earth life.
Could be different for alien life forms.



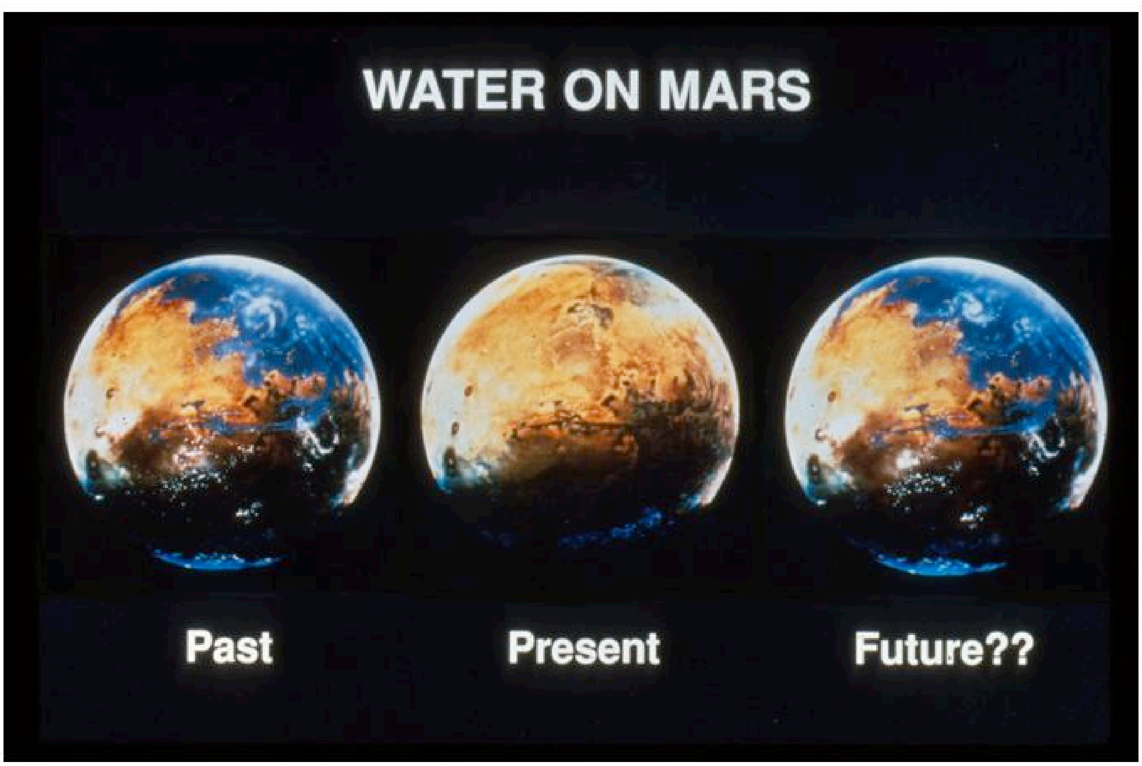
Lehninger, *Biochemistry*, 1975 page 21



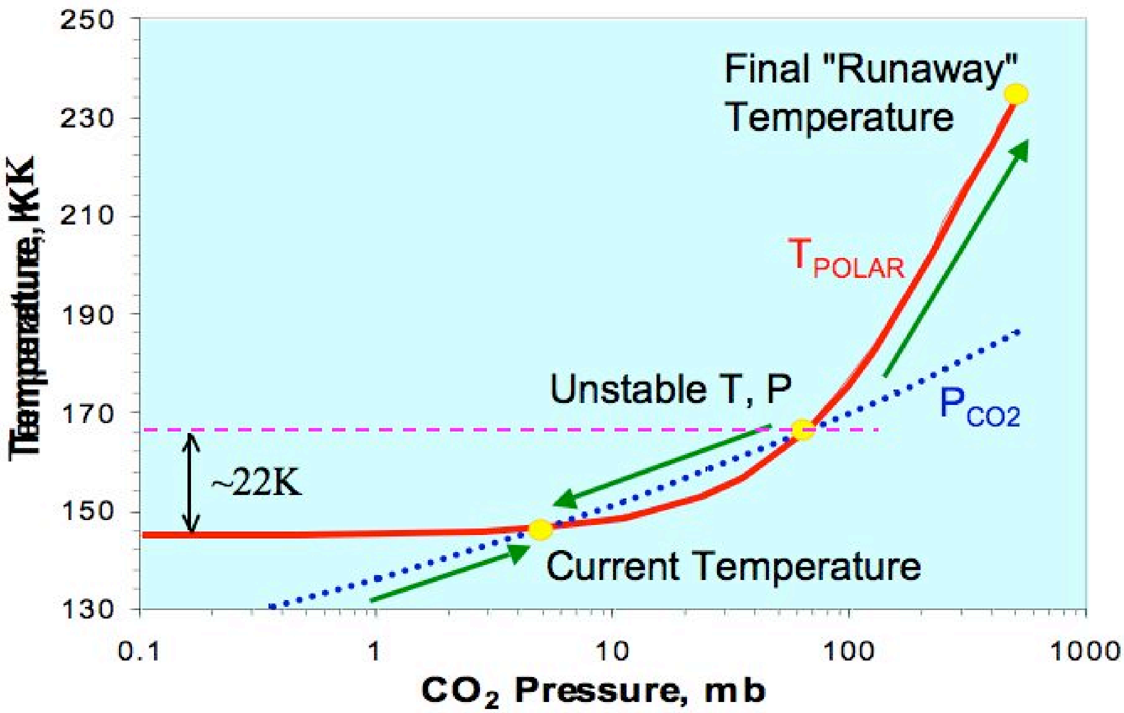
Abiotic distributions are smooth
Biotic distributions are spiked

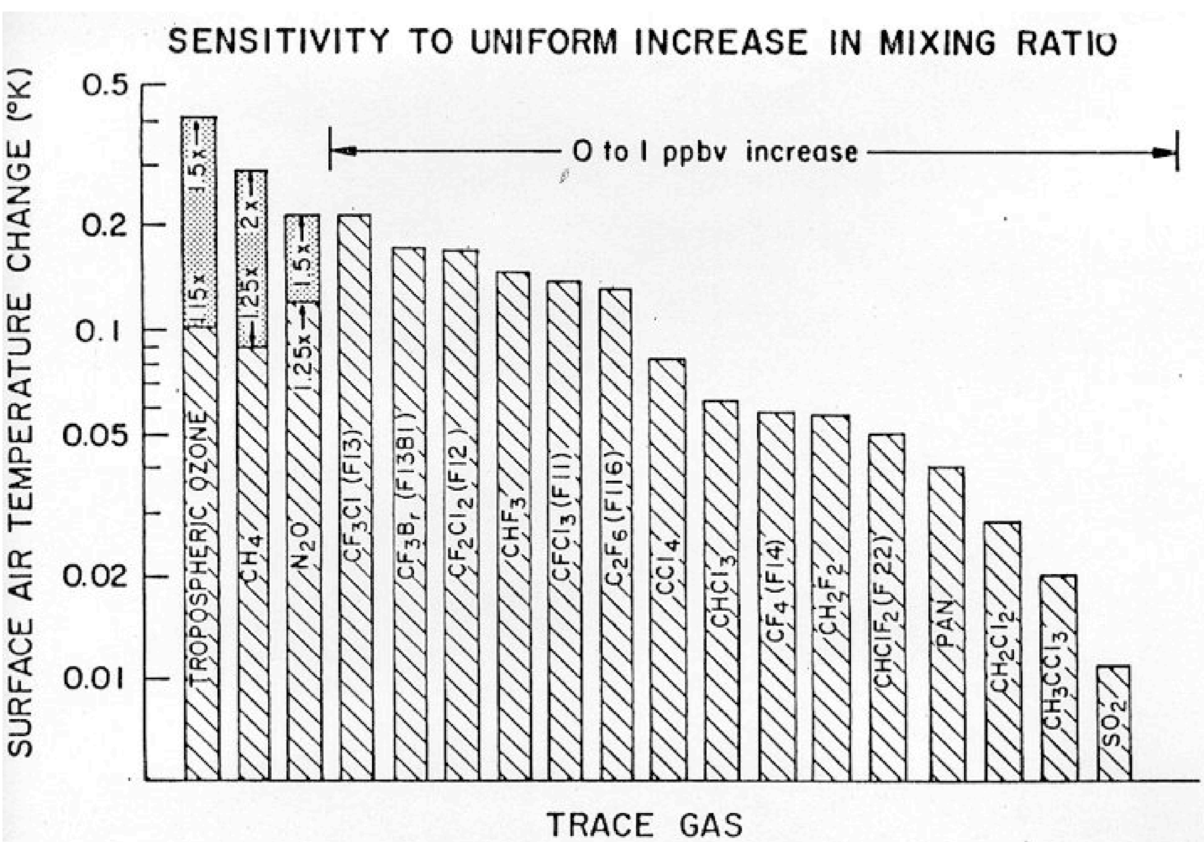


McKay 2004 *PLoS Biol* 2(9)1260-12623



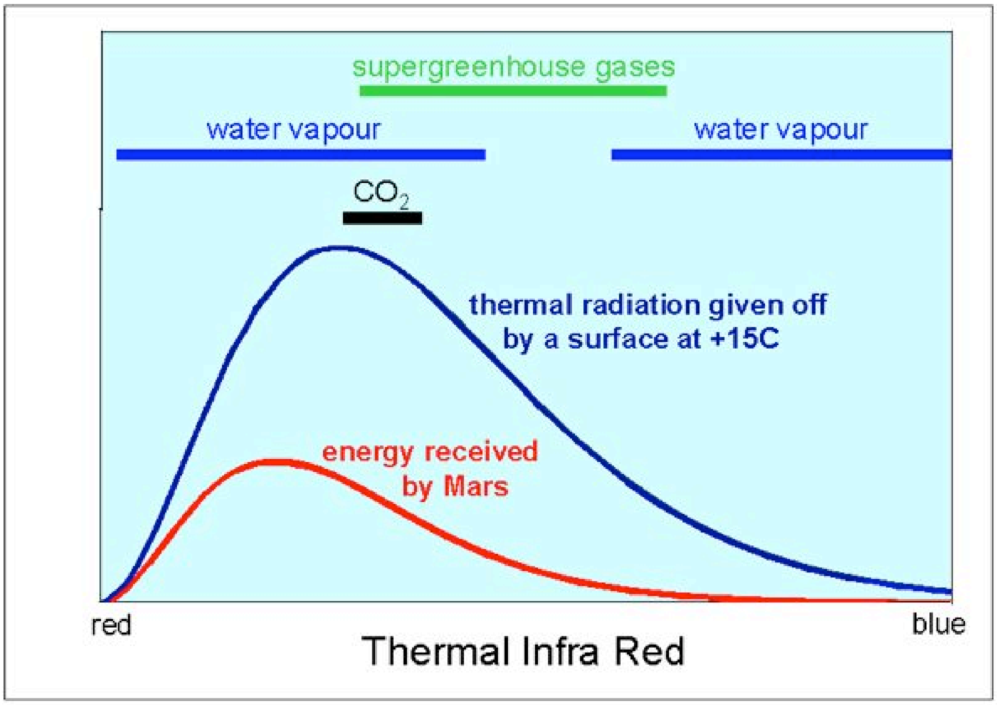
How much warmer?



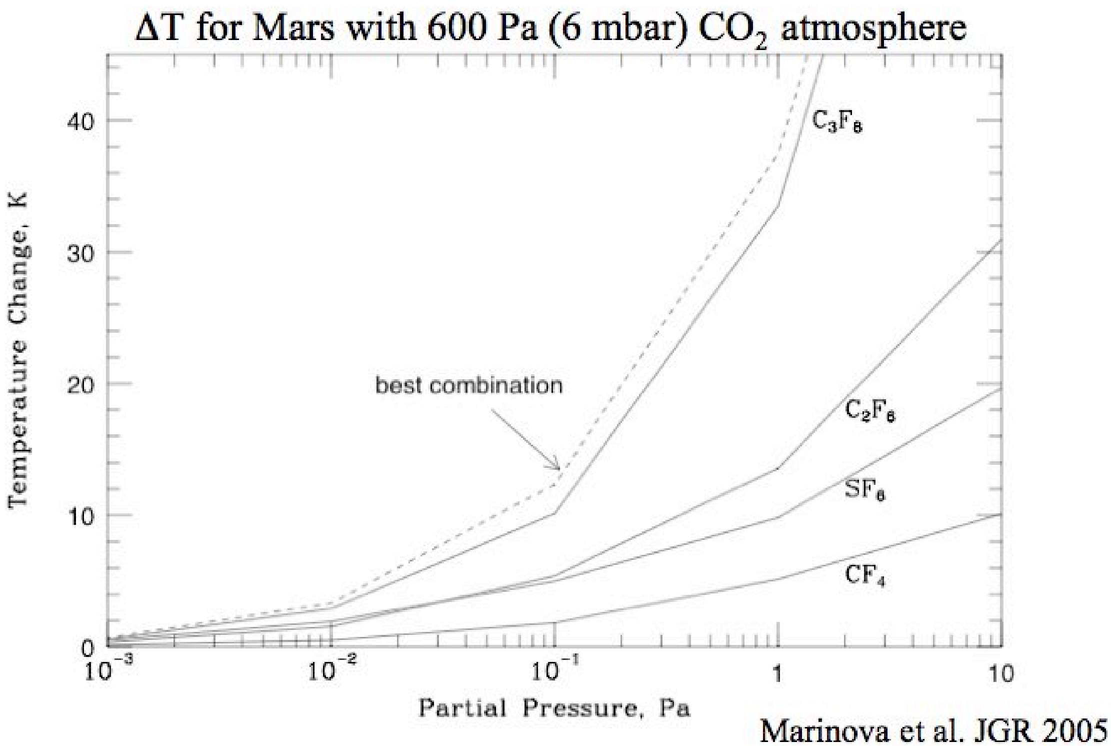


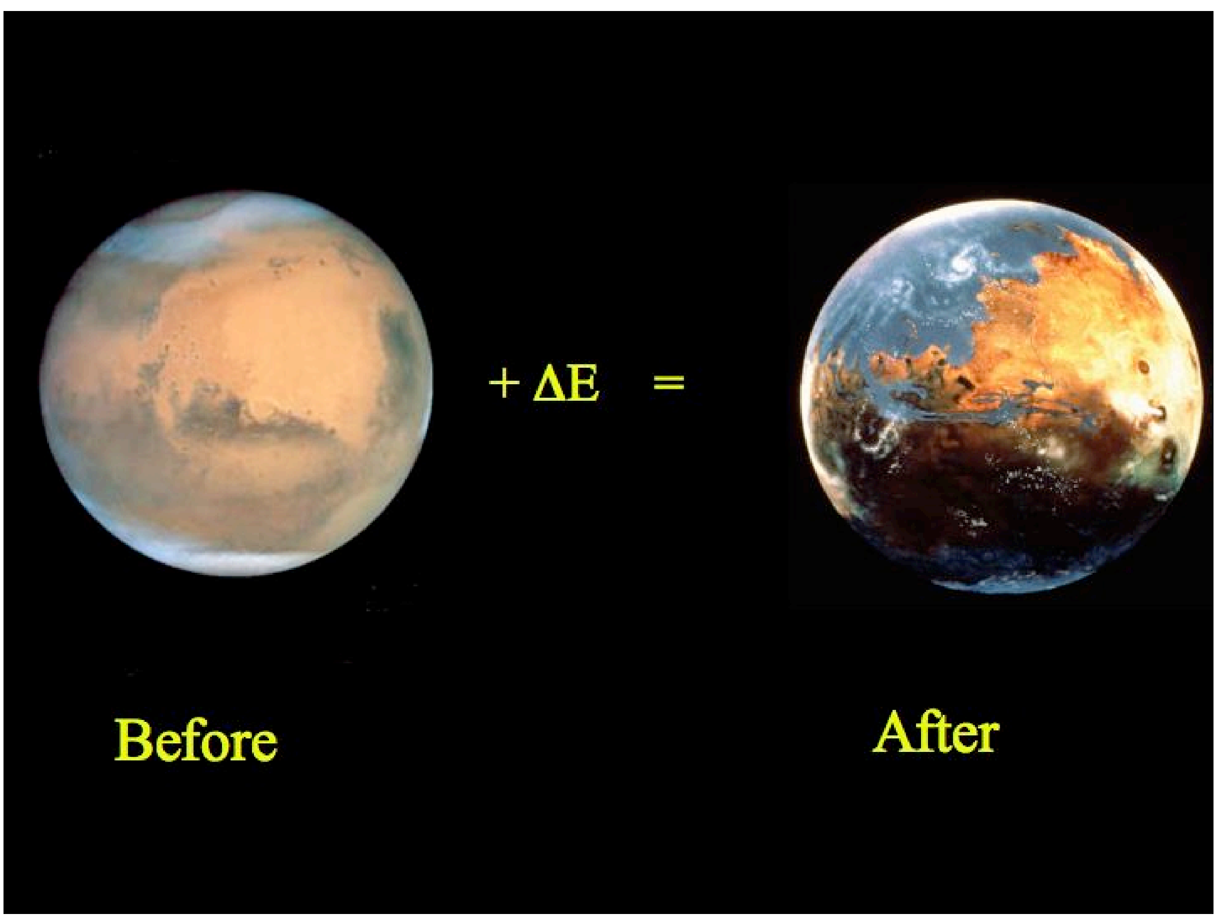
from Ramanathan et al. J. Geophys. Res. 1988.

The Greenhouse Gases Blanket



Results

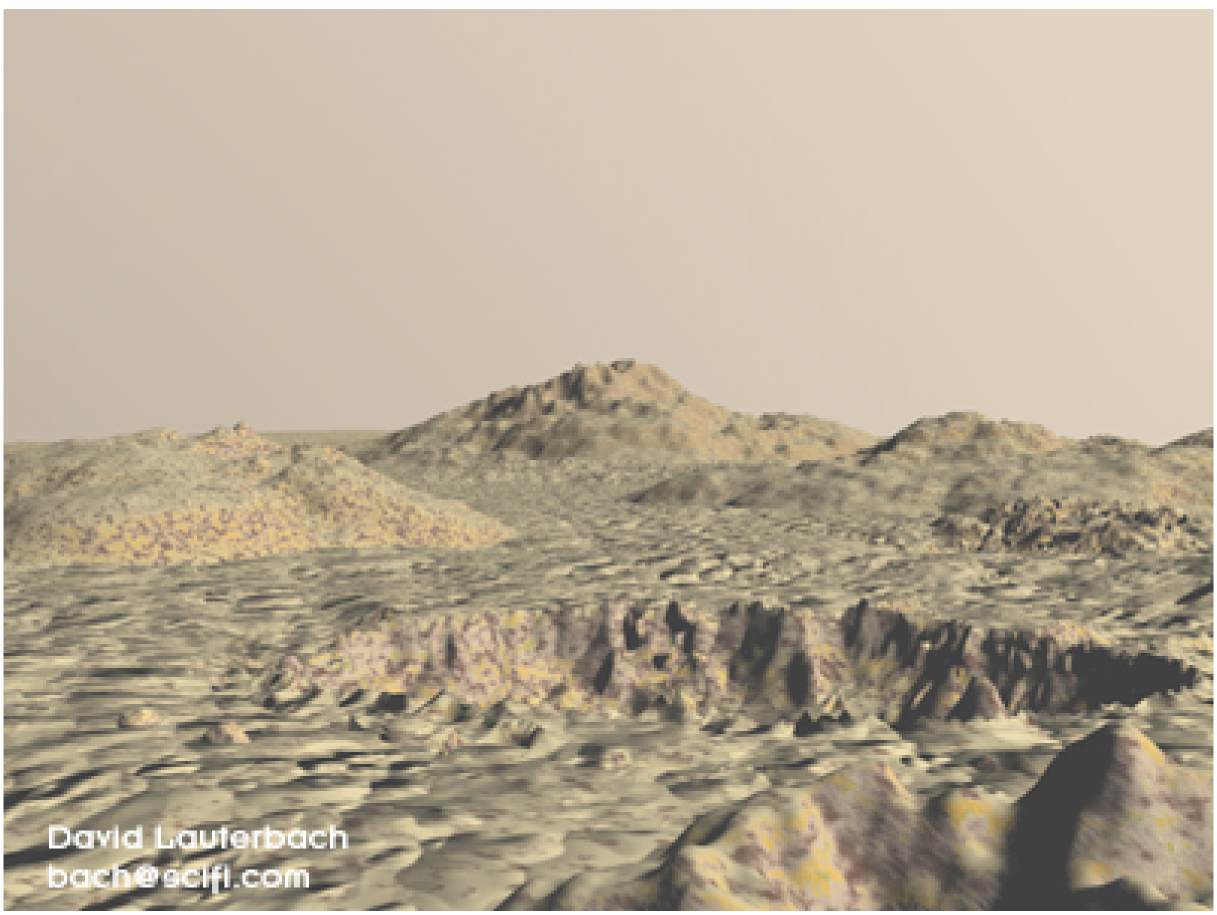

ΔT for Mars with 600 Pa (6 mbar) CO2 atmosphere
Temperature Change, K
Partial Pressure, Pa
best combination
C3F8
C2F6
SF6
CF4
0
10
20
30
40
10−3
10−2
10−1
1
10
Marinova et al. JGR 2005


+ ΔE =
Before
After

Energy & Time Requirements for Terraforming Mars

Initial State	Final State	Amount	Energy [J m^{-2}]	Solar Energy[a] [years]	Time [years]
		Surface Warming			
CO_2(s) at -125°C	CO_2(g) at 15°C	200 kPa; 5.4x10^4 kg m^{-2}	3.7x10^{10}	7.9	
Dirt at -60°C	Dirt at 15°C	~10 m; 2x10^4 kg m^{-2}	1.2x10^9	0.3	
H_2O(s) at -60°C	H_2O(l) at 15°C	10 m; 1x10^4 kg m^{-2}	5.5x10^9	1.2	
H_2O(s) at -60°C	H_2O(g) at 15°C	2 kPa; 5.4x10^2 kg m^{-2}	1.6x10^9	0.33	
			Total:	10	100
		Deep Warming			
H_2O(s) at -60°C	H_2O(l) at 15°C	500 m; 5x10^5 kg m^{-2}	2.8x10^{11}	56	500
		Making O_2			
CO_2(g) + H_2O	CH_2O + O_2(g)	20 kPa; 5.4x10^3 kg m^{-2}	8x10^{10}	17	100000

[a] Energy divided by the total solar energy reaching Mars in a year, 4.68x10^9 J m^{-2} yr^{-1}
Adapted from McKay *et al*., 1991. *Nature* **352**, 489-496.

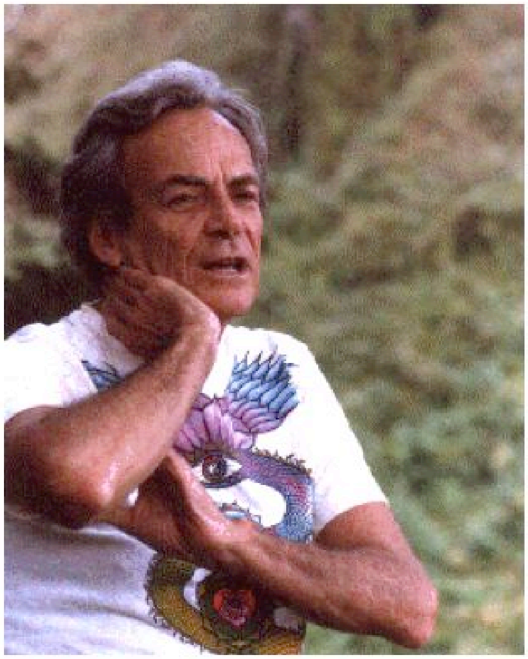


The Astrobiology Questions

(from the first CAN for Astrobiology from NASA HQ 1997)

1. How do habitable worlds form and how do they evolve?
2. How did living systems emerge?
3. How can other biospheres be recognized?
4. How have the Earth and its biosphere influenced each other over time?
5. How do rapid changes in the environment affect emergent ecosystem properties and their evolution?
6. What is the potential for survival and biological evolution beyond the planet of origin? *NEW*

What I cannot create I do not understand.



Richard P. Feynman
written on his office blackboard
as he left it for the last time
in January 1988


"That's all Folks!"