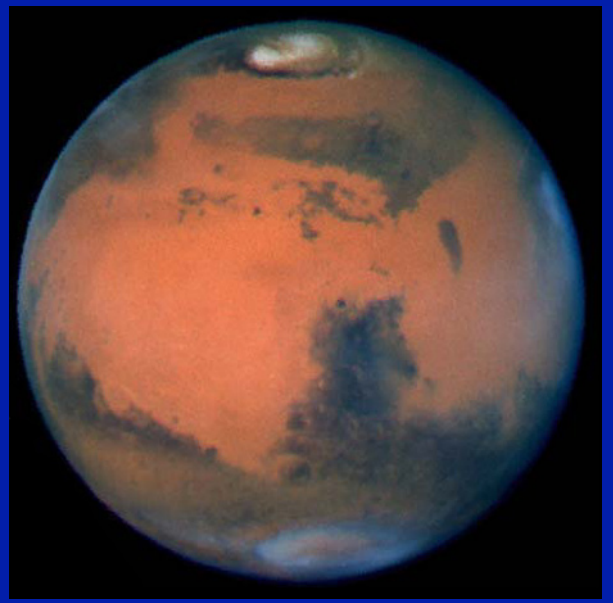
Earth, Moon and Mars: How They Work

Professor Michael Wysession
Department of Earth and Planetary Sciences
Washington University, St. Louis, MO

Lecture 10: Mars - I

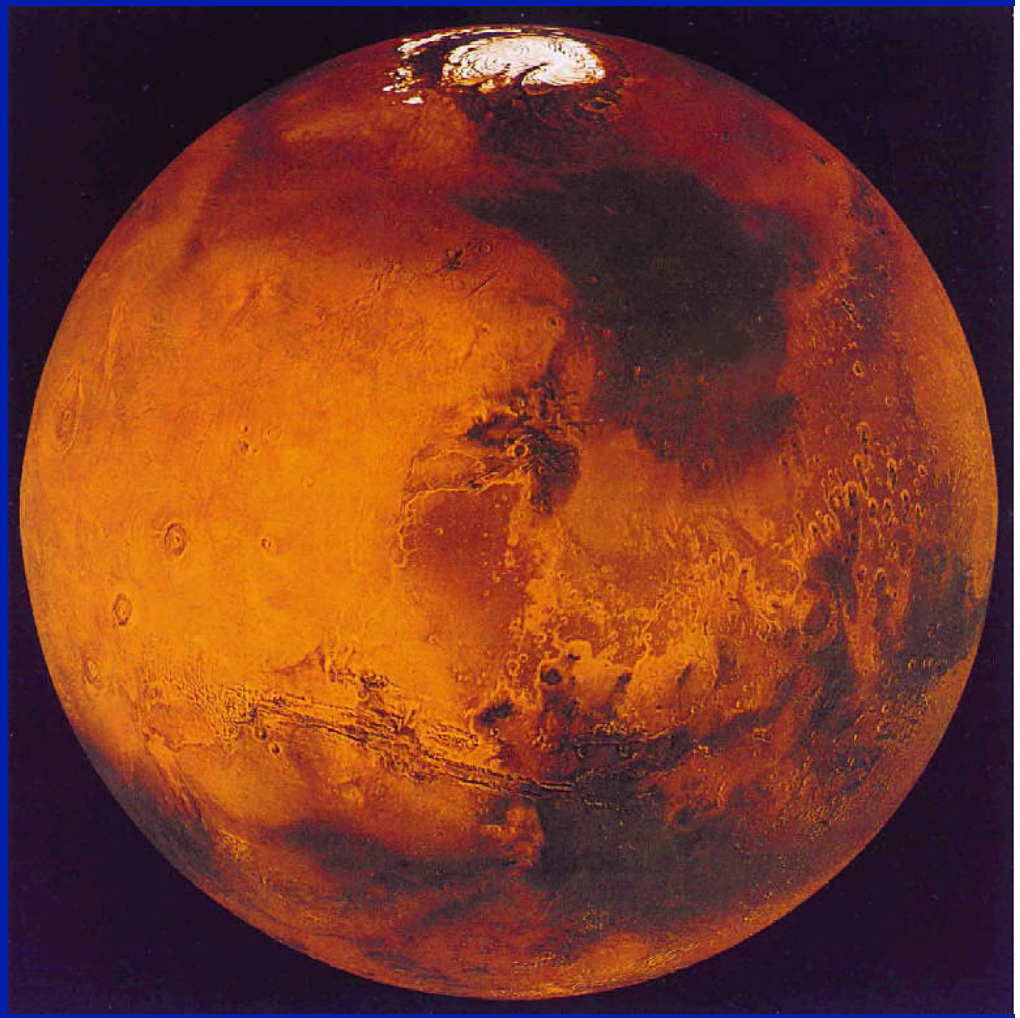
(Thanks to Bob Anderson, Ray Arvidson, Jim Head, and Ashwin Vasavada)



MARS
Mass = 10.7% of Earth's
Radius = 3397 km (53.2%)
g = 37.9% of Earth's
day = 24.66 hours
axis tilt = 25.2°
Atm = < 0.01 bar

Yellow-orange color of surface due to oxidized iron in regolith.

Pink-orange color of sky caused by extremely fine red dust suspended in thin atmosphere.



Representative Chemical Composition of the Soil (Viking)

Elemental Constituent	Concentration (%)
SiO_2	43.4
Fe_2O_3	18.2
Al_2O_3	7.2
SO_3	7.2
MgO	6.0
CaO	5.8
Na_2O	1.34
Cl	0.8
P_2O_5	0.68
TiO_2	0.6
MnO	0.45
Cr_2O	0.29
K_2O	0.1
CO_3	<2
H_2O	0-1

First Period of Mars Observations

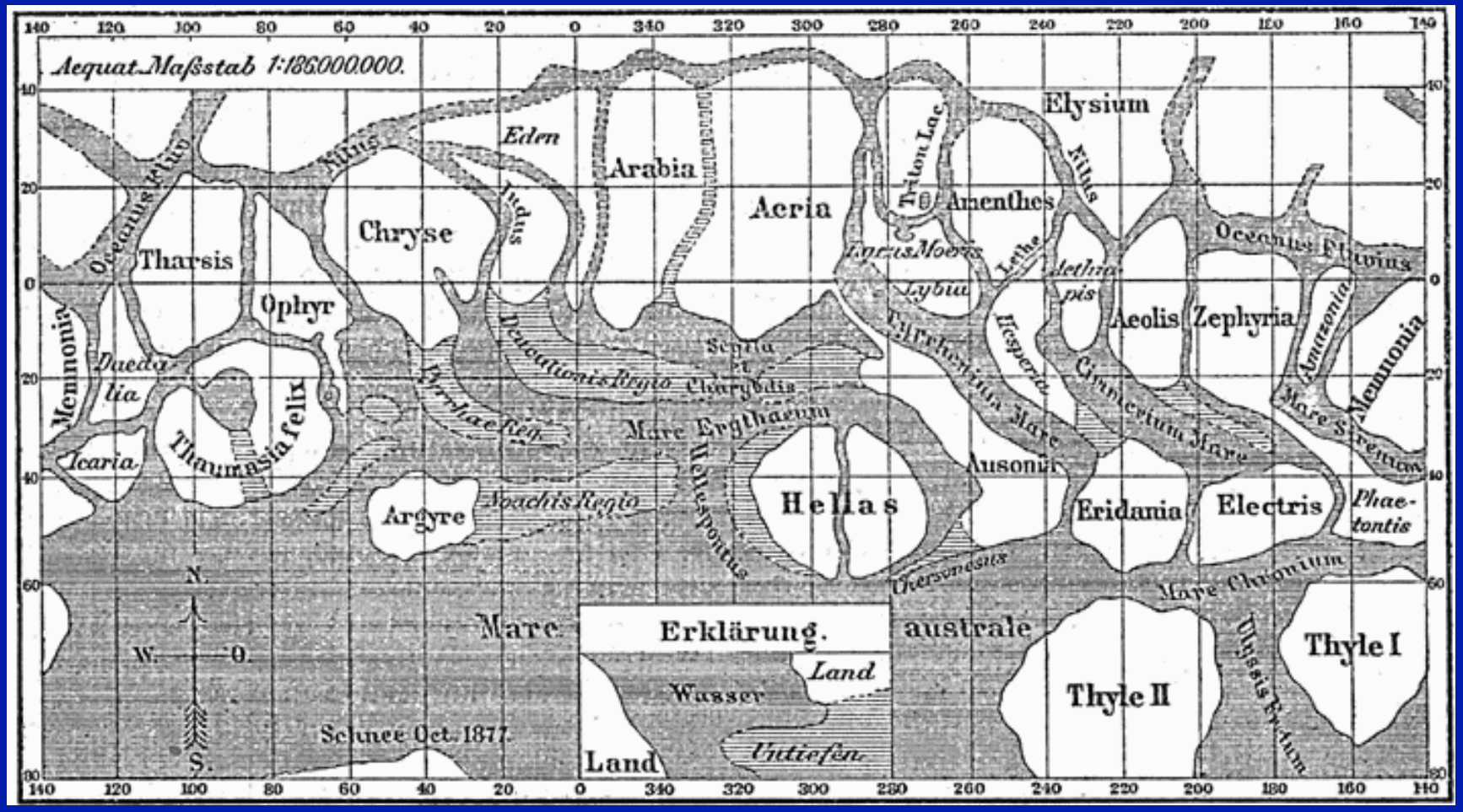
- Galileo Galilei (1609) believed he saw phases of Mars.
- Francisco Fontana of Naples (1638) 2 sketches and hotter than the sun.
- Christiaan Huygens (1659)
  - made the first complete drawing of Mars.
  - "the rotation of Mars, like that of the Earth, seems to be in a period of 24 hours".
- Giovanni Cassini –Bologna
  - made 20 sketches
  - Calculated the rotation to be 24 hours 40 min.
  - First to notice a polar cap (southern)

Canals

For a time in the late 19th and early 20th centuries, it was believed that there were canals on Mars.

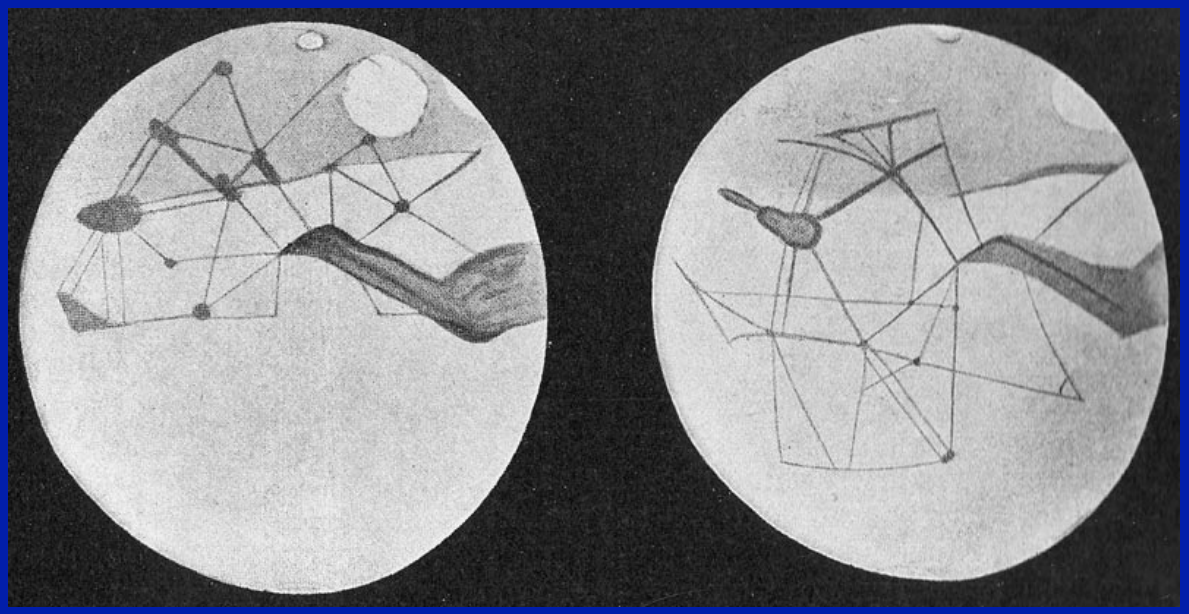
- Network of long straight lines that appeared in drawings of the planet Mars in the equatorial regions from 60° N. to 60° S.
- First observed by Italian astronomer Giovanni Schiaparelli in1877.
- Schiaparelli called them “canali,” which was translated into English as “canals”.
- Irish astronomer Charles E. Burton made some of the earliest drawings of straight-line features on Mars, although his drawings did not match Schiaparelli's.

Schiaparelli



Martian Life?

Percival Lowell pushes the idea that the canals were irrigation canals built by an intelligent civilization on Mars.



Schiaparelli considers much of the detail on Lowell's drawings to be imaginary.

In 1899 inventor Nikola Tesla observed repetitive signals that he later surmised might have been radio communications coming from another planet, possibly Mars.

Martian Life?

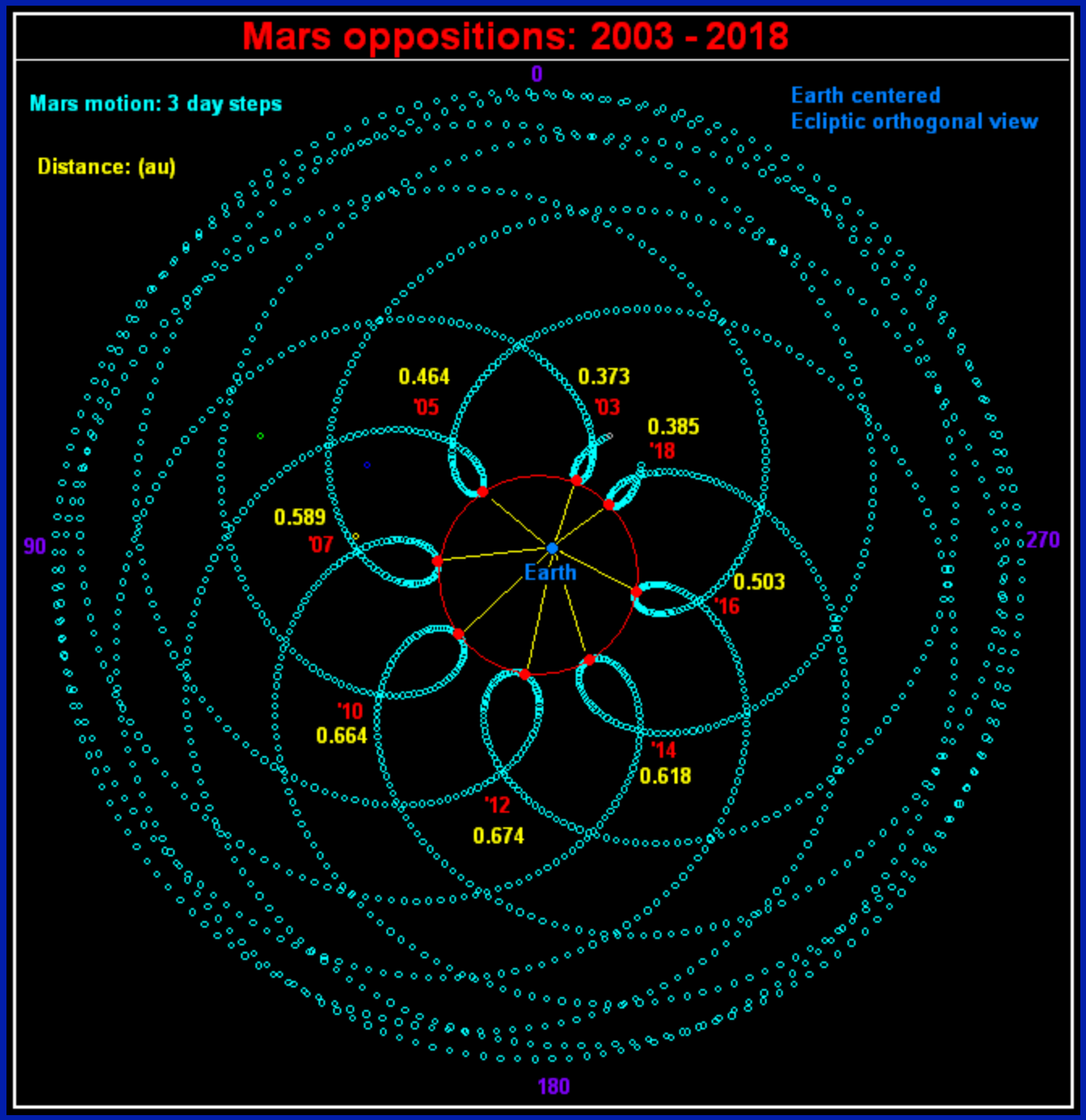
In 1901, Edward Charles Pickering, director of the Harvard College Observatory, received a telegram from Lowell Observatory in Arizona that confirmed that Mars was trying to communicate with the Earth.

Pickering proposed creating a set of mirrors in Texas with the intention of signaling Martians.

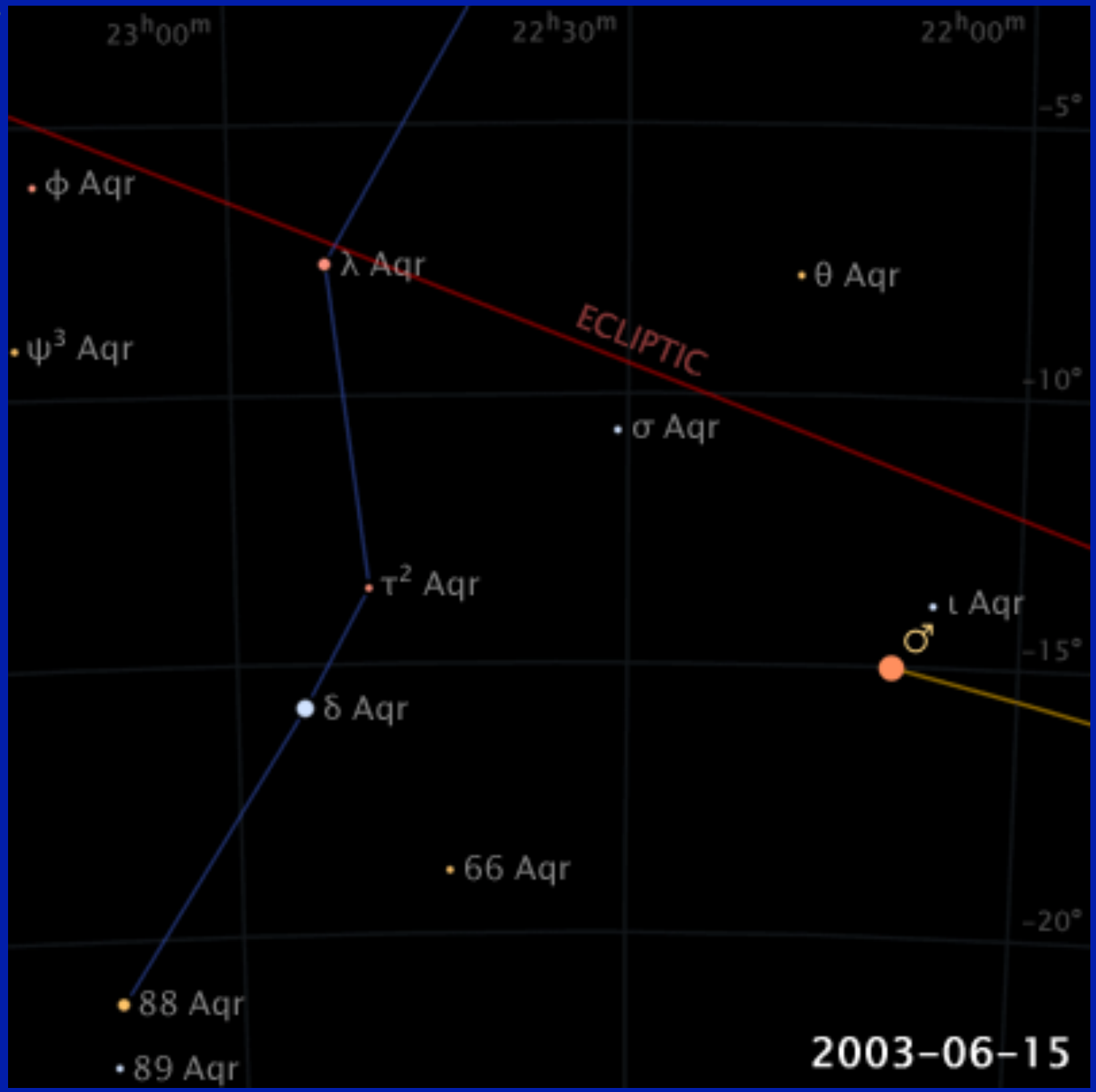
H. G. Wells' The War of the Worlds, published in 1898, in which Martians seek to escape their dying planet by invading Earth.

A subsequent radio version of The War of the Worlds on October 30, 1938 was presented by Orson Wells as a live news broadcast, and many listeners mistook it for the truth.

Motion of Mars with respect to Earth



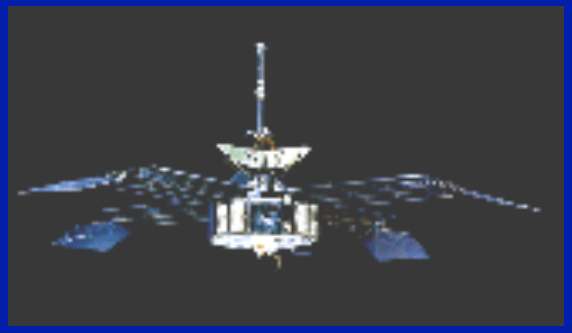
Mars' retrograde motion with respect to Earth



The Last 50 Years of Mars Research

Mariner 3 and 4: identical spacecrafts designed to carry out the first flybys of Mars.

Mariner 3 launched November 5, 1964. Shroud encasing the spacecraft atop its rocket failed to open properly. Failed to get to Mars.



Mariner 4 launched November 28, 1964.

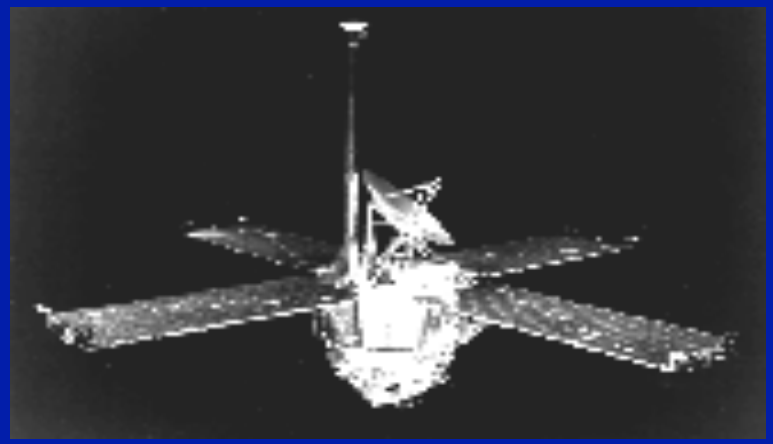
- Flew past Mars on July 14, 1965
- First close-up photographs of another planet.
- Pictures showed lunar-type impact craters (just beginning to be photographed at close range from the Moon), some of them showing frost.

The Last 50 Years of Mars Research

Mariner 6: Launched February 24, 1969

Mariner 7: Launched March 27, 1969

- First dual mission to Mars.
- Flew by equator and south polar regions
- Analyzed Martian atmosphere and surface with remote sensors.
- Both flew over cratered regions and missed both the giant northern volcanoes and the equatorial grand canyon (discovered later).
- Showed that the dark features on the surface seen from Earth were not canals.



The Last 50 Years of Mars Research

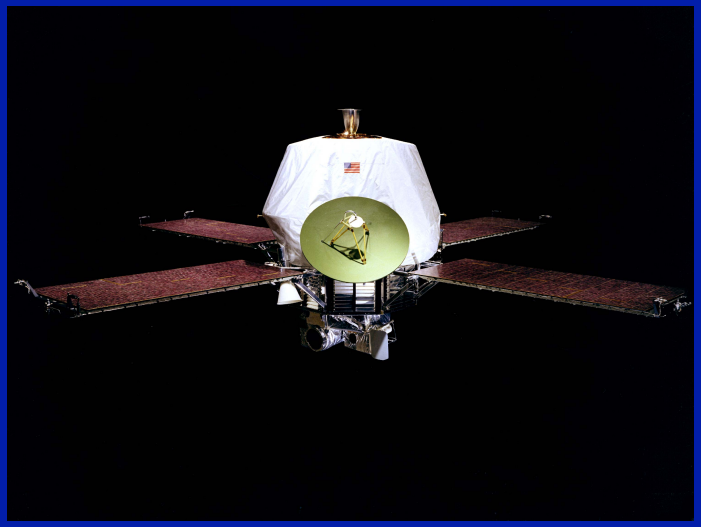
Mariner 8 failed during launch

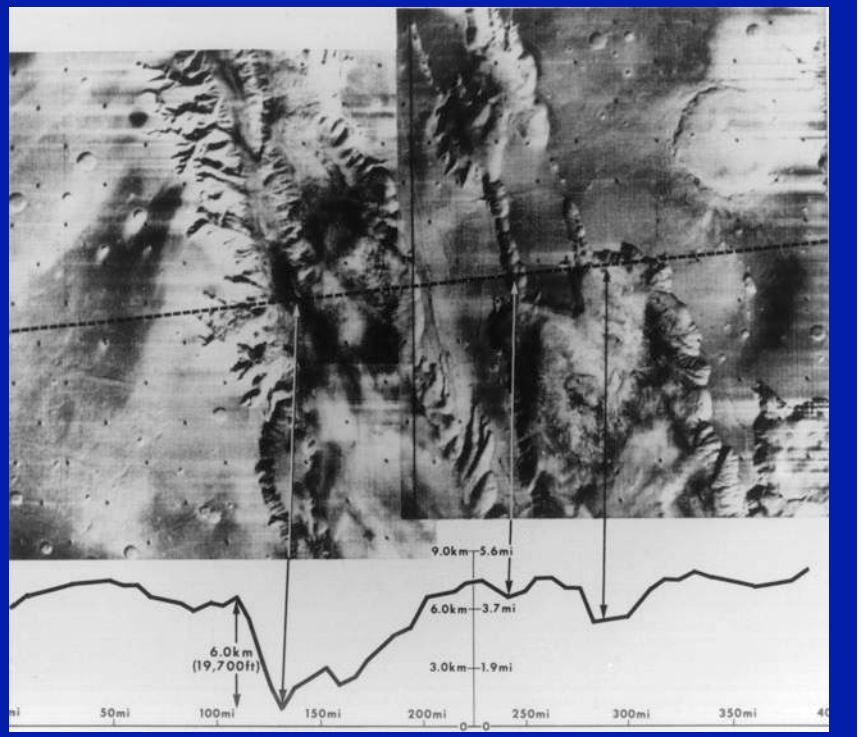
Mariner 9 Launched May 30, 1971; Arrived at Mars November 13, 1971

- First artificial satellite of Mars.
- Orbited Mars nearly a year, until October 27, 1972.

Mariner 9 observed:

- a great dust storm obscuring global surface.
- gigantic volcanoes and a grand canyon stretching 4,800 km
- ancient riverbeds on seemingly dry and dusty planet.

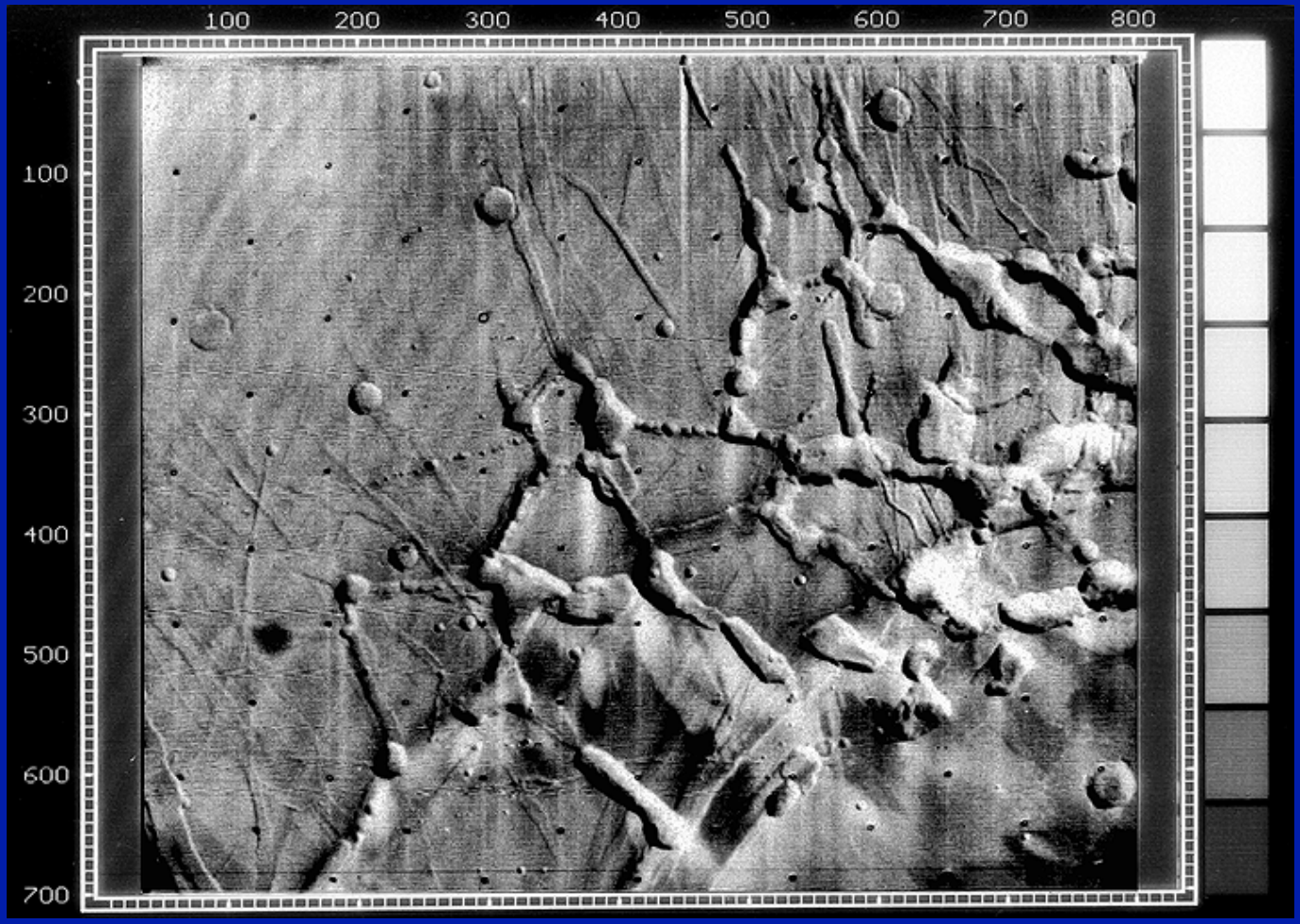




The Last 50 Years of Mars Research

Mariner 9 exceeded all primary photographic requirements by photo-mapping100% of planet's surface.

Provided first close-up pictures of Phobos and Deimos.



The Last 50 Years of Mars Research

Viking 1 & 2 – Orbiters and Landers

Viking 1 lands July 20, 1976

Viking 2 lands September 3, 1976

Lander Mass: 576 kilograms (1,270 pounds)

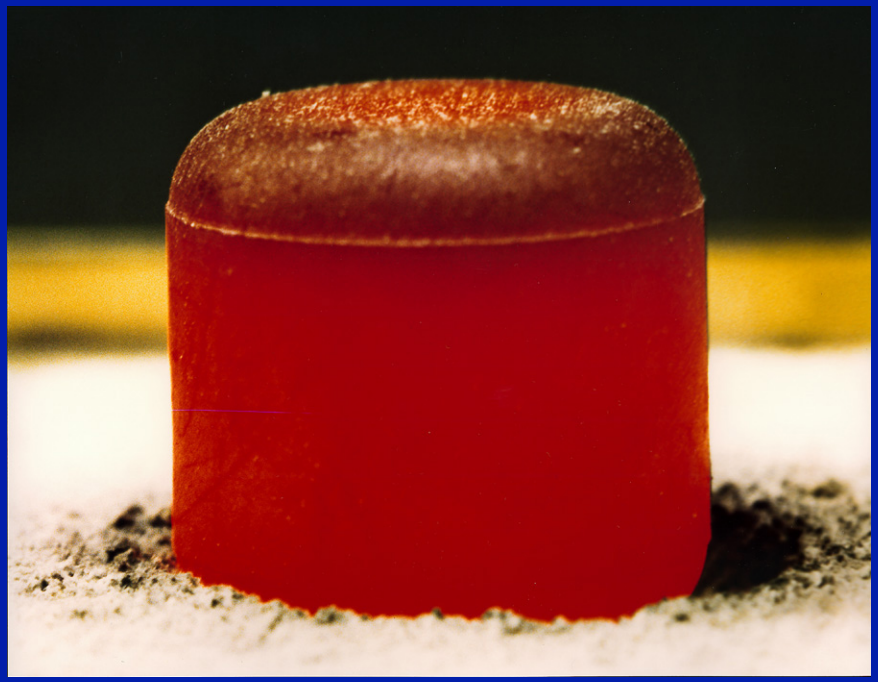
- First U.S. mission to land a spacecraft on Mars and return images.
- Two identical spacecraft, each consisting of a lander and and orbiter.
- Viking 1 touched down on the western slope of Chryse Planitia (the Plains of Gold).
- Viking 2 lander settled down at Utopia Planitia.
- Viking Orbiter 1 continued operations for four years with 1,489 orbits of Mars, concluding its mission August 7, 1980.

The Last 50 Years of Mars Research

Viking Orbiter 1 continued operations for four years with 1,489 orbits of Mars, concluding its mission August 7, 1980.

Viking Lander 1 made its final transmission November 11, 1982.

Both landers powered by radioisotope thermoelectric generators (plutonium 238).



The Last 50 Years of Mars Research

Mars Observer: Launched September 25, 1992; Mission failed

- Payload of science instruments was designed to study the geology, geophysics, and climate of Mars.
- On August 22, 1993, contact was lost with the spacecraft shortly before it was to enter orbit around Mars.
- Science instruments from Mars Observer get reflown on two other orbiters, Mars Global Surveyor and 2001 Mars Odyssey.

The Last 50 Years of Mars Research

Mars Global Surveyor: Launch: Nov 7, 1996; Arrival: Sep 12, 1997.

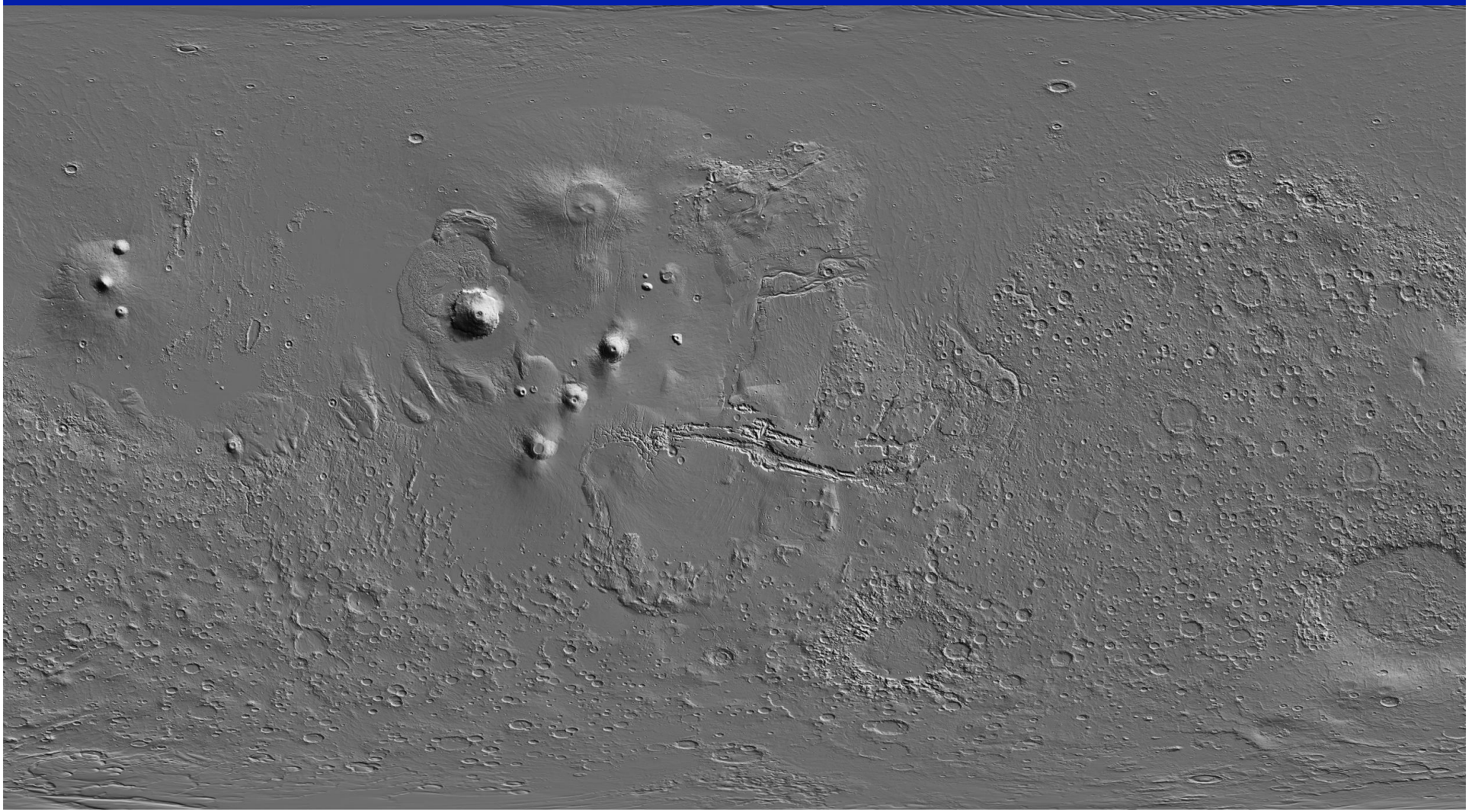
Studied the entire Martian surface, atmosphere, and interior.

- Very repeatable weather patterns.
- Local disturbances and dust devils during spring-summer.
- Gullies &debris flows suggest liquid water once present at surface.

Mars Global Surveyor:

- Magnetometer readings → no global magnetic field
  - But localized magnetic fields in some areas.
- Images show Phobos covered by a >1 m thick layer of powder
  - pulverized output of millions of years of meteoroid impacts.
- Laser altimeter data give first 3-D views of surface.
- Changes in radio transmissions refracted by Martian atmosphere provide vertical profiles of atmospheric T & P.
- Spacecraft accelerations due to gravity give better understanding of interior of Mars.
- → Mars is a dynamic planet with a history of seasonal and long-term change recorded in the planet's surface.

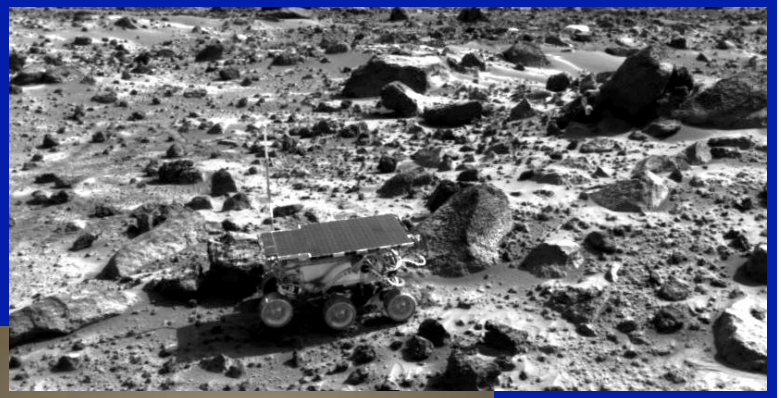
Mars Topography – MOLA (Mars Orbital Laser Altimeter, on Mars Global Surveyor)



Past Mars Research

Mars Pathfinder: Launched Dec 4, 1996; Mass: 10.6 kg (23 lbs)

- Originally designed as a tech demo
- Returned unprecedented amount of data
- Entry: parachute & system of giant airbags
- Landing site is ancient flood plain in northern hemisphere --Ares Vallis (among the rockiest parts of Mars!).
- Chosen because scientists believed it to be a safe surface to land on!



Past Mars Research

Mars Climate Orbiter: Launched Dec 11, 1998; Mission failed

Lost on arrival September 23, 1999

Designed to function as interplanetary weather satellite and communications relay for Mars Polar Lander

Carried two science instruments: copy of an atmospheric sounder on the Mars Observer spacecraft lost in 1993, and a new, lightweight color imager

Probably entered planet's atmosphere too low and burned up

Past Mars Research

Mars Polar Lander & Deep Space 2:
Mass - 3.6 kg (7.9 lb): Mission failed

Mars Polar Lander and Deep Space 2 were lost at arrival December 3, 1999.

Science instruments: Sample collection/ water detection experiment, soil thermal experiment, atmospheric descent accelerometer, impact accelerometer

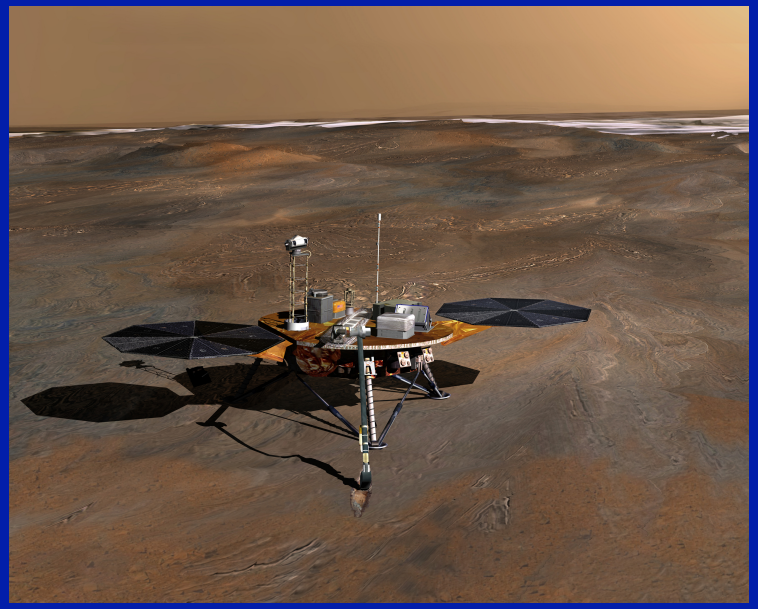
Mars Polar Lander: designed to set down near edge of south polar cap and dig for water ice robotic arm.

Deep Space 2: Piggybacked on lander, designed to impact Martian surface

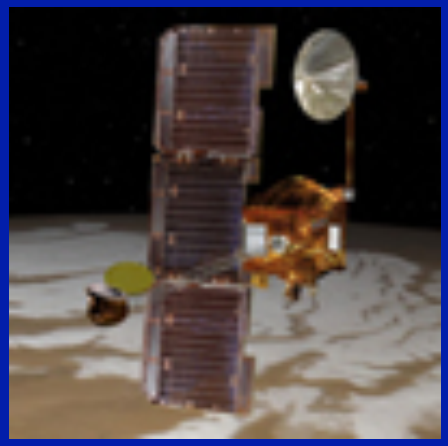
Past Mars Research

Phoenix: Launch: August, 2007;
Arrival: May 25, 2008

- First in NASA's Scout Program
- Designed to study history of water and habitability potential in arctic ice-rich soil
- Characterize the climate & geology and potential for life
- Prepare for human exploration
- Search for evidence of a habitable zone and assess the biological potential of the ice-soil boundary



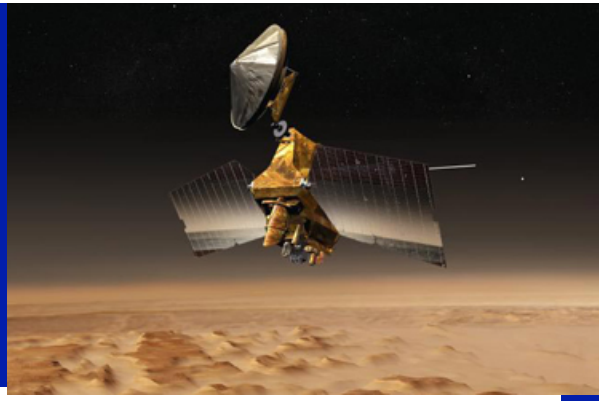
Present Mars Research



2001 Mars Odyssey

- Primary science mission Feb 2002 -Aug 2004; extended mission began Aug 24, 2004
- Mapped amount & distribution of chemical elements & minerals
- Maps of hydrogen distribution led scientists to discover vast amounts of water ice in polar regions just beneath the surface.
- Enough propellant to go to 2015

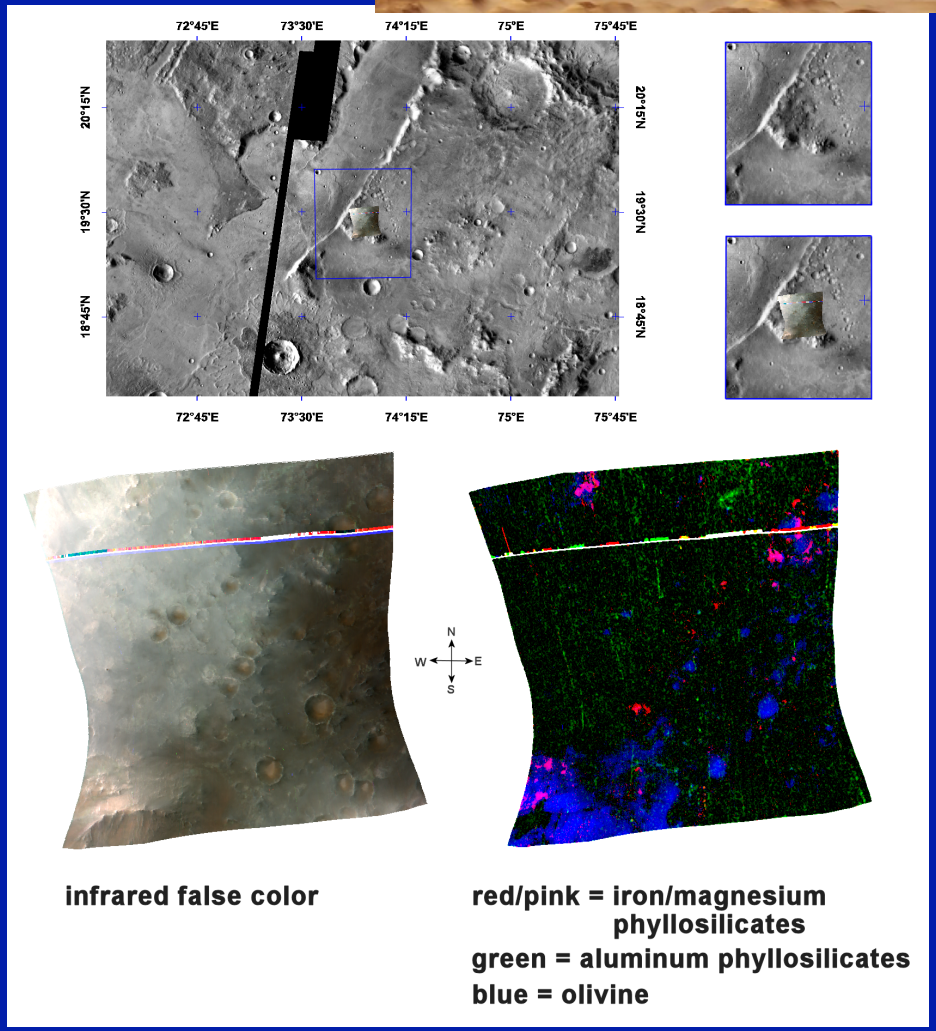
Present Mars Research



Mars Reconnaissance Obiter (MRO)

Launched Aug 12, 2005;
Entered orbit March 10, 2006

- Providing unprecedented detail about the surface, subsurface, and atmosphere
- Helped characterize potential landing sites for other missions such as Phoenix and Mars Science Laboratory.



Present Mars Research

Mars Exploration Rovers –Spirit and Opportunity

NASA's twin robot geologists; Launched June 10 and July 7, 2003; landed January 3 and January 24, 2004

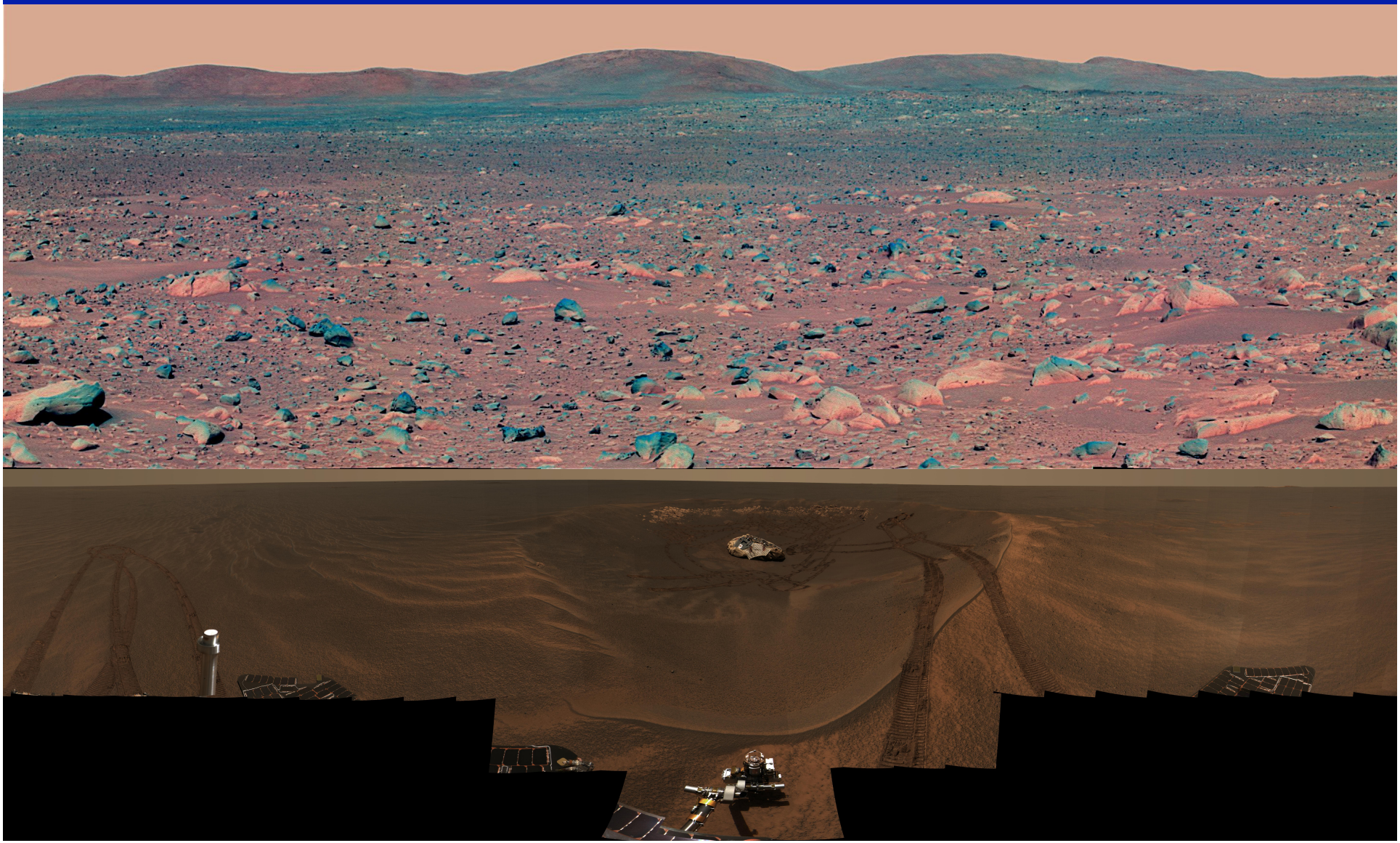
Goals to search for and characterize wide range of rocks and soils that hold clues to past water activity

Target sites on opposite sides of Mars that appear to have been affected by liquid water in the past

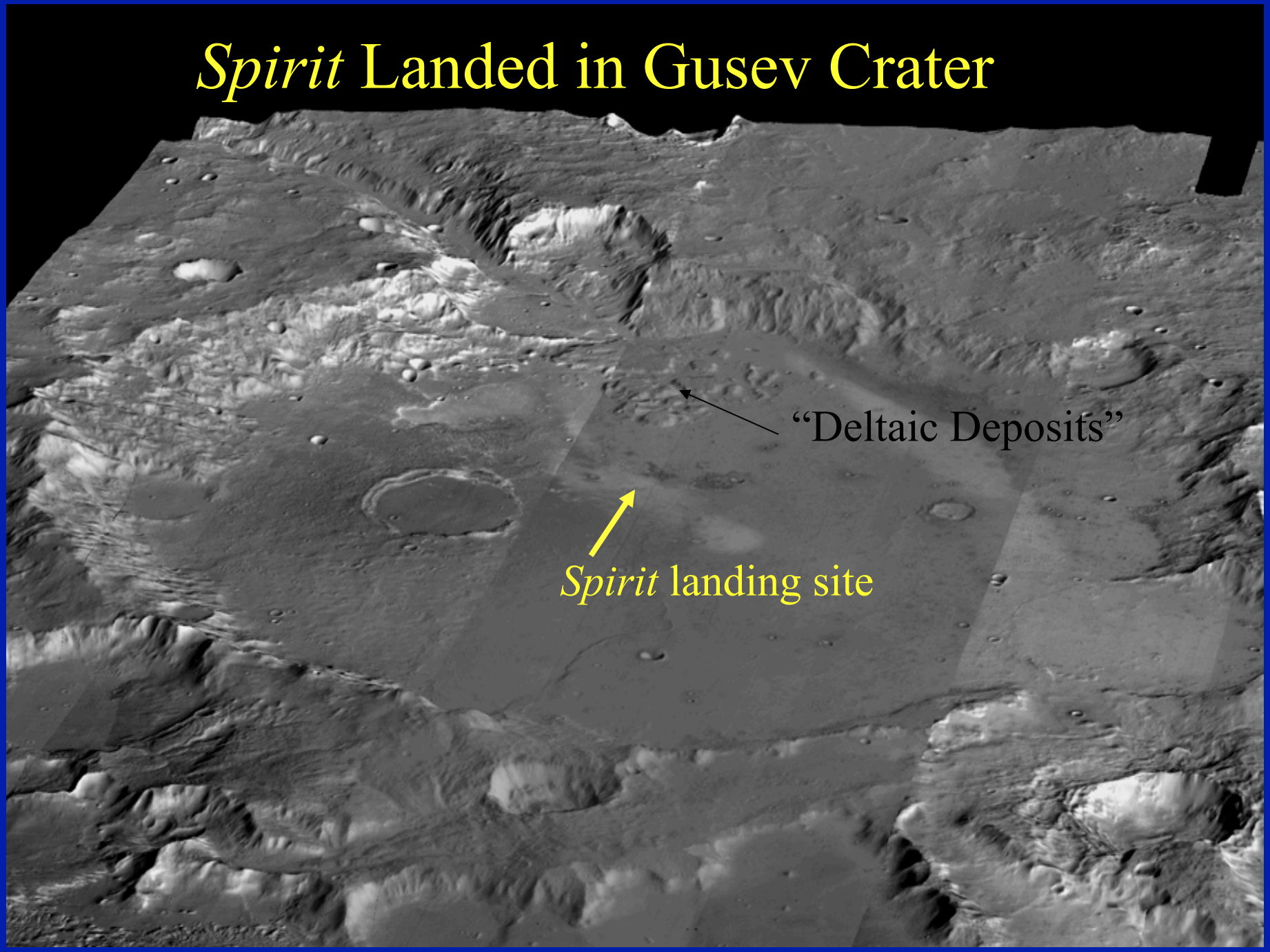
The landing sites are at Gusev Crater, a possible former lake in a giant impact crater, and Meridiani Planum, where mineral deposits (hematite) suggest Mars had a wet past

Still going, and going, and going…(sort of)

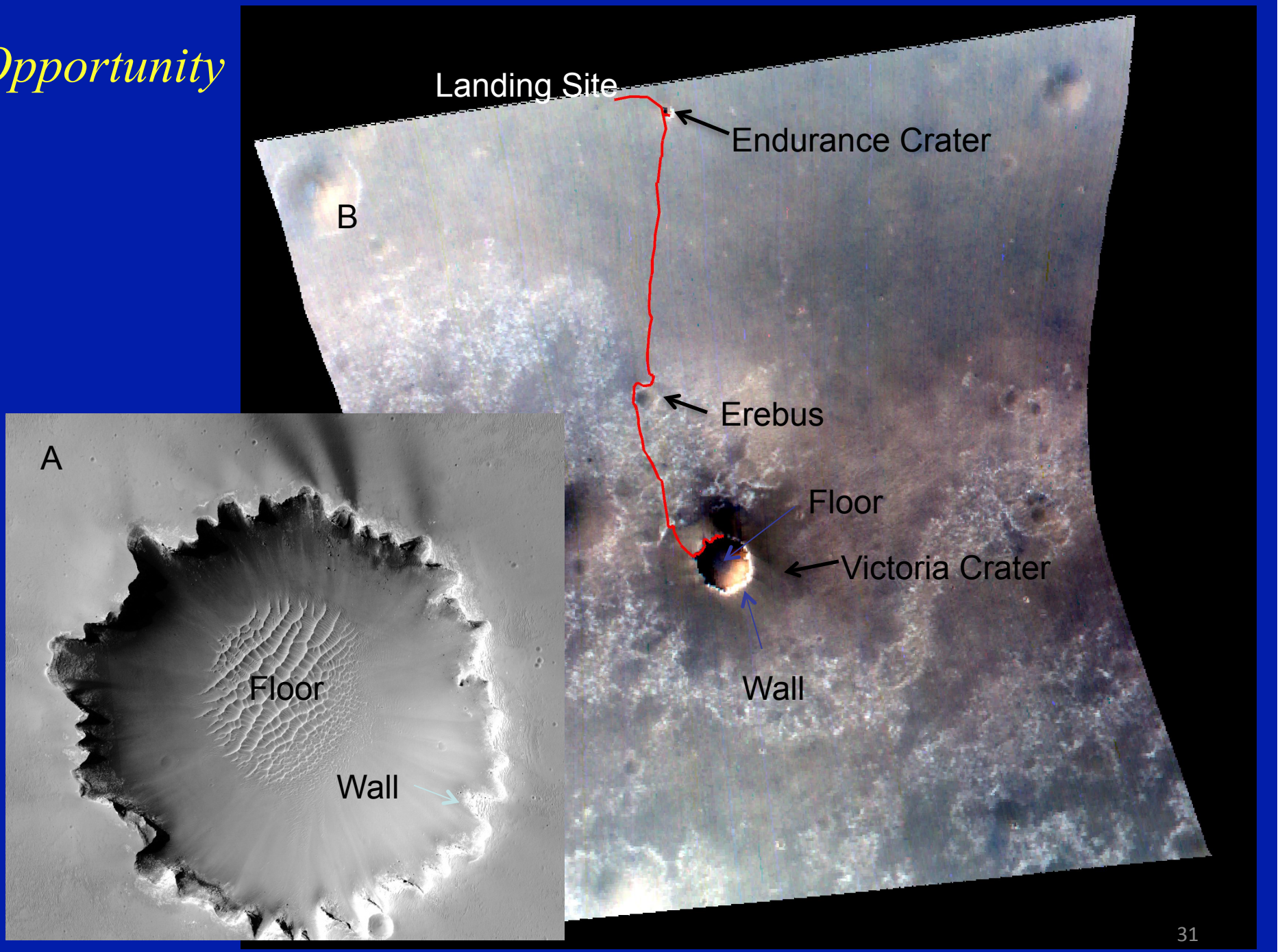
Mars Exploration Rovers



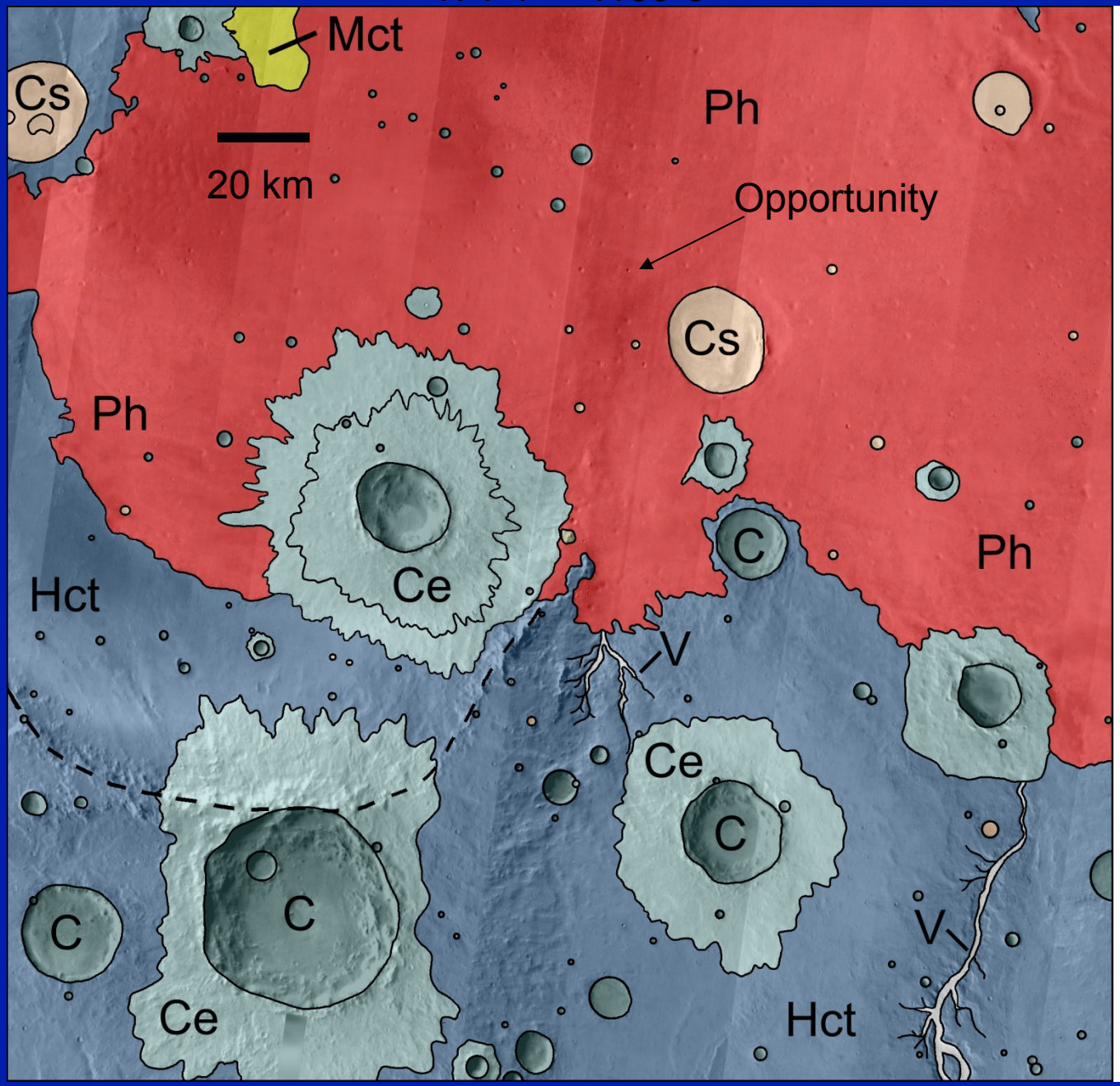
Spirit Landed in Gusev Crater



Opportunity

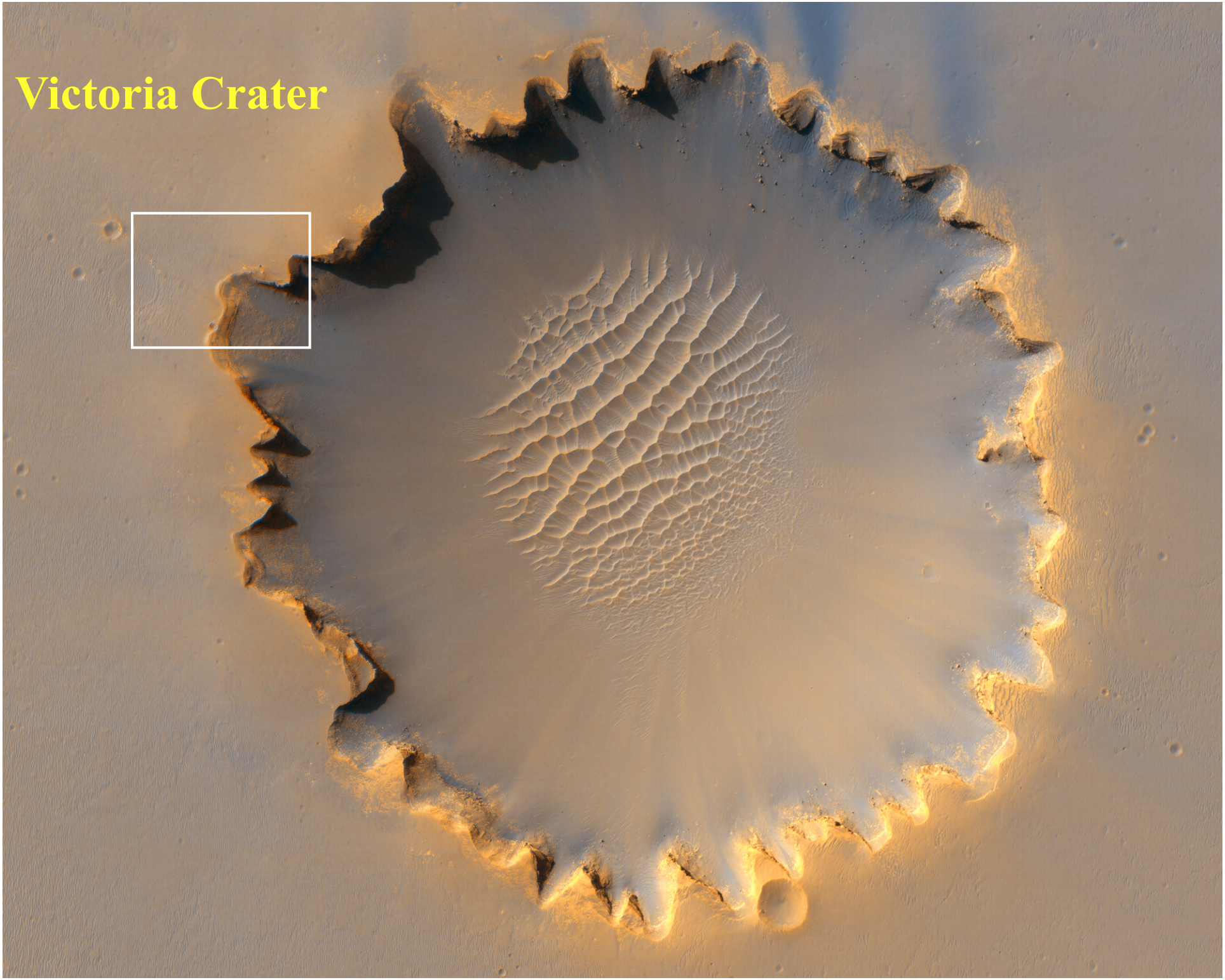


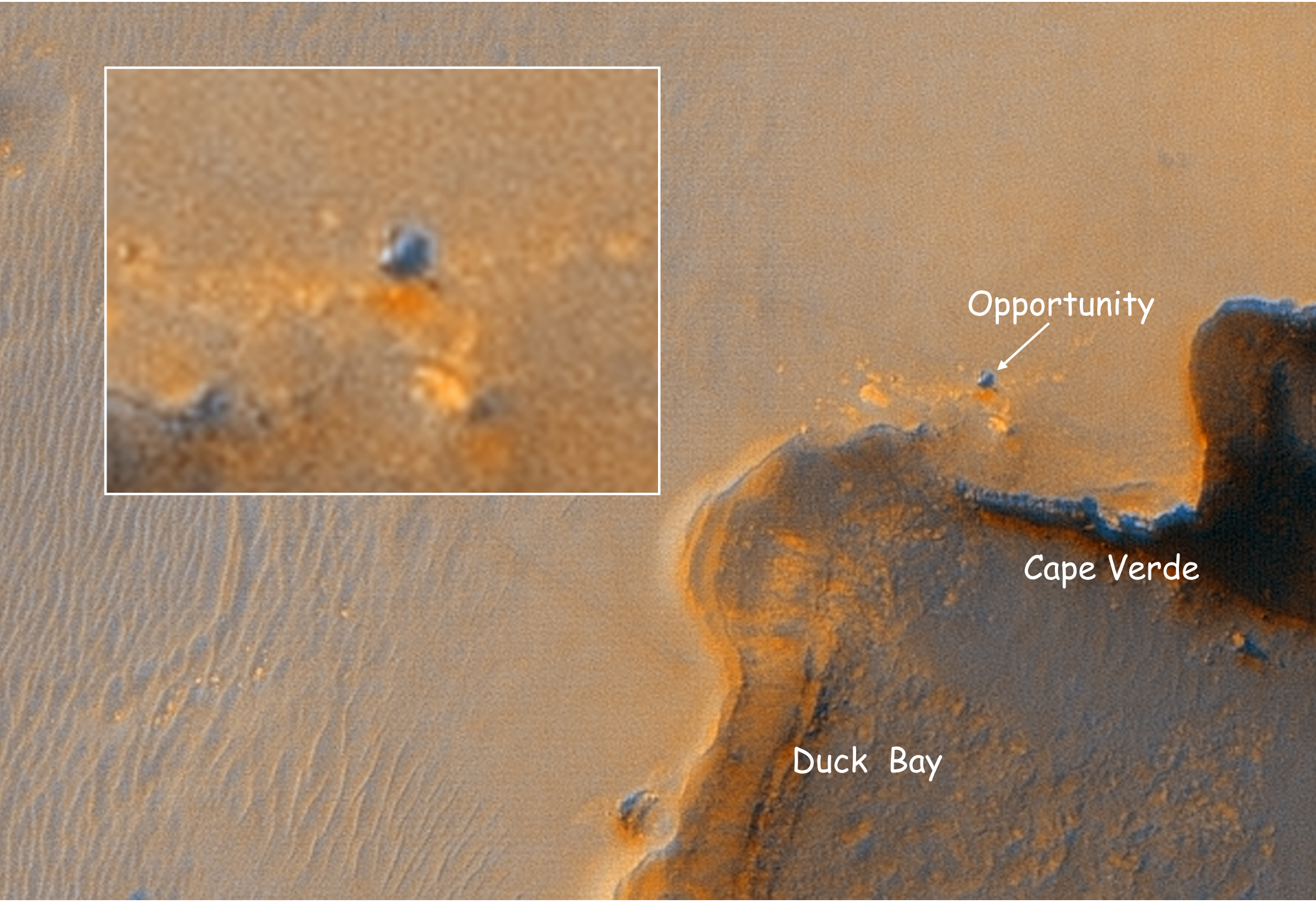
171-1 1183-5



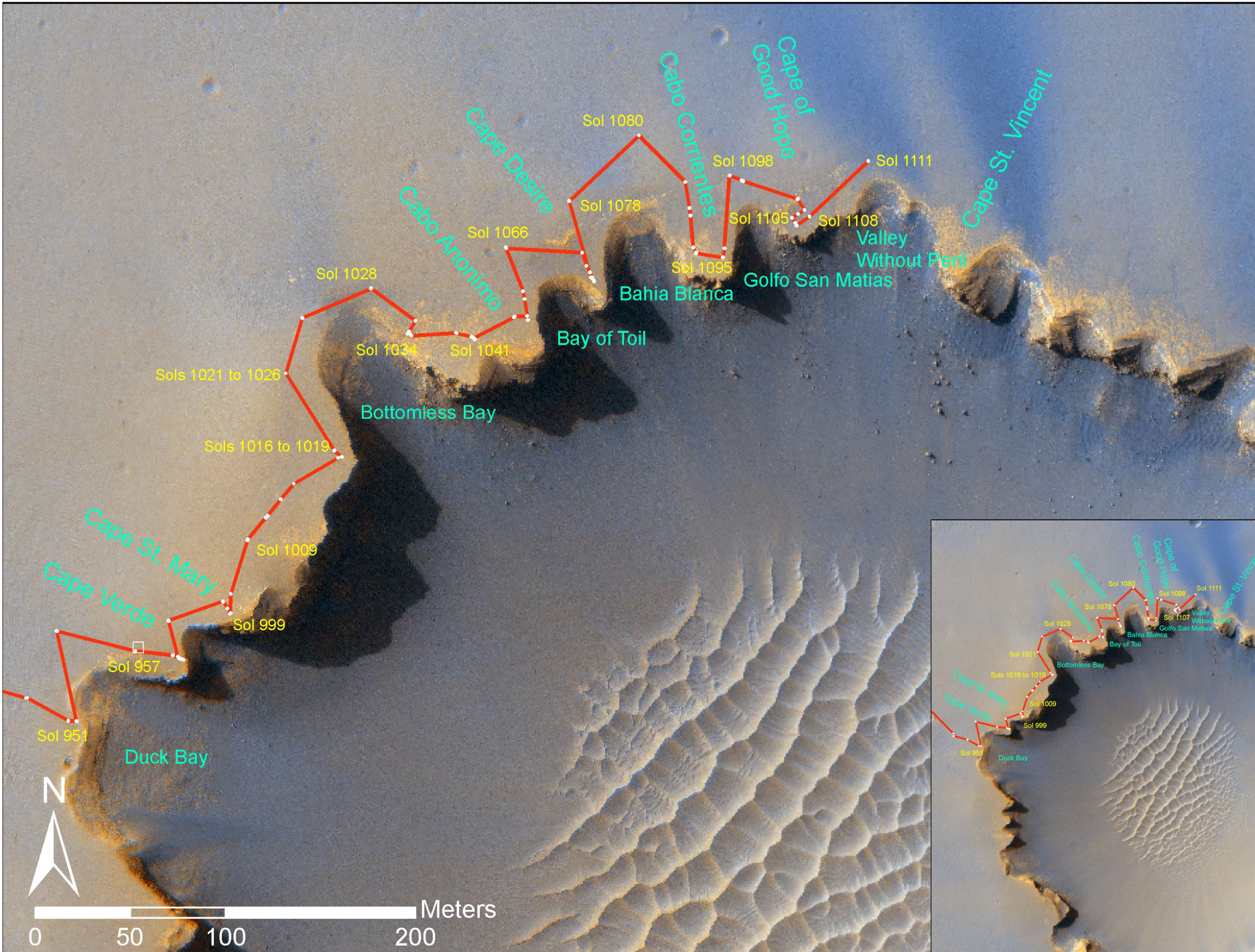
Units & Symbols

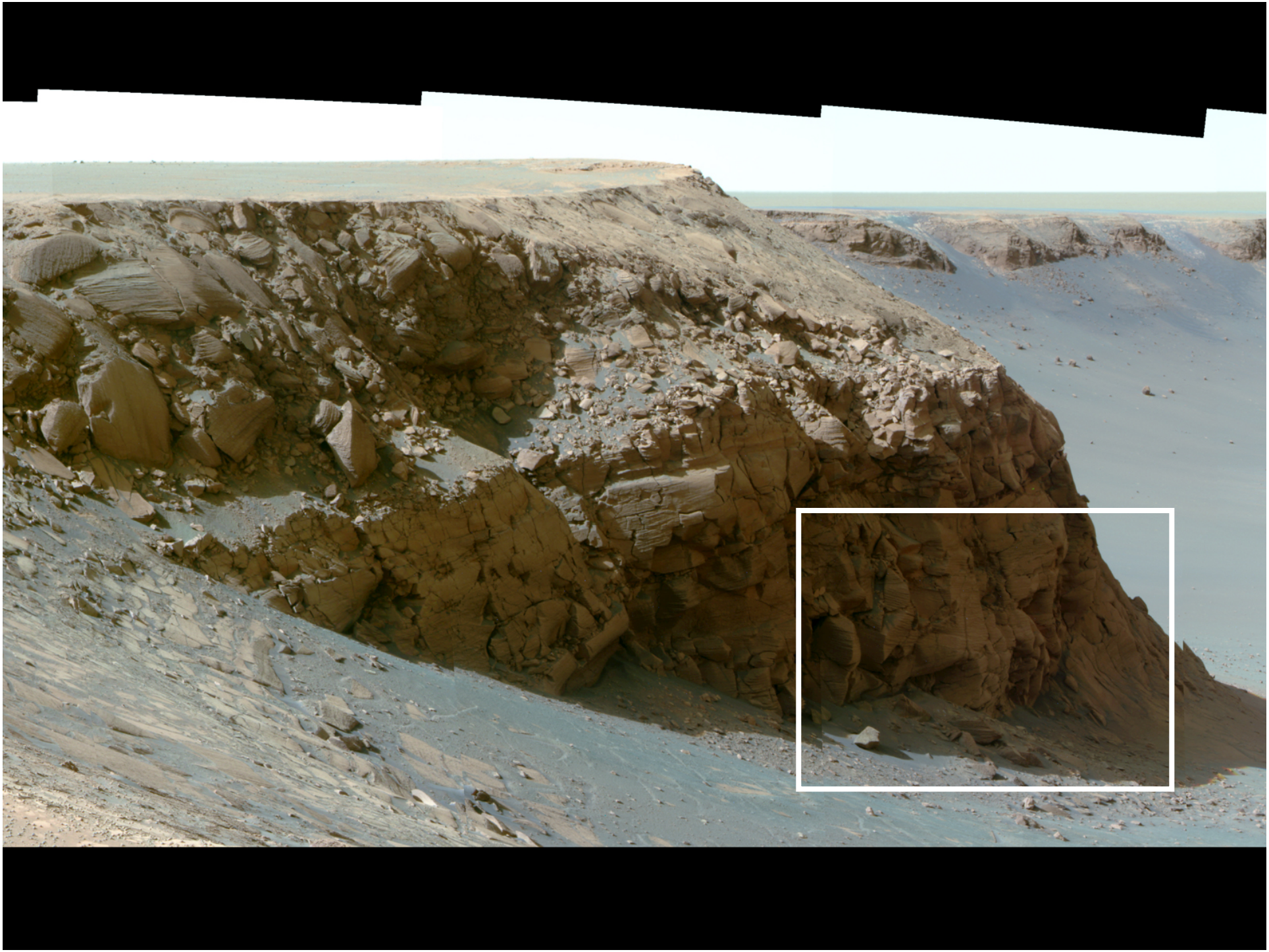
- C — Crater
- Ce — Crater ejecta
- Cs — Crater, subdued
- Ph — Hematite-bearing Plains
- V — Valley
- Hct — Cratered Highlands
- Mct — Mantled Terrain
- – – – Ridgeline trace

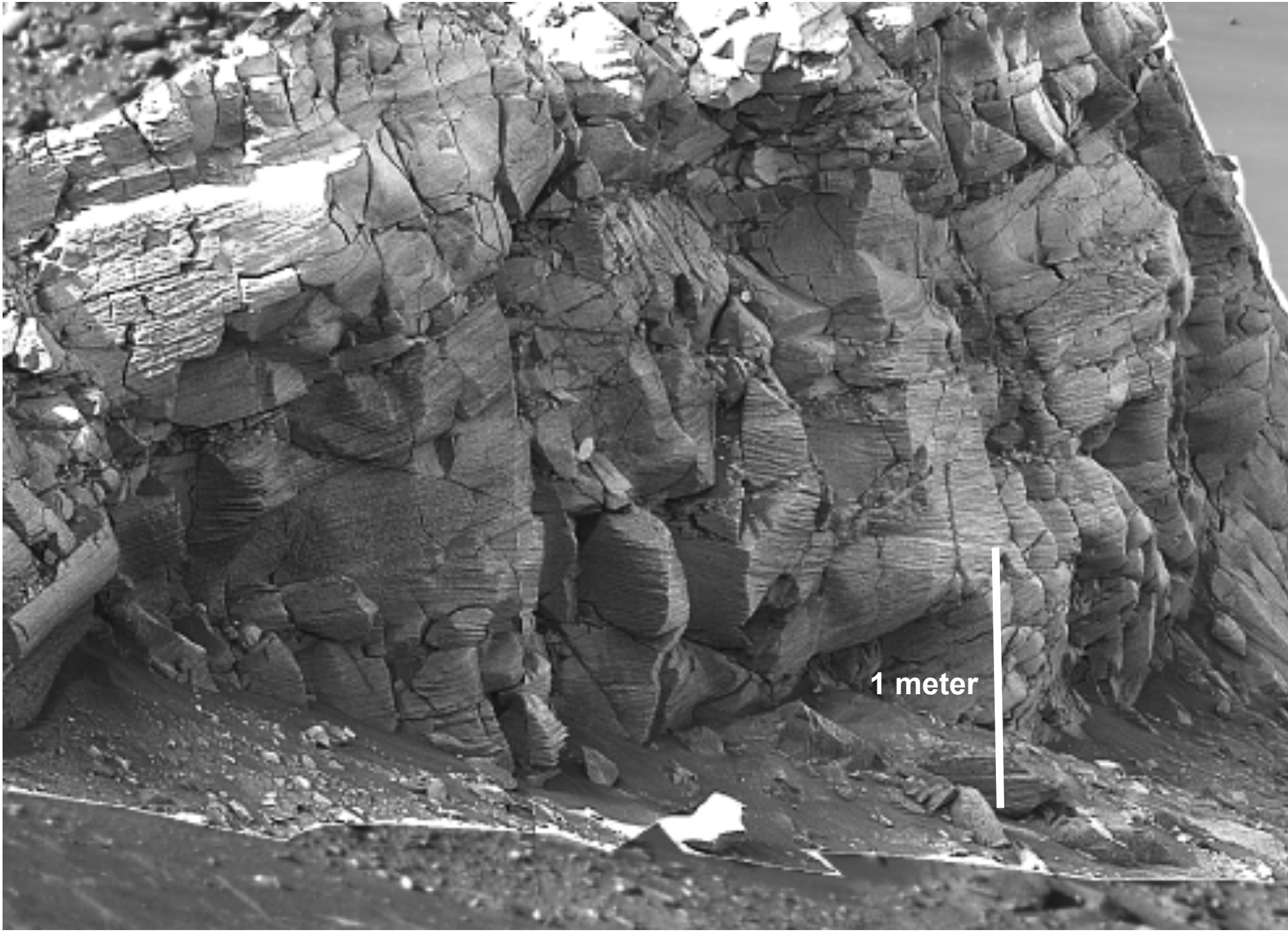

Victoria Crater


Opportunity
Cape Verde
Duck Bay

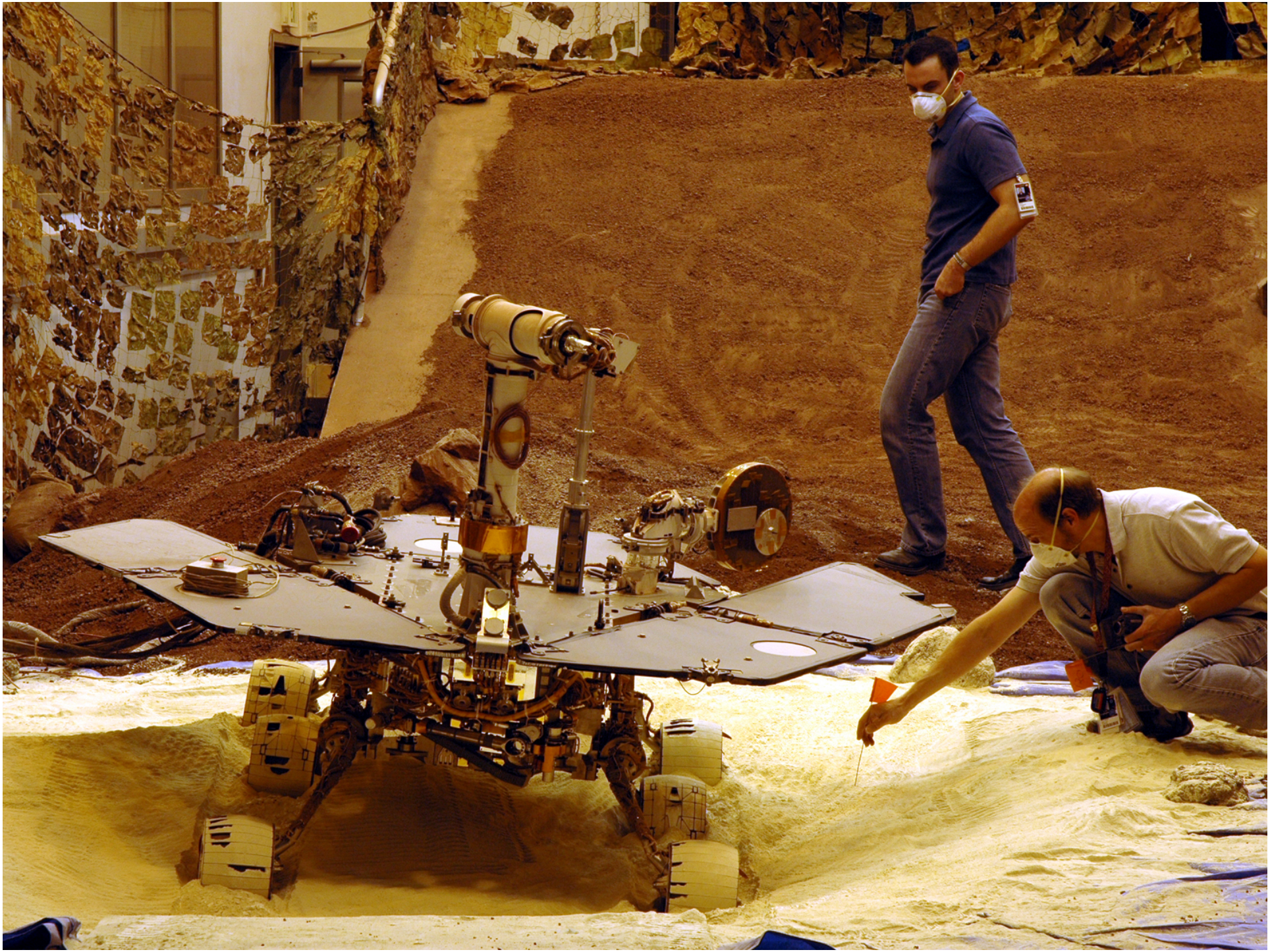
Opportunity Traverse Map (Sol 1111)

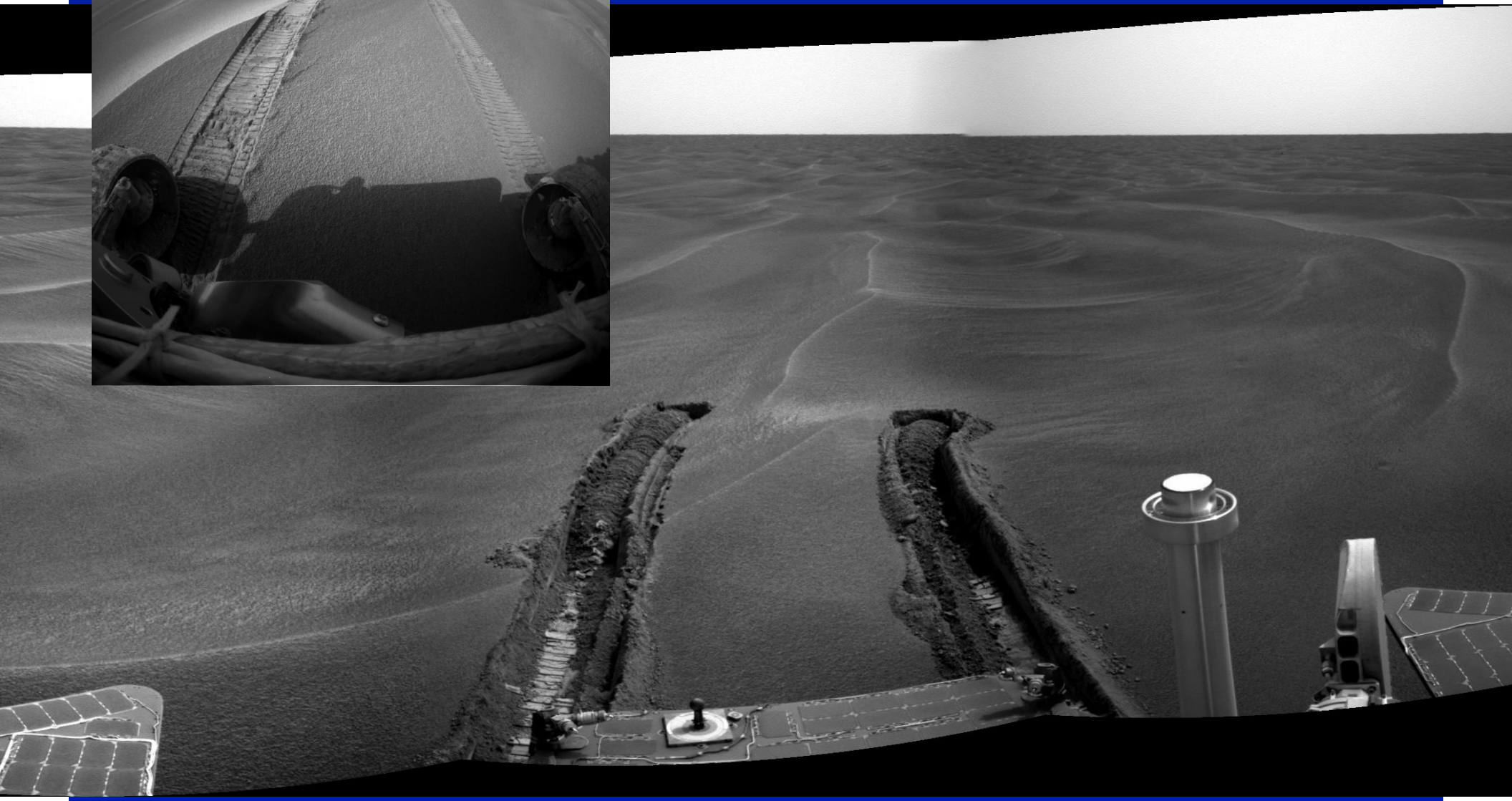




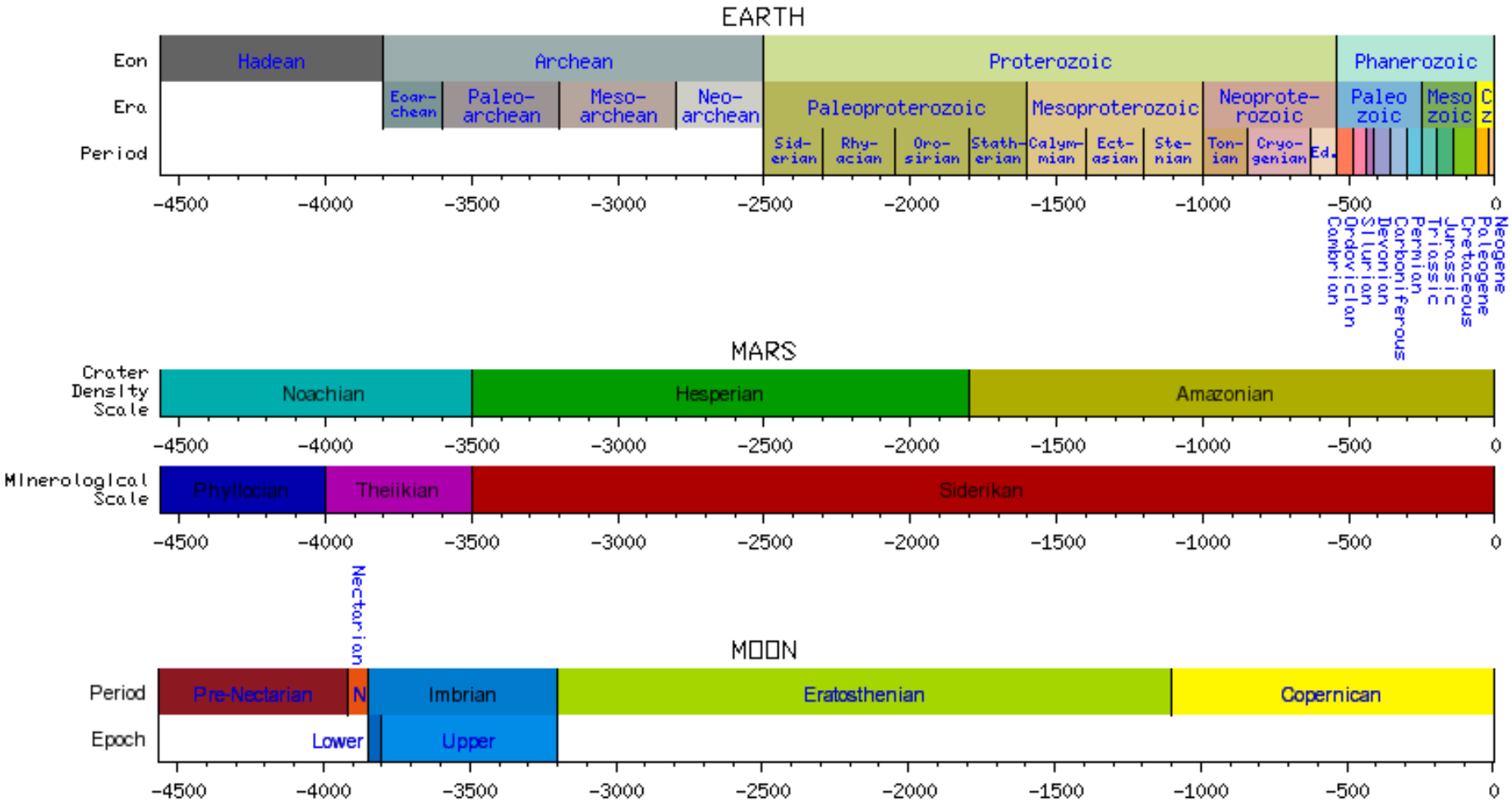

1 meter

Purgatory ripple (took 5 weeks to get Opportunity out)





What do we know about Mars today?
Geologic History



Mars Geologic Units

Noachian epoch (named after Noachis Terra): 4.6 -3.5 Ga

- Noachian surfaces scarred by many large impact craters
- Formation of Tharsis bulge late in epoch, with extensive flooding by liquid water

Hesperian epoch (named after Hesperia Planum): 3.5 -1.8 Ga

- Marked by the formation of extensive lava plains

Amazonian epoch (named after Amazonis Planitia): 1.8 Ga - present

- Surfaces have few meteorite impact craters but are otherwise quite varied
- Olympus Mons formed, along with lava flows elsewhere on Mars

Mars Mineralogical Units

Phyllocian (named for characteristic clay-rich phyllosilicate minerals) 4.6 - 4.0 Ga

- An alkaline water environment would have been present for the phyllosilicates to form

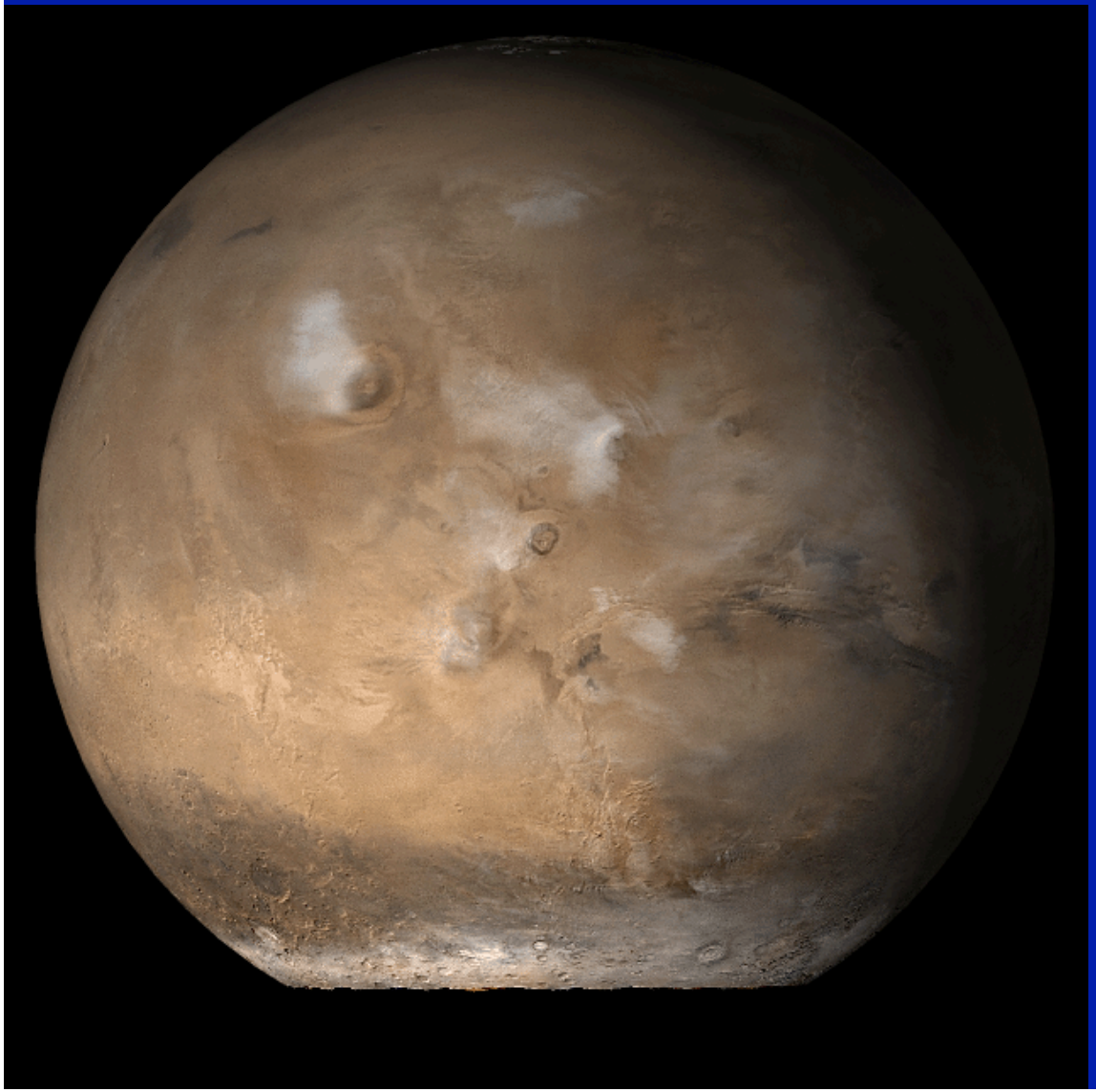
Theiikian (named for characteristic sulfate minerals that formed) 4.0 – 3.5 Ga

- Period dominated by volcanic activity
- Lava & gasses (particularly sulfur dioxide) were released, combining with water to create sulfates and an acidic environment

Siderikan 3.5 Ga – present

- Reduction in volcanism and the absence of liquid water
- Oxidation of iron-rich rocks by atmospheric peroxides
- Red iron oxides give the planet its familiar color.

Martian Volcanoes

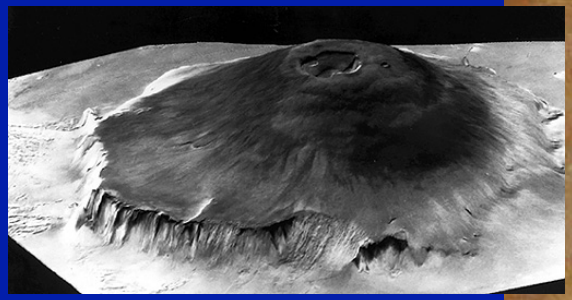


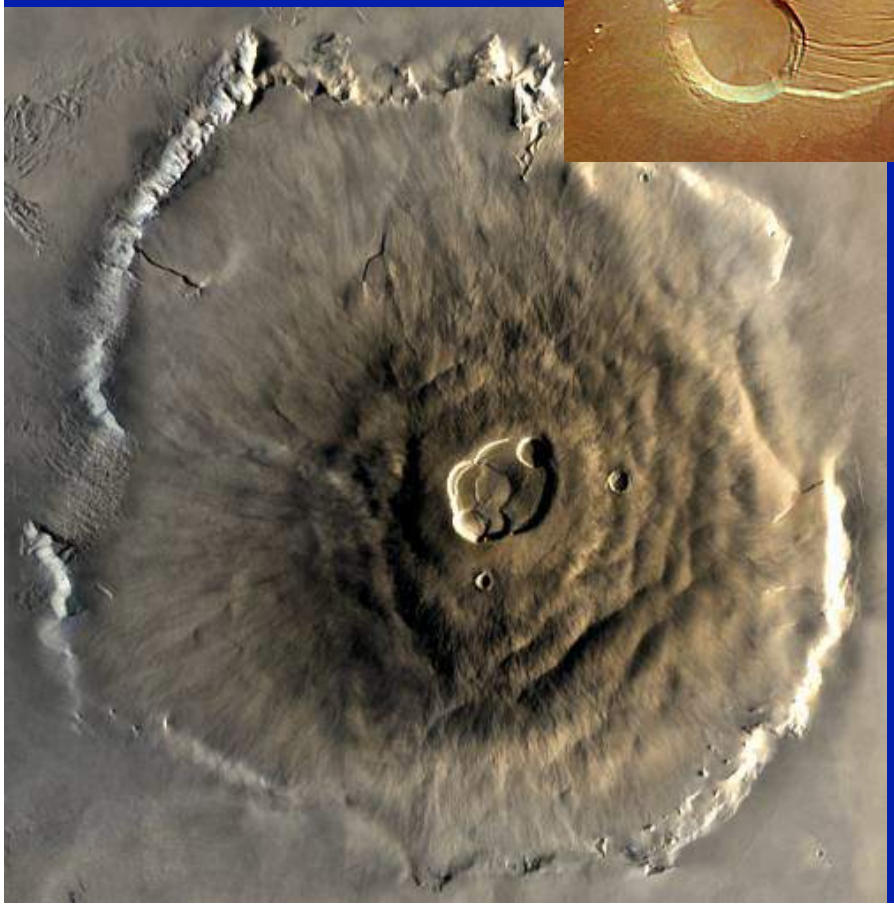
Majority of the volcanoes on Mars are located within the Tharsis Rise.

Include:

- Olympus Mons
- Tharsis Montes
- Alba Patera
- Elysium

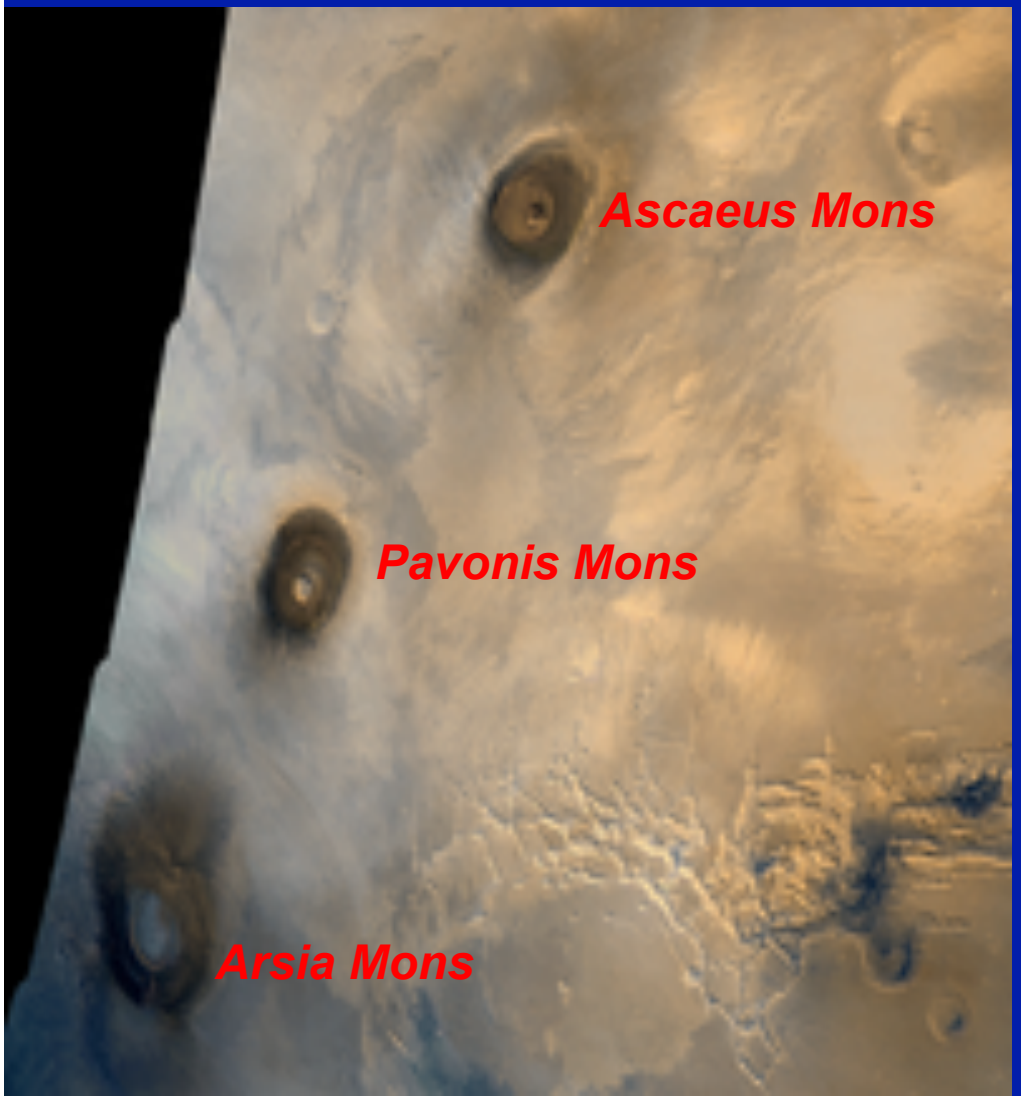
Martian Volcanoes – Olympus Mons





- Central caldera is 27 km above mean surface level
- ~ 3x elevation of Mount Everest above sea level
- 550 km wide
- Caldera complex is 85 km long, 60 km wide, and up to 3 km deep.
- Outer edge defined by an escarpment up to 6 km tall, unique among the shield volcanoes of Mars.

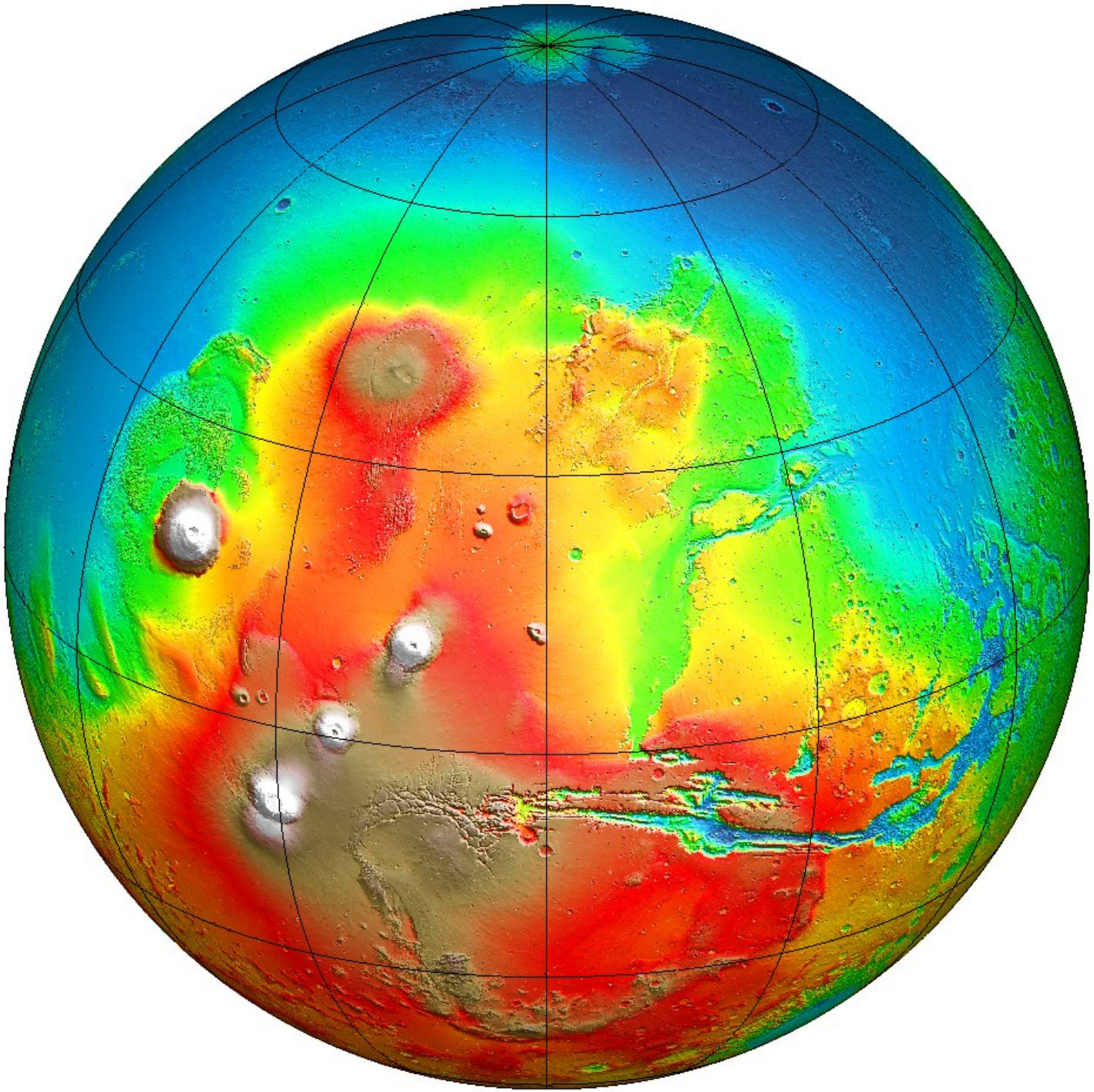
Martian Volcanoes – Tharsis Montes



Tharsis Montes consists of 3 volcanoes:

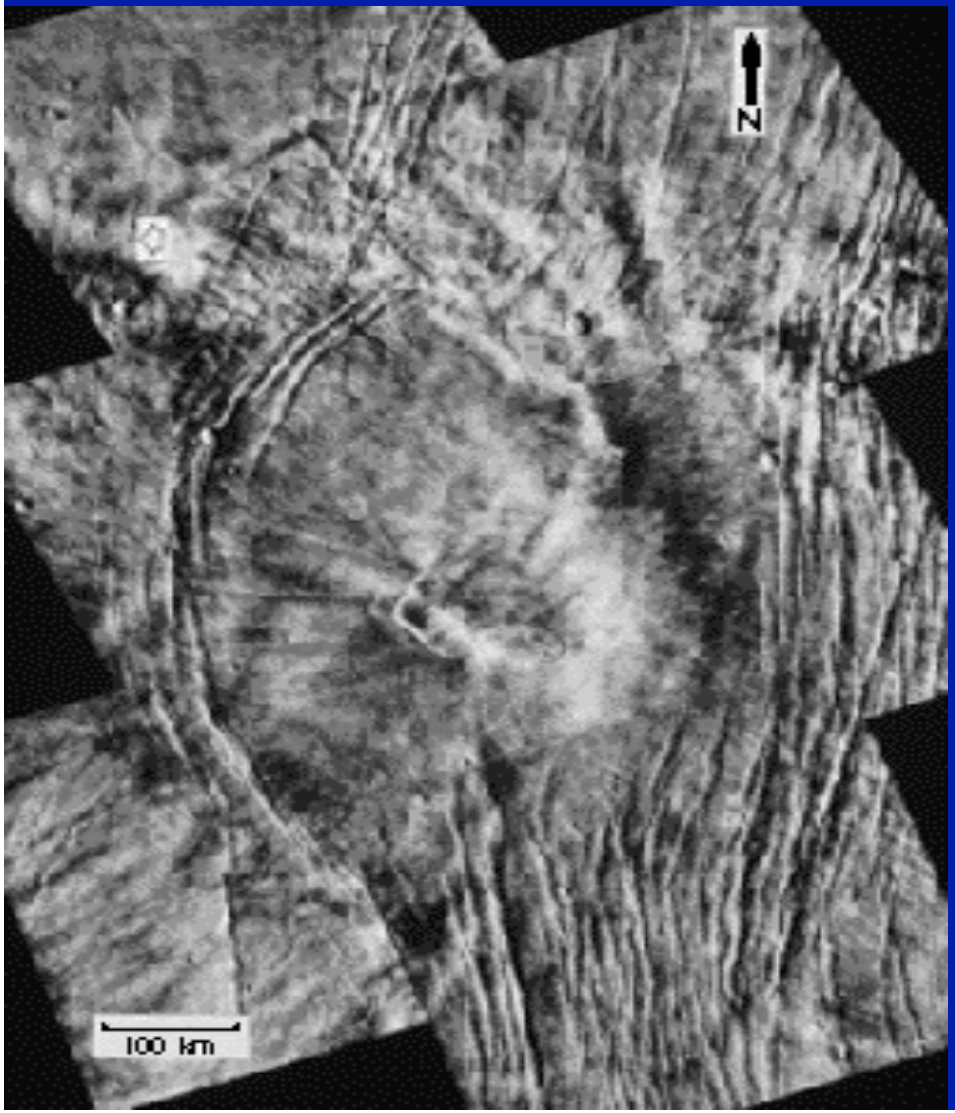
- Arsia Mons
- Pavonis Mons
- Ascraeus Mons

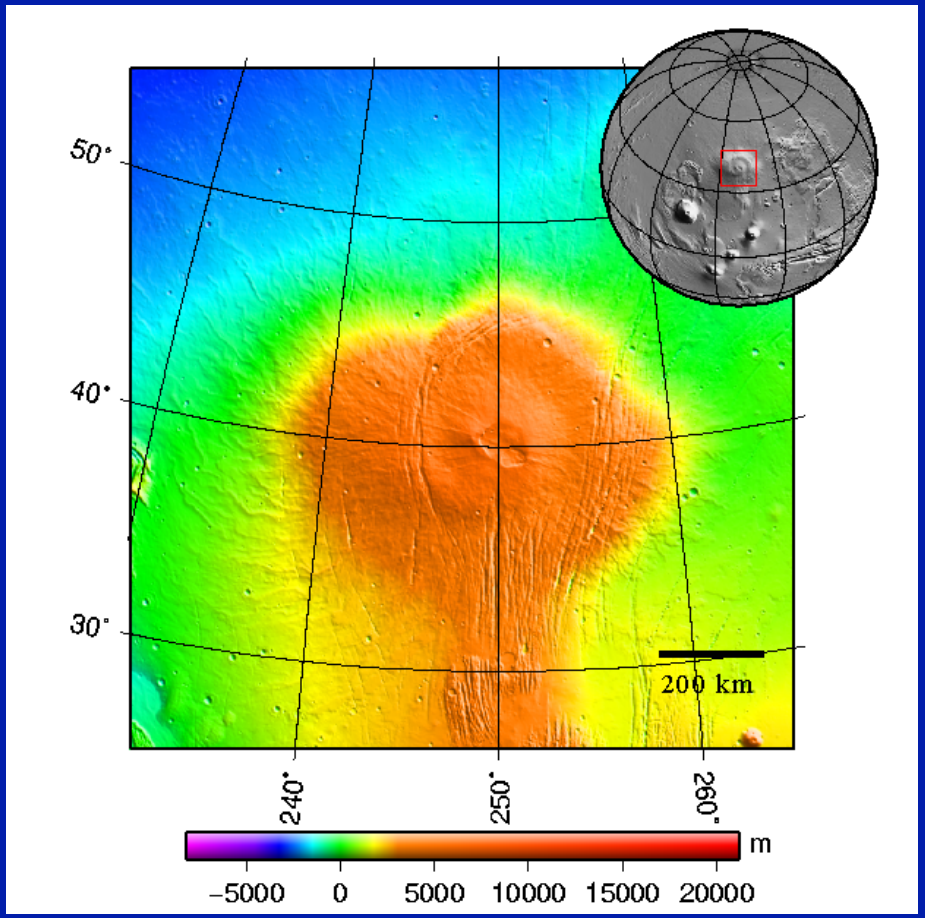
(At lower right is Noctis Labyrinthus, westernmost extension of Valles Marineris)



Martian Volcanoes – Alba Patera

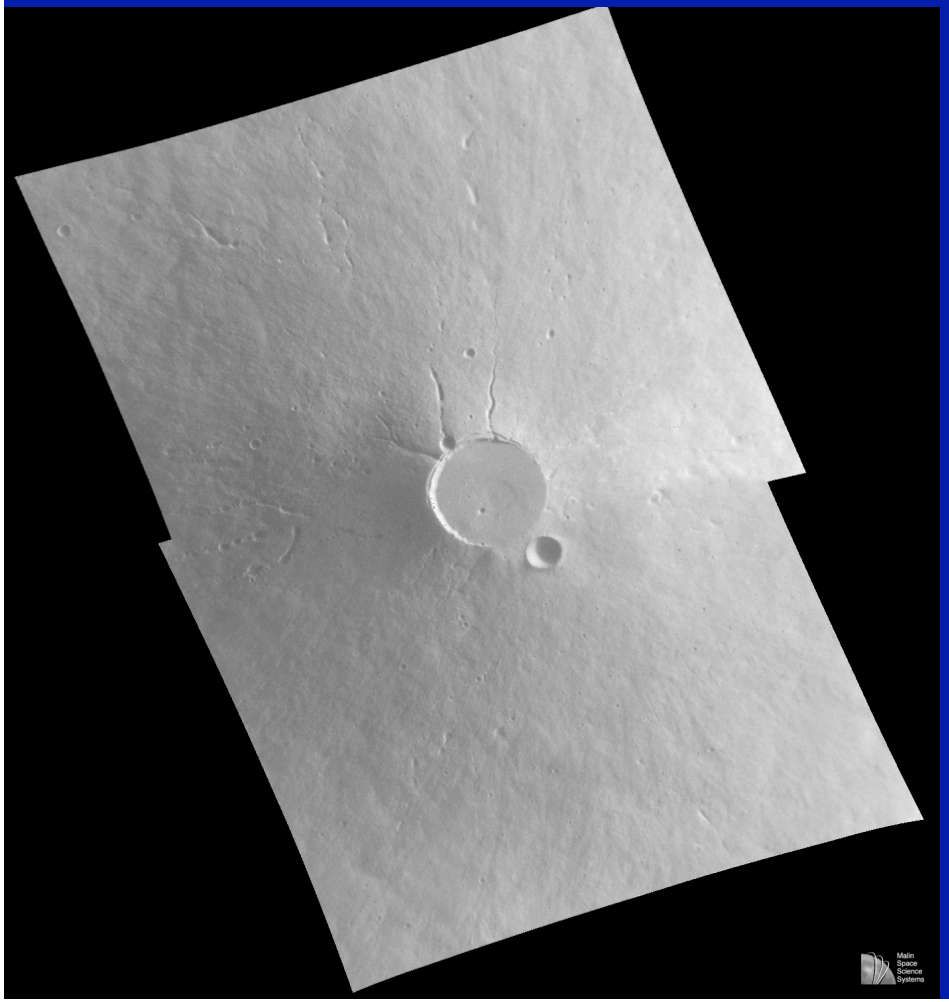
- Largest volcano on Mars
- ~1600 km across; Very flat
- Total height only ~3 km

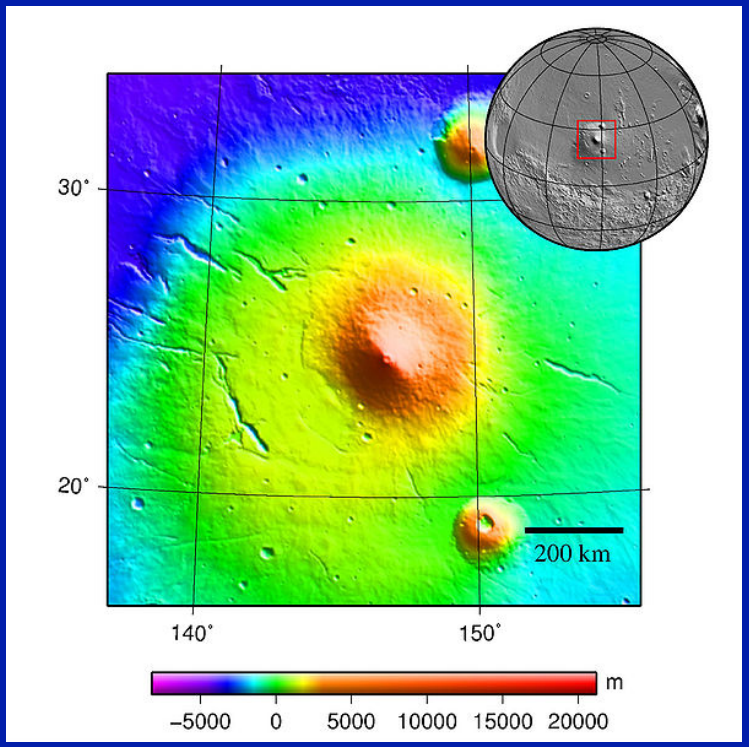




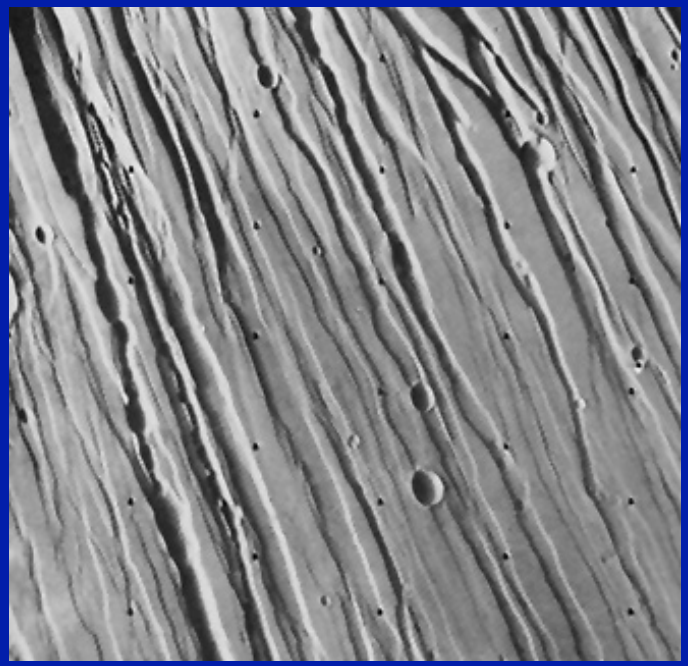
Martian Volcanoes – Elysium

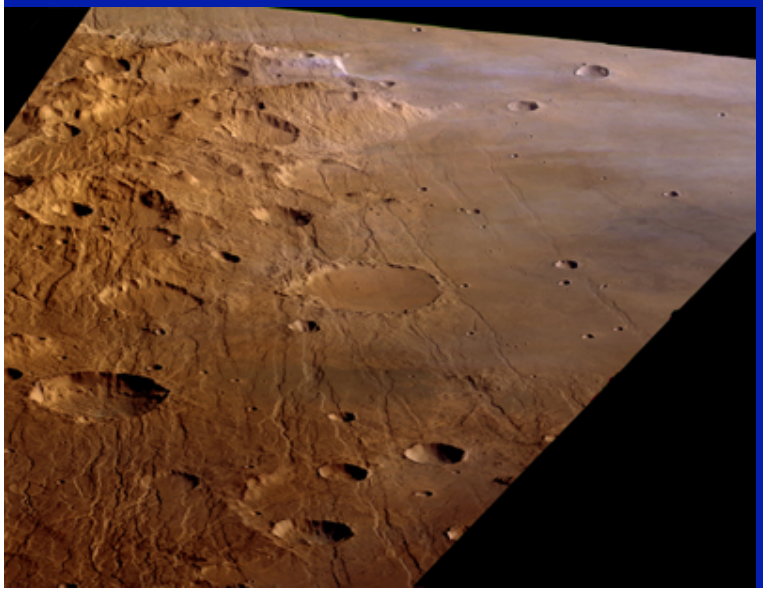
- Located in Elysium Planitia, in eastern hemisphere
- Stands ~13.9 km above surrounding lava plains, and ~16 km above Martian datum
- Diameter is ~240 km, with summit caldera ~14 km across

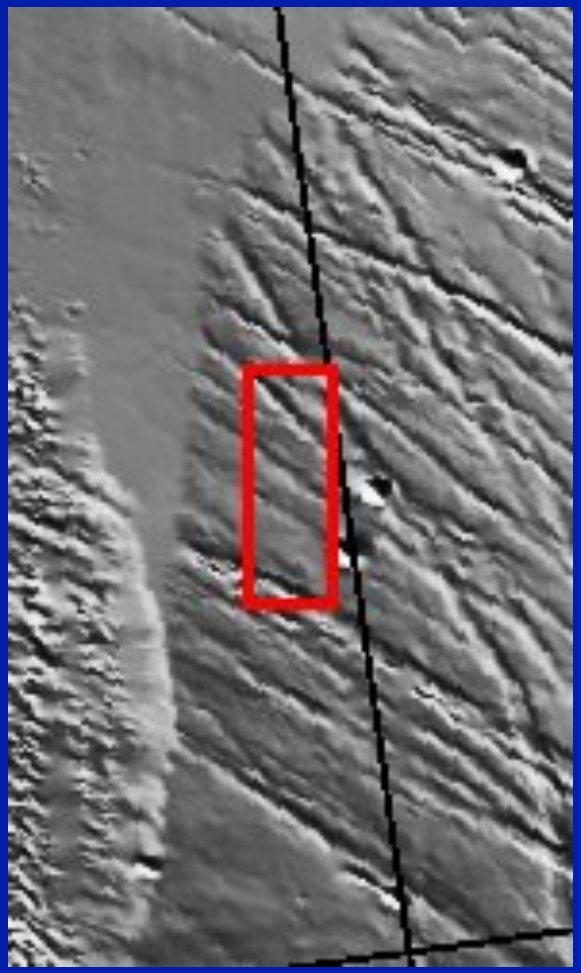


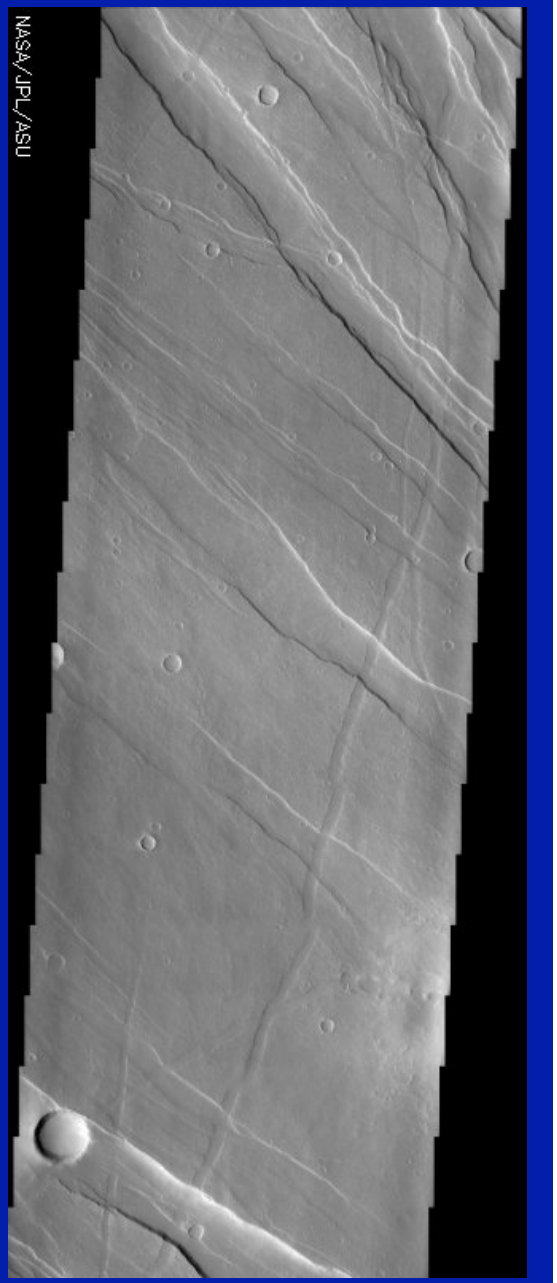


Martian grabens show evidence of tectonic extension

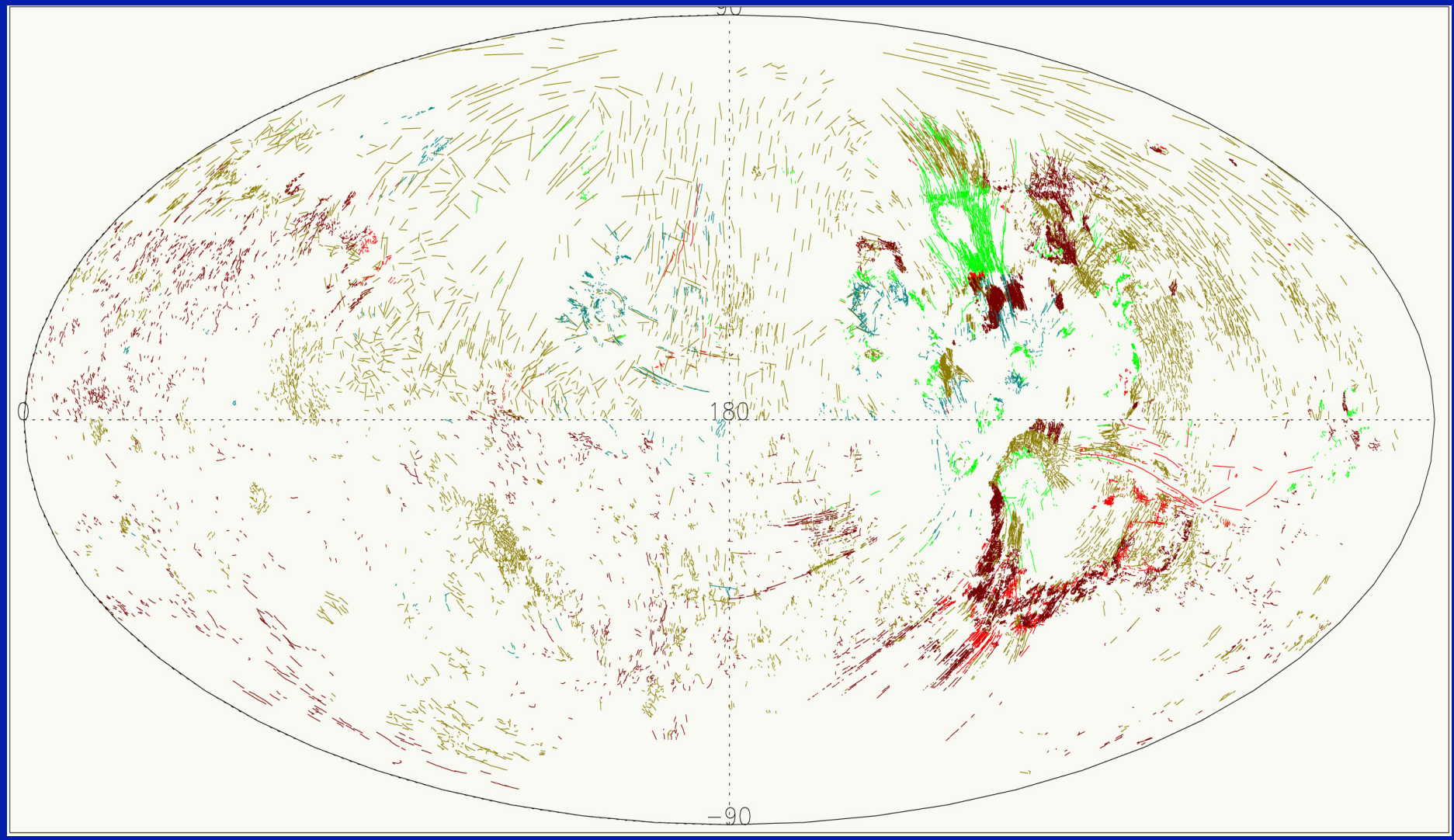








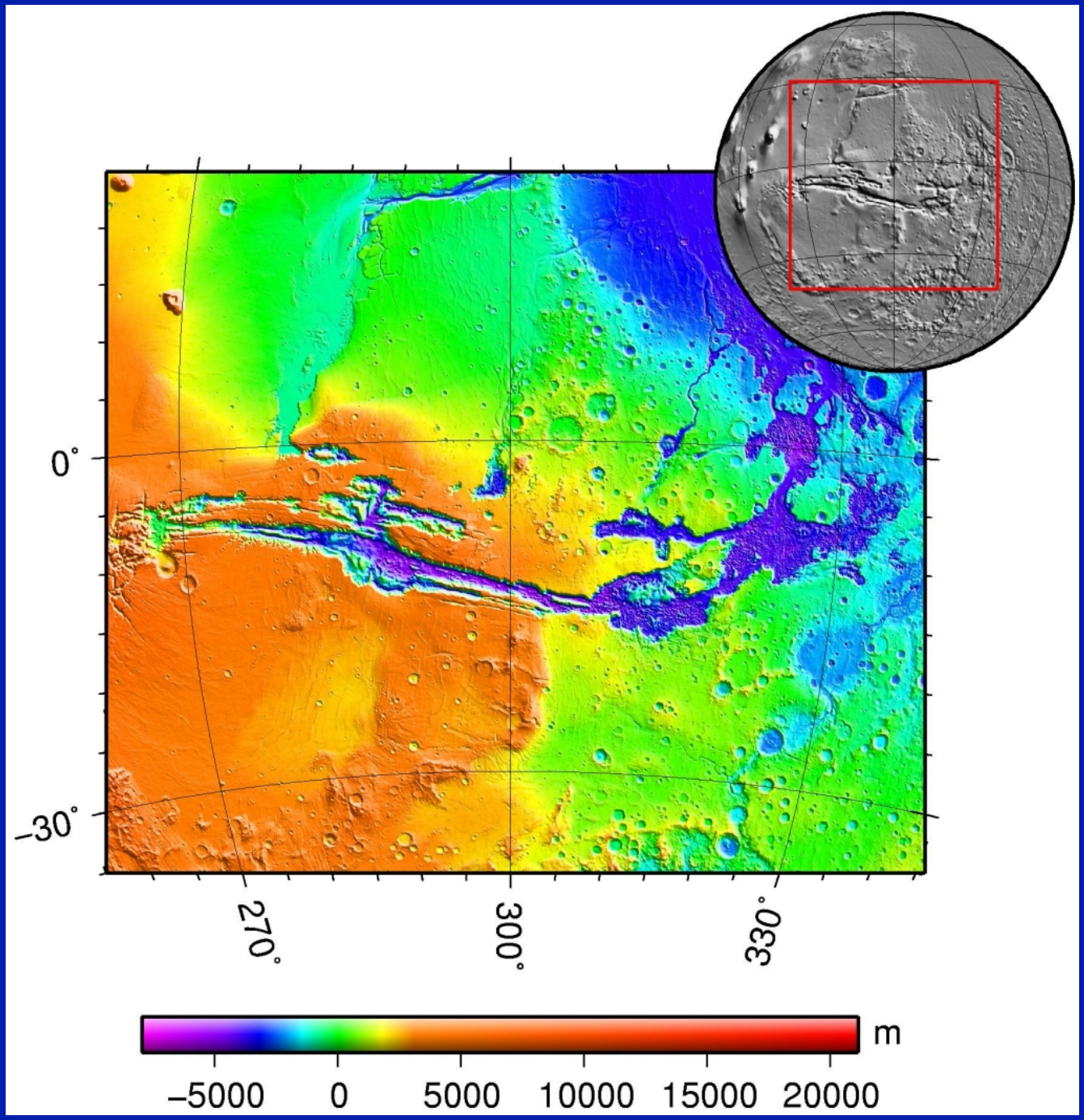
Martian Tectonics: Map of Faults



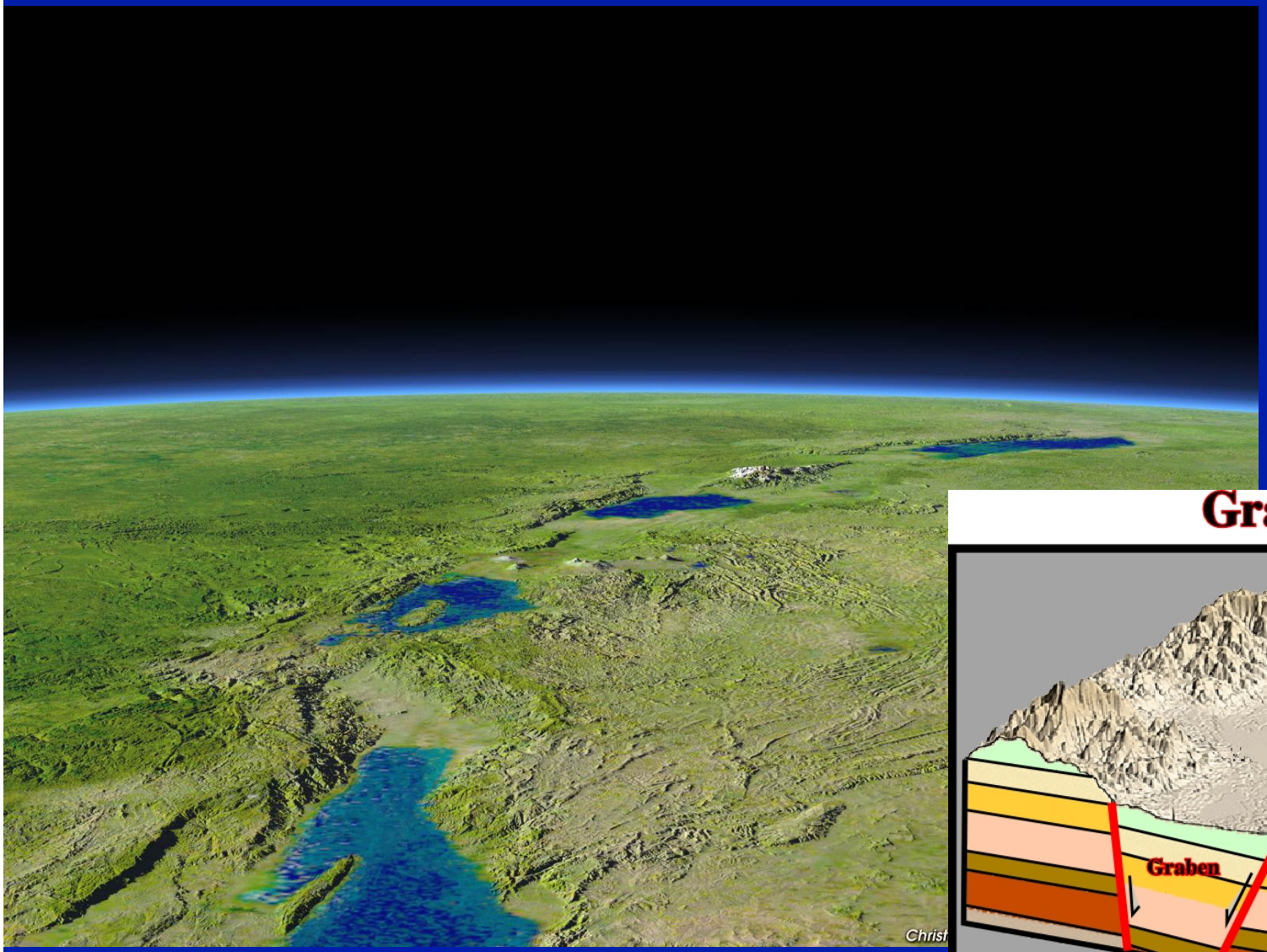
Tharsis Rise

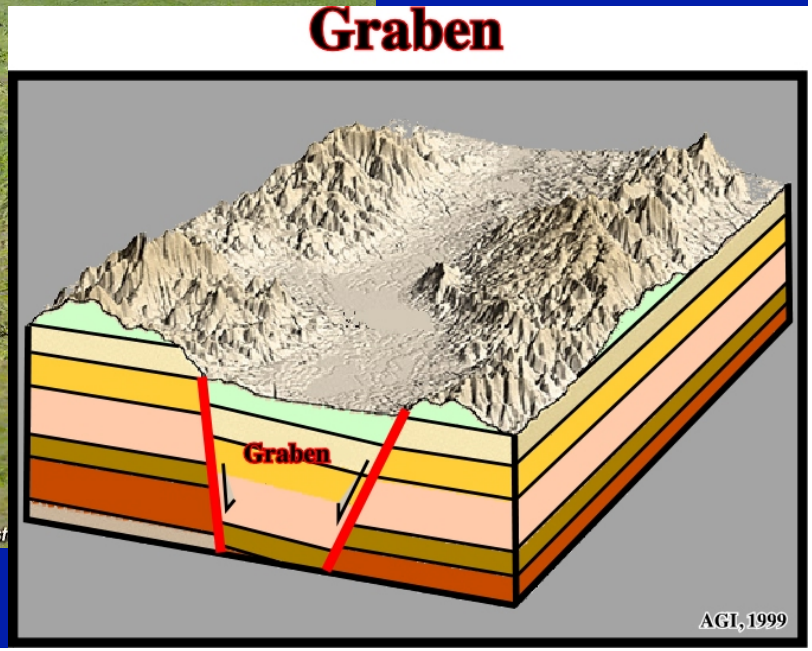
Valles Marineris

- Longest and deepest canyon in solar system
- >4,000 km long
- 200 km wide
- 7 km deep
- Covers almost 1/4 of Mars' equator
- Would stretch across the entire United States



Analogous to East African Rift Valley?





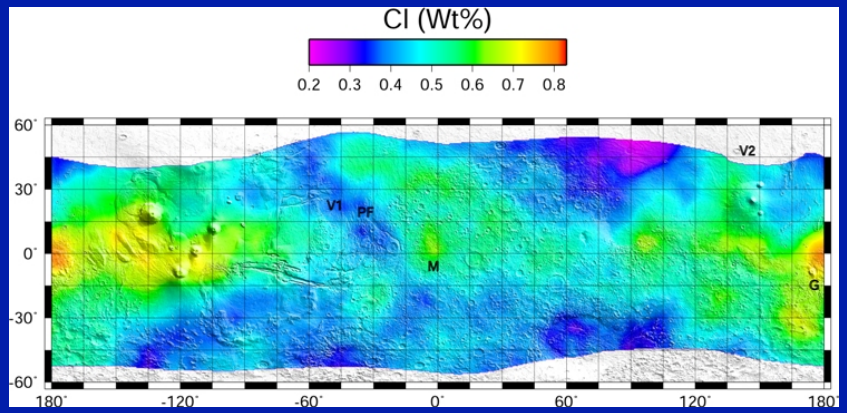
Surface Chemistry

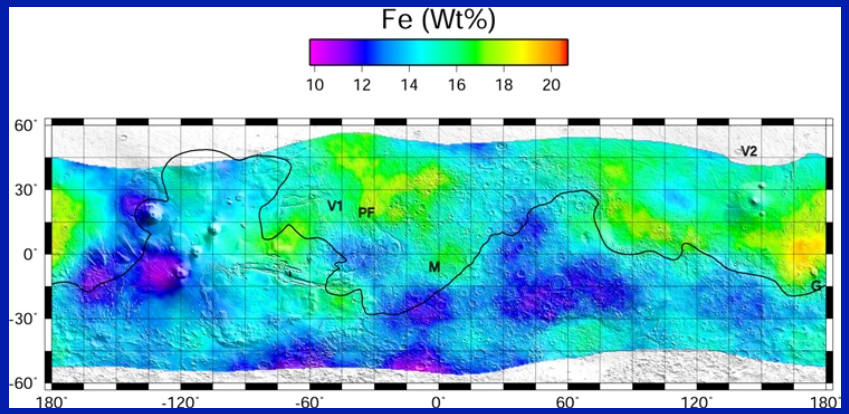
- Surface of Mars is primarily composed of basalt, based upon observed lava flows from volcanoes, Martian meteorites, and data from landers and orbital observations
- Lava flows from Martian volcanoes show the lava has very low viscosity, typical of basalt
- Analysis of soil samples by 1976 Viking landers indicate iron-rich clays consistent with weathering of basaltic rocks

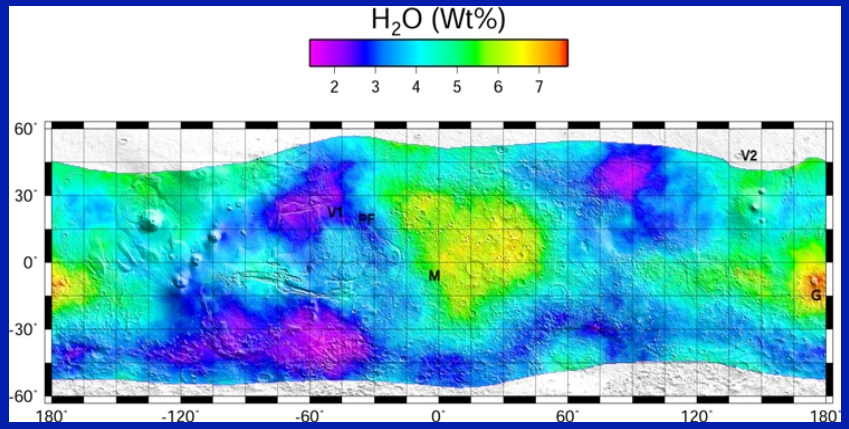
Surface Chemistry

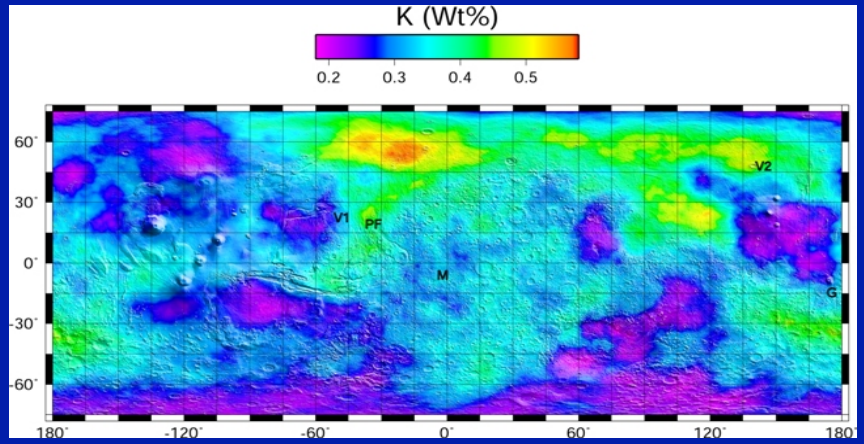
- Some portions of the Martian surface *might* be more silica-rich than typical basalt, perhaps similar to andesitic rocks on Earth (though these observations may also be explained by silica glass, phyllosilicates, or opal)
- Much of the surface is deeply covered by ultra-fine dust
- The red/orange appearance of Mars' surface is caused by iron(III) oxide (Fe_2O_3) (rust).
- Little evidence for significant quantities of carbonate deposits on the surface (would be of great interest to both exobiologists and geochemists)

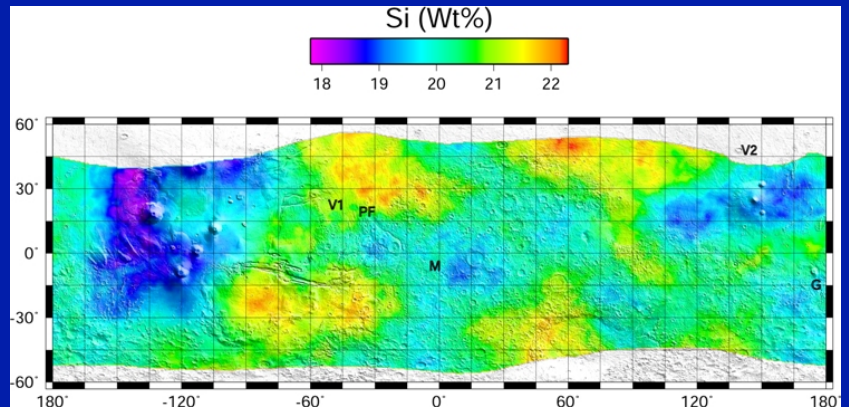
Surface Chemistry-Gamma-Ray Spectrometer Elemental Data

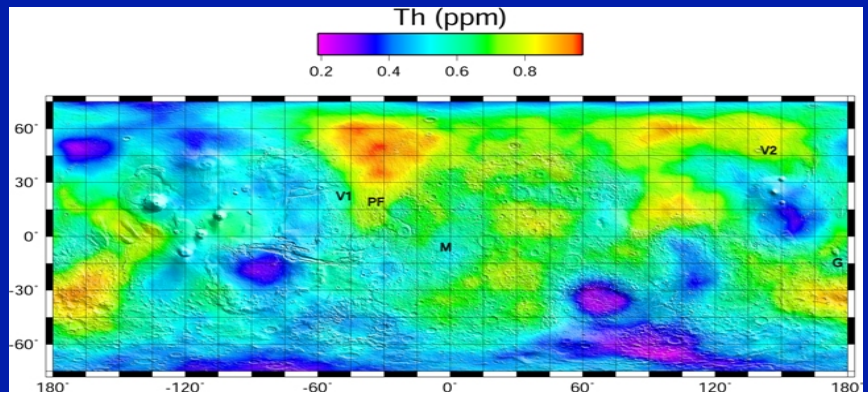




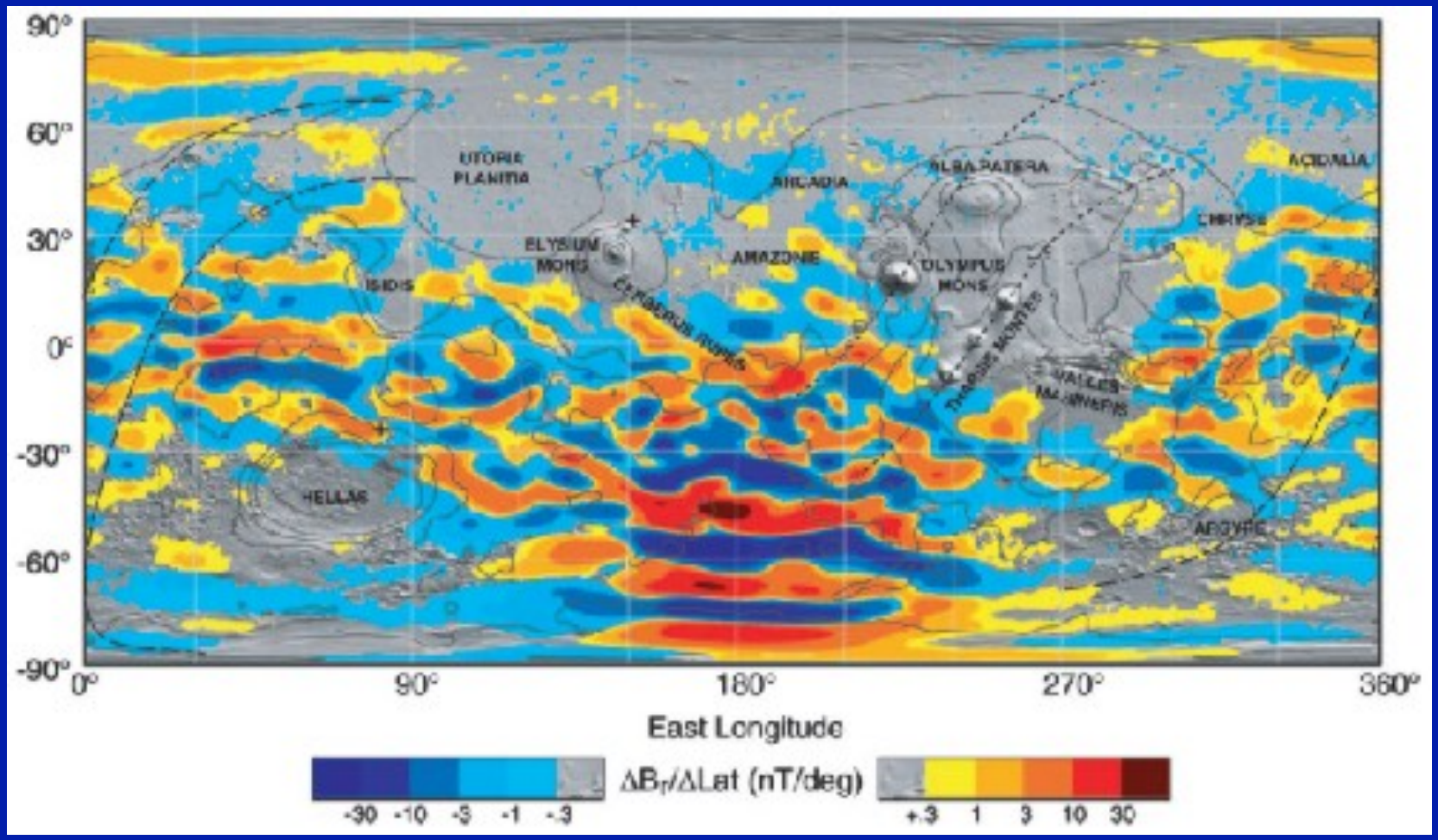






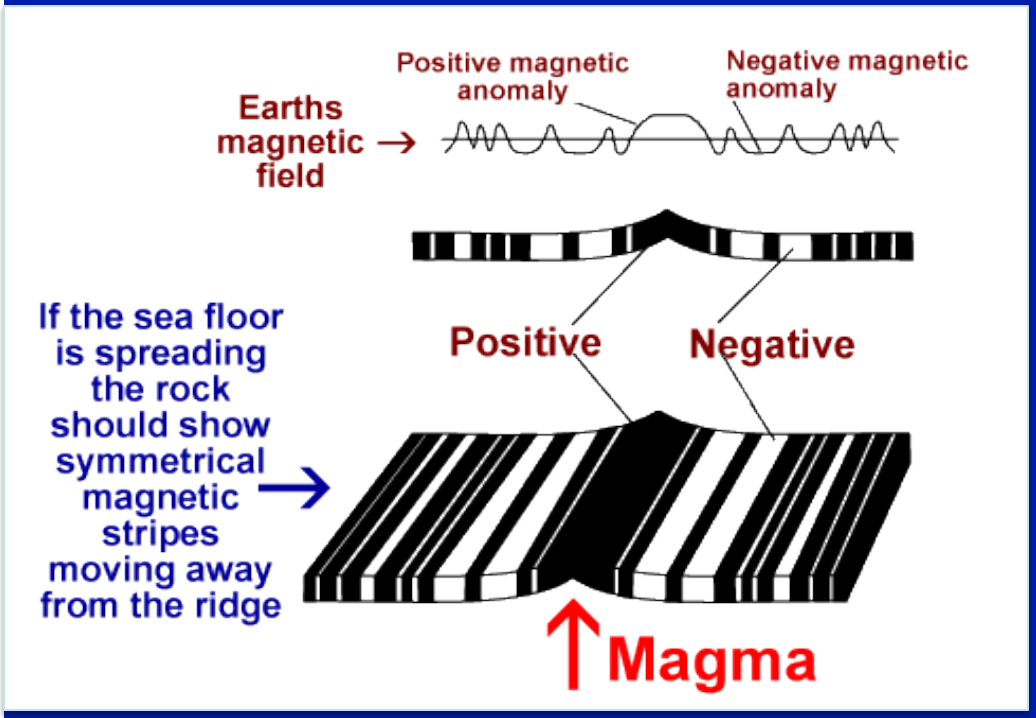


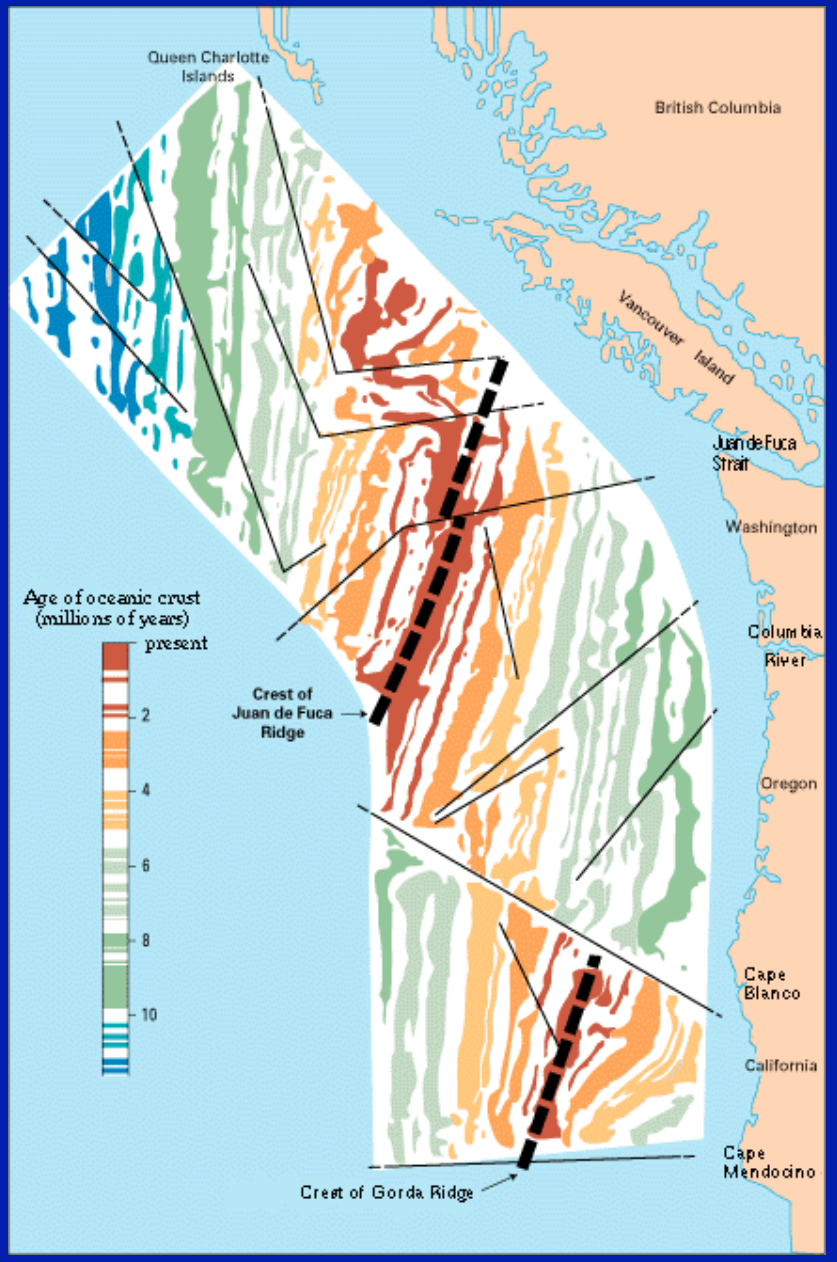
Magnetic field and internal structure



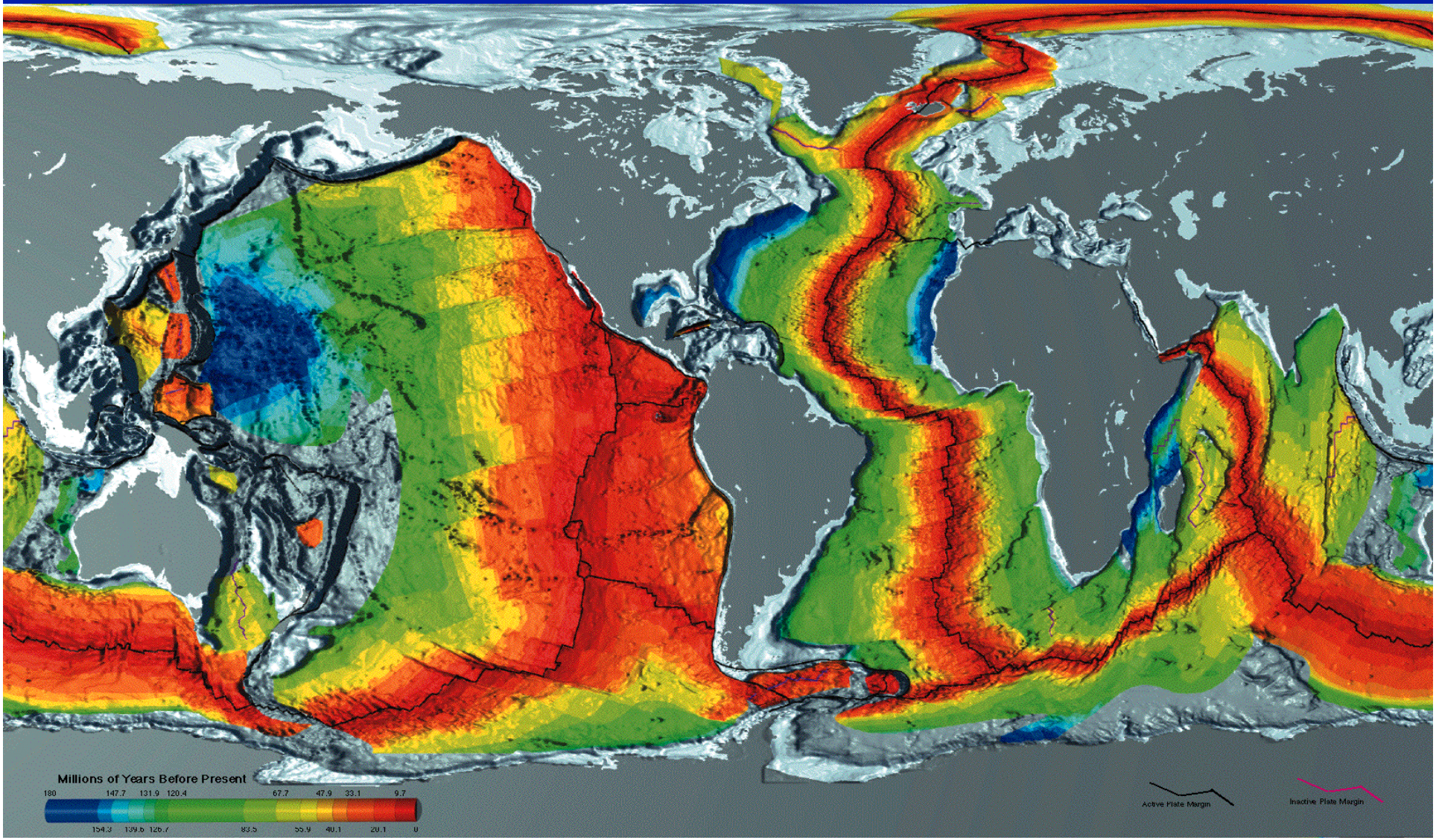
- Mars has no global-scale intrinsic magnetic field today
- Parts of the planet's crust have been magnetized; Polarity reversal of its dipole field may have occurred when the central dynamo ceased, leaving only residual permanent crustal fields.

Ocean Sea Floor Ages from Paleomagnetic Stripes





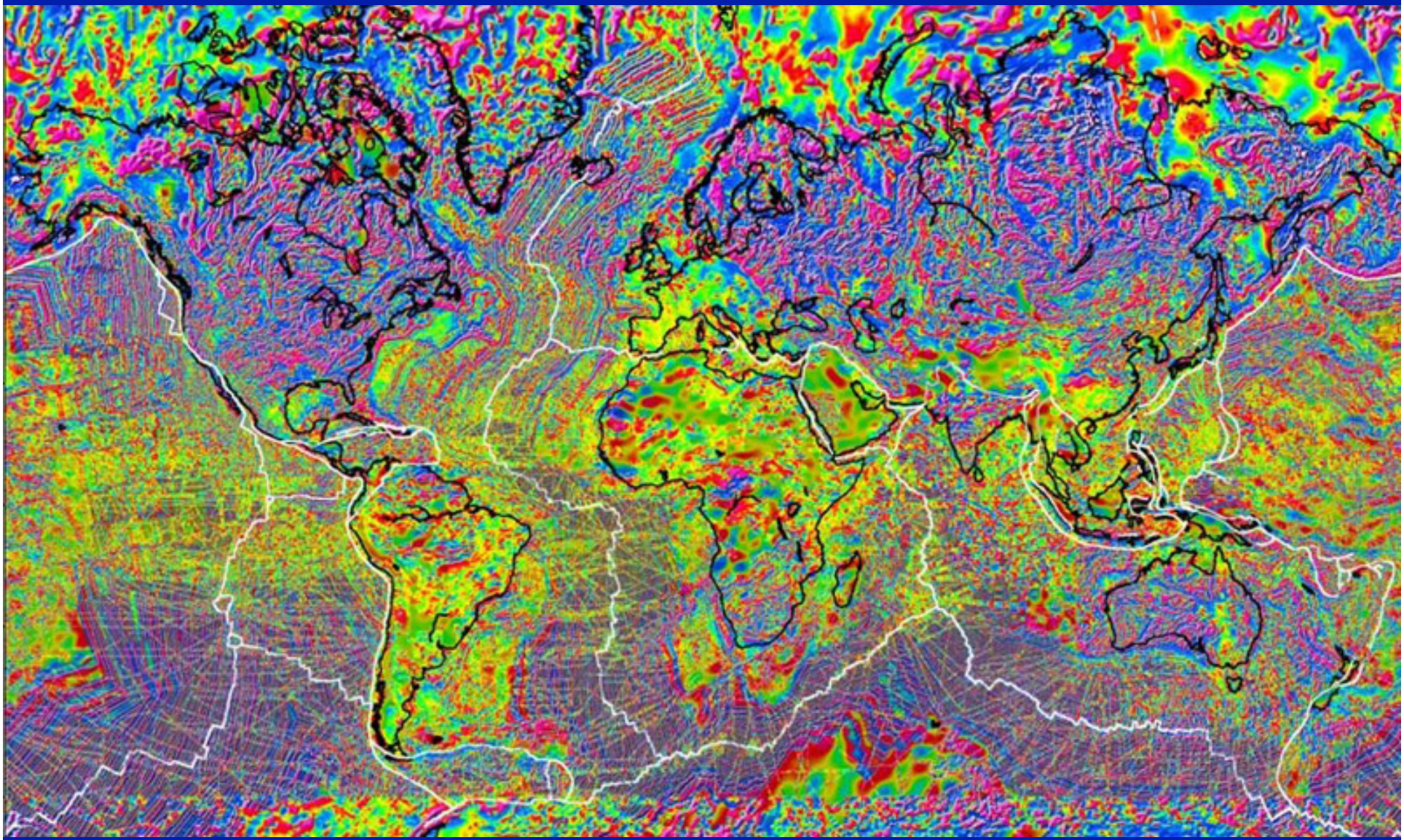
Ocean Sea Floor Ages from Paleomagnetic Stripes



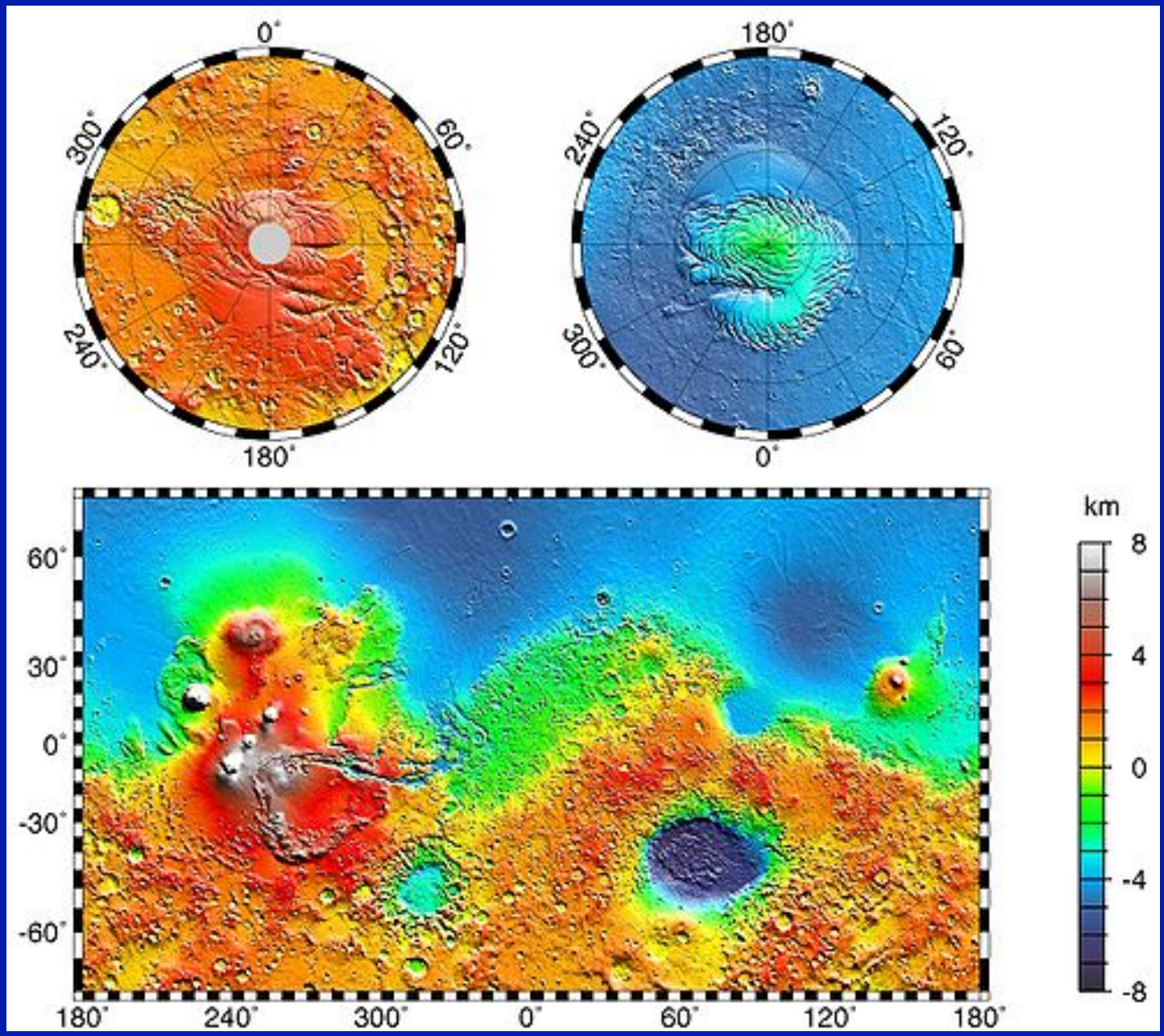
Magnetic field and internal structure

- Similar to the alternating bands found on the ocean floors of Earth.
- Mars' magnetic field varies over its surface, and while it is mostly very small it can in places be locally as high as on Earth.
- Bands may provide evidence of past polar wandering, the change in orientation of Mars' rotation axis.
- It may be possible to date the time when Mars' dynamo turned off:
  - The Tharsis Bulge and large impact basins Hellas and Argyre, aged 4 Ga, are unmagnetized, so the dynamo would have to have turned off ***before*** then, otherwise the molten rock would have remagnetized.
- One theory → bands are evidence of the past operation of plate tectonics on Mars 4 Ga ago, before Mars' planetary dynamo ceased.

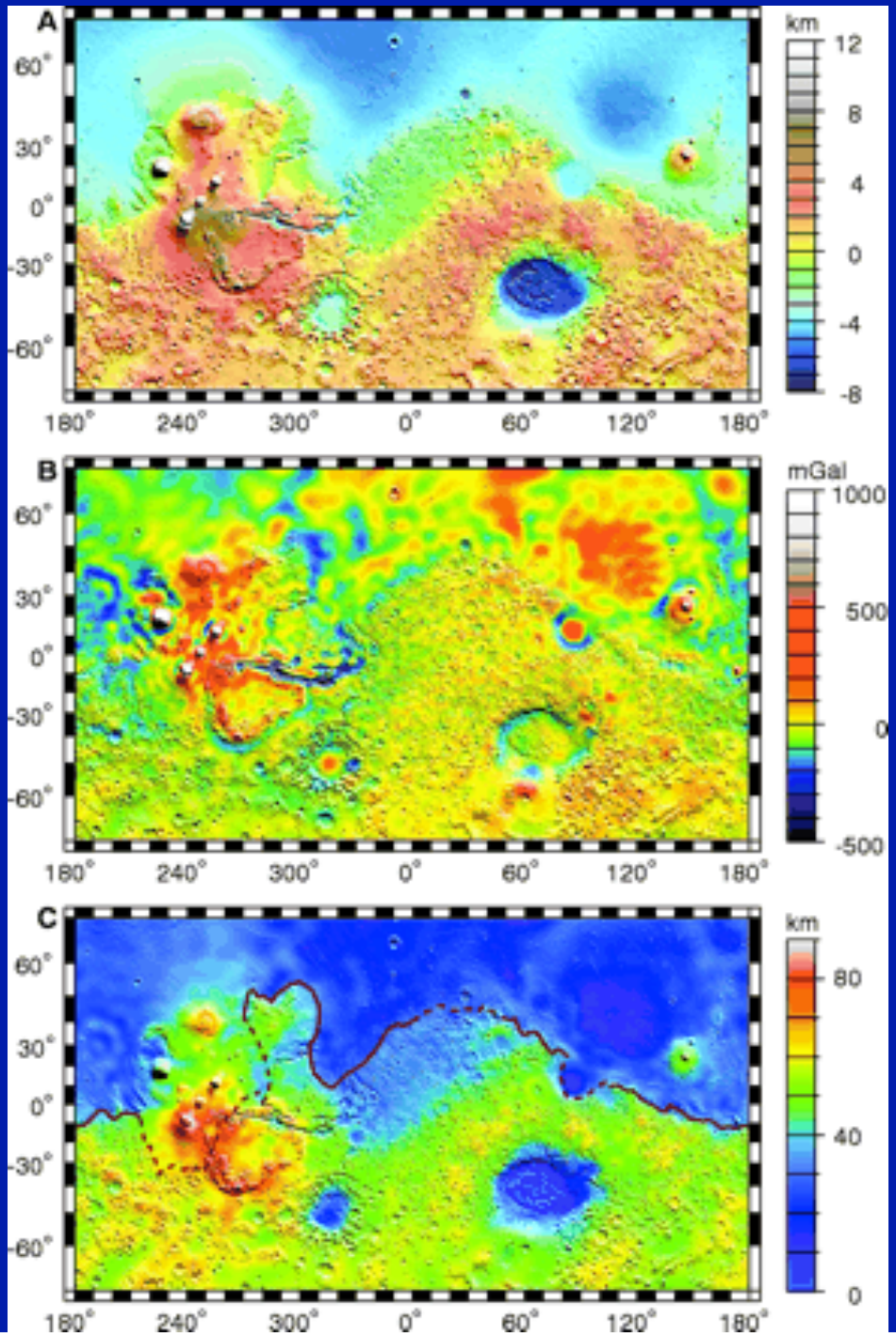
Magnetic Patterns May be More Similar to Continental Magnetic Bands that Reflect Tectonic Events



Martian dichotomy (in elevation)



Internal structure

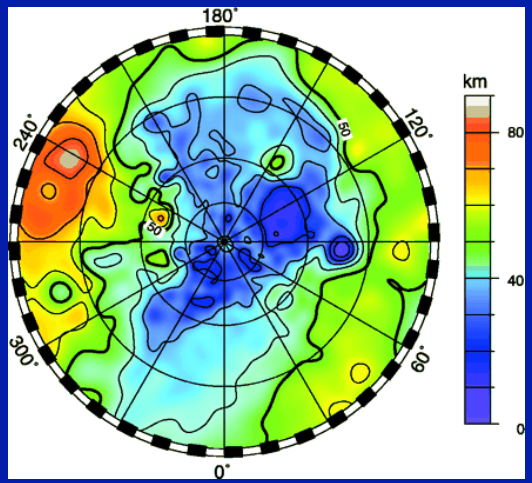


Global maps of Mars from Zuber et al., 2000:

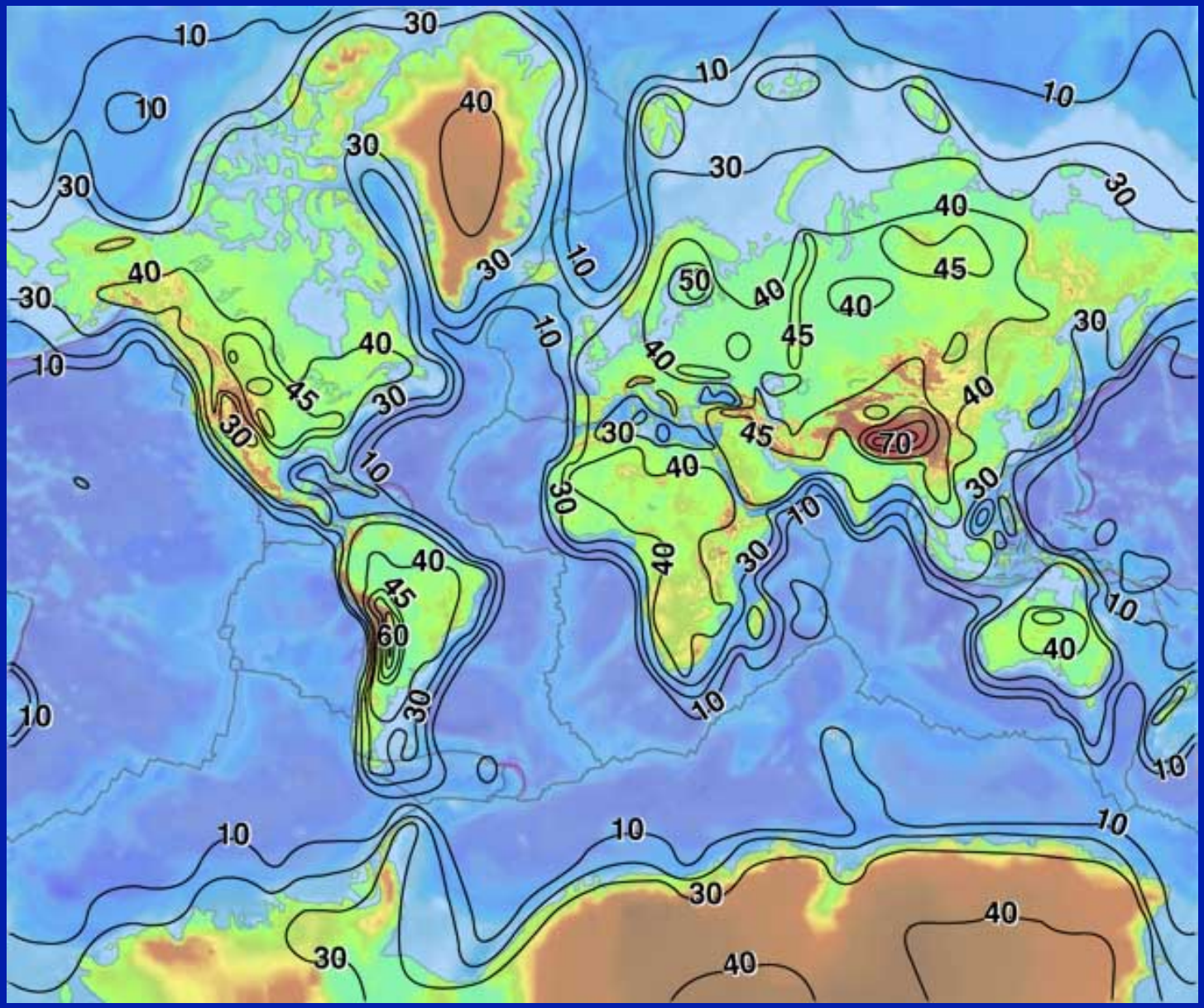
(A) topography,

(B) free-air gravity,

(C) crustal thickness of Mars.



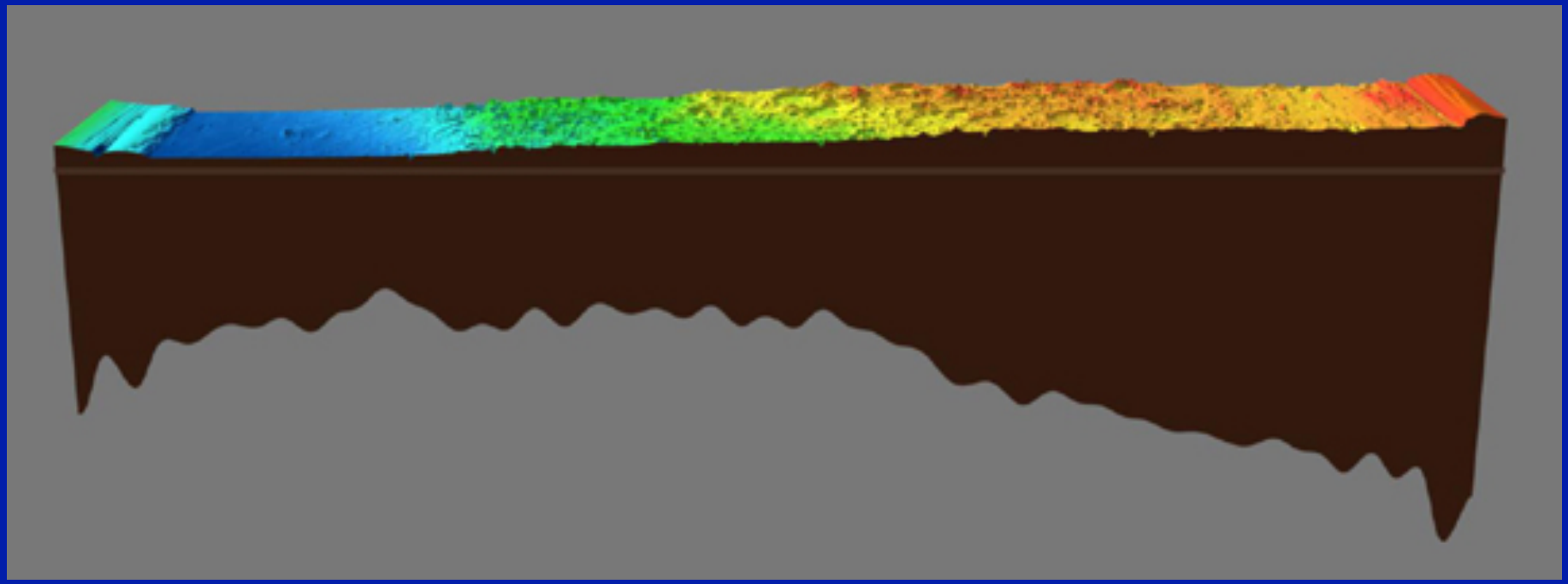
Crustal Thickness on Earth



Internal structure

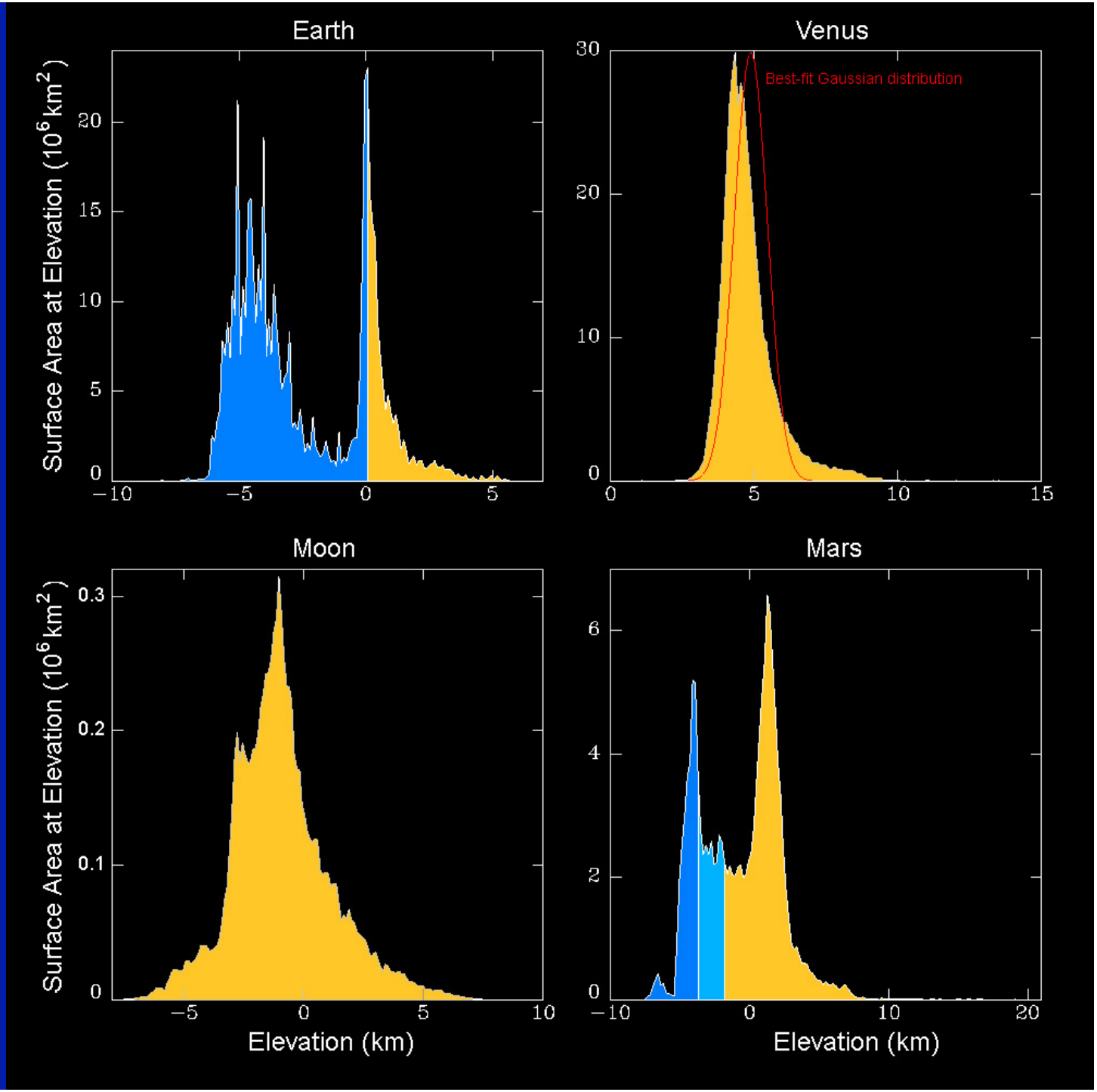
Crust:

- Average thickness is about 50 km; no thicker than 125 km
- This is much thicker than Earth's crust, which is 5 - 70 km.
- Crust is stiff: a radar map of the south polar ice cap showed that it does not deform the crust despite being about 3 km thick.



[Zuber et al., 2000]

Hypsometric Curves:

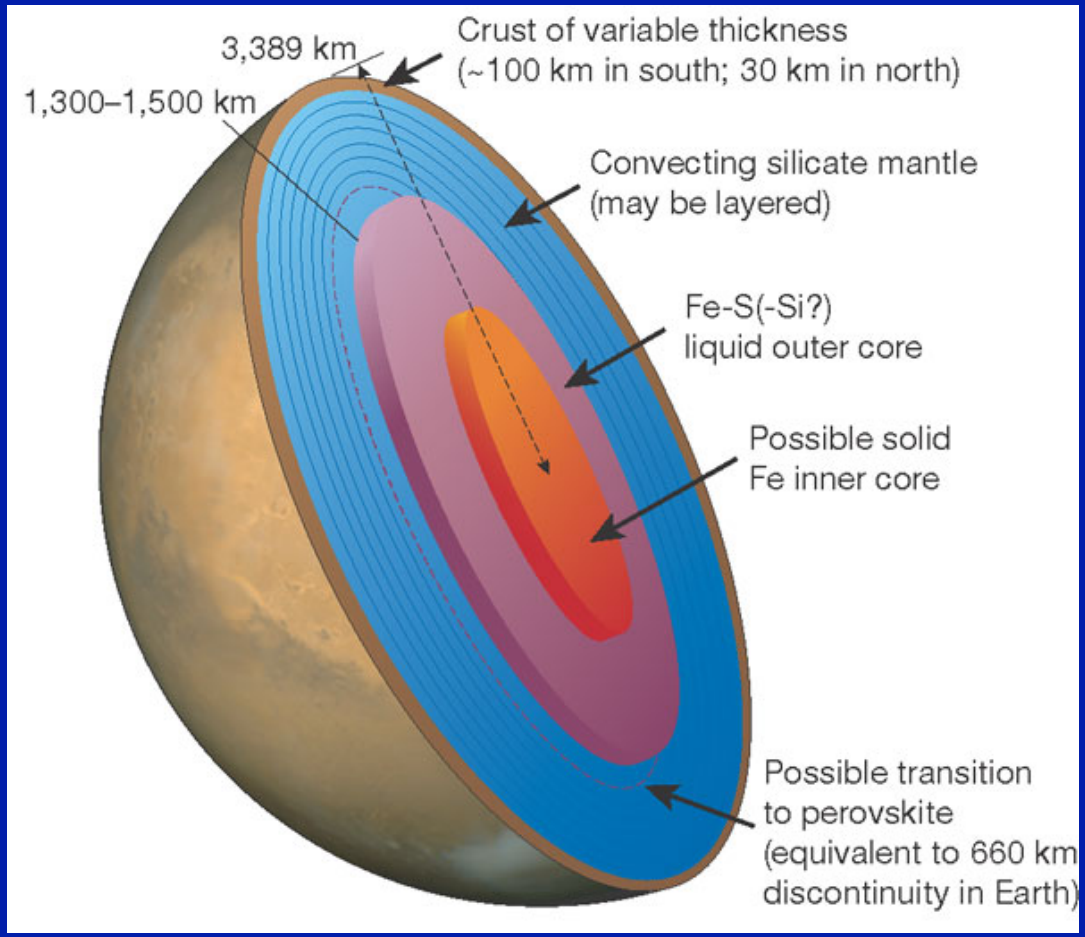


[Paul Stoddard & Donna Jurdy]

Internal structure

Mantle:

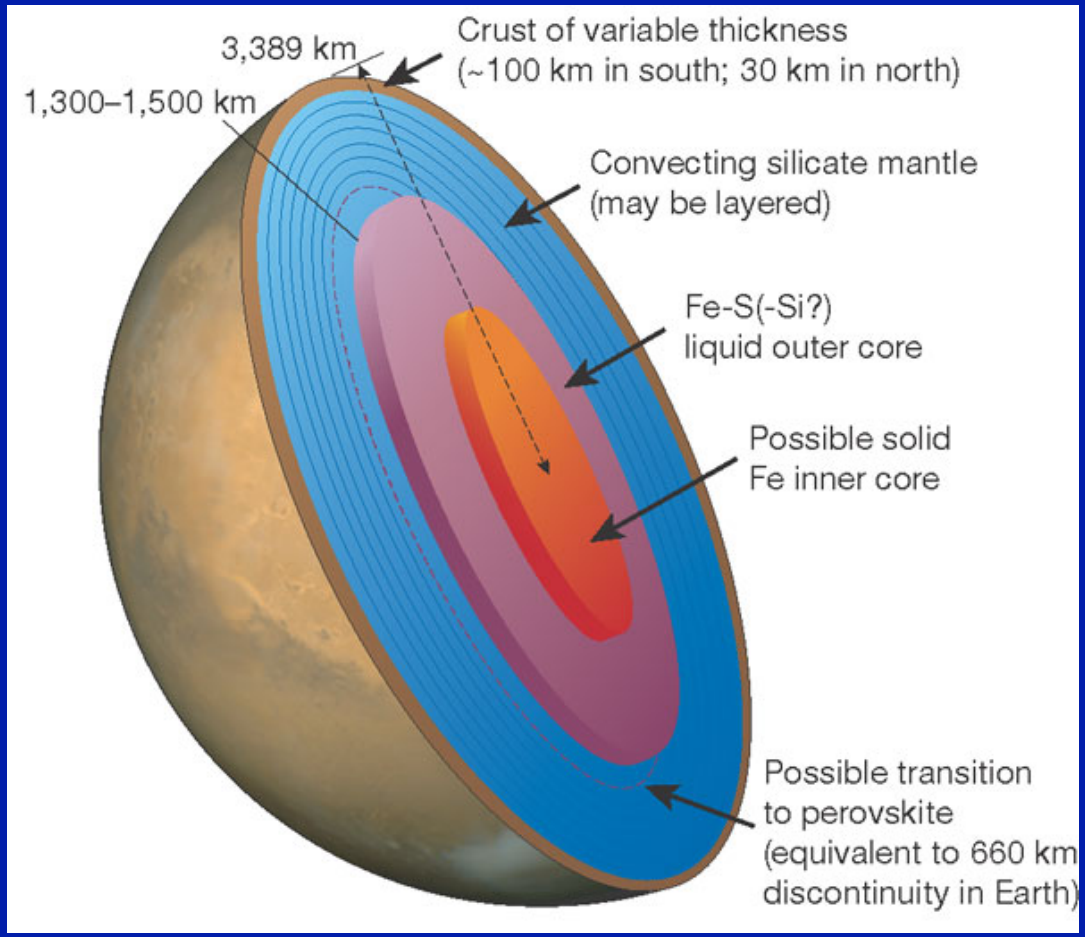
- Primarily silicate, like Earth
- Should still be convecting
- May have mineral phase transitions similar to Earth, though pressure increase is less



Internal structure

Core:

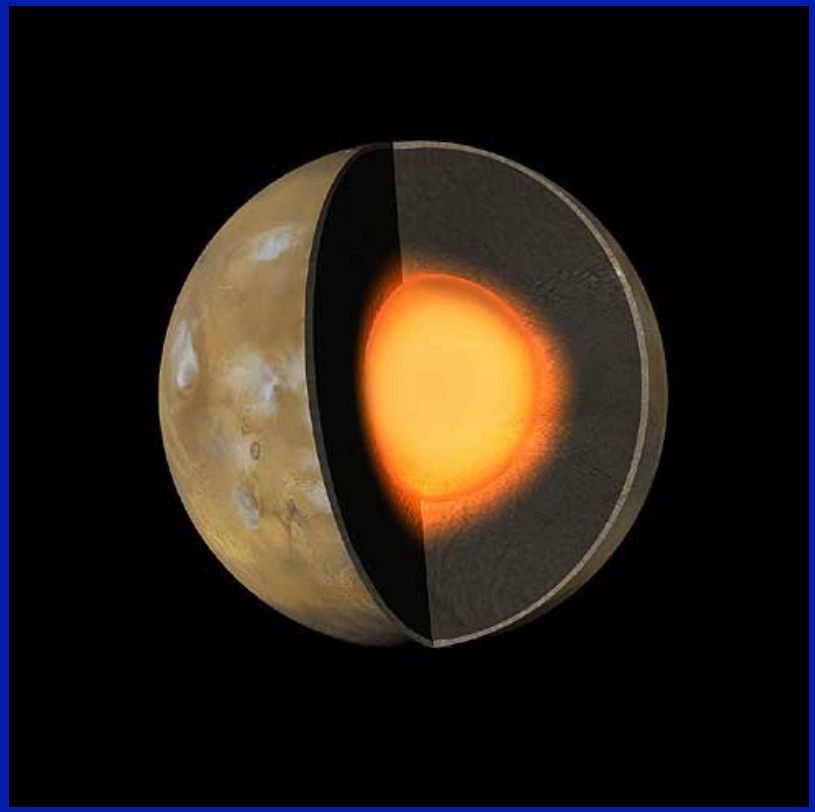
- ~1,480 km in radius (just less than half the total radius)
- Primarily of iron with about 15-17% sulfur??
- A high sulfur content of Mars' core would give it a very low viscosity.



Internal structure

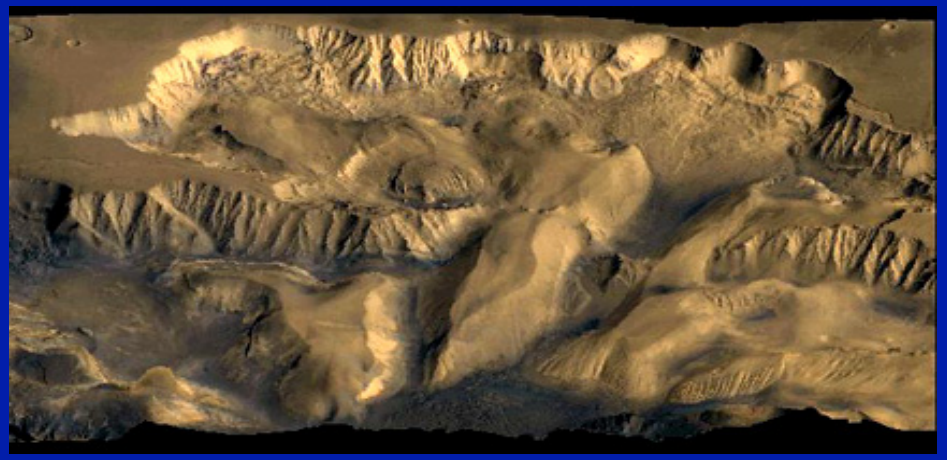
Core is Partially Liquid:

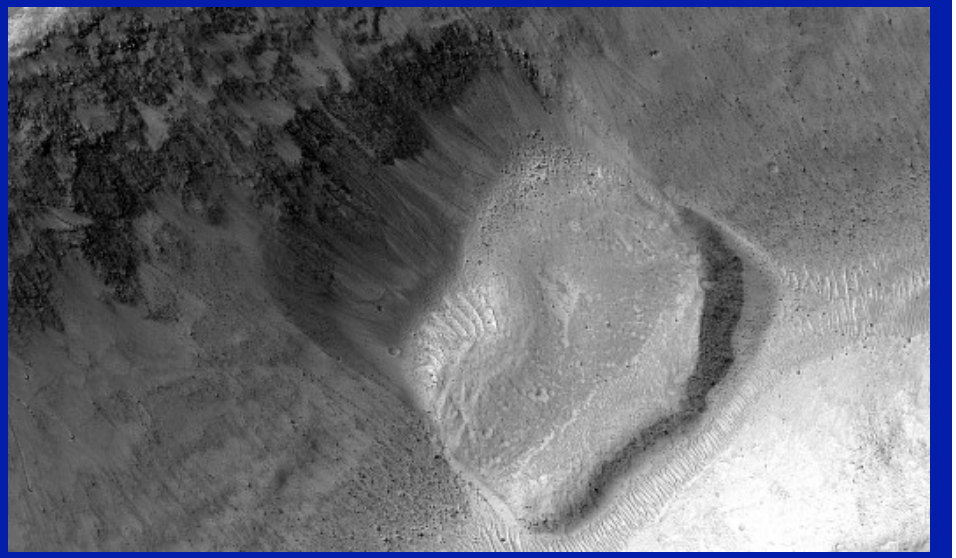
- From size of Mars' solid tidal bulge from the Sun (<1 cm)
- Caused a drift in the tilt of the Mars Global Surveyor's orbit around Mars of 1/1000 of a degree over a month (measurable!)
- Impossible to tell how much of core is liquid and/or solid



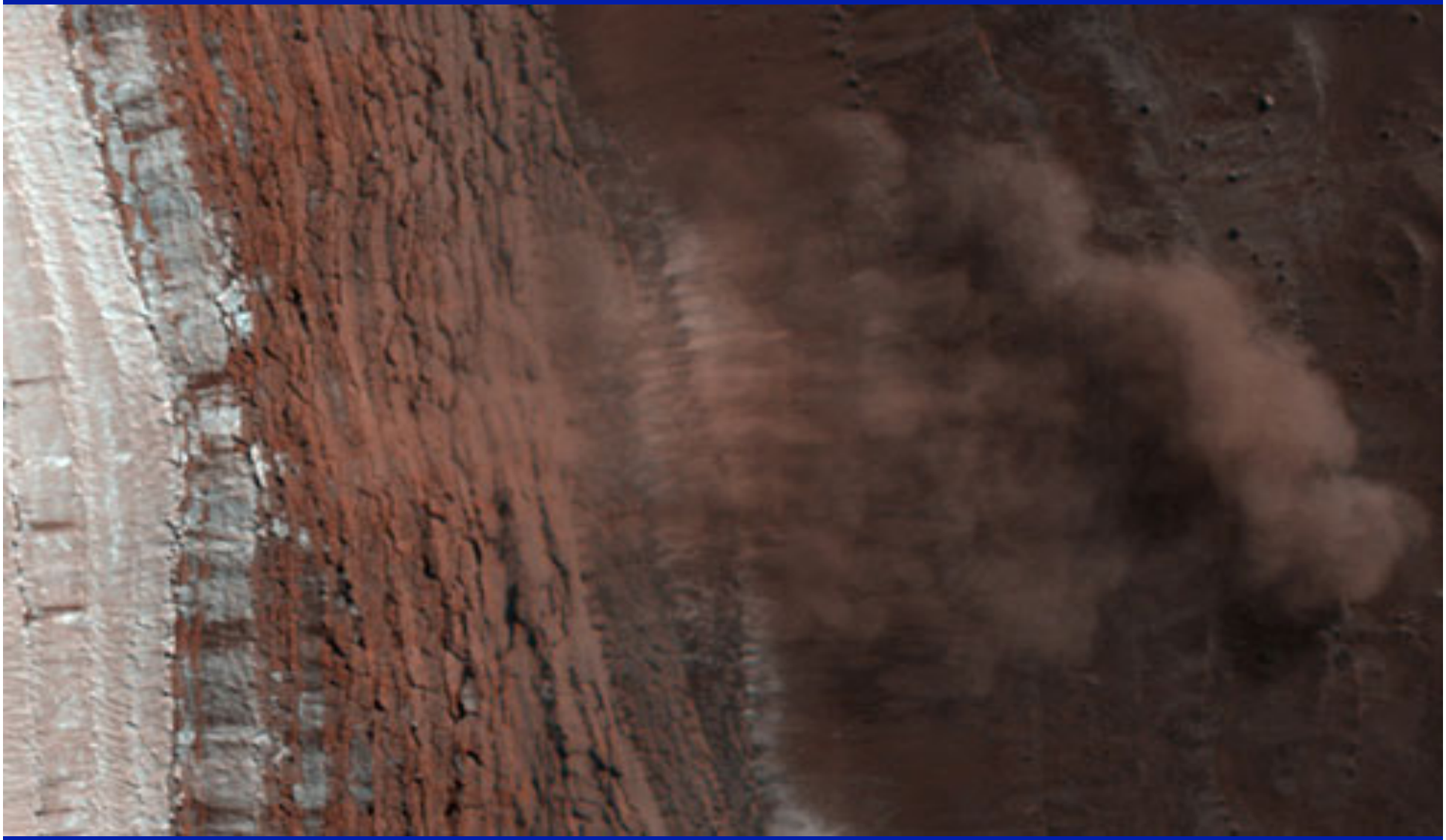
Mass Wasting – Landslides and Slumps (Earth)

Mass Wasting – Landslides and Slumps (Mars)





Mass Wasting – Active Landslide on Mars



Is Mars Seismically Active?

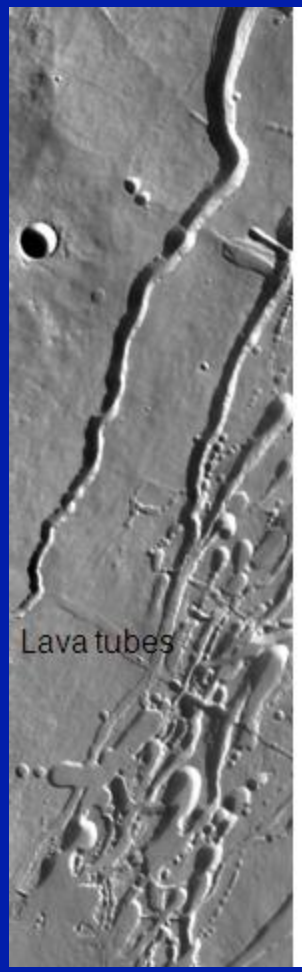
Earth

Mars

"Pit Chains" on Earth often form along extensional faults

Is Mars Seismically Active?

Mars



Context for image on left.

Earth

But Pit Chains Could Also be Collapsed Lava Tubes

Future Missions to Mars

MSL (Mars Science Laboratory)!!