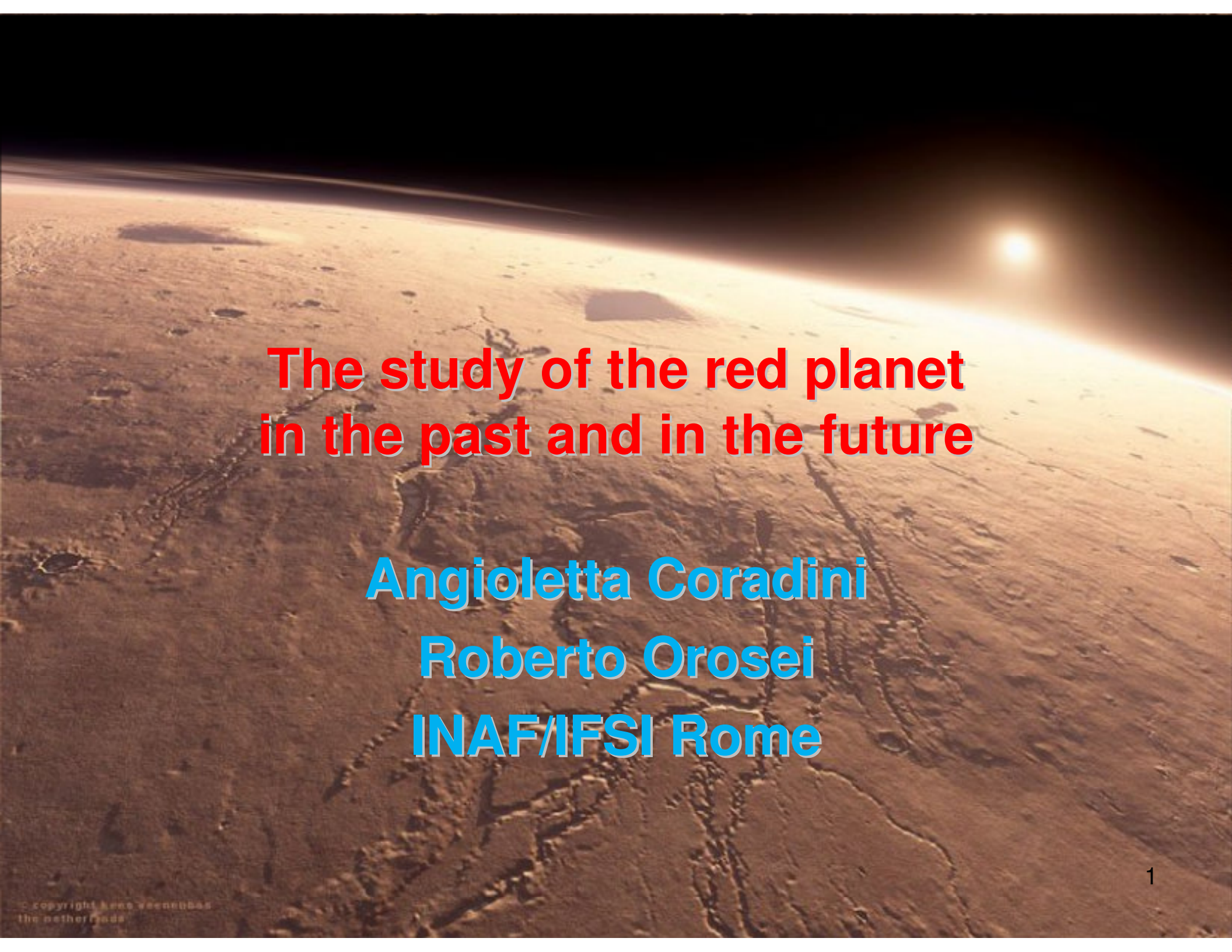
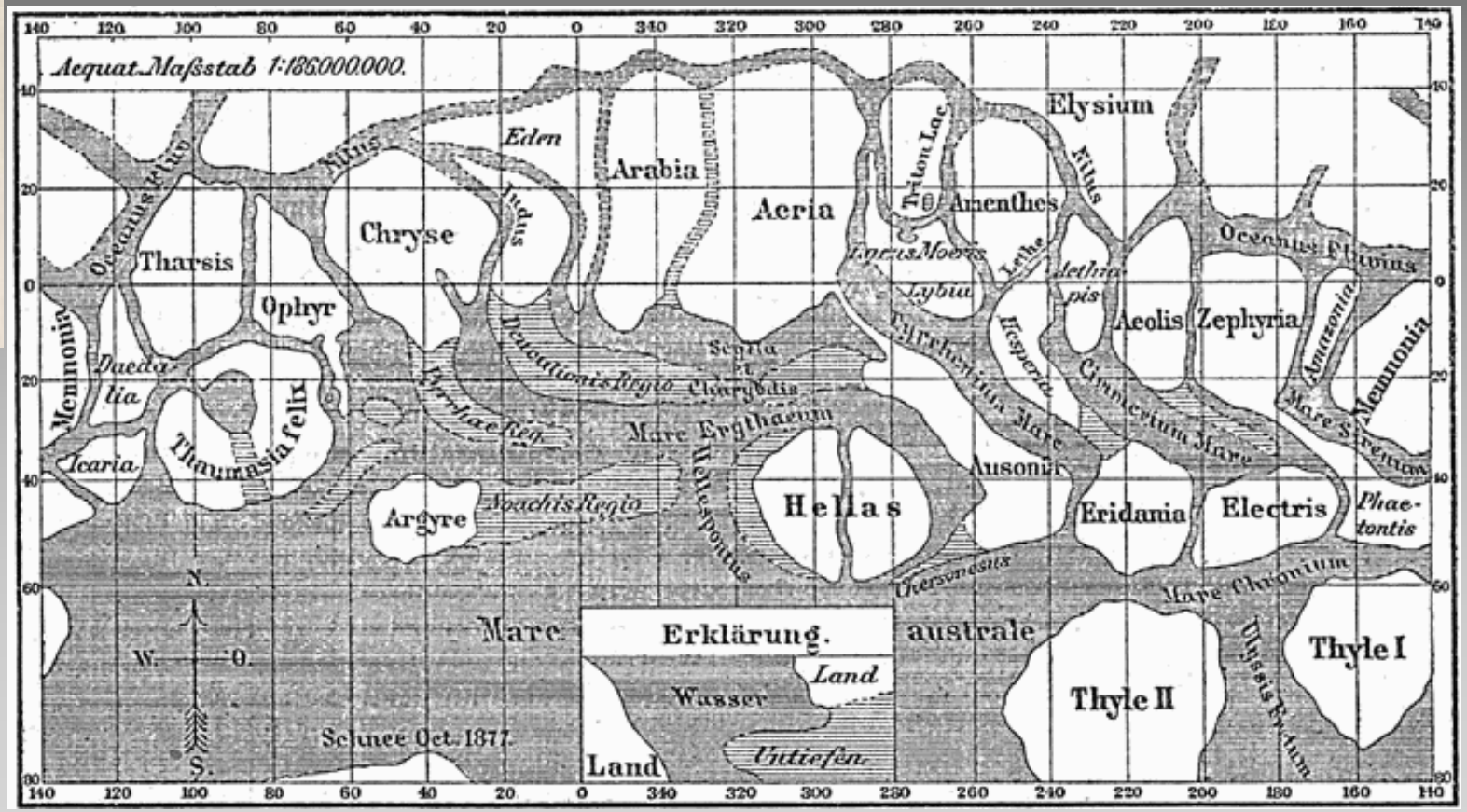


The study of the red planet in the past and in the future

Angioletta Coradini
Roberto Orosei
INAF/IFSI Rome

Early Observations

Schiaparelli's "canals/channels"



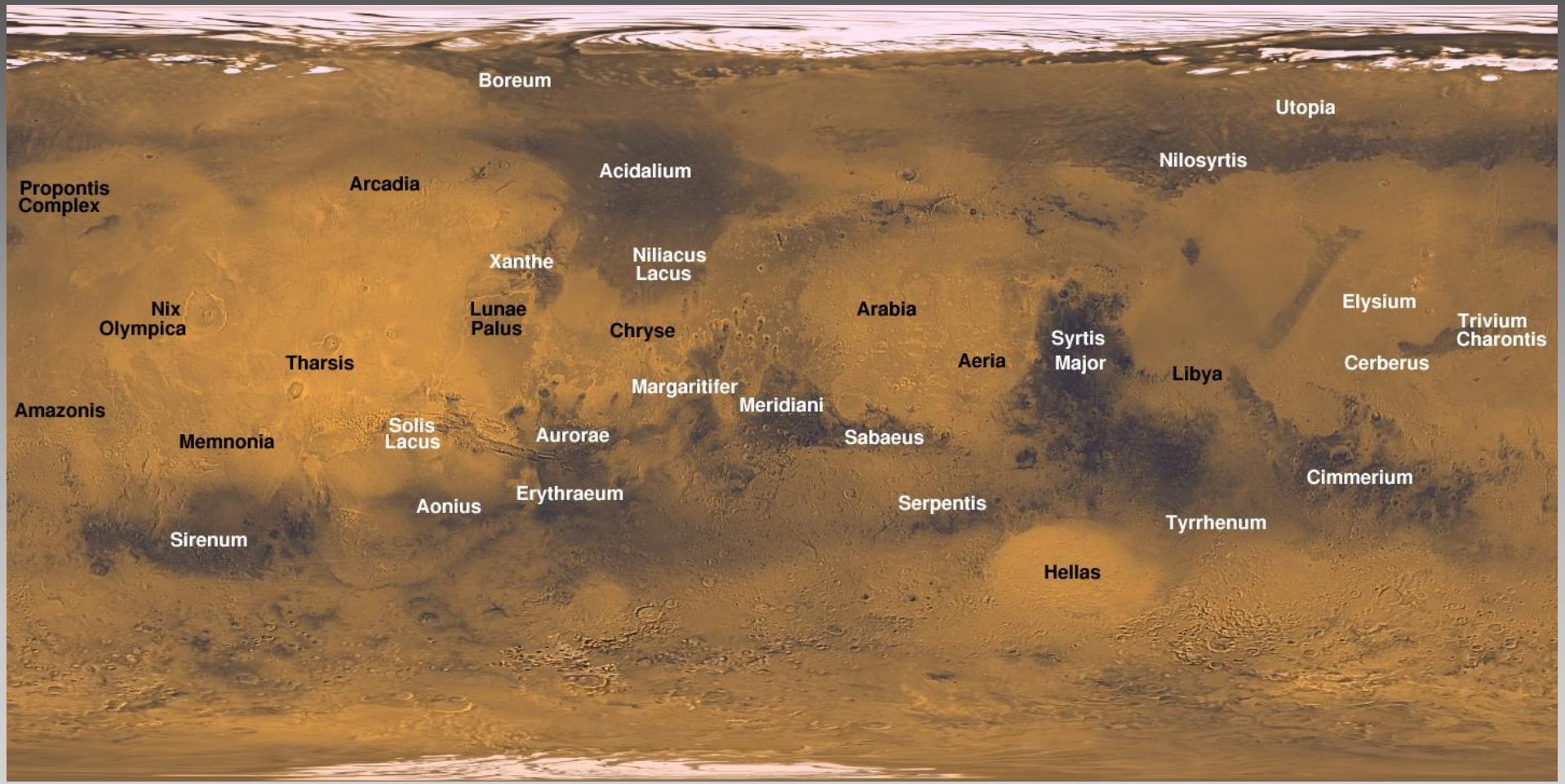
Percival Lowell (1855-1916)

- Lowell Observatory
- Martian "civilizatio

Percival Lowell

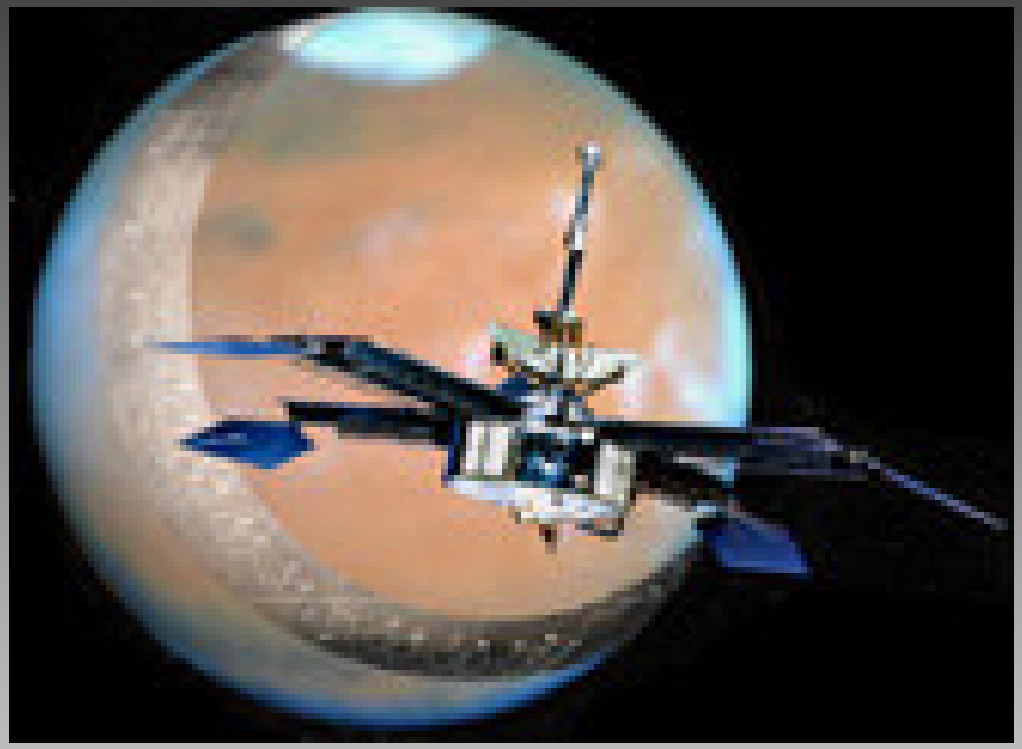
apped by
late 1800s.

Still, many of feature names in Schiaparelli's maps are used today…



The Mariner and Viking era

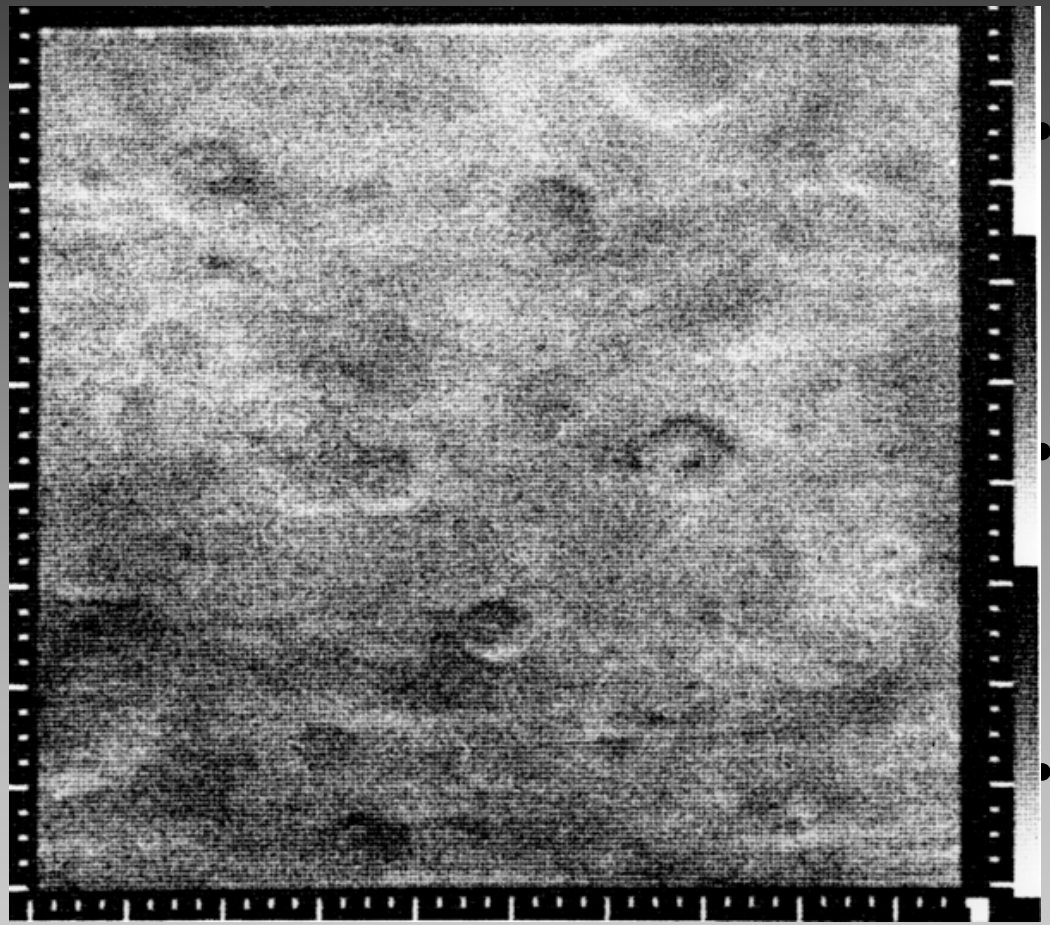
FLY BY Space Mission in 1965 – MARINER 4



- Revealed Mars to be rust-colored, heavily cratered and no sign of life or ***"canals"!!***
- Later we would discover ***"channels"***

- **Mariner 4** – NASA 1965
- **Fly by** on July 14, 1965 came as close as ~12000 Km
- **TV** camera, which took 22 television pictures covering about 1% of the planet
- **Initially** stored on a 4-track tape recorder, pictures took **four days** to transmit to Earth!

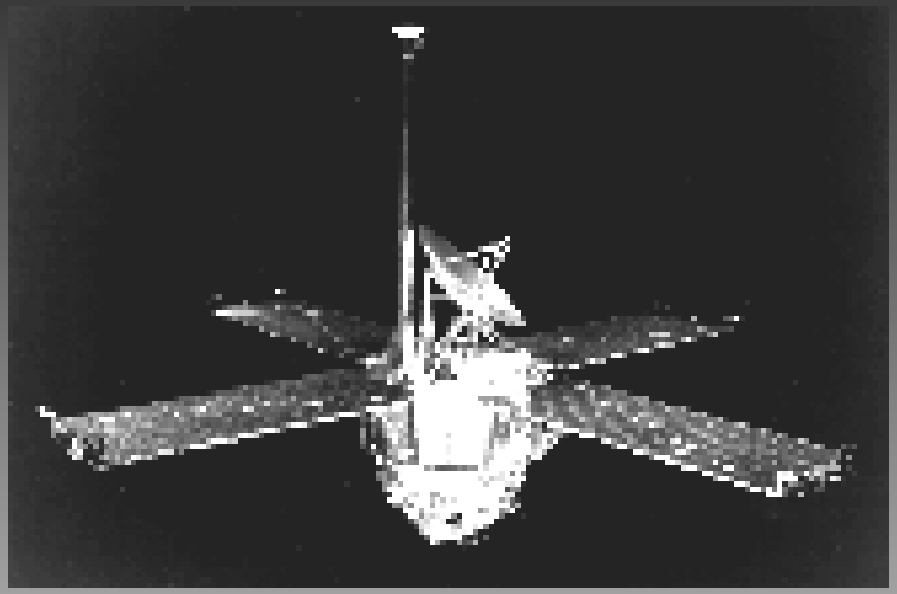
FLY BY Space Mission in 1964 – MARINER 4



1965-07-15 T 00:28

- Mariner 4 image shows > 20 craters on Mars, resembling the lunar surface.
- The image was taken from 13,000 km and shows a Region of 253 by 225 km.
- Mariner 4's instruments also determined that the atmosphere of Mars is
  - ***THIN (1% Earth's)***
  - ***primarily CO2***

Mariners 6 and 7



Fly by of Mars on 31 Jul 1969

- came within 2,130 miles of Mars
- pictures of ~20% surface (missed important volcanic features)
- sent back ~80 photos (Mar. 6) and ~120 photos (Mar. 7)

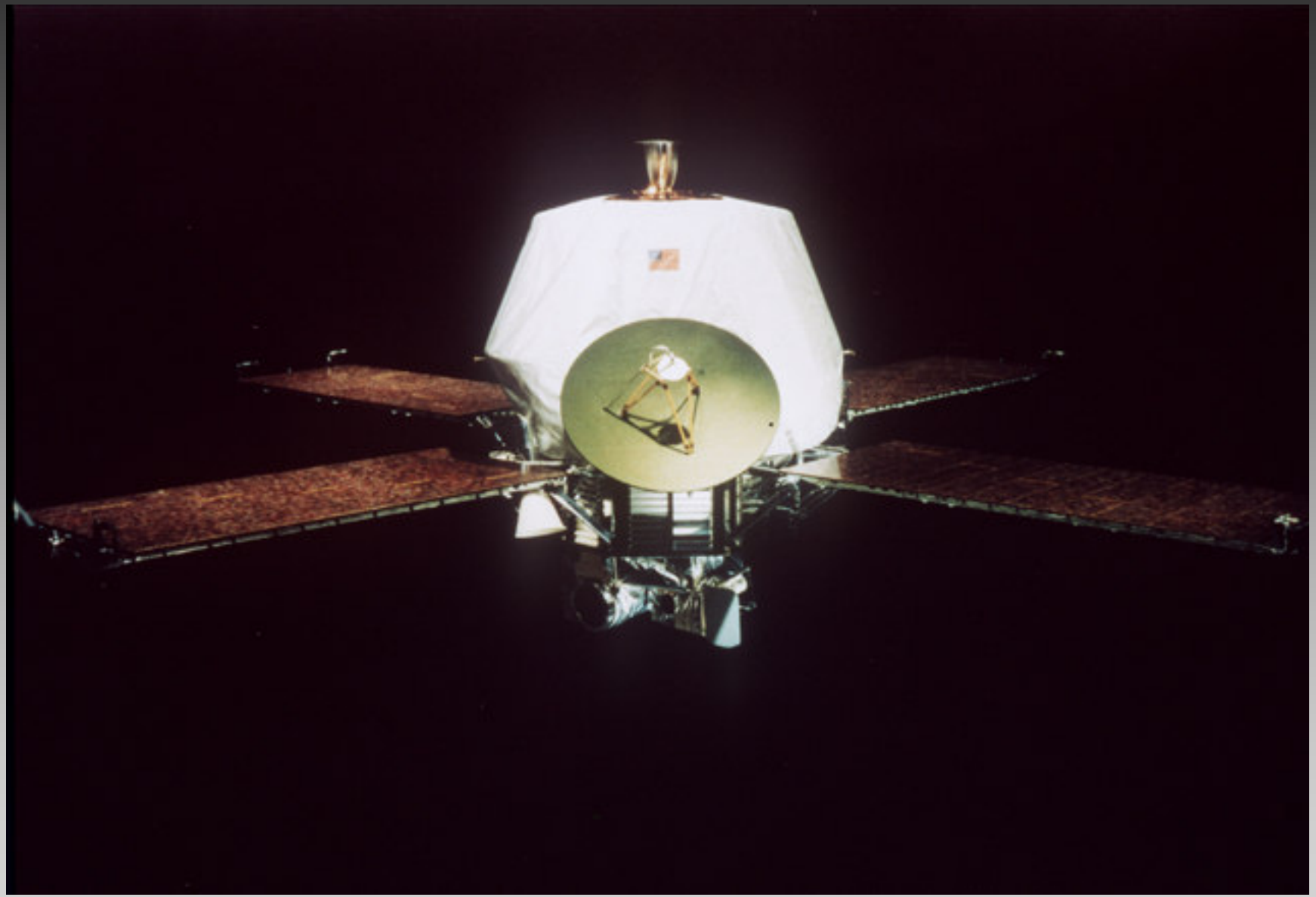
Mariners 6 and 7 had scientfic instruments to study Martian atmosphere:

- composition, pressure, density, and temperature
- two cameras
- infrared spectrometer
- ultraviolet spectrometer

Martian surface covered with craters!

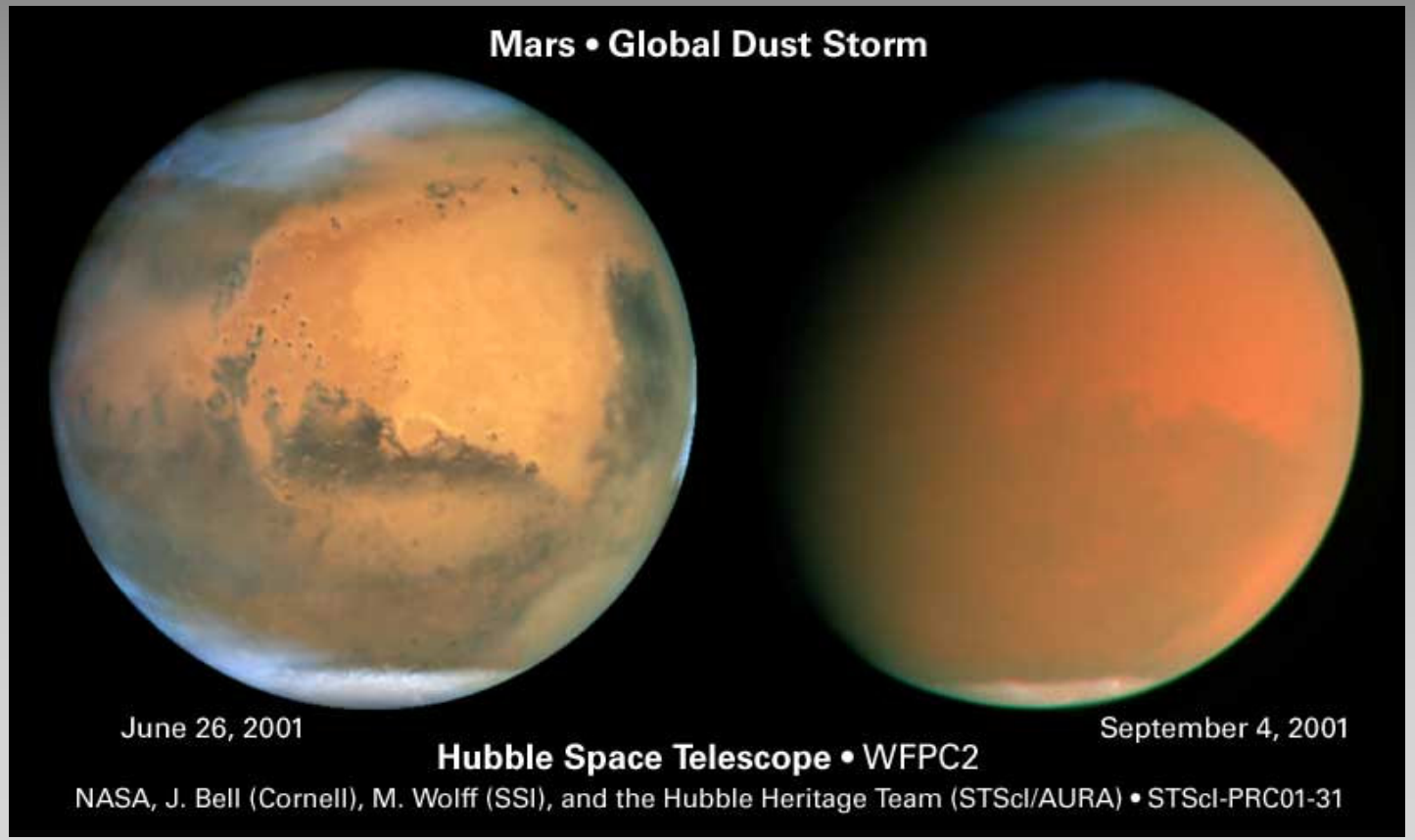
- surface isn't smooth (as historical observations thought)
- similar to Moon surface (being studied simultaneously)
- must be old: peak in impacts ~3.8 billion years ago
- difficult to see from Earth, but Mars' thin atmosphere
- many gave up hope for seeing "water"/ "life" on Mars

Mariner 9 – first ORBITER spacecraft!!



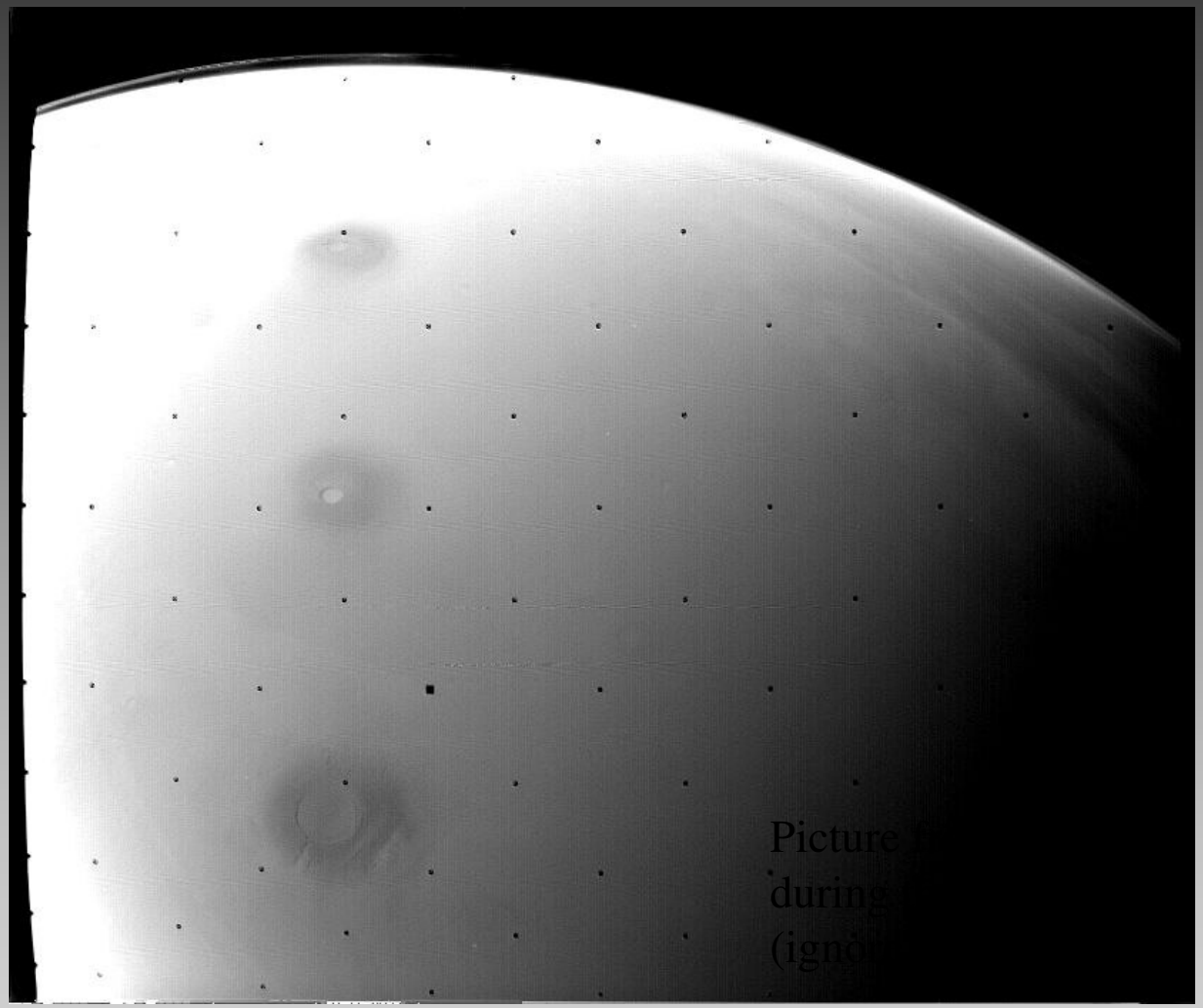
- **Mariner 9** was *the first spacecraft to orbit another planet*
  - arrived at Mars 14 November 1971
  - orbited Mars for more than a year

- Major dust storm on Mars when Mariner 9 arrived!
  - -surface was not visible for an entire month
  - -however, the cones of major volcanoes (new discovery) were visible



Craters weren't all that was found on Mars!!

Even though dust covered, there were several 'crater-like' features visible rising above the dust...



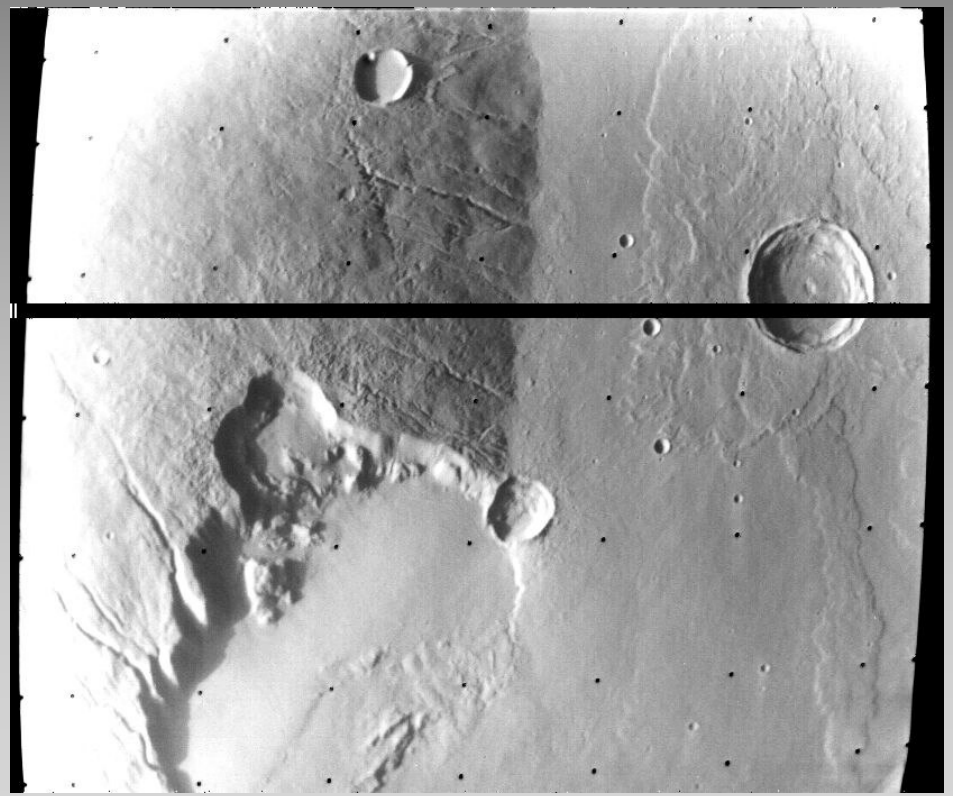
Carl Sagan took a polaroid of the TV screen in the headquarters of Mariner 9 – he rushed into a group of scientists in the next room and they realized that these were volcanic calderas!!

Mariner 9's Mars Milestones

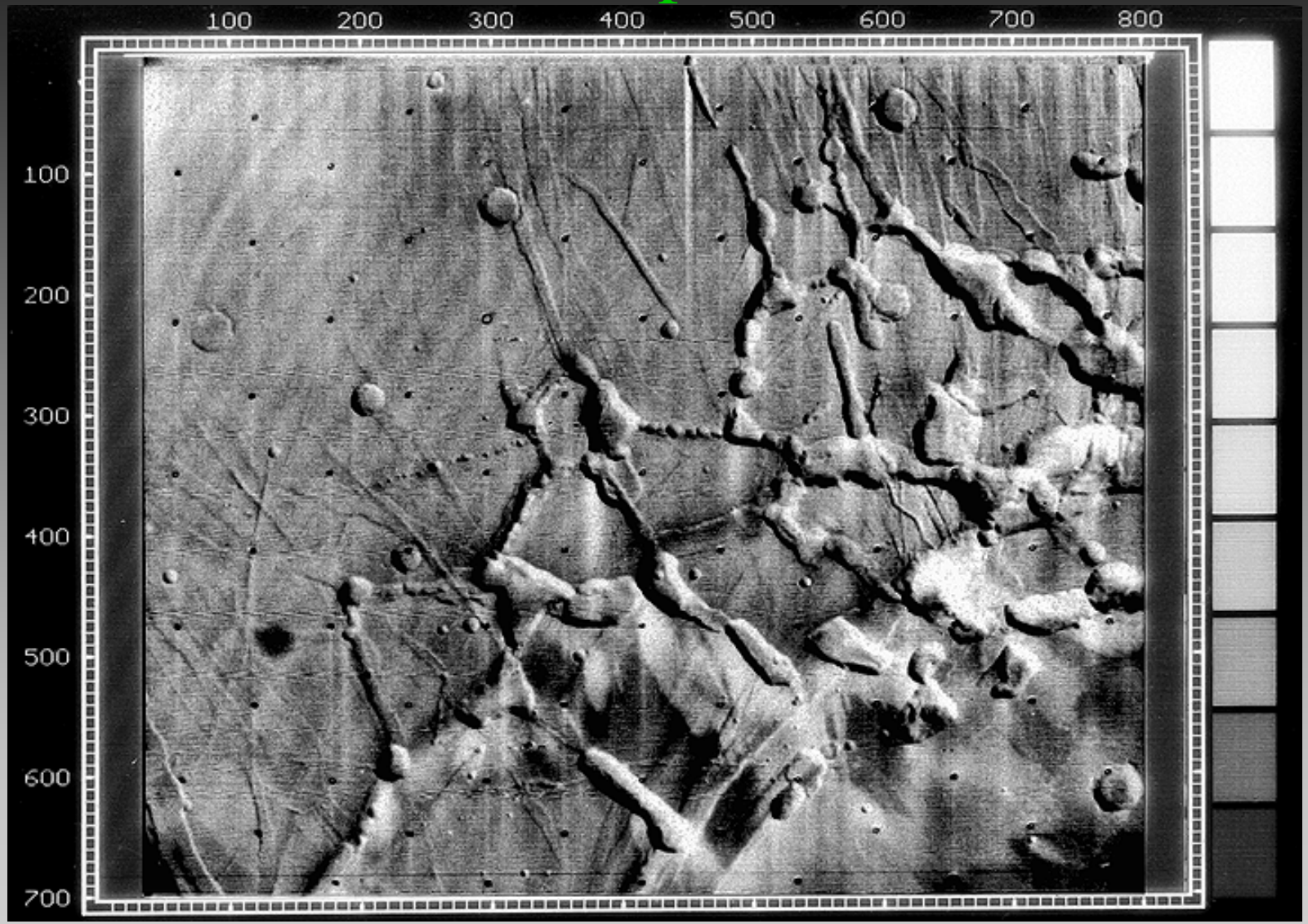
- 349 days in orbit (circled Mars twice daily for a year)
- Mariner 9 transmitted **7,329** images, covering over 80% of Mars' surface
- lowest altitude images distance of spacecraft ~900 miles above surface
- An infrared radiometer was included to detect volcanic activity
- Mars' tiny moons, *Phobos and Deimos*, were also photographed.

Channels on the flanks of the volcano Hecates Tholus. Various radial channels have been interpreted as erosional ash channels, lava channels or channels eroded by fluvial processes.

Mariner 9 narrow angle camera.

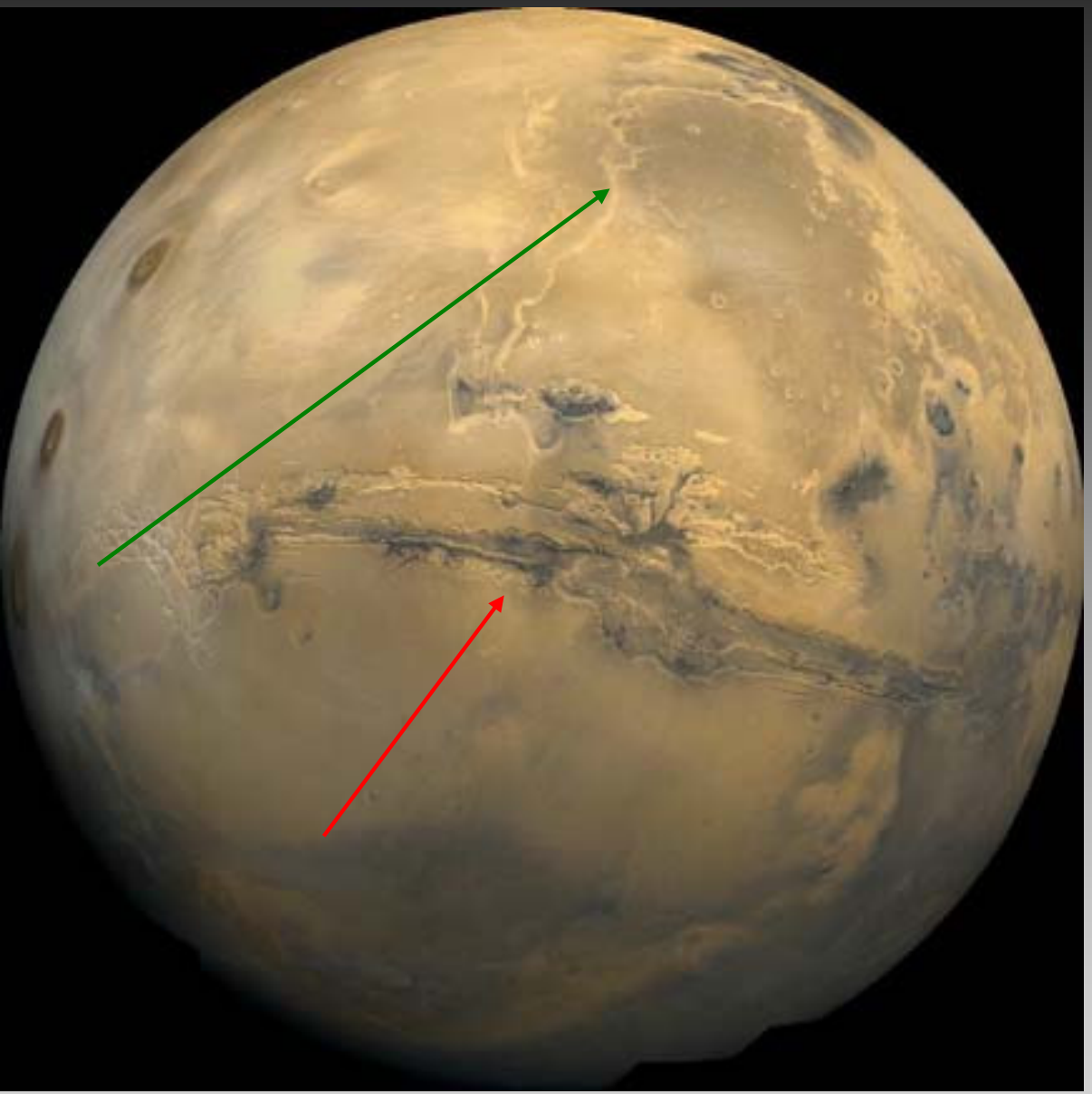


Valles Marineris – picture from Mariner



Valles Marineris - system of canyons over 4,000 km (2,500 miles)
- revived people's interest in possible water/life

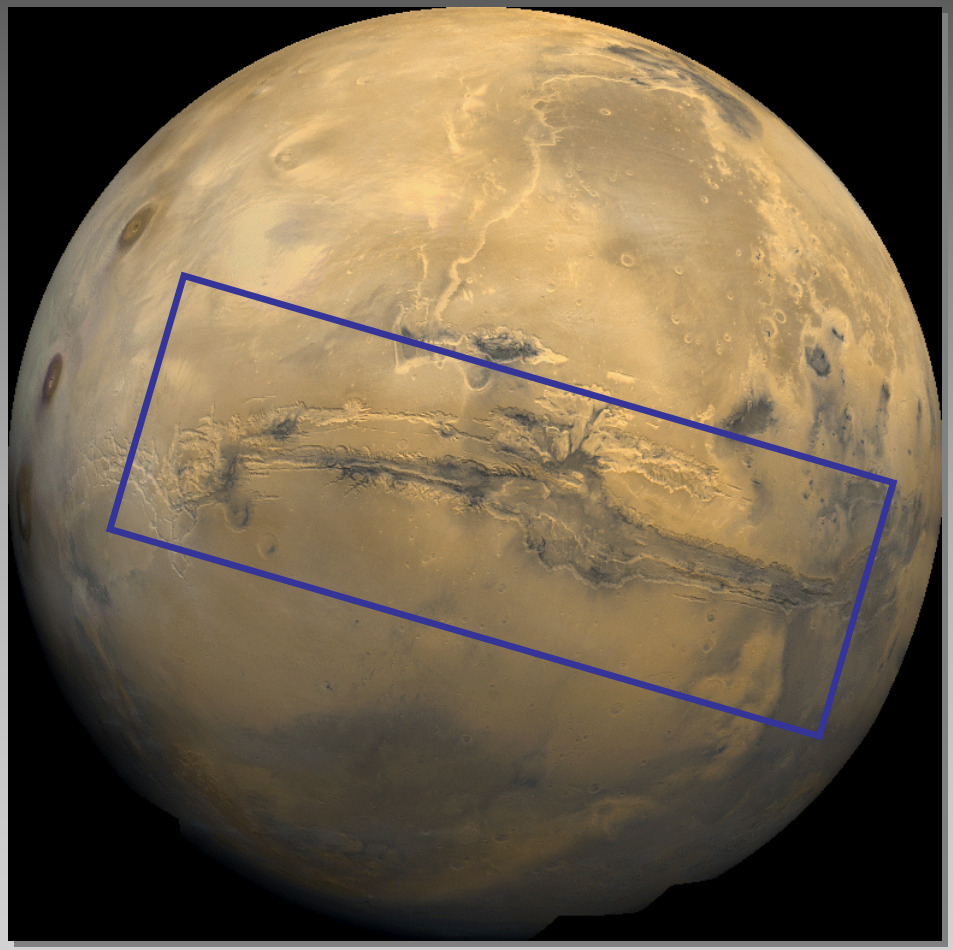
Viking Orbiter



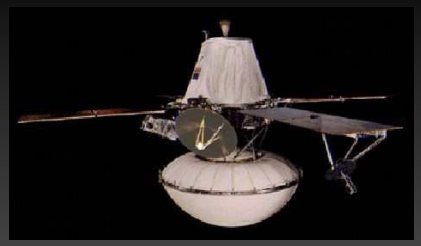
- *This image is a mosaic of the Valles Marineris hemisphere of Mars.*
- The center is the **Valles Marineris** system – 3,000 km long and up to 8 km deep.
- Many **huge ancient channels** begin from the chaotic terrain and north-central canyons and run north.
- Many of the channels flowed into a **basin called Acidalia Planitia**, which is the dark area in the extreme north.
- The three **Tharsis volcanoes** (dark red spots), each about 25 kilometers high, are visible to the west.

Valles Marineris - "Grand Canyon of Mars"

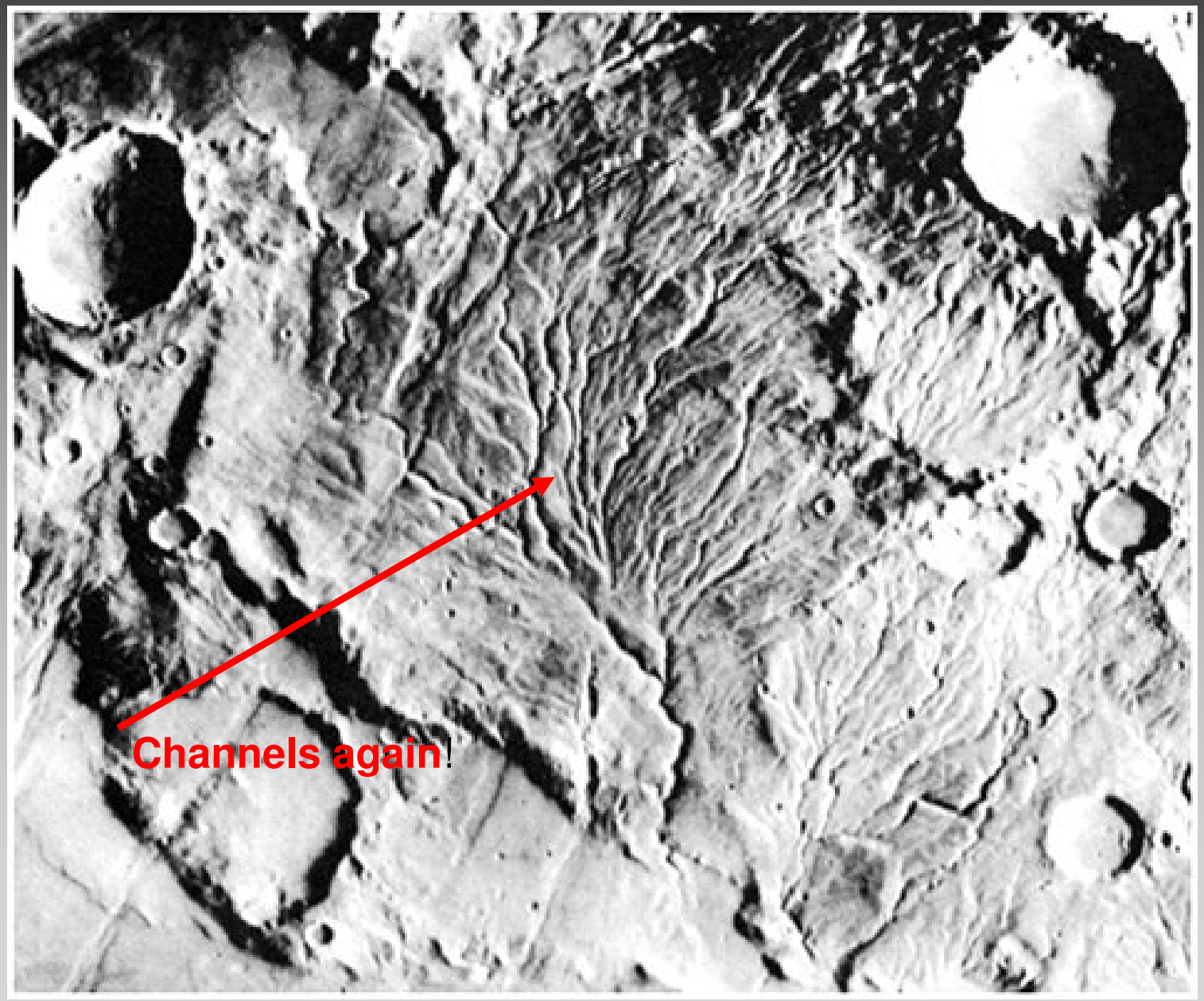
- "rift valley" – region broken by crust motions earlier in Mars' history



- signs of river erosion in early history of Mars (3-4 Billion yrs ago) like Grand Canyon

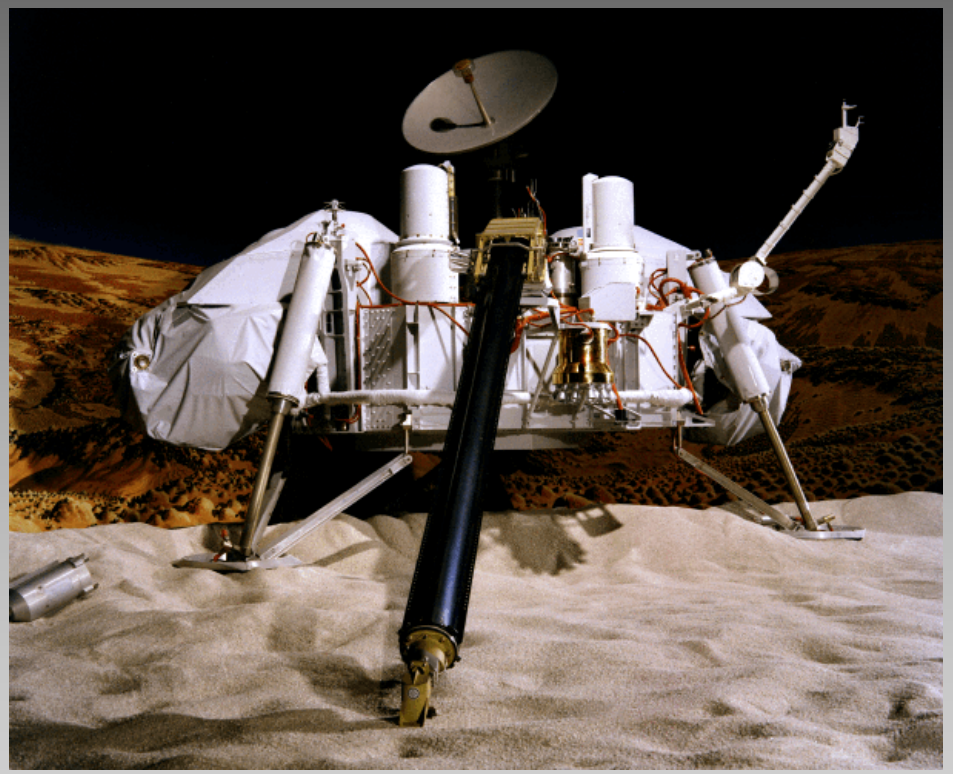


Viking 1 and 2 – Orbiter & Lander

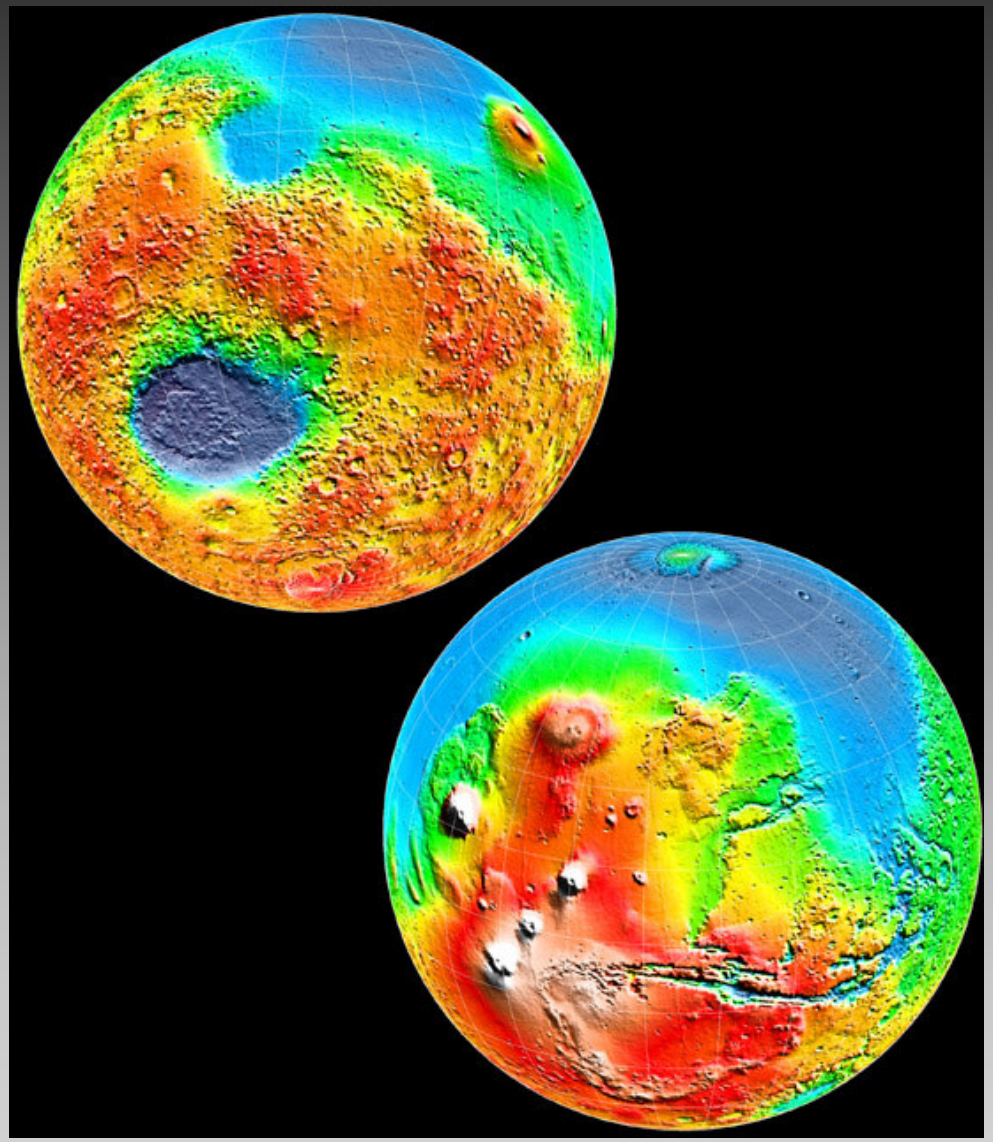


Viking and the search for life

- The three biology experiments ***discovered unexpected and enigmatic chemical activity in the Martian*** but provided no clear evidence for the presence living microorganisms in soil near the landing sites.
- According to mission biologists, Mars is selfsterilizing
- Drill the surface, search in the rocks (***remember the Methane biological hypothesis)***



Interlude: A Guide to Mars



Fast Facts on Mars:

- **size = 5974 km/4200 miles**
  ~53% Earth's size

- **mass = 6.5 x 10^{23} kg or**
  0.1 Earth's mass

- **density = 3900 kg/m^3**
  (Earth's density = 5510 kg/m^3)

- **gravity/physics will be different on Mars, i.e., mts., activity in planet's core**

Physical Features of Mars

- **Mars Dichotomy**
- **Large Scale Geology**
  - Craters
  - Volcanoes
  - plains
- **Polar Caps**
  - Water/ Ices and other volatiles
- **The Martian Atmosphere**

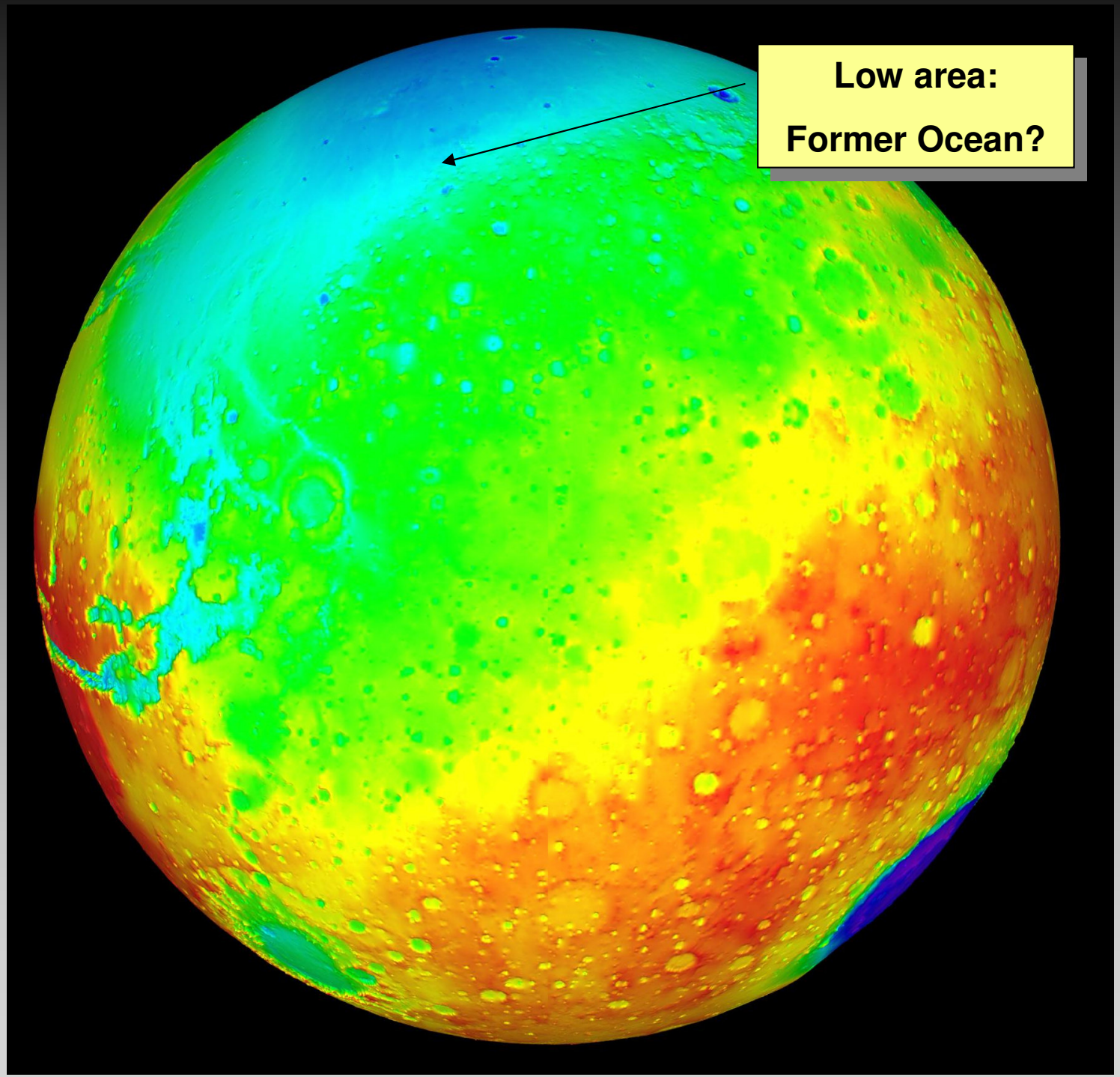
Map of Martian surface

MOLA

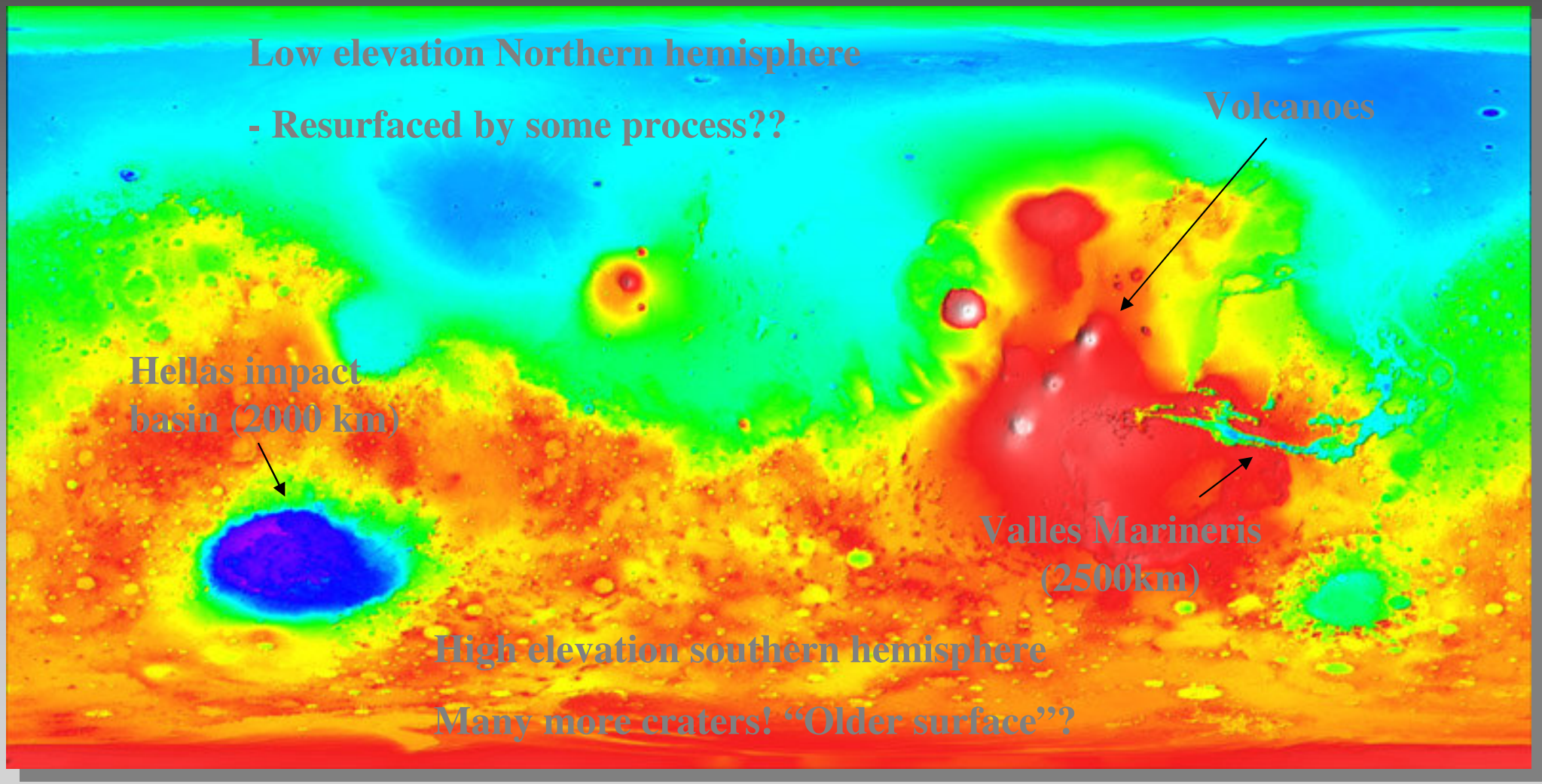
(Mars Orbiter Laser Altimeter)

Color indicates elevation

(Blue =low, red= high)



Mars Topographic Map
(MOLA radar 1998/99)



Mars' Crustal Dichotomy = noticeable differences between N and S hemispheres

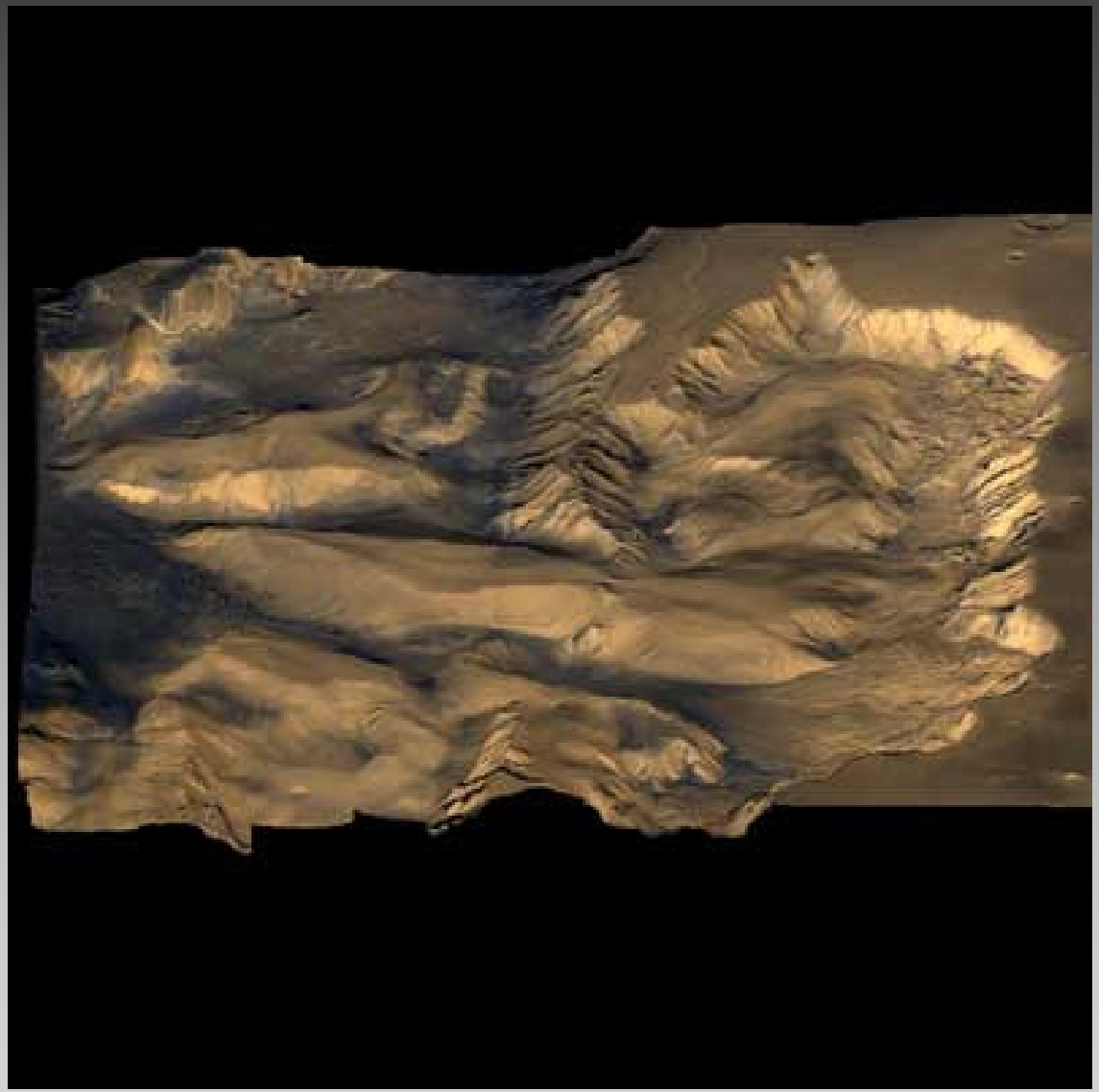
- *Altitudes (N lowlands, S highlands)*
- *Cratering (age of surfaces?)*

Various Explanations:

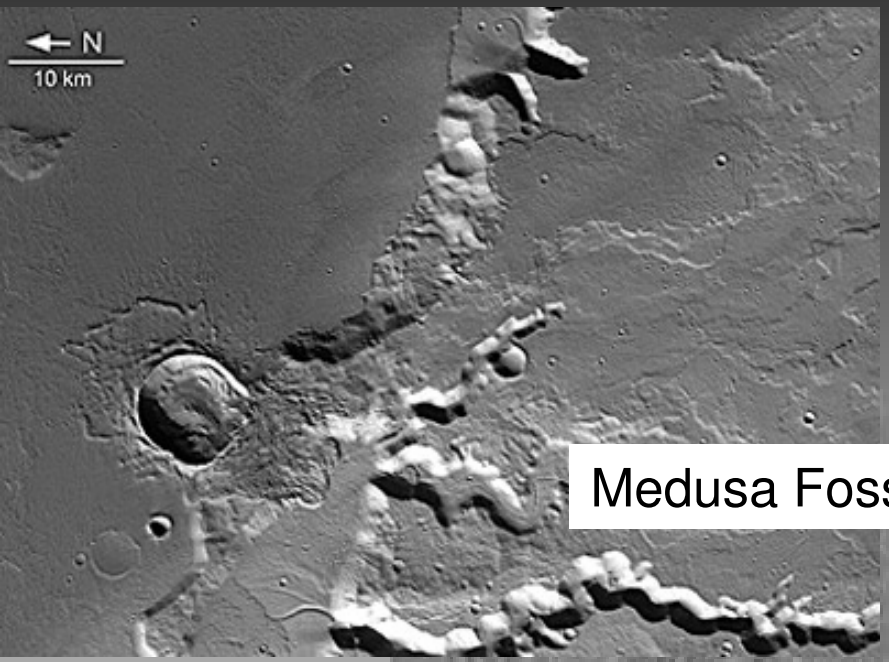
- large impact (asteroid) on Mars
- plate tectonics (although Mars too small for hot core)
- volcanic eruptions which smoothed parts of the planet

Tectonic, Volcanism and Erosion

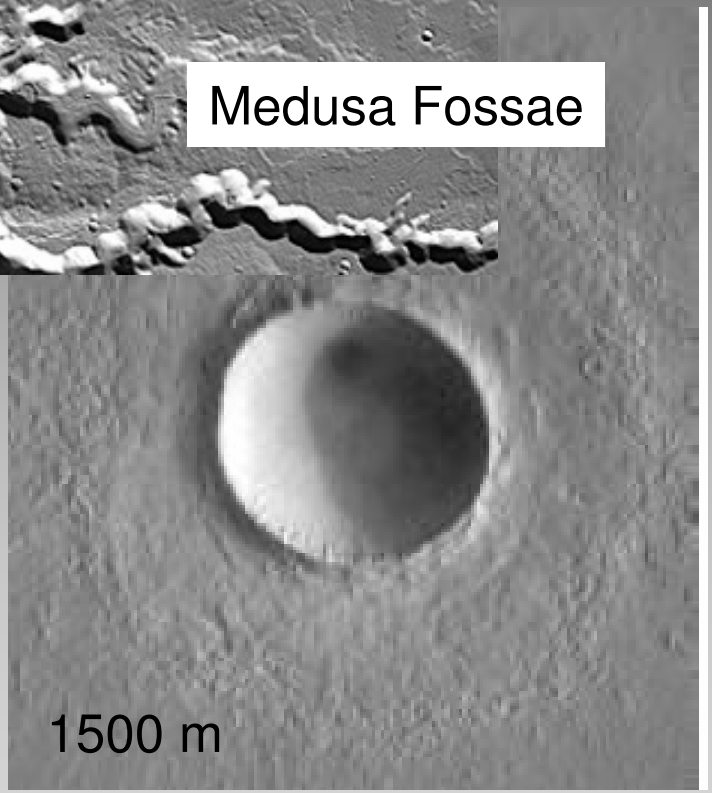
- This oblique view of Candor Chasma in Valles Marineris on Mars was mosaicked from high resolution black and white images acquired by Viking 1, and color images by Viking 2.
- The geomorphology is shaped by tectonics, landslides, wind, and perhaps by water and volcanism.

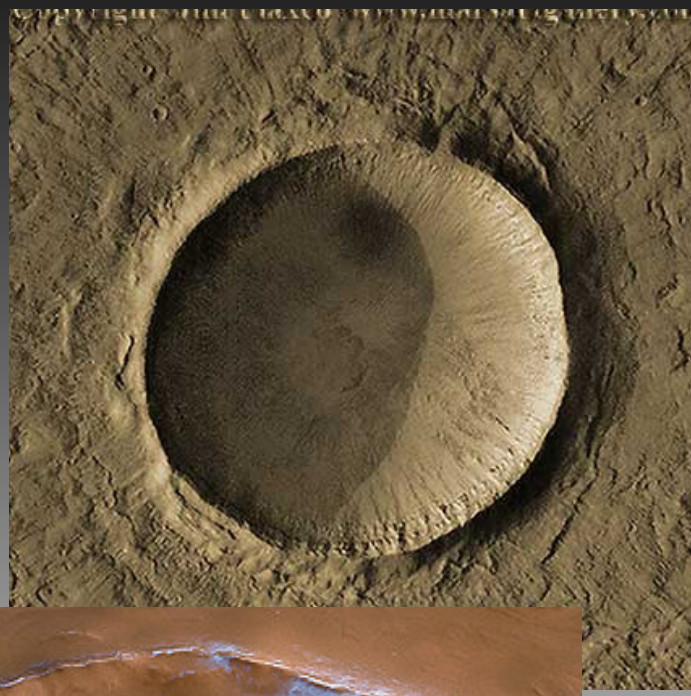


Craters on Mars



Medusa Fossae



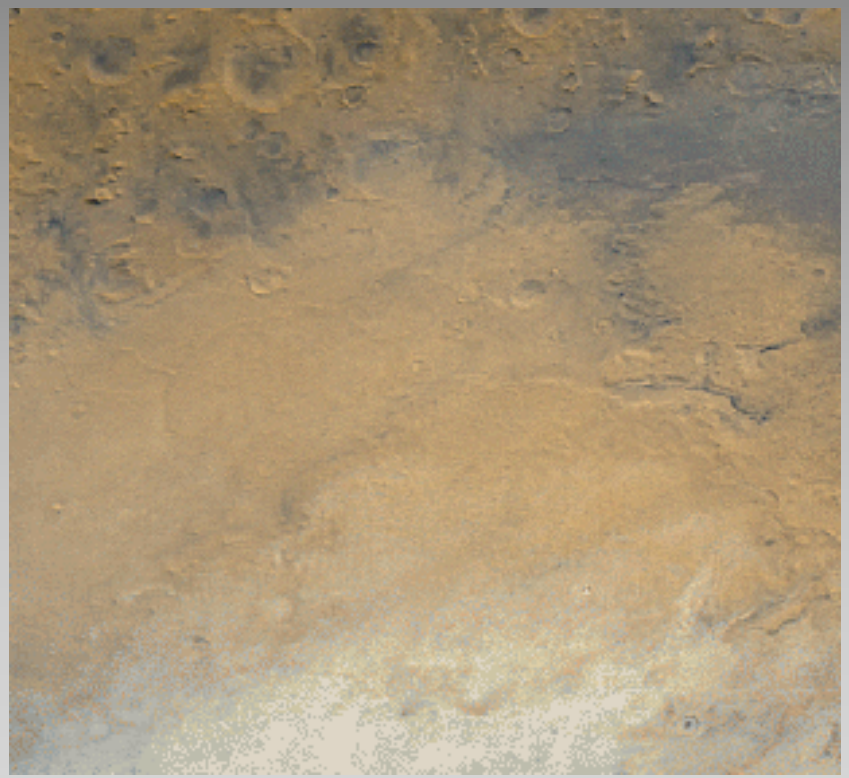


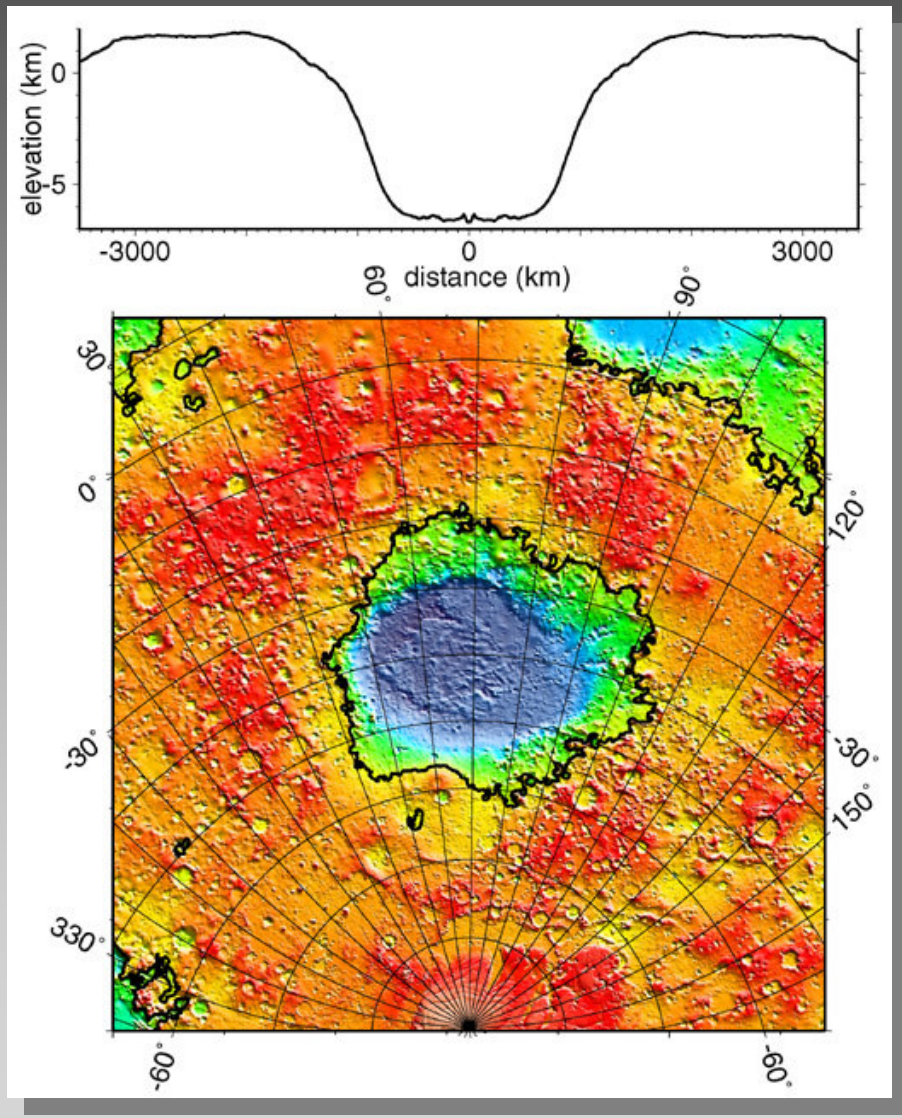
Vastitas Borealis

Craters on Mars: the role of volatiles

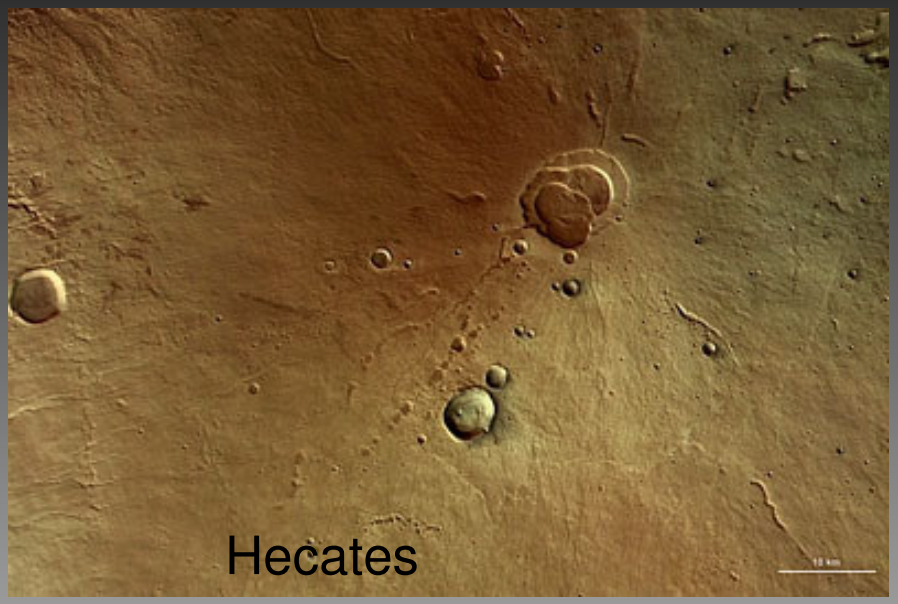
Hellas Impact Basin

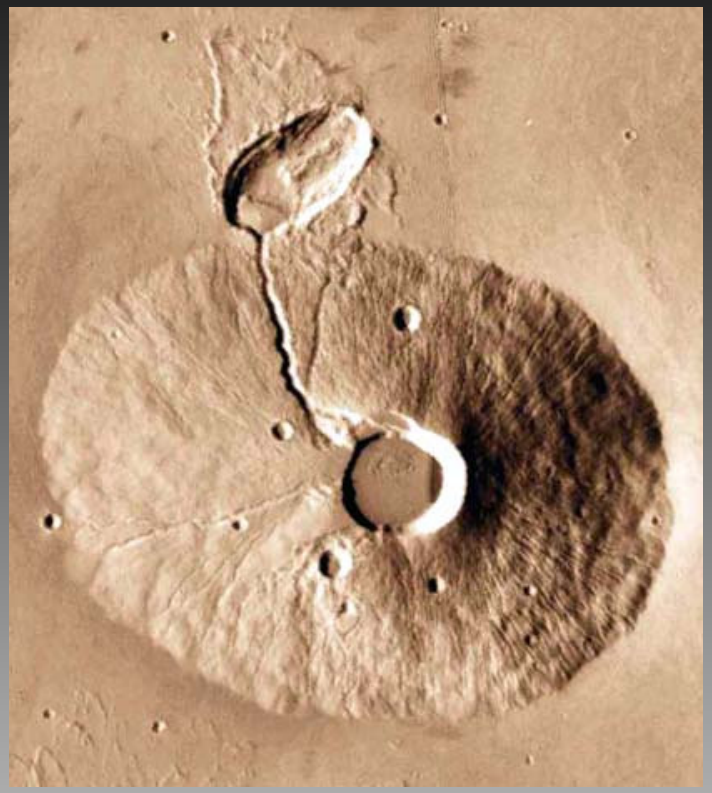
- ✓*2000 km diameter, 9 km deep!*
- ✓ *Probably formed by asteroid impact*
- ✓ *Debris from collision would cover US with layer 3 km thick*





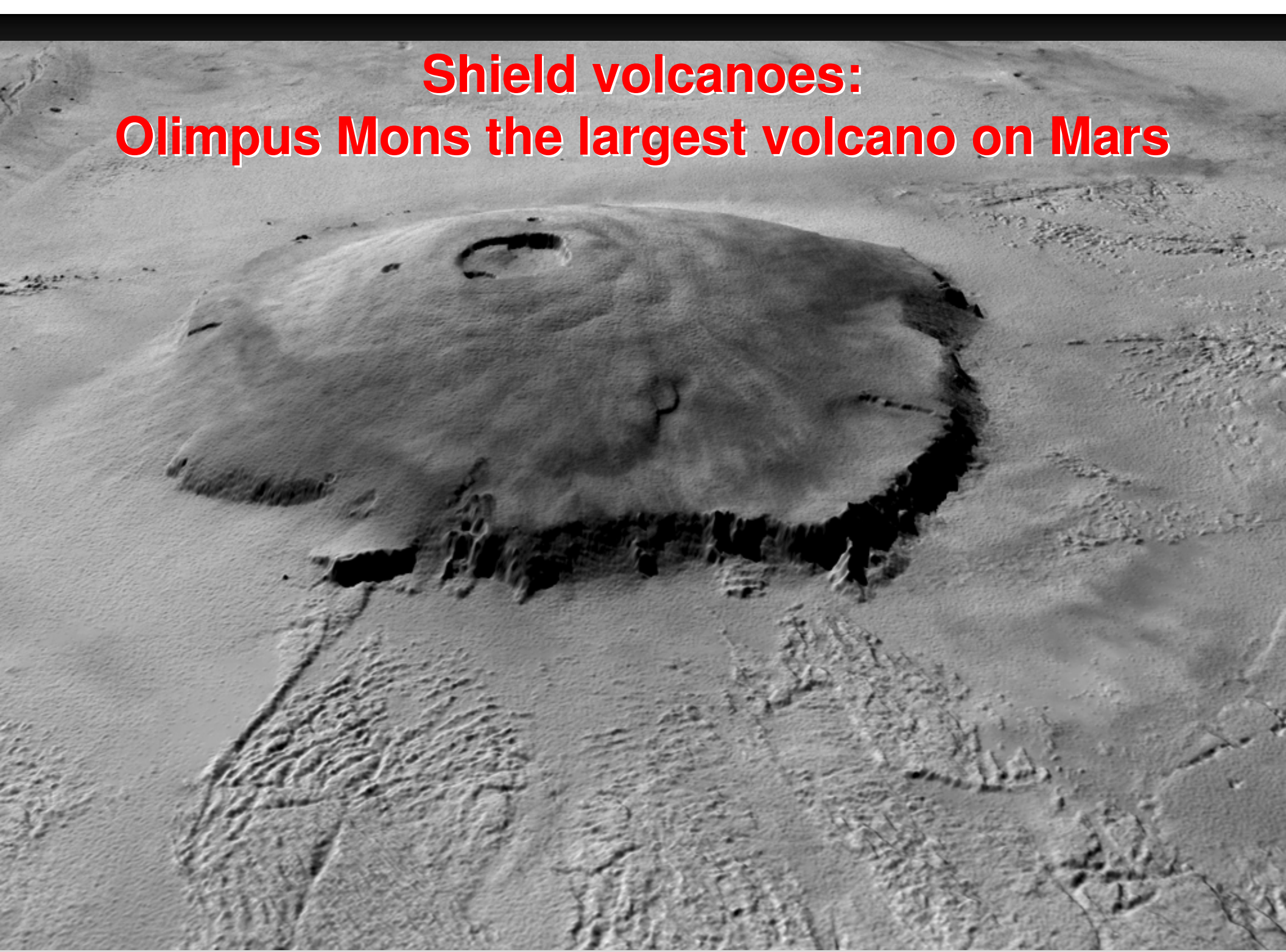
Mars Volcanoes



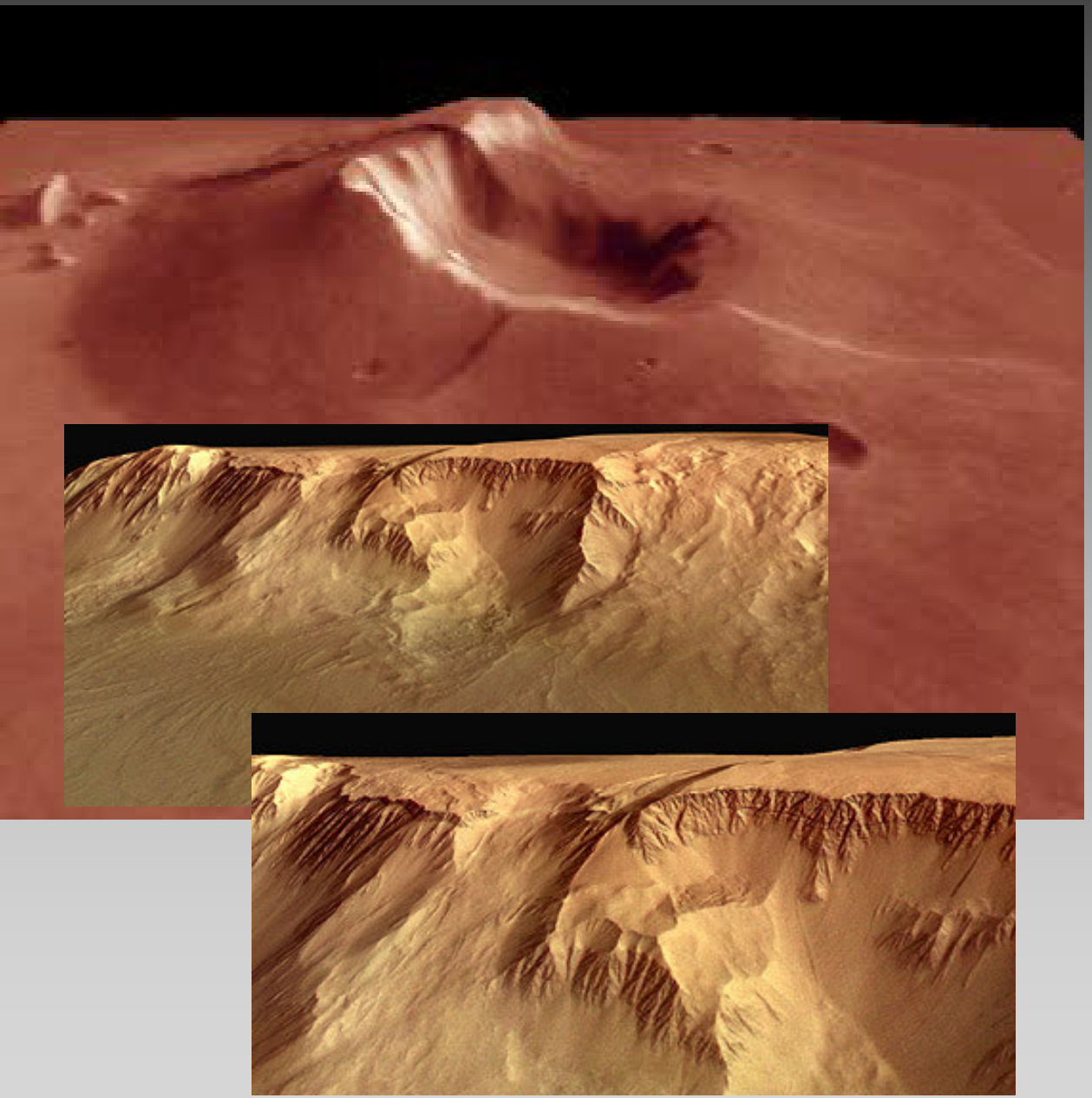


- Mars is characterized by 3 different kind of volcanoes:
  - Montes
  - Tholi (domes)
  - Paterae (complex collapsed shields)

Shield volcanoes:
Olimpus Mons the largest volcano on Mars

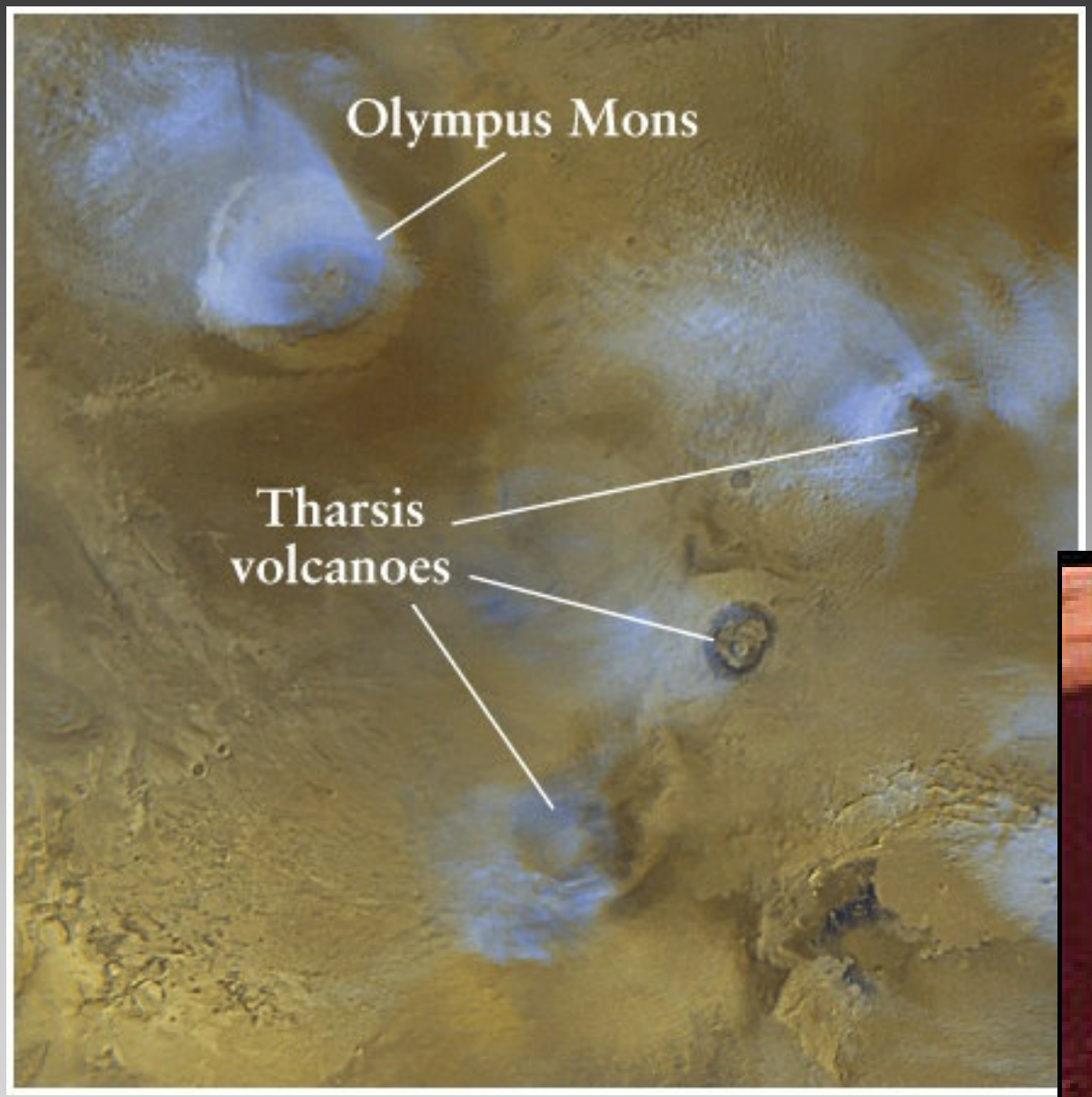


Olympus Mons – largest volcano in S.S.

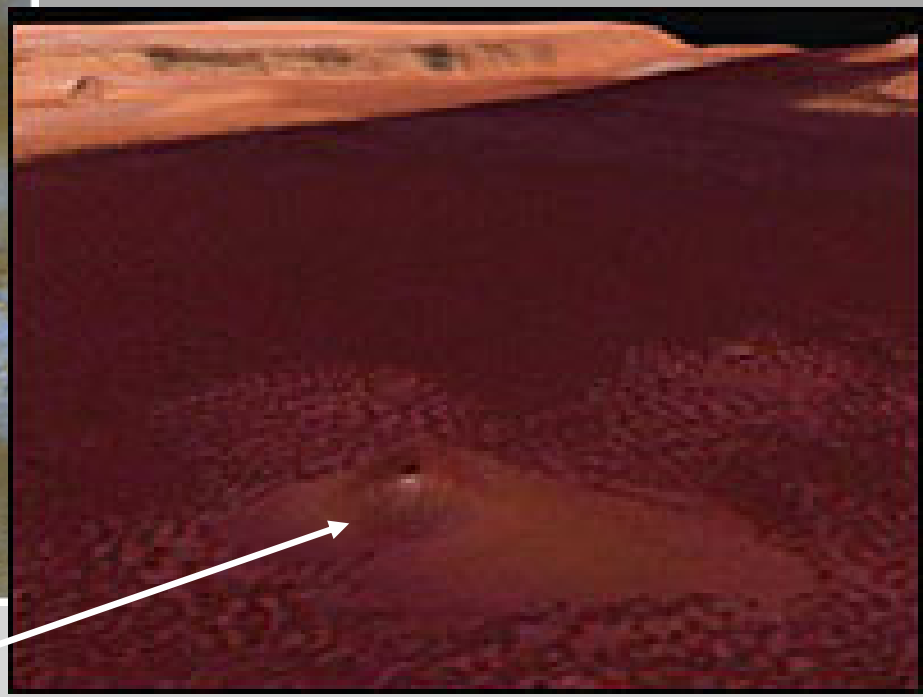


- This shield volcano, similar to volcanoes in Hawaii, measures 624 km in diameter by 25 km high. It is 100 times larger than Mauna Loa on Earth and three times as tall as Mt. Everest
- Located on the Tharsis Plateau near the equator, Olympus Mons is bordered by an escarpment.
- "hot spot" volcanism like in Hawaiian Islands

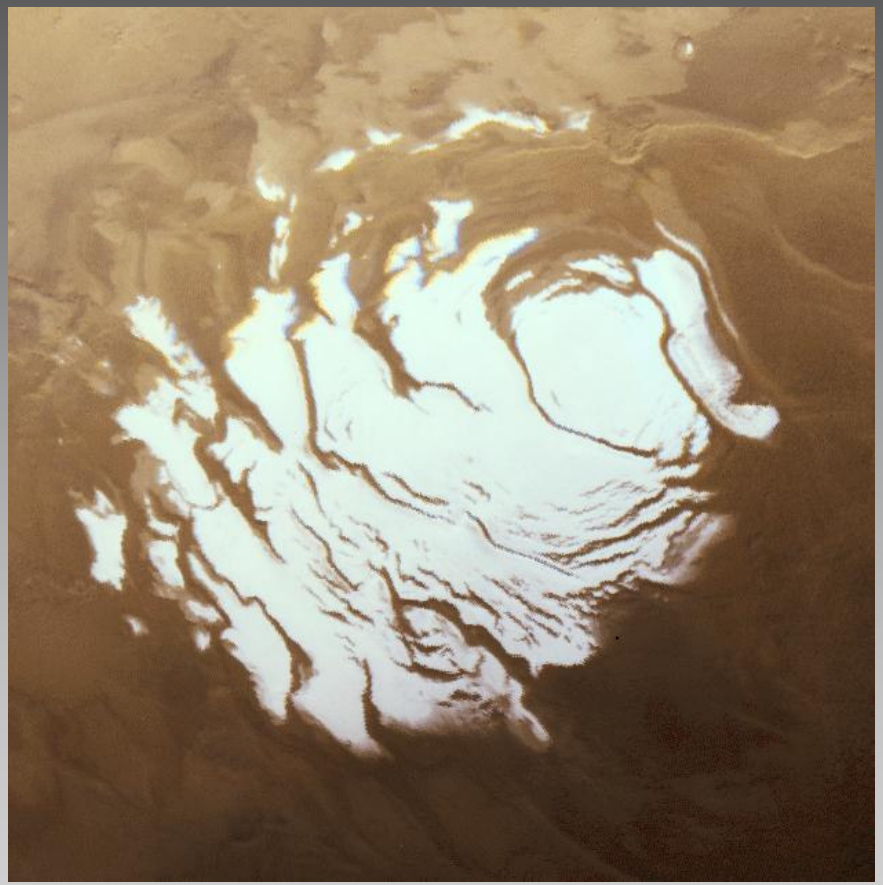
Tharsis Rise – cluster of large volcanoes



- near Olympus Mons
- blue/white clouds often seen over these volcanoes
- these clouds result when:
  - warm air (water) rises
  - cools at the high altitude
  - freezes into cloud



Seasonal Effects on the Polar Ice Caps

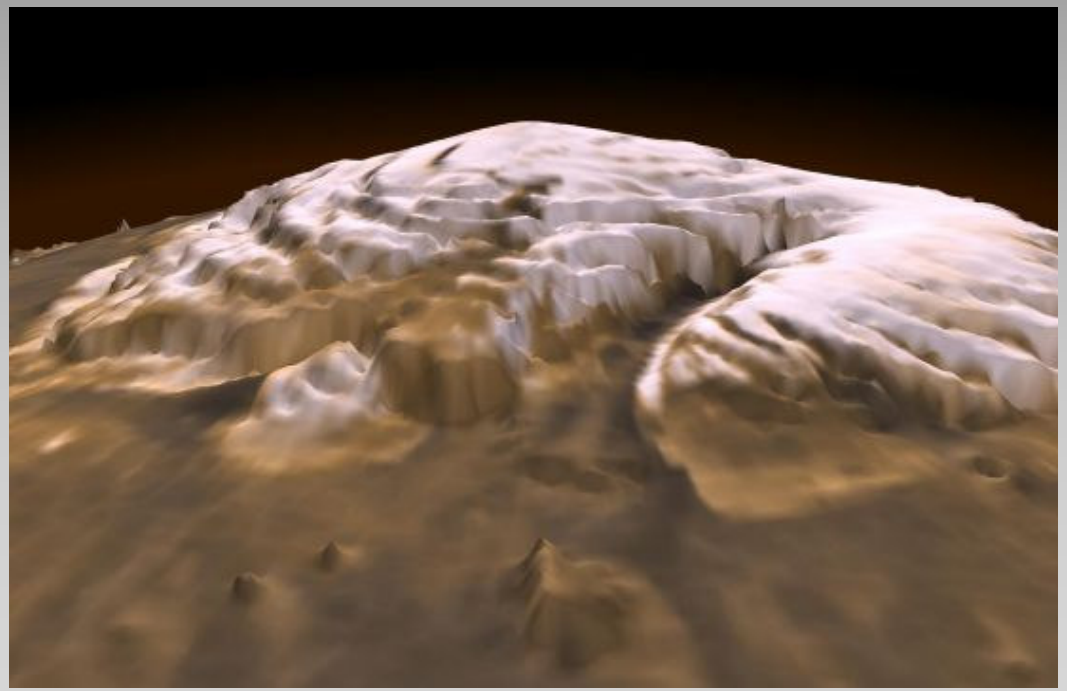


South Polar Cap in Summer –
much of it is sublimated

South Polar Cap in Spring –
a larger region is frosty and frozen

Carbon Dioxide ("Dry Ice") Polar Caps!

- Caps are frozen carbon dioxide CO2 ('dry ice') and some frozen water traces on frozen CO2
- - CO2 freezes at T~150 K (~ -200 F)
- - block of 'dry ice' T~ -110 F
- - sublimes directly ice to gas
- Southern residual cap is ~300 km across, T ~150 K.
- Northern cap is ~1,000 km, T~200K (implies mostly water ice b/c CO2 ice would be sublimating)



Channels and Valleys: Tiu valley

- Most of the outflow channels are in northern lowlands north of Valles Marineris, just west of the Chryse region.
- The outflow channels are large, often more than 100 km wide and as much as 2000 km long.
- They emanate from cracked terrain (chaotic terrain) and have distinct flow features such as eroded craters with teardrop-shaped tails, scour marks, and "islands".

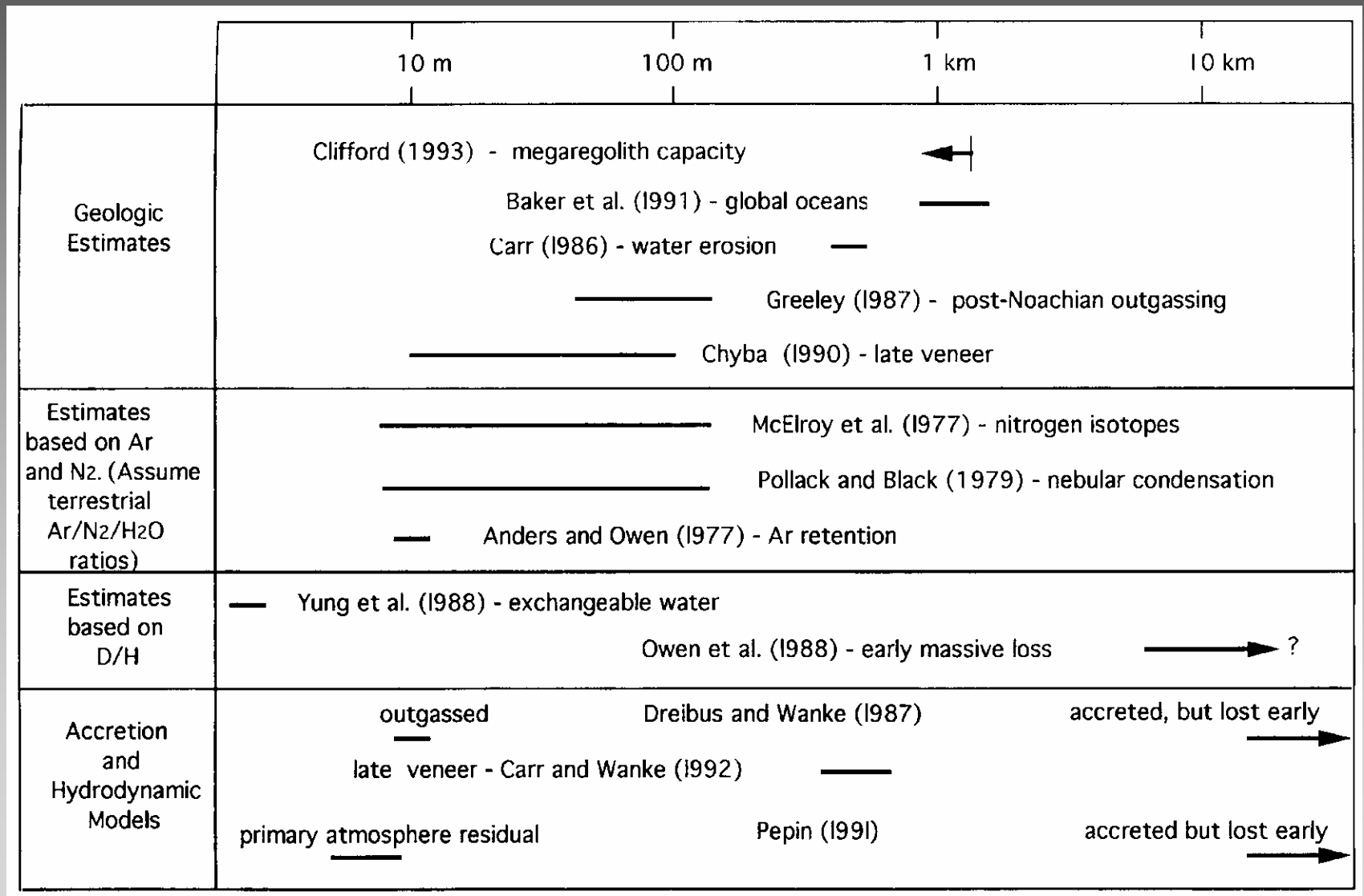
Water on Mars?

- A series of troughs and layered mesas in the Gorgonum Chaos region of the Martian southern hemisphere.
- Gullies proposed to have been formed by seeping ground water emanate from a specific layer near the tops of trough walls, particularly on south-facing slopes.
- The bottom image shows evidence for the past existence of liquid water on Mars. Two streamlined islands formed when the water was diverted by two large craters.

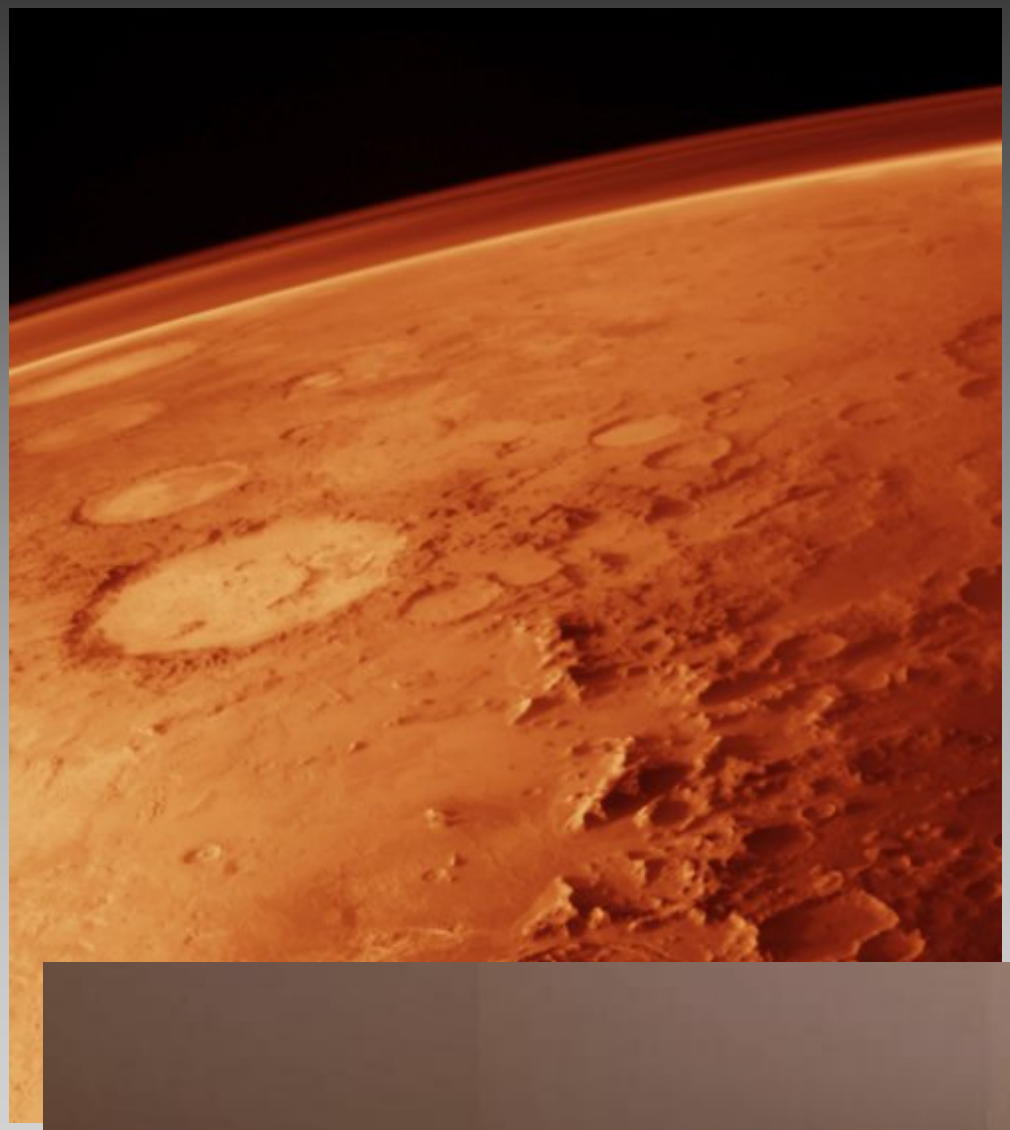
The search for water on Mars

- Images from Viking hinted at the presence of large quantities of water on Mars.
- Water vapor in the atmosphere amounts to an equivalent layer of a few tens of microns.
- Polar caps may contain the equivalent of a layer a few tens of meters thick.
- Where has the water gone? Can it be stored underground?

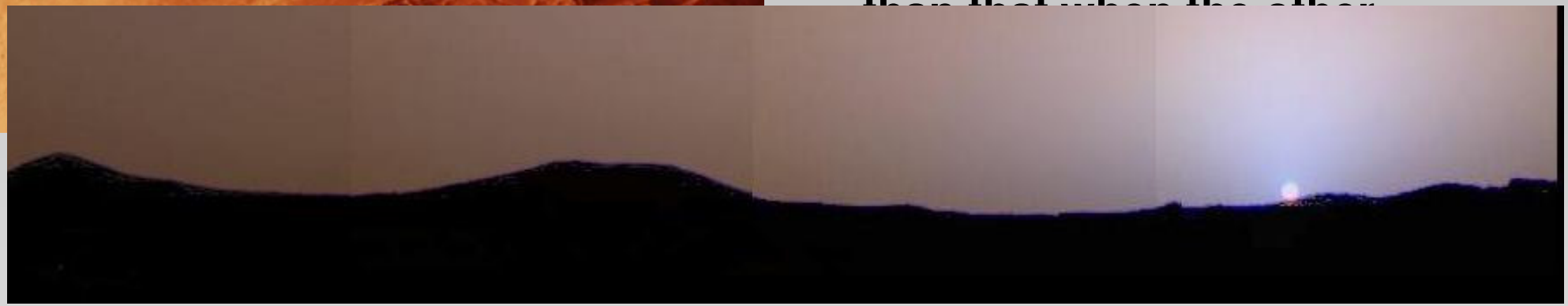
Estimates of the initial quantity of water on Mars (equivalent layer)



The Atmosphere



- The atmospheric pressure is controlled by the balance between the cold and warm pole.
- The pressure remains roughly constant over the year, as CO2 vaporized at one pole only to sublime at the other.
- Due to the eccentricity of Mars' orbit *the insolation* of one pole is in sunlight is significantly different



Martian Atmosphere

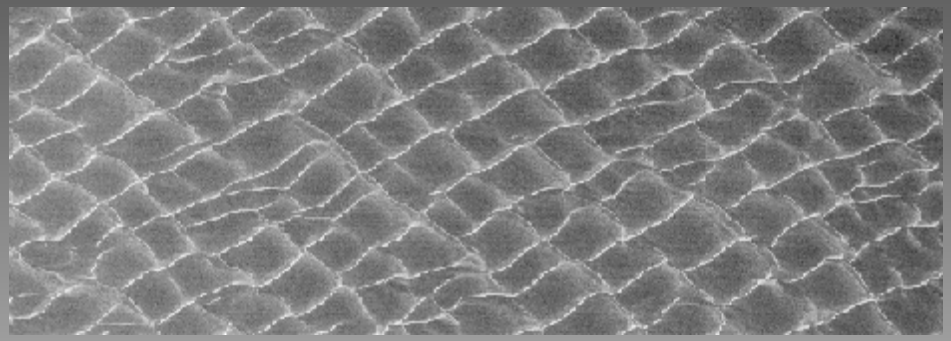
Composition	**95.3% carbon dioxide (CO_2),** **2.7% nitrogen (N2),** **1.6% argon (Ar),** **0.15% oxygen (O2),** **0.03% water vapor (H_2O)**
Surface pressure	**1-9 millibars, depending on altitude; average 7 mb**

- The low-density is still thick enough to support strong winds and enable occasional planet-wide dust storms to obscure the surface for months at a time.
- On the other hand, the Martian atmosphere results in only a weak greenhouse effect that raises the surface temperature by about 5℃.

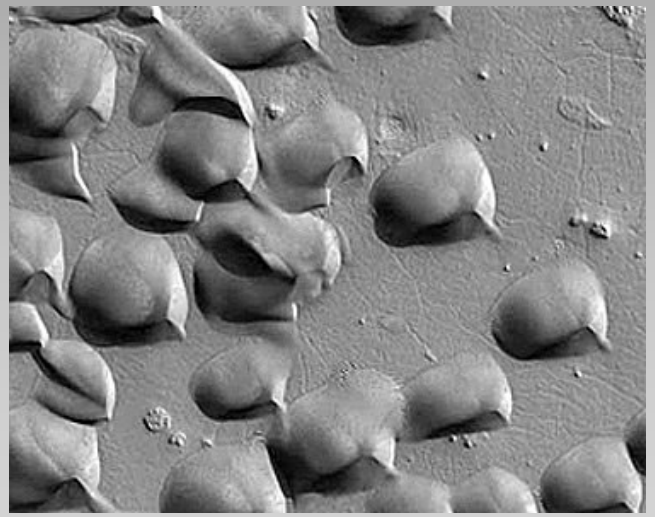
Mars mineralogy vs deposits: the role of atmosphere

- The data obtained by the two Viking Landers (6500 km apart from each other) showed a Martian soil chemical ***composition almost identical, indicating that the lowlands are covered with soil intensely mixed and homogenized by dust storms.***

- The rover-mounted APX spectrometer of the *Pathfinder* mission ***showed that the composition of the rocks differ greatly from that of the soil***, and found considerable variations in surface composition.



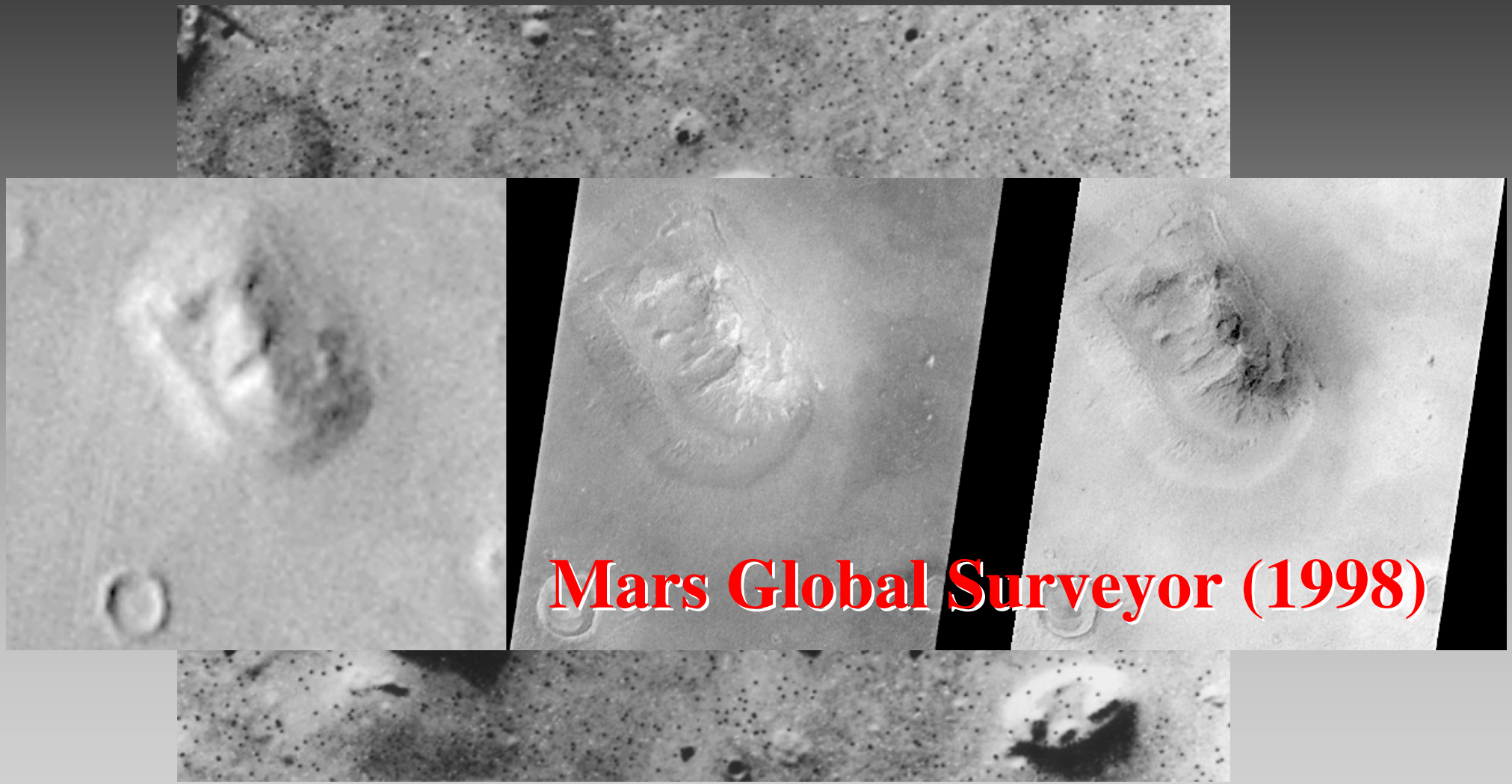
Dunes imaged by by MGS



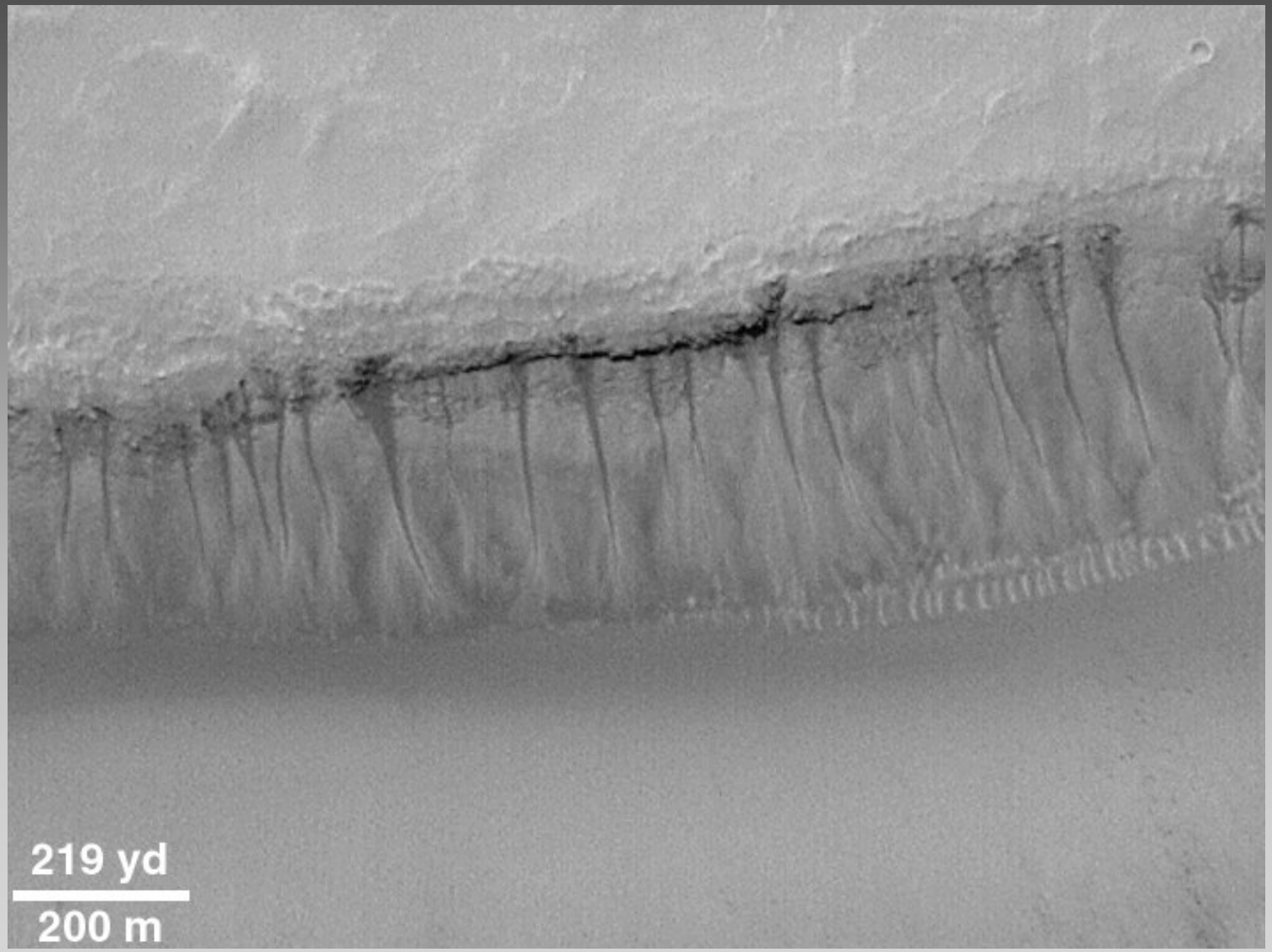
Mars Global Surveyor

Launch: November 7, 1996

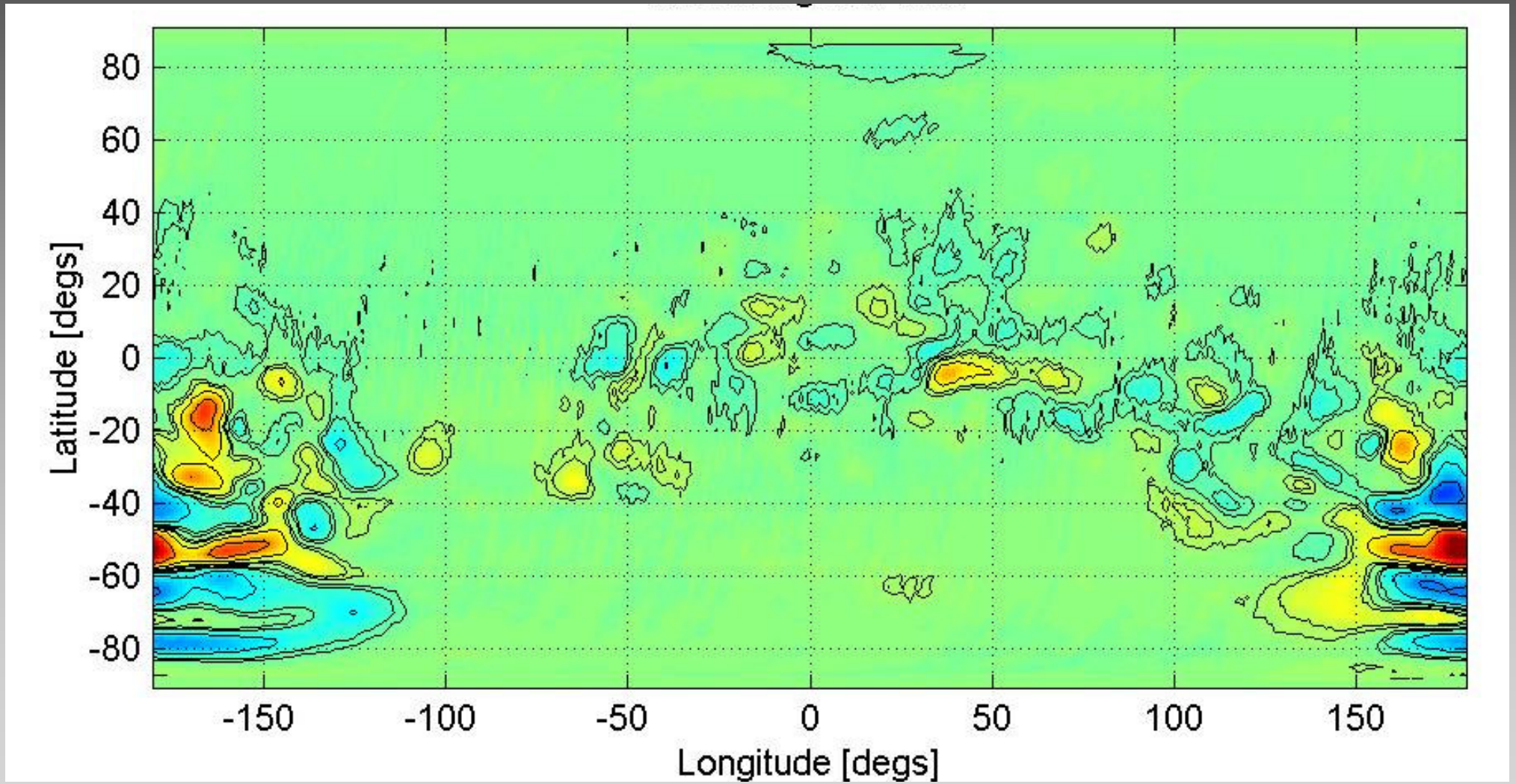
The "Face" on Mars (Viking Image from 1976)

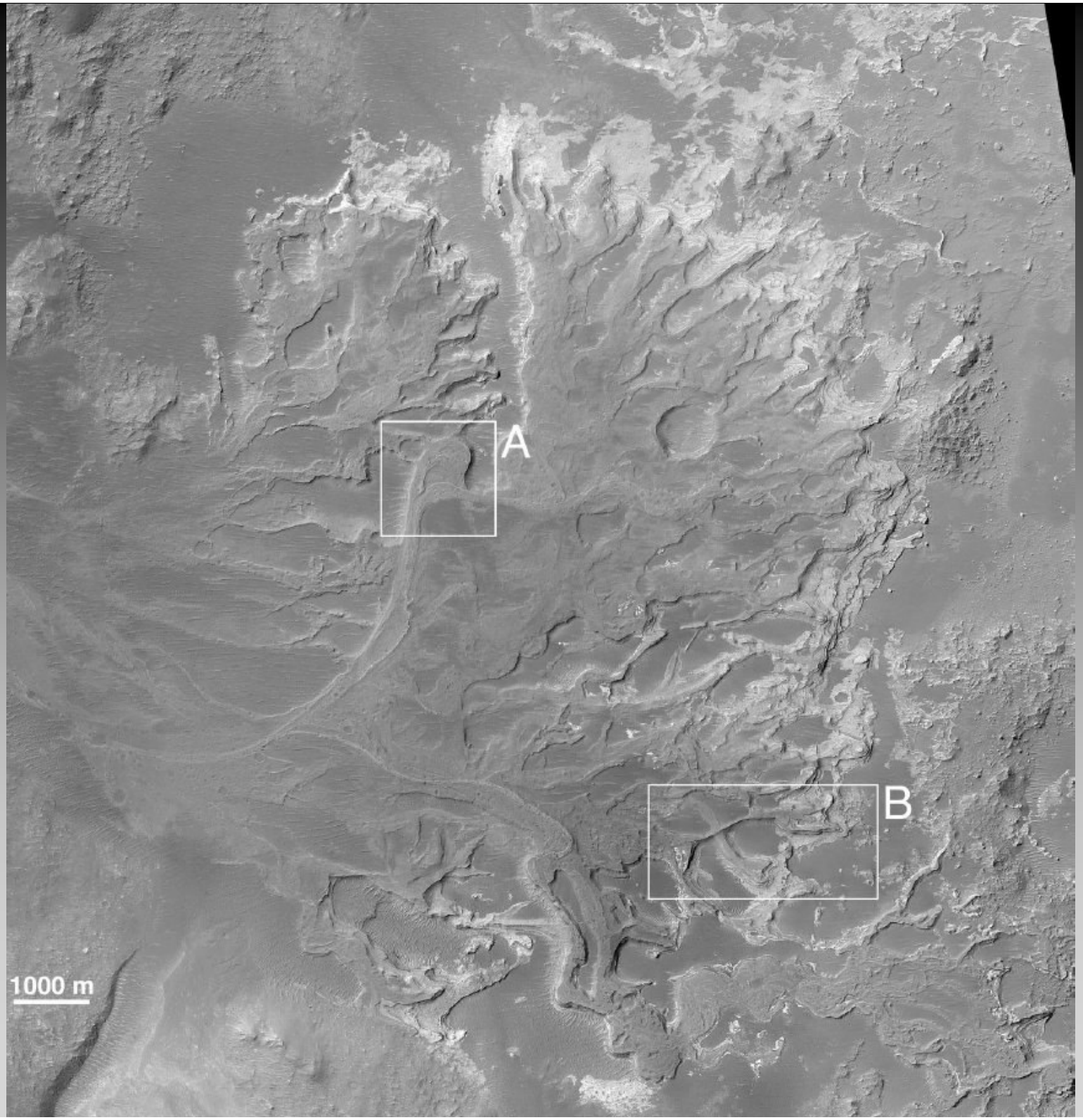


Recent release of liquid water at the surface?



Paleomagnetism



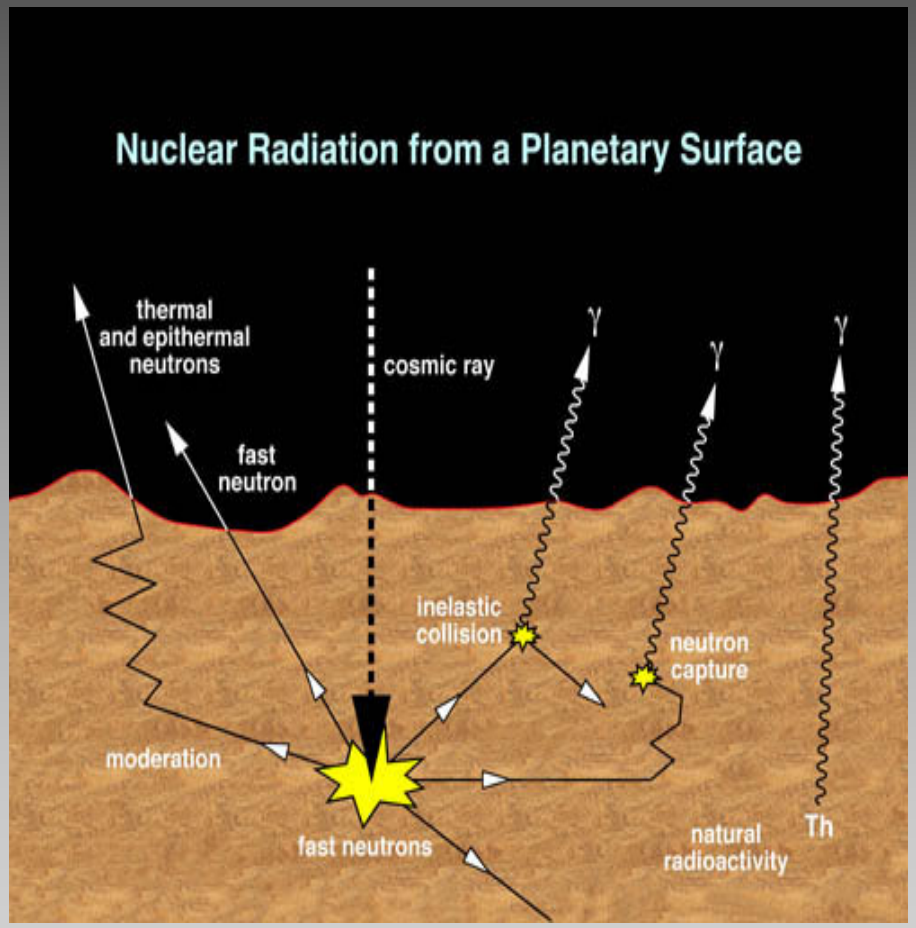

A
B
1000 m

2001 Mars Odyssey

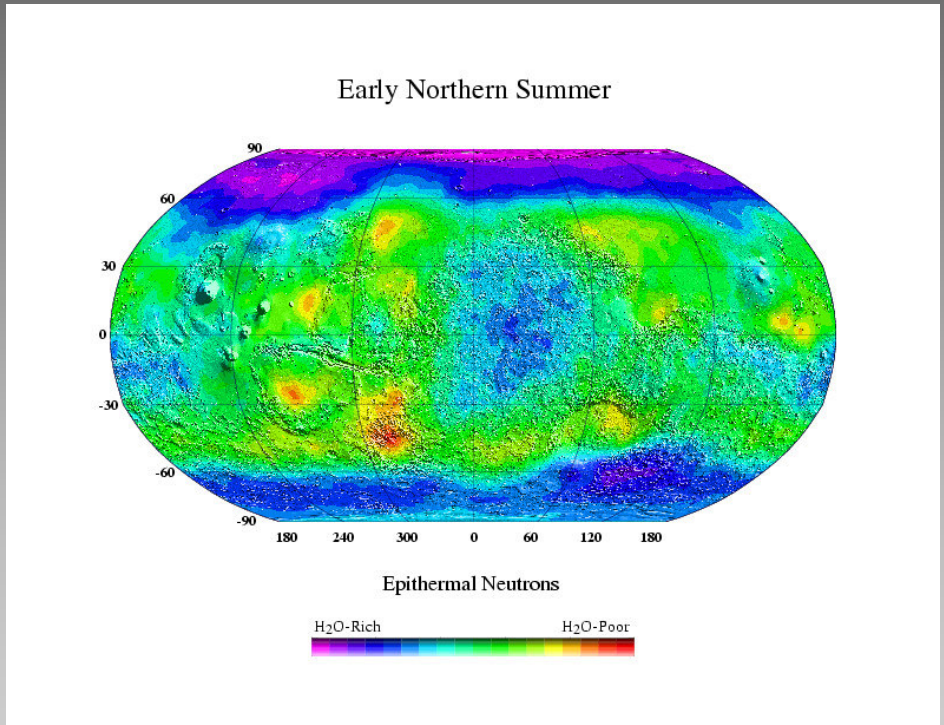
Launch: April 7, 2001

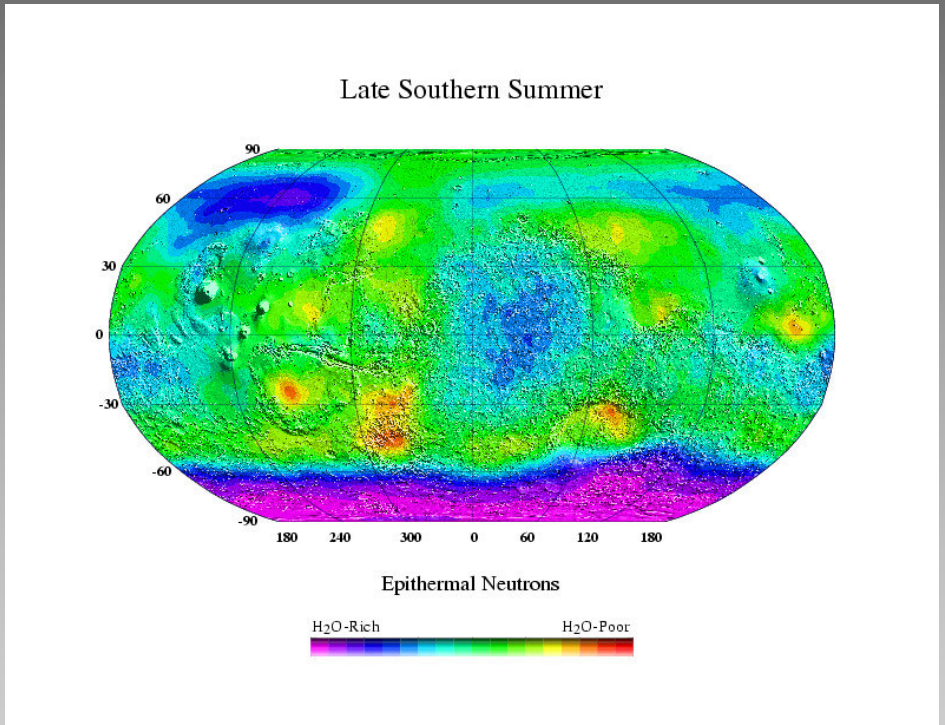
Odyssey: a strong indication of shallow water

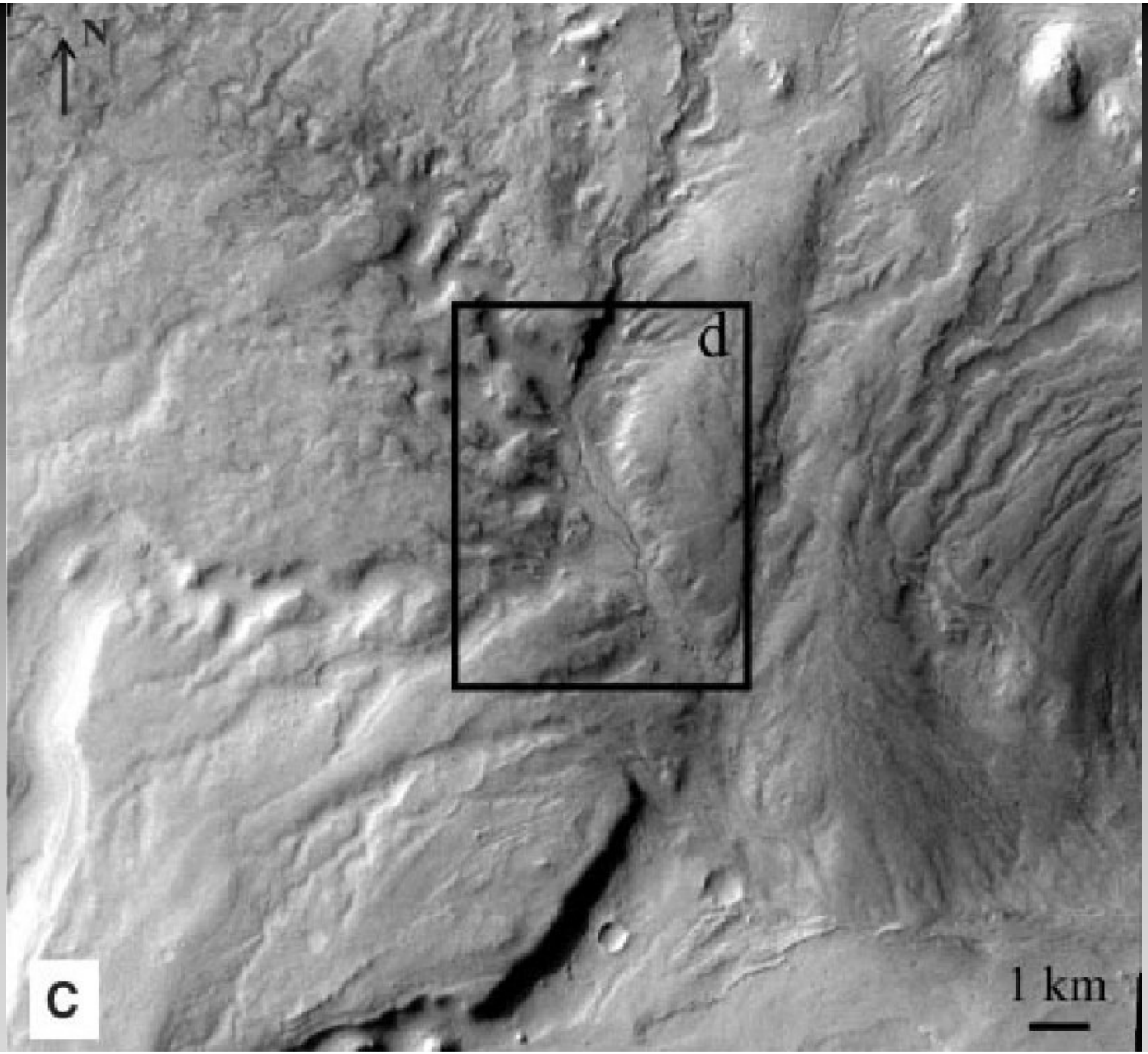
- By measuring neutrons, it is possible to calculate the abundance of hydrogen on Mars, thus inferring the presence of water.
- Since hydrogen is most likely present in the form of water ice, the spectrometer is able to measure directly the amount of permanent ground ice and how it changes with the seasons.



Ice in the first meter of Martian soil






N
d
c
1 km

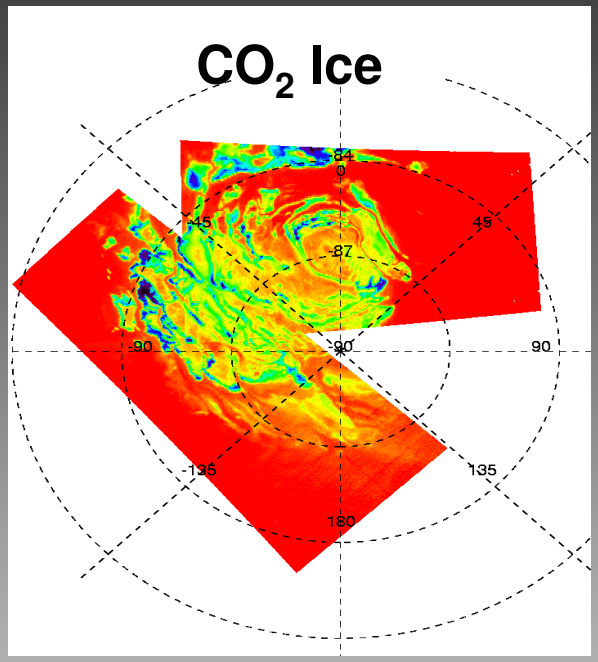
Mars Express

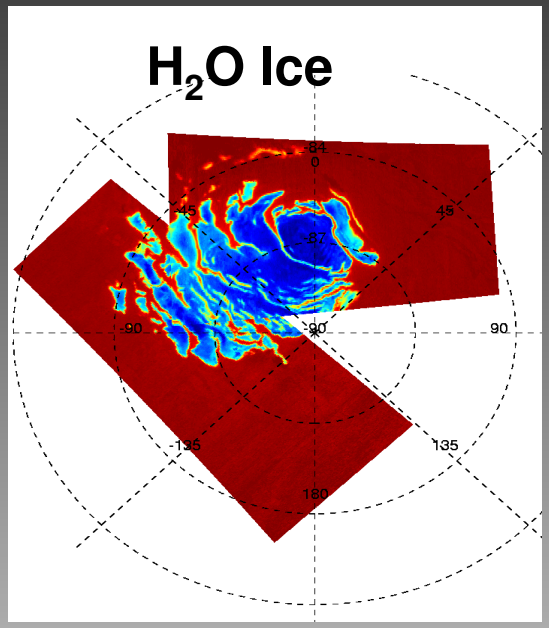
Launch: June 2, 2003

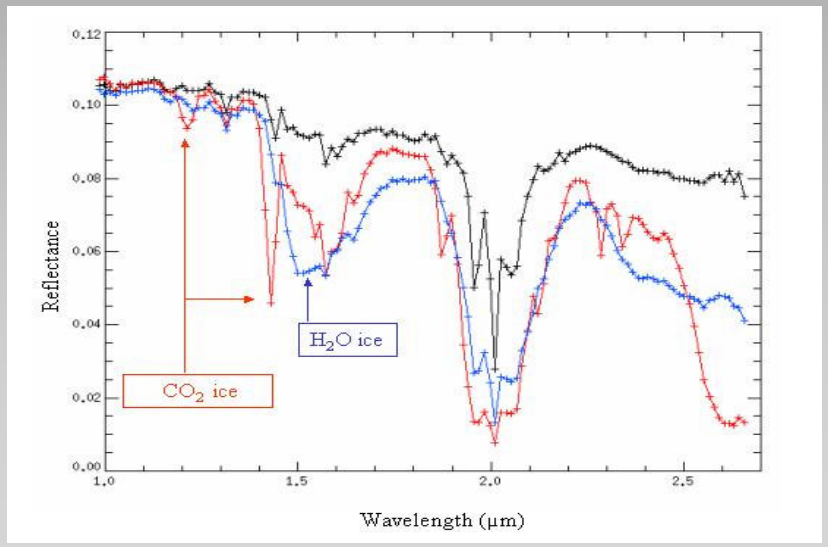
Mars Express Launch June 2, 2003

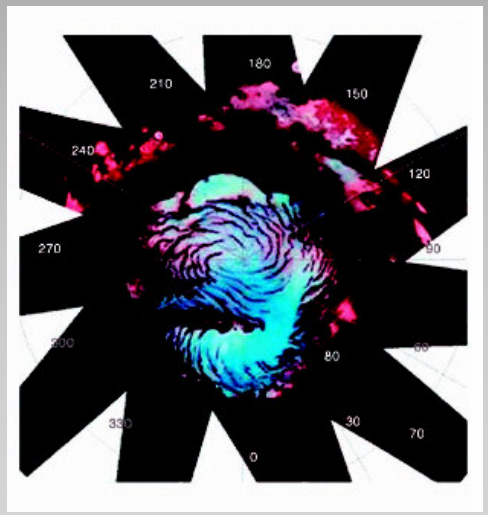
Mars express mounted on the Fregat upper stage. (Stage IV)

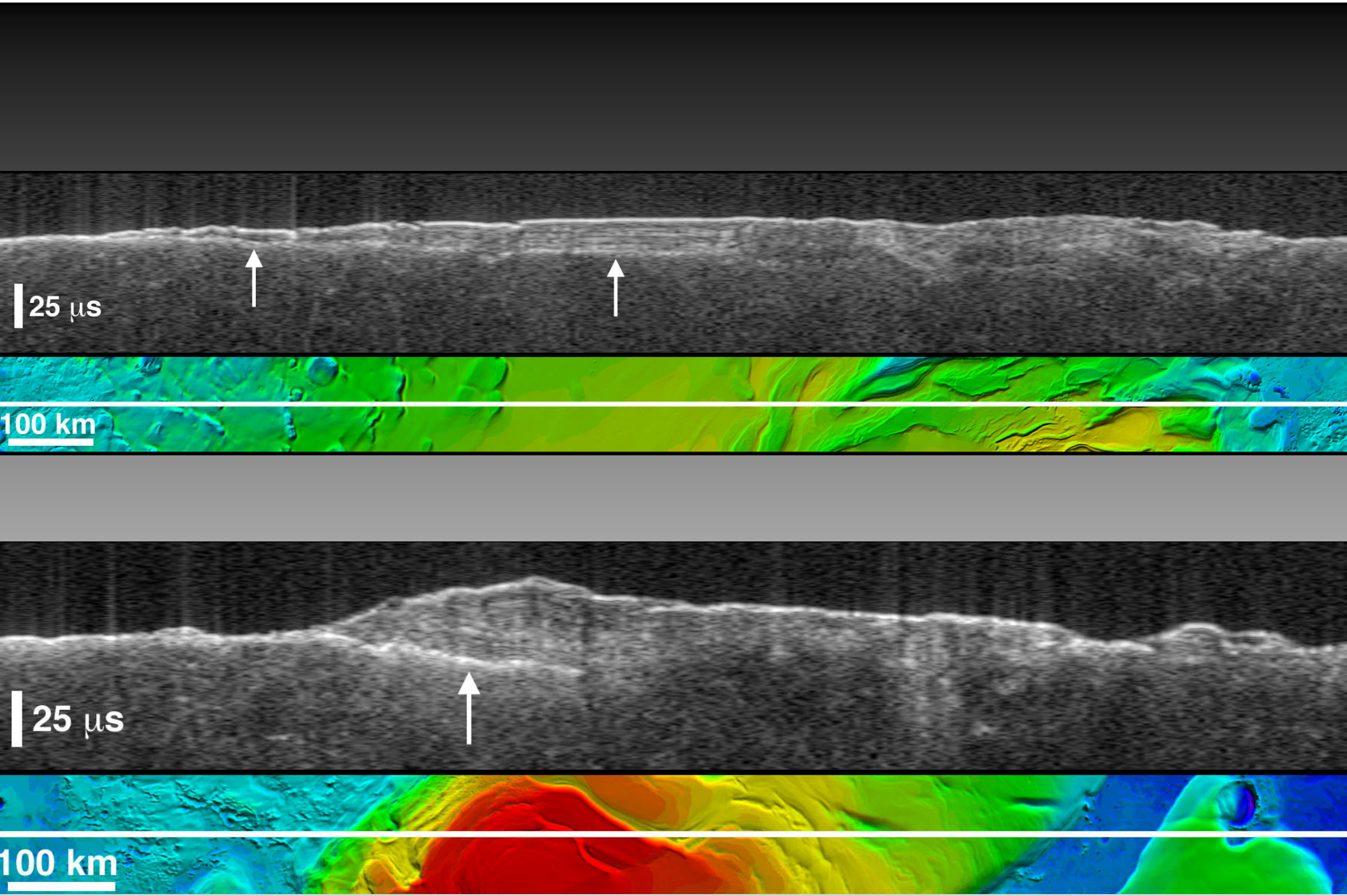
MEX – OMEGA : a clear ice identification

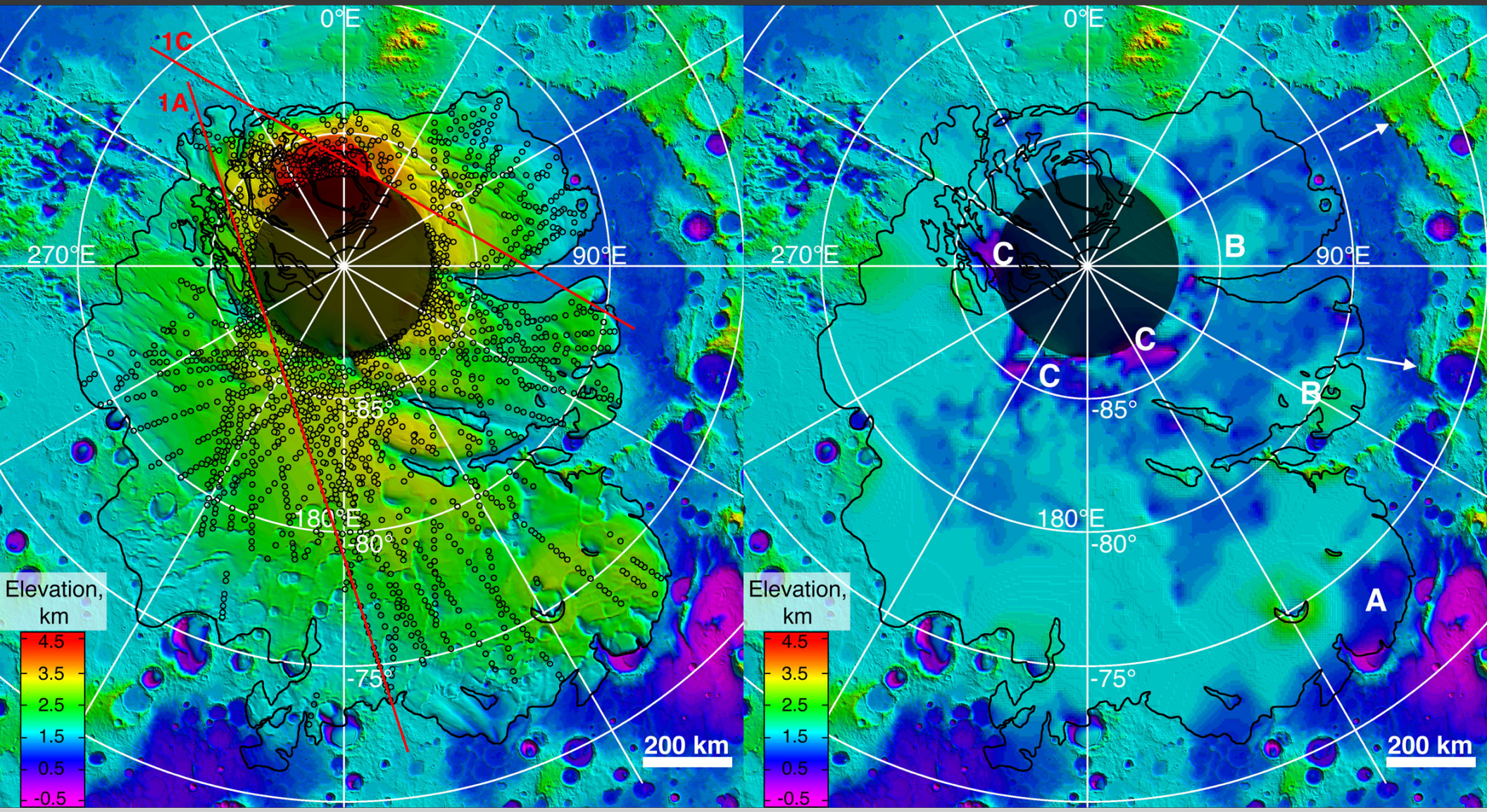






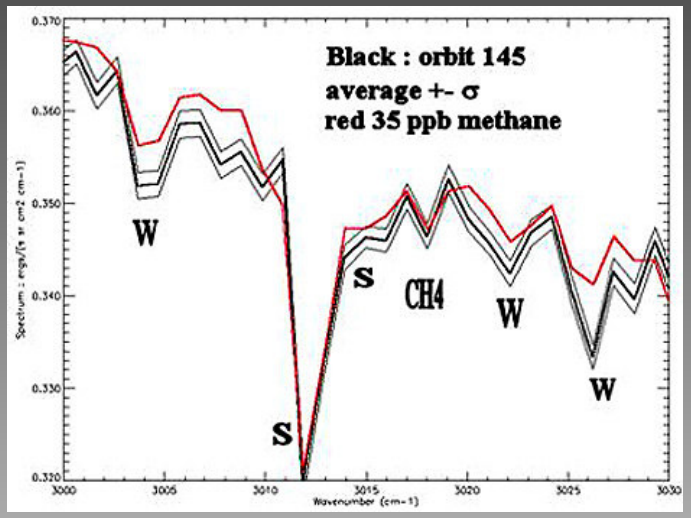


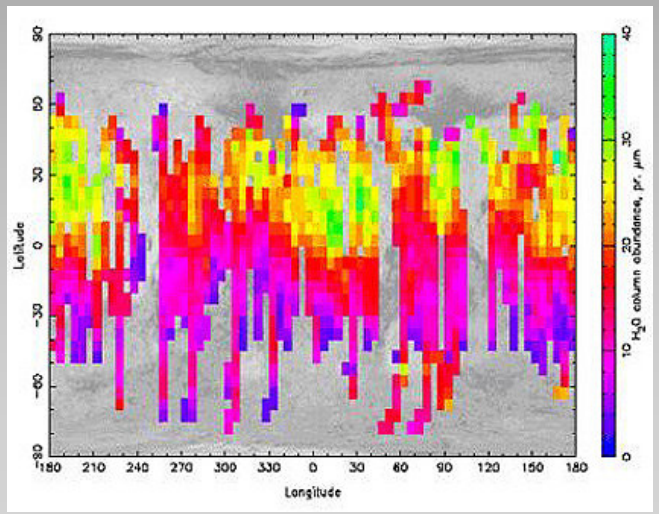

25 μs
100 km
25 μs
100 km


0°E
1C
1A
270°E
90°E
-85°
180°E
-80°
-75°
Elevation, km
4.5
3.5
2.5
1.5
0.5
-0.5
200 km
0°E
270°E
C
B
90°E
C
C
B
-85°
180°E
-80°
A
Elevation, km
4.5
3.5
2.5
1.5
0.5
-0.5
-75°
200 km

PFS Discoveries

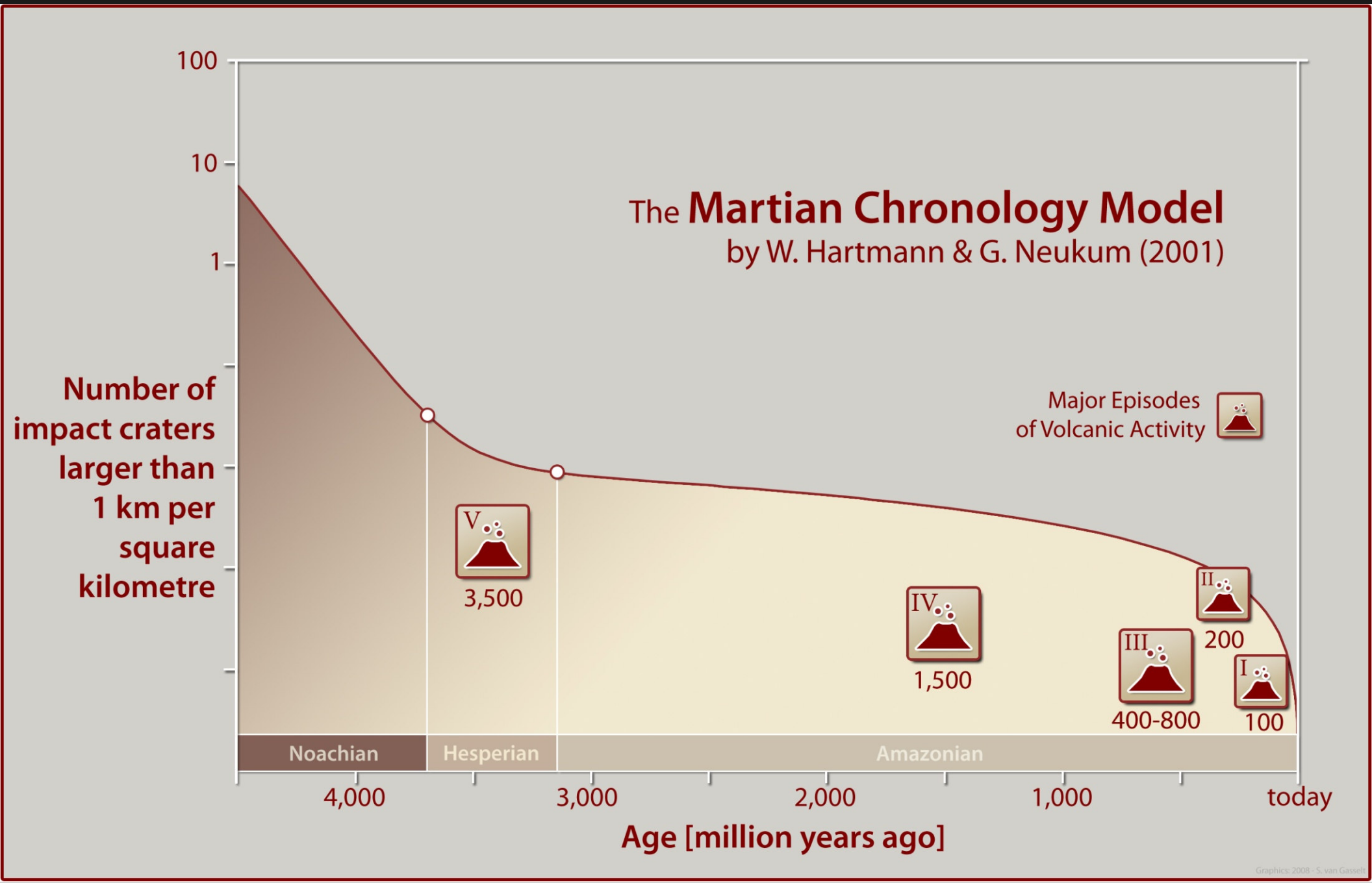
- The most significant findings by Mars Express so far are the detection, using the Planetary Fourier Spectrometer [PFS]) of trace amounts (10 parts per billion [ppb]) of methane (CH4) and water vapor in the martian atmosphere.
- These seem to be more concentrated in certain regions.



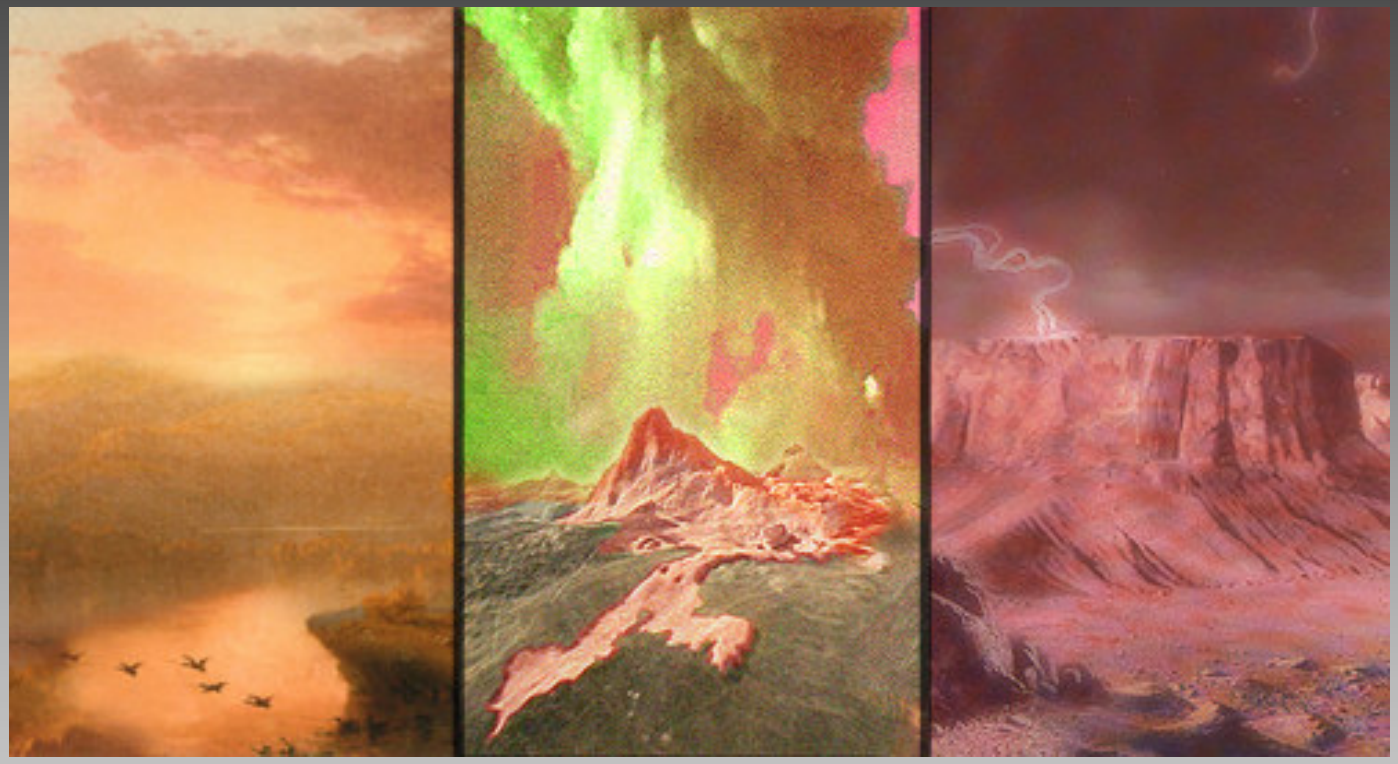


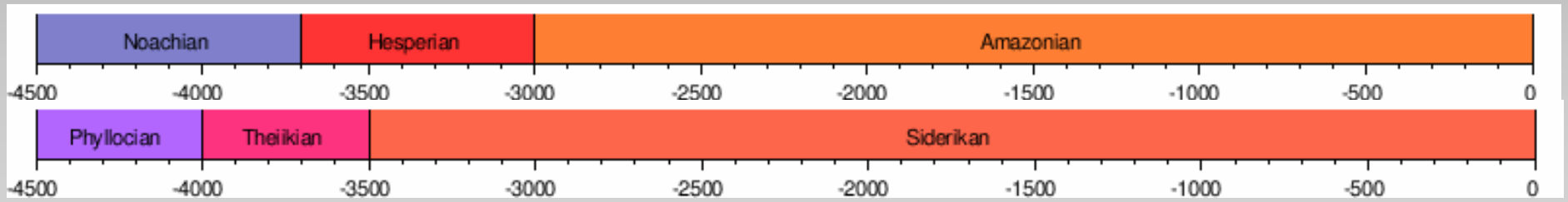
The Methane Origin

- The methane may be residual from early days in the evolution of the atmosphere but its presence may indicate some youthful source(s). One could be from vaporized comet(s) that impacted the surface, but no large young craters have been found.
- A second possibility is from volcanic release, but again no visual evidence of recent volcanism has been detected.
- The third option is both provocative and conjectural: release from the decay of organic matter in surficial deposits.
- The co-association of methane and water vapor could point to either of the second and third options. But the presence of small volcanoes over the "highs" in Arabia Terra place this last option as presently the most favored


The Martian Chronology Model
by W. Hartmann & G. Neukum (2001)
Number of impact craters larger than 1 km per square kilometre
100
10
1
Major Episodes of Volcanic Activity
V
3,500
IV
1,500
III
400-800
II
200
I
100
Noachian
Hesperian
Amazonian
4,000
3,000
2,000
1,000
today
Age [million years ago]
Graphics: 2008 - S. van Gasselt

The ages of Mars: cratering vs mineralogy





Beyond Remote sensing

- The Odyssey and MEX results seem to indicate:
- The identification of large quantities of hydrogen in the near surface.
- The presence of water and CO2 ices in the southern polar caps
- The presence of water vapor in the atmosphere as well as of Methane.
- The camera results on Elysium seem to suggest the existence of a frozen ocean

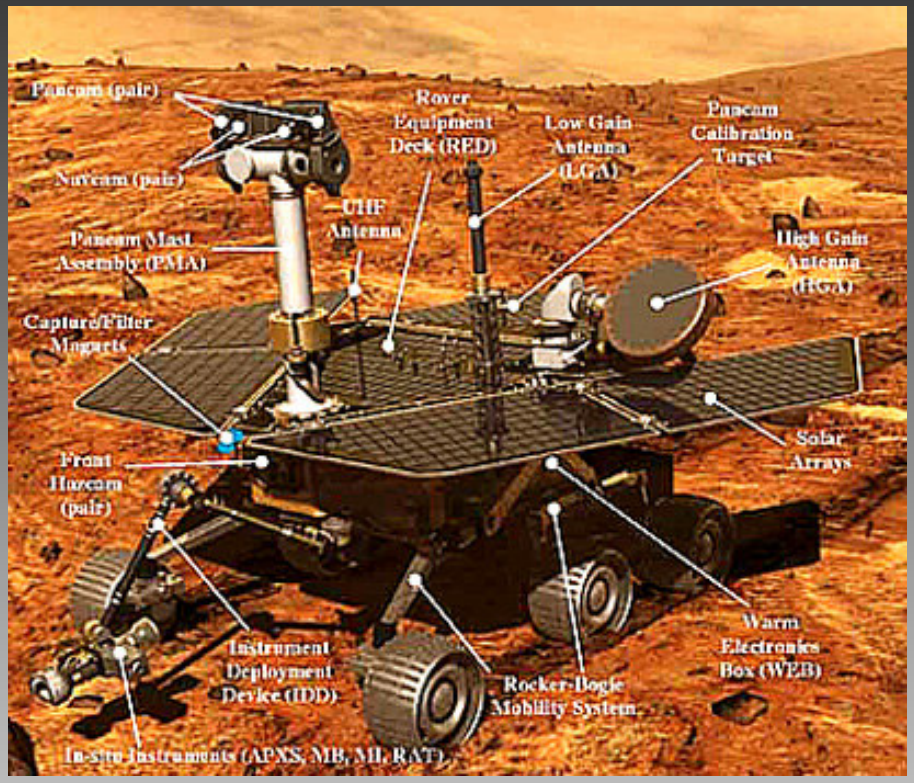
IN SITU NEEDED

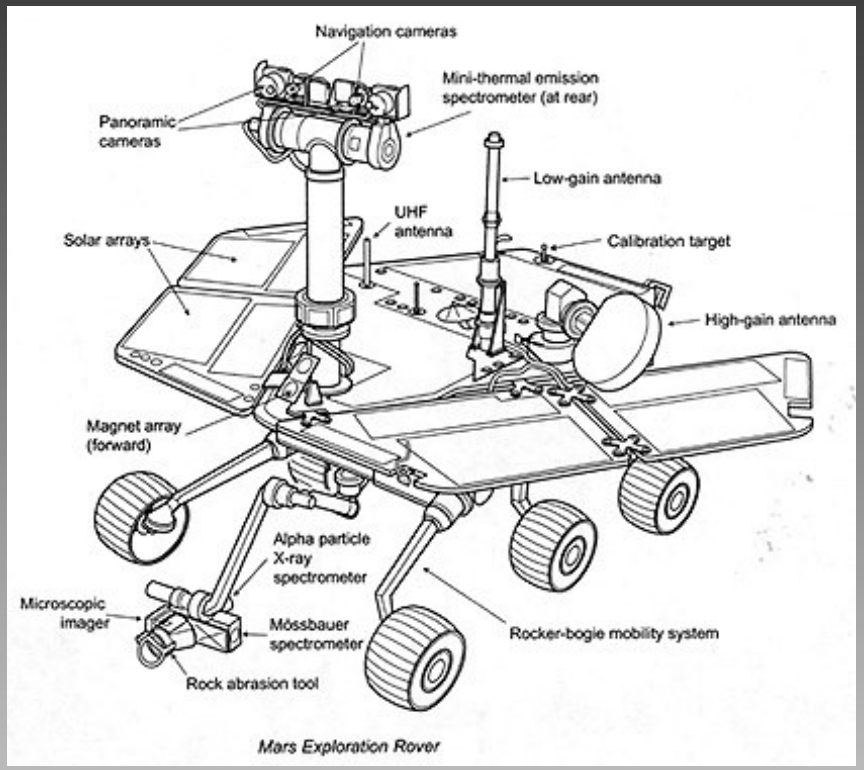
2003 Mars Exploration Rovers

Spirit Launch: June 10, 2003

Opportunity Launch: July 7, 2003

The MER Program

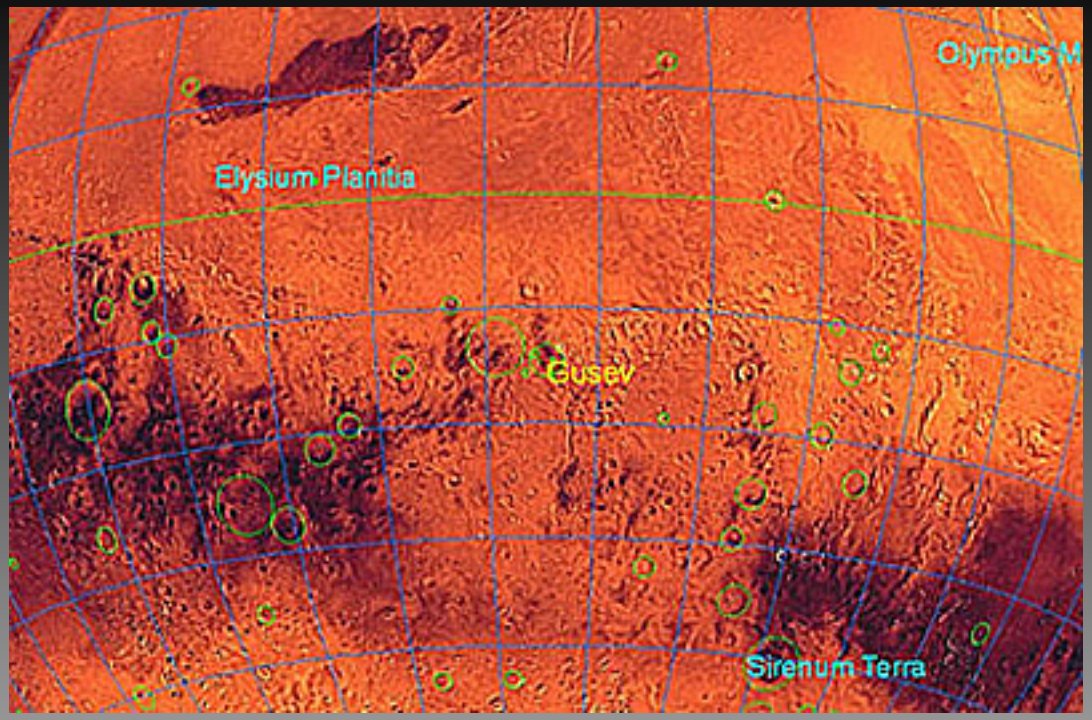


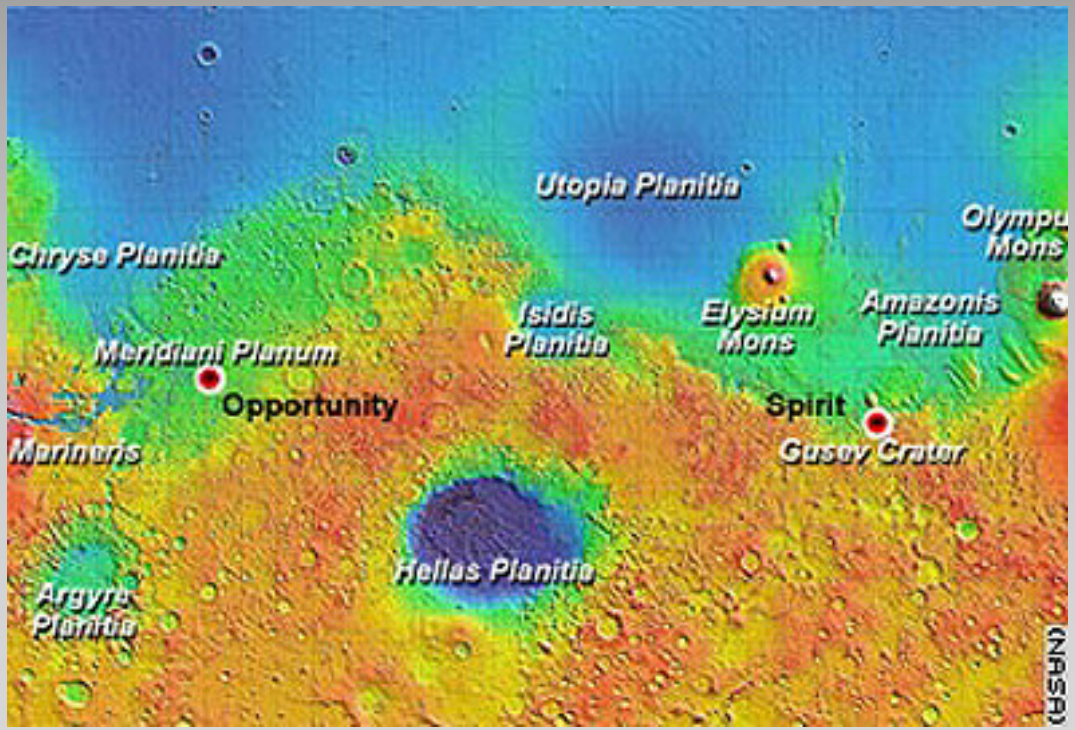


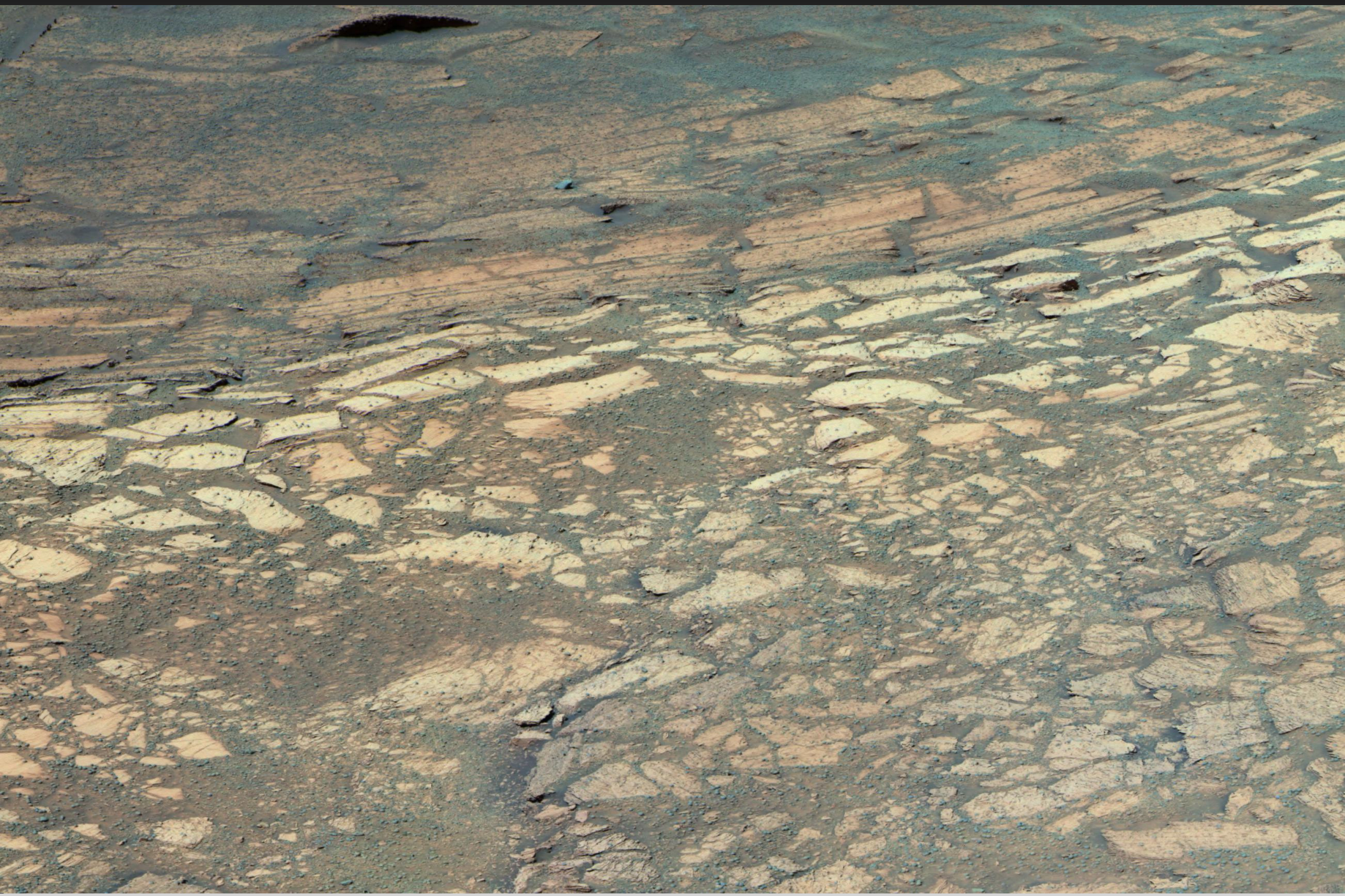
- **The Mars Exploration Rovers have landed on Mars with the primary scientific goal of determining the current or past existence of water on Mars.**

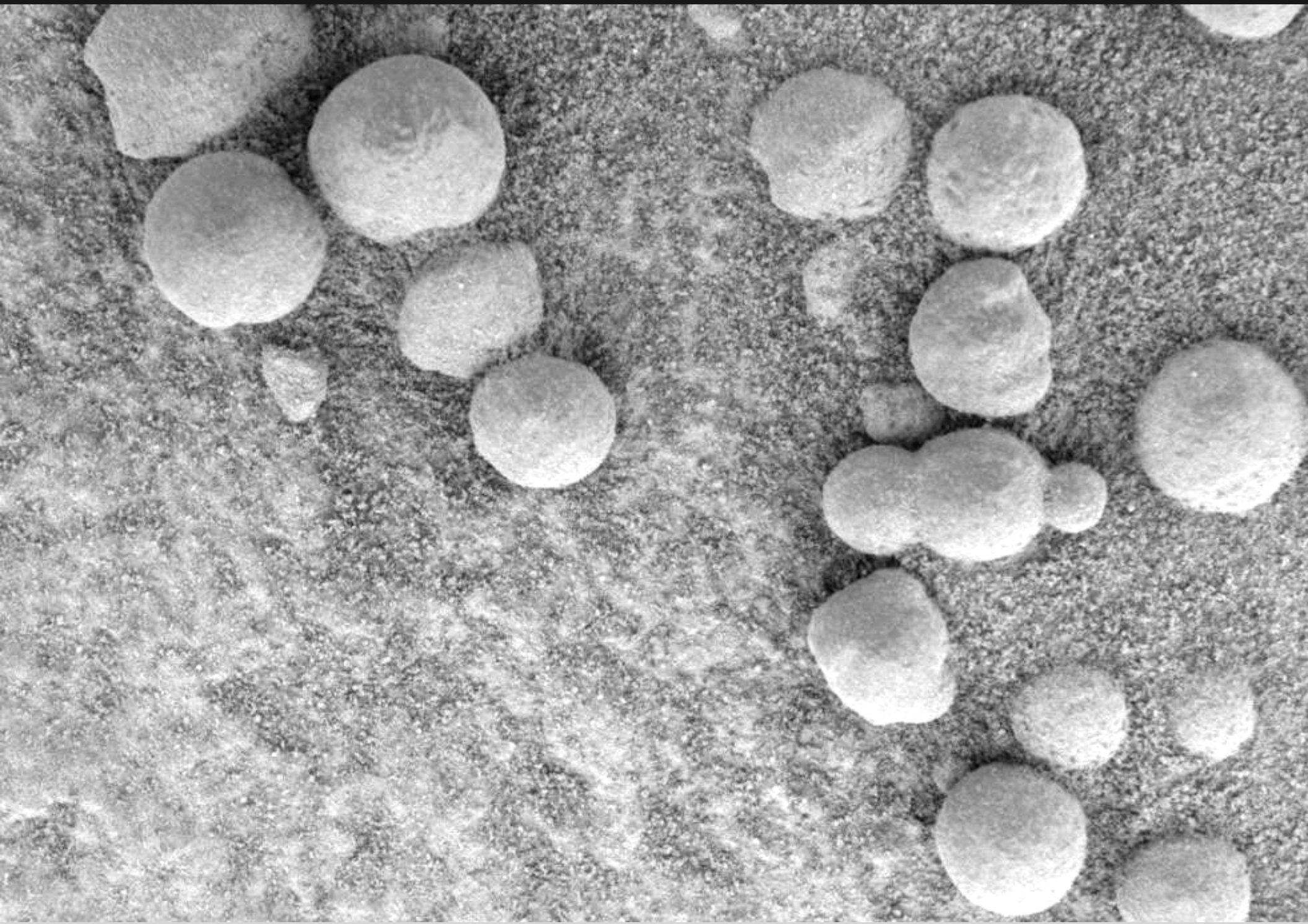
The 2 MER

- **Spirit** landed in the expansive Guzev Crater
- **Opportunity** went to Meridiani Planum and landed among rocks rich in hematite (iron oxide) which can be associated with water-rich conditions.



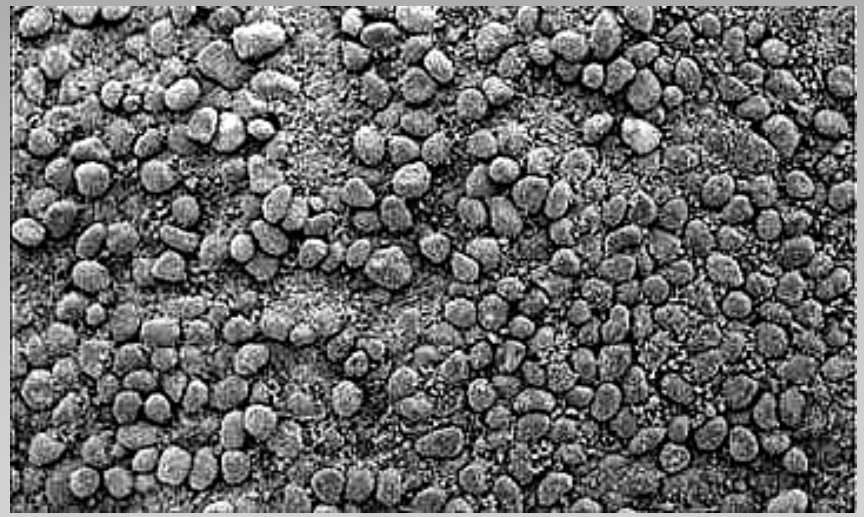






- *An important Spirit discovery was the existence of one unusual rock lying as float on the surface.*
- **This rock is splitting into thin flaky layers or chips, similar to a fissile shale on Earth but is richer in iron than most shales.**
- **Such layering is usually a consequence of *continuing deposition in a fluid medium, usually water***

SHALE?

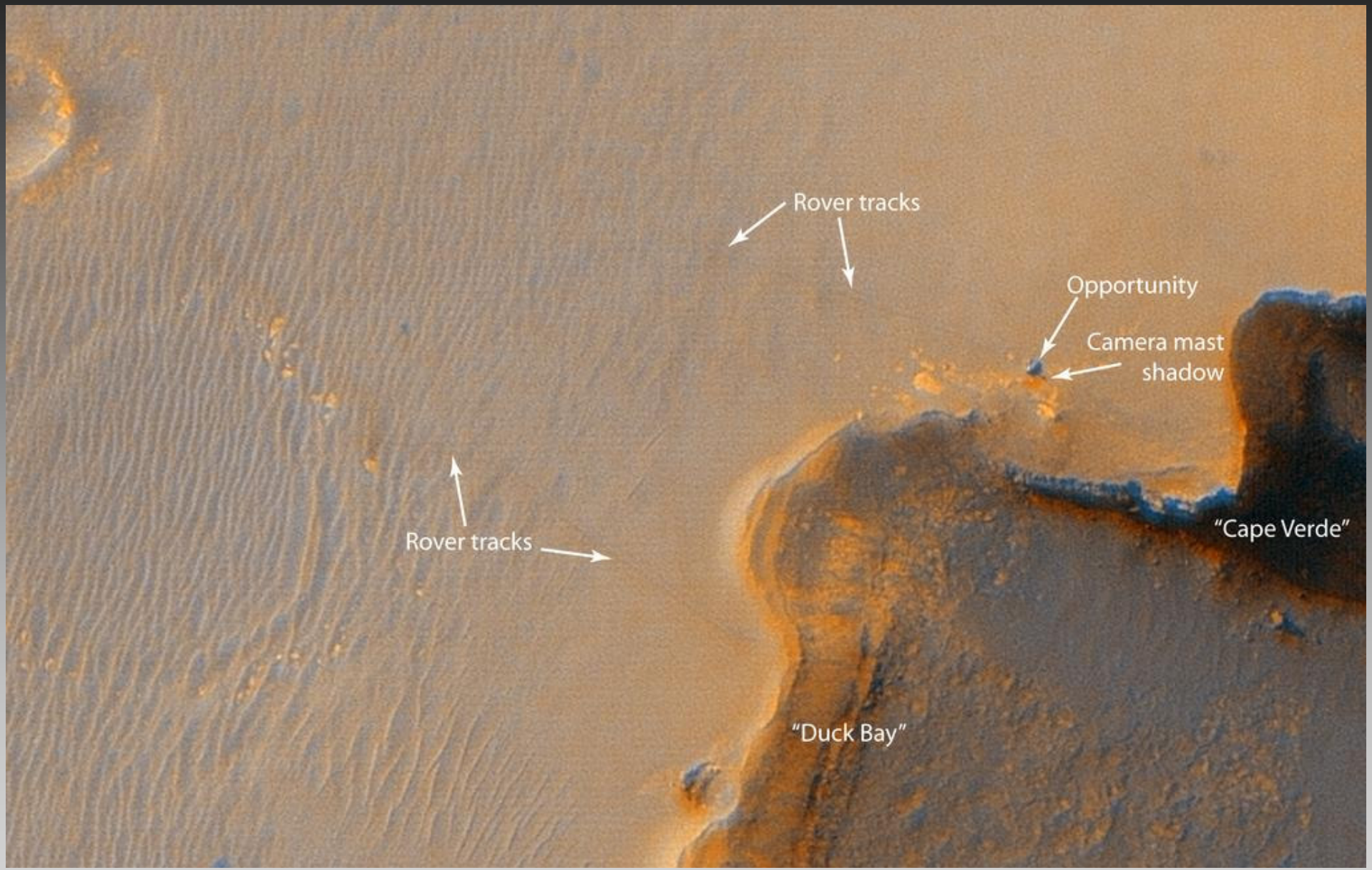


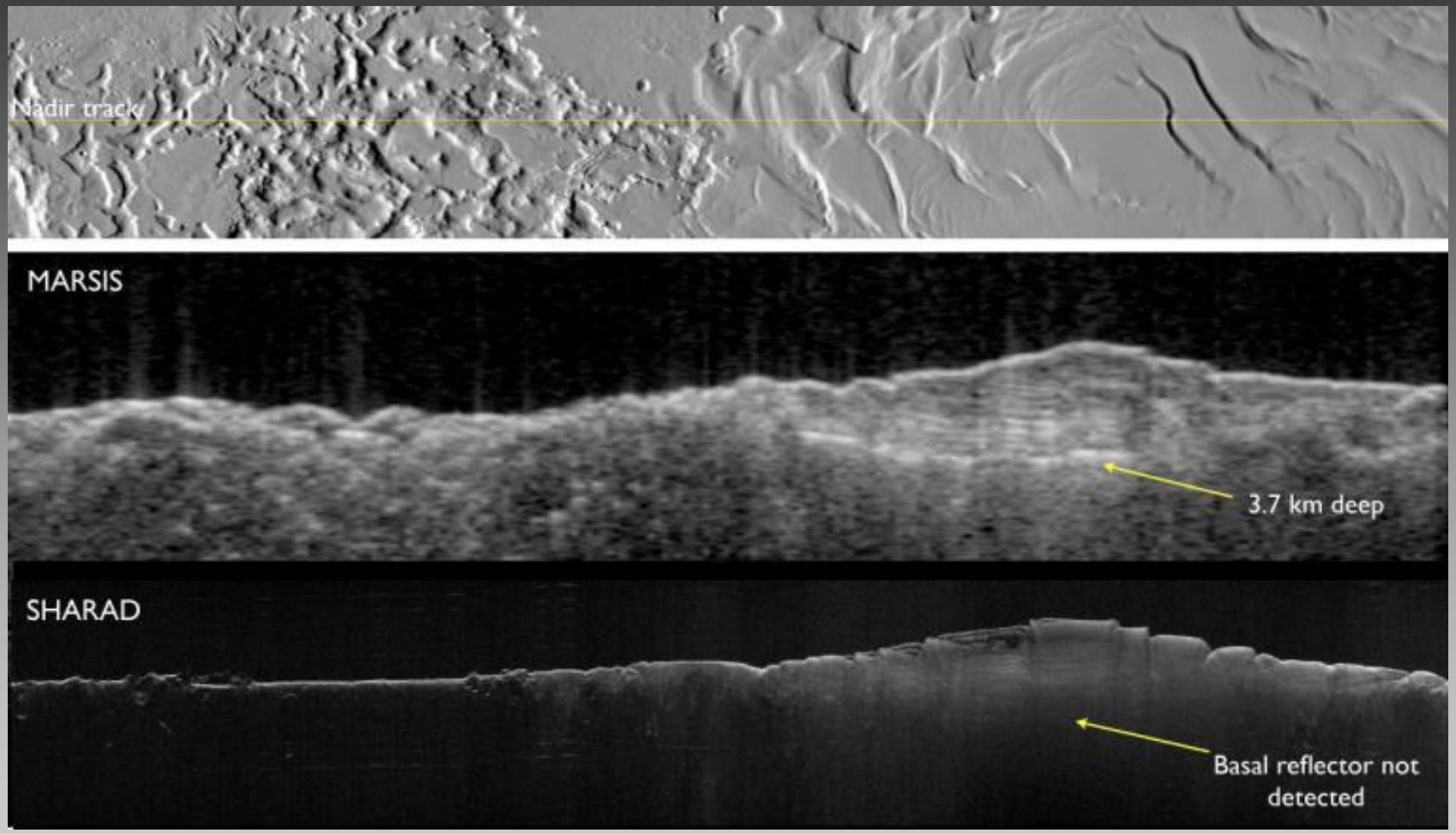
MER vs Orbiter

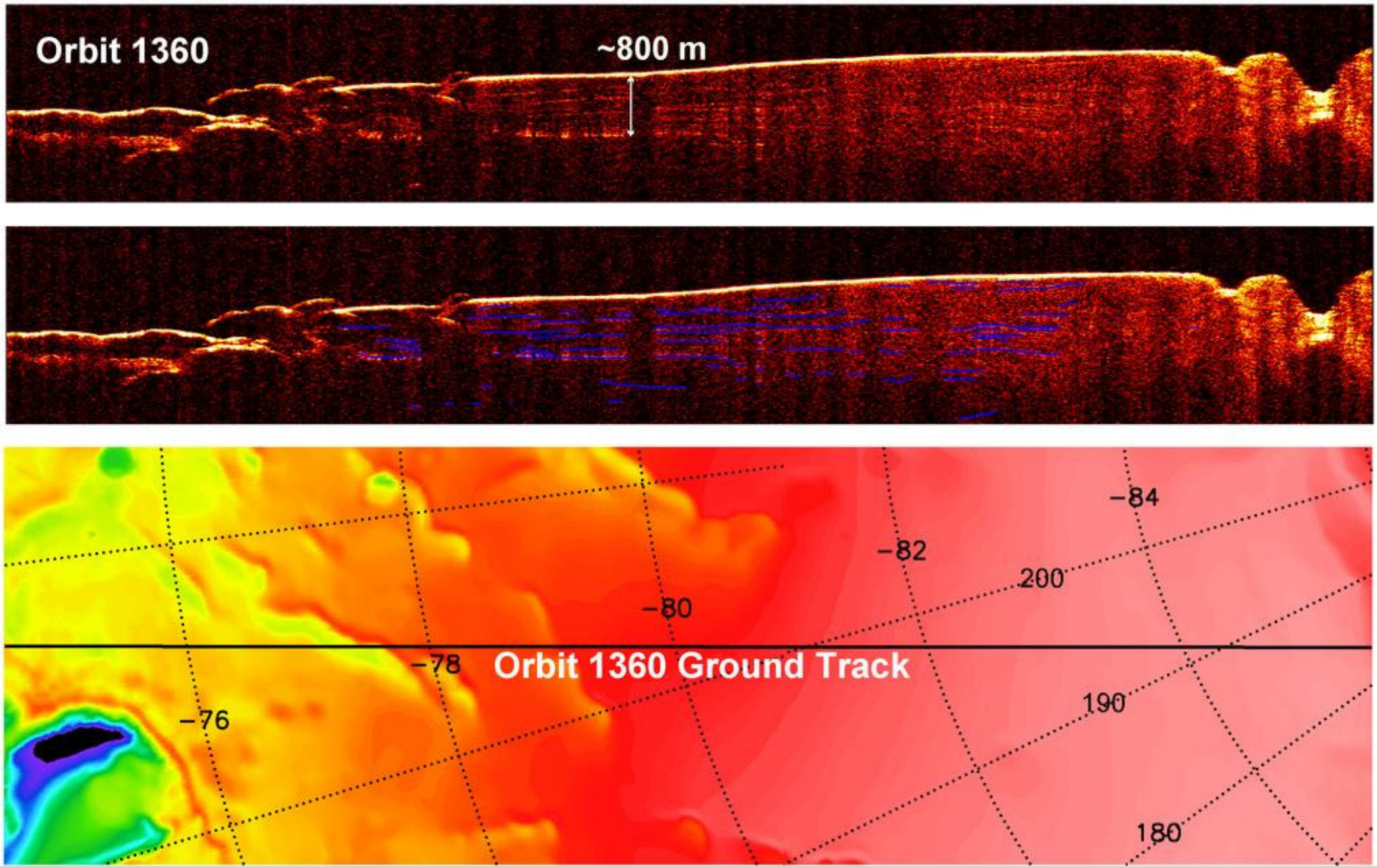
- MEX , Odyssey and MGS results indicate that shallow water can be present near the surface, or, in a shallow subsurface layer
- MER data, despite of their large mobility seem to indicate ... not a clear indi... present
- MEX ... that CH4 of volcanic or biol... origin can be present
- Viking wasn't able to identify this activity on the surface
- MER weren't able to identify localized volcanic activities on the suface

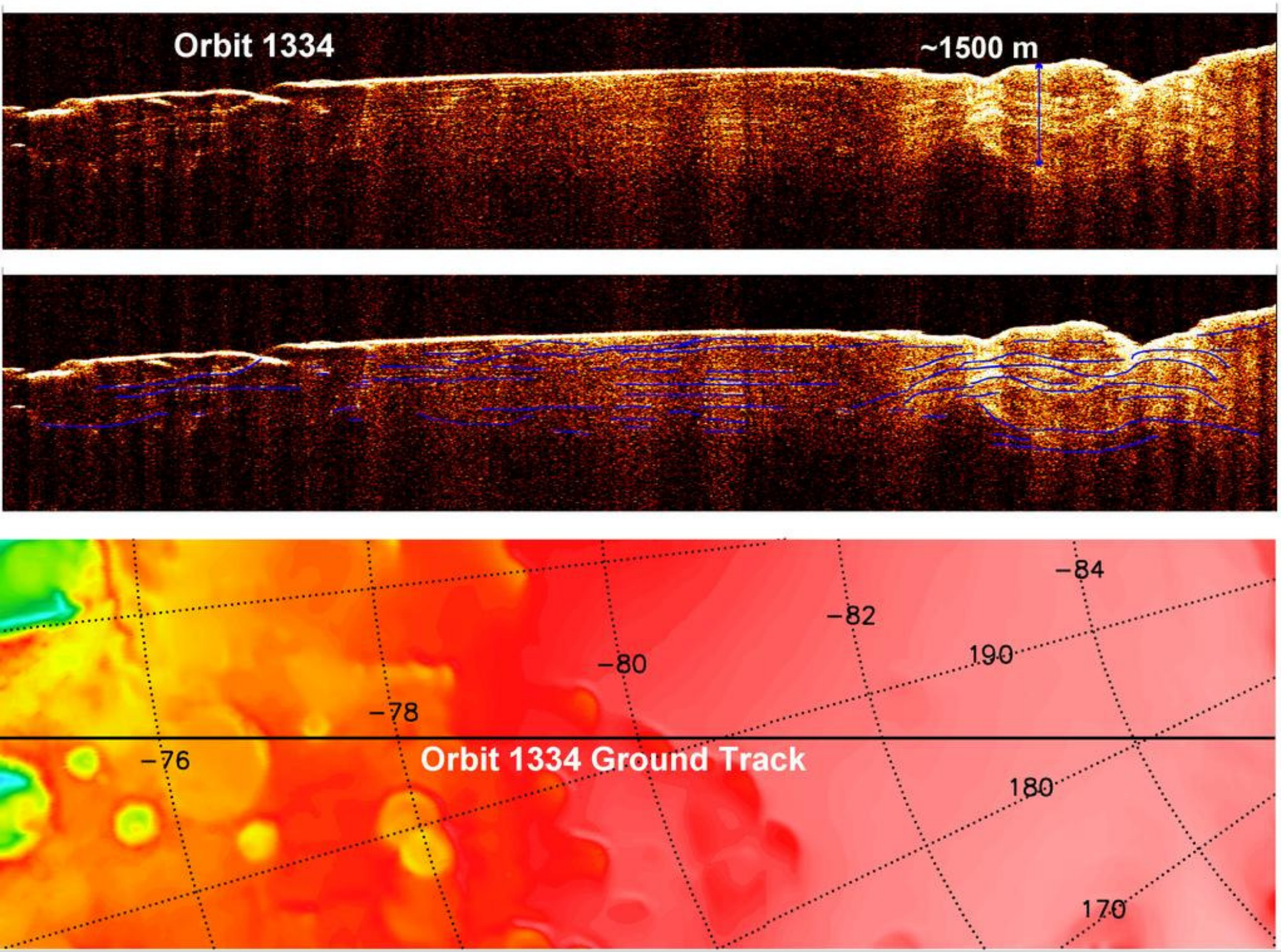
Mars Reconnaissance Orbiter

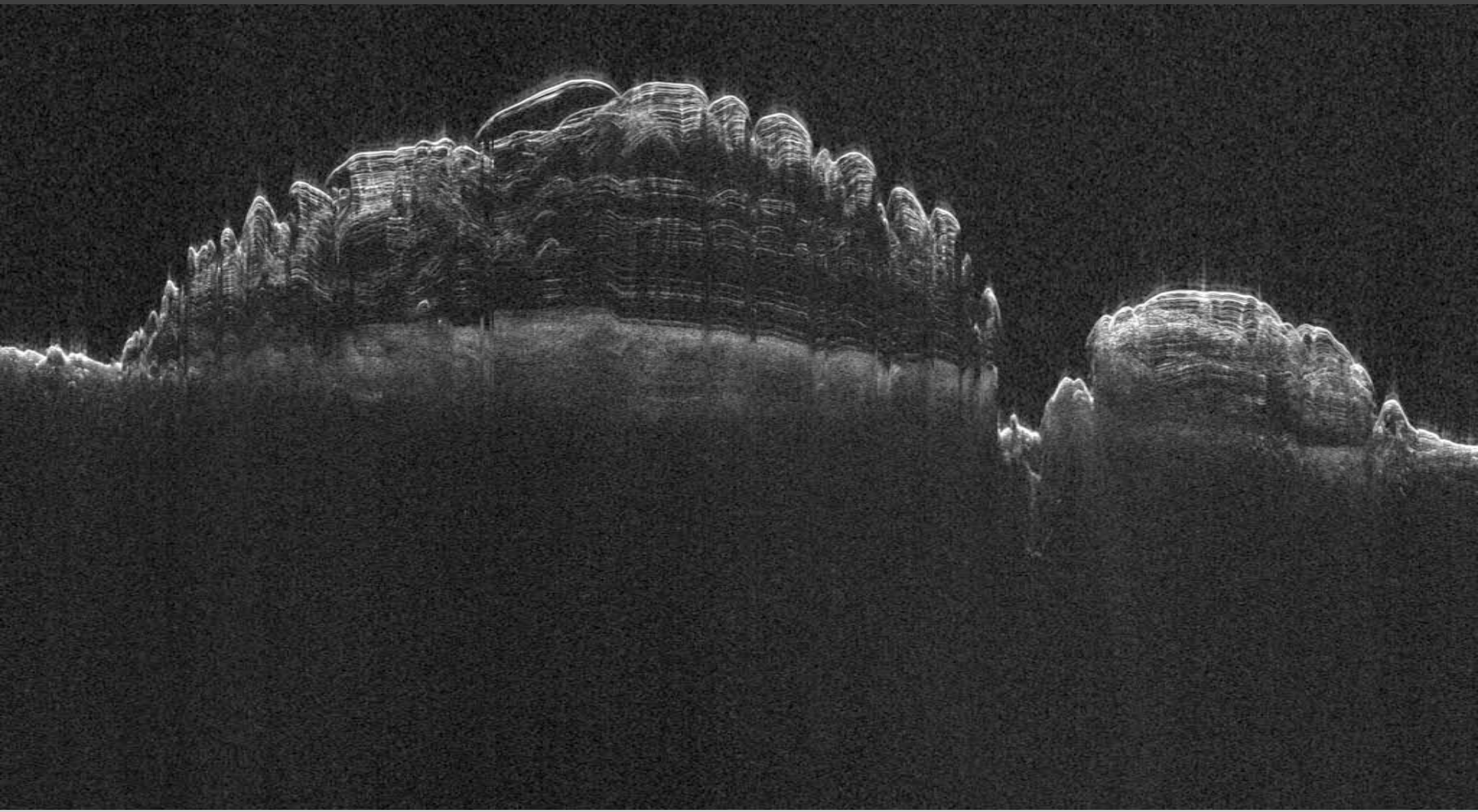
Launch: August 12, 2005


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


Nadir track
MARSIS
3.7 km deep
SHARAD
Basal reflector not detected


Orbit 1360
~800 m
−84
−82
200
−80
−78
Orbit 1360 Ground Track
190
−76
180


Orbit 1334
~1500 m
−84
−82
190
−80
−78
−76
Orbit 1334 Ground Track
180
170

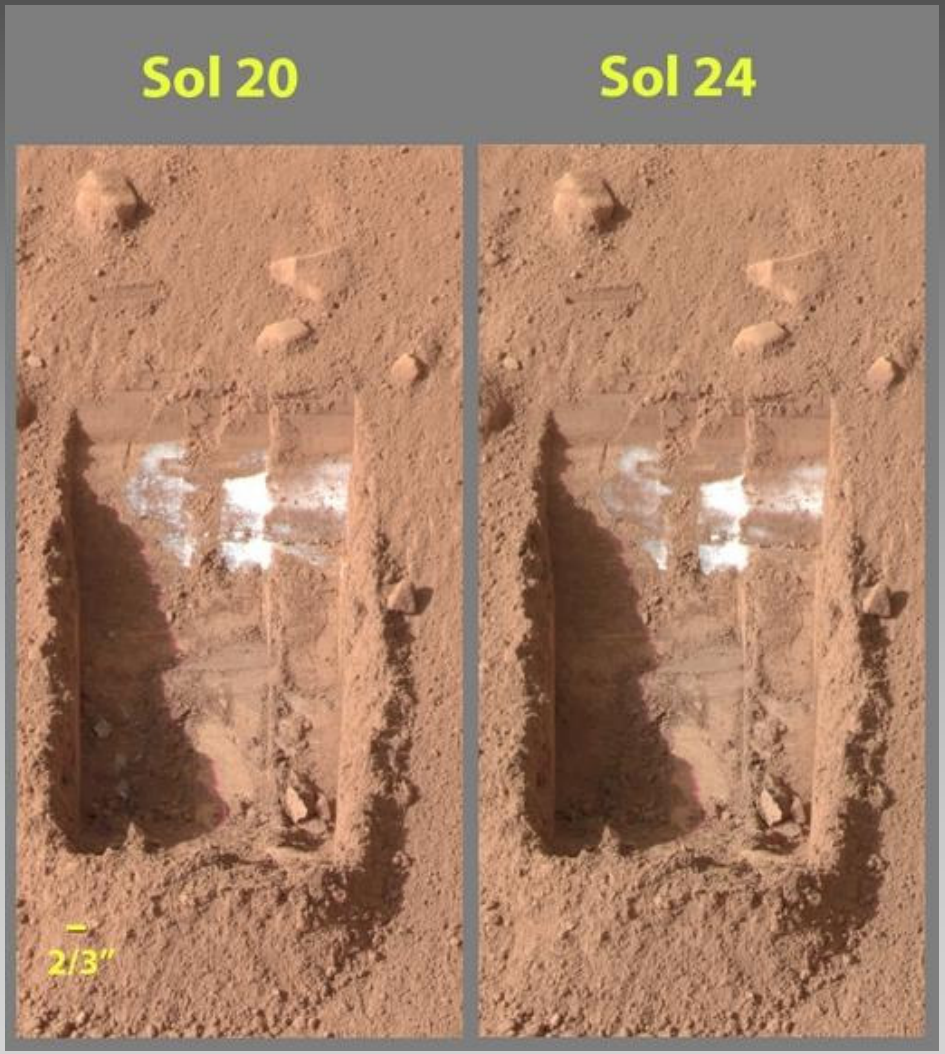


Phoenix

Launch: August, 2007

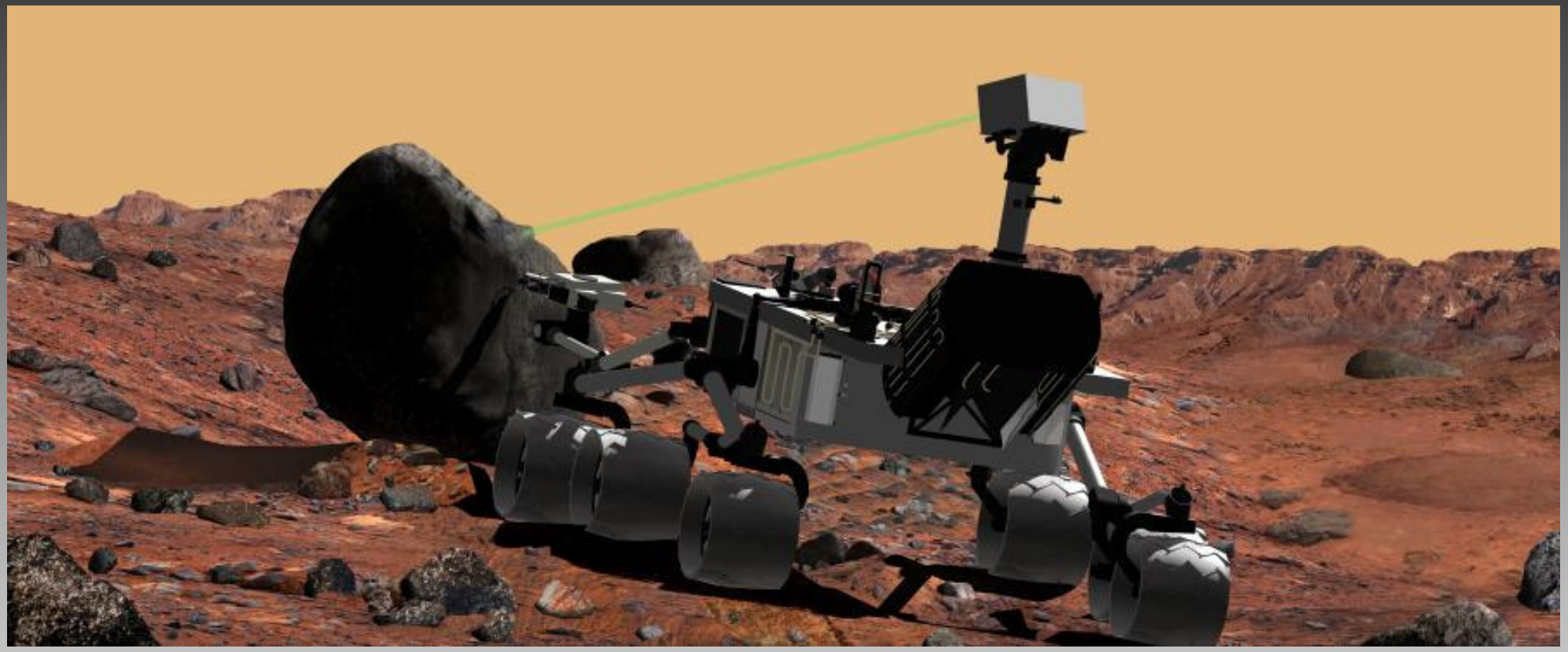
Digging in the northern plains of Mars

- As expected, ice was found under a few cm's of regolith.
- Phoenix observed H2O snow falling from the sky, and sublimating before reaching the ground.
- Wet chemistry experiments revealed the presence of salts, implying a wet (relatively) recent past.



The Future

Mars Science Laboratory

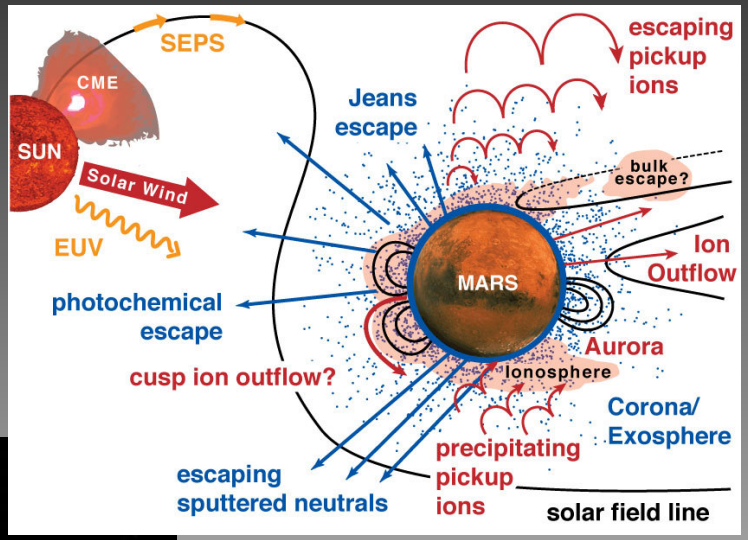


- **Planned Launch: Fall, 2011**
- **Objective: to collect Martian soil and rock samples and analyze them for organic compounds and environmental conditions that could have supported microbial life now or in the past**

Planned missions

MAVEN - Nov 18-Dec 7, 2013

- **Measurements of the Martian atmosphere to help understand dramatic climate change on the red planet over its history**



ExoMars/Trace Gas Orbiter - January 2016

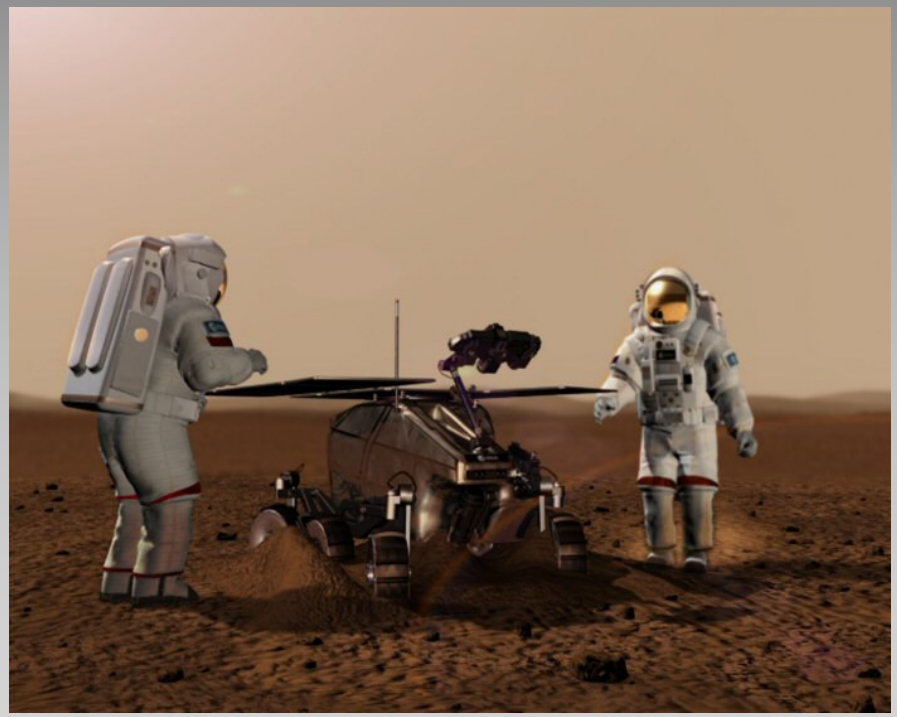
- **Survey of trace gases in the Mars atmosphere, in order to understand their atmospheric lifetimes and the location and nature of subsurface sources that produce gases, such as methane**

ExoMars Lander - May 2018

- **Characterization of the biological environment on Mars in preparation for robotic missions and then human exploration**

Beyond 2020

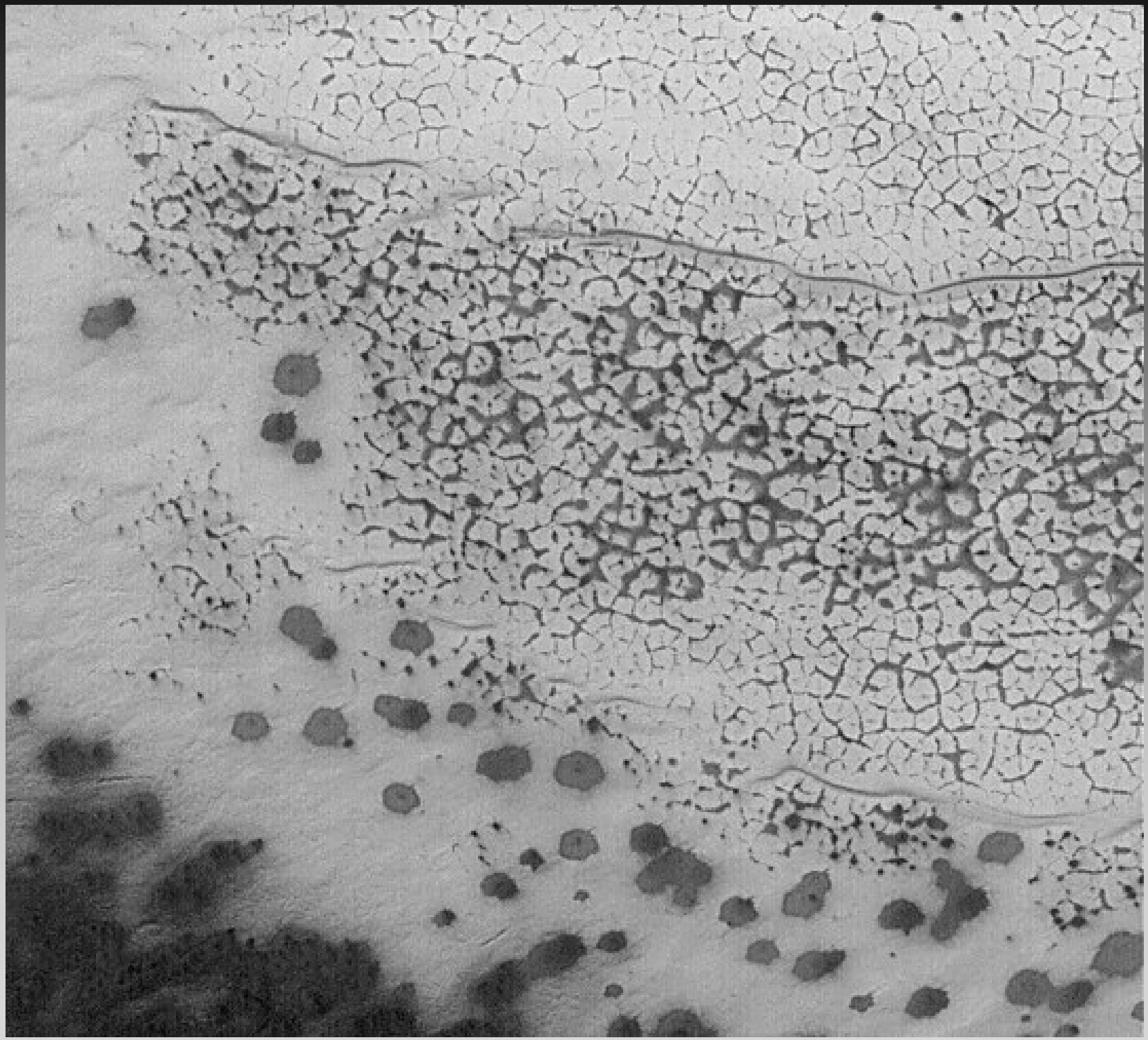
Sample return

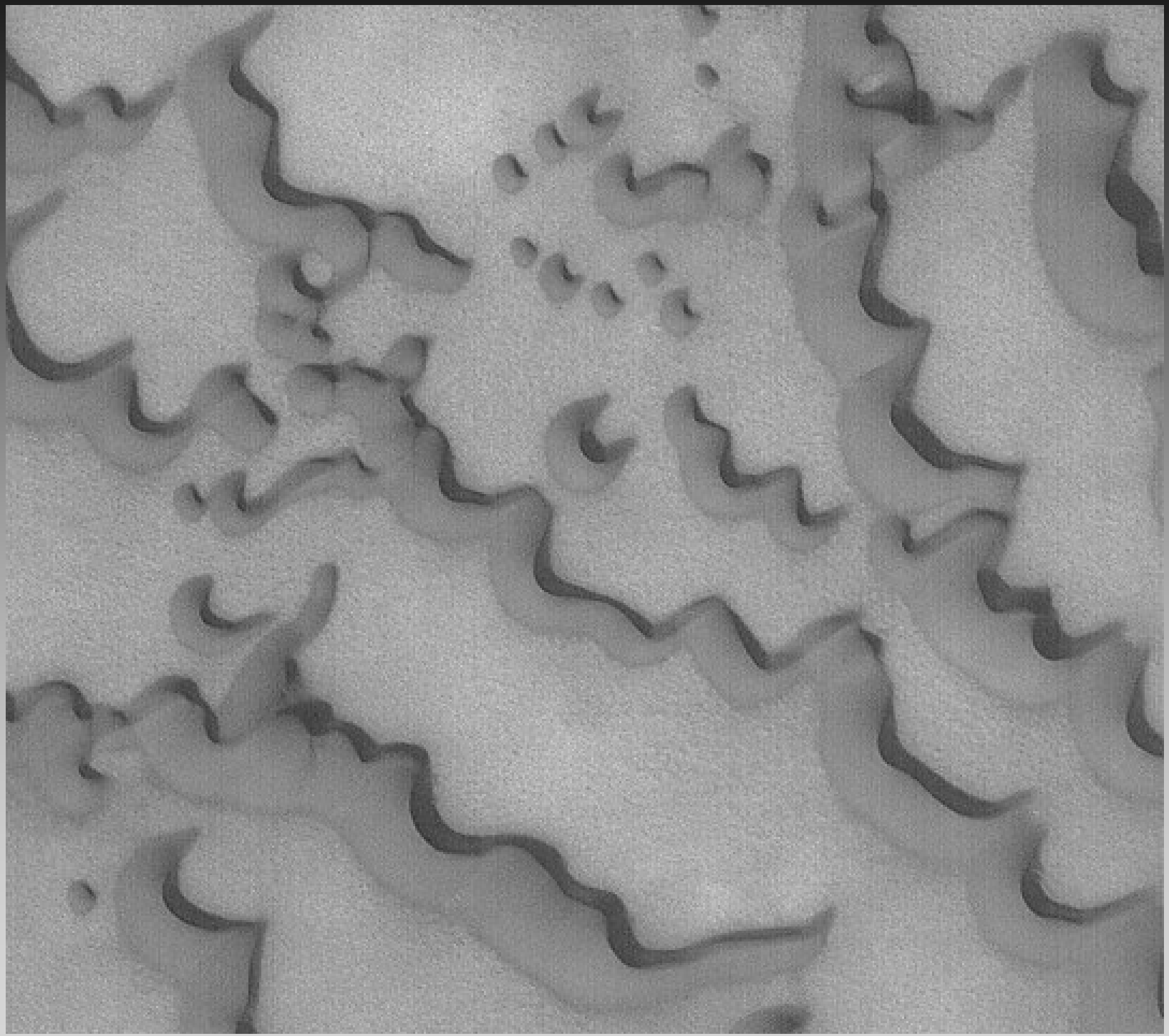


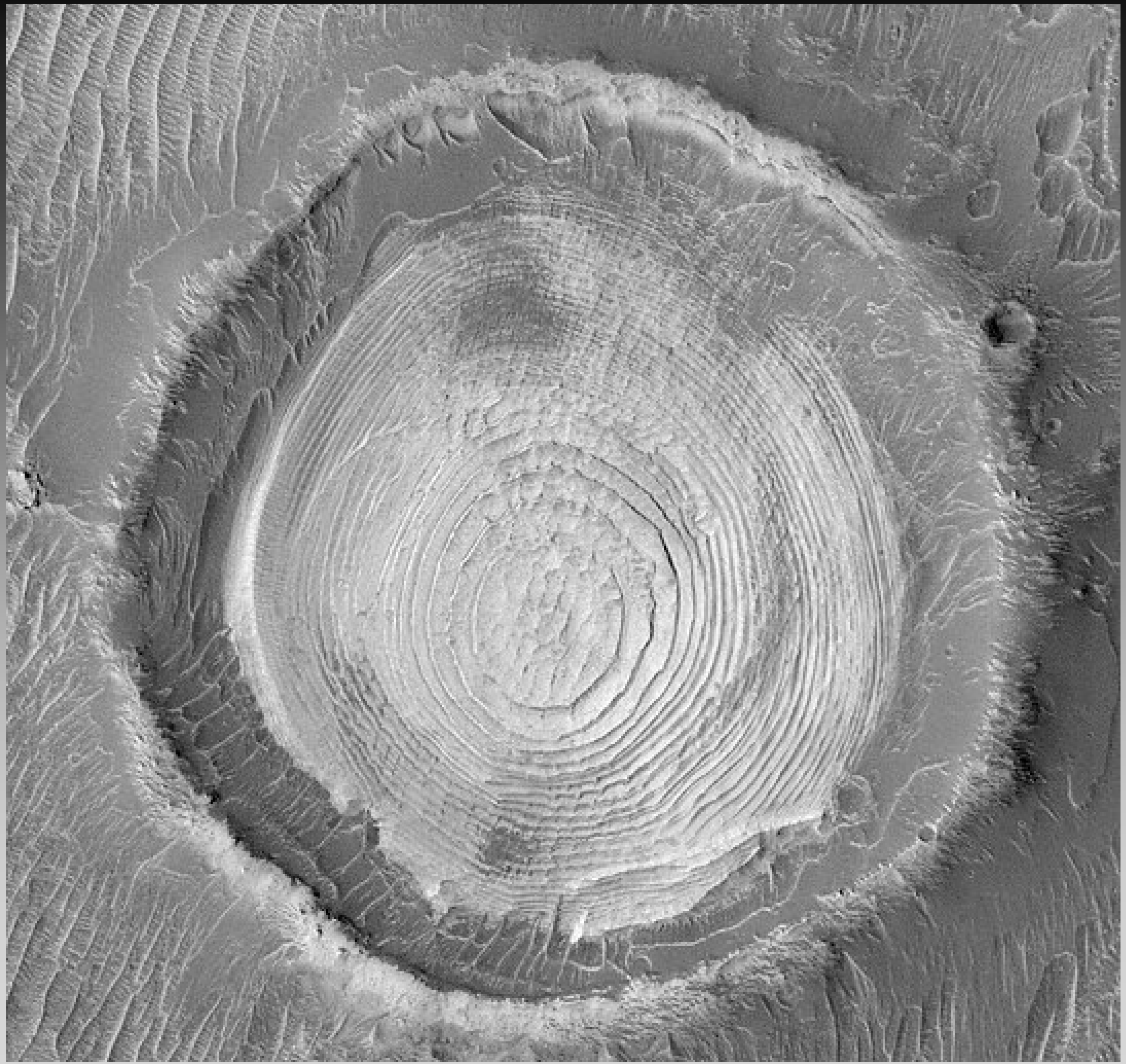
Human exploration

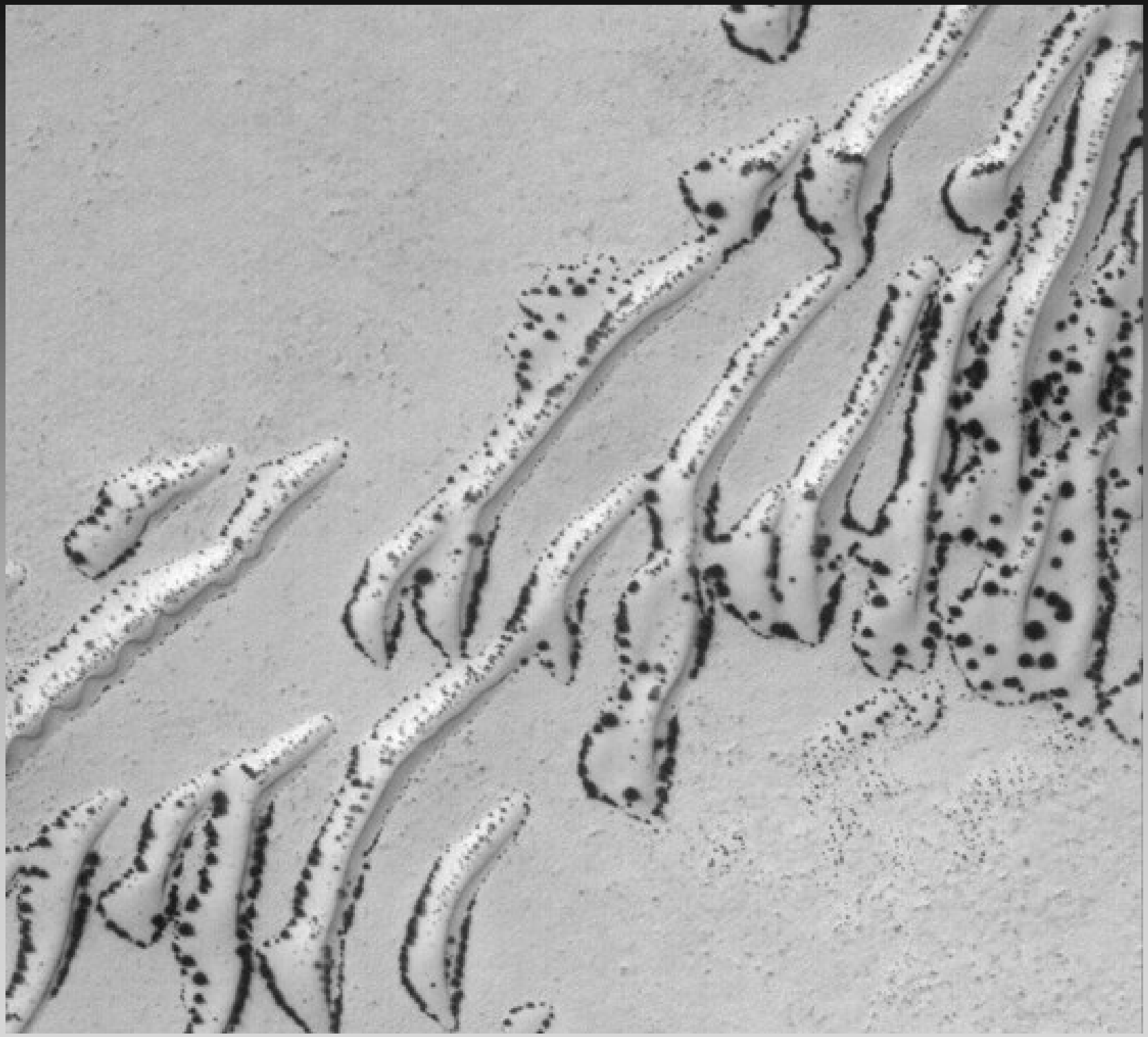
Postcards from Mars

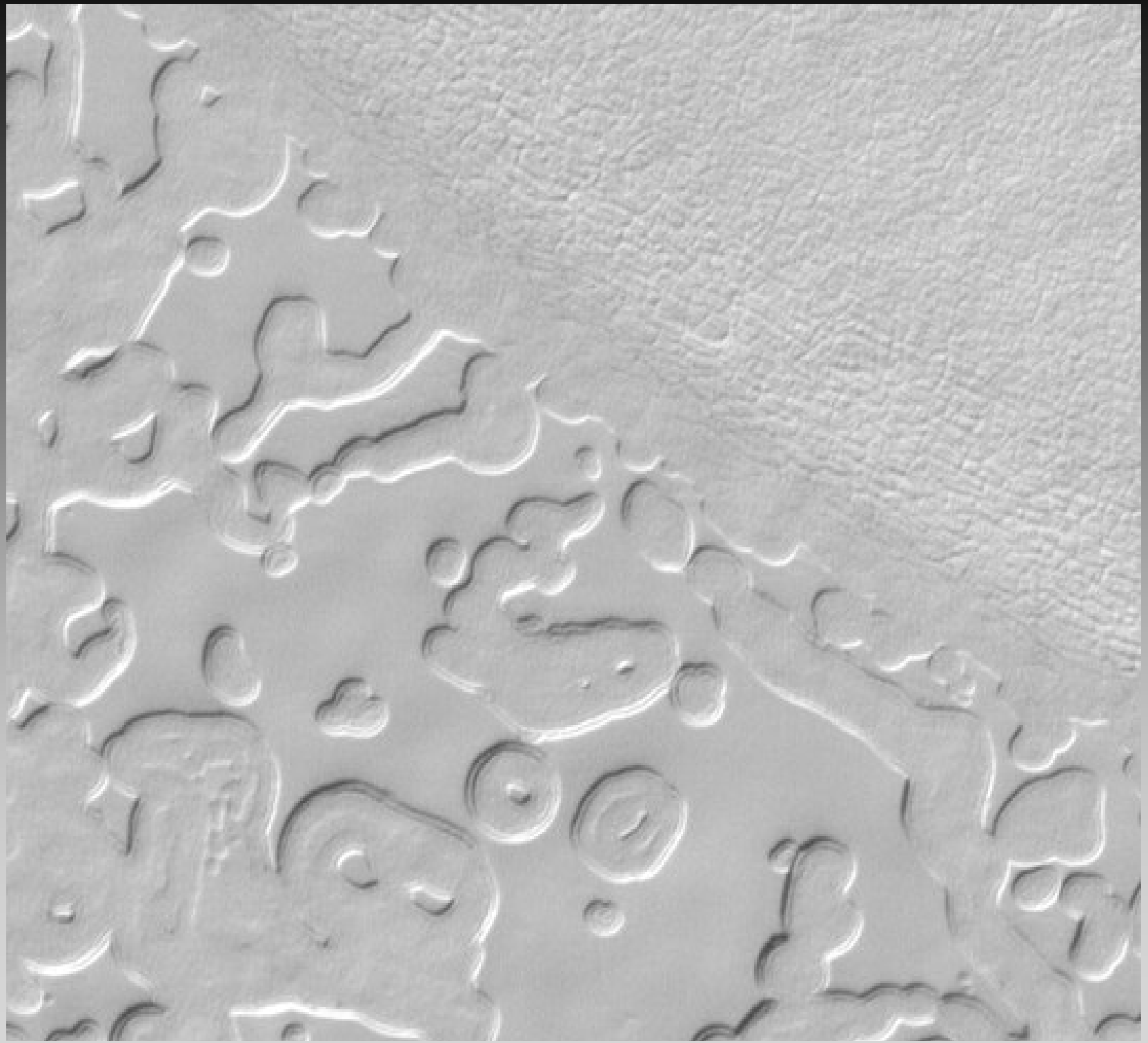
For your viewing pleasure,
if time allows…

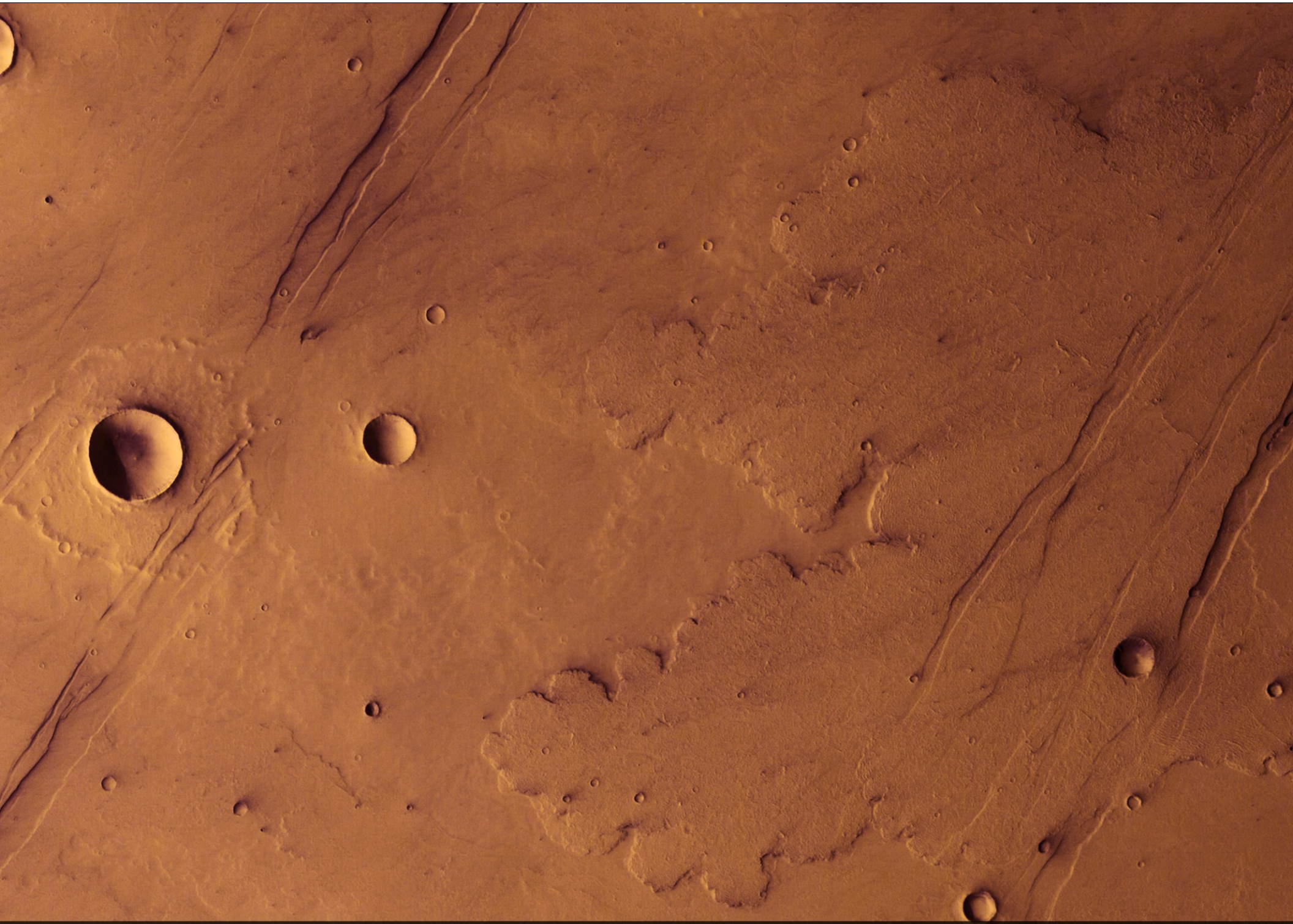






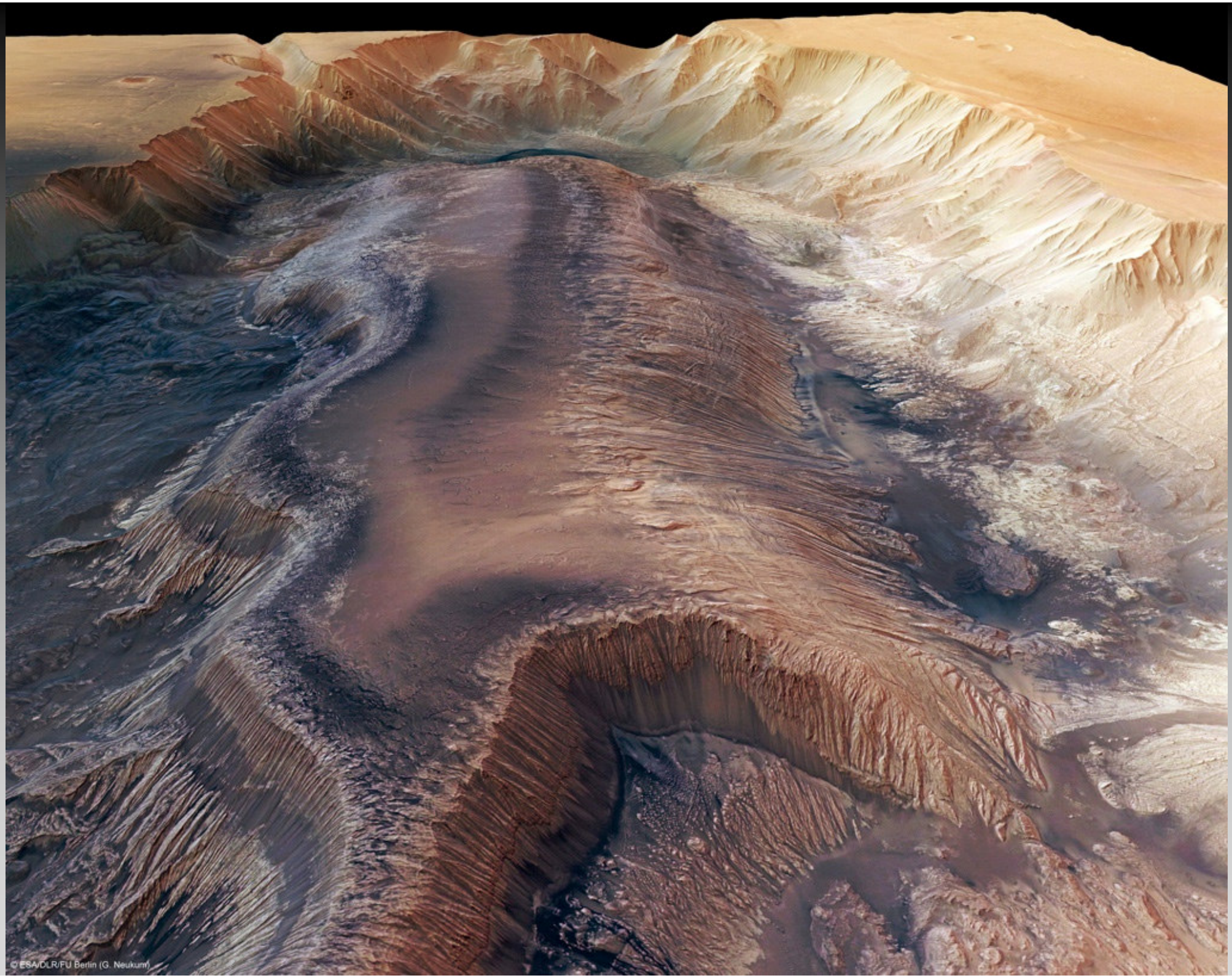


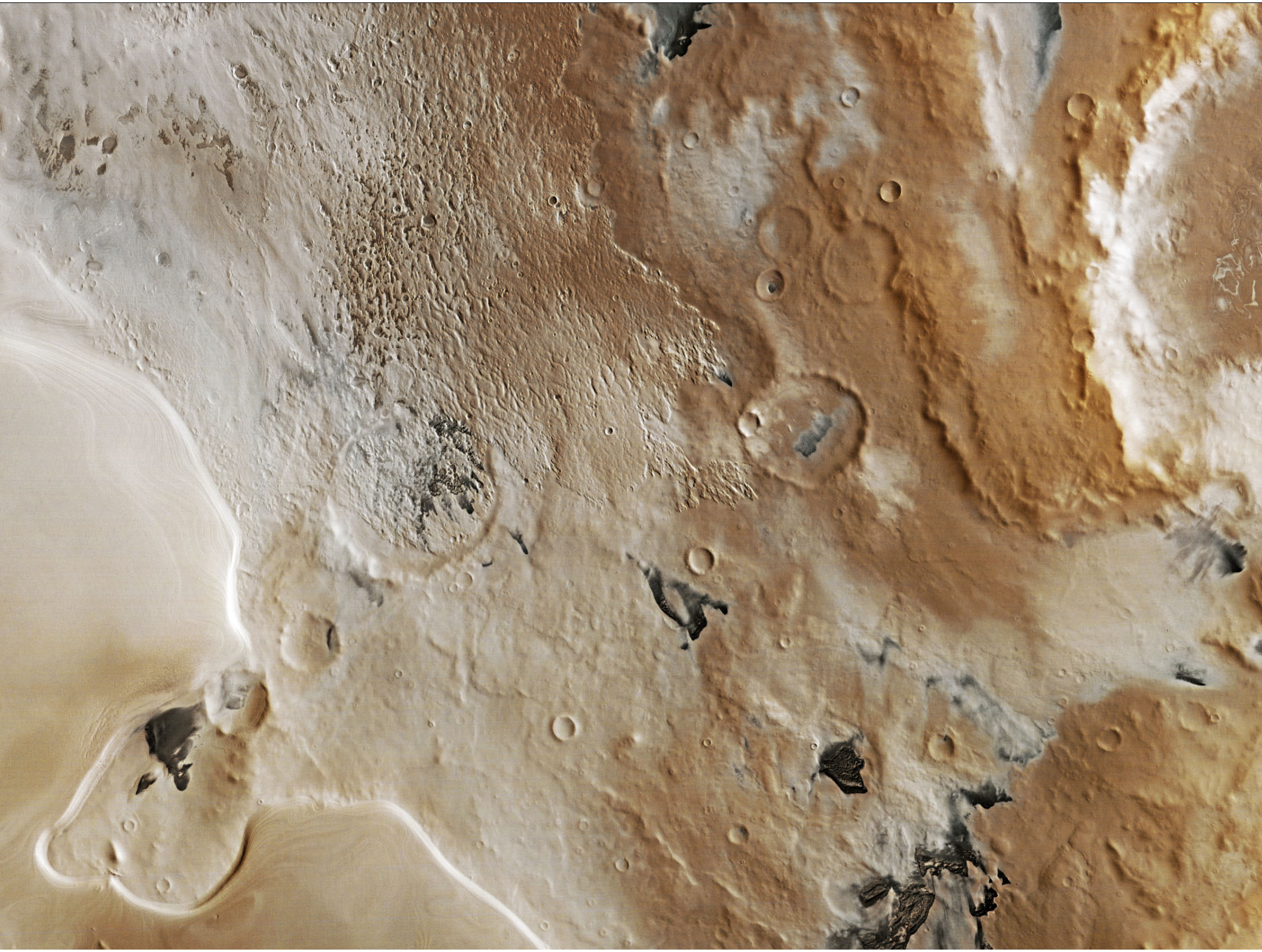


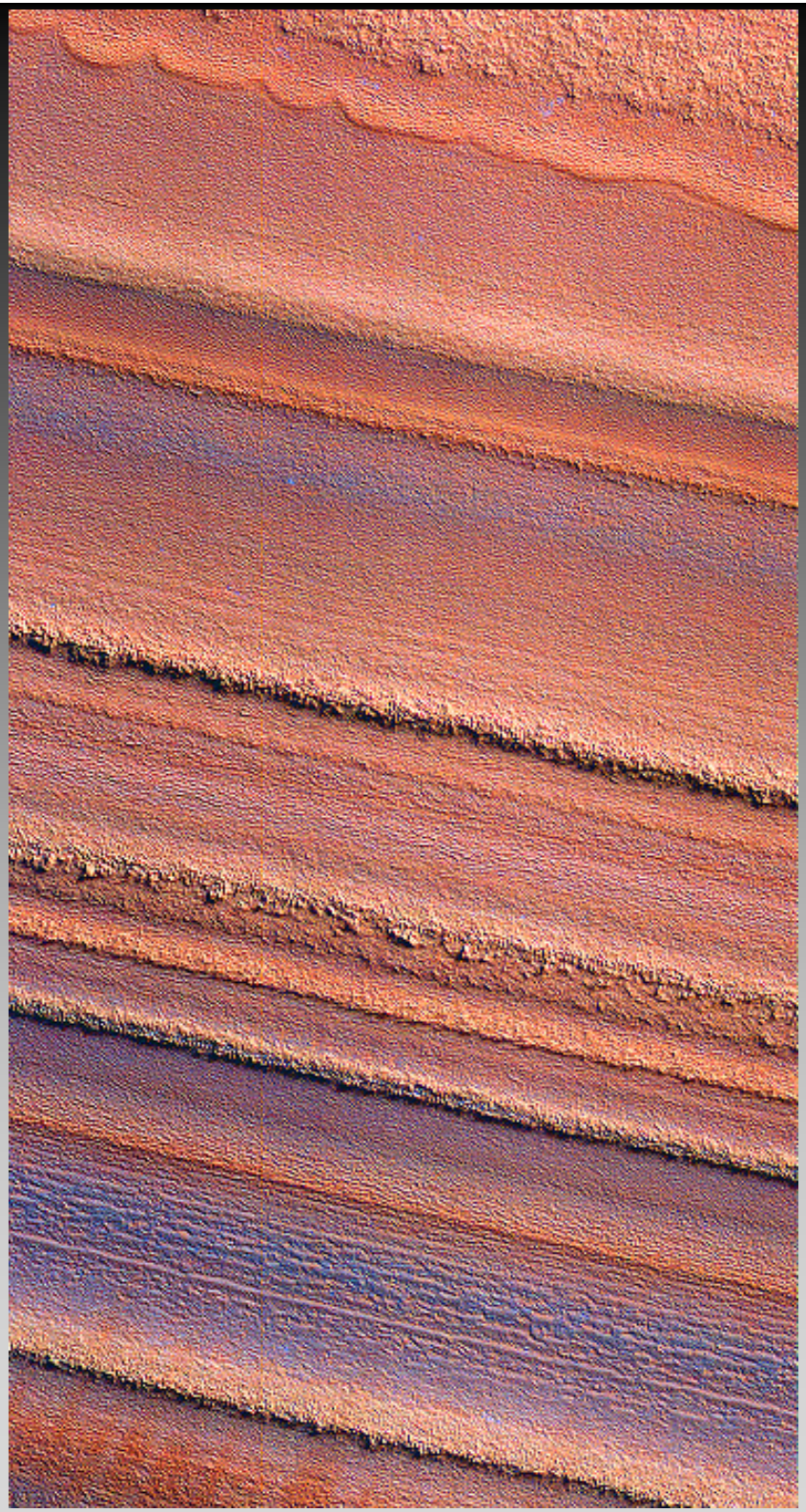


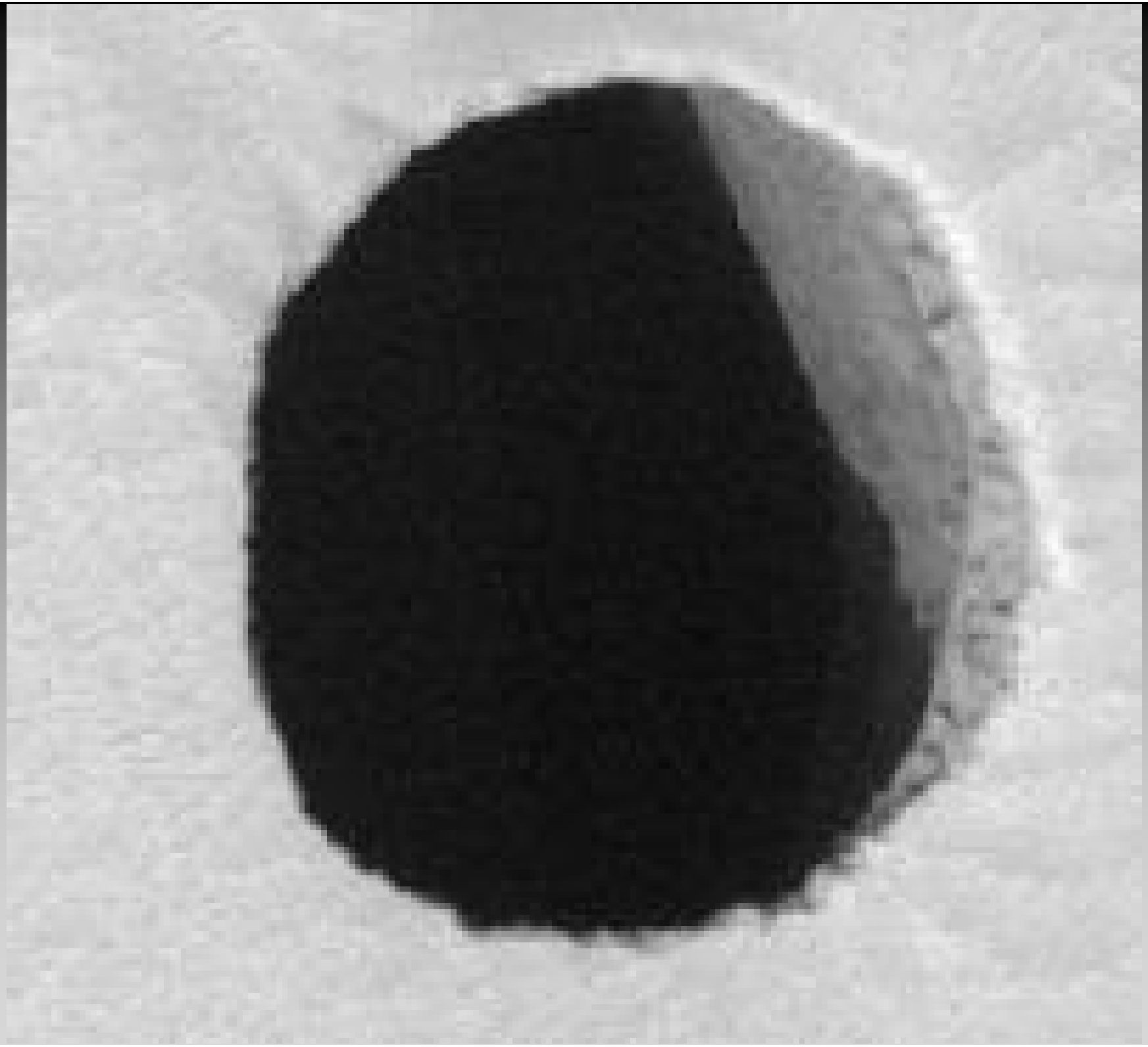
Mars Express High Resolution Stereo Camera in Orbit 1937

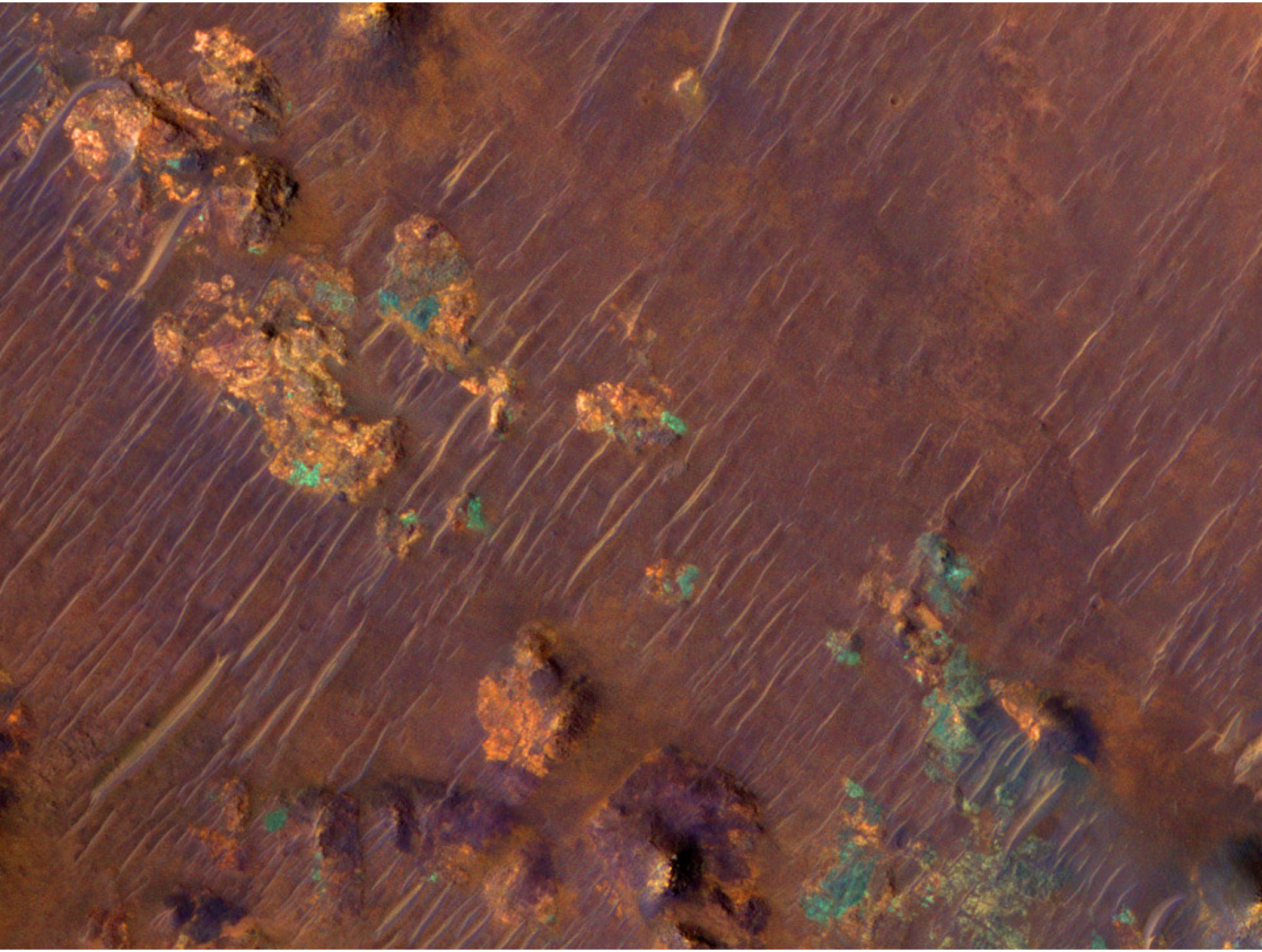
ARSIA MONS LAVA FLOWS
Image Center at 235.4°E, 26.2°S. Image Width: 100 km

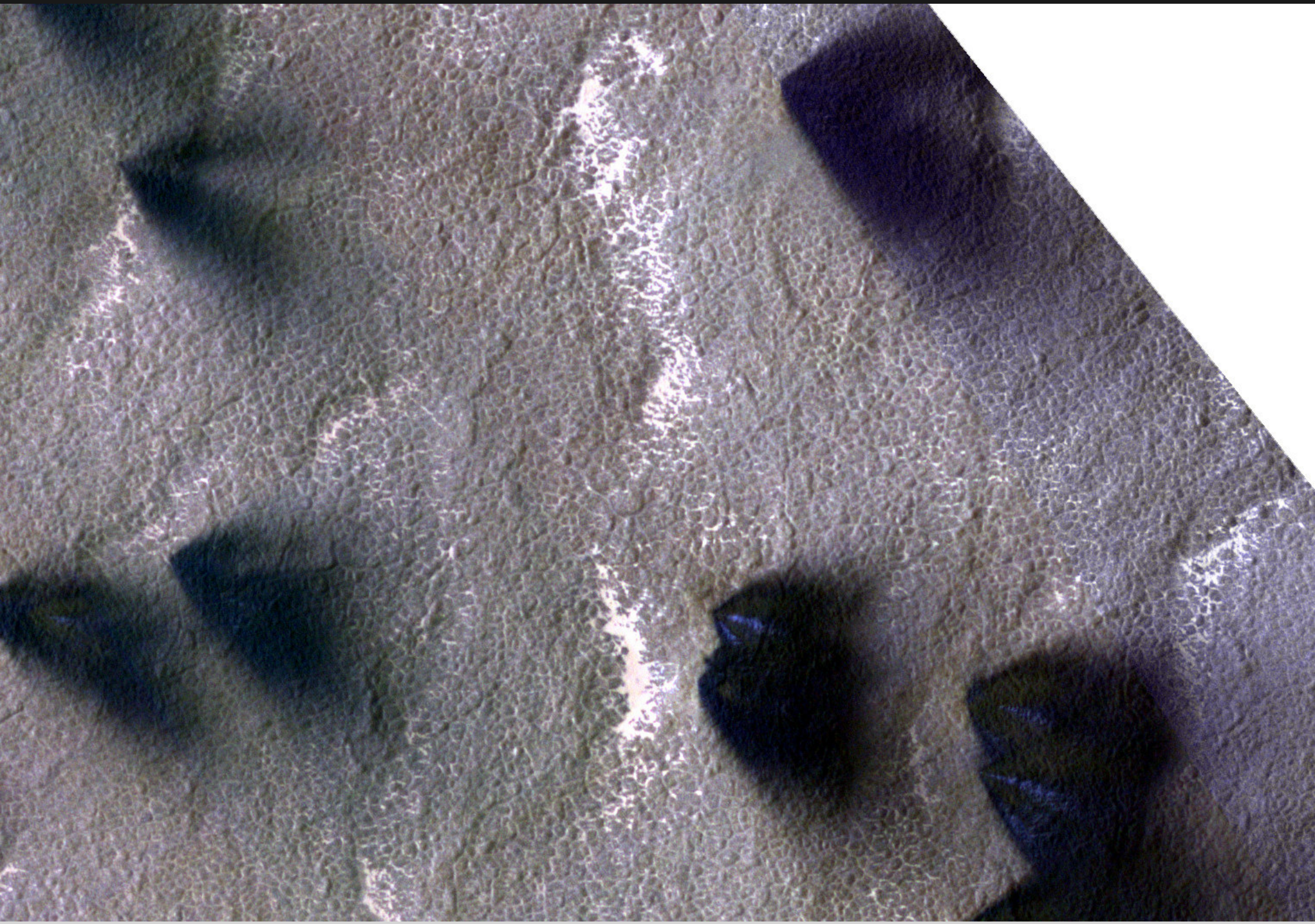

© ESA/DLR/FU Berlin (G. Neukum)











"Ingrid's Avalanches" 2008 Feb 19

83.7N 235.8E

PSP_007338_2640