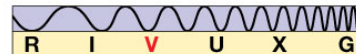


Terrestrial Planets 3

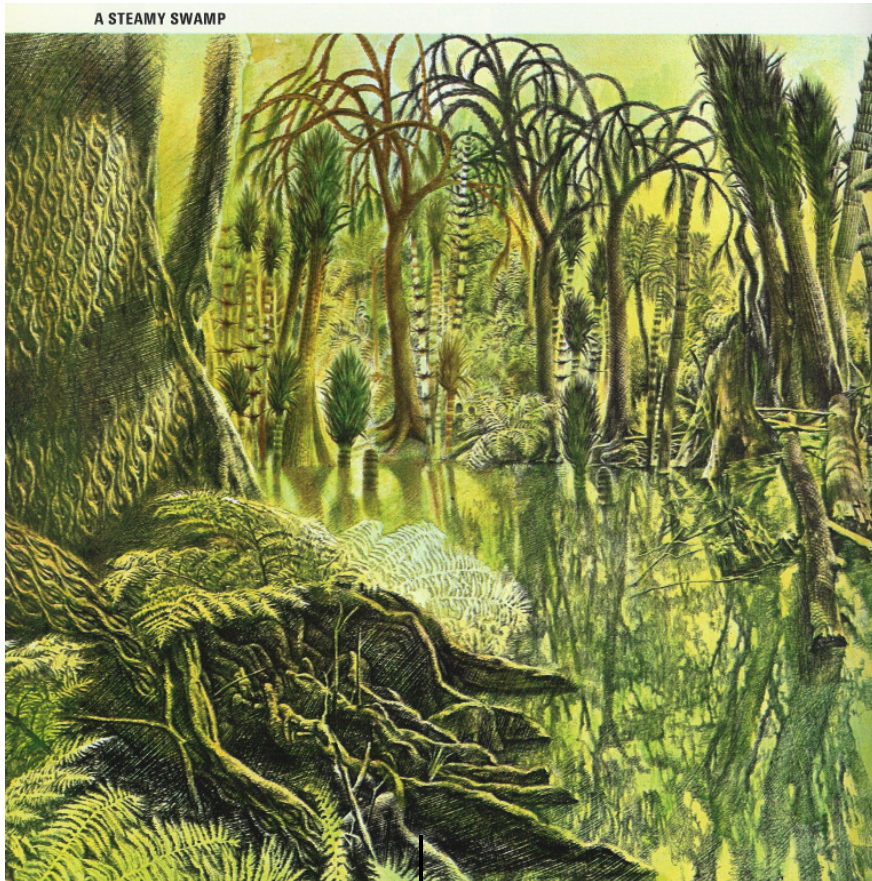
Venus



As seen
from Earth



Early Speculations - limited by cloud-covered surface

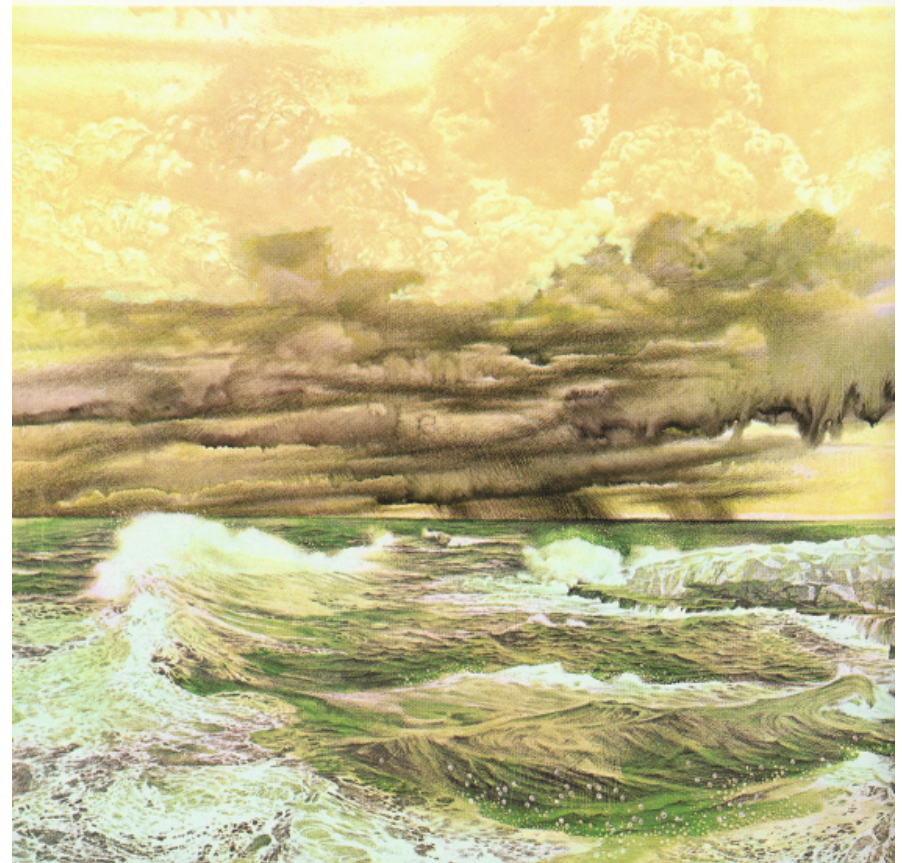


See original paintings by [Charles Knight](#) (C .1930's)

A PETROLEUM PLANET



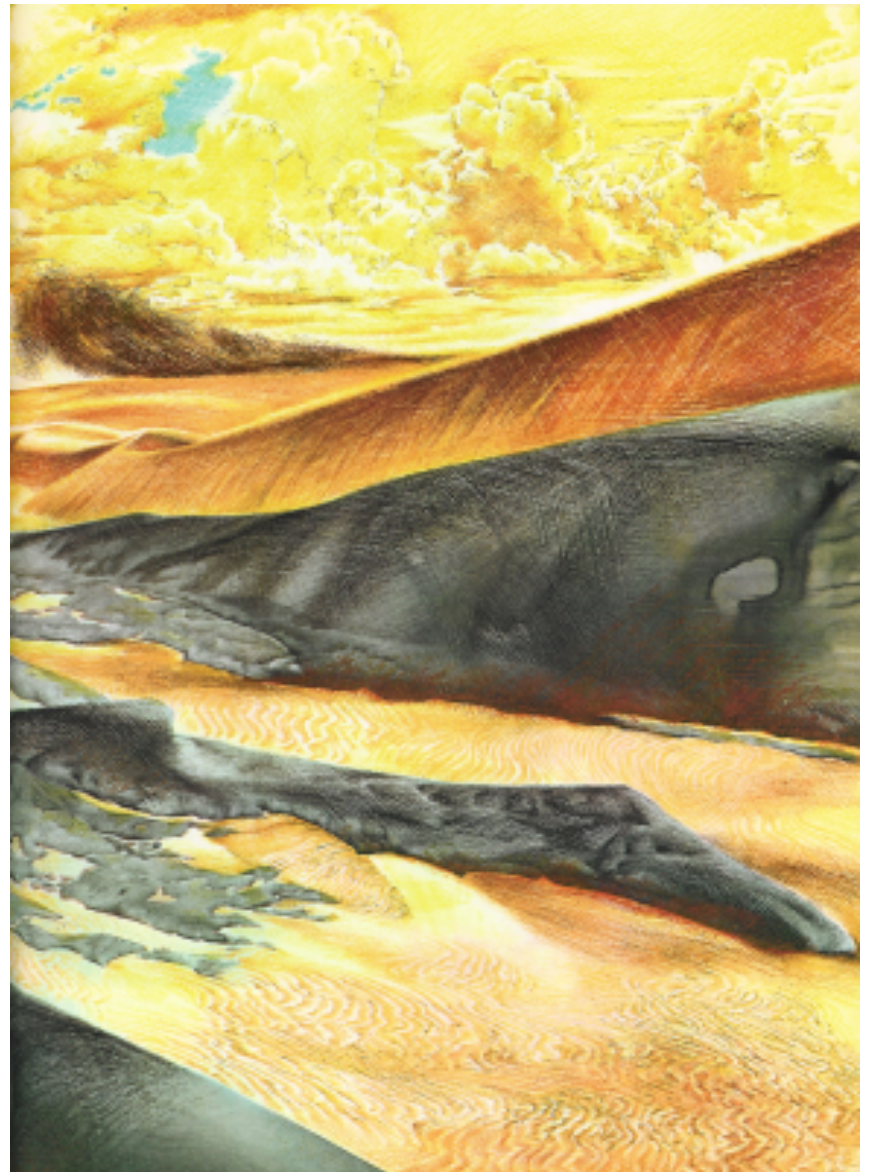
A CARBONATED SEA



Post Mariner 2 (1962) View



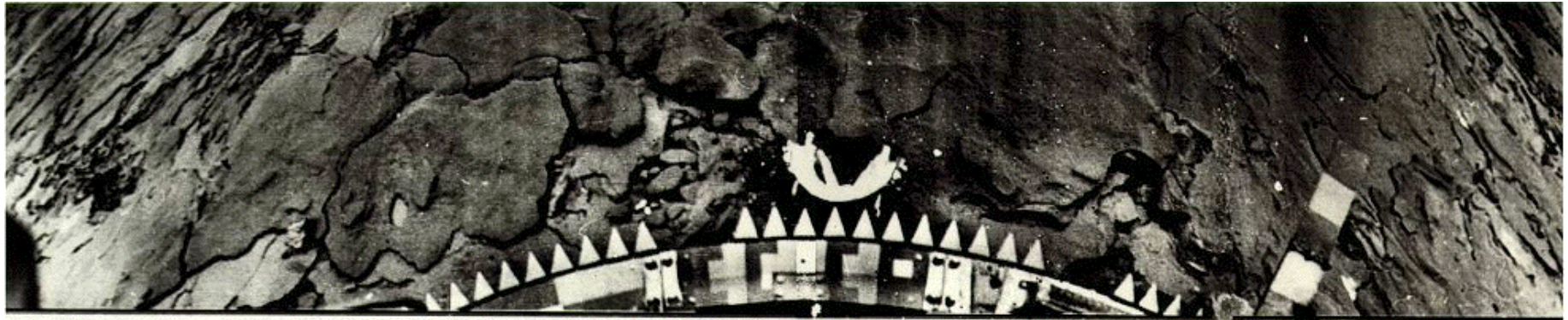
Infrared
measurements
confirmed radio
observations from
Earth that Venus
was HOT!!



Venus is like Earth in Size & Mass, but little else

Basaltic Surface

Venera-14 (1983)



ВЕНЕРА-14 ОБРАБОТКА ИППИ АН СССР И ЦДКС

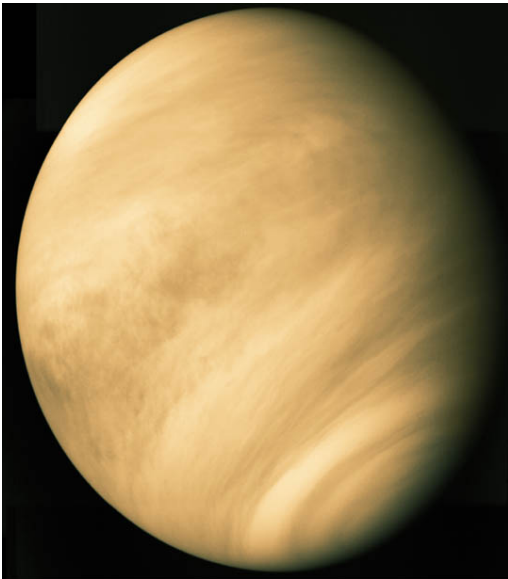


ВЕНЕРА-14 ОБРАБОТКА ИППИ АН СССР И ЦДКС

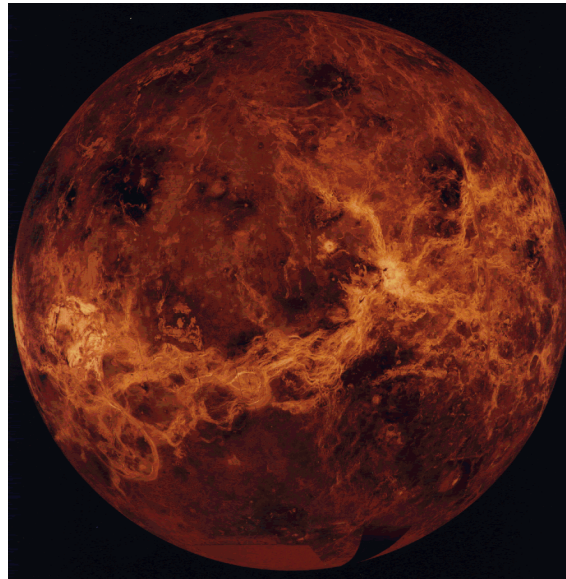
X-ray Fluorescence Spectrometer extended

Mariner 10 (1974-1975 flyby of Venus once and Mercury 3 times)
Magellan (1990-1994 orbiter)

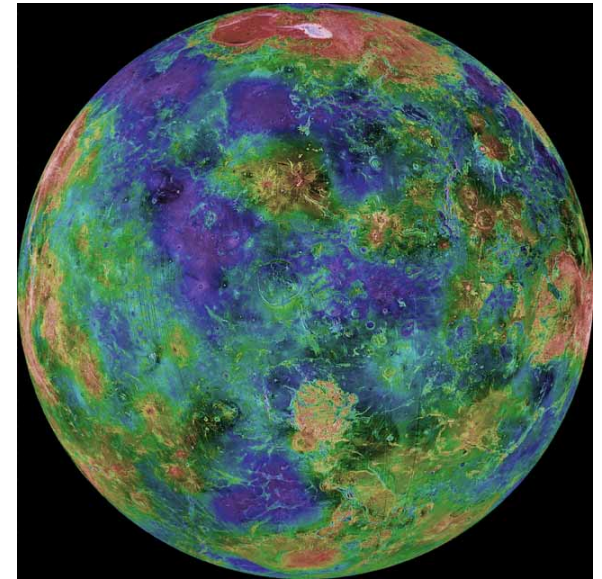
3 faces of Venus



Visible Light
(Mariner 10)

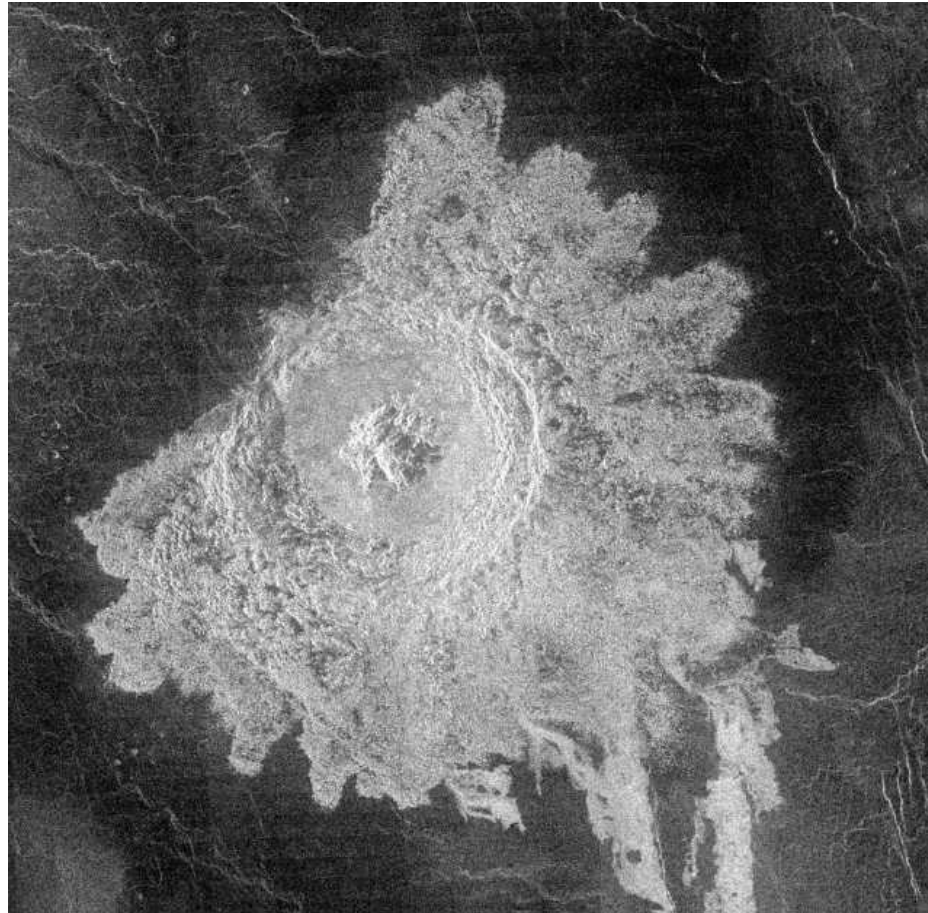


Radar map
(Magellan) color
as seen from
surface

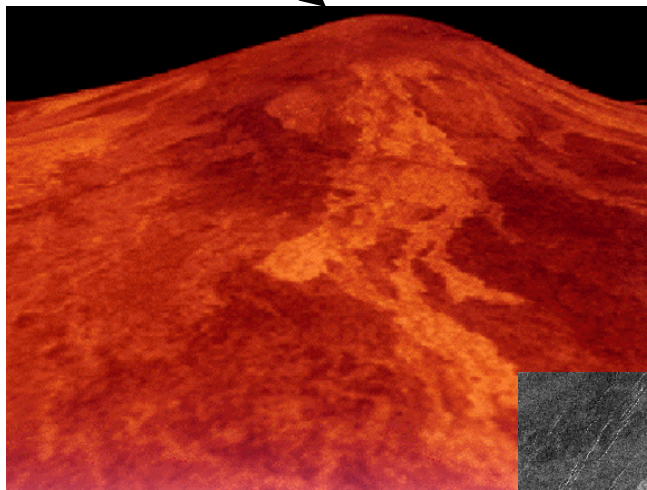


Radar map
color-coded
for elevation

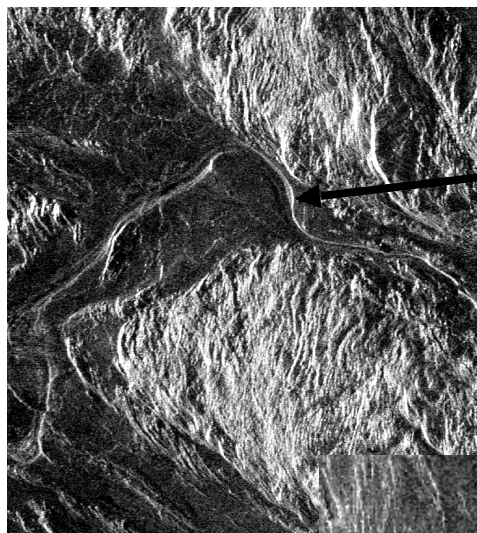
Craters



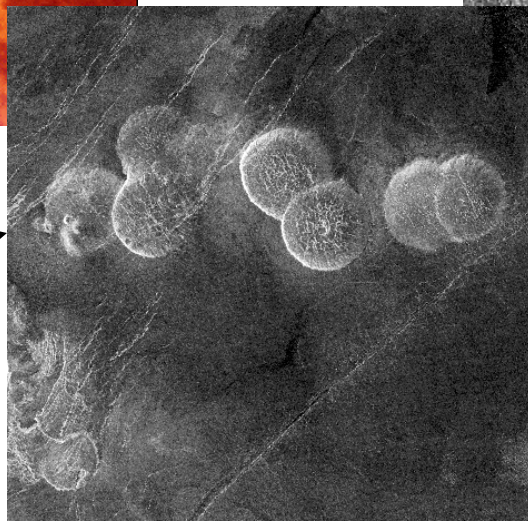
Sif Mons



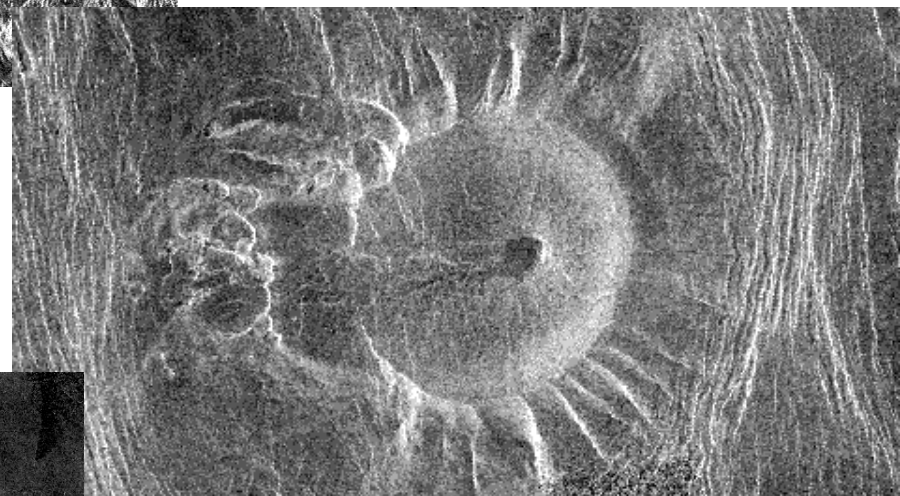
Lava channel

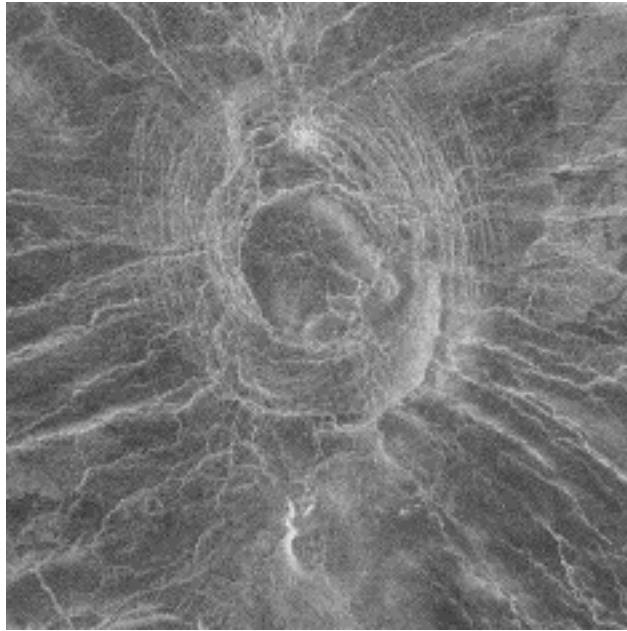


Lava domes



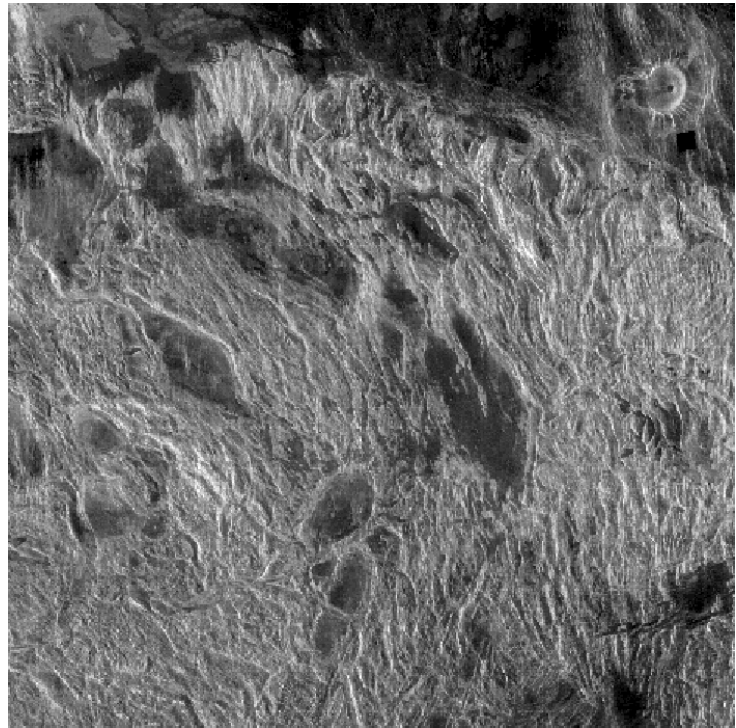
The “Tick”



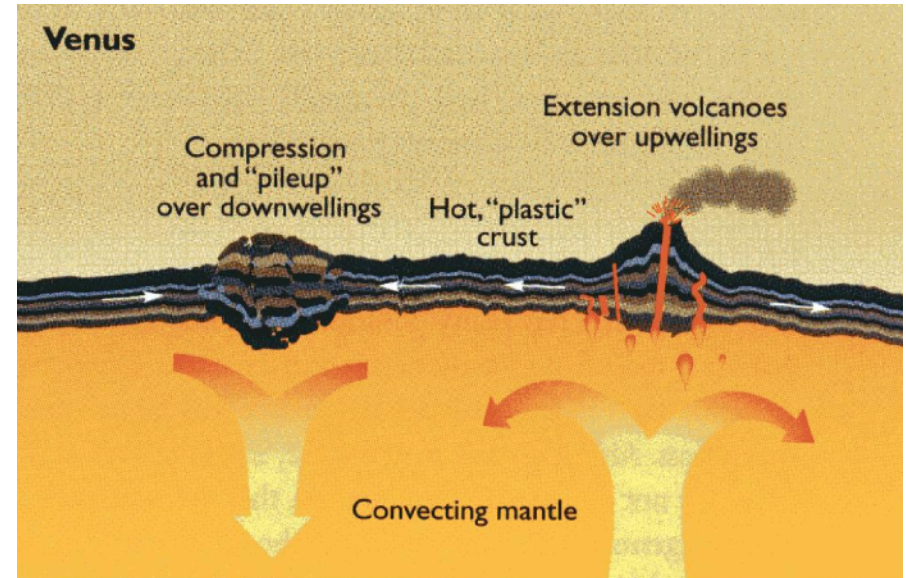
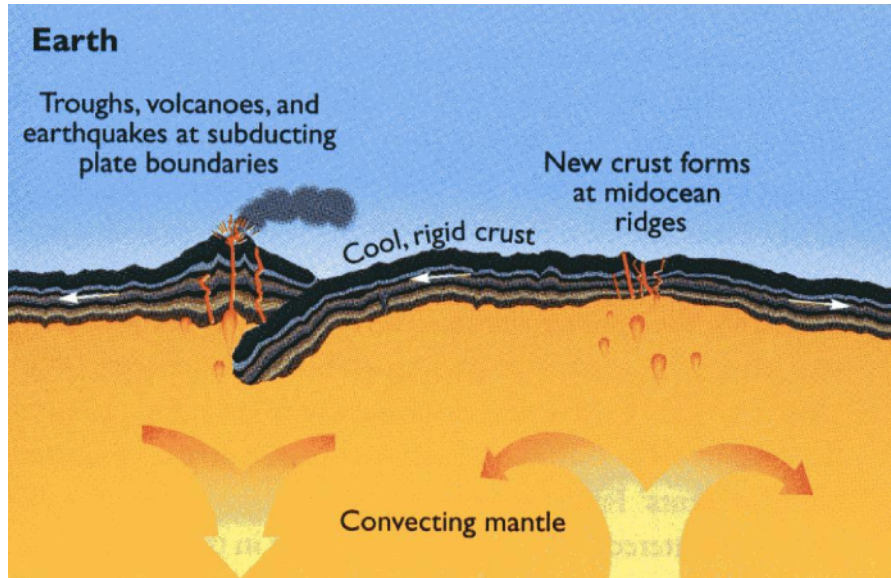


Typical corona

A portion of Alpha
Regio, showing
tesseraed terrain



Comparison of Plate Activity for Earth & Venus



Cool crust

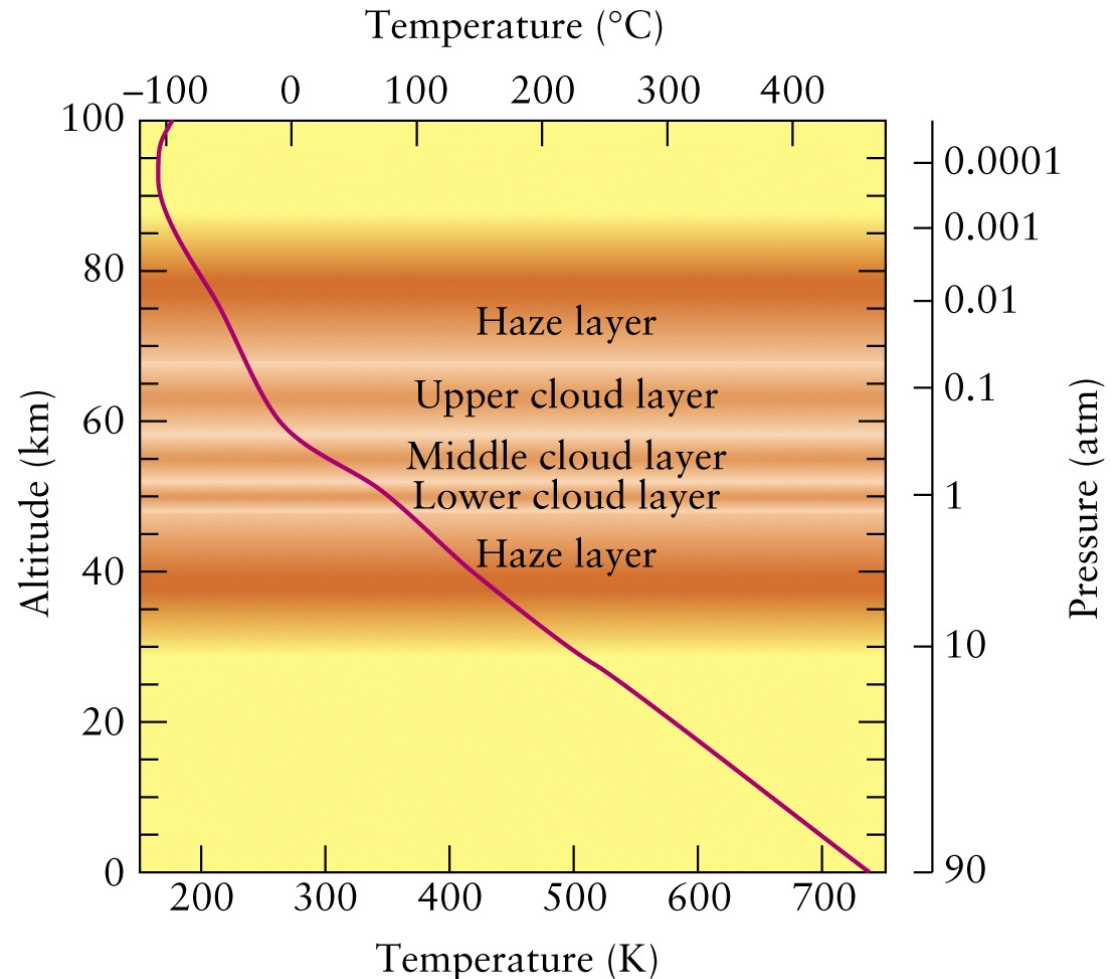
Water lubricates
tectonic motion

Warm crust

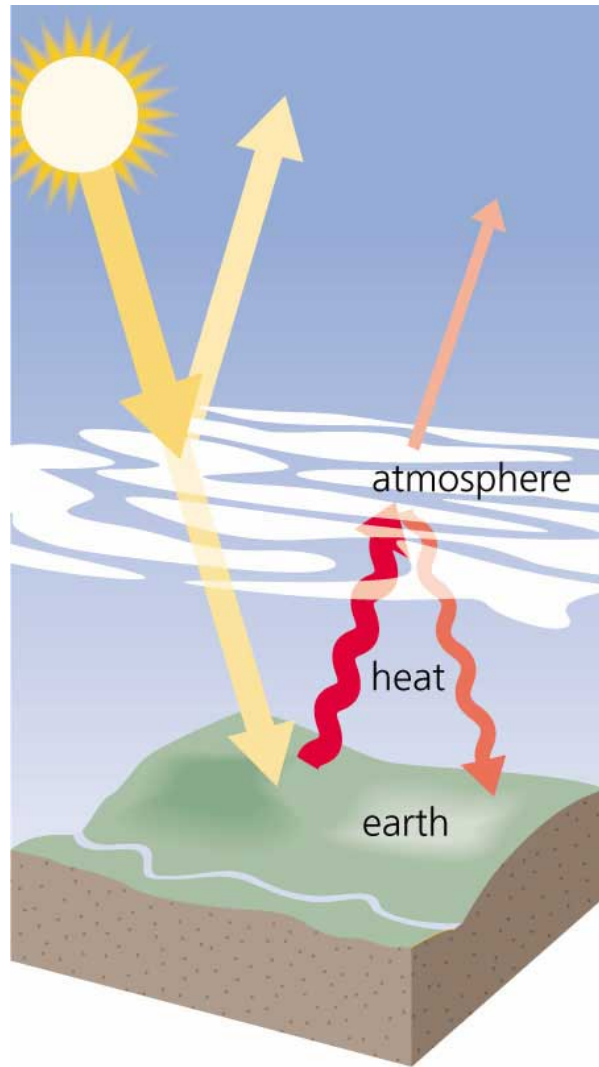
No water

However, it appears that Venus underwent a *resurfacing* event about 500 million years ago, spurred on by widespread volcanism. Does it still have active volcanos??

- 96% CO_2 , 3% N_2
- $P_{\text{surface}} = 90 \text{ bars}$
- Clouds: Mostly
Droplets of
concentrated
sulfuric
acid (H_2SO_4)



Why is Venus so different? - Greenhouse Effect



Precision Graphics

1. Visible light, to which atmosphere is transparent, absorbed by ground - heats it
2. Ground re-radiates energy as infrared light, to which the atmosphere is opaque
3. Warmed atmosphere re-radiates some of the IR back to the ground, keeping everything warmer

Facts & Mistakes

Earth:

Major Greenhouse Gases: Water Vapor & Carbon Dioxide

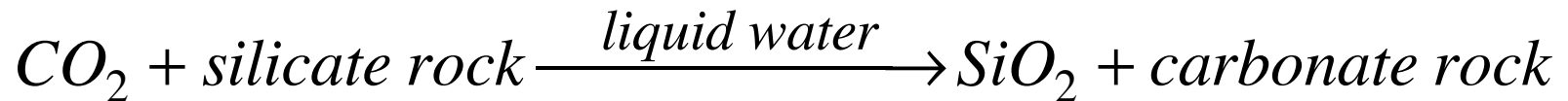
Other greenhouse Gases: Methane, Ozone, Nitrous Oxide

Venus: Carbon Dioxide - a LOT of it!!

COMMON MISCONCEPTION: greenhouse effect is NOT synonymous with the ozone layer!!!! Ozone is a (minor) greenhouse gas, but that is all.

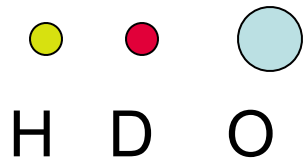
Why Different Greenhouse Effects?

Earth's water removes CO₂ and sequesters it in rocks.
The *Urey Reaction*, in its simplest form:

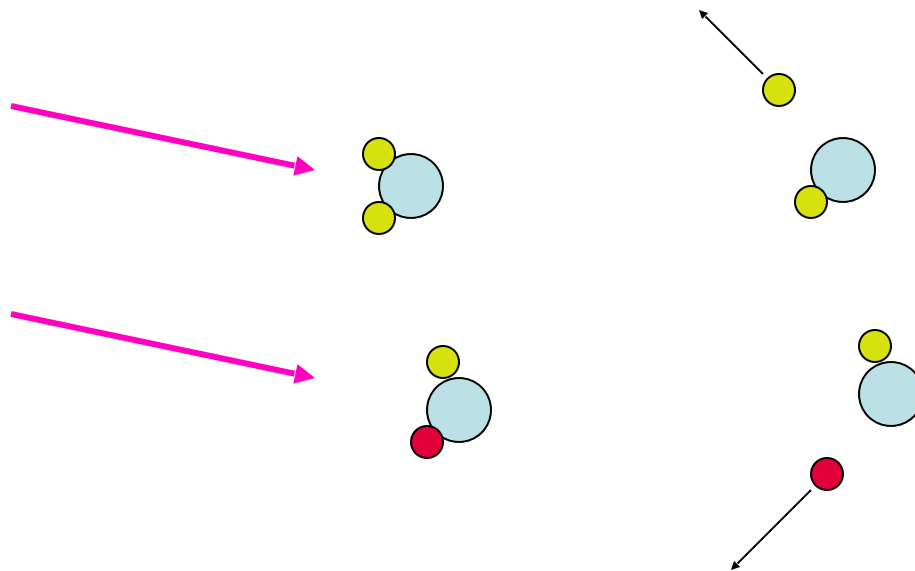


“Great Idea”: *if all the CO₂ in rocks were released, we would have an atmosphere similar to that of Venus! (and we would all die...)*

Past Water on Venus



(reminder: D is simply ^2H - hydrogen with a neutron in its nucleus, not just a proton)



But D is twice as heavy as H, and held by gravity better, increasing D/H with time

For Venus, D/H is 150x that of Earth - indicating Venus had a lot more water in the past than today - a *wet greenhouse* (*on Earth most of the water is stored in the oceans....*)

Runaway Greenhouse Effect - Venus

Suppose Venus did have oceans a long time ago

On Venus:

1. Atmosphere of CO_2 & H_2O provides greenhouse warming
2. Warming evaporates oceans to release more H_2O
3. Increase in H_2O increases greenhouse warming, etc.
4. Liquid water removed - leaving CO_2

“Normal” Greenhouse Effect - Earth

1. Atmosphere of CO_2 & H_2O provides greenhouse warming
2. Warming evaporates oceans to release more H_2O , but more slowly
3. Water helps store CO_2 in rocks, reducing greenhouse effect
4. Moderated greenhouse effect reaches equilibrium with slightly elevated temperature, plenty of liquid H_2O , and little CO_2 in atmosphere

Runaway Greenhouse Effect - Earth

1. Atmosphere of CO_2 & H_2O provides greenhouse warming
2. Excess CO_2 leads to increased greenhouse effect
3. Added warming causes some melting of polar caps and more evaporation of oceans to release more H_2O ,
4. Reduced polar caps make Earth overall less reflective
5. More dark ground, more H_2O vapor, more CO_2 lead to increased warming, etc.

Complications for Understanding Details on Earth

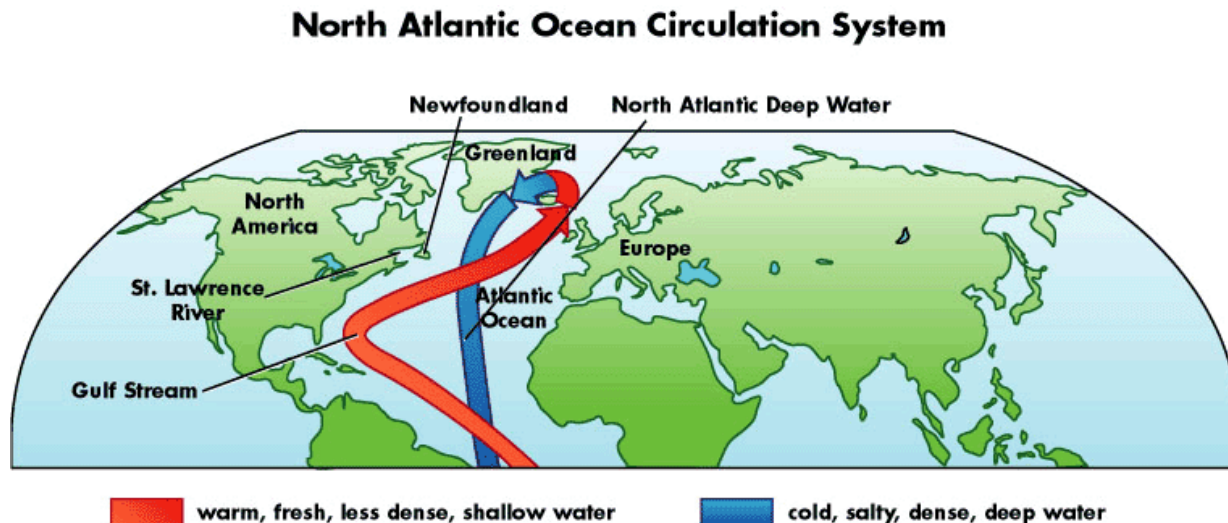
H₂O probably dominates over CO₂ as a greenhouse gas

H₂O undergoes phase changes - vapor, liquid, solid

Solid (ice) and liquid (water clouds) reflect light & can help cool the Earth

Climate also affected by solar activity, which is variable

Climate is affected by ocean currents



Life on Venus?

Today - not likely - hot enough to melt lead

Past? - not impossible that some thermophiles could have existed, but could not have lasted for long. Little chance of finding evidence.

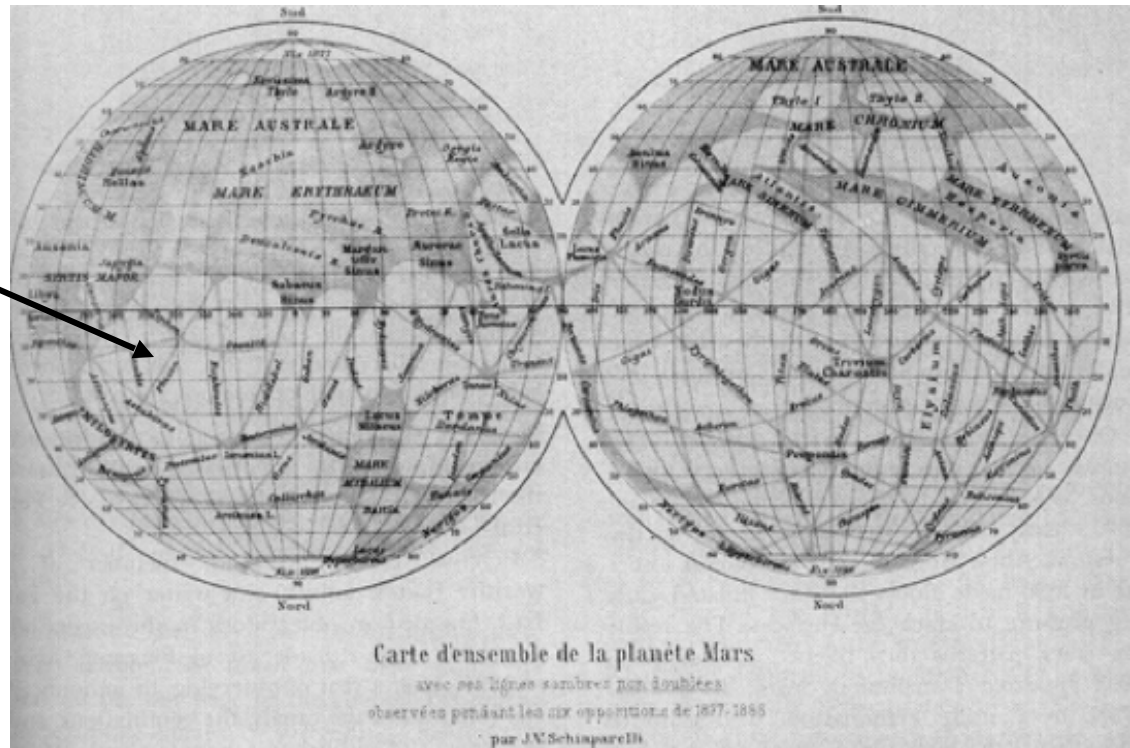


Mars

Earliest (?) drawing of features on Mars by Christiaan Huygens, made in 1650s. The triangular marking is Syrtis Major.



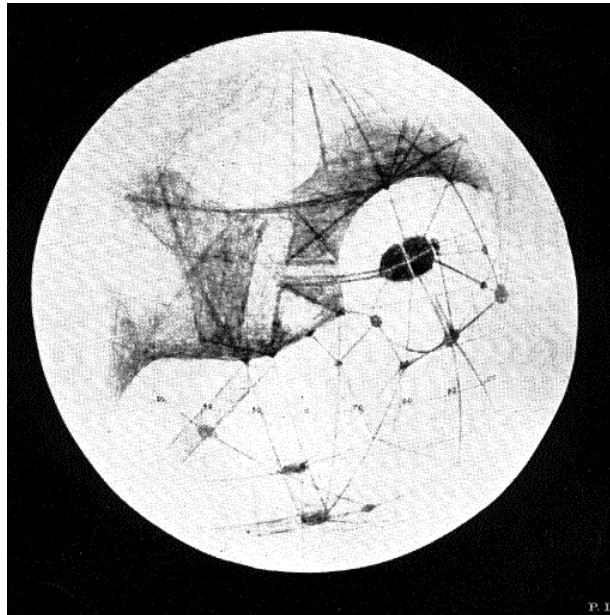
1877 – Schiaparelli describes long dark streaks as *canali*, Italian for *channel*. Although not implying intelligent origin, the term is quickly translated (in English at least) to be *canal* – an *artificial* structure.



1900 - Percival Lowell

Claims to see canals on Mars

Describes physiological, social, and political traits of martians.....



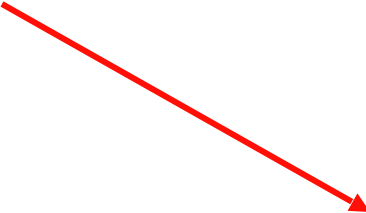
CHAPTER III

THE PLANETS AND THEIR SATELLITES

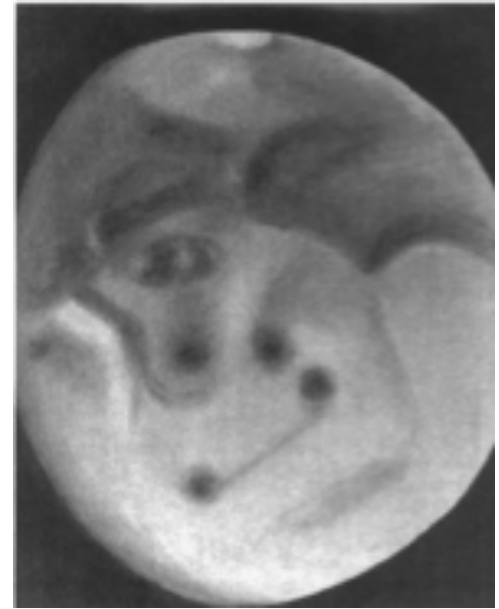
For many people there is just one question in astronomy: Is there life upon Mars? The possibility that astronomers may find in some other planet traces of intelligent life has exercised a fascination that inspires the novelist, the dramatist, and above all the journalist. So the world has become quite familiar with the idea that something or other has been found upon Mars which seems to prove the presence of intelligent inhabitants. For Mars, at any rate, the question is considered almost settled: why else did a generous benefactor leave to the Paris Academy of Sciences a magnificent prize, to be given to the man who first succeeds in establishing communication with a planet *other than Mars*.

A rapid survey of the planets will show us why it is always Mars that is chosen for the abode of life. Mercury is very near the sun; Mercury, if he has an atmosphere, which

For many, life on Mars was practically a "given"!



Not everyone was so easily swayed -
such as E.E. Barnard, one of the finest
observers of his generation



Drawing by Barnard - 1909

Antoniadi to Barnard (1909 letter):

“My general conclusion on the ‘canals’ are:

- I. That the true appearance of the planet is a natural one*
- II. That the geometrical network of Dr. Lowell is entirely non-existent;
and*
- III. That the so-called “canals” of Schiaparelli (and Schiaparelli only) do
have some basis, - in this sense, that they are the optical products of
very complex and irregular natural duskiness, sporadically scattered
all over the Martian surface.”*

The Buildup of Knowledge

1934 - O₂ measured - 0.1% that of Earth

1947 - CO₂ measured - Gerard de Vaucouleurs (1950, *The Planet Mars*) suggested that the composition of the Martian atmosphere was 98.5% N₂, 1.2% Ar, 0.25% CO₂, <0.1% O₂. (He was wrong.)

1963 - H₂O vapor measured - difficult! Have to avoid H₂O lines in OUR atmosphere!

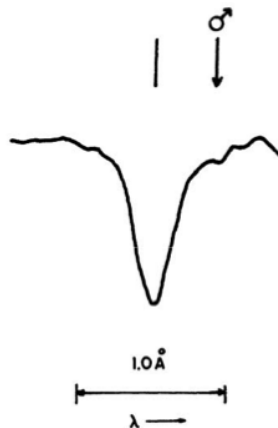
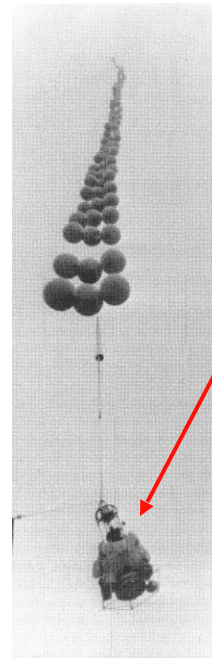
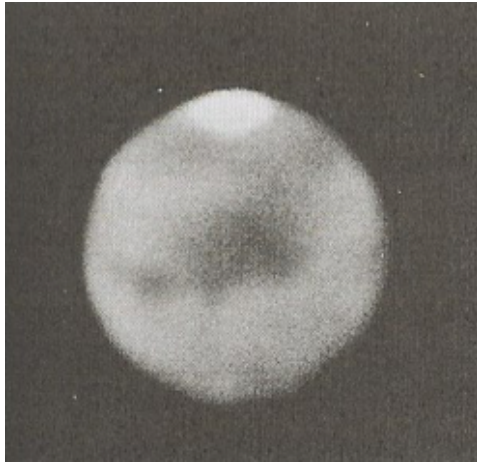


FIG. 2.—The averaged profile of the four H₂O lines shown in Fig. 1. The calculated position of the Martian H₂O line is indicated by the arrow below the Mars symbol; the faint Mars water-vapor line is visible there.



Audouin Dollfus on his second balloon-borne attempt to detect water vapor on Mars. In this flight, he was lifted to an altitude of 46,000 feet (!) but was unsuccessful. He later was able to detect water vapor from a mountain pass high in the Swiss Alps.

“Wave of Darkening”



Changes are seasonal

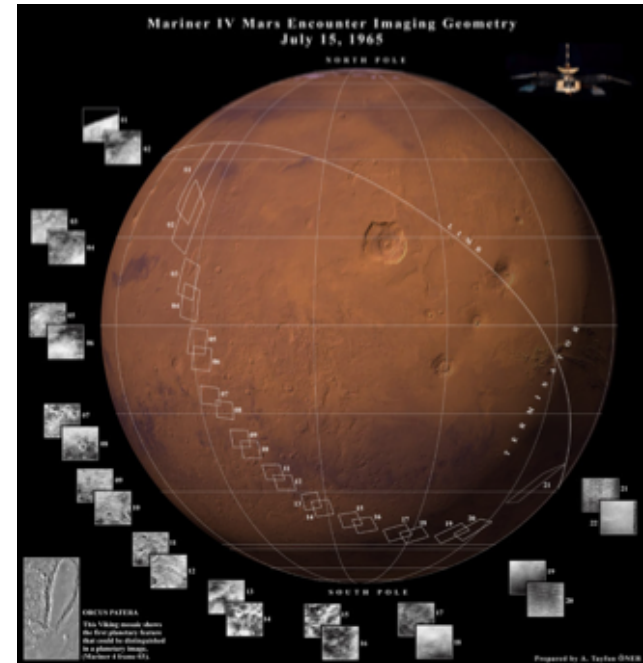
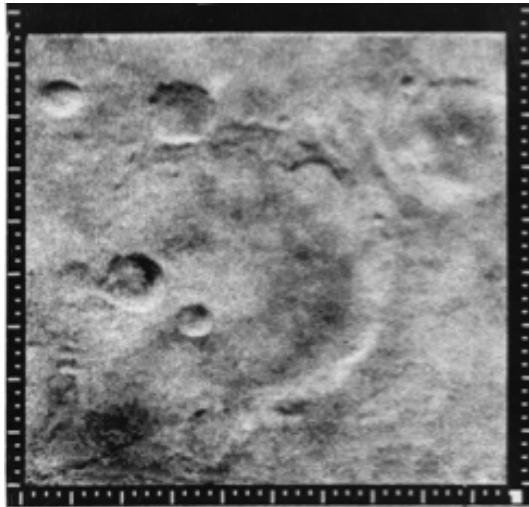
Move from poles to equator

Response of vegetation to water moving from poles to equator?

(NOPE! - most likely changes due to variations in airborne dust)

Mariners to Mars

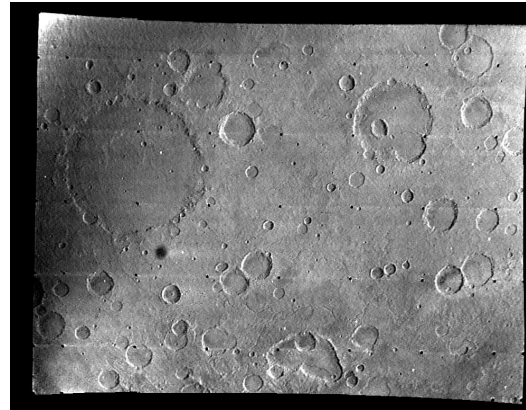
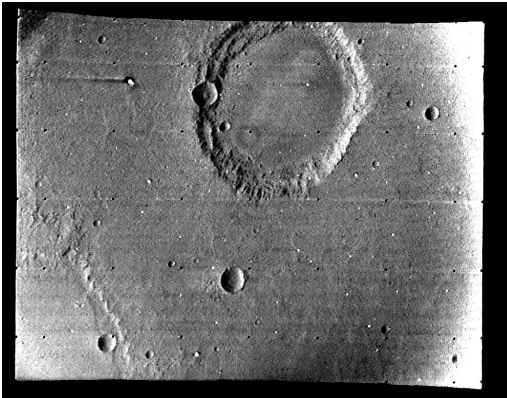
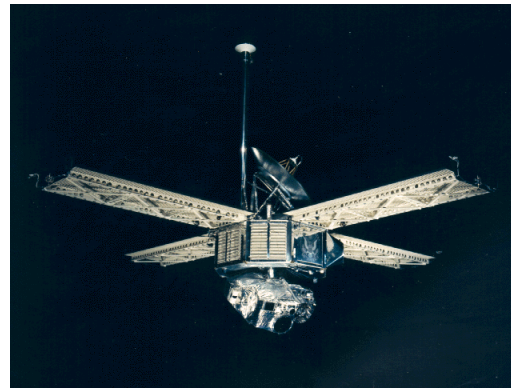
Mariner 4 - July 14, 1964. “Everything Changed” - Returning a whopping 22 (!!) pictures (many so poor as to be useless) during flyby, but it revolutionized our understanding of the planet.



Lots of craters - looked much like our lifeless Moon. Elation & depression amongst planetary scientists

Mariners 6 & 7 - 1969

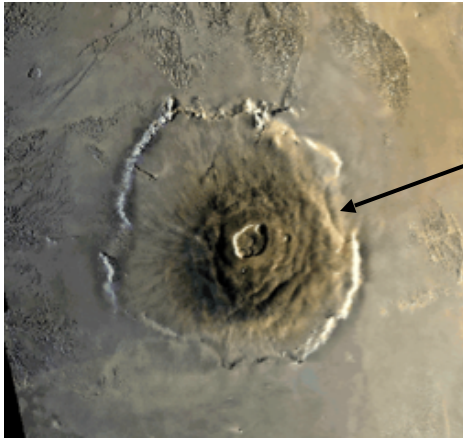
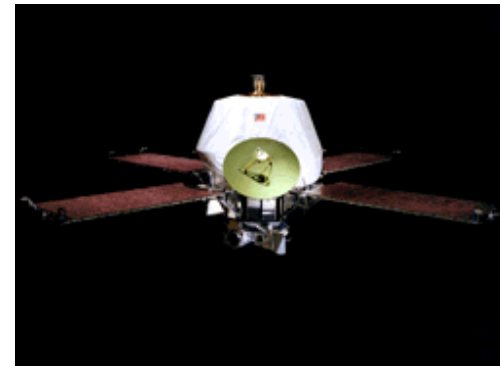
More of the same, but higher quality images



The impression created by Mariner 4 was not changed, only enforced. *Mars seemed as dead as the Moon.* There seemed little chance of finding anything resembling living organisms here, and even the hope of finding evidence for past life vanished.

But not so fast.....

Mariner 9 Orbiter

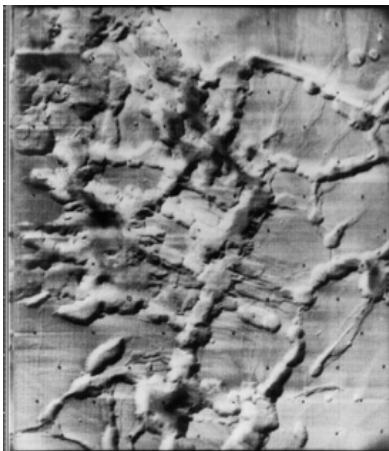
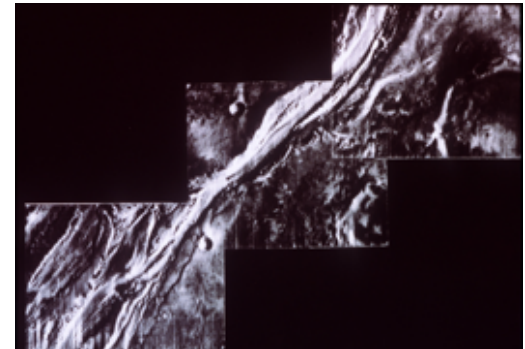


Volcanoes

Gullies

Collapsed Terrain (thaw in underground ice?)

Canyon walls with slumping and other erosional effects



Viking 1 & 2 - 1976

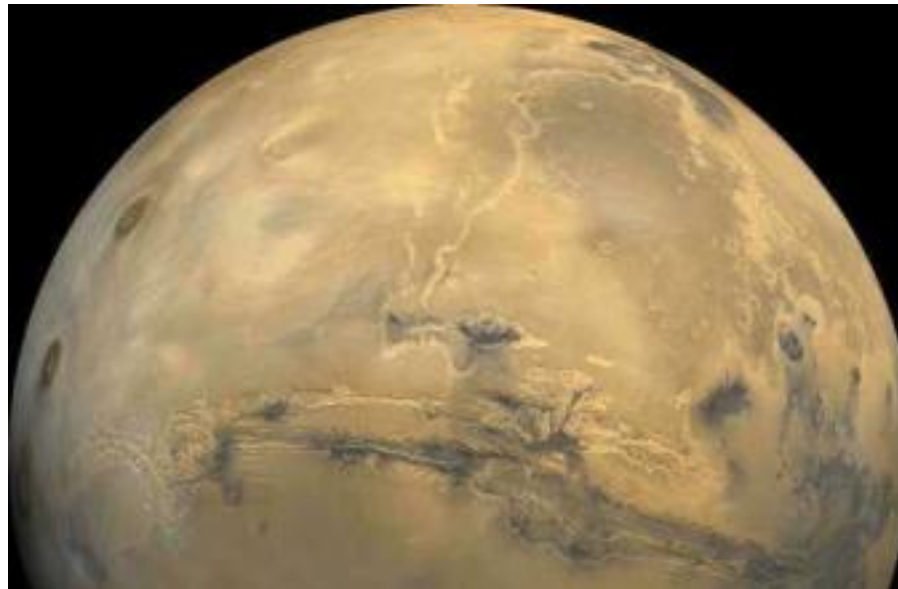
Each consisted of an Orbiter and a Lander

Viking 1

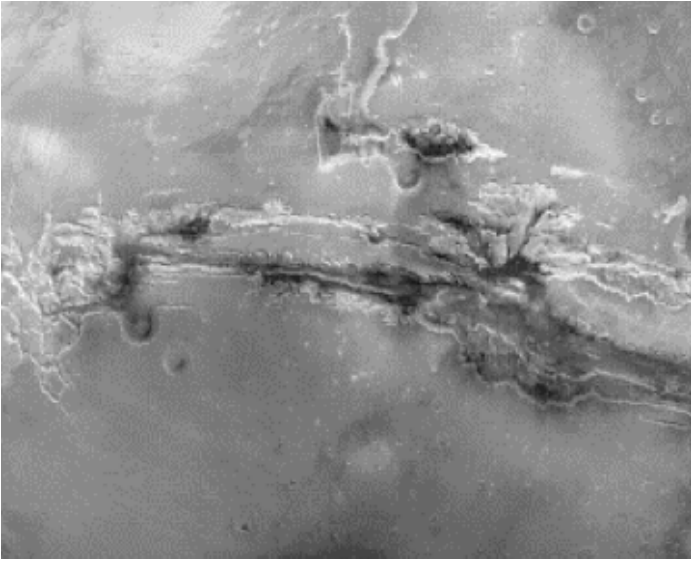
08.20.75: Launch
06.19.76: Arrival at Mars
07.20.76: Mars Landing
08.07.80: End of Mission (Orbiter)
02.01.83: End of Mission (Lander)

Viking 2

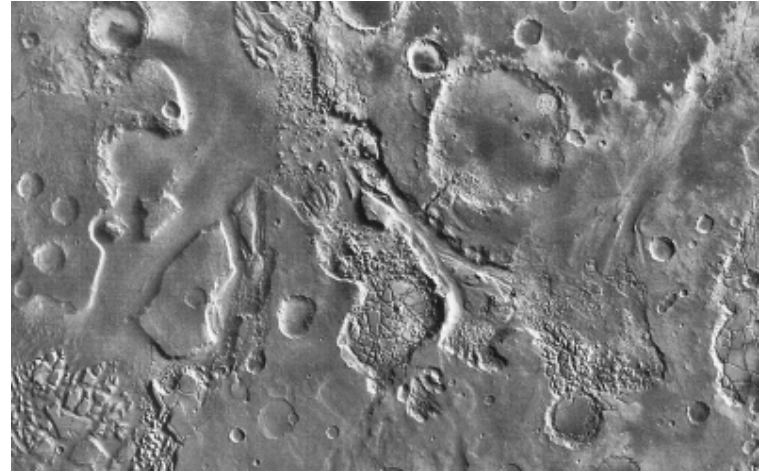
09.09.75: Launch
08.07.76: Arrival at Mars
09.03.76: Mars Landing
07.24.78: End of Mission (Orbiter)
04.12.80: End of Mission (Lander)



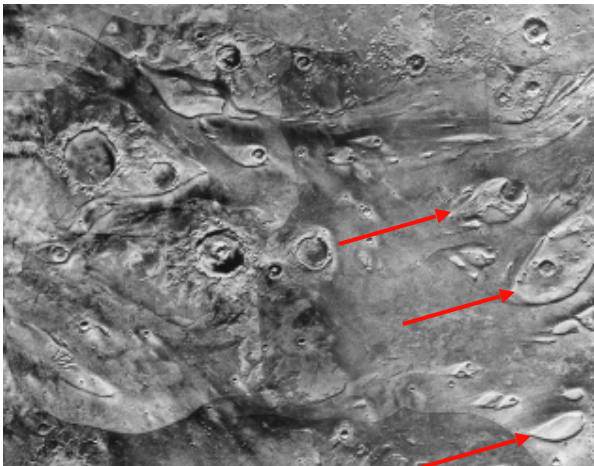
The Quest for Water



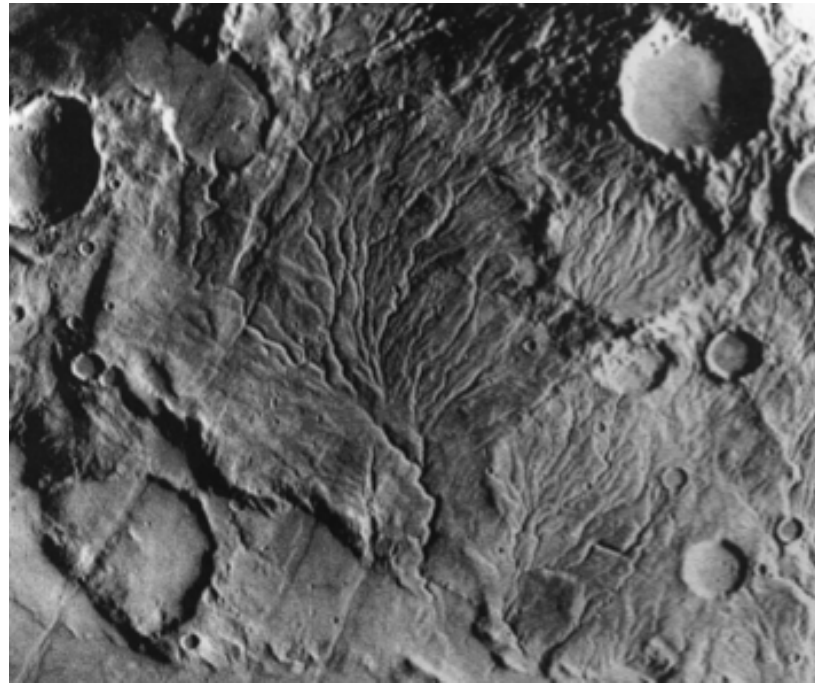
Valles Marineris Canyon



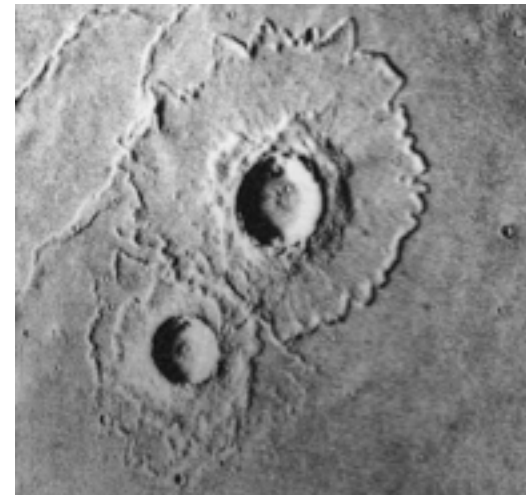
“Outflow channels” - sometimes start in “collapsed” terrain - some show sandbar structures



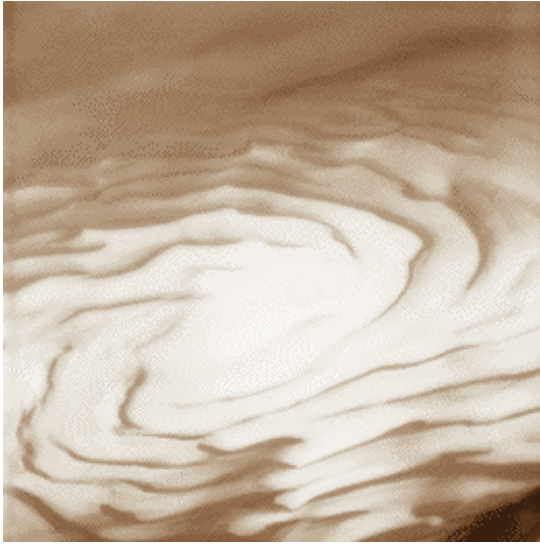
Sinuuous “runoff channels” like
dry riverbeds on Earth



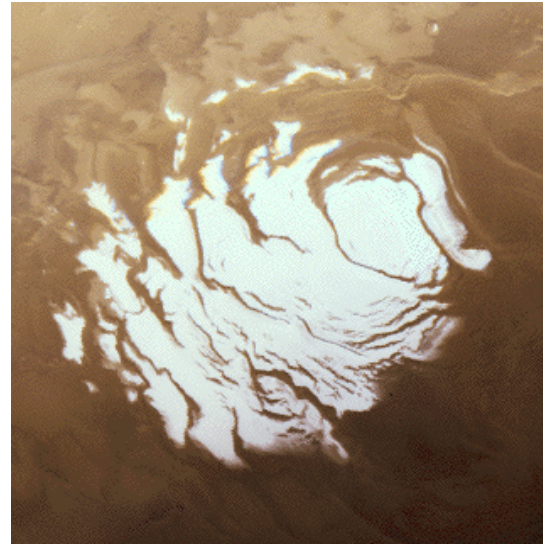
“Lobate” craters -
impacts in ground with
ice? Only found far
from equator



Polar Caps



North Polar Cap



South Polar Cap

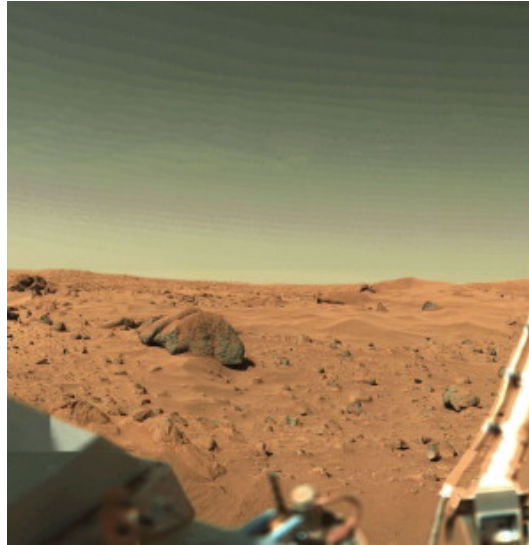
CO₂ caps – seasonal advance & retreat

H₂O caps – little/no change. - permanently frozen

In addition, much of the surface (under the dust layer) probably covered with *permafrost*

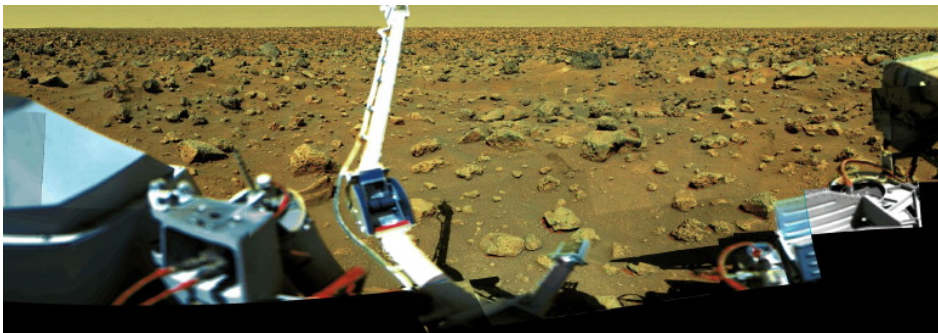
Viking Landers

Both landing sites
rocky & sandy - with
similar composition



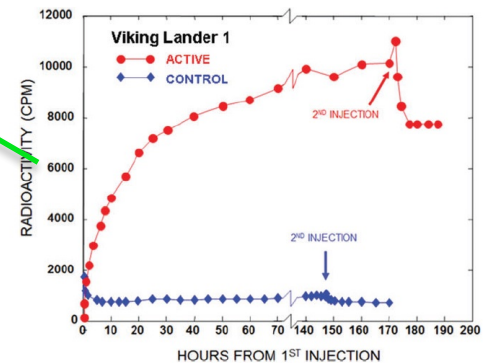
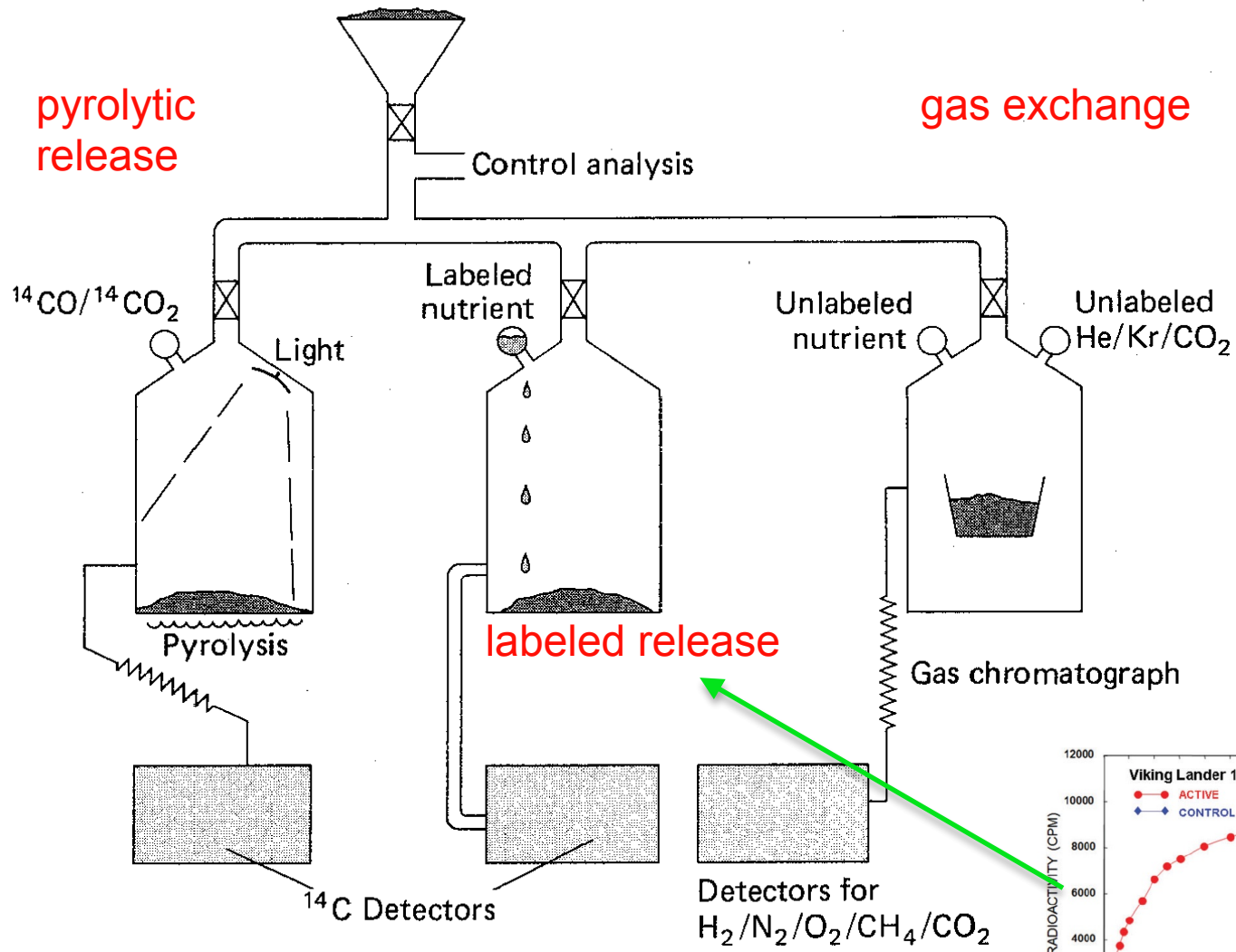
Viking 1

Red color - iron oxides “rusty planet”



Viking 2

Biology Experiments - search for *biological activity*

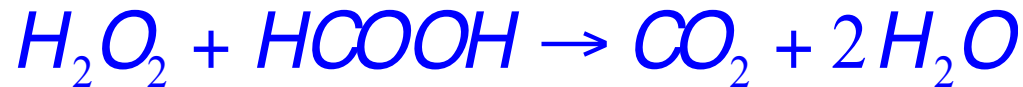


RESULTS

response”

“None seemed biological” - initially strong, then weaker

Chemical reactions with peroxides in surface suspected



Gas chromatograph (molecule-weighing) - no trace of complex (heavy) molecules used by life

Cameras - no ‘creatures’ wandered by....

Nevertheless, water does appear to have been present in past

How long ago?

Probably 3-3.5 by ago - same time required for rise of stromatolites on Earth

Where did it go?

Atmospheric erosion

Early bombardment period (remember the Moon...)

Later loss - closer to asteroid belt!

Smaller planetary mass

less tectonic & volcanic activity to re-circulate CO₂

Atmospheric Evolution Earth, Venus, Mars

All probably started with CO₂-dominated atmospheres. On Earth, this was removed by locking it into rocks (Urey Reaction).



Lack of liquid water on Venus prevented the removal of massive CO₂ atmosphere.

Mars is so cold, most of the little water present is frozen. It provides no GH warming. When it is present, it removes CO₂! Lack of tectonism prevents recycling of CO₂ back to atmosphere.

**WE WOULD NOT
RETURN TO MARS FOR
ANOTHER 20 YEARS....**

RETURN TO MARS

- 1993 - Mars Observer (MO) - lost**
- 1997 - Mars Global Surveyor (MGS)**
- 1998 - Mars Climate Orbiter - lost (crashed)**
- 1999 - Mars Polar Lander (MPL) - lost (crashed)**
- 1999 - Mars Pathfinder (MP)**
- 2001 - Mars Odyssey (MO)**
- 2003 - Mars Express (MX) & Beagle 2 - lost**
- 2004 - Mars Exploration Rovers (MERs) Spirit & Opportunity**
- 2006 - Mars Reconnaissance Orbiter (MRO)**
- 2008 - Mars Phoenix Lander (also near Mars N Pole)**
- 2012 - Mars Science Lab - Curiosity**
- 2018 - Mars Insight Lander**
- 2020 - ExoMars**
- 2020 - Mars 2020**

Mars Global Surveyor (MGS)

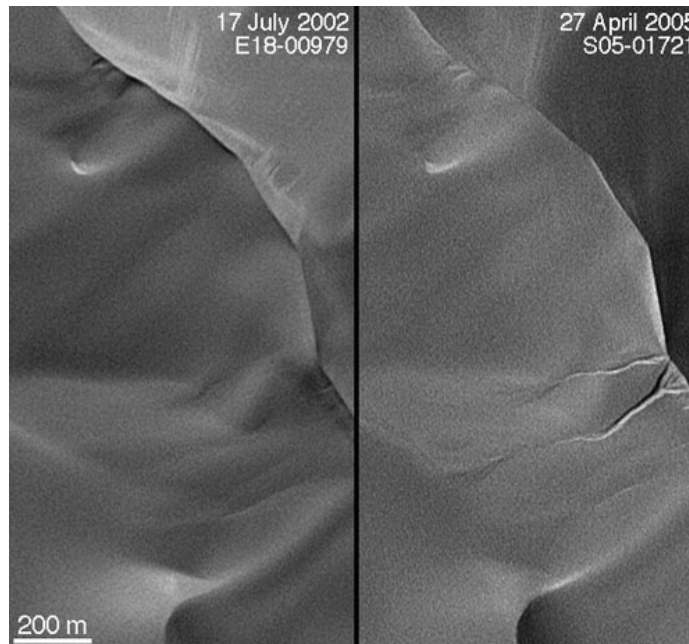


Gullies may be carved
by running water
released from ground.
Or...?



8 years of continuous
operation allows
changes to be
observed

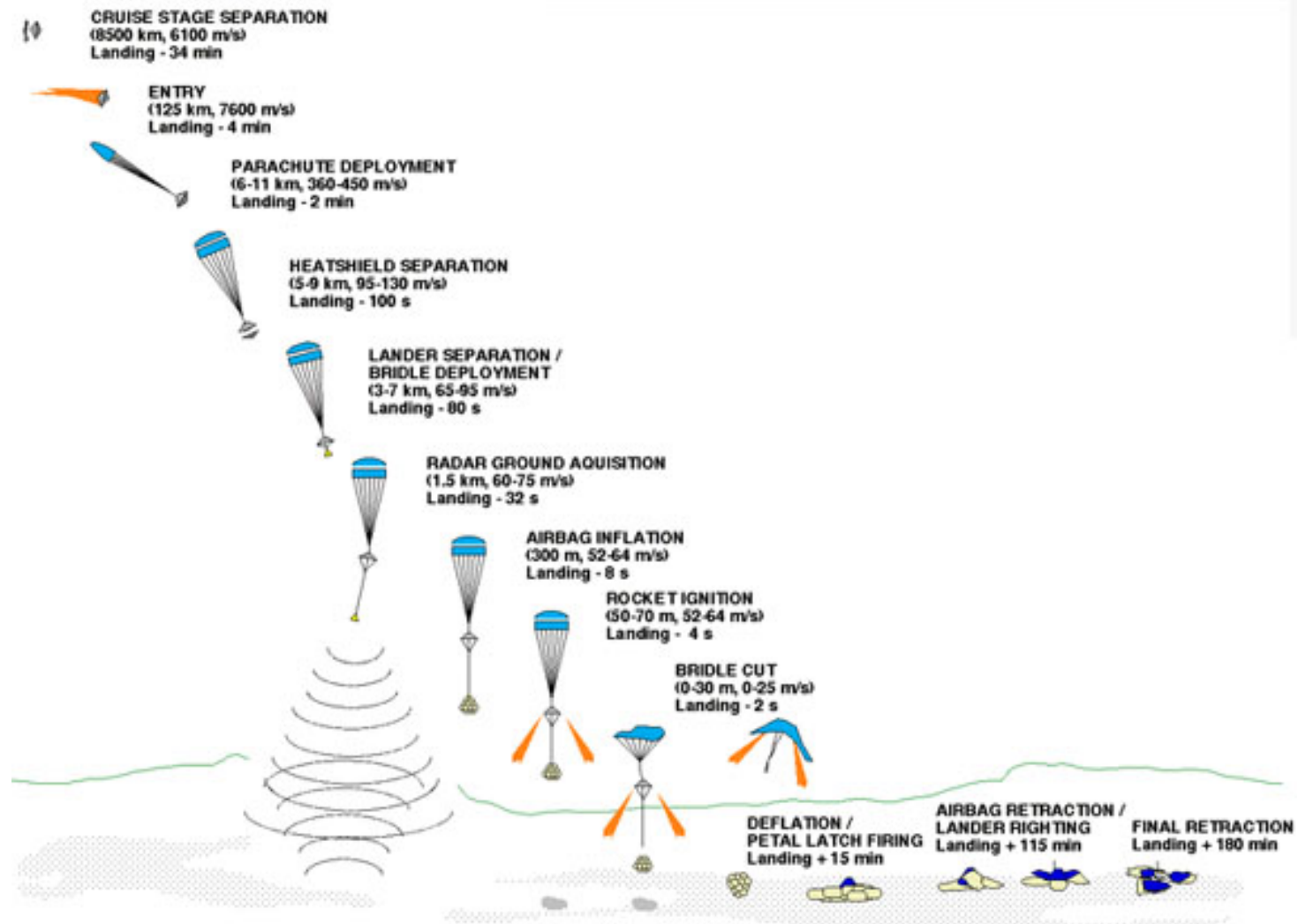
*gullies in sand
dunes*



south polar region



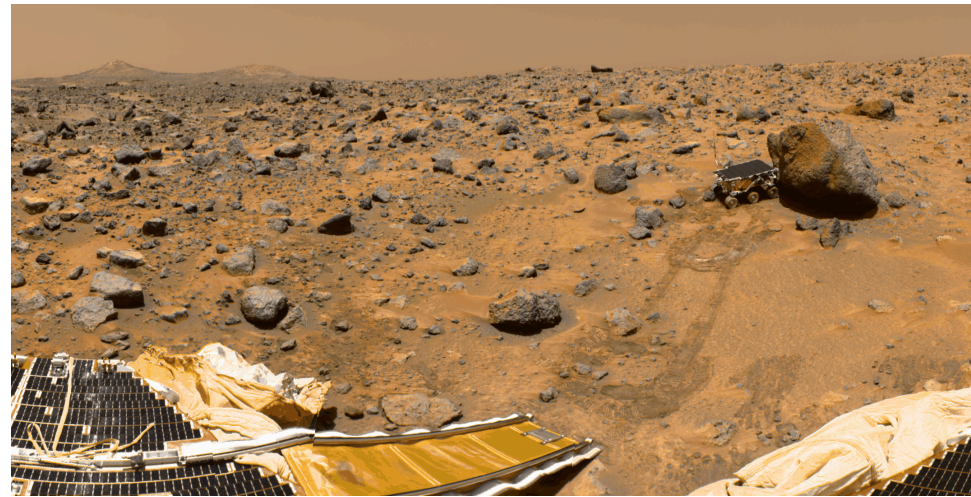
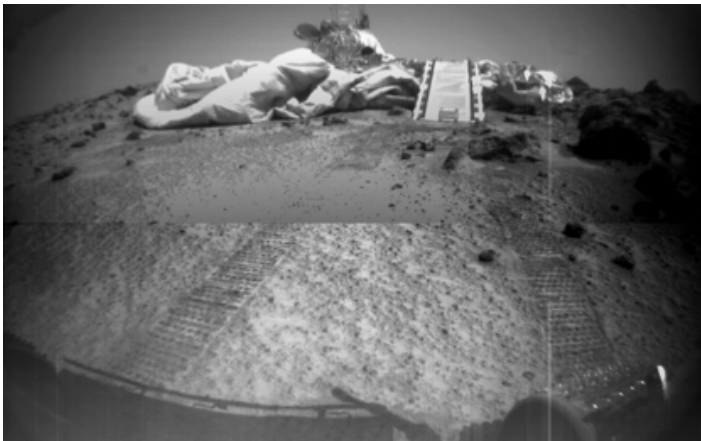
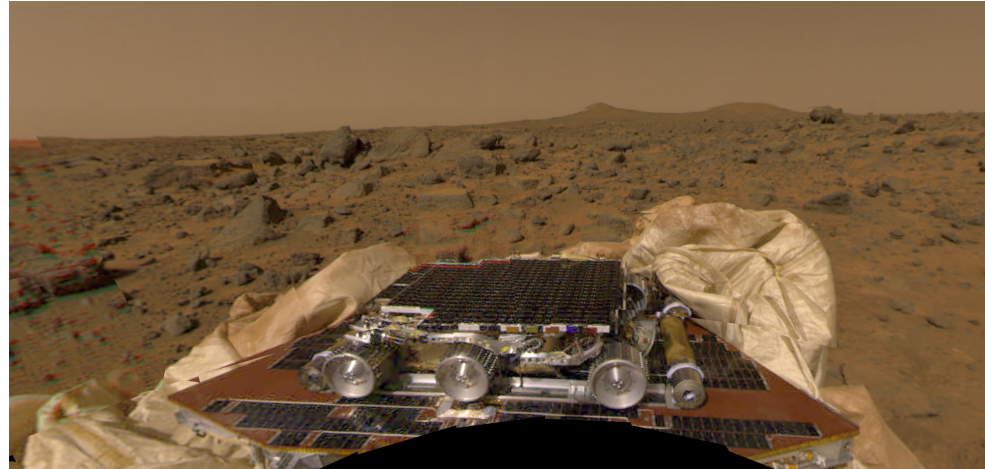
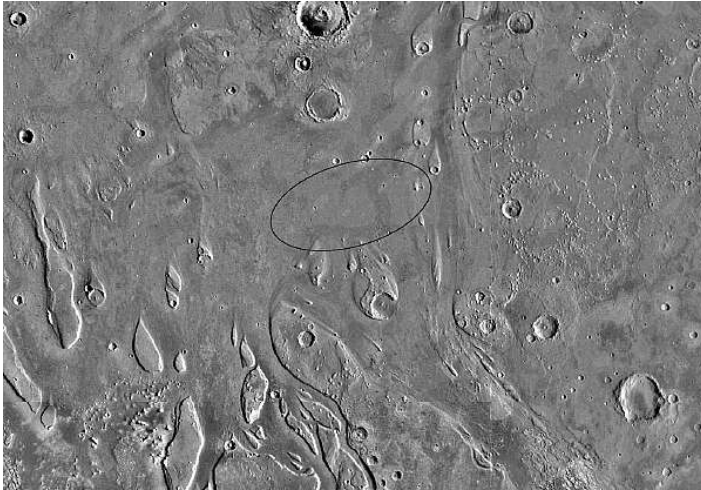
Mars Pathfinder



ROBIL 4.11.06

Airbag technology for landing

Landed in Ares Vallis, where
flowing water would deposit a
variety of rock types

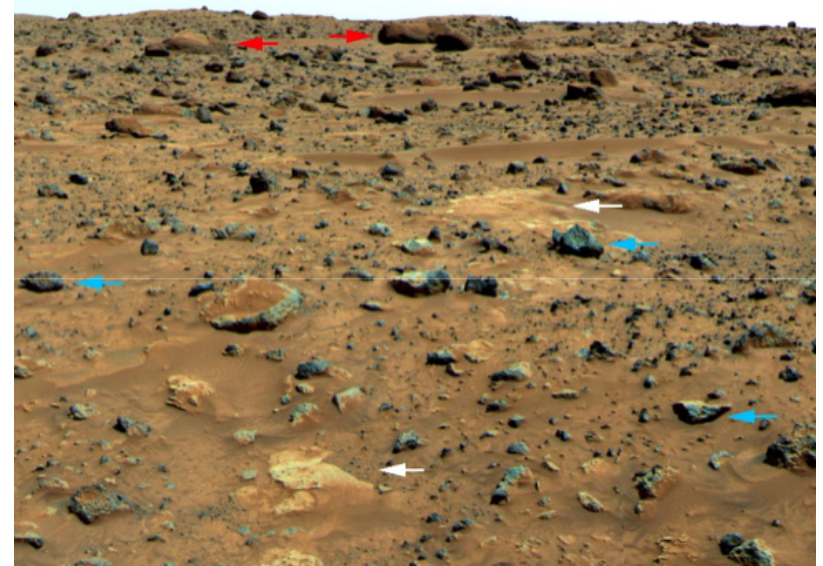


Carl Sagan Memorial Station,
as seen by rover Sojourner

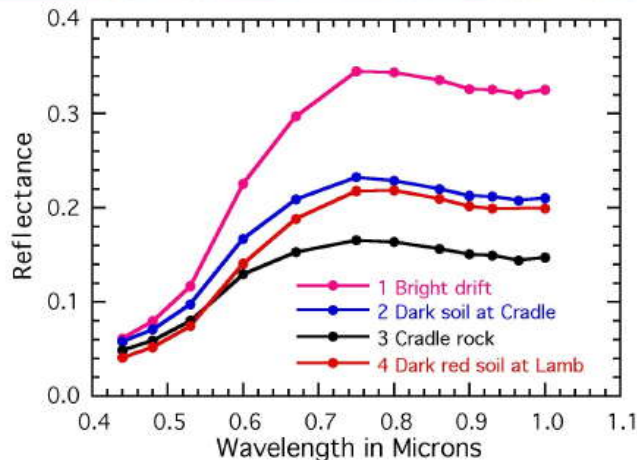
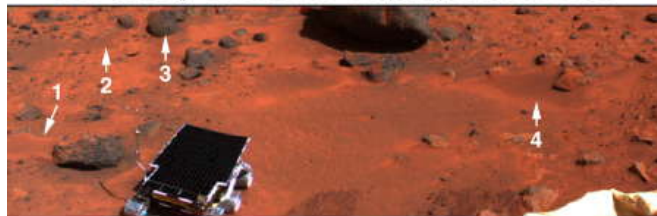
The *red* arrows - rocks believed to be rounded by the action or water in a flood.

Blue arrows - rocks with sharp points thought to come from impact craters or volcanic eruptions.

White arrows seem to be deposits left by evaporating water. - view from Sagan Station



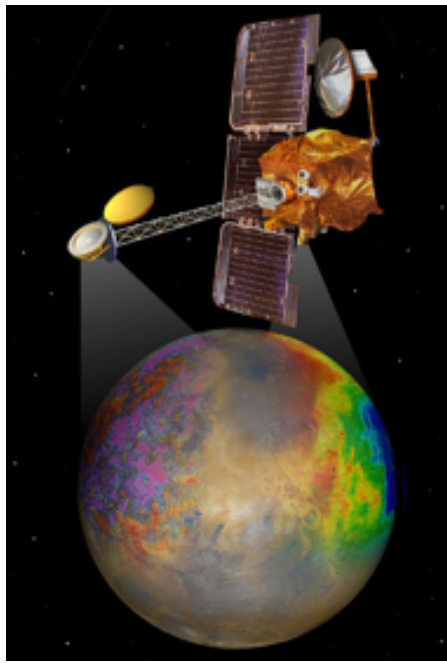
Diversity in Rover Deployment Area



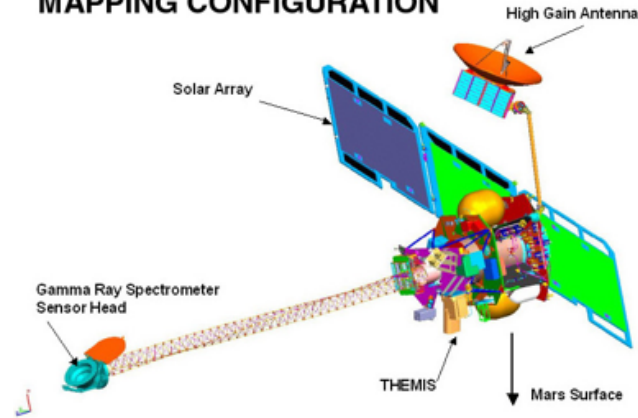
Sojourner inspecting a rock

Mark Watney and Pathfinder in "The Martian"



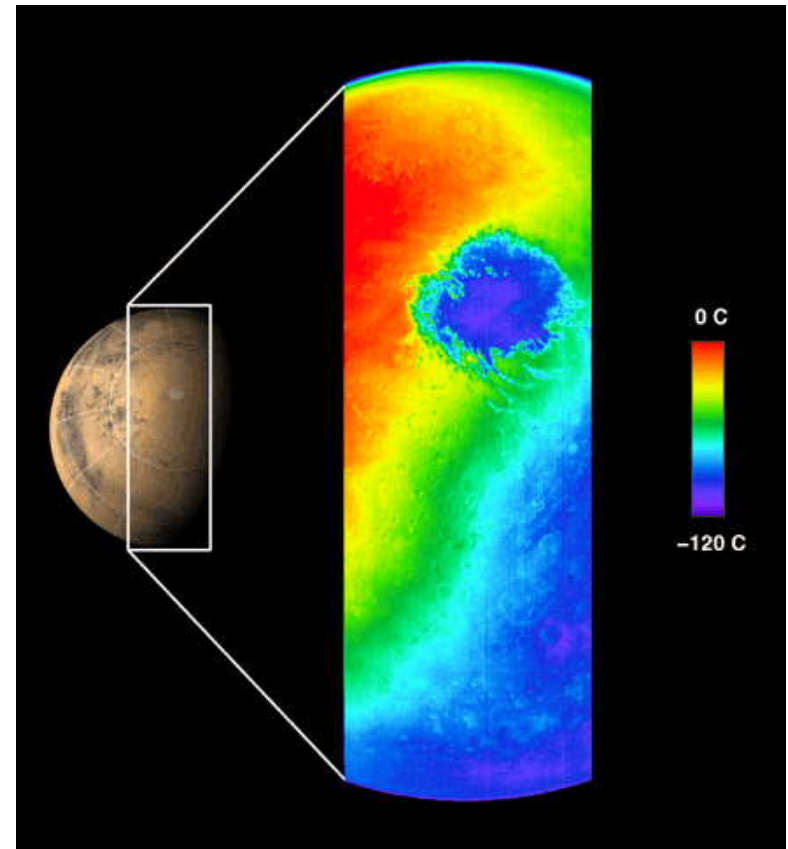


MAPPING CONFIGURATION

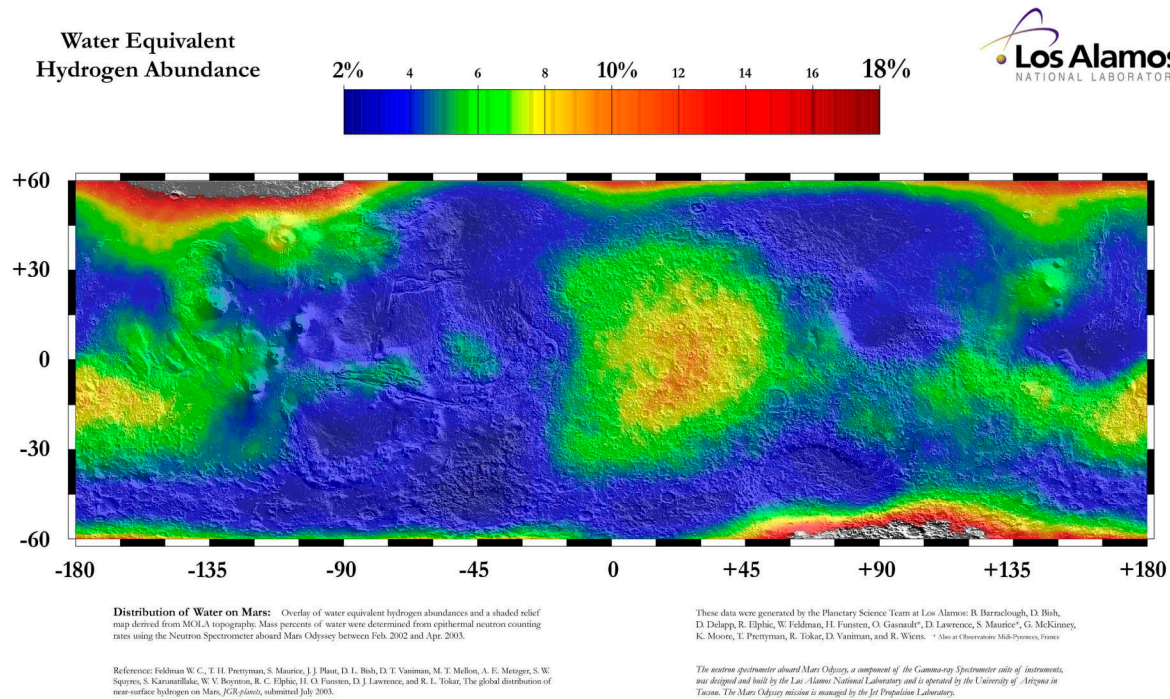


Mars Odyssey

Thermal Emission Imaging System ([THEMIS](#)). This imager combines 5 visible bands with 10 infrared bands. The wavelengths were chosen to be centered in various *diagnostic bands for minerals*. The spatial resolution is not as fine as the highest-resolution visible-light images of the MGS, but is superior to the IR mapper of MGS. *Looks for minerals forming in presence of water.*

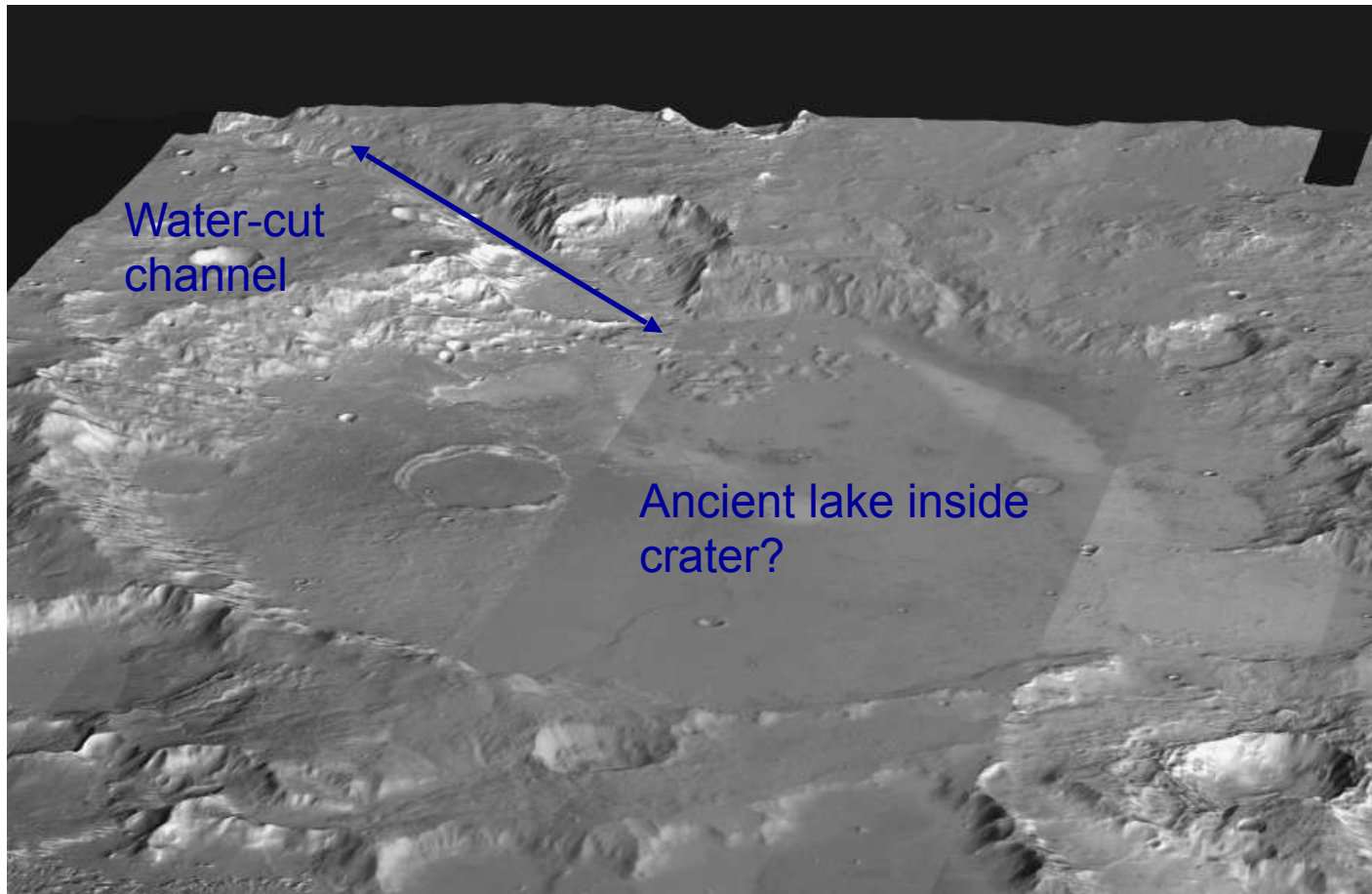


MO neutron spectrometer - detects H, inferred to be from H₂O



Mars Express (later) & Earth-based telescopes also find CH₄ (methane) in same regions! Usually associated with biological production, it may also be from non-biological sources.

THEMIS IR images of Gusev Crater draped over MGS topography data. Temperatures run from -45°C (black) to -5°C (white) and are due to differences in illumination.



Mars Exploration Rovers

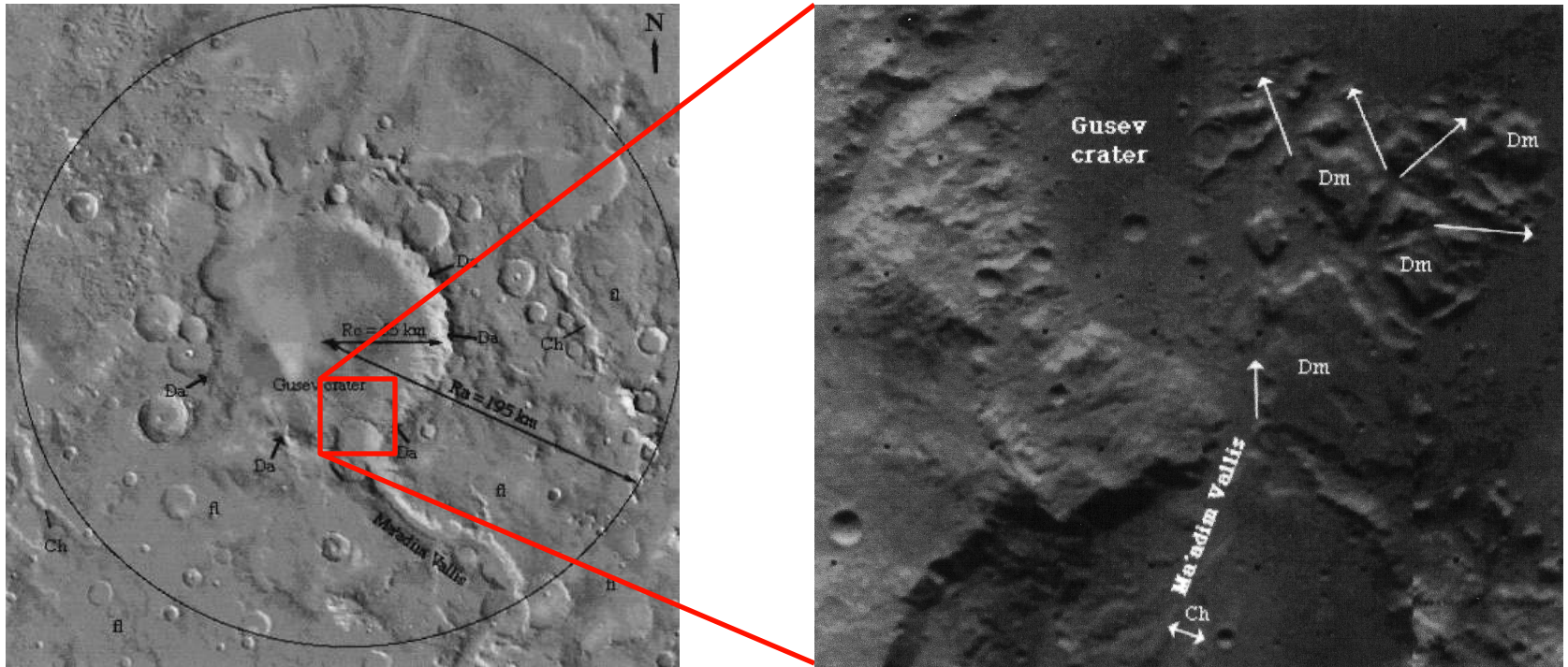


MER-A "Spirit"



MER-B "Opportunity"

Site Selection

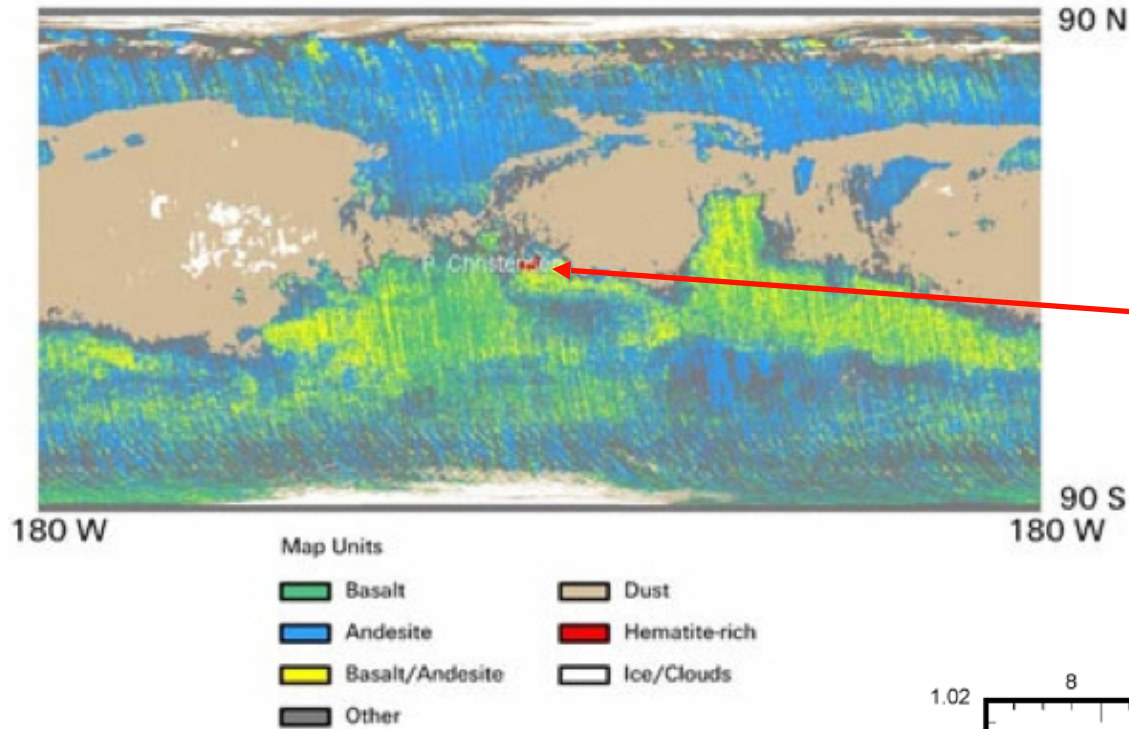


Gusev Crater - *physical* signs of water

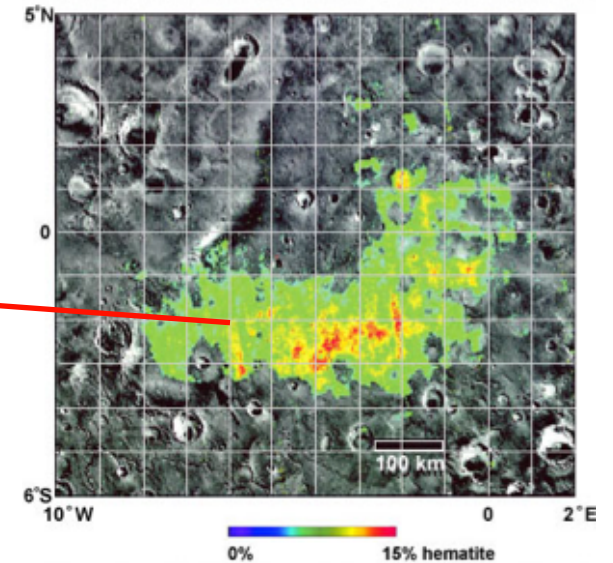
Target for "Spirit"

MER (and most other images) Courtesy NASA/JPL-Caltech

TES Geologic Map of Mars



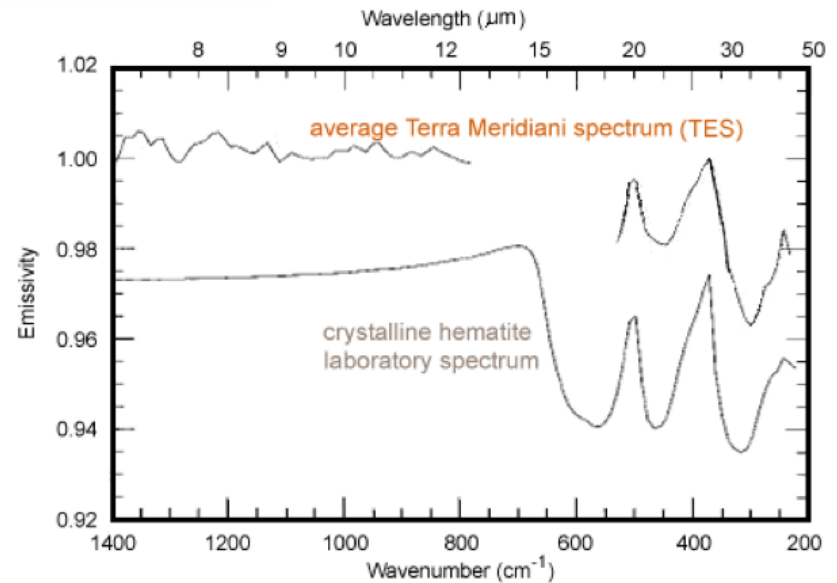
HEMATITE DISTRIBUTION MAP FROM TES DATA



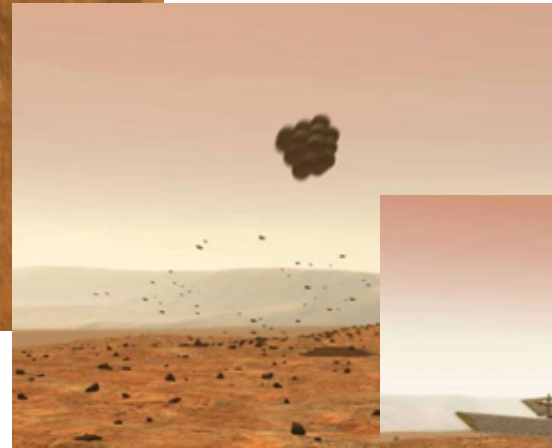
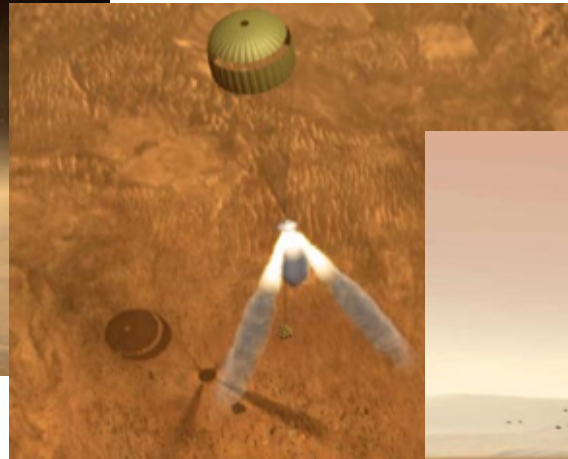
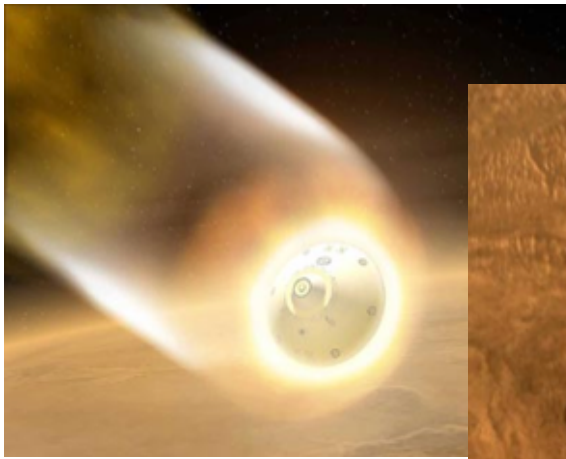
(Figure based on Christensen et al., (2001) JGR, v. 106(E10), Plate 2, p. 23,877.)

Meridiani Planum - *chemical* signs of water - **hematite usually forms in water**

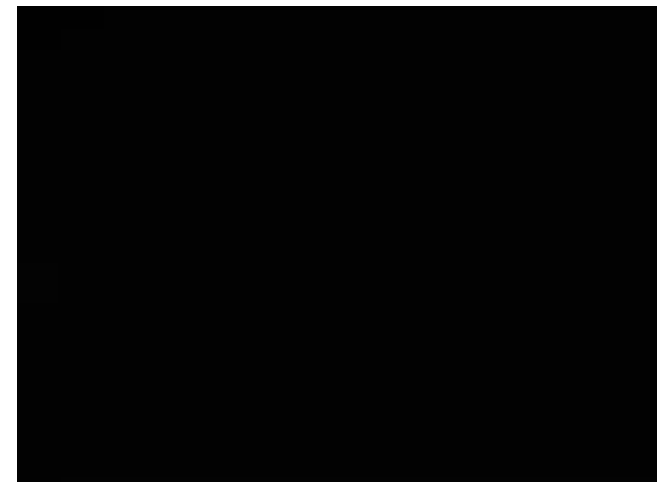
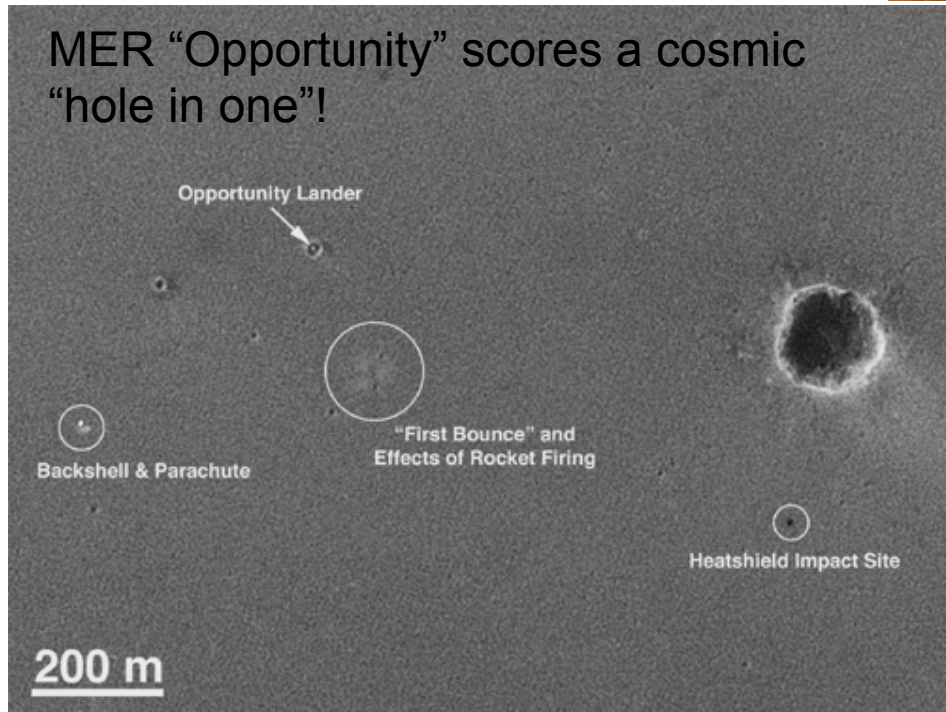
Target for “Opportunity”



(Figure based on Christensen et al., (2000) JGR, v.105(E4), Fig. 4, p. 9628.)

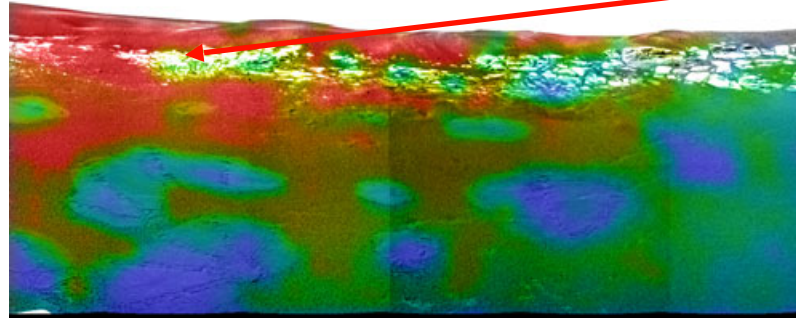
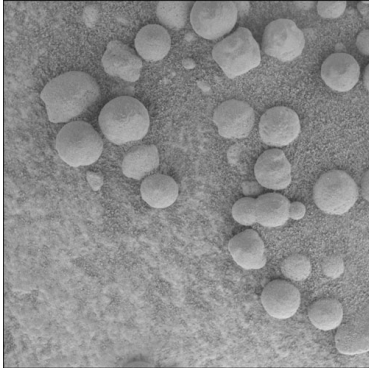


MER "Opportunity" scores a cosmic
"hole in one"!

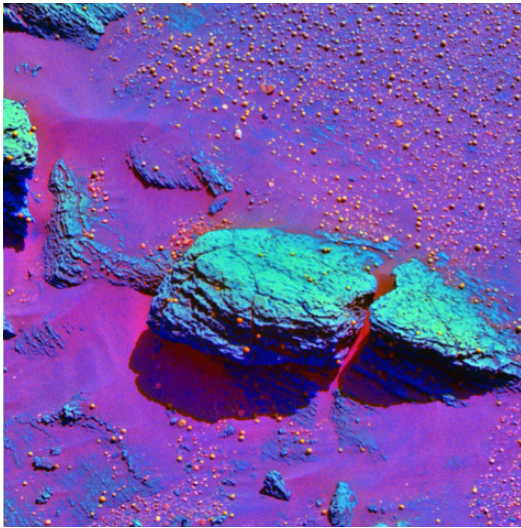


Immediate Success for Opportunity

“blueberries”



Spectral image
- red areas -
hematite



Spectral analysis indicated that blueberries were also made of hematite!!

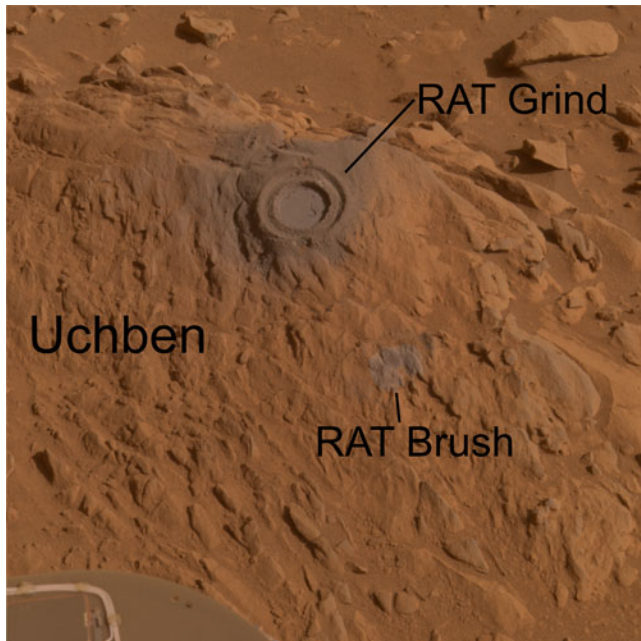
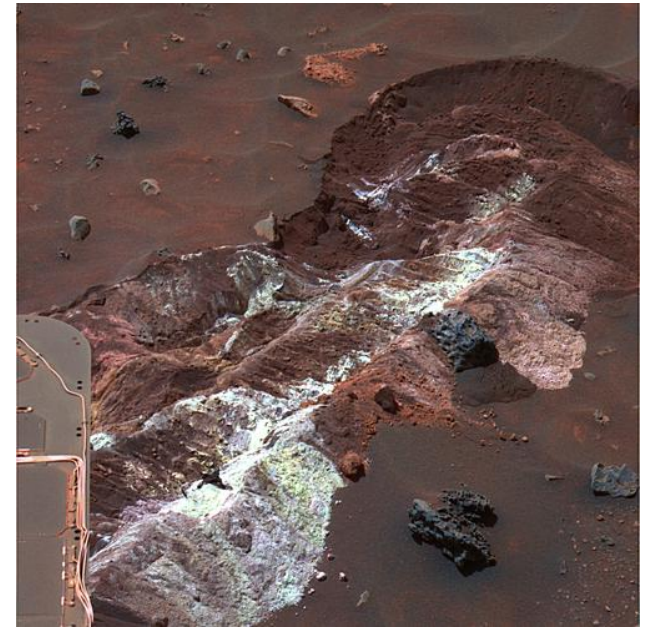
Also present - **sulfates** - salts that are usually produced as mineralized water evaporates!

BUT - olivine (silicate) present instead of carbonates....

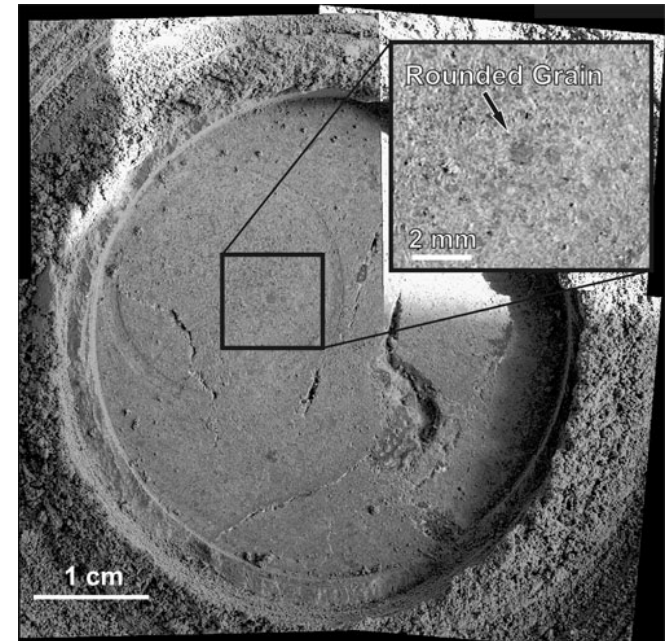


Salty material
“excavated” when
Spirit did a U-turn

Real (left) & false
color (right)

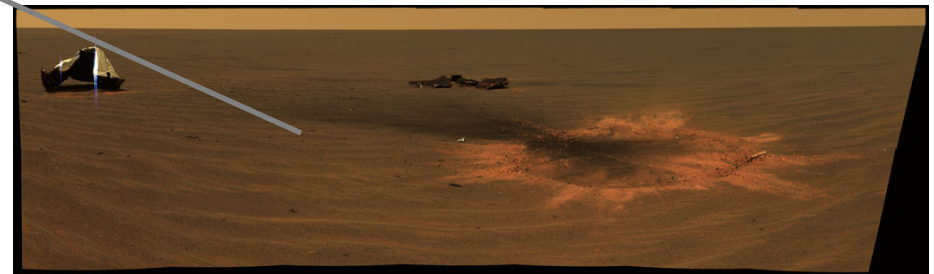
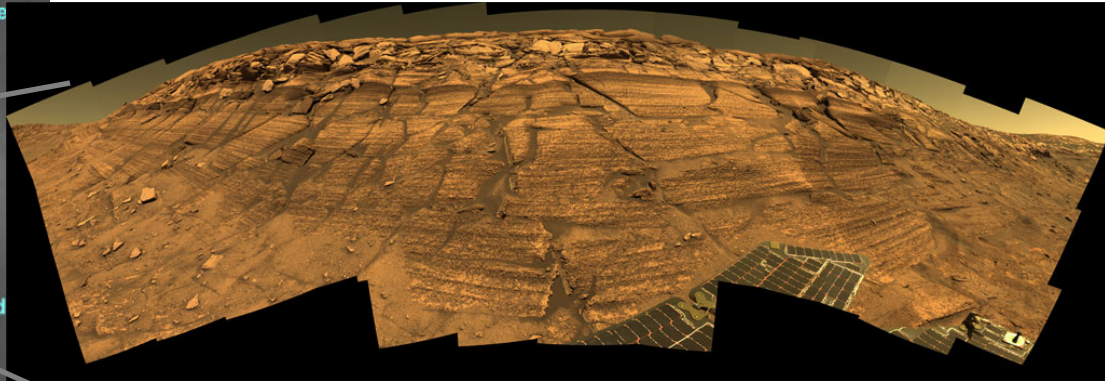
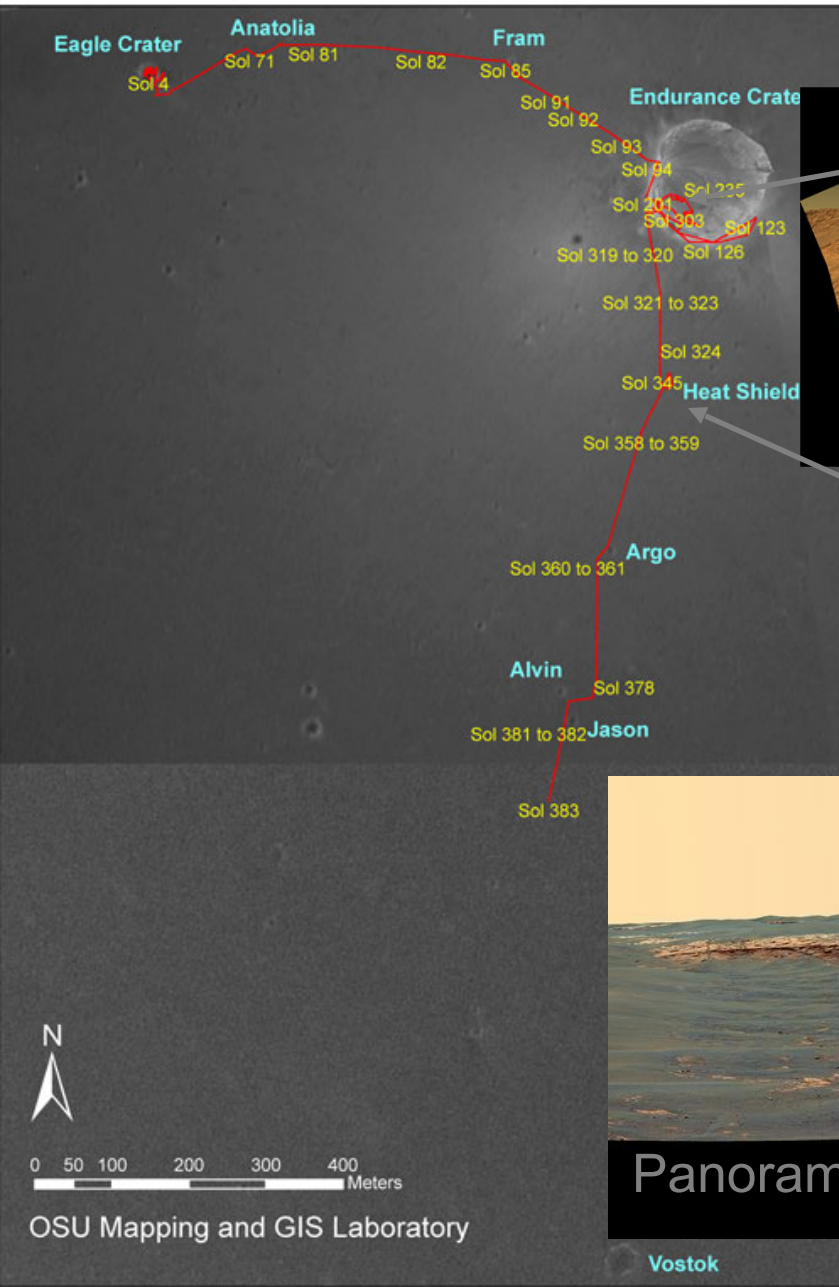


Brushing &
grinding to get
beneath the
surface



Opportunity Rover Traverse Map (Sol 383)

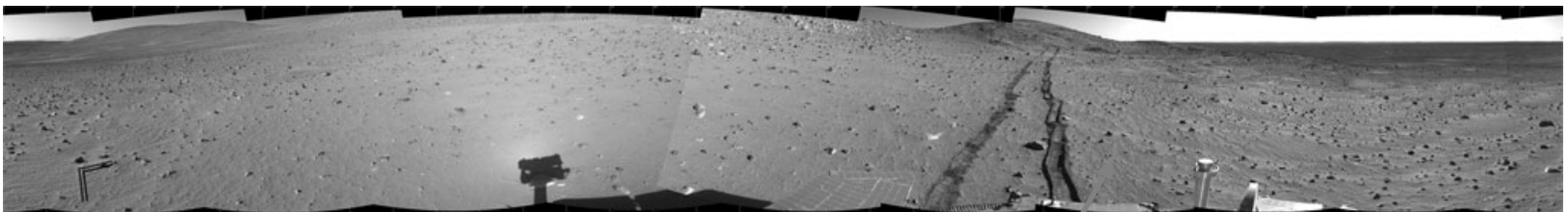
Burns Cliff in Endurance Crater



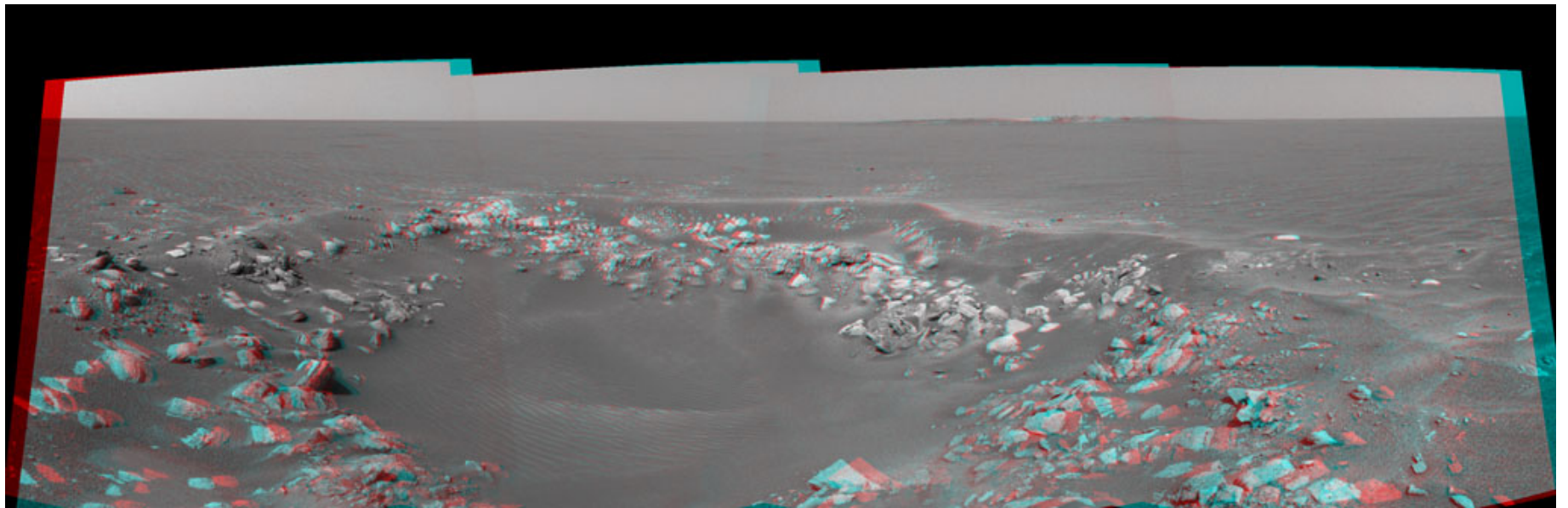
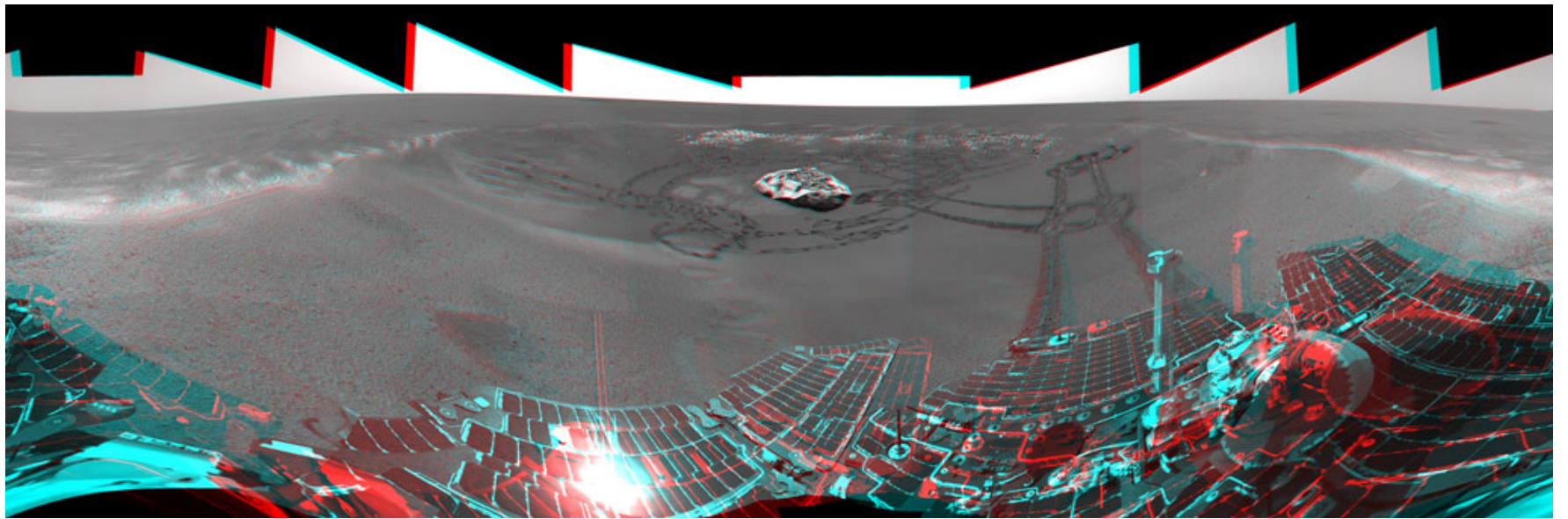
Panorama by Opportunity - Sol 744

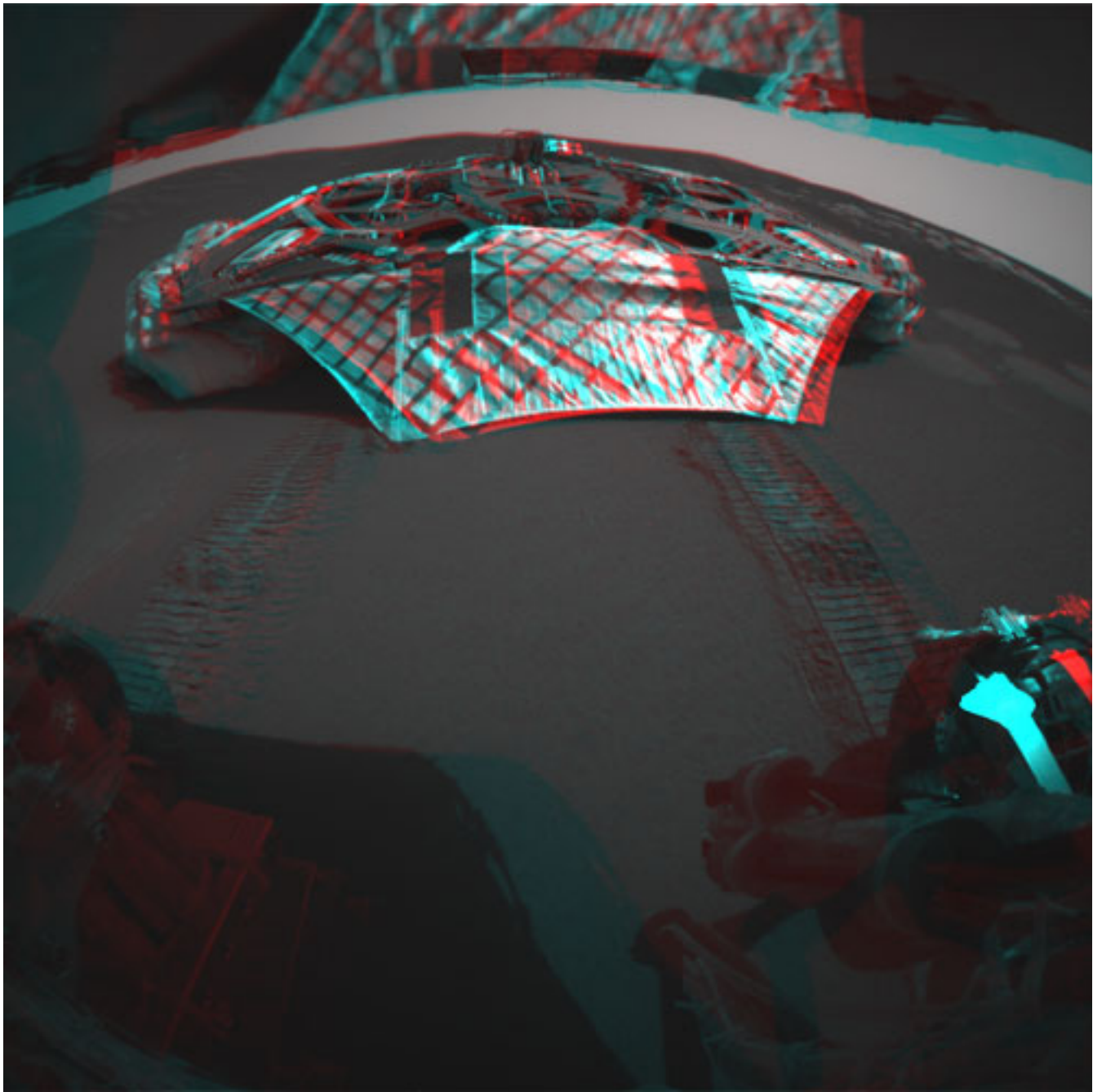
Vostok

Trying to cross sand dunes can be tough!

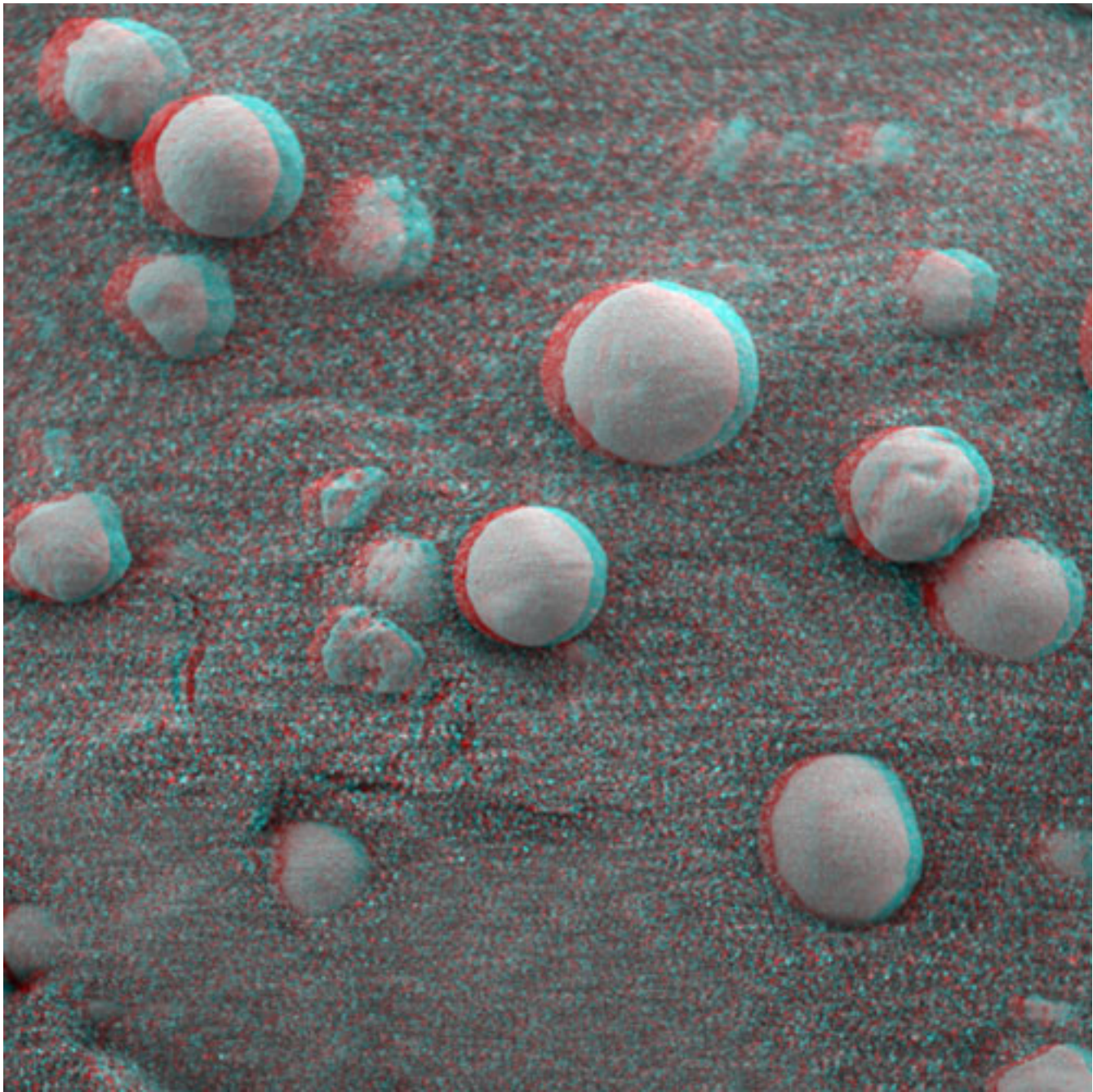


Spirit developed a stuck front wheel & had to drive backwards while dragging the immobile wheel behind!





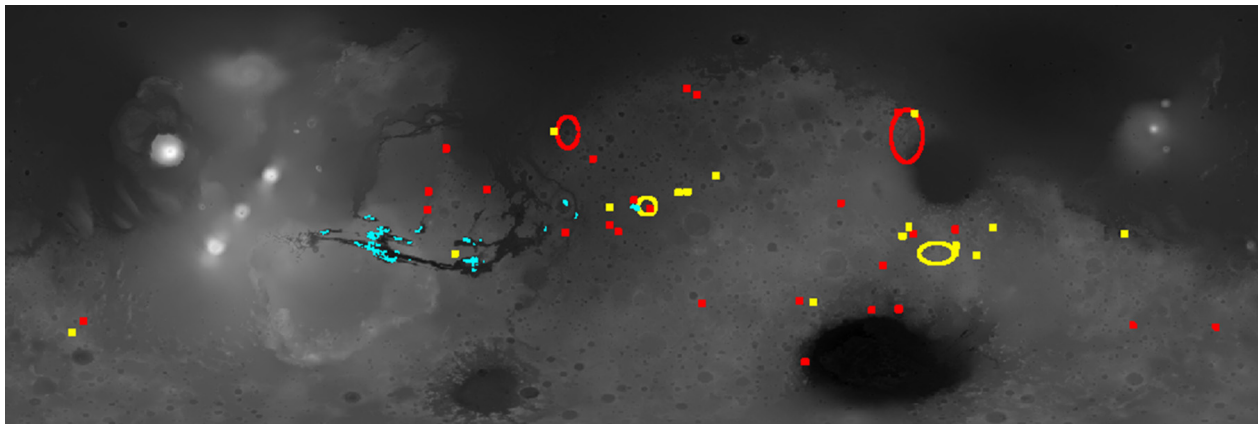
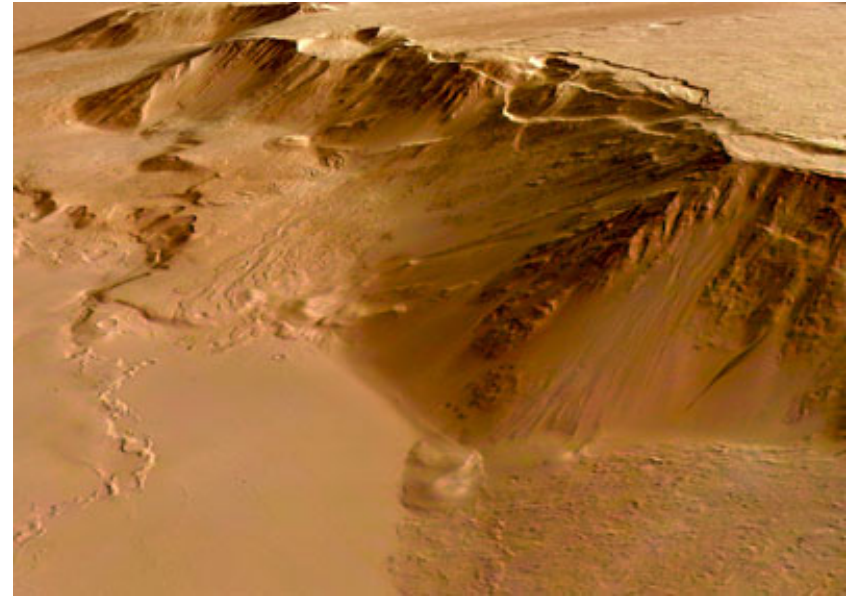




Summary-

Mineral deposits (hematite, sulfates, etc) as well as physical formations all point to the existence of liquid water some time in the past

Mars Express (great stereo imaging!)



red - hydrated silicates blue - sulfates yellow other hydrated minerals

Types-

“Nadir” (standard views from above)

Perspective” reconstructed to appear as viewed from a more oblique angle

“3D anaglyph” views where the 2 stereo images are color-coded to be viewed with “3D glasses”.



nadir



perspective



3D

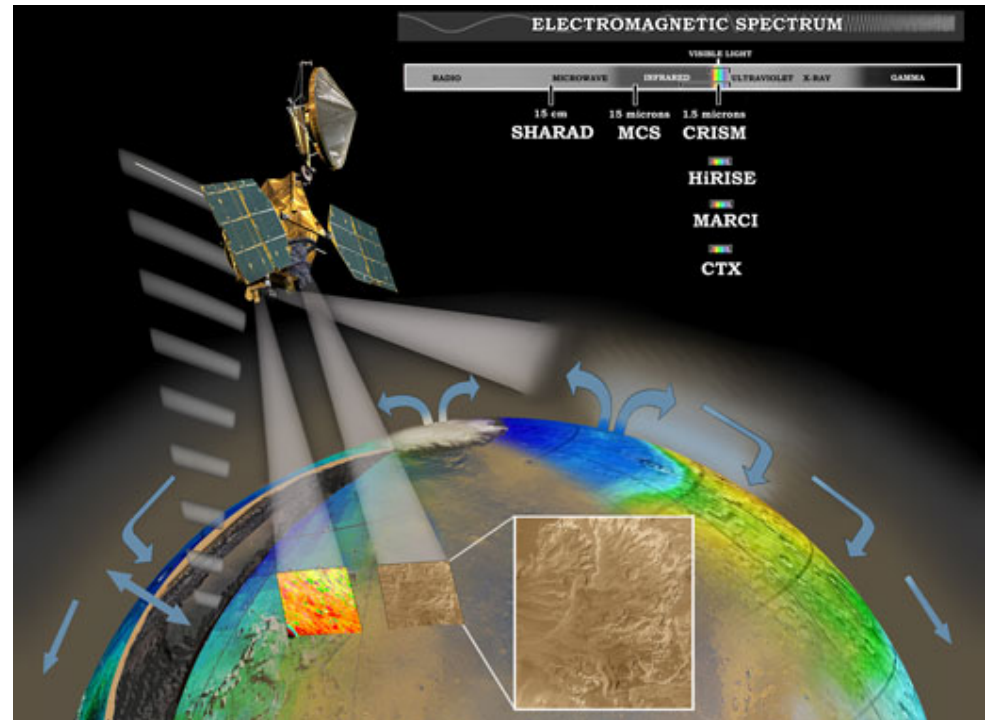
Mars Reconnaissance Orbiter

Higher data transmission rate than all others before

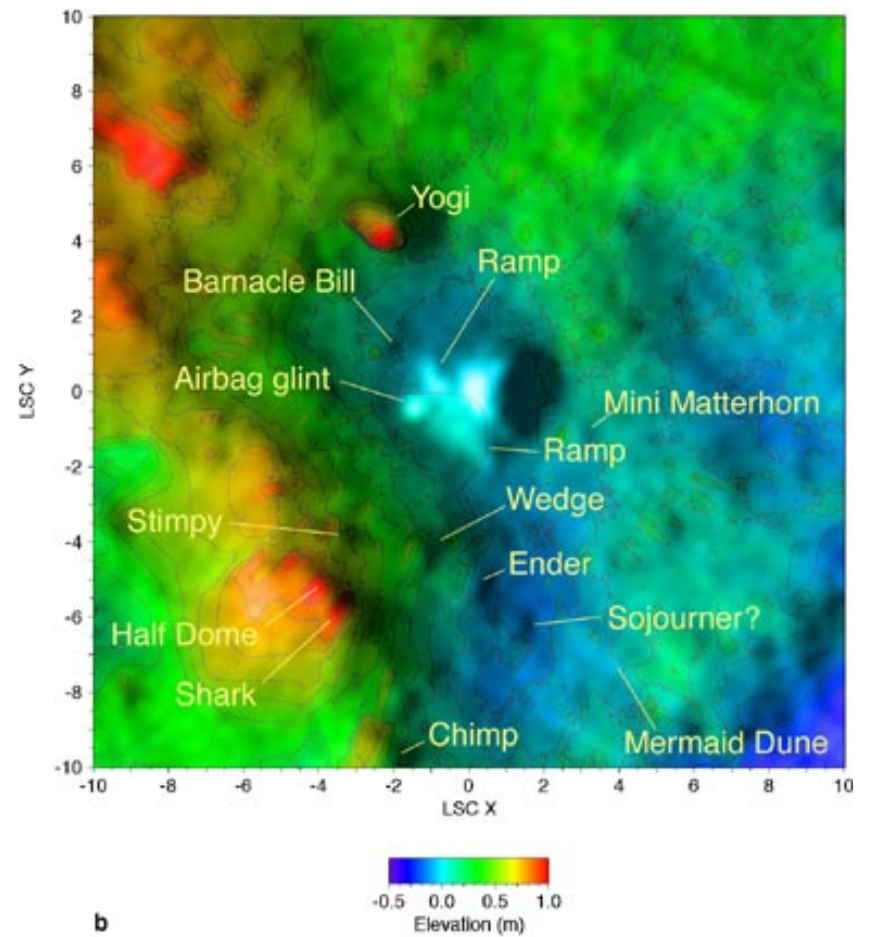
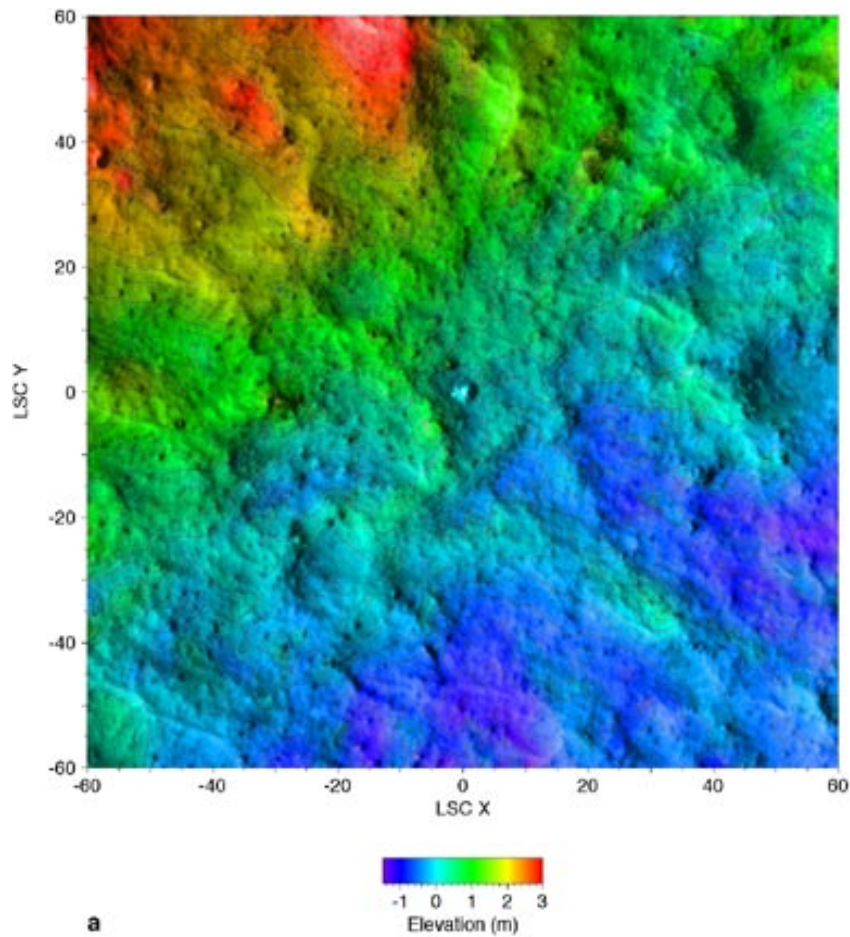
Very high resolution cameras

Improved imaging spectrometers - minerals

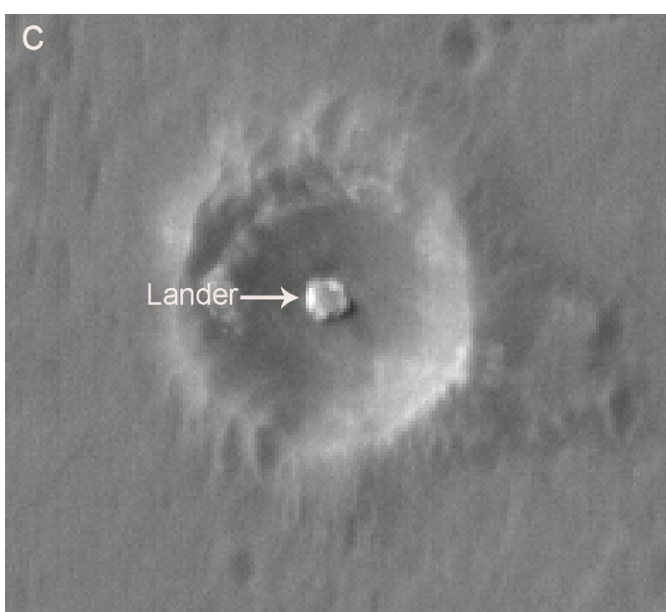
Radar penetration of surface to find ice



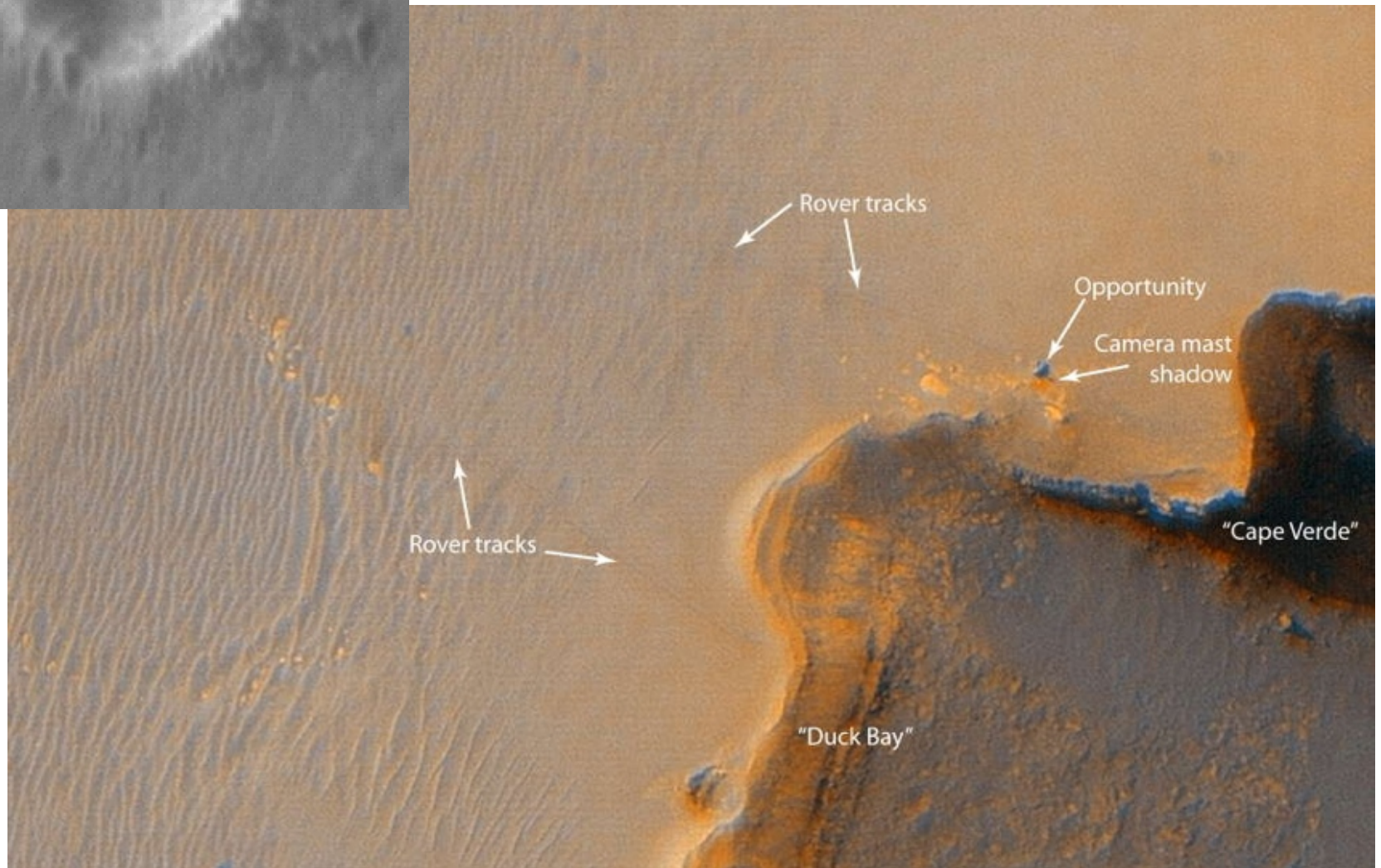
MRO view of Pathfinder Site



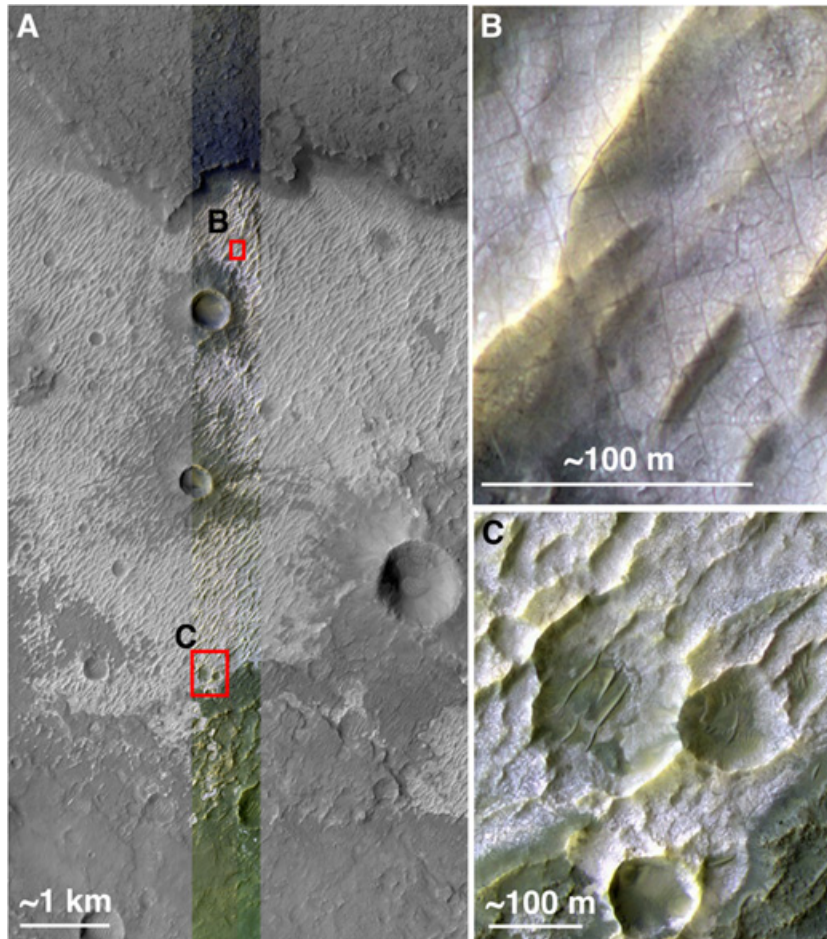
C



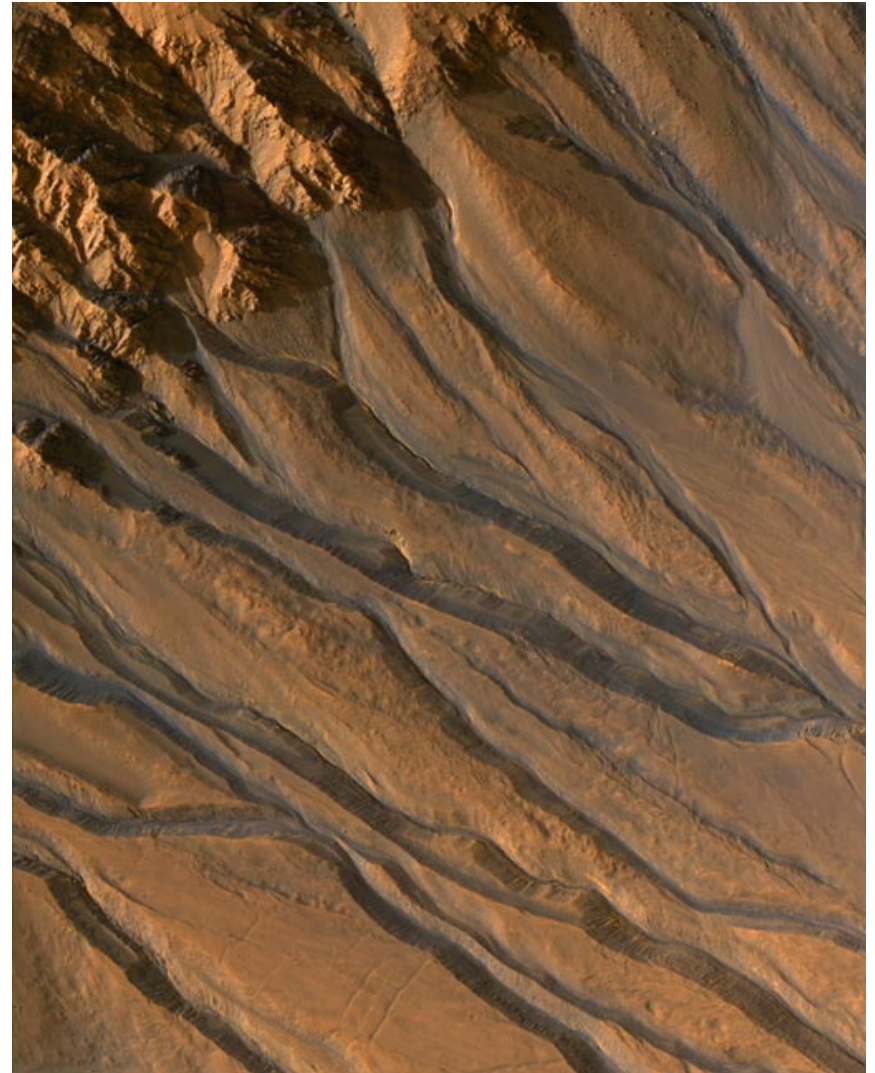
MRO views of Opportunity

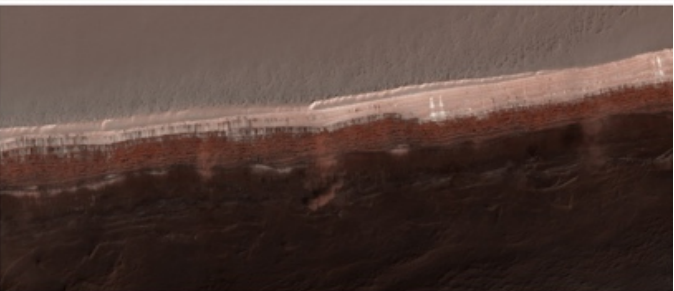


Chloride Salt Deposits



Gullies - Cut by Water?





"Ingrid's
Avalanches" 2008 Feb 19

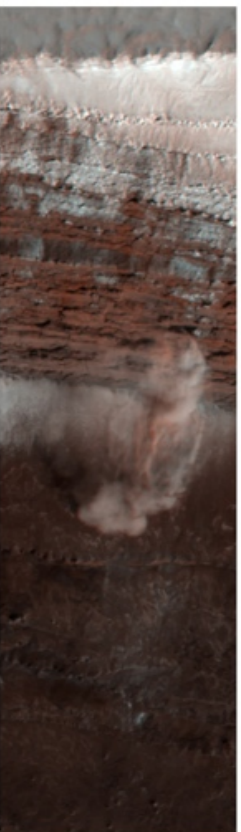


83.7N 235.8E

PSP 007338 2640

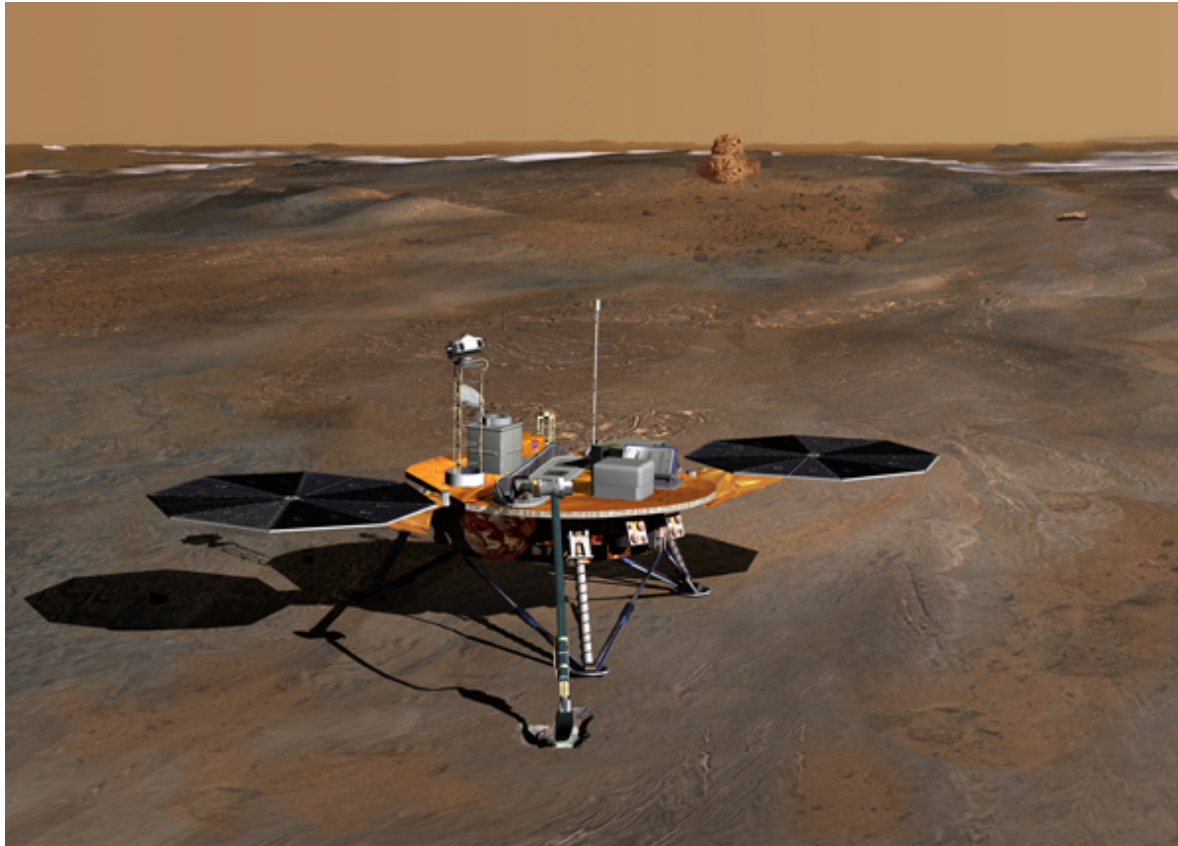


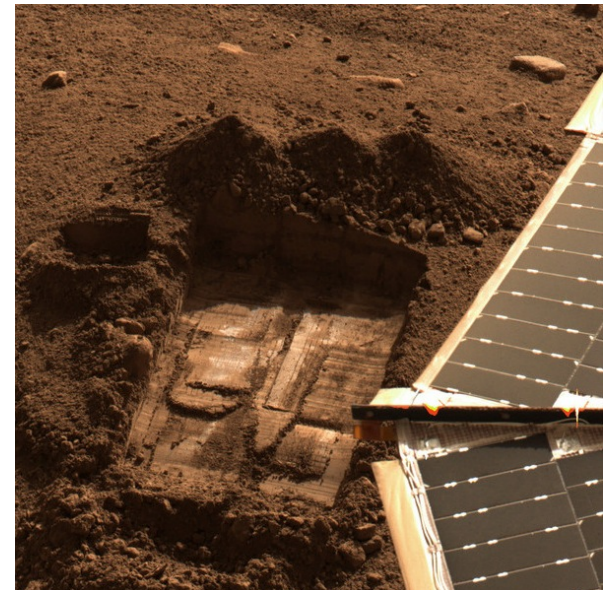
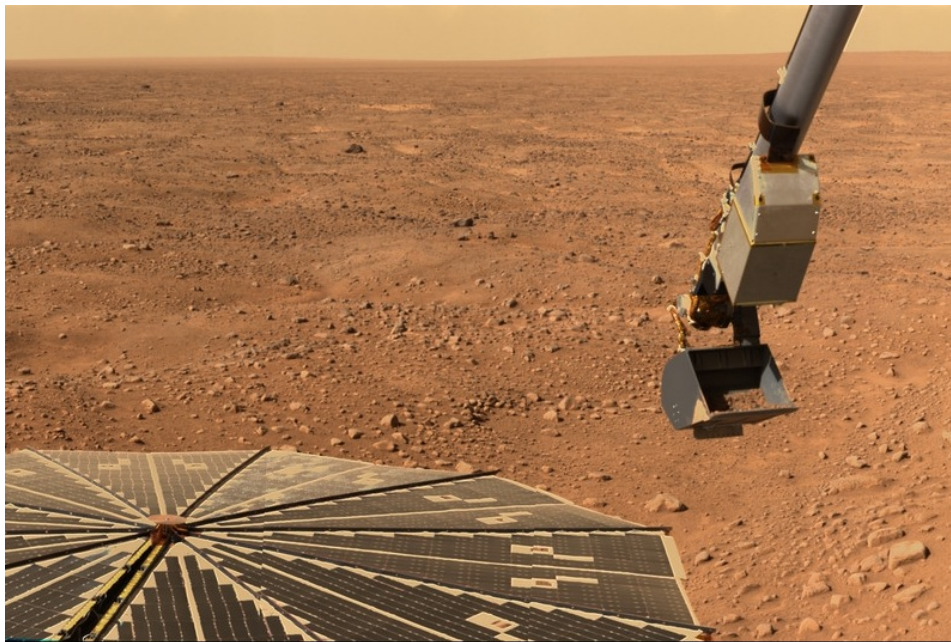
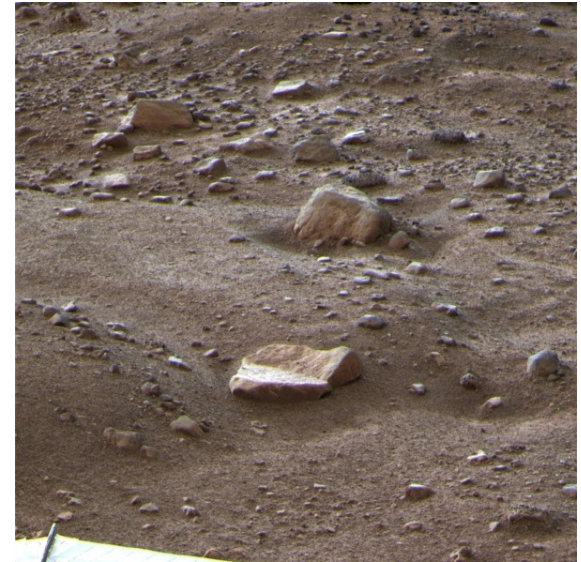
Avalanche!



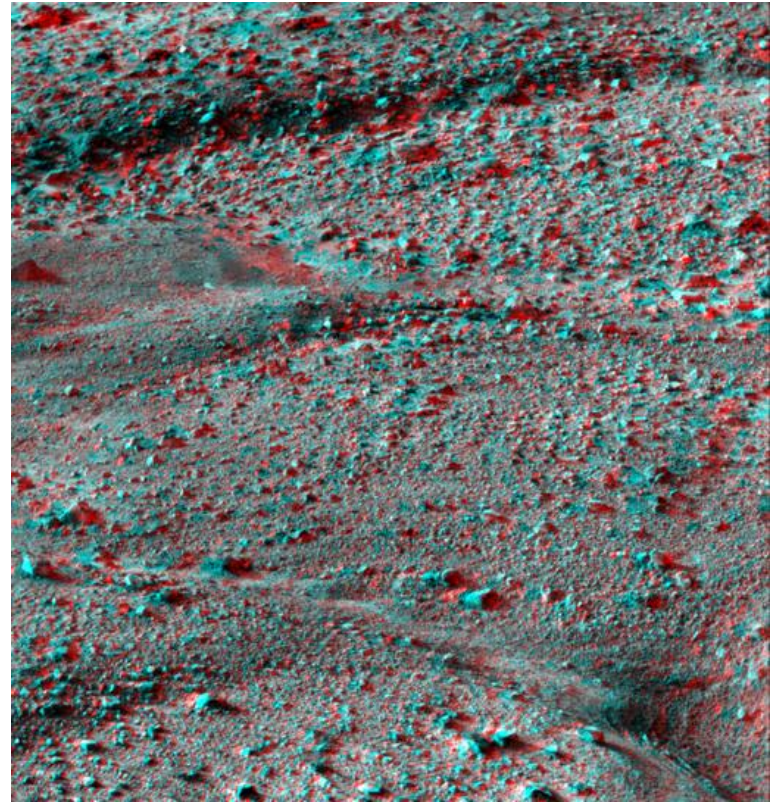
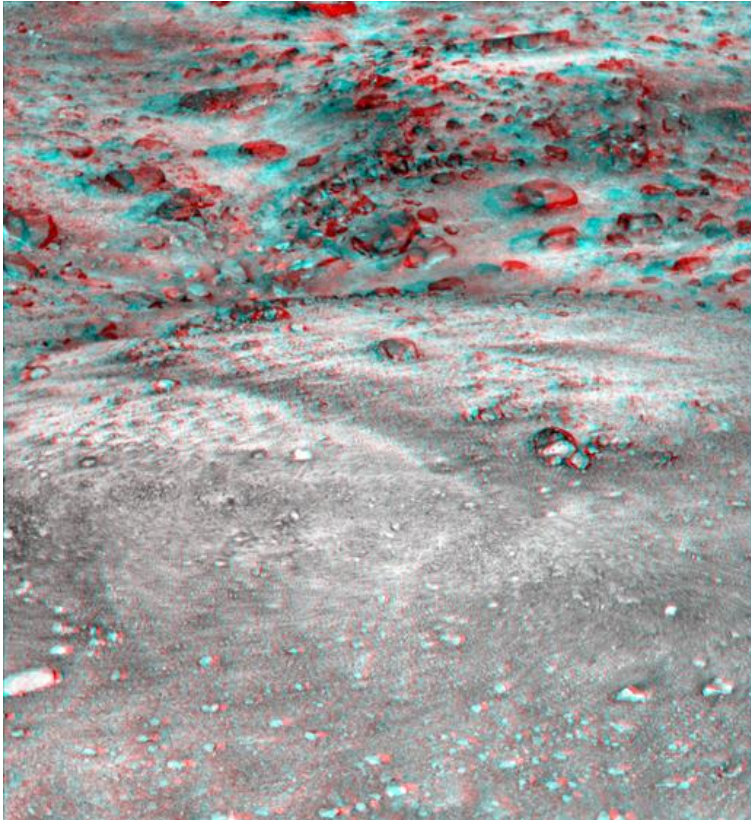


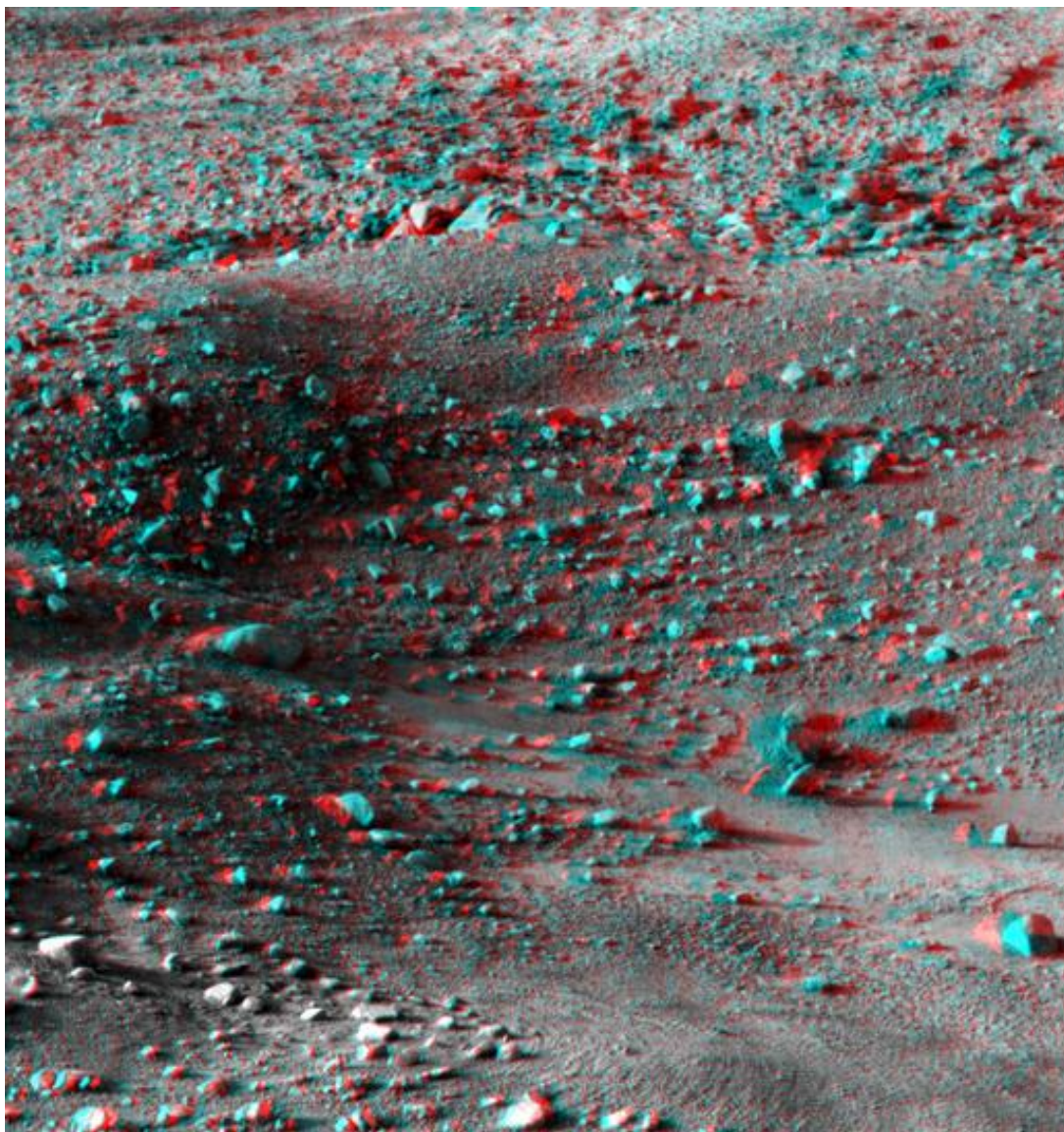
[NASA's Phoenix Mars Lander](#), landed on May 25, 2008 on the North Polar Cap





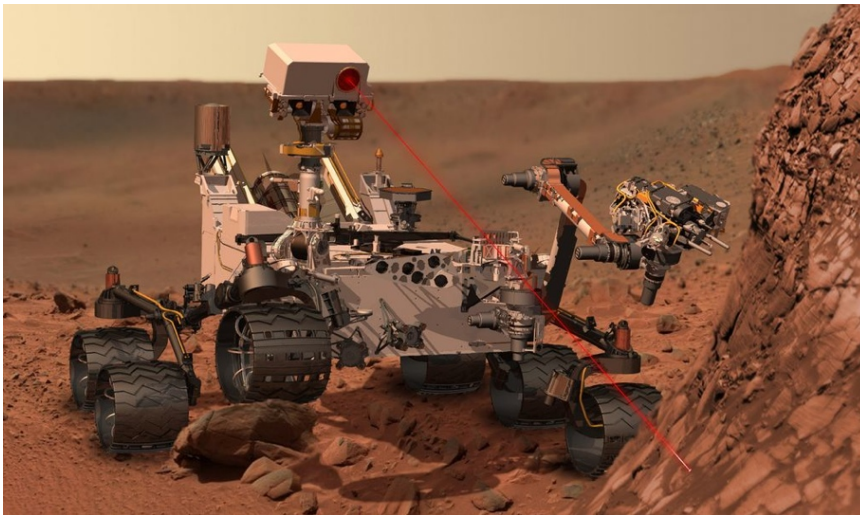
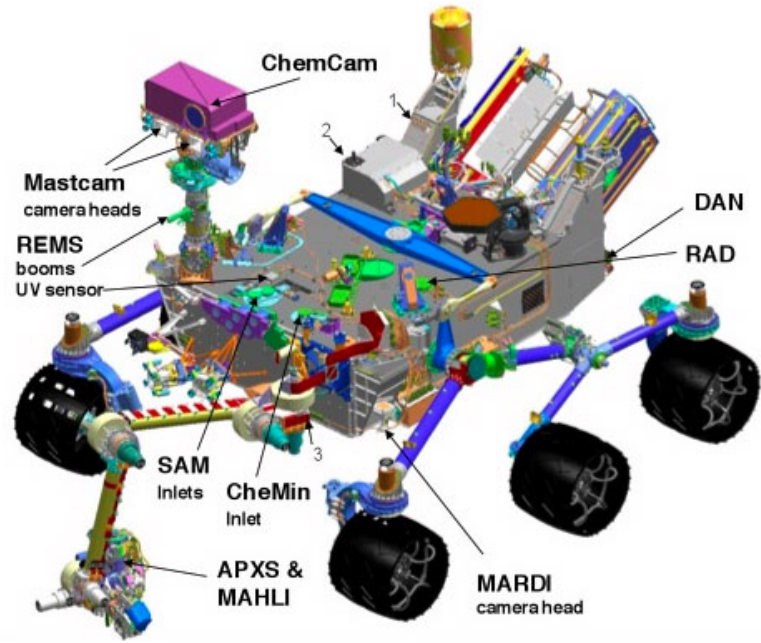
3D!!





Mars Science Laboratory

“Curiosity” lands on Mars August 2012



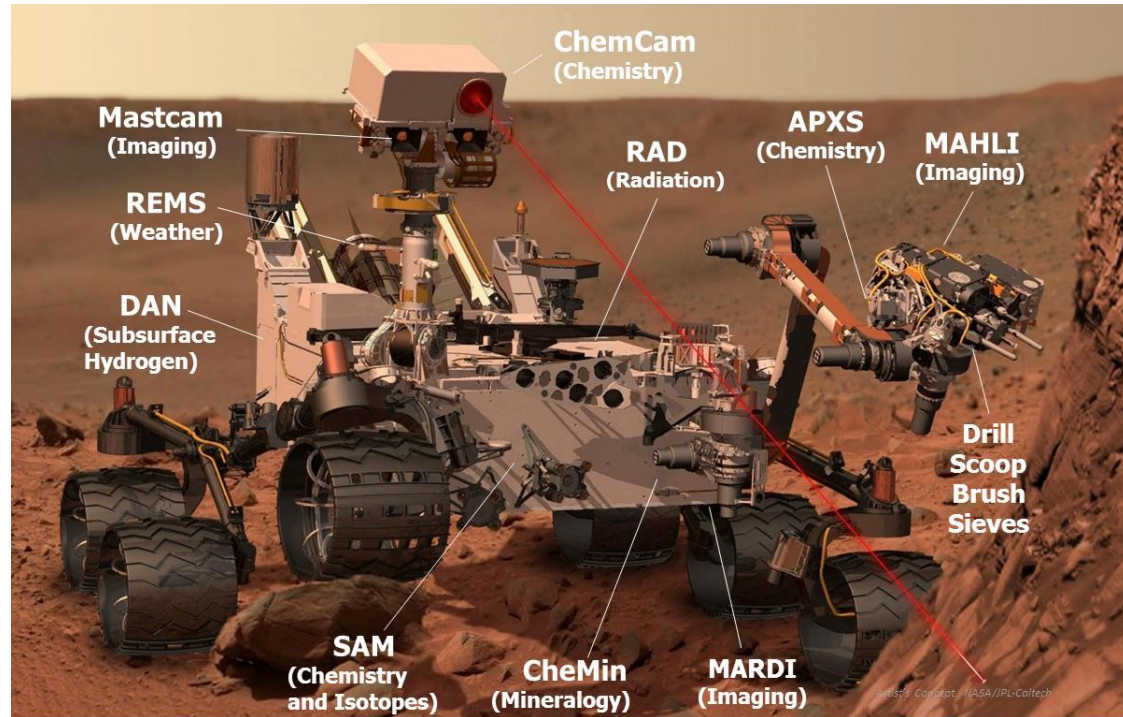
Find out more at:

<http://marsprogram.jpl.nasa.gov/msl/>

Instruments

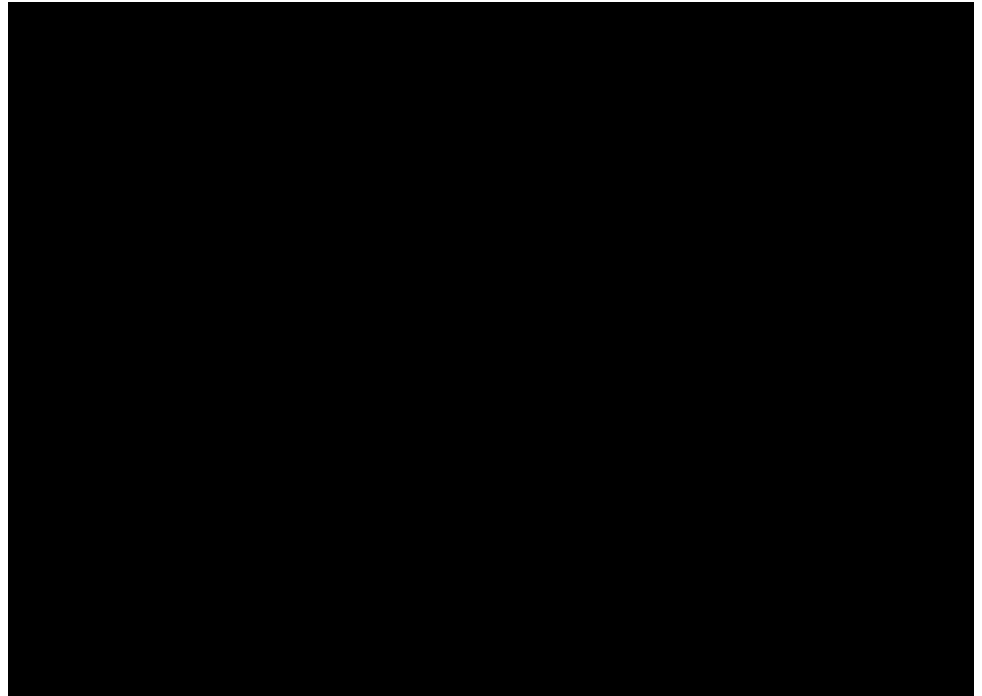
Mast Camera (Mastcam)
Mars hand Lens Imager (MAHLI)
Mars Descent Imager (MARDI)

Alpha Particle X-Ray
Spectrometer (APXS)
Chemistry & Camera
(ChemCam)
Chemistry & Mineralogy X-ray
Diffraction/X-ray Fluorescence
Instrument (CheMin)
Sample Analysis at Mars (SAM)
Instrument Suite

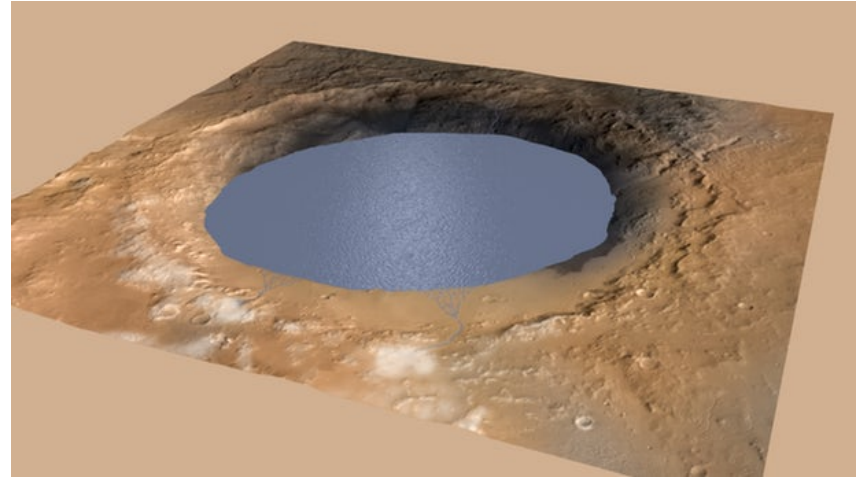
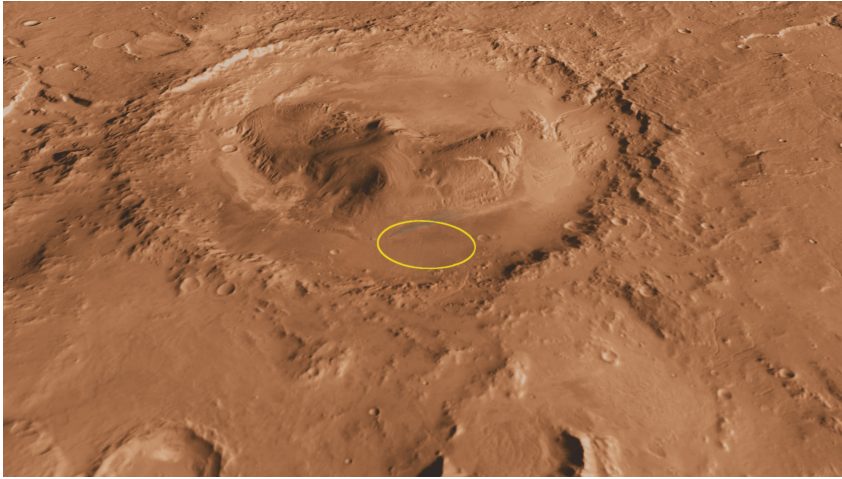


<https://marsprogram.jpl.nasa.gov/msl/>

Landed using a "Sky Crane"!!



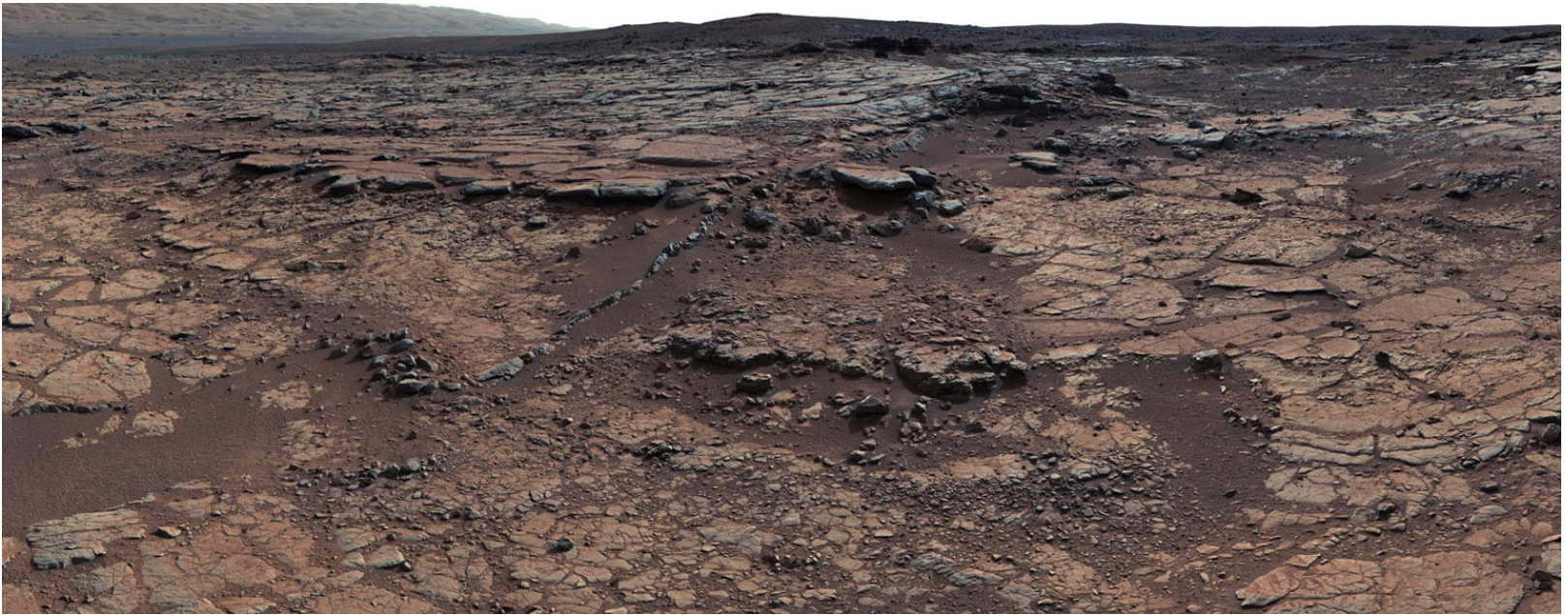
Landing Site - Gale Crater & Sharp Mountain



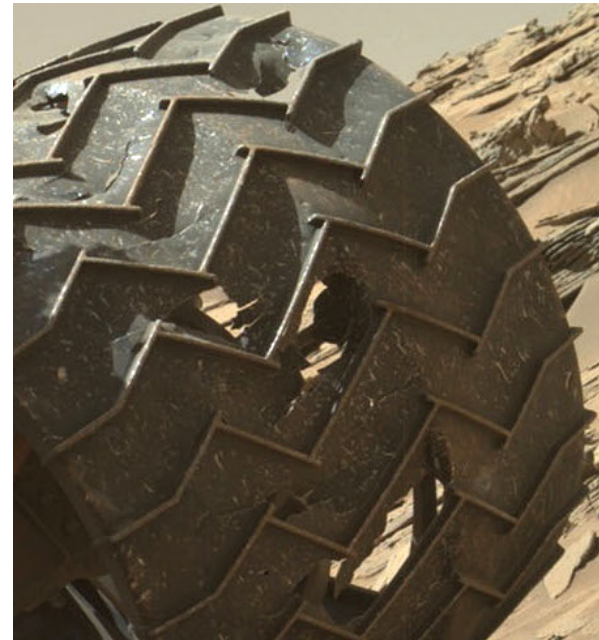
Formerly a lake???

Nice video of "the plan"

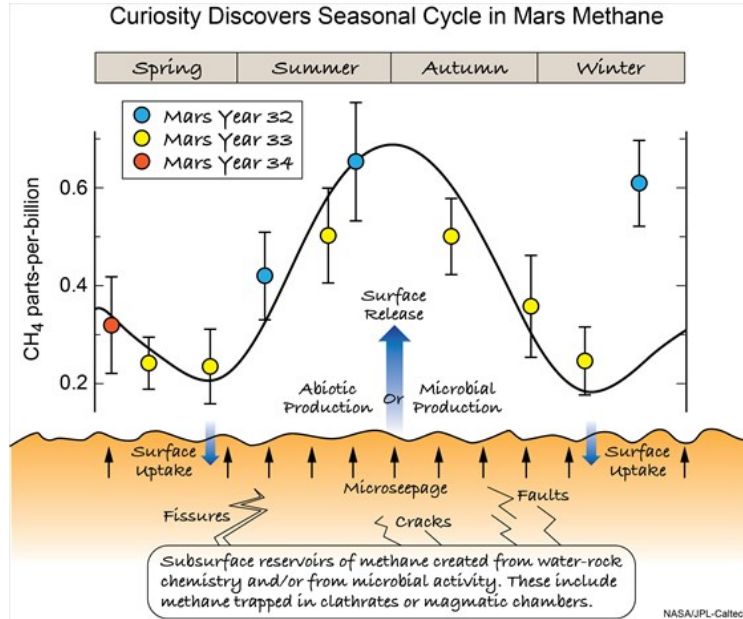
<https://youtu.be/qrxvbRA2xCI>



Some areas are very hard & rough, causing damage to the wheels.



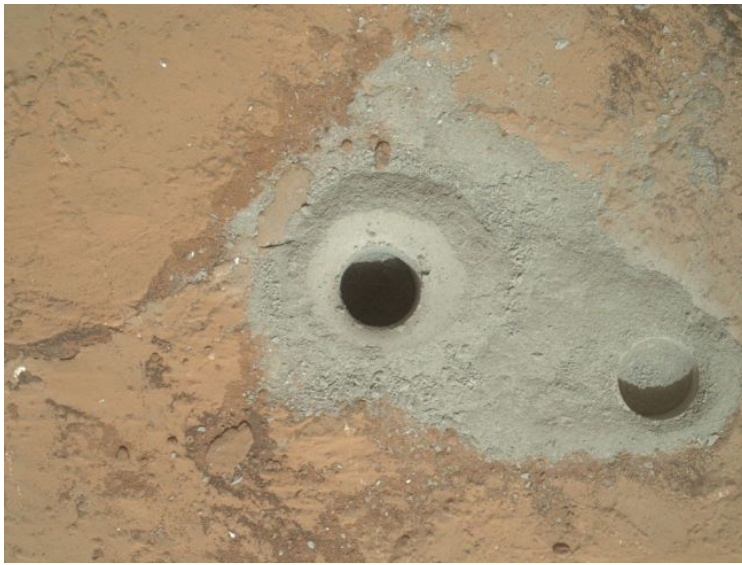
Some Major Discoveries



Methane - often associated with life, it is uncertain if this is anything but "natural leakage"

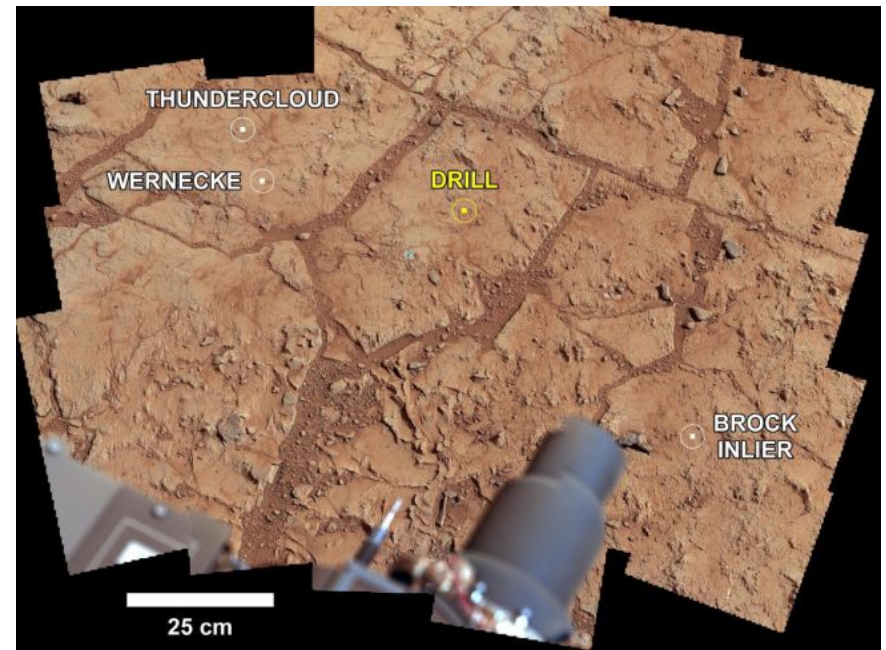
Finding an ancient stream bed. Knee-deep for thousands of years at a time?





Deep drilling to see what it was like maybe billions of years ago?

"Curiosity spotted some of the key chemical ingredients for life in the gray powder it drilled out of the John Klein rock, including sulfur, nitrogen, hydrogen, oxygen, phosphorus and carbon. The fine-grained rock also contains clay minerals, suggesting a long-ago aqueous environment — perhaps a lake — that was neutral in pH and not too salty, researchers said."



<https://www.space.com/20396-mars-rover-curiosity-big-discoveries.html>

Experience Curiosity

An interactive web page

<https://eyes.nasa.gov/curiosity/>

Find out more at:

[http://marsprogram.jpl.nasa.gov/
msl/](http://marsprogram.jpl.nasa.gov/msl/)

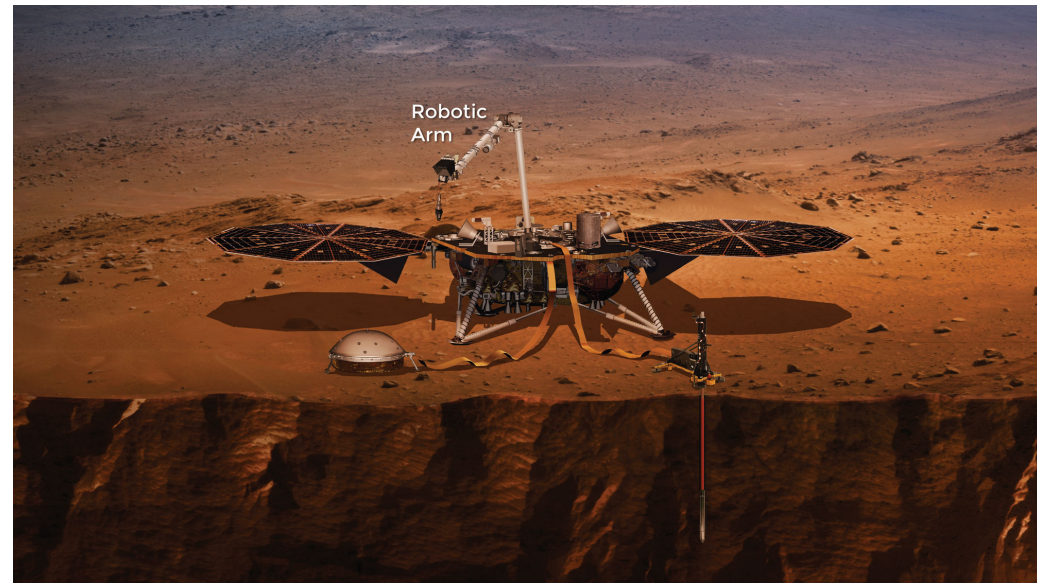
NASA's InSight

<https://mars.nasa.gov/insight/>

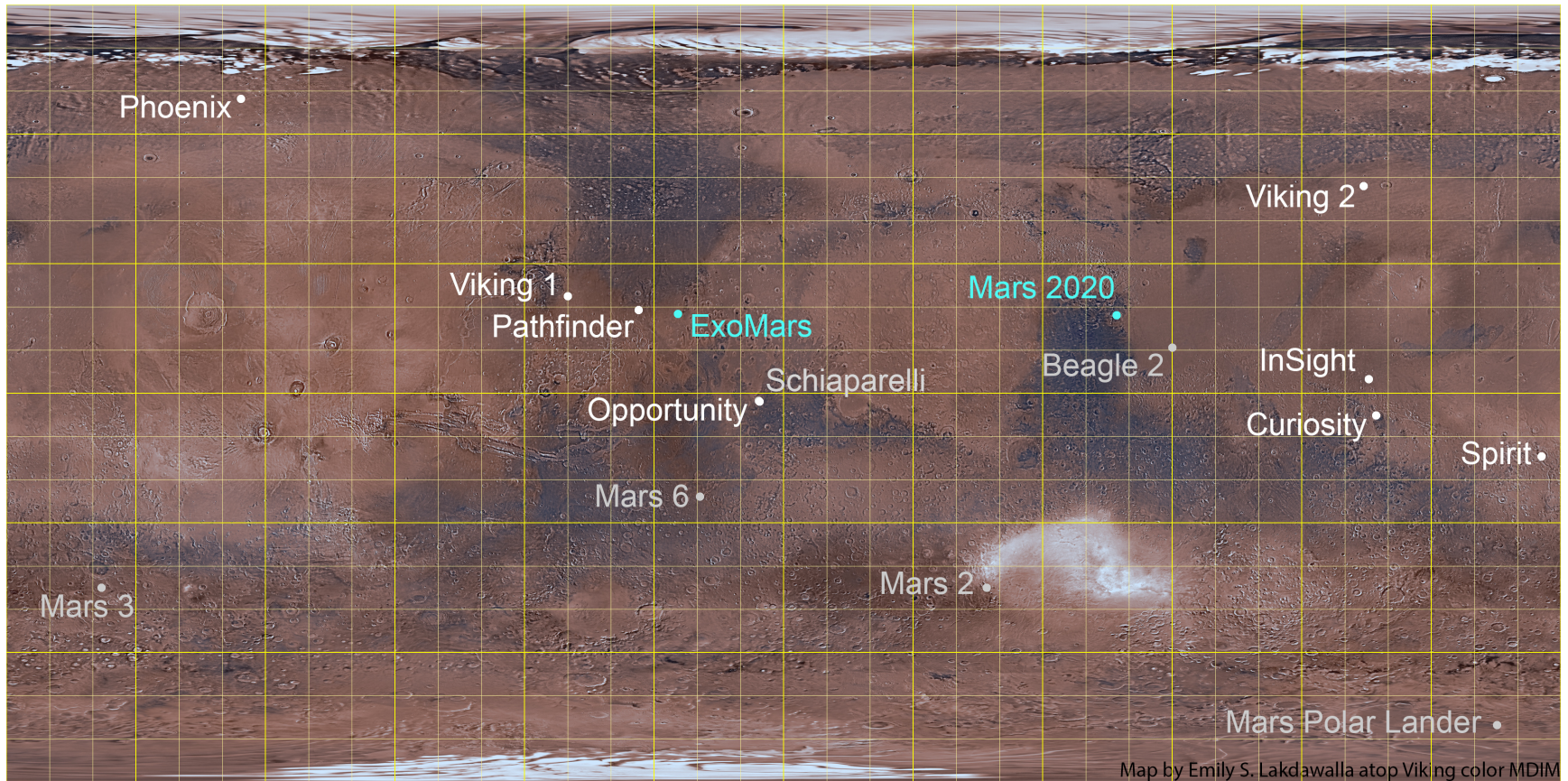
2 Main Goals:

Measure "Marsquakes"

Measure heat flow



Past & Future Landing Sites



ExoMars (2020) will be a semi-autonomous rover
Mars 2020 is a rover with a helicopter

The picture NASA didn't want you to see!

