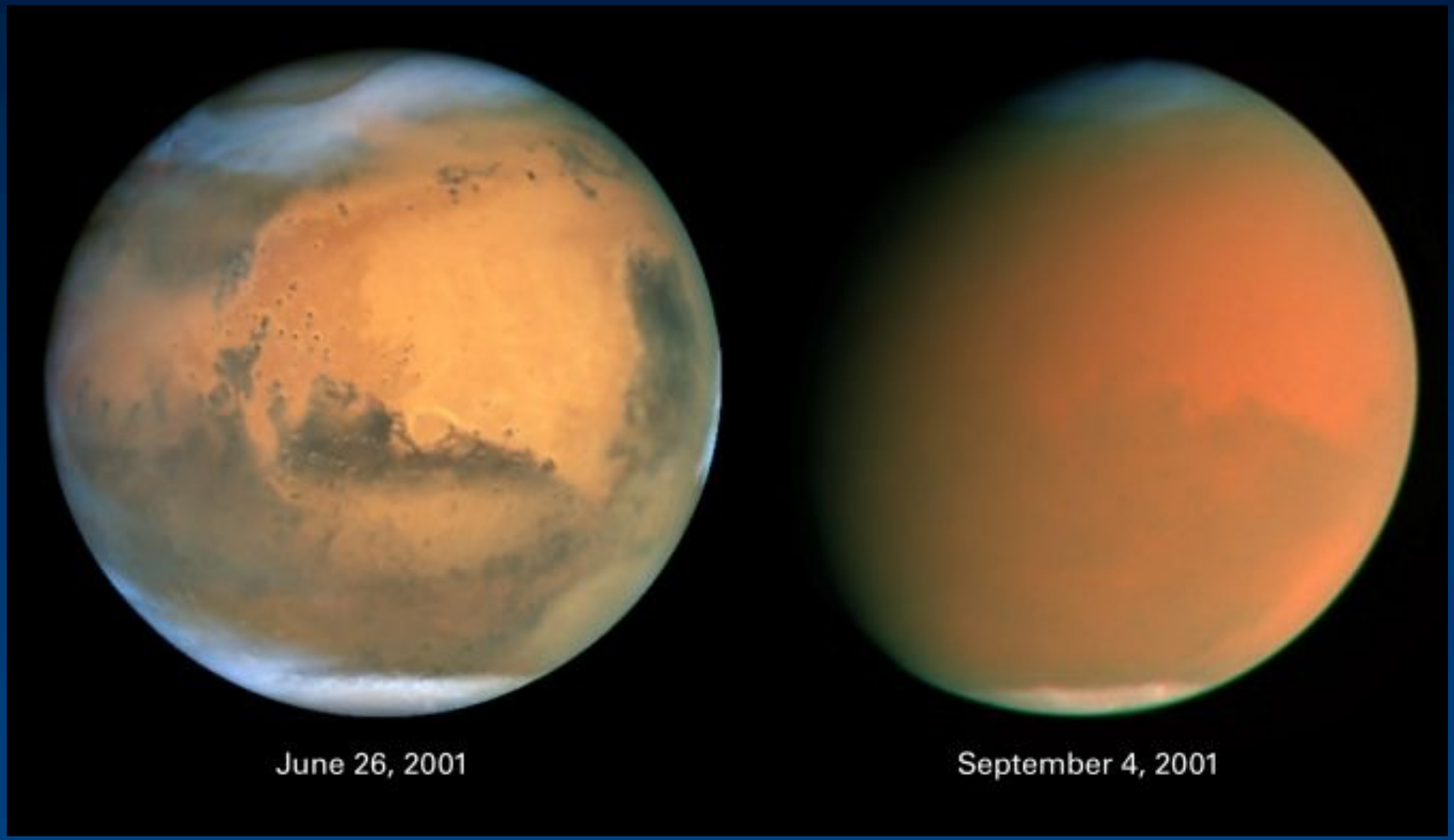
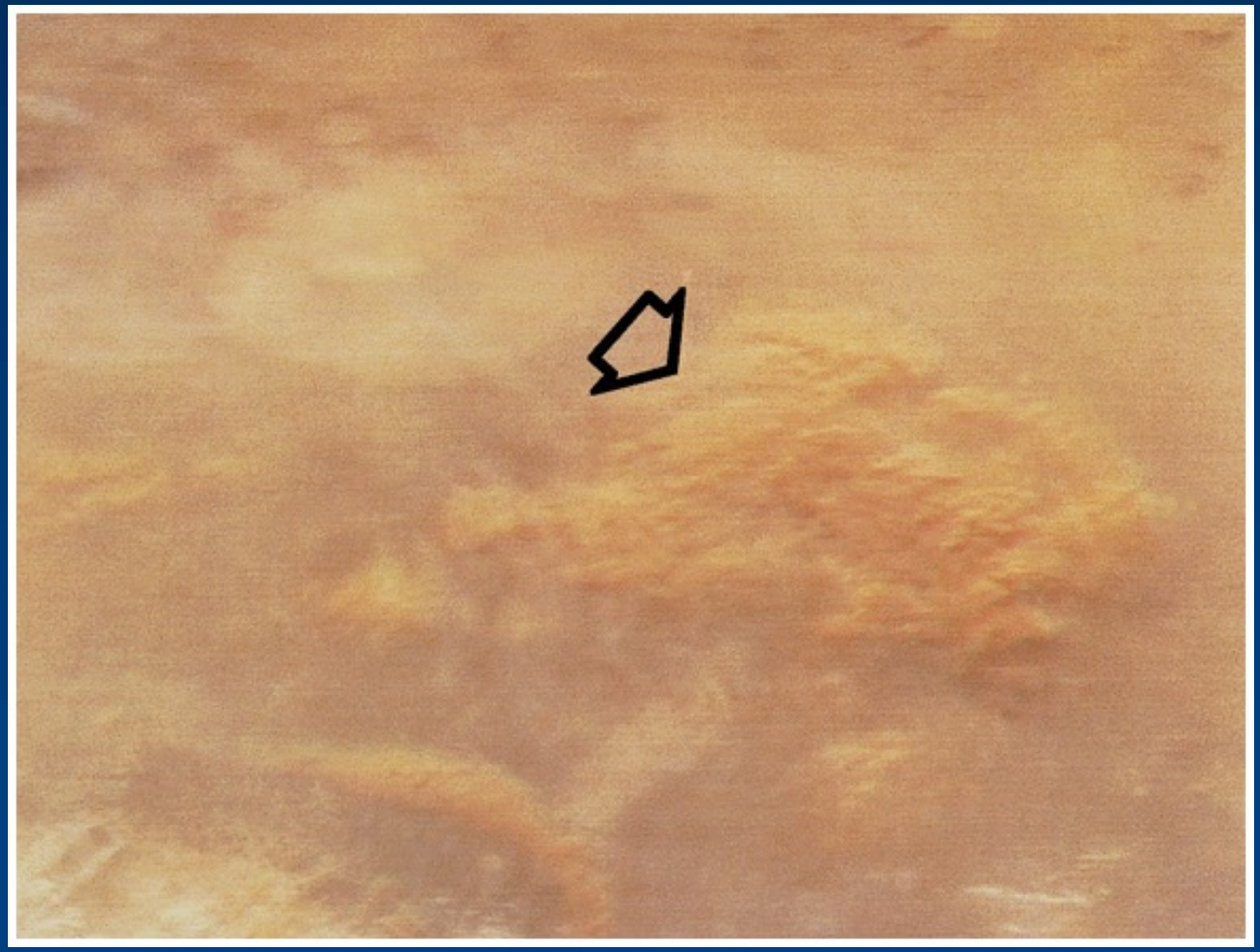
Announcements

- HW7 is in the boxes
- HW8 Due April 4
- Extra Credit: Take a photo of yourself with the eclipse on Monday and e-mail it to me. Evidence of the eclipse could be from shadows, a pin-hole camera, an image through a telescope, etc

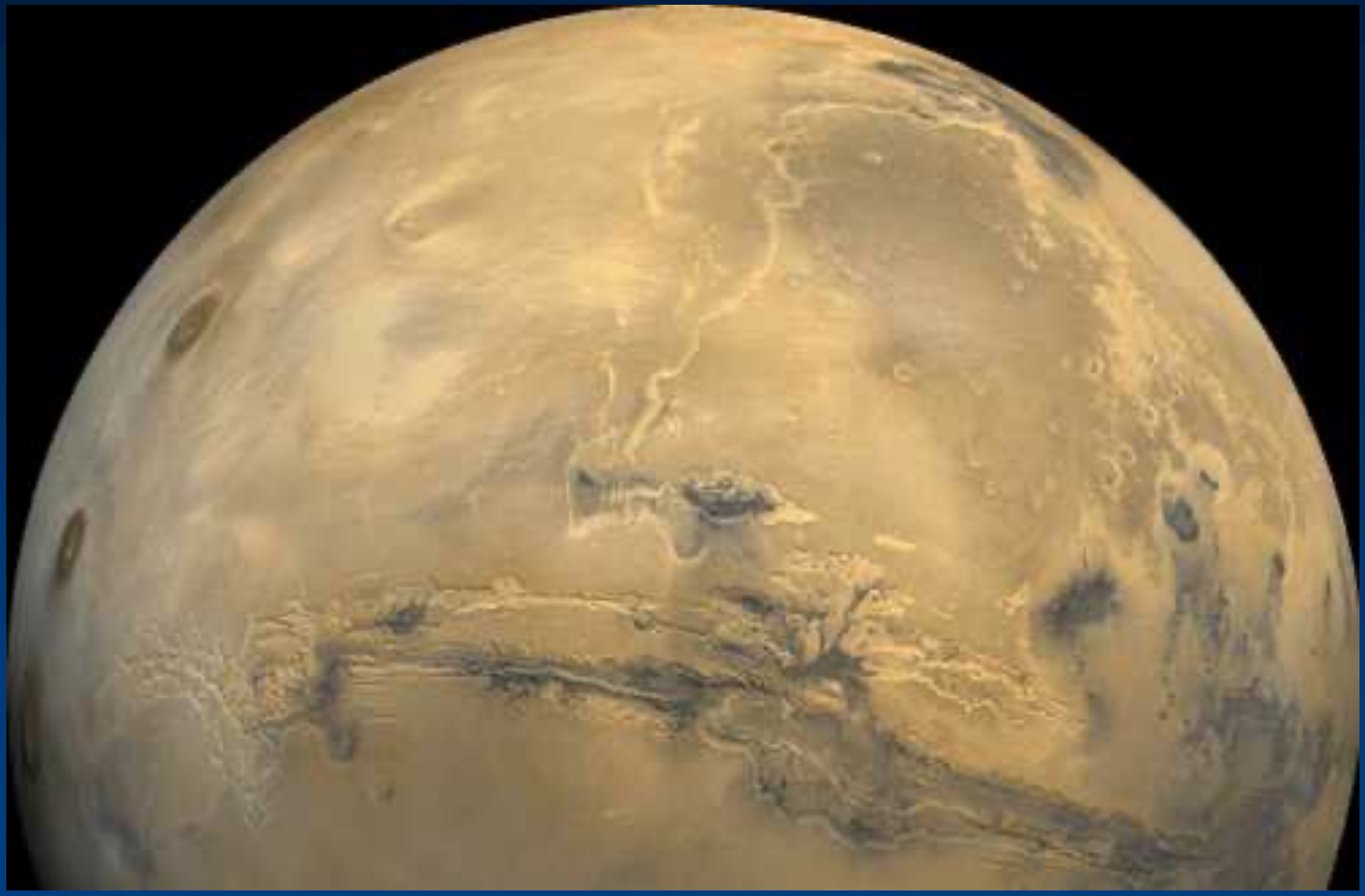

June 26, 2001
September 4, 2001

From space – starting with Mariner missions in 1960s

First images showed no detail; initial thoughts of problems with the cameras gave way to an understanding that there was a planet-wide sandstorm. With time we saw craters, mountains, valleys, etc.

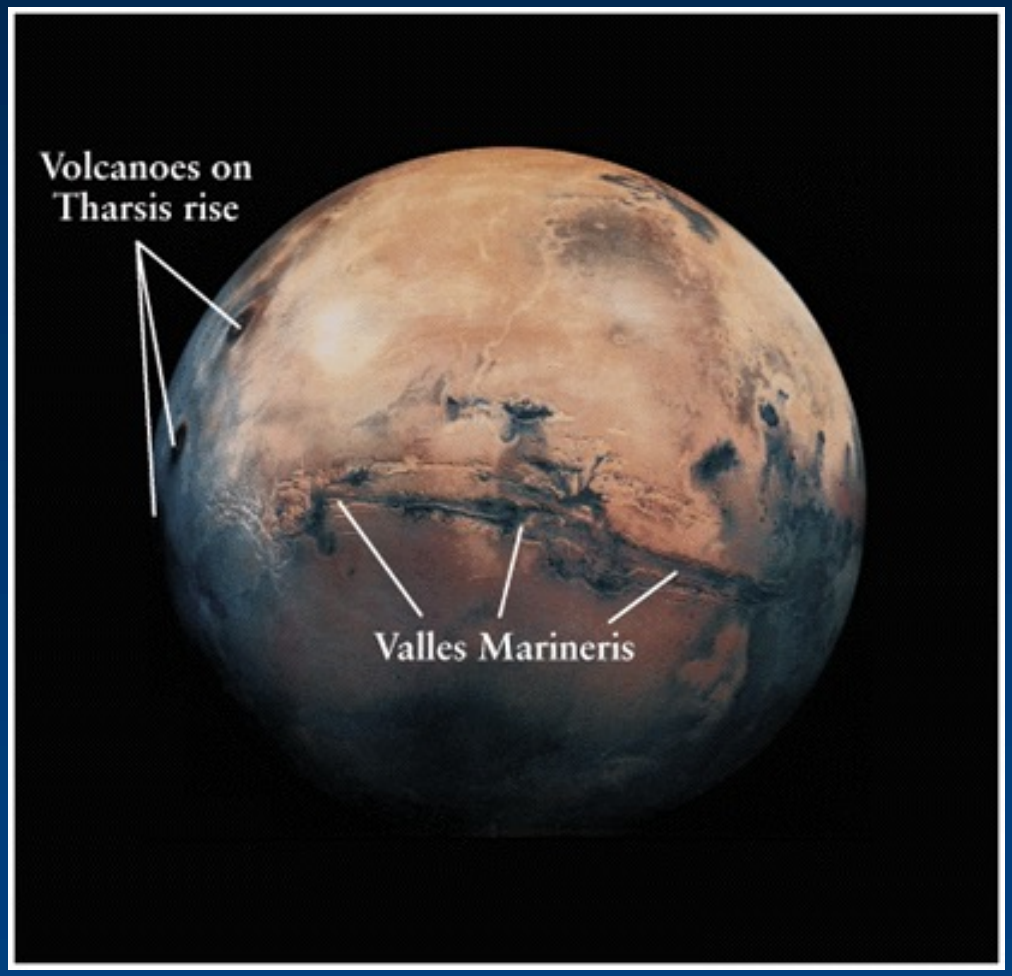


Viking Orbiter image of a Martian dust storm



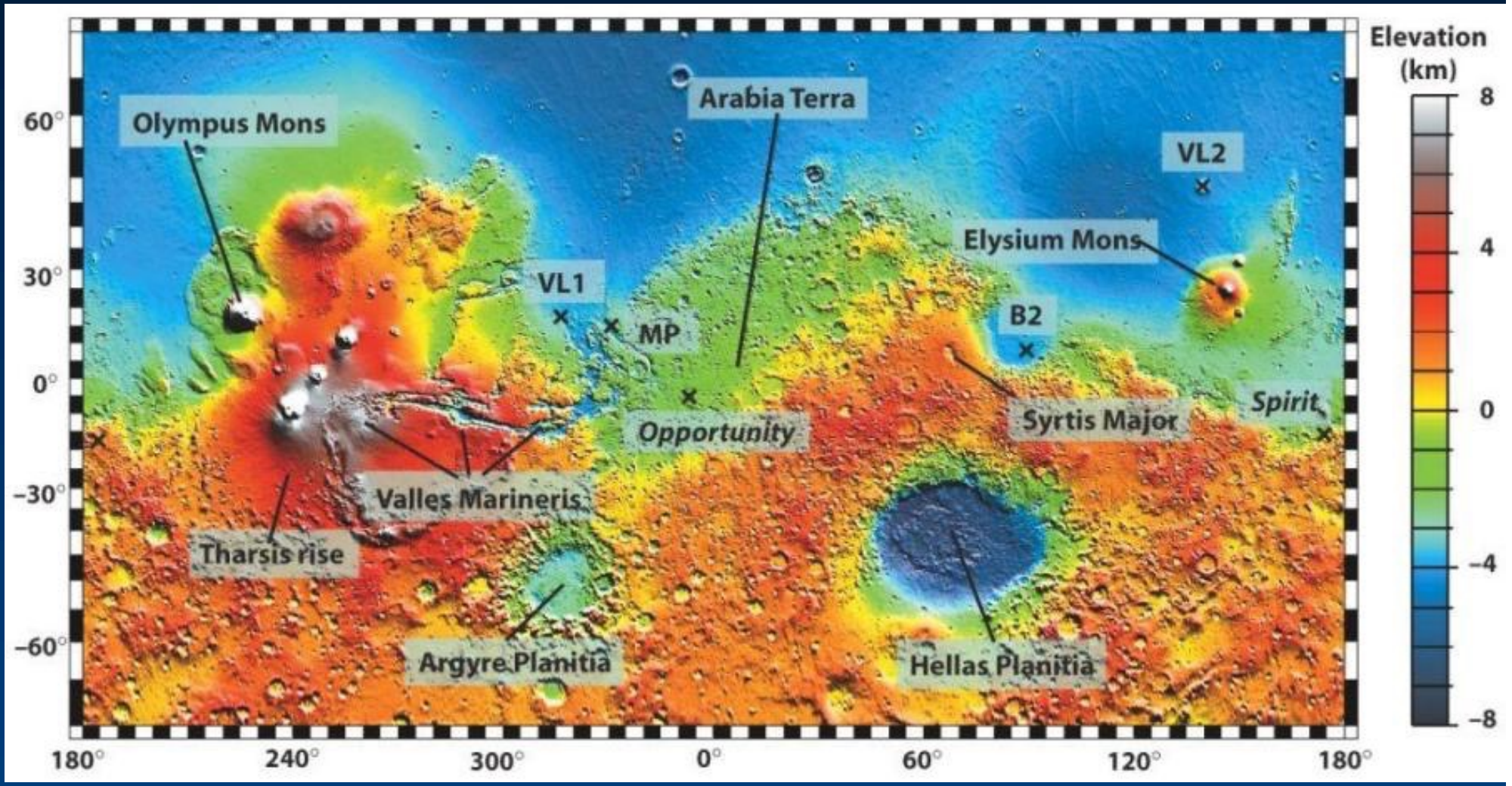
Mariner 9 ('71): meteor craters (Hellas largest), volcanic plains, volcanic cones, huge gorges (Valles Marineris)

Mosaic of Viking Orbiter (1970s) images shows huge volcanoes and enormous rift valley – Valles Marineris is about the width of continental US.



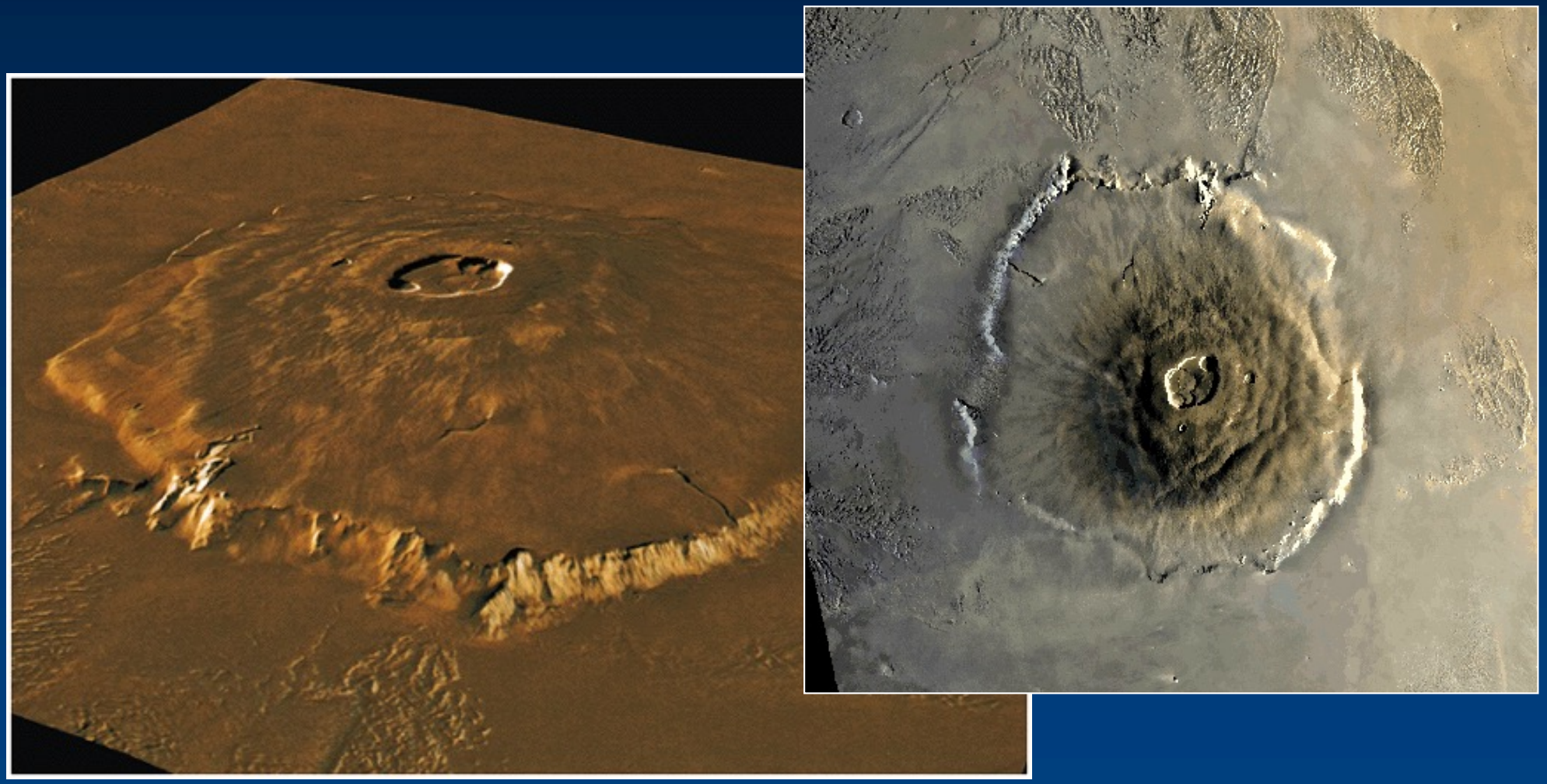
Probably a rift in surface caused by rise of the Tharsis bulge – a convection feature.

Valles Marineris from Mars Express mission (stereo camera used)



Topographical map by *Mars Global Surveyor*, showing major features, landing sites. Northern hemisphere is relatively smooth and flat. "Crustal dichotomy": northern lowlands, southern highlands. But like Venus, no plate boundaries.

Solar System's largest volcano: Olympus Mons (3xMount Everest. Rises 24 km (15 mi), diameter of 600 km (370 mi).

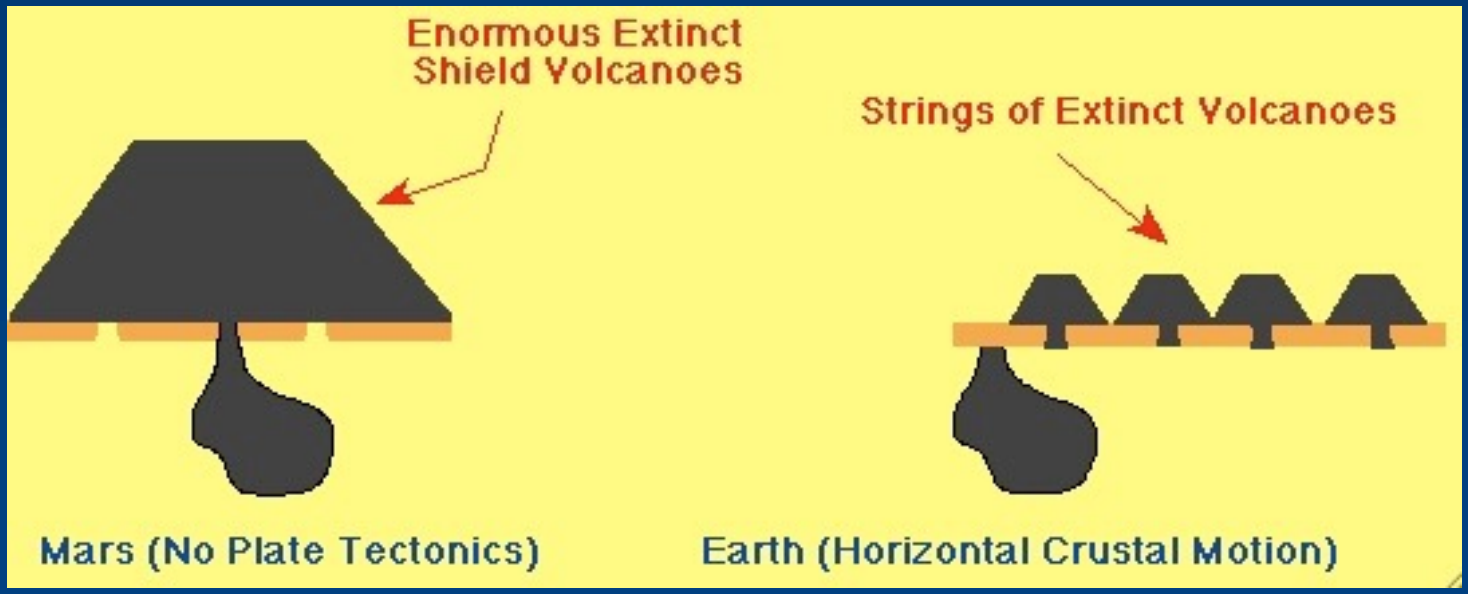


Viking Orbiter (`71).

Surface: plate tectonics?

Current thinking NO, or if so only briefly.

- Absence of plate tectonics (or brief period due to shorter cooling time)
- Crust is thick and solid
- Lower surface gravity (0.38 of Earth's) helps volcanoes to grow high



Is Mars geologically dead?

- No directly observed volcanic activity
- Youngest lava flows on Olympus Mons are less than 5 million years old – volcanoes may still be active, just dormant right now
- Valles Marineris is probably rift in surface caused by rise of the Tharsis bulge – a convection feature
- Lack of magnetic field indicates no interior dynamo

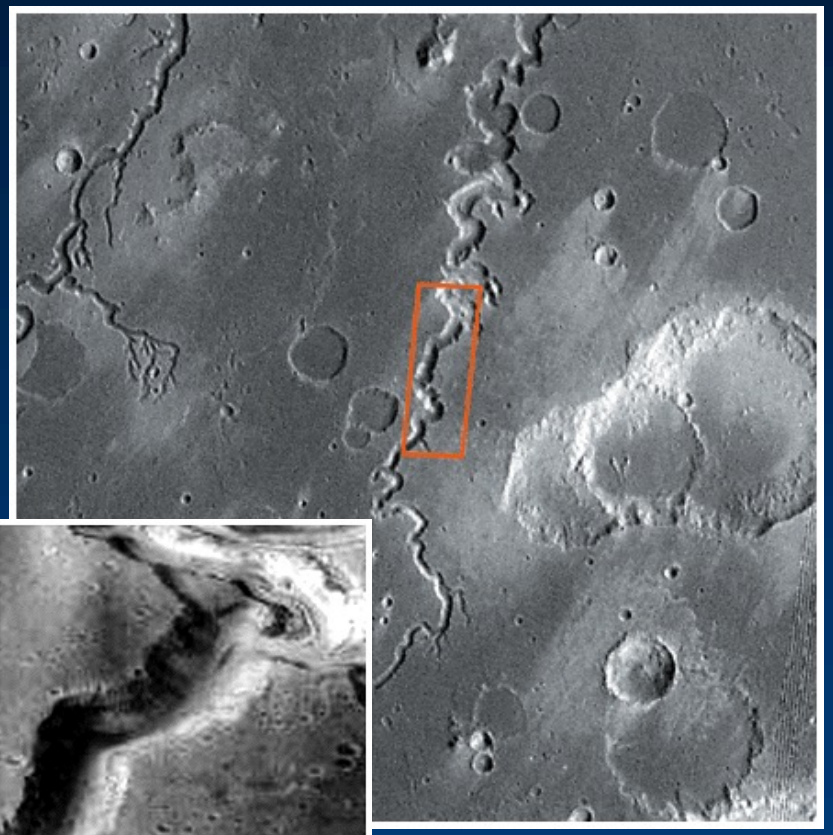
Water on Mars?

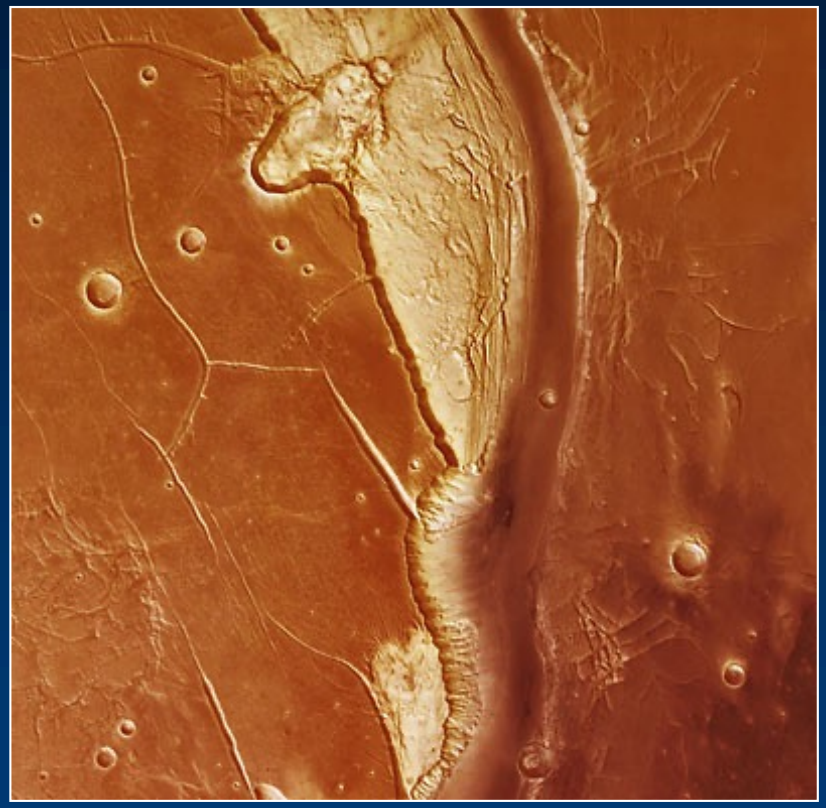
Martian Channels (can be 1500 km long, 200 km wide)

Features that look carved by running water.

NB: Current atmospheric pressure too low for liquid water.

Islands carved by water?

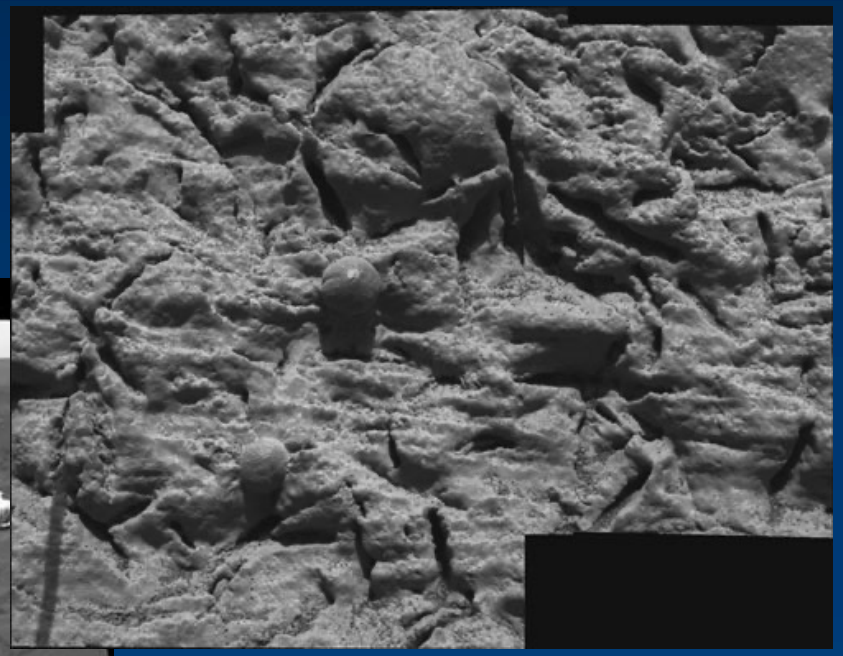


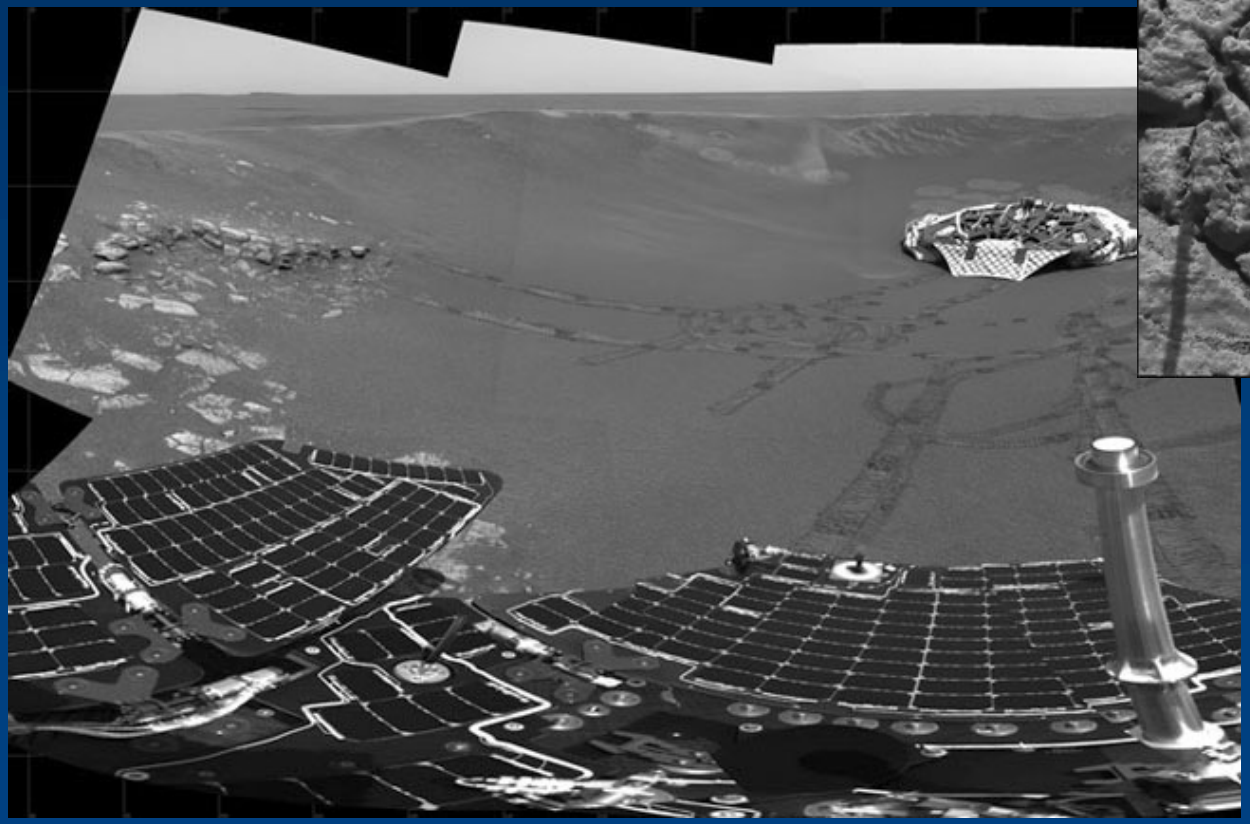


Mars Global Surveyor & Mars Express: in the canyons, there are evidence of terraces, looking like riverbeds on Earth.

Further evidence Mars was wet: appearance of surface, and presence of *sulfates* – on Earth, found only in rocks exposed to water over long periods.

Opportunity rover images:





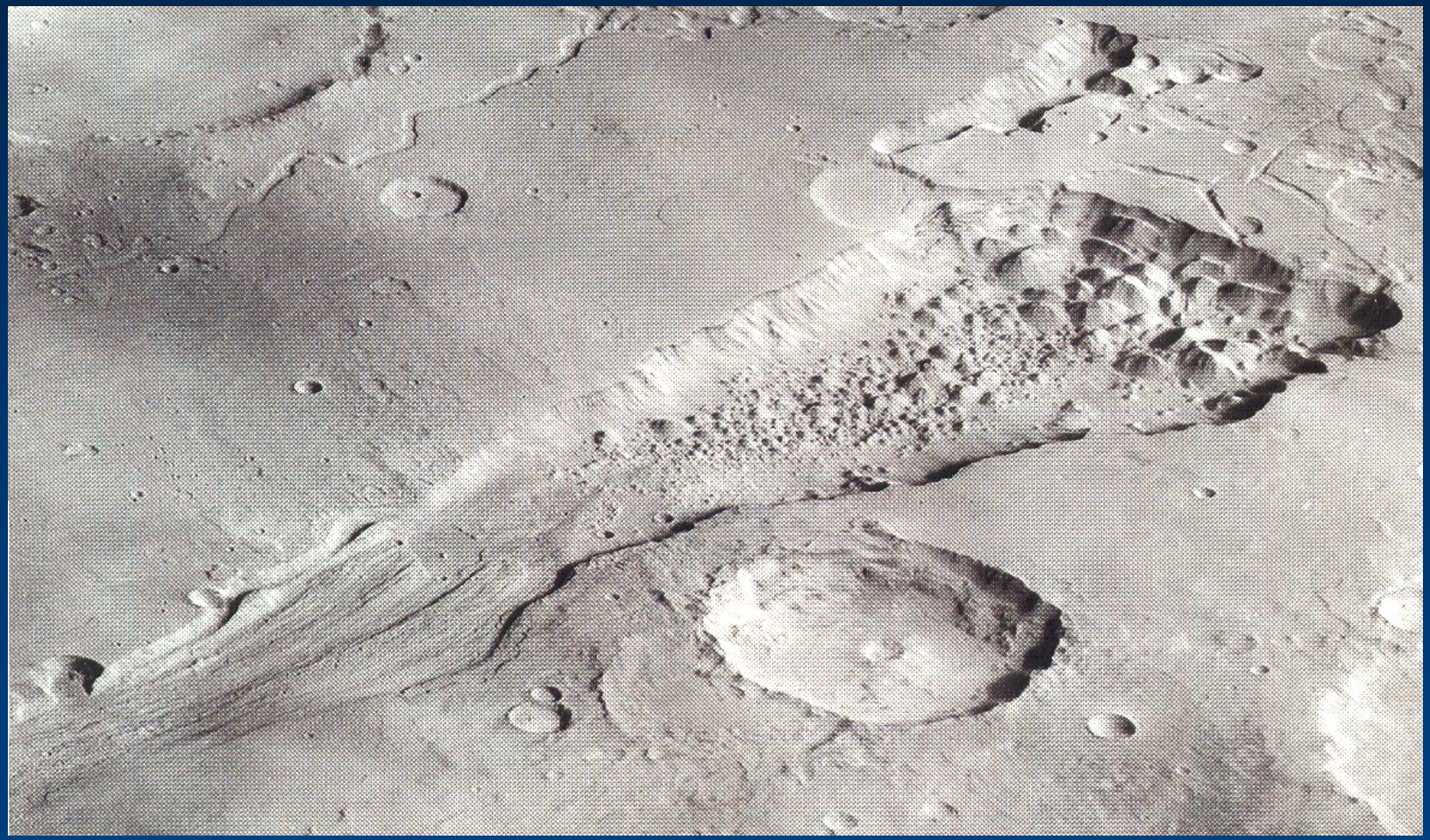
Martian atmosphere is too thin for water to exist as liquid on surface. Could it in the past?

From crater density calculations, runoff channels date back about 4 billion years.

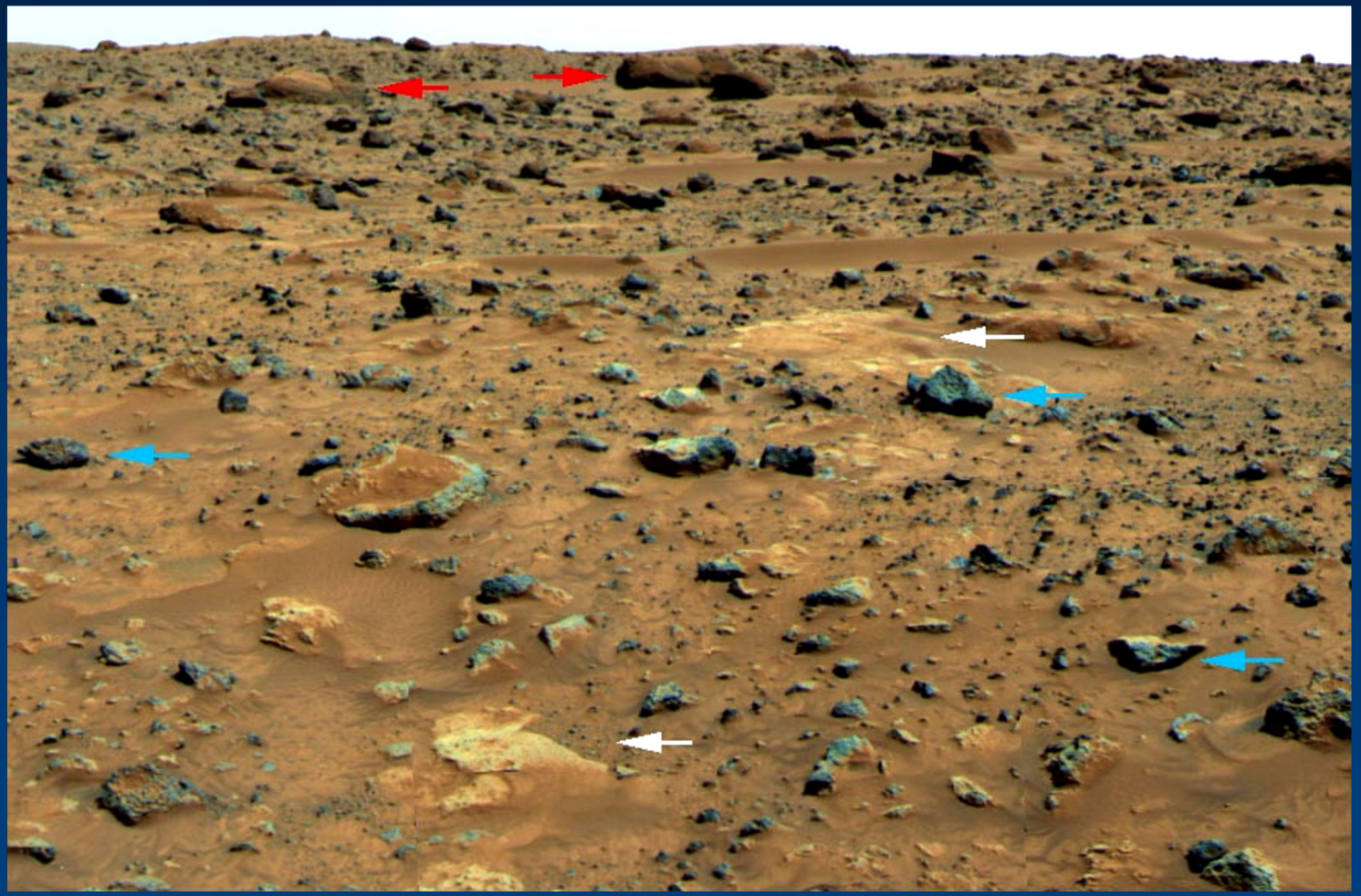
More recently (current)?: Melting of permafrost could create outflow features.

Melted by subsurface heat?

Valles Marinaris flyover movie

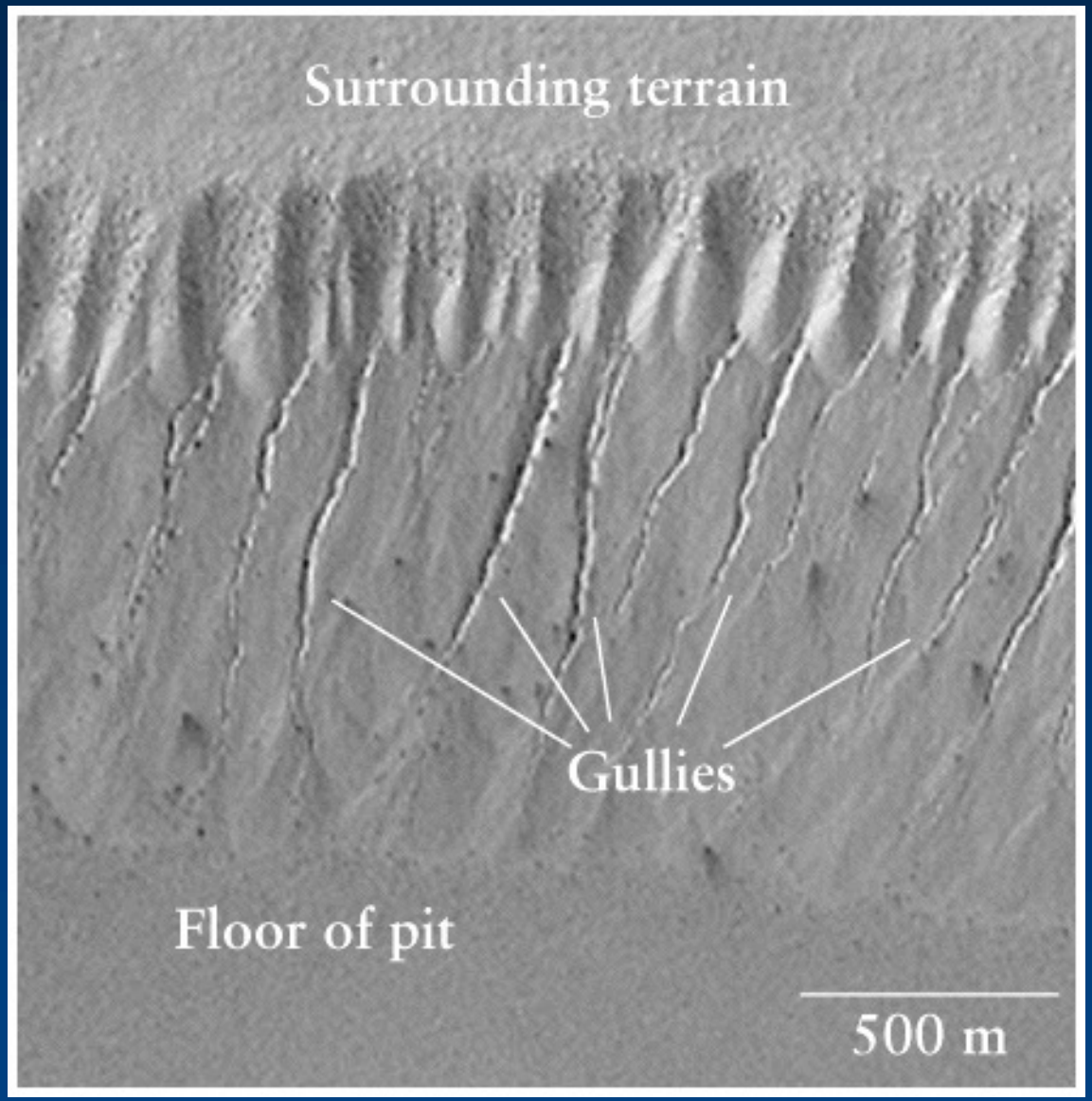


Pathfinder site was an outflow channel

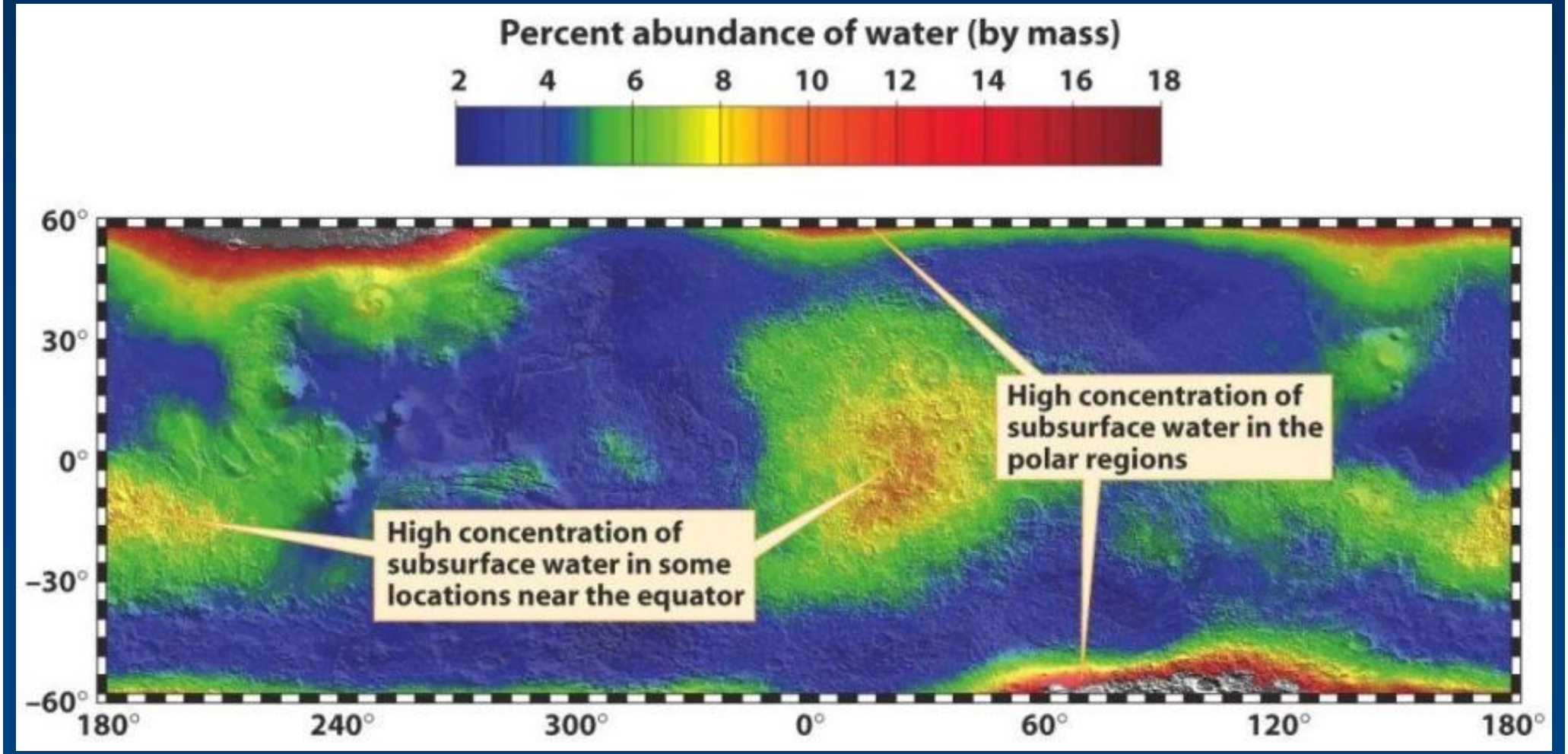


Red arrows: rounded boulders indicating water erosion?
White arrows: "conglomerate" rock, like in Earth's riverbeds?
Blue arrows: sharp-edged boulders, volcanic rock?

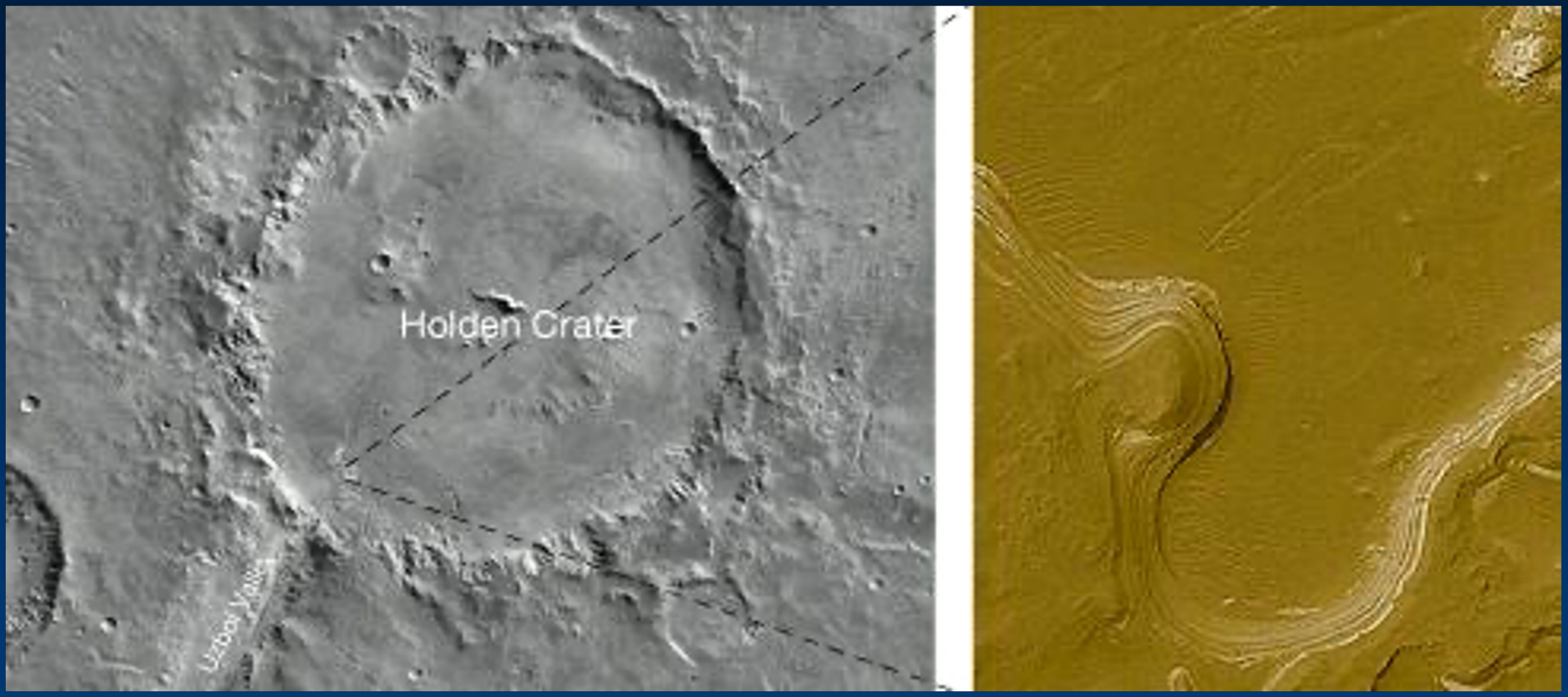
Most intriguing: Very crisp (=new) gullies, evidence for water erosion. Liquid subsurface water?



Data from Mars Odyssey mission: much hydrogen in top 1 meter of surface, mostly in southern hemisphere. Most likely compound is water ice – permafrost.

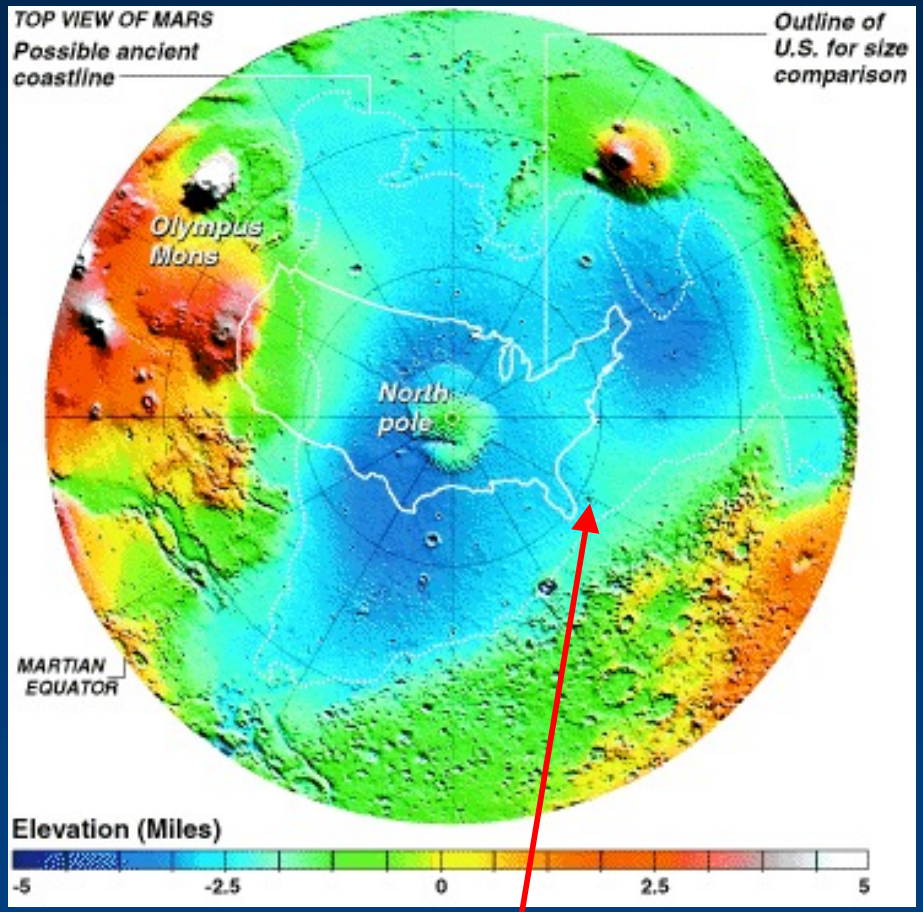


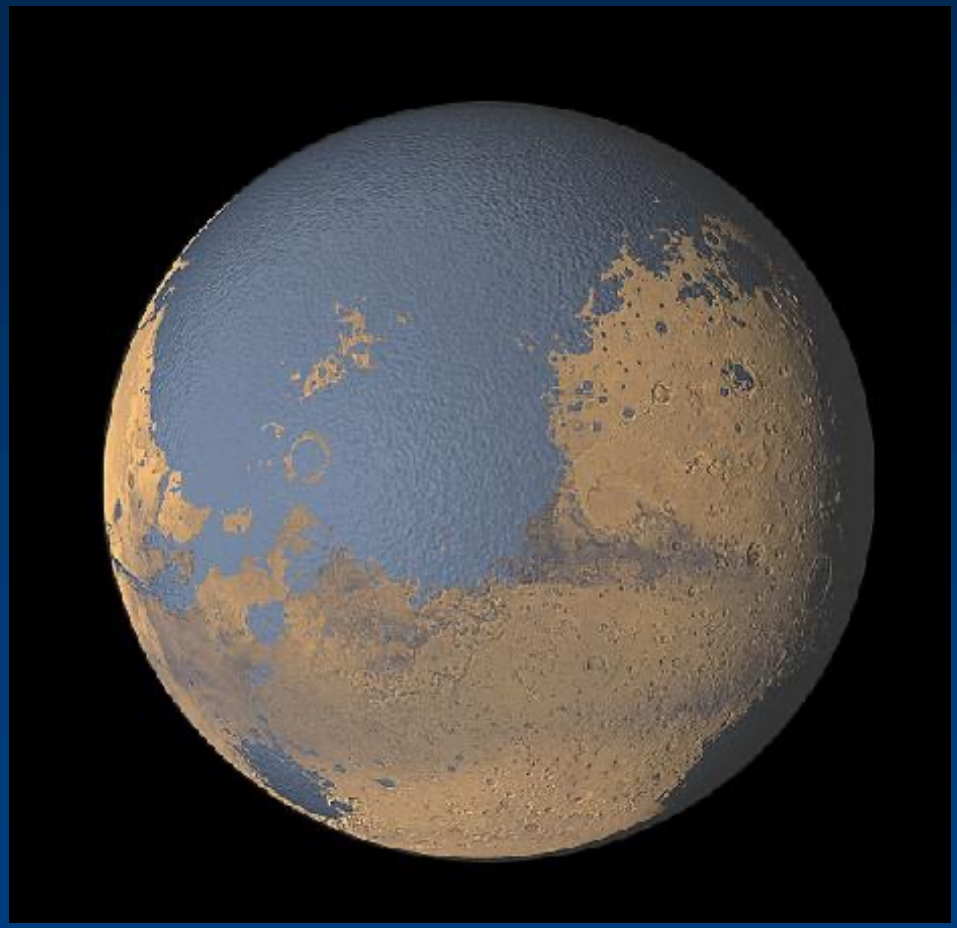
Yet more evidence of subsurface ice: “splosh craters”, suggesting liquefied ejecta
Not seen on dry surfaces, like the Moon.



standing water erosion in craters?

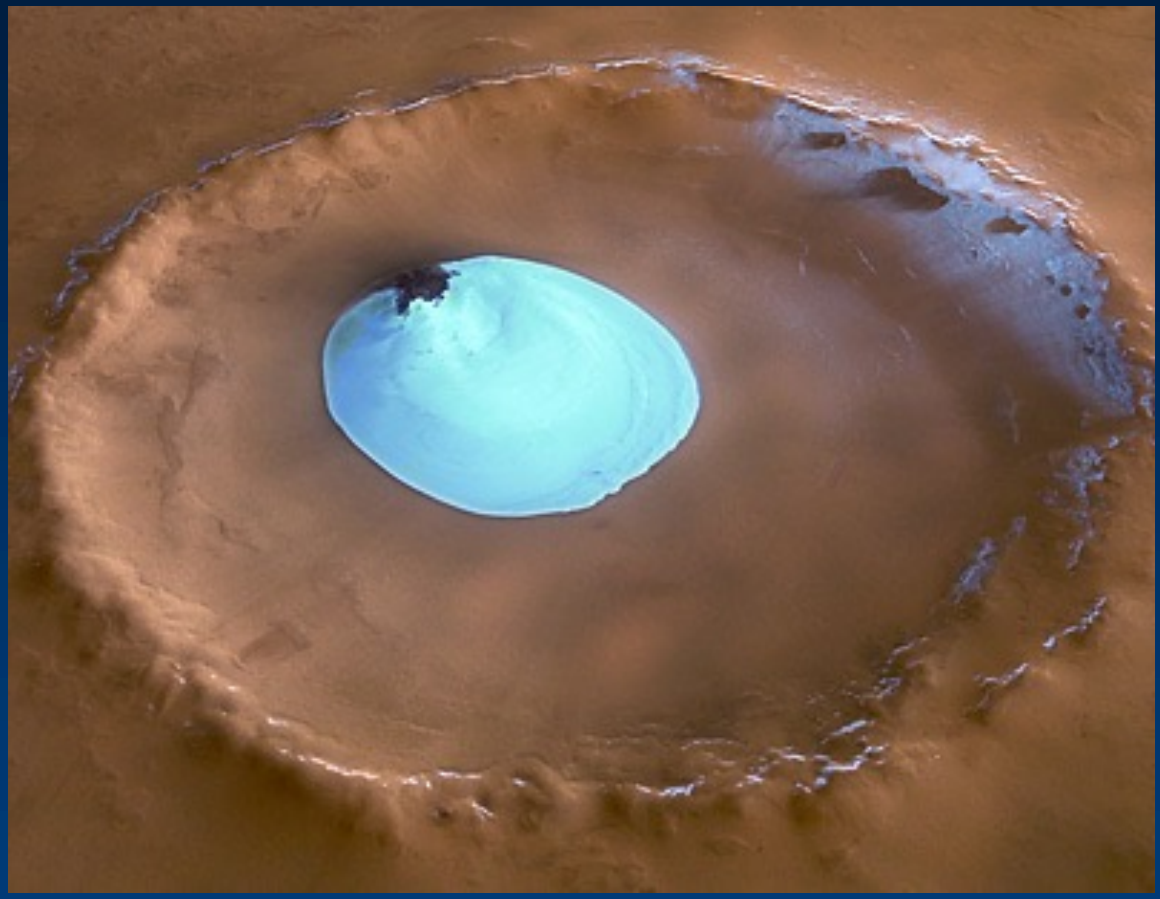
Did Mars once have a huge ocean?





Long stretches along border are very even in elevation, like a coastline

Ocean fed by outflow channels from higher elevation southern hemisphere?



Residual water ice in crater (Mars Express).

The Atmosphere of Mars

Table 9-4 Chemical Compositions of Three Planetary Atmospheres

	Venus	Earth	Mars
Nitrogen (N_2)	3.5%	78.08%	2.7%
Oxygen (O_2)	almost zero	~~20.95%~~	almost zero
Carbon dioxide (CO_2)	96.5%	0.035%	95.3%
Water vapor (H_2O)	0.003%	about 1%	0.03%
Other gases	almost zero	almost zero	2%

0.042%

Currently about 1% of Earth's atmospheric pressure. No liquid water possible now. What little atmosphere is there consists mostly of CO_2.

Possible evolution of atmosphere

- Original atmosphere product of outgassing (CO_2, H_2O, N_2)
- Greenhouse effect was possibly strong enough early in Mars's history that some water was liquid – rain.
- About 4 billion years ago, rainfall may have washed much CO_2 out of the atmosphere, creating carbonate rocks (as on Earth).

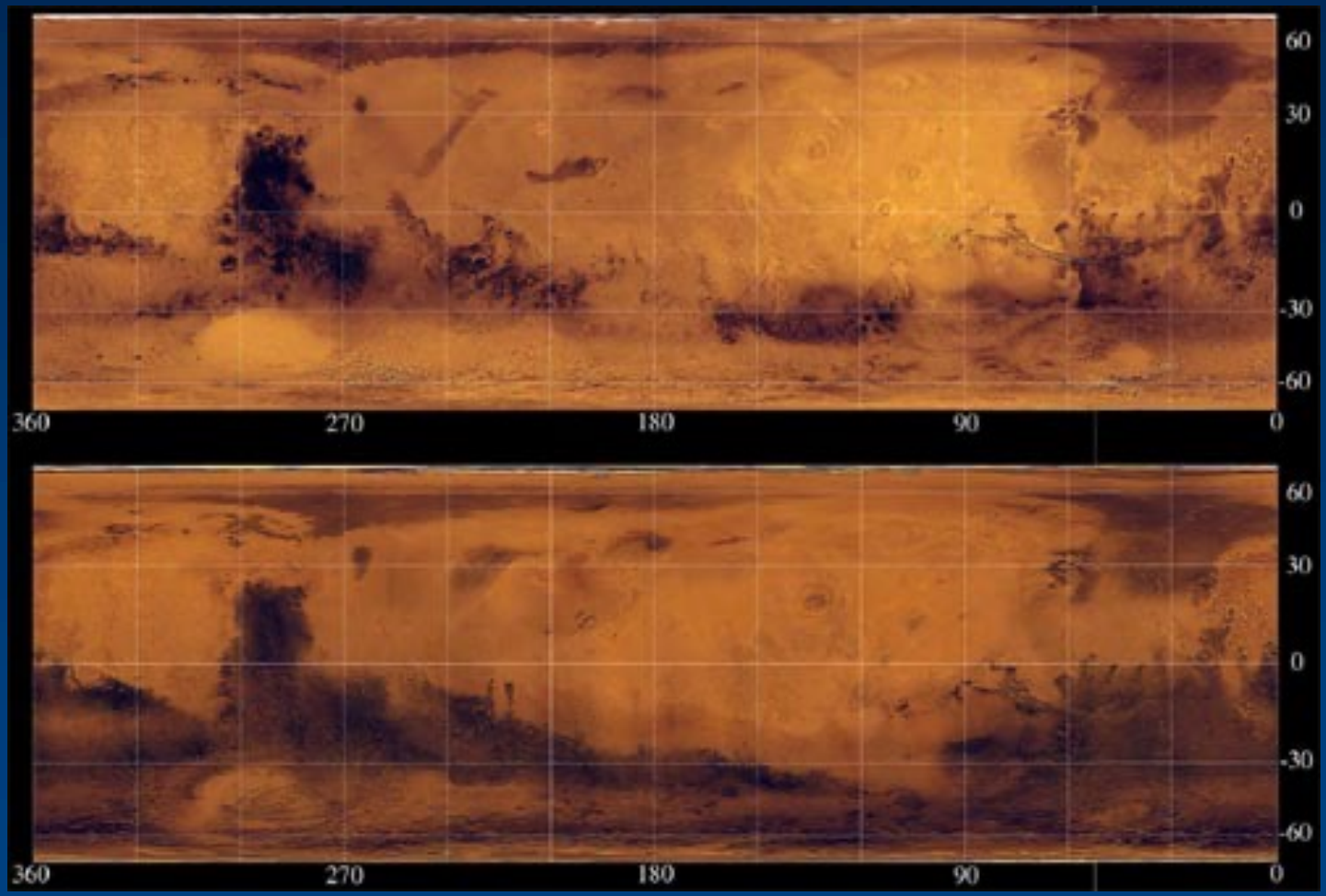
- CO_2 not returned to atmosphere since no plate tectonics on Mars. Depletion of CO_2 from atmosphere into rocks was permanent.

- As CO_2 in atmosphere declined, it got colder. More water vapor would have precipitated out, taking more CO_2 with it, dropping the temperature further, causing more precipitation… Runaway icehouse effect!

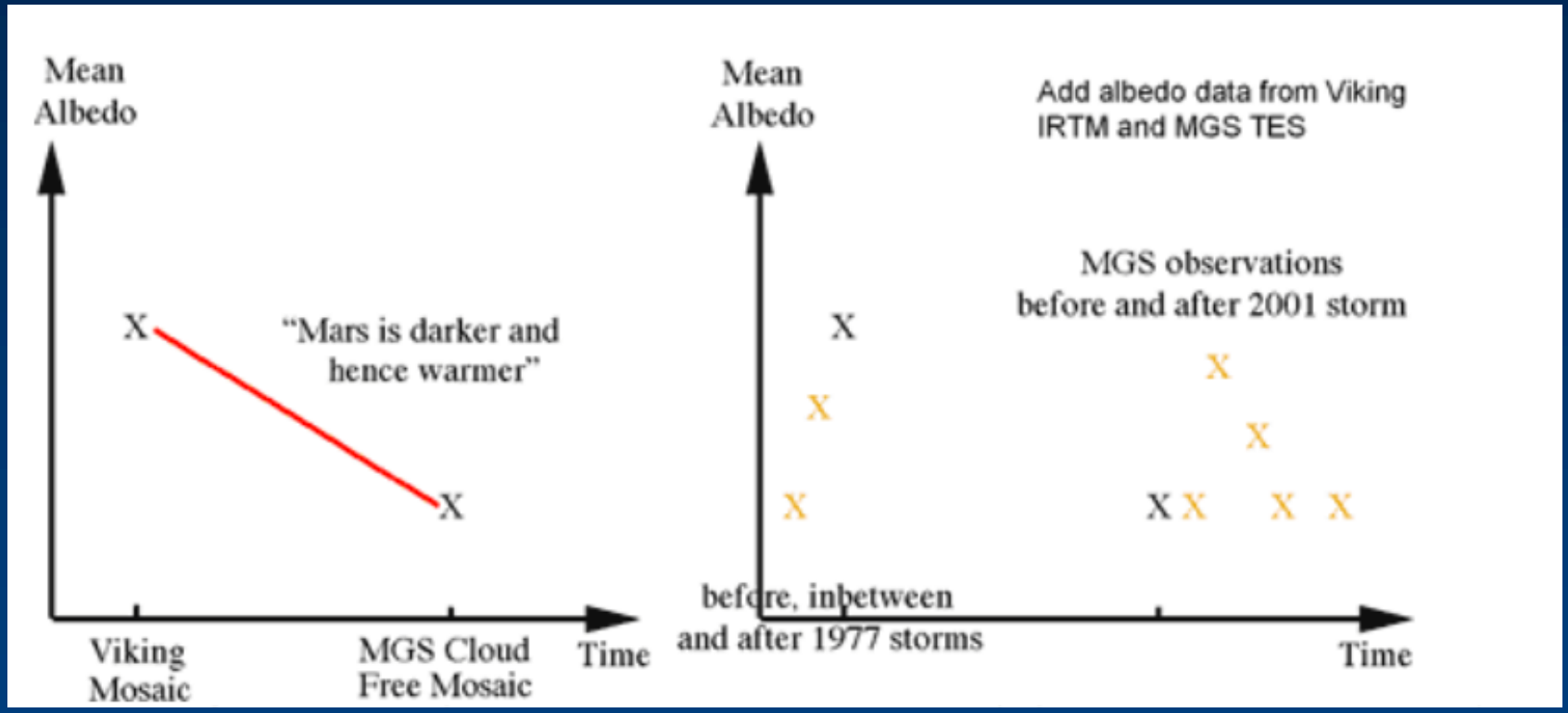
- With thin CO_2 atmosphere remaining, temps stabilized.
- Solar UV photons broke up much of remaining H_2O, CO_2, and N_2 $\Rightarrow$ their atoms had sufficient energy to escape into space.
- Some oxygen would have "rusted" surface, giving reddish color.

Global Warming of Mars?

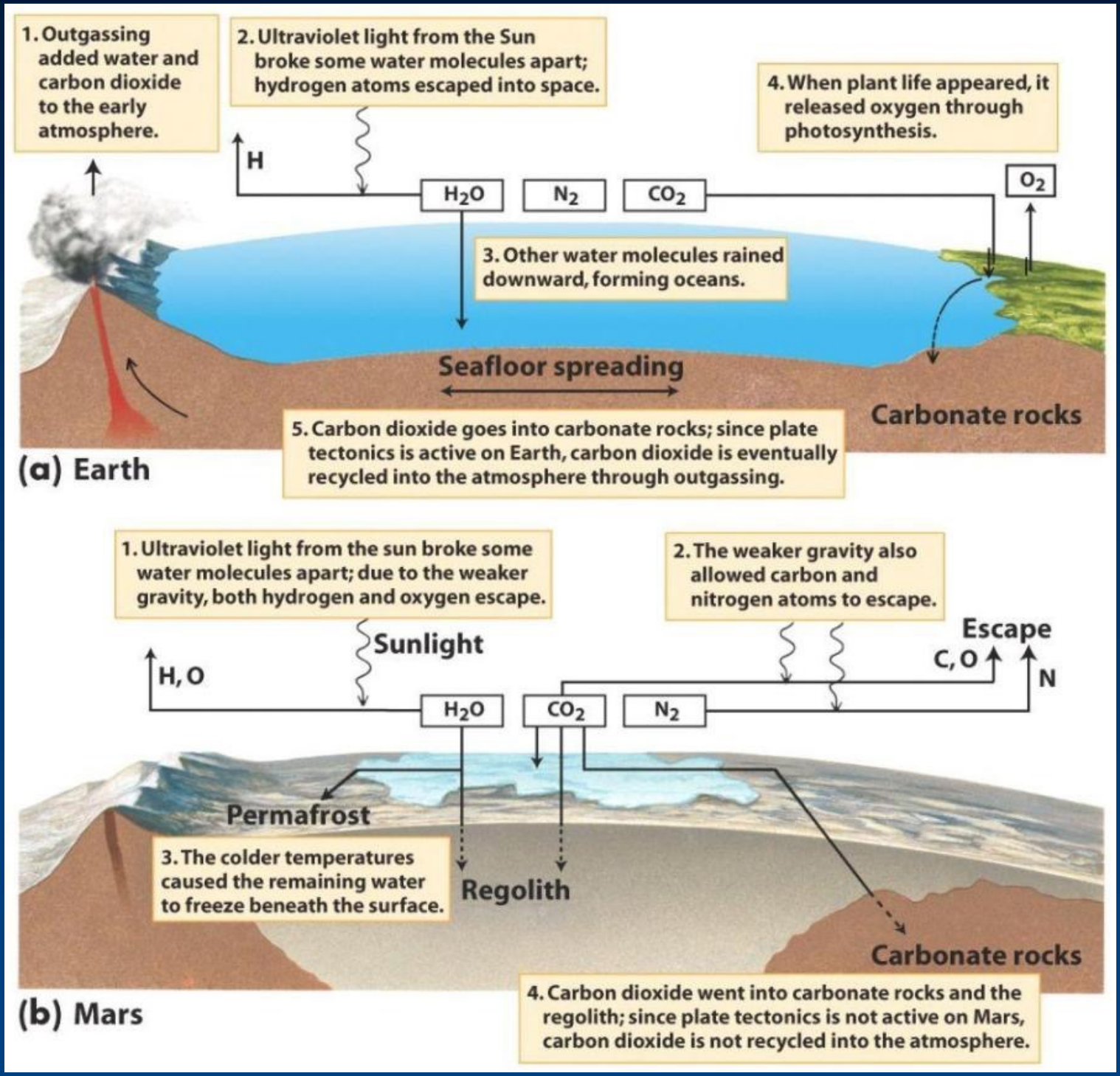
Changing Albedo from 1977 (top) to 1999 (bottom)



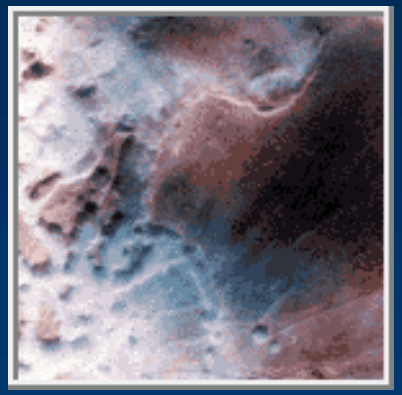
Global Warming of Mars?

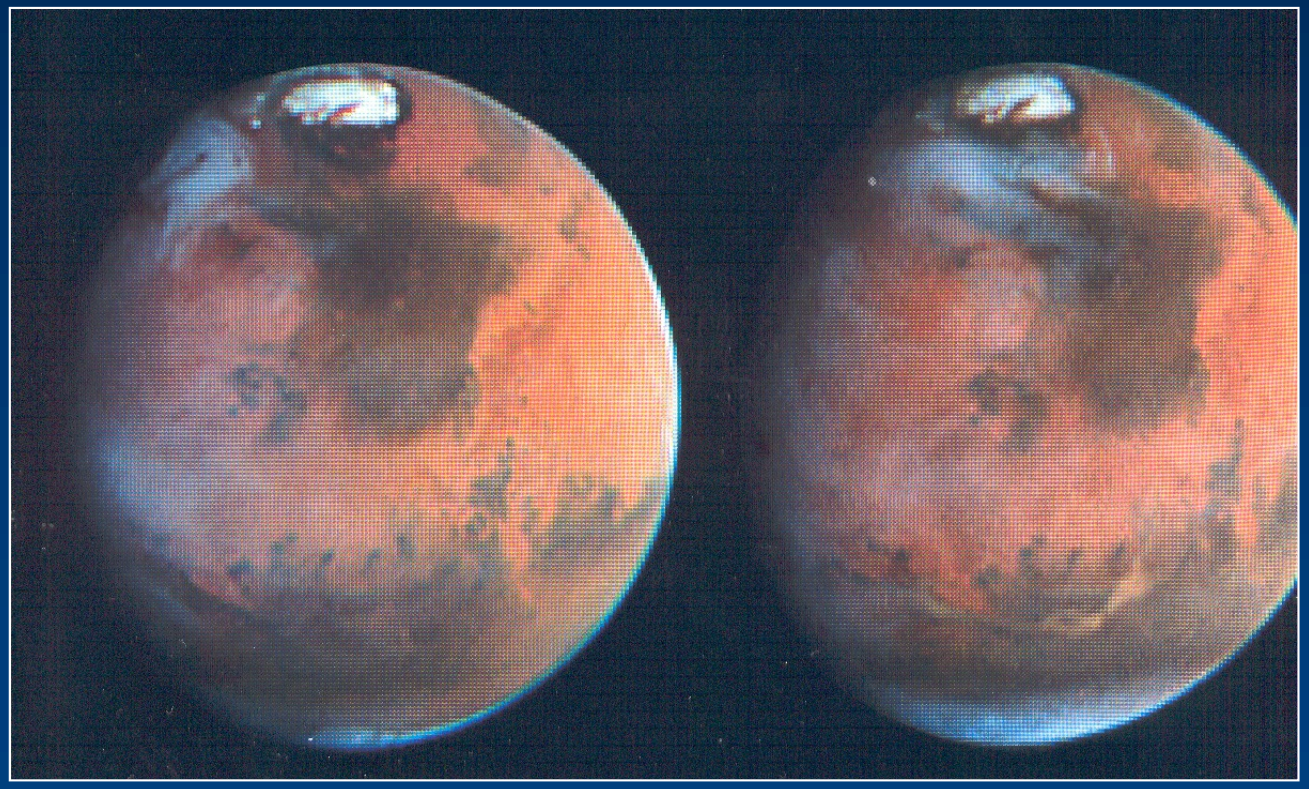


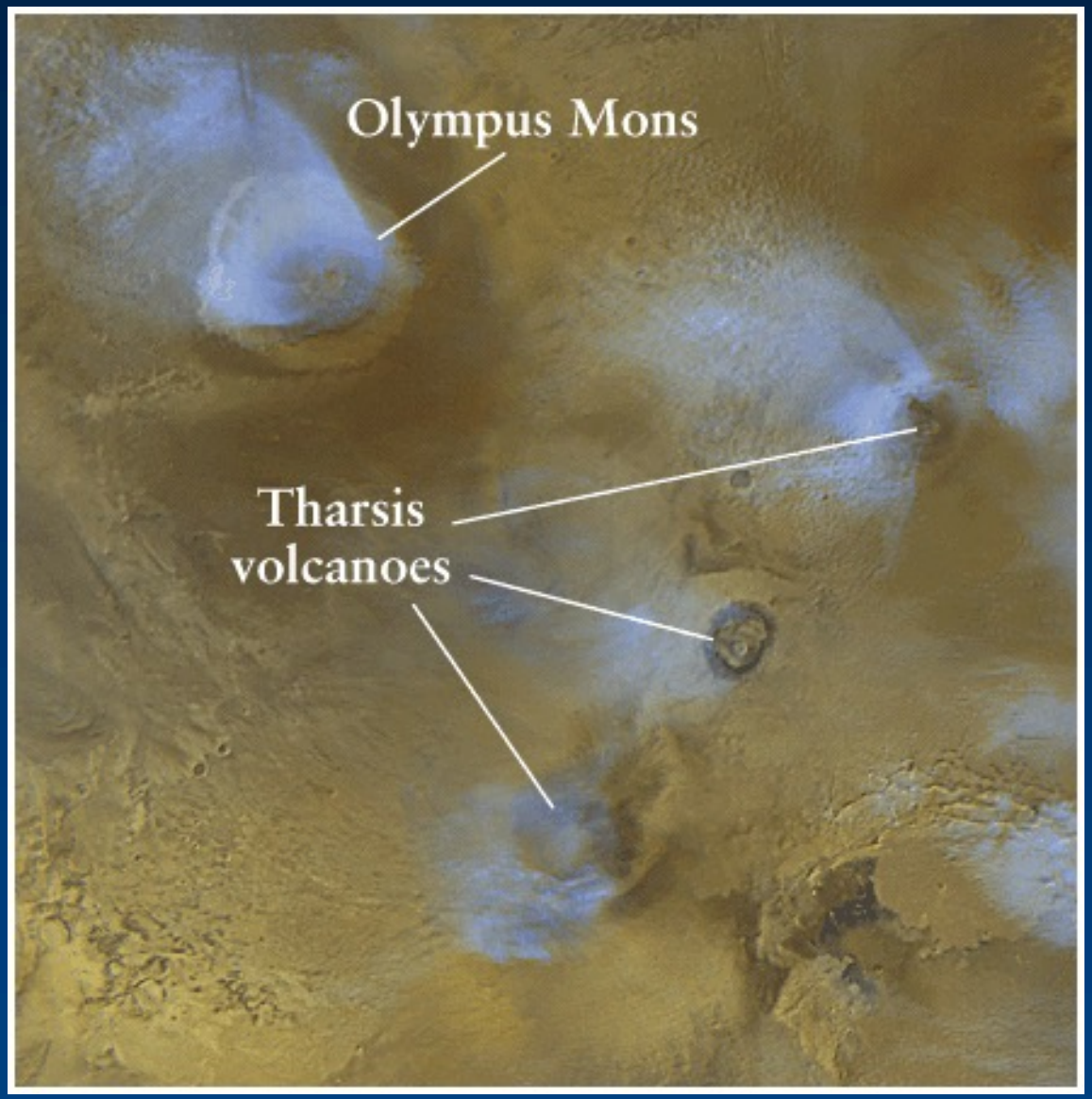
Looking at more data shows that there is no warming trend


1. Outgassing added water and carbon dioxide to the early atmosphere.
2. Ultraviolet light from the Sun broke some water molecules apart; hydrogen atoms escaped into space.
4. When plant life appeared, it released oxygen through photosynthesis.
H
H_2O
N_2
CO_2
O_2
3. Other water molecules rained downward, forming oceans.
Seafloor spreading
Carbonate rocks
5. Carbon dioxide goes into carbonate rocks; since plate tectonics is active on Earth, carbon dioxide is eventually recycled into the atmosphere through outgassing.
(a) Earth
1. Ultraviolet light from the sun broke some water molecules apart; due to the weaker gravity, both hydrogen and oxygen escape.
2. The weaker gravity also allowed carbon and nitrogen atoms to escape.
Sunlight
Escape
H, O
C, O
N
H_2O
CO_2
N_2
Permafrost
3. The colder temperatures caused the remaining water to freeze beneath the surface.
Regolith
Carbonate rocks
4. Carbon dioxide went into carbonate rocks and the regolith; since plate tectonics is not active on Mars, carbon dioxide is not recycled into the atmosphere.
(b) Mars

In spite of rarefied atmosphere, there are clouds and there is weather.






Olympus Mons
Tharsis
volcanoes

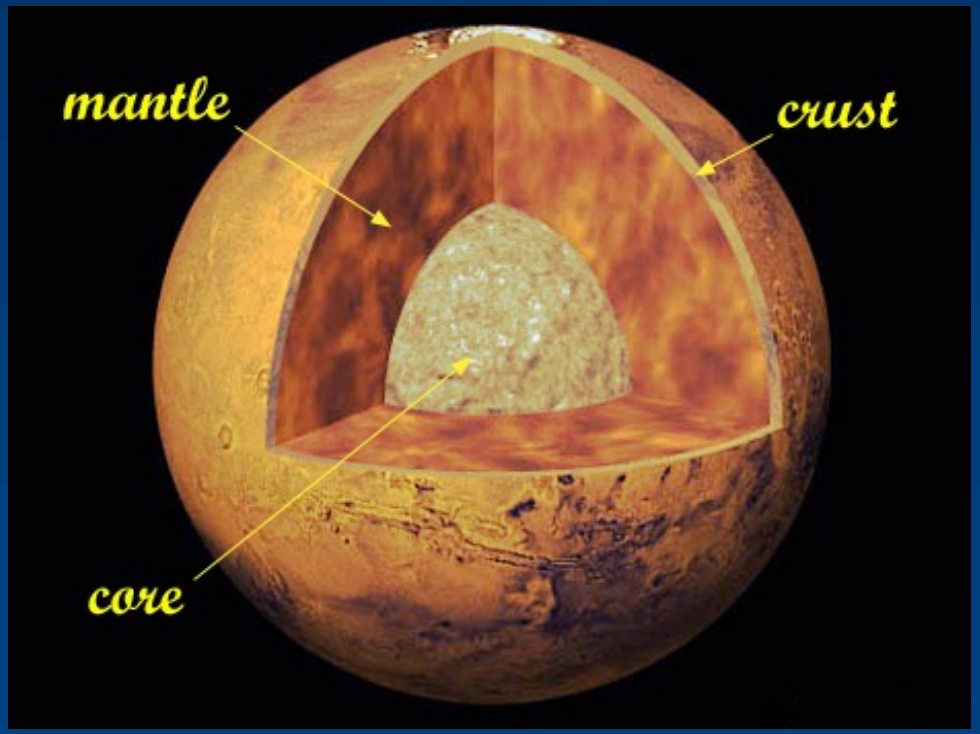
Martian dust devil across Gusev Crater, March 15, 2005. Photos from the rover Spirit. Times in seconds. Note also two smaller dust devils in the background.

Dry ice frost – CO_2 precipitates out of atmosphere during winter. Polar caps grow and shrink seasonally.

The Martian interior

- Revealed by Insight measurements of marsquakes
- Density of Mars less than that of Earth

  => larger concentration of lighter material relative to the core
- Crust 20-40 km
- Core is liquid (surprise)
- Solid inner core?



InSight Lander

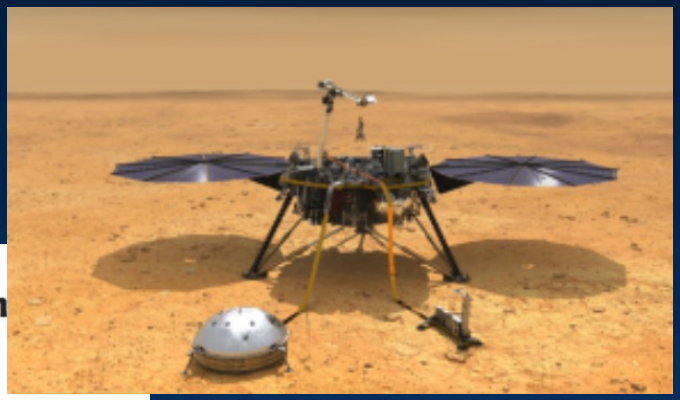
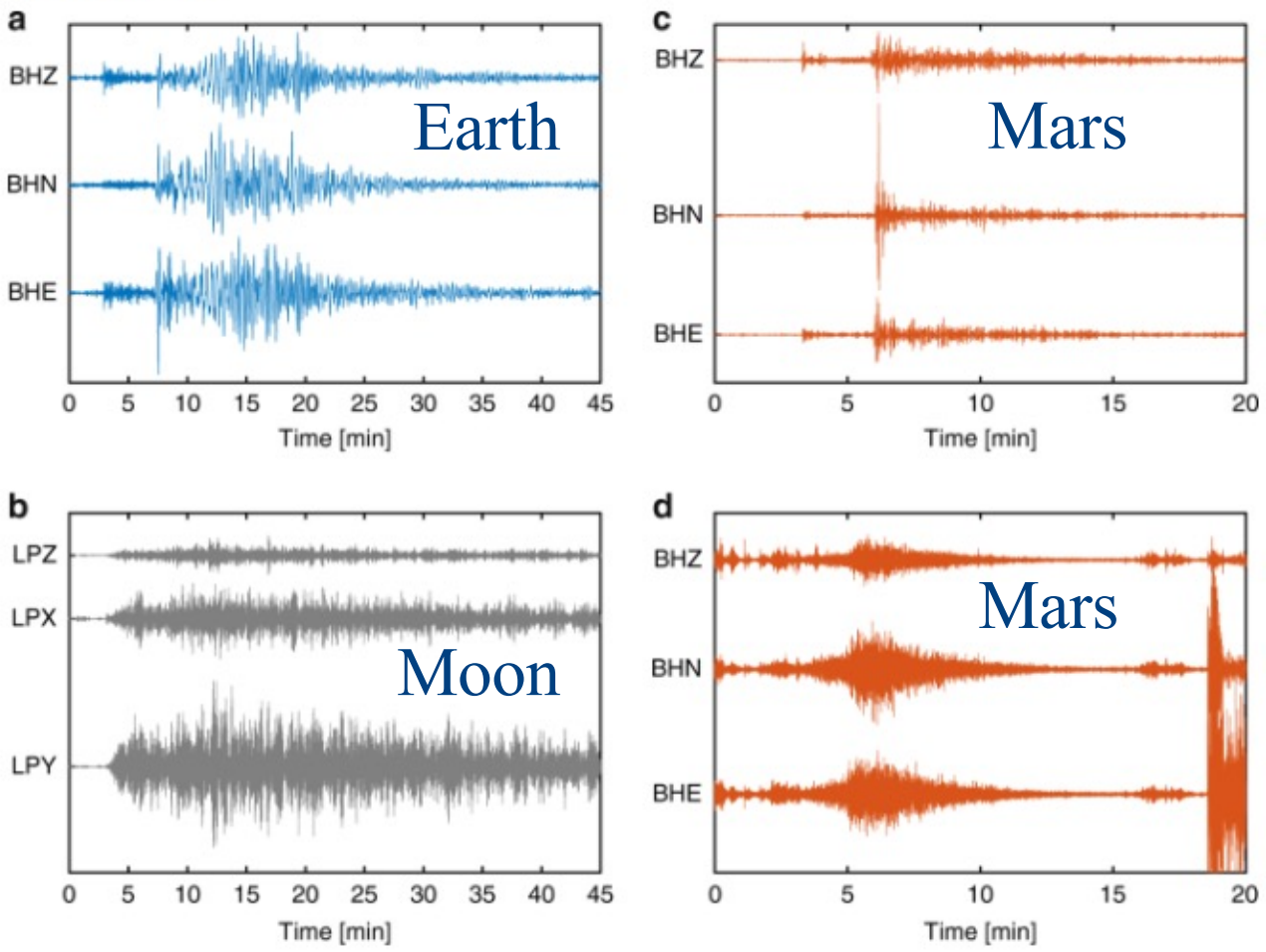


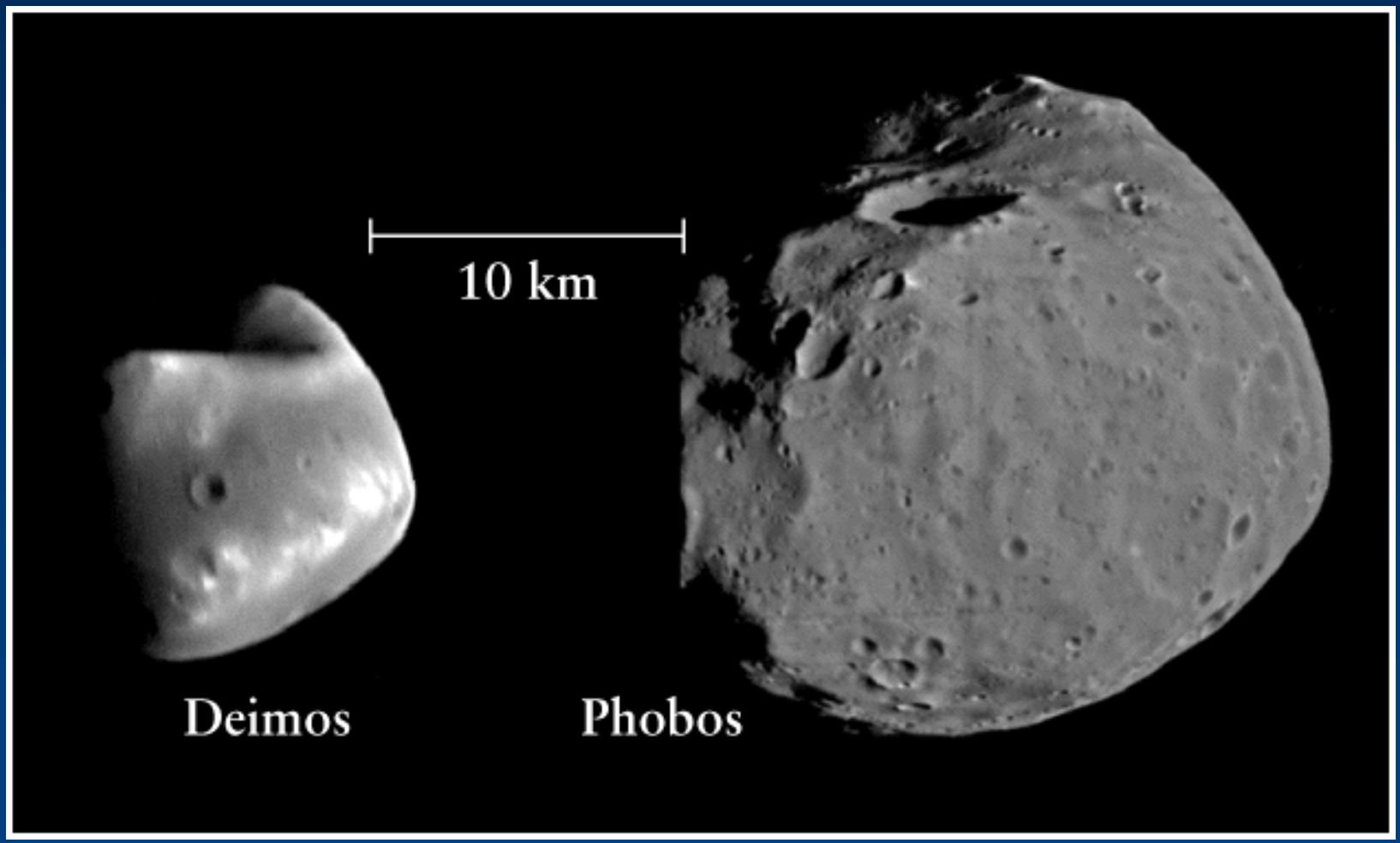
Fig. 2: Comparison of seismograms of earthquakes, moonquakes, an marsquakes.



Knapmeyer-Endrun & Kawamura 2020

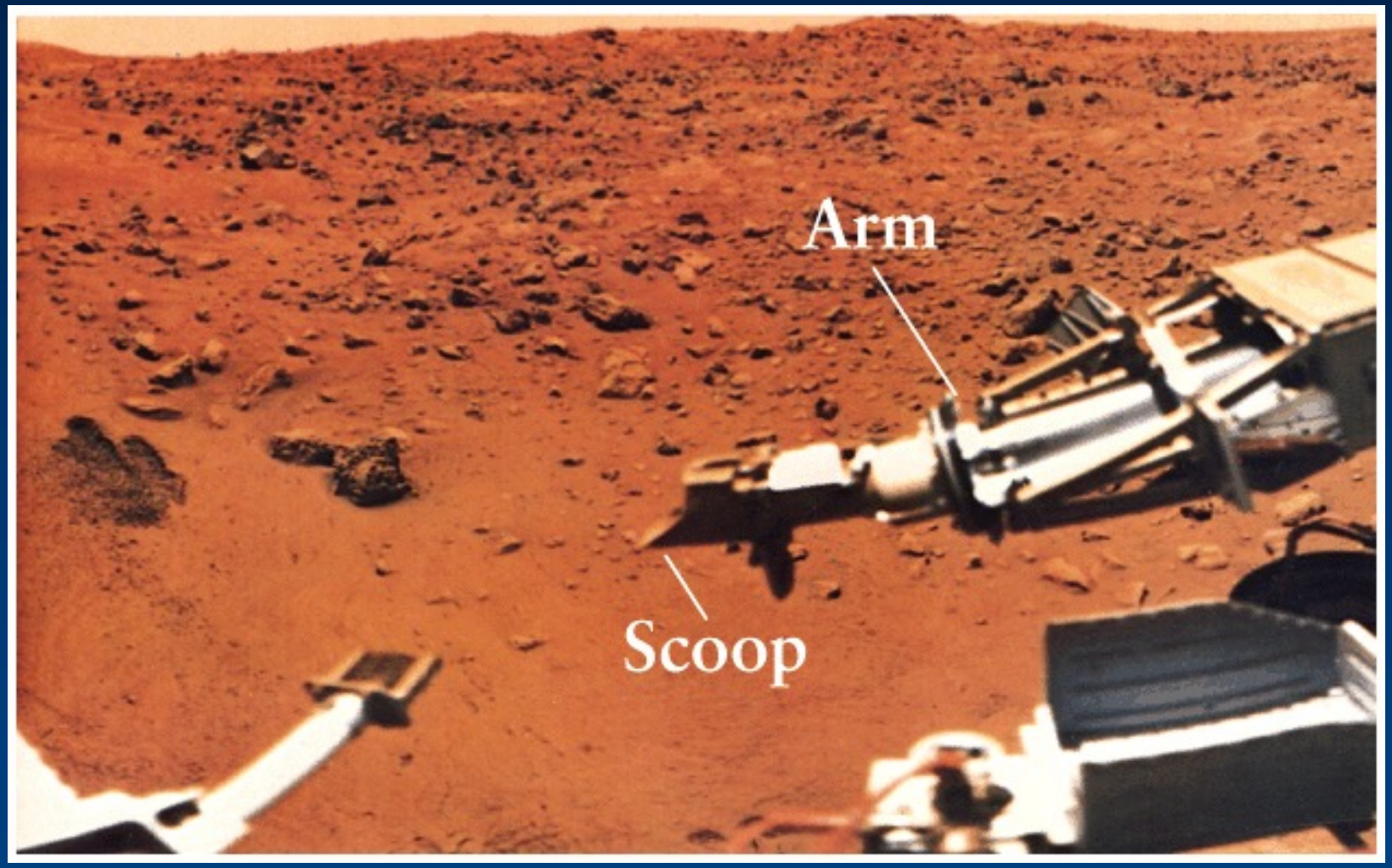
Moons

Two small moons are probably captured asteroids.
Phobos (fear) and Deimos (panic)



The Viking, Pathfinder, Mars Exploration Rover Missions

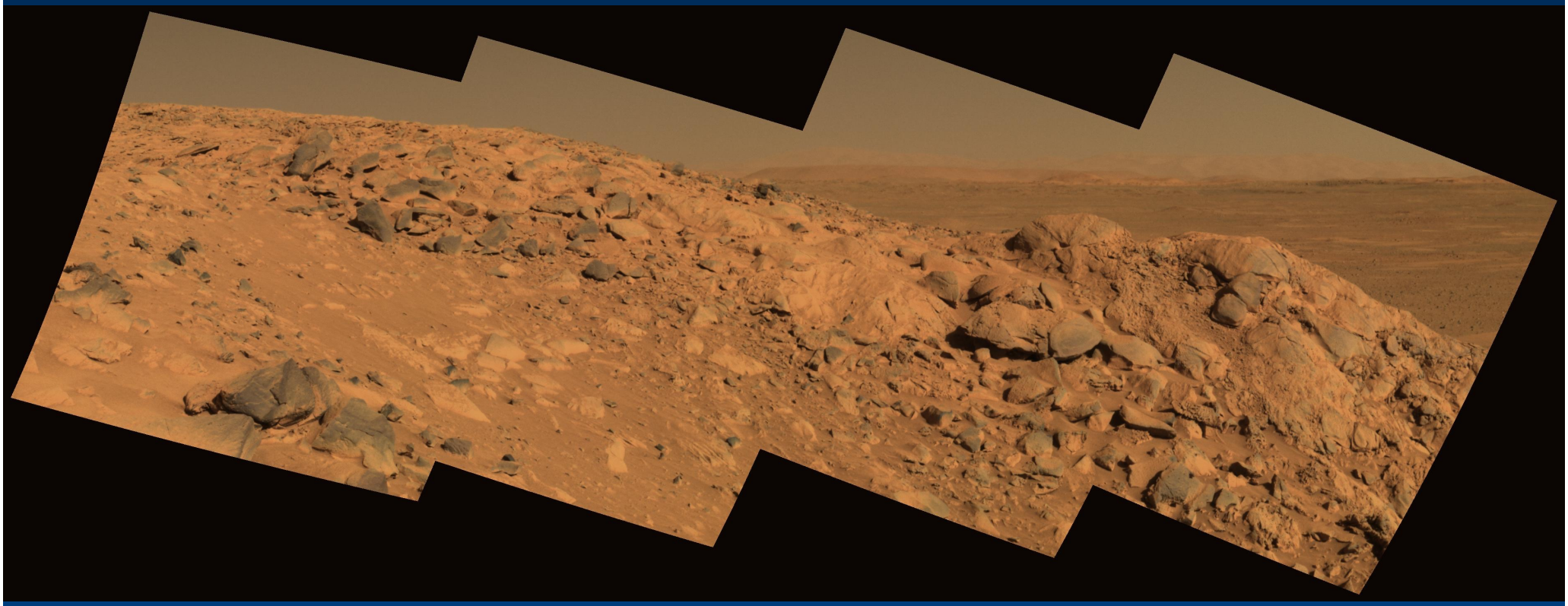
Viking: Two landers in 1976; performed several experiments including 4 testing for life. Results consistent with no life.



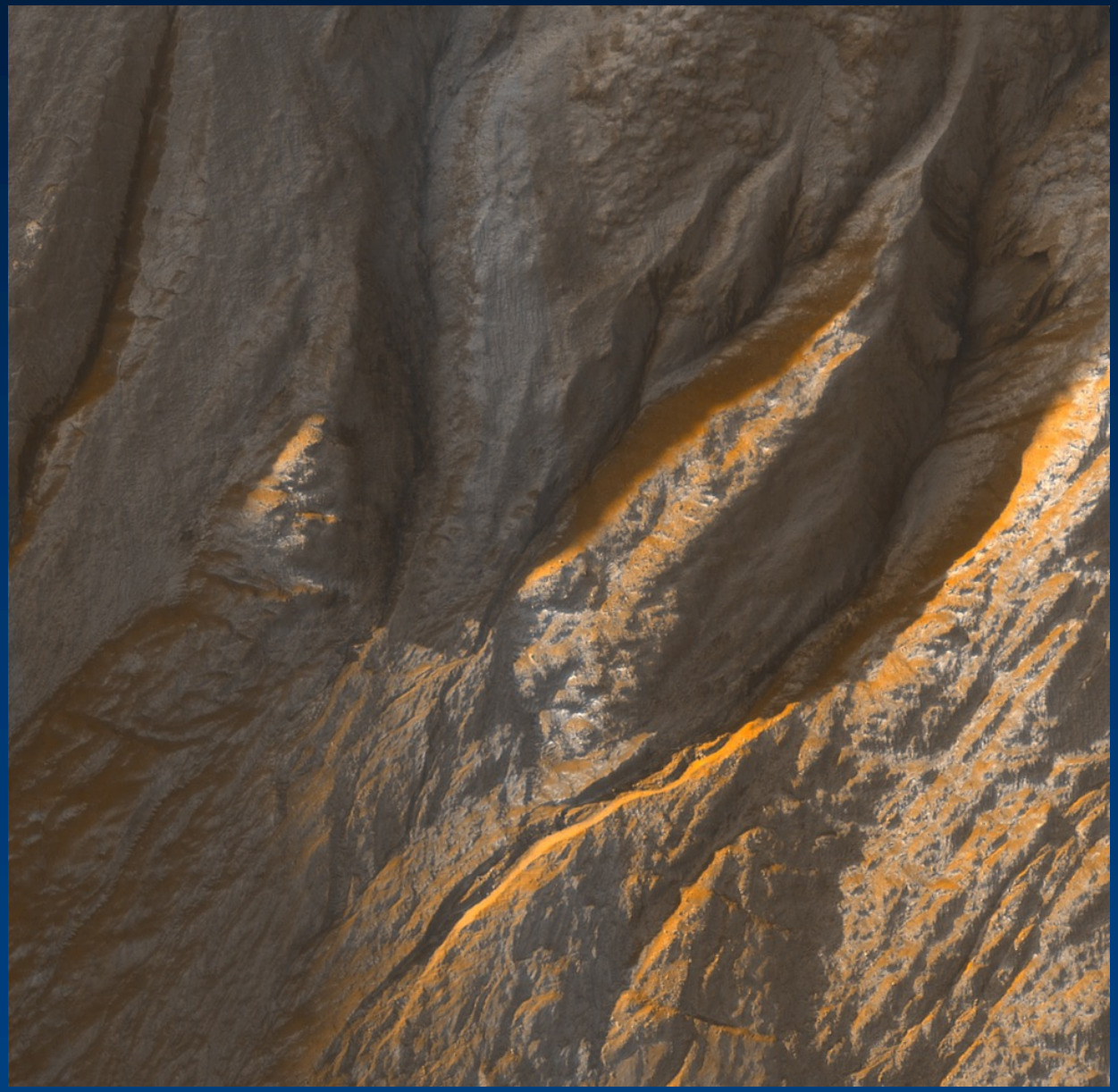
View from Viking Lander 1

Pathfinder and its rover Sojourner in 1997

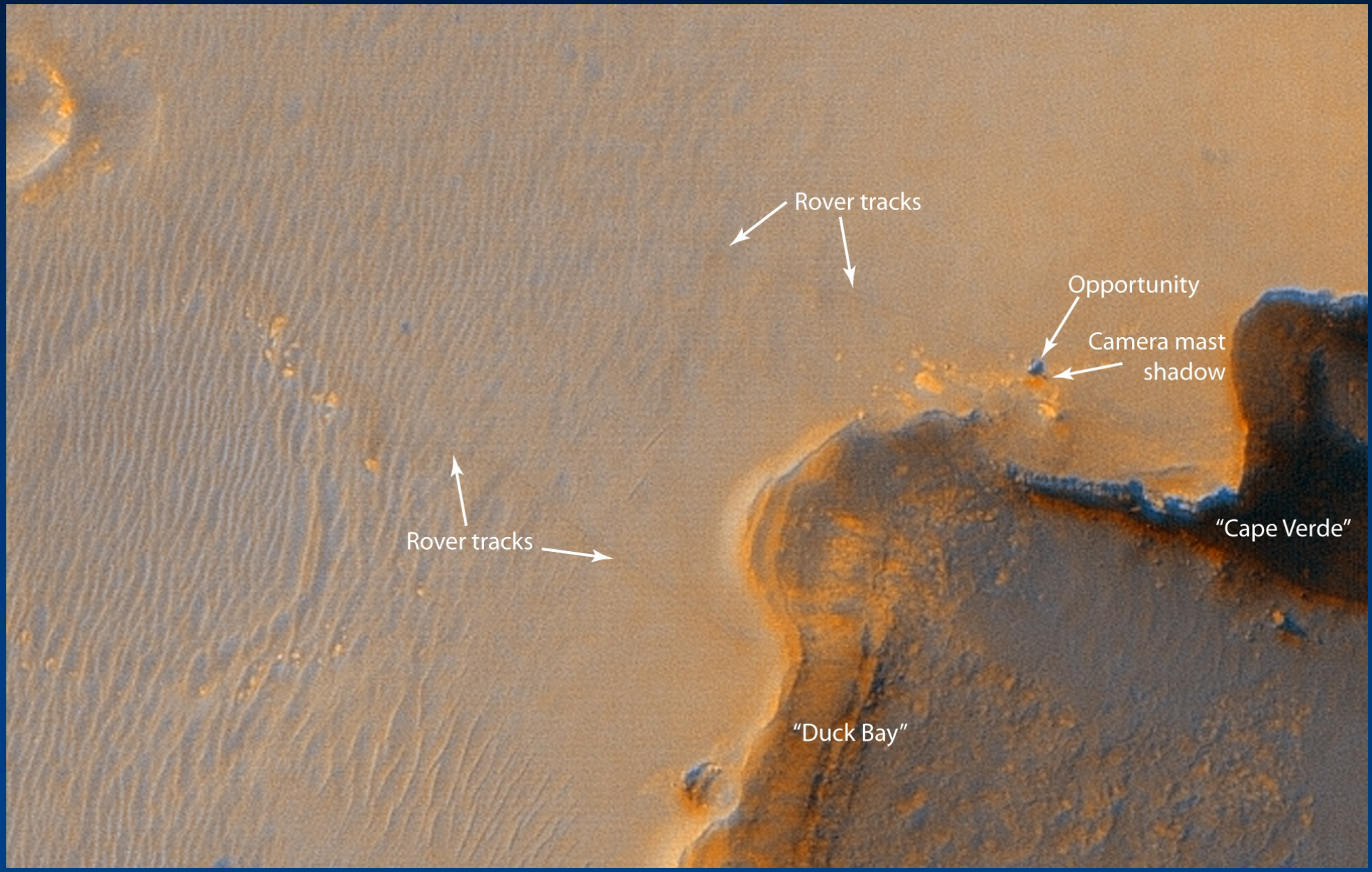
b



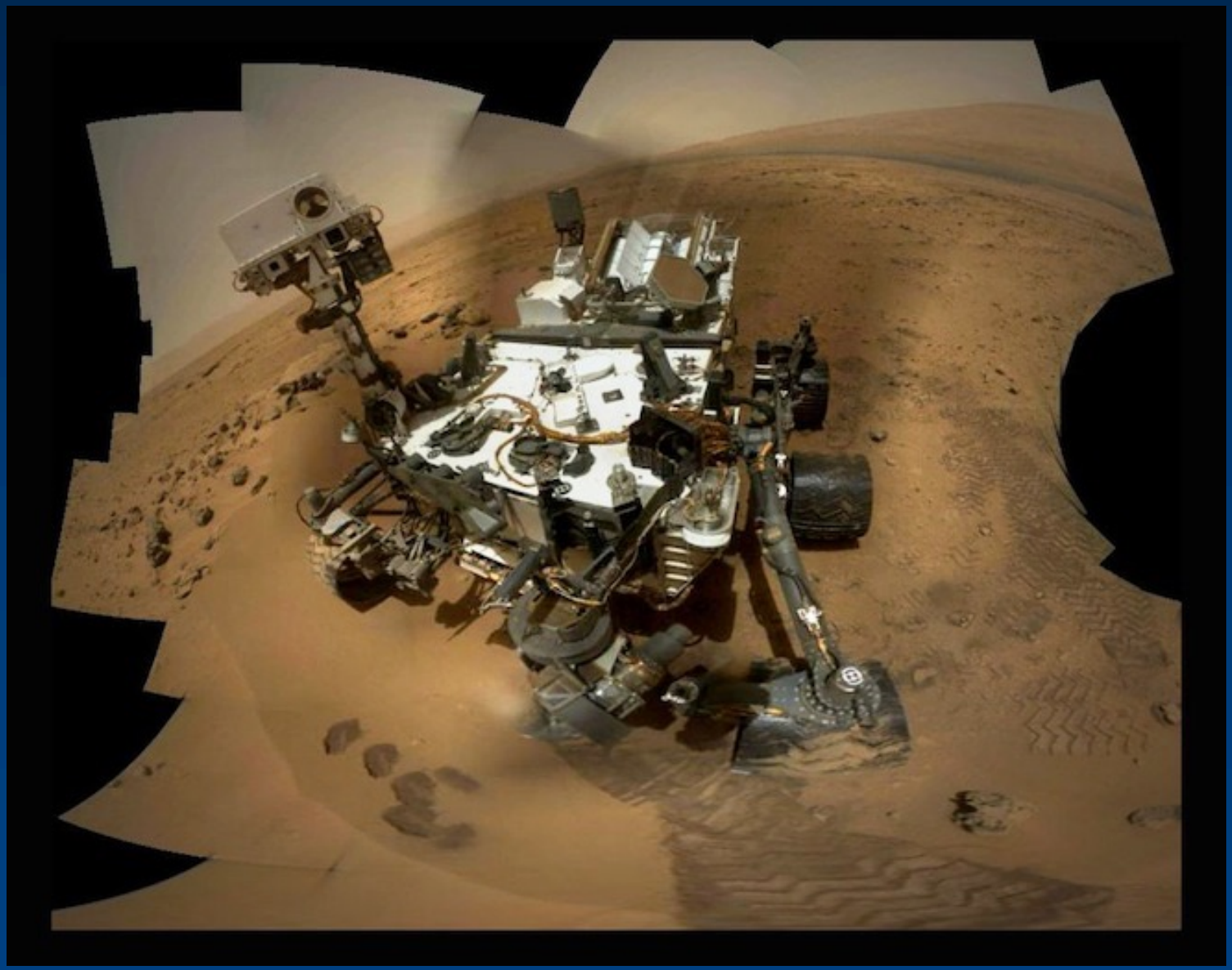
Mars Reconnaissance Orbiter view of Victoria Crater



- More detailed views of gullies


Rover tracks
Opportunity
Camera mast
shadow
Rover tracks
"Cape Verde"
"Duck Bay"

Curiosity



The “face”

Viking orbiter photos showed this:

Newer, high resolution photo – Mars Global Surveyor 1998