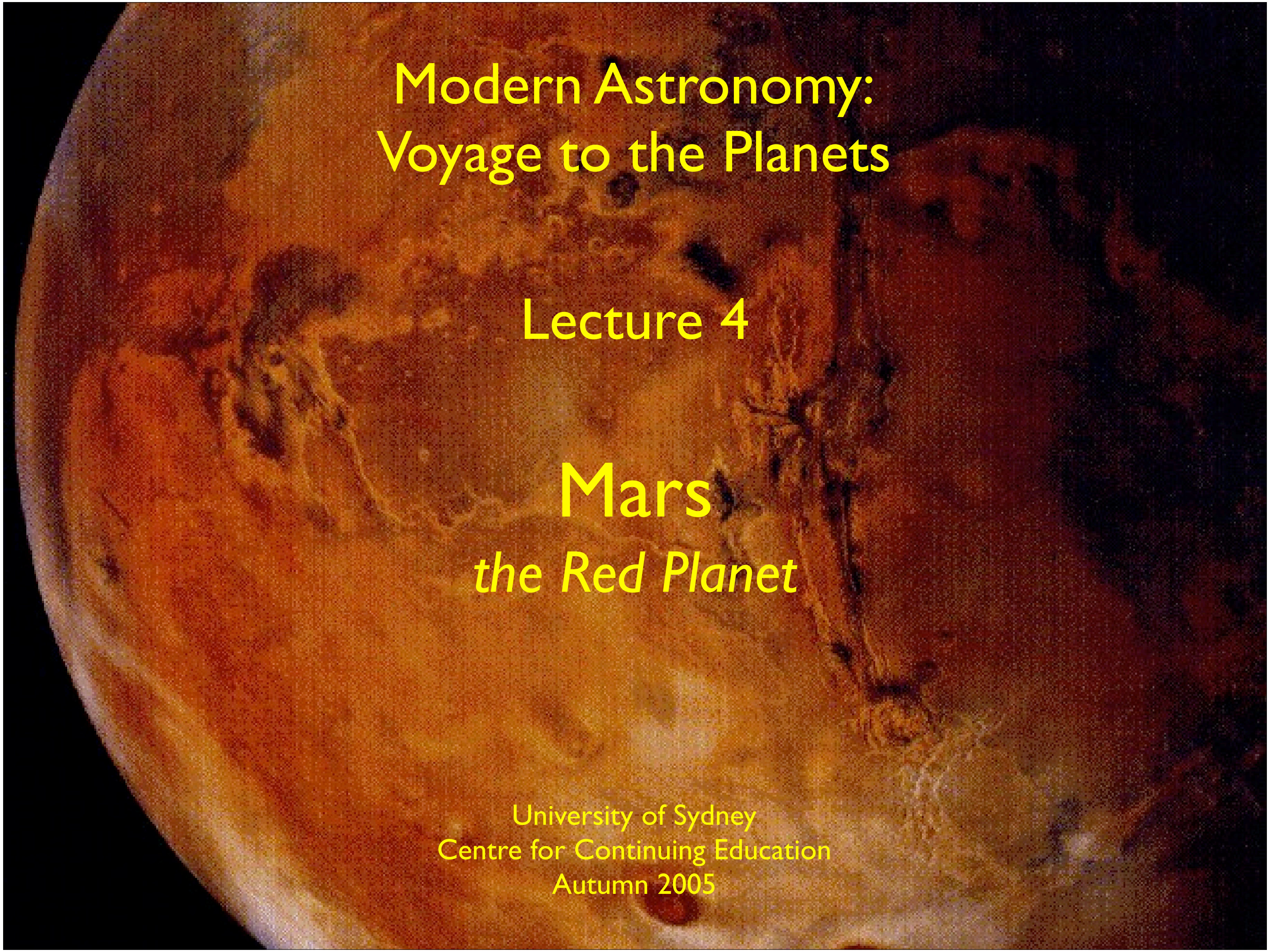
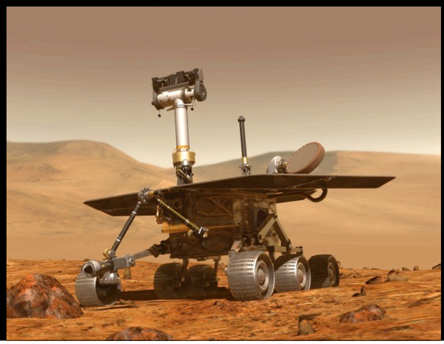
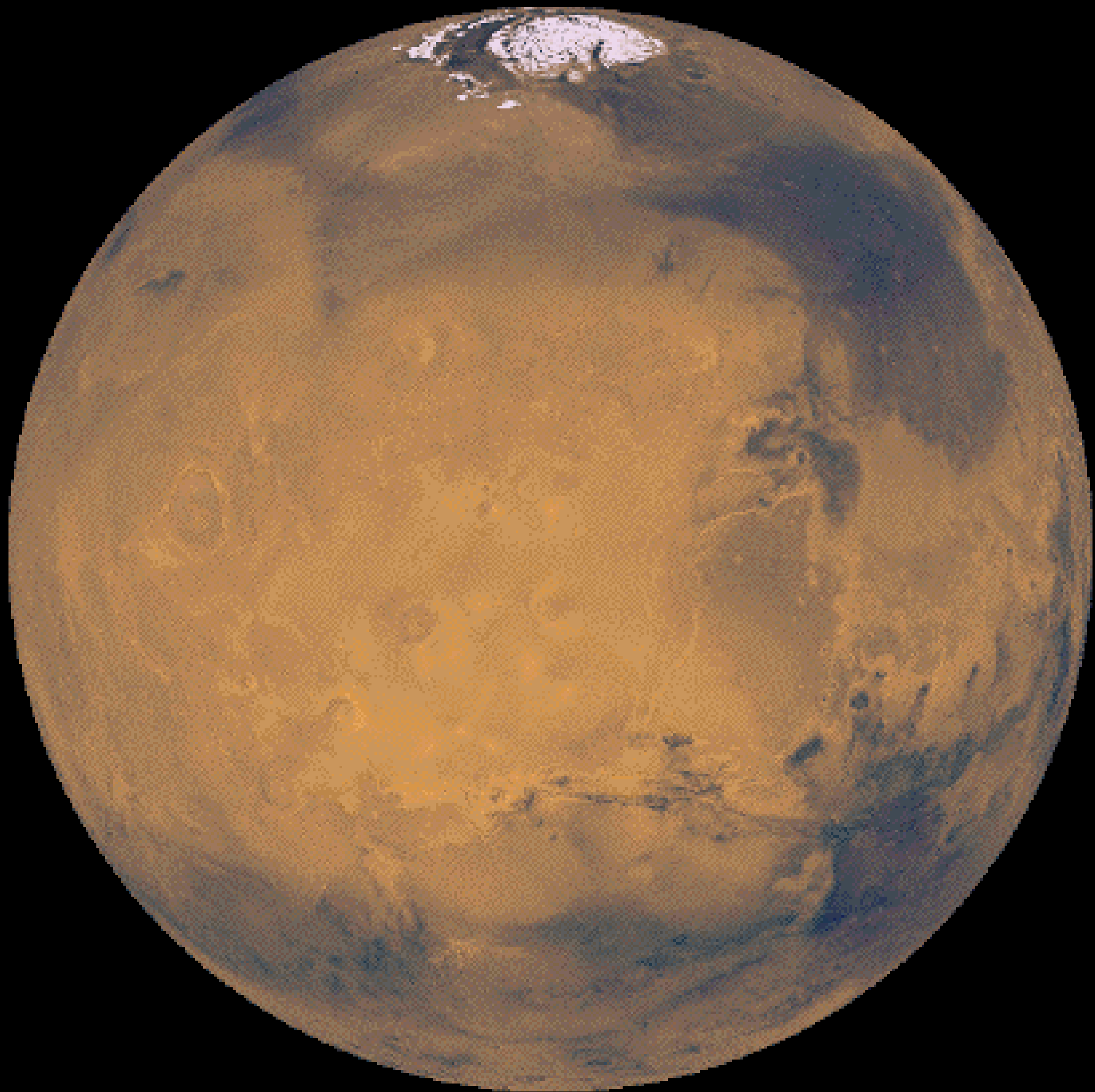

Modern Astronomy:
Voyage to the Planets
Lecture 4
Mars
the Red Planet
University of Sydney
Centre for Continuing Education
Autumn 2005

There have been many spacecraft sent to Mars over the past few decades. Here are the successful ones, with a description of the highlights of each mission.



Mariner 4	flyby 1965	first spacecraft to reach Mars
Mariner 6	flyby 1969	
Mariner 7	flyby 1969	
Mariner 9	orbiter	
Mars 5	USSR orbiter 1973	
Viking 1	orbiter/lander 1976-1982	Landed Chryse Planitia
Viking 2	orbiter/lander 1976-1980	Landed Utopia Planitia
Mars Global Surveyor	orbiter 1997-present	Laser altimeter
Mars Pathfinder	lander & rover 1997	Landed Ares Vallis
2001 Mars Odyssey	orbiter 2001-present	Studying composition
Mars Express/ Beagle	ESA orbiter + lander 2003–present	Geology + atmosphere
Spirit & Opportunity	rovers 2003–present	Landed Gusev Crater & Meridiani

The Face of Mars



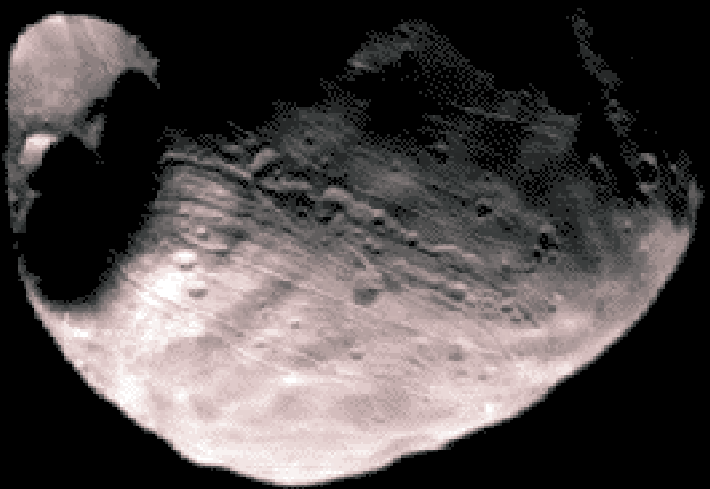
Basic facts

	Mars	Mars/Earth
Mass	0.64185×10^{24} kg	0.107
Radius	3397 km	0.532
Mean density	3.92 g/cm^3	0.713
Gravity (equatorial)	3.71 m/s^2	0.379
Semi-major axis	227.92×10^6 km	1.524
Period	686.98 d	1.881
Orbital inclination	1.85°	-
Orbital eccentricity	0.0935	5.59
Axial tilt	25.2°	1.074
Rotation period	24.6229 h	1.029
Length of day	24.6597 h	1.027

Mars is quite small relative to Earth, but in other ways is extremely similar. The radius is only half that of Earth, though the total surface area is comparable to the land area of Earth. It take nearly twice as long to orbit the Sun, but the length of its day and its axial tilt are very close to Earth's.

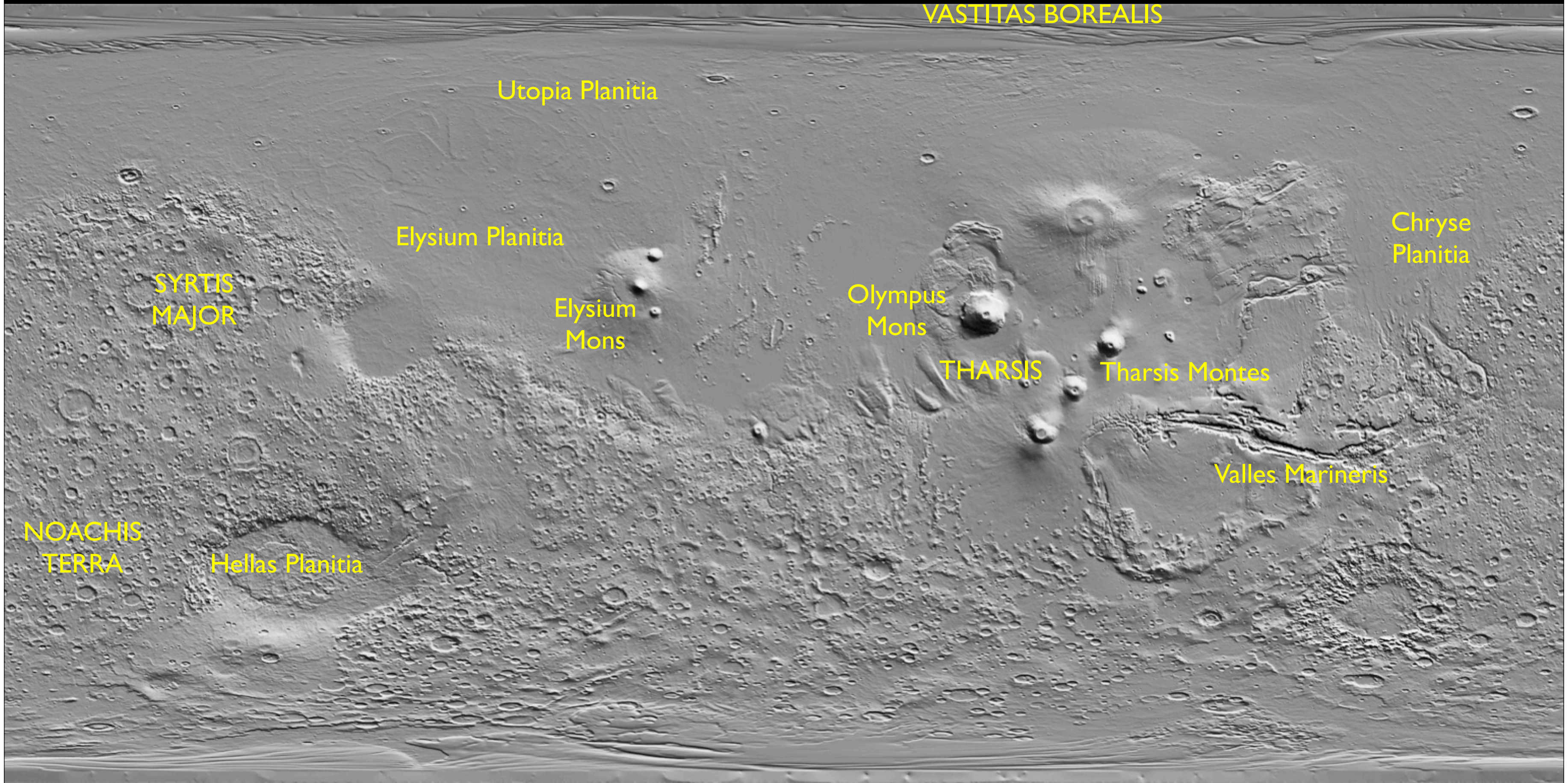
The eccentricity of Mars' orbit is much greater than that of Earth, making its orbit distinctly non-circular. The amount of sunlight received is about 40% greater at perihelion than at aphelion, which has important consequences for Martian seasons.

Mars has two tiny moons: Phobos (27 km long) and Deimos (15 km). They are almost certainly asteroids which approached close to Mars and were captured. They orbit only 9000 km and 23000 km from the surface.

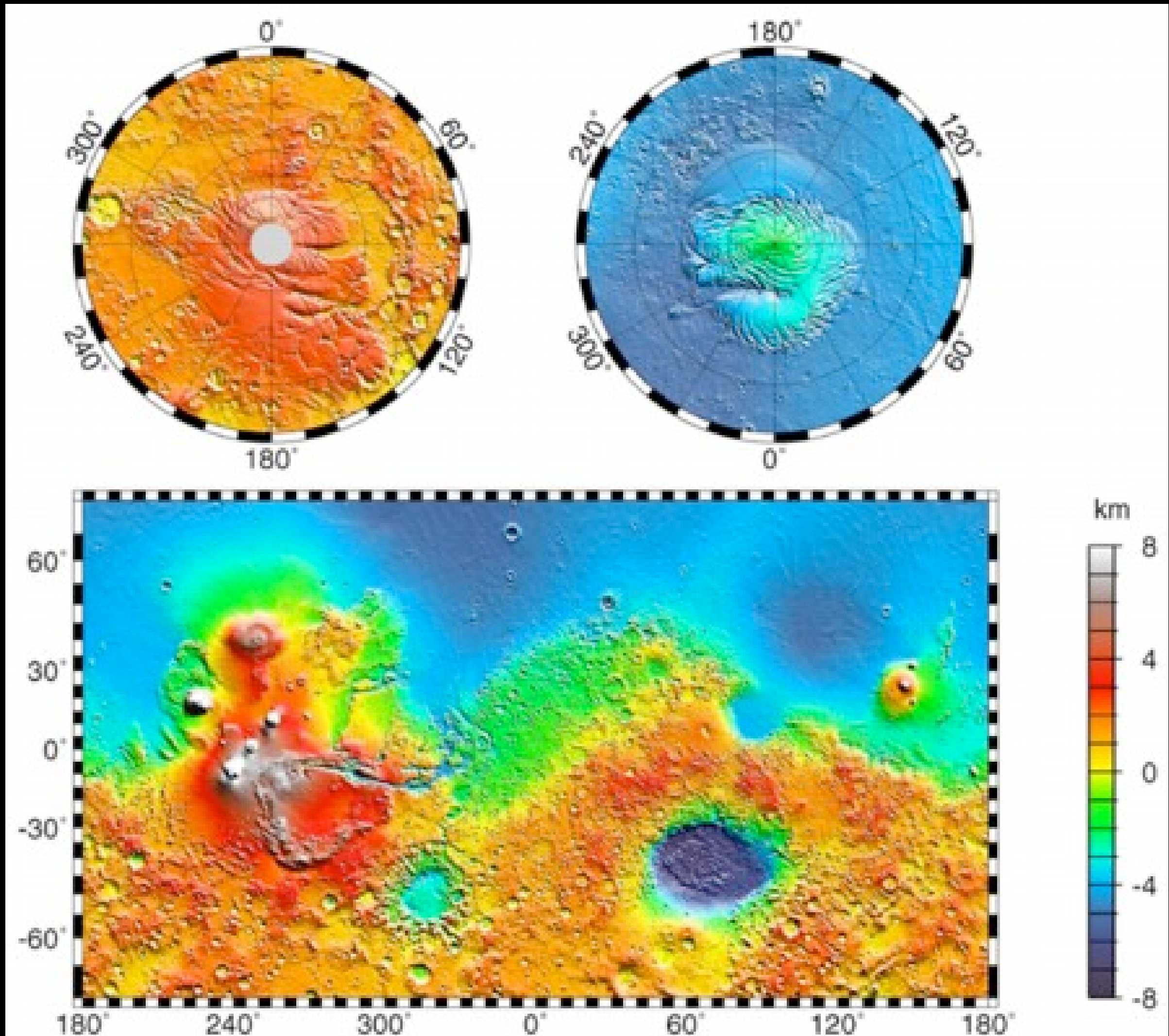


Phobos (left) and Deimos (right)

The major features of Mars which we will mention:

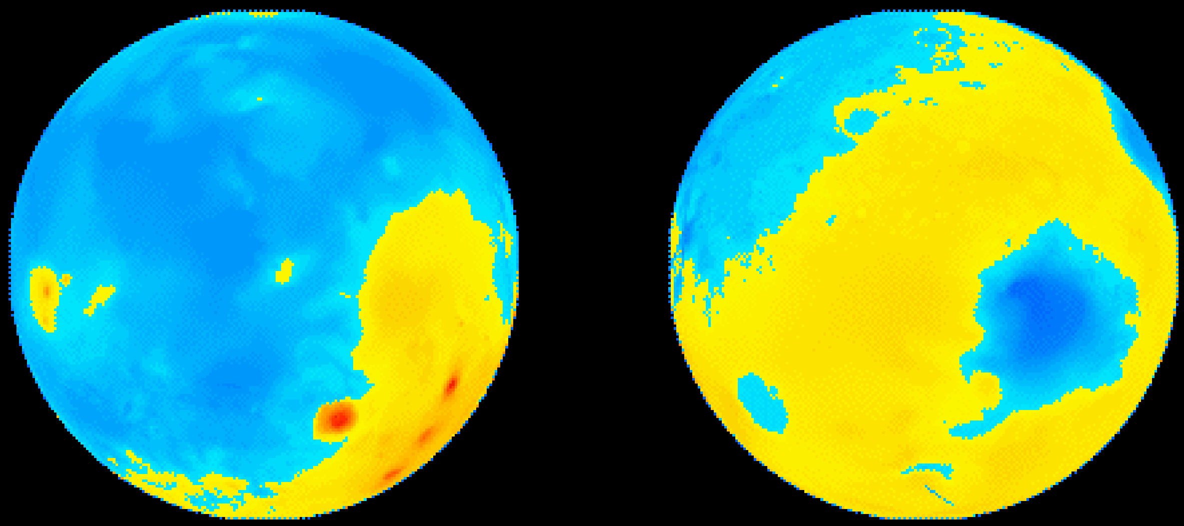


Mars' surface shows a global asymmetry: the southern hemisphere is several kilometres higher than the northern.



Half the planet is heavily cratered and raised 1–4 km, the other is relatively smooth. This is known as the *crustal dichotomy*.

The boundary is not at the equator: the planet is roughly divided in half by a line inclined at about 35° to the equator. This can be seen in the following images, where we can find positions to view the planet from which the side facing us is almost all low (blue – except for the red areas around the volcanoes) and almost all high (except for the Hellas basin)

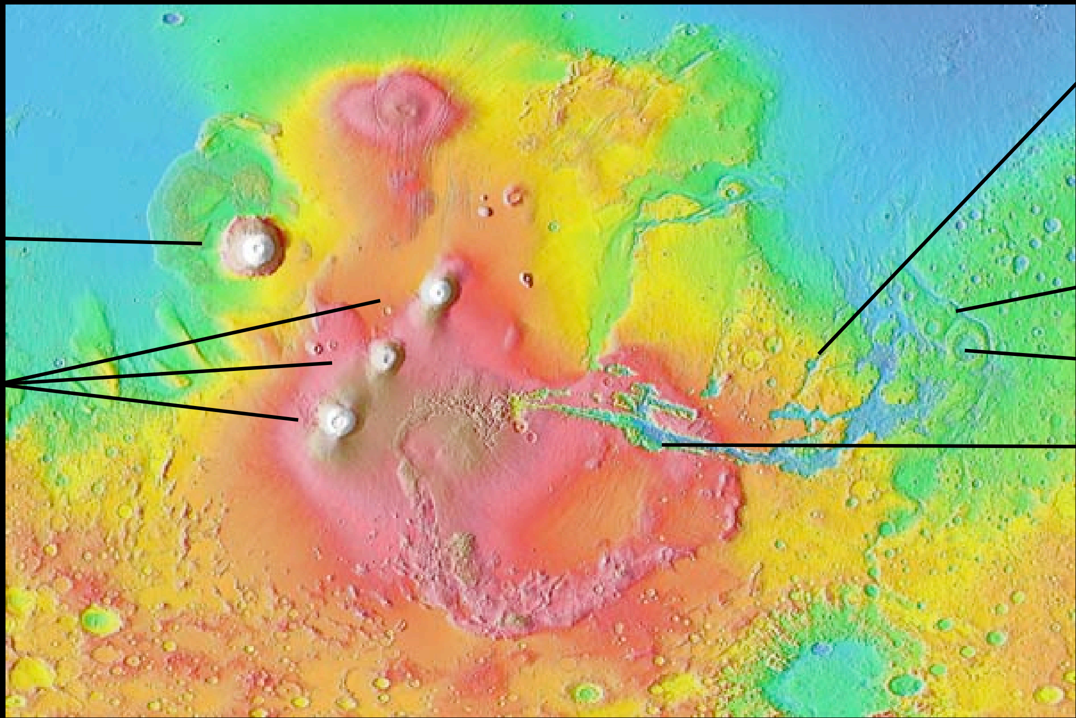


The cratered highlands in the south looks very like the Moon, but there are important differences. Many craters on Mars have ejecta blankets which appear to have flowed to their current positions. This suggests there was ice or water in the crust during the bombardment.

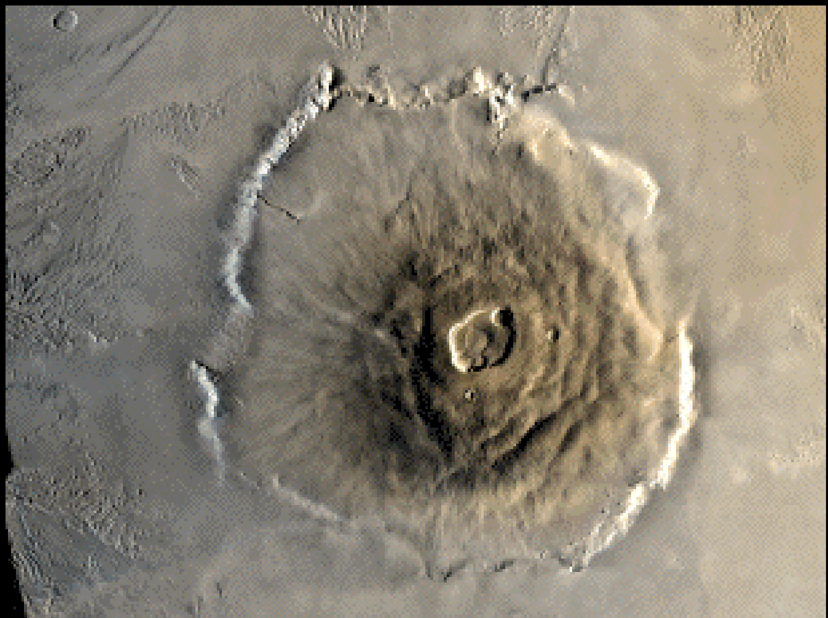
Ejecta around the crater Yuty (19 km in diameter), with lobes in the ejecta blanket.

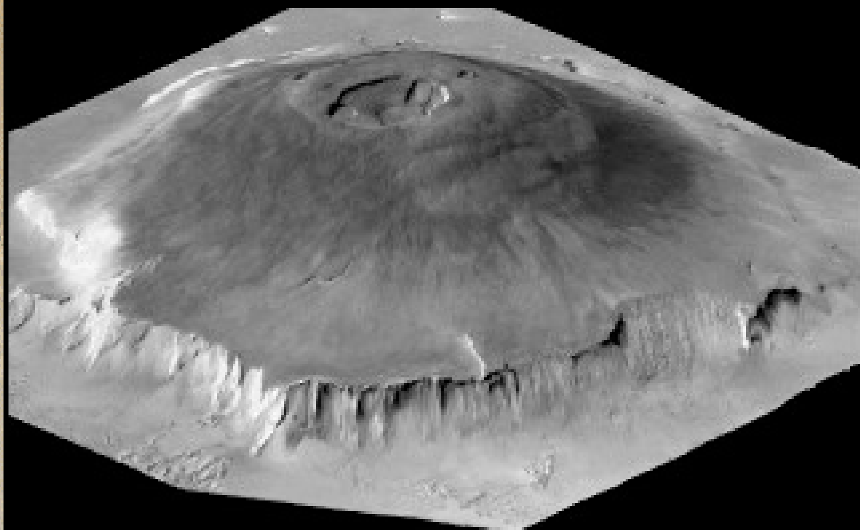
Volcanoes and lava plains are found over the whole planet. There are three main centres of volcanism:

- The *Tharsis region* is a 10-km high dome, several thousand km in radius, which contains the three Tharsis Montes, as well as the largest volcano in the solar system, Olympus Mons.

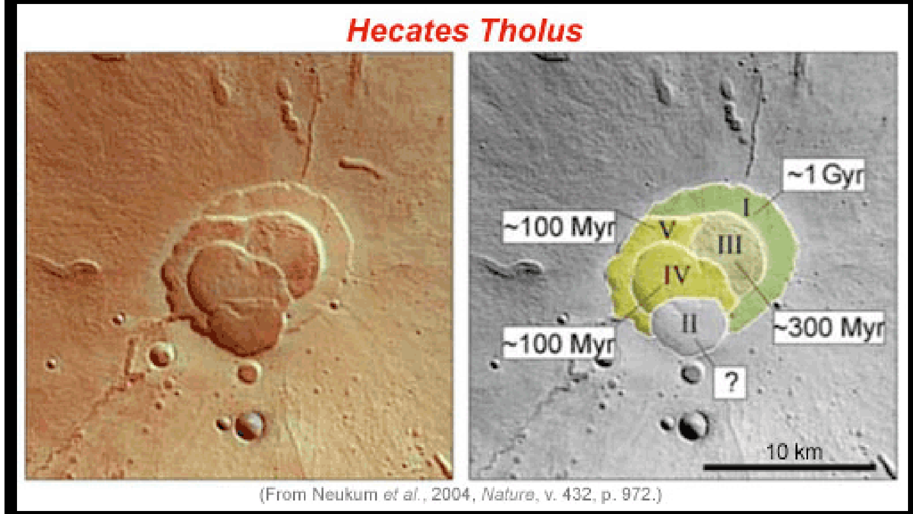


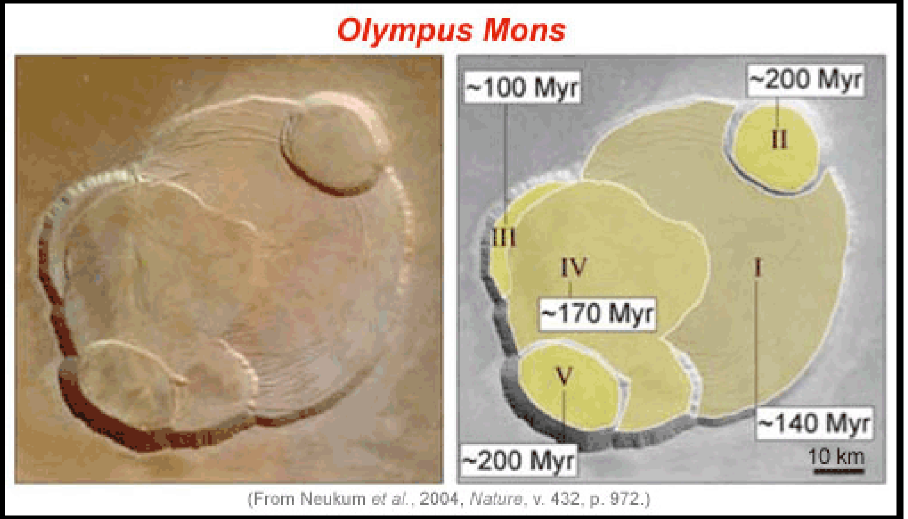
The Tharsis region is about 4000 km wide, and rises 10 km above Mars' mean surface level. The three Tharsis Montes – Ascraeus, Pavonis, and Arsia – rise another 15 km higher, while Olympus Mons rises 18 km above the surrounding high plains, to a total height of 27 km. Its base is nearly 600 km wide.





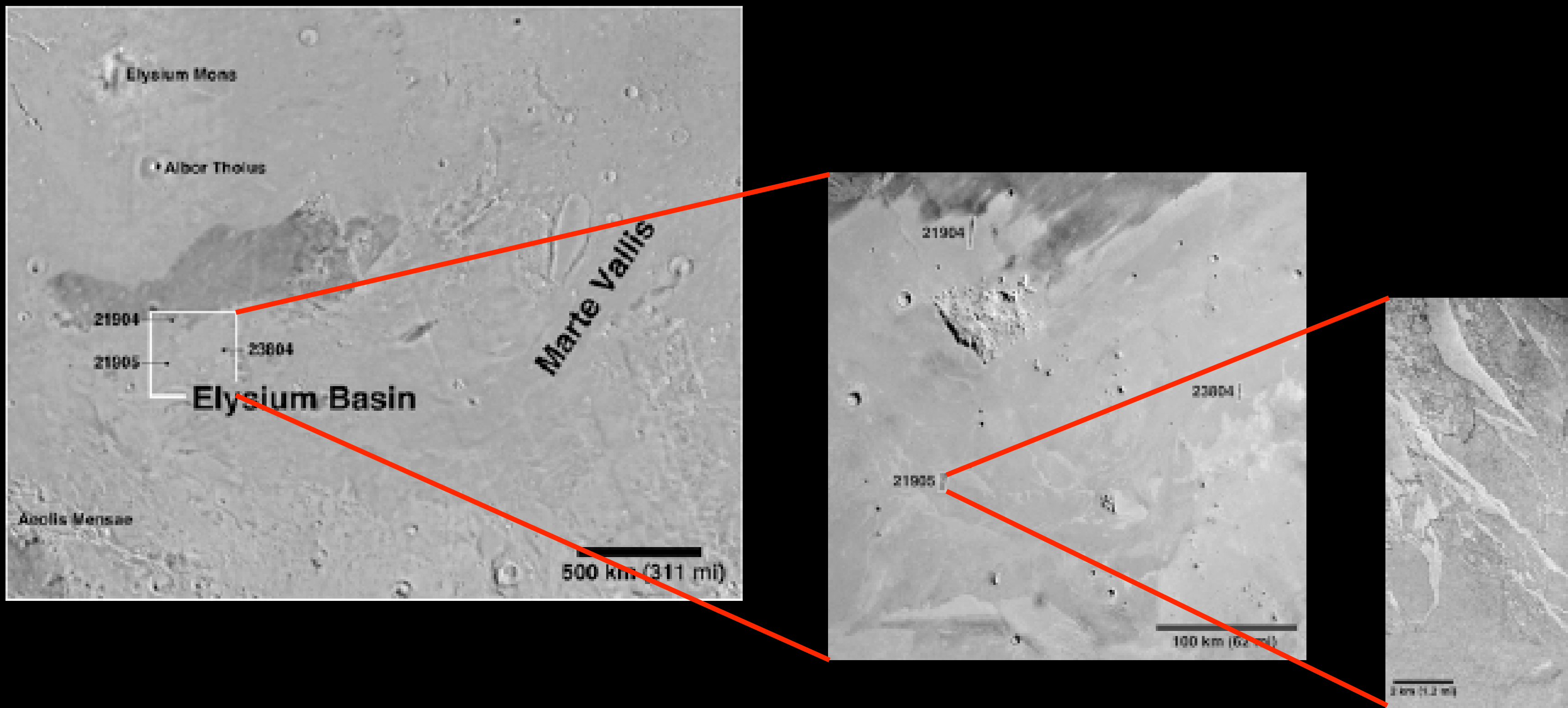
Crater counts in the calderas of six volcanoes in high resolution images suggest that the volcanoes have been active for billions of years, and that the most recent lava flows on Mars may be as young as two million years. This implies the volcanoes may be still active.



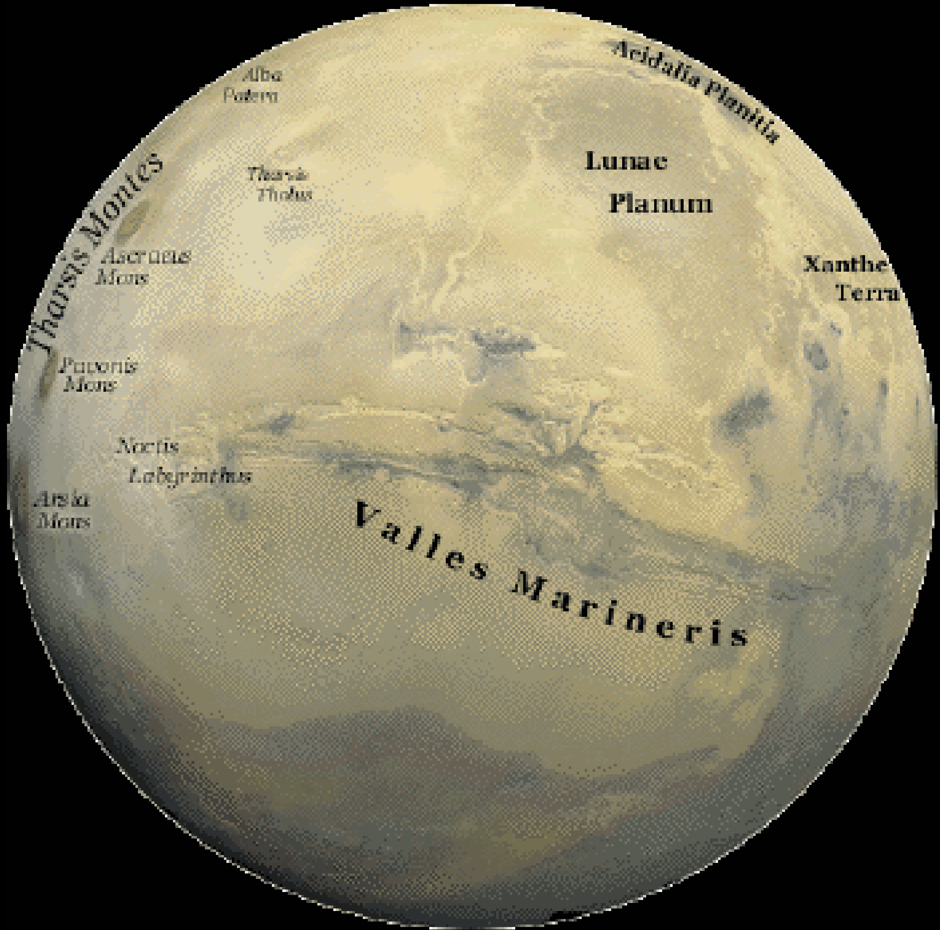


Images of two volcanic calderas, with the crater-counting areas and their derived absolute ages.

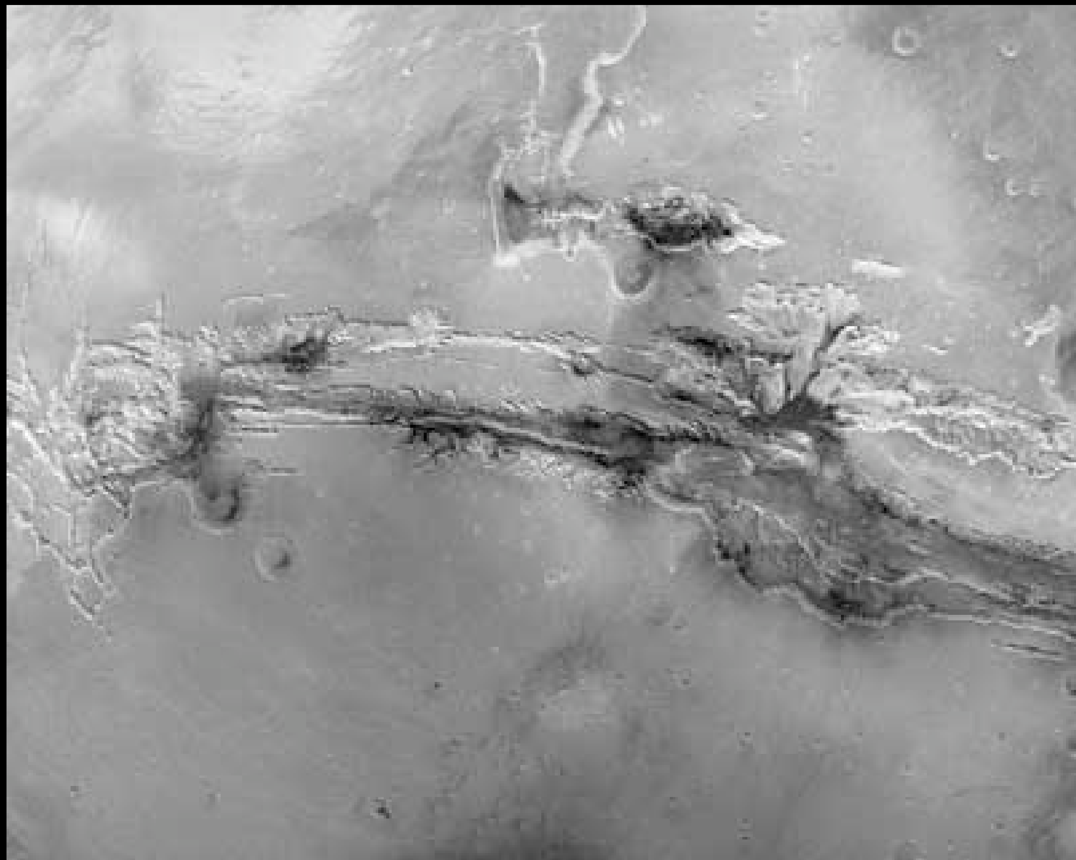
The Elysium region is a broad dome with two large volcanoes, Elysium Mons and Hecates Tholus. To the south is the Elysium Basin, a depression 3000 km wide covered with lava.



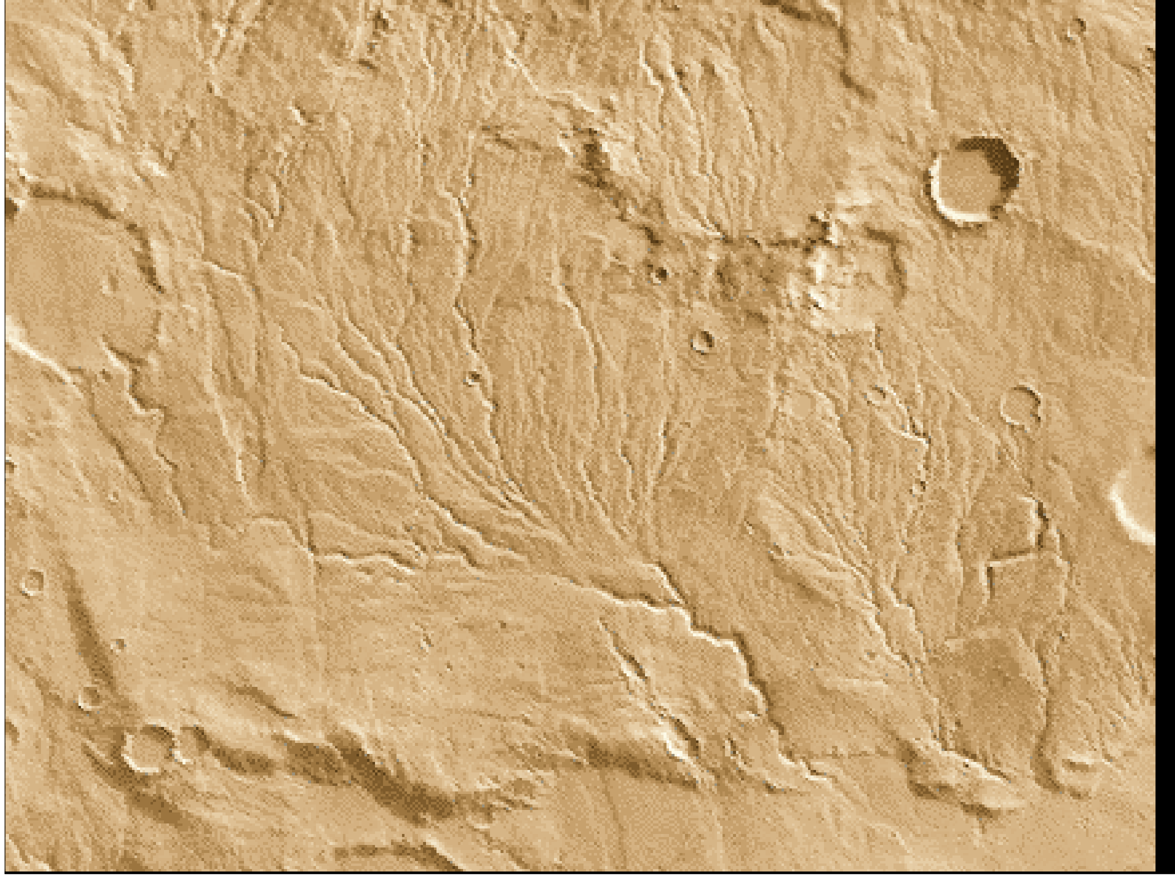
There is a giant canyon, up to 100 km wide and several thousand kilometres long, called the Valles Marineris. It covers about a fifth of the circumference of Mars.



This canyon shows that Mars had active plate tectonics at some stage in the past. The crust pulled apart to create parallel faults, between which the crust subsided, then erosion and landslides widened the canyons.

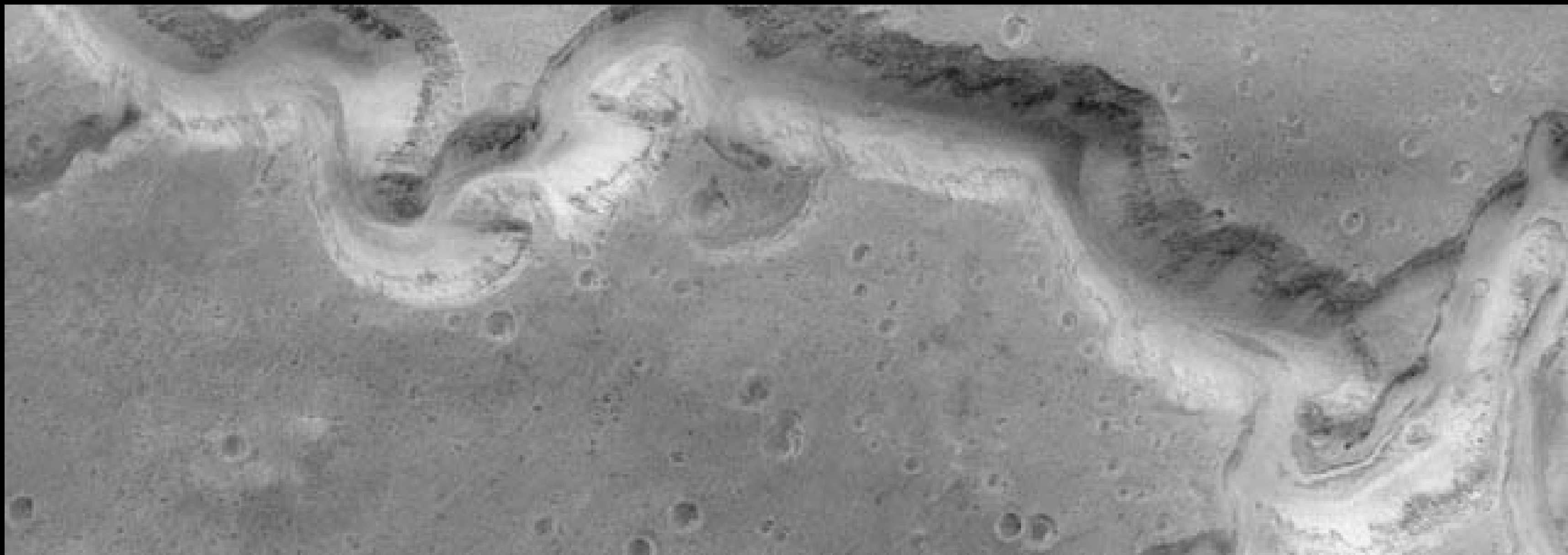


The Martian surface has many channels which look exactly like river systems on Earth, evidence that liquid water must have been present on the surface in large quantities. These networks are confined to old regions, suggesting the Martian climate may once have been warmer and wetter.



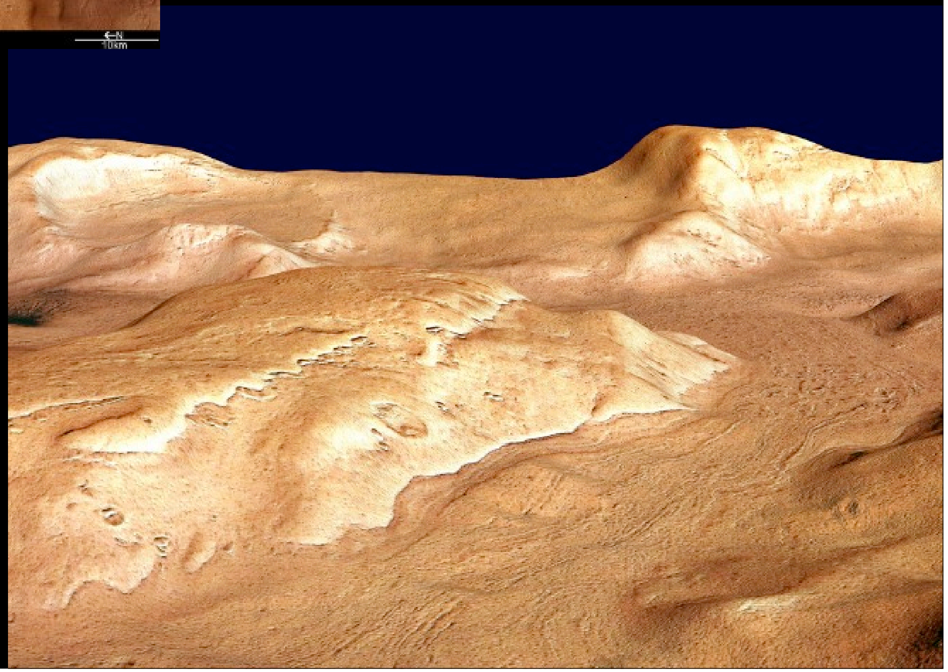
Network of drainage channels, suggesting sustained flows of water.

There are also larger, meandering channels, suggesting that the valley might have been carved by water that flowed through this system for an extended period of time.



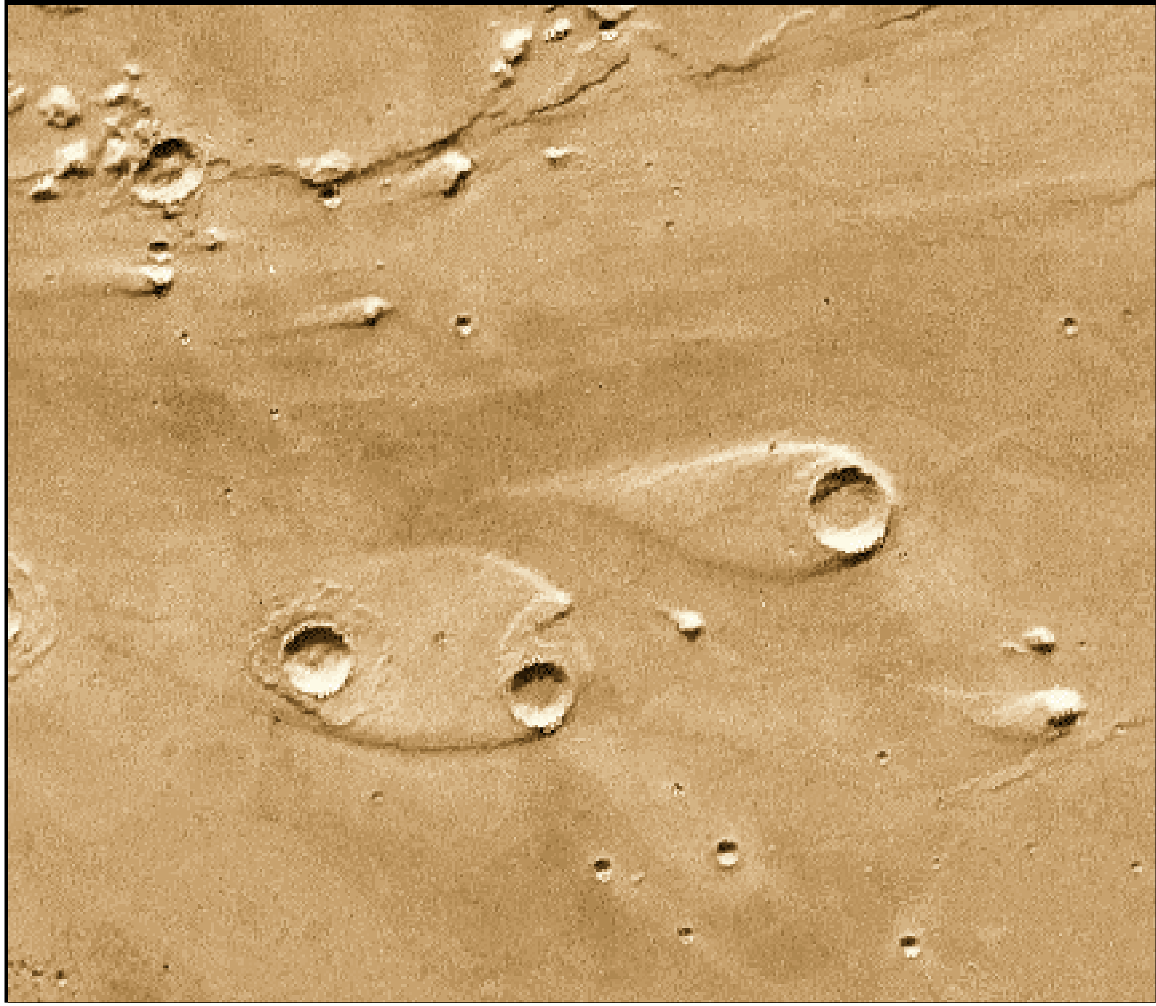
The Nanedi Valles system, cutting through the smooth cratered plains of the Xanthe Terra region.

ESA's *Mars Express* took these images of an outflow channel in Reull Vallis



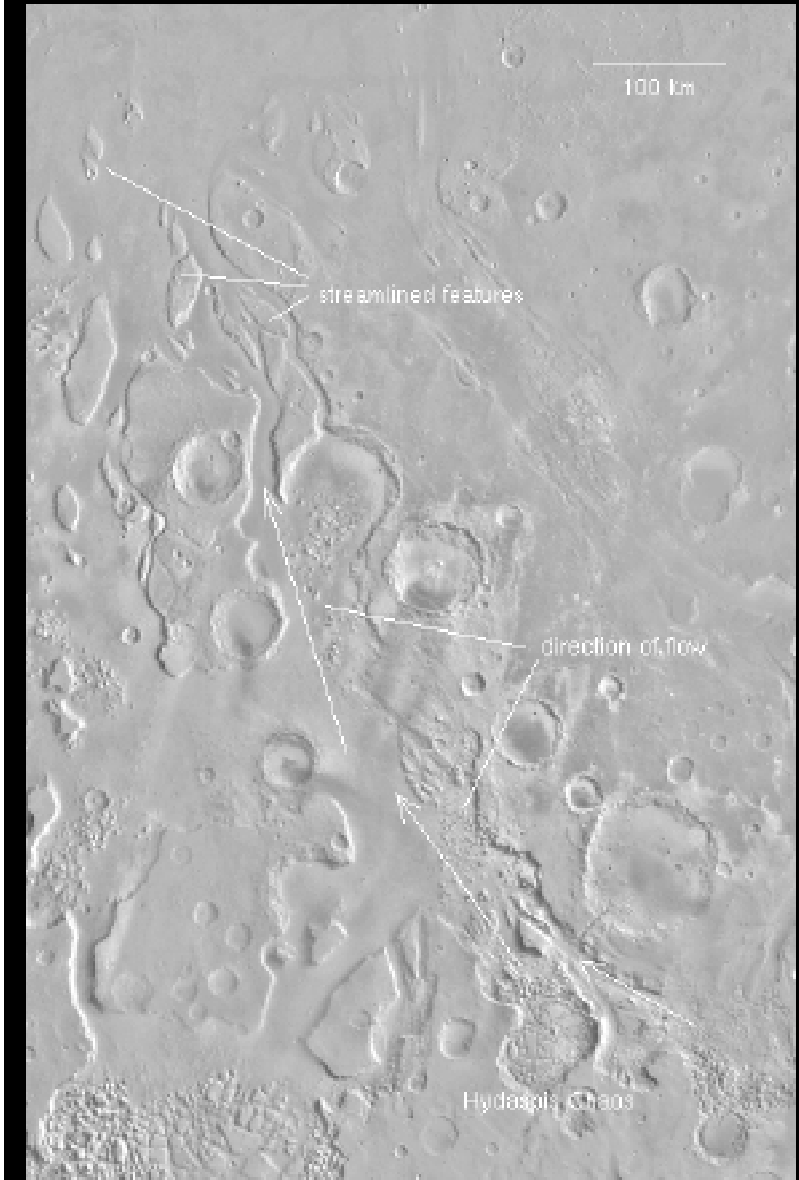
Perspective view of Reull Vallis, looking west.

In other channels, known as outflow channels, teardrop-shaped islands suggest vast, catastrophic flows of water, flooding the plains.



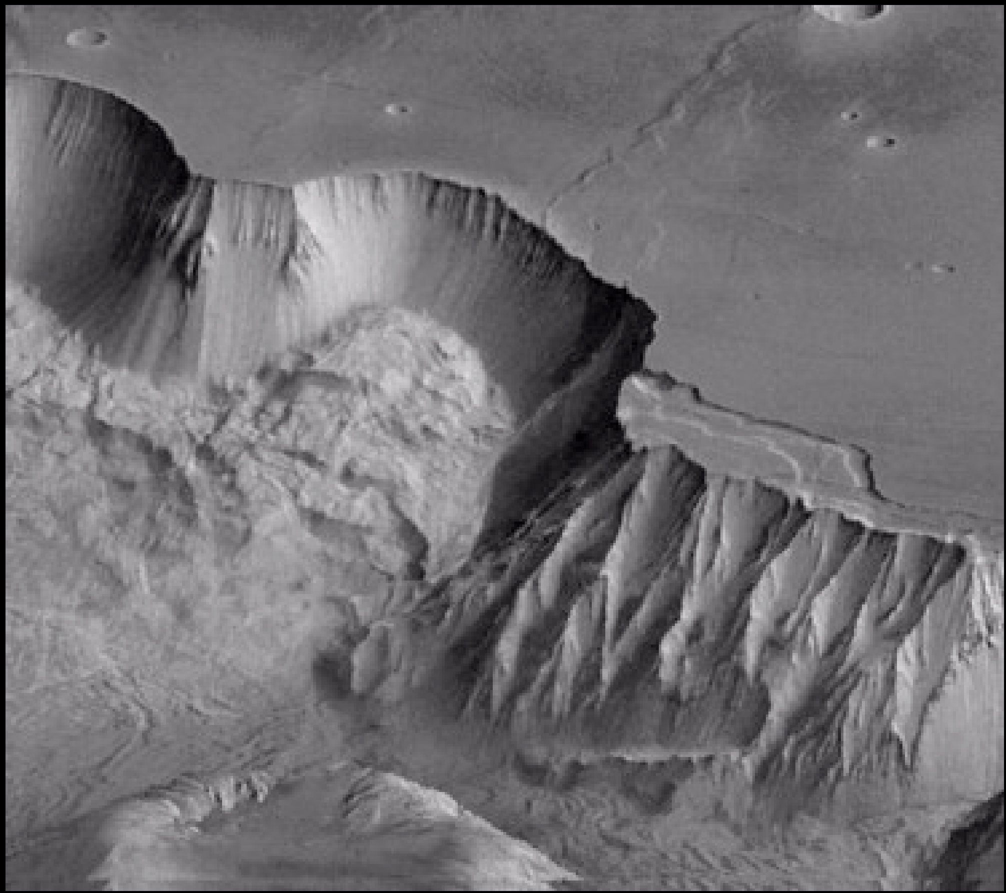
Islands carved as water was diverted by craters near the mouth of Ares Vallis in Chryse Planitia.

Large reservoirs of groundwater were suddenly released, and the water flowed across the terrain, simultaneously freezing and evaporating.

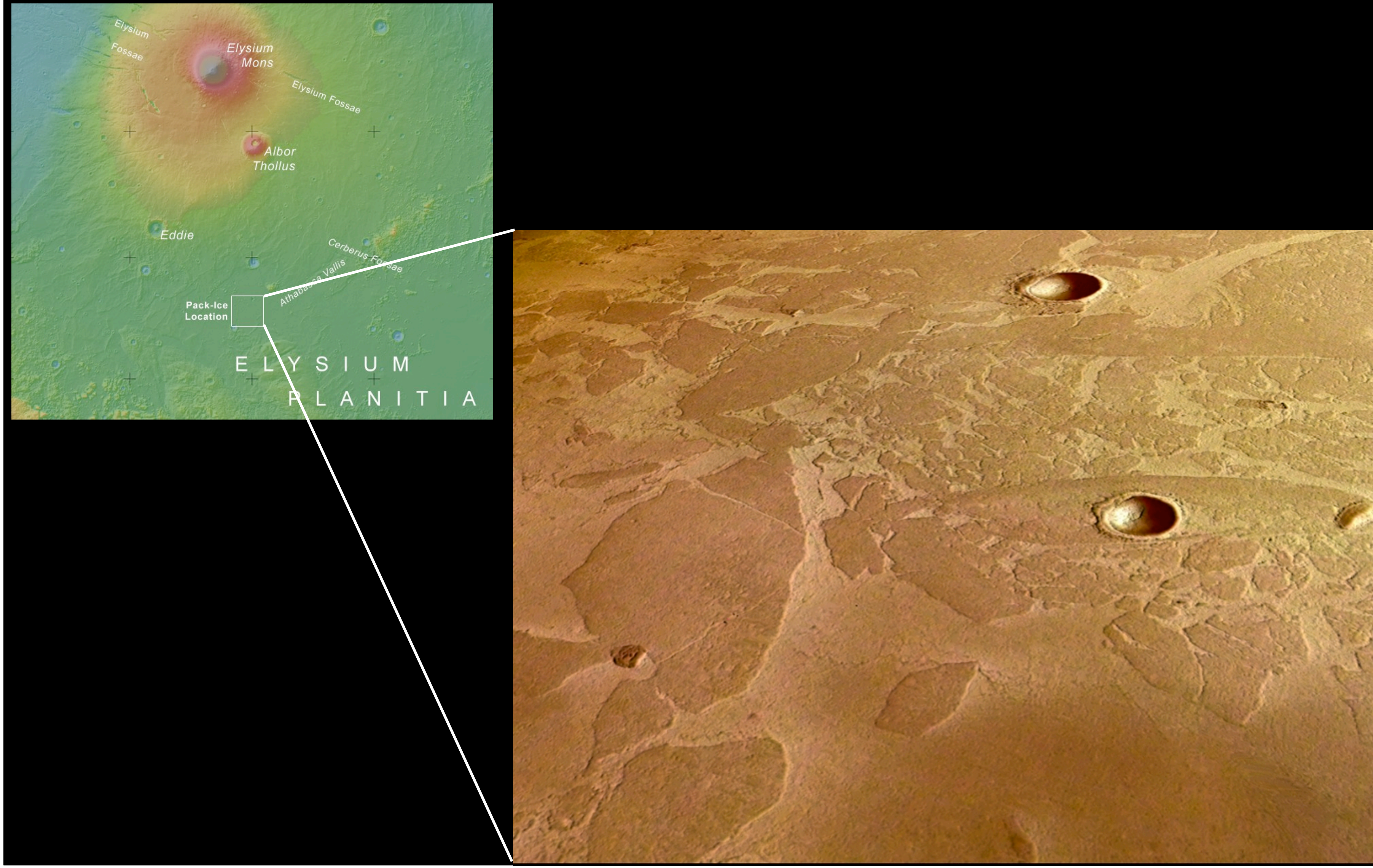


Tiu Vallis appears to have started from an area of collapsed terrain known as Hydaspis Chaos, moved northward through a fairly narrow channel, and then spread out and eroded a large area to the north and west

Huge avalanches have also altered the shapes of many of the canyons and other surface features.



Mars Express took images of what appears to be a dust-covered frozen sea.

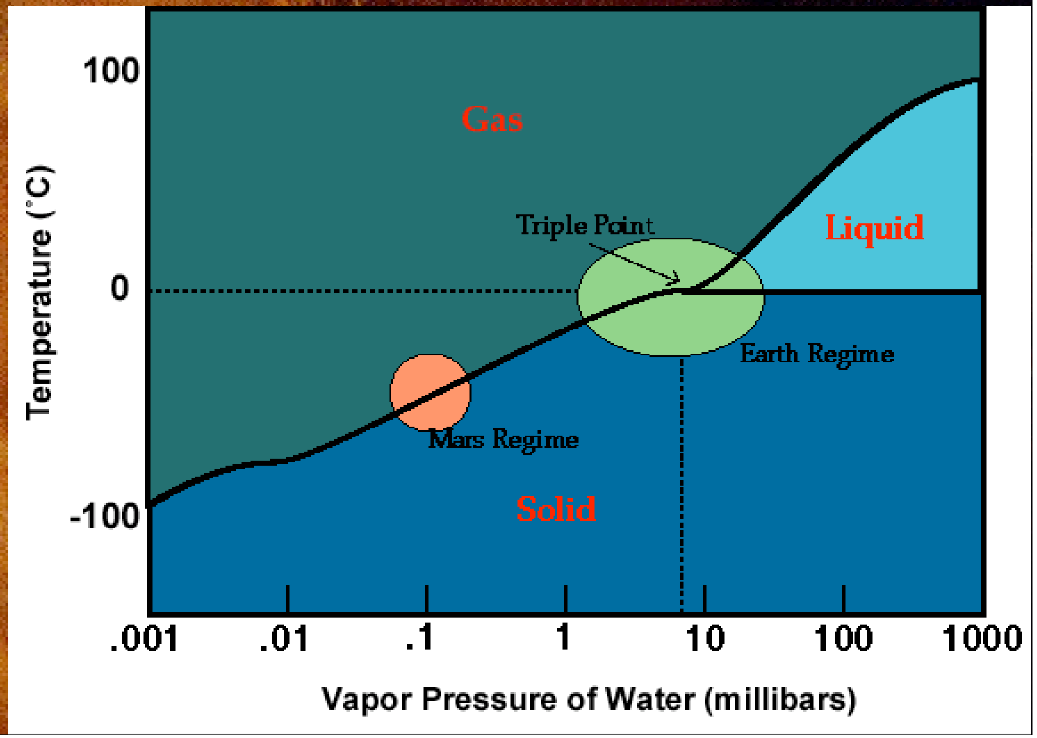


The problem is that water cannot exist in liquid form on Mars: at its current temperature and pressure, water can exist only as a solid or a gas. Even even in the most favourable spots, where the pressure is higher than average, water would boil at 10° C.

So how were all these features formed?

They suggest that Mars had a thicker atmosphere and was warmer at one time.

Of course, we don't know *when* and for *how long*...



Surface composition

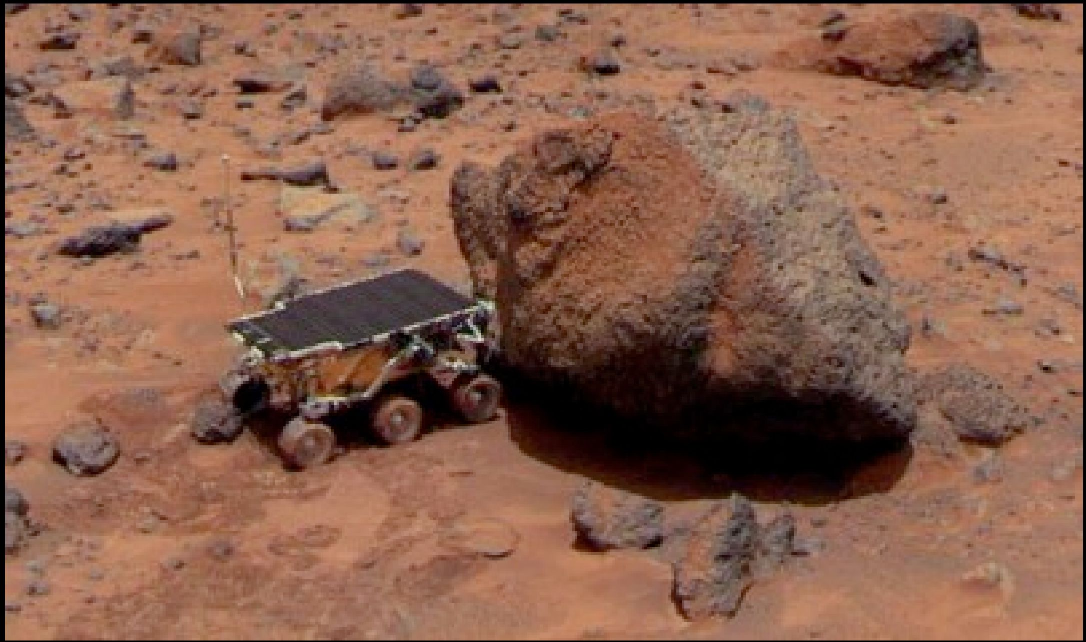
The soil on Mars' surface seems to be remarkably homogeneous – presumably due to major dust storms. It is rich in iron, magnesium, and calcium, and low in potassium, aluminium and silicon. In general, they look more like rocks in Earth's mantle than the rocks which make up Earth's crust.

Part of a panorama taken by Pathfinder: Sojourner is next to Yogi rock.

Which image is Earth, and which is Mars? One of the above images was taken by the robot Spirit rover currently climbing Husband Hill on Mars. The other image was taken by a human across the desert south of Morocco on Earth. Both images show vast plains covered with rocks and sand. Neither shows water or obvious signs of life. Each planet has a surface so complex that any one image does not do that planet justice.

(Astronomy Picture of the Day, 2005 April 12)

The rocks analysed by Pathfinder were igneous, but not basalts (the most common rock type on Earth): they have too much silicon. Other rocks look almost sedimentary, with layered cross-sections, rocks with embedded pebbles, and rounded pebbles on the ground.

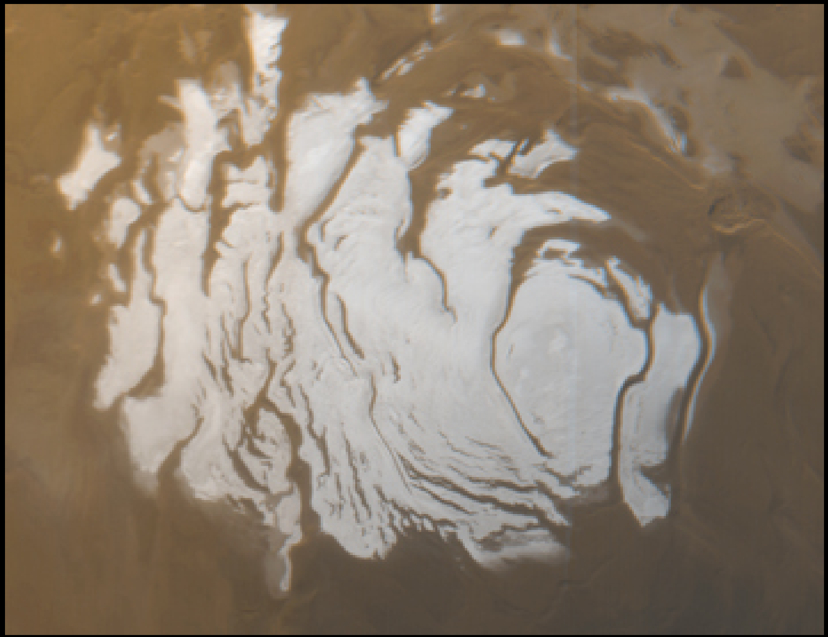


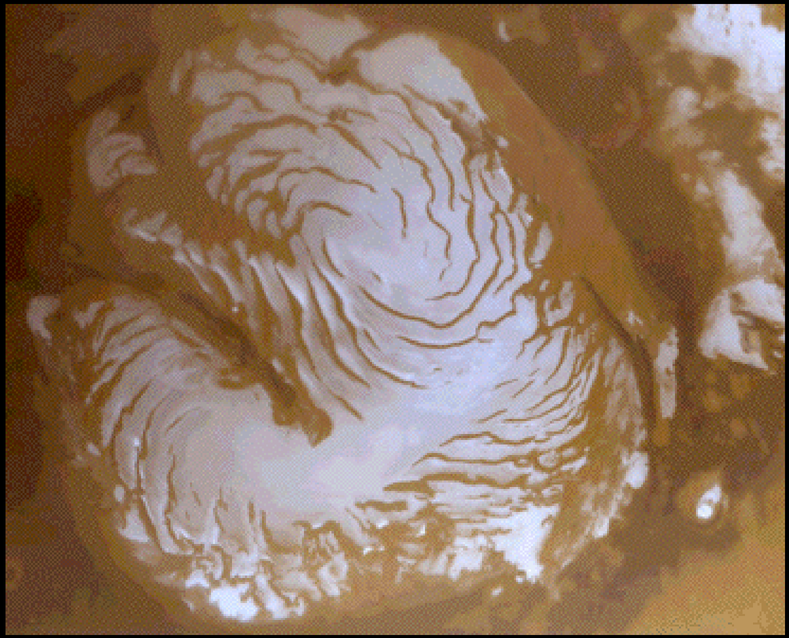
Seasons

On Earth, nearly all of the annual variation in temperature occurs because of the axial tilt. Mars, however, has a much higher orbital eccentricity than Earth: its distance from the Sun varies from 1.36 AU to 1.64 AU during a Martian year. This gives rise to much larger seasonal temperature changes than on Earth. Summer in the southern hemisphere is much warmer than summer in the northern hemisphere, because Mars is much closer to the Sun during the southern summer. This difference means that the atmospheric pressure changes by 25% during the year, as more carbon dioxide freezes out during the southern winter.

Polar caps

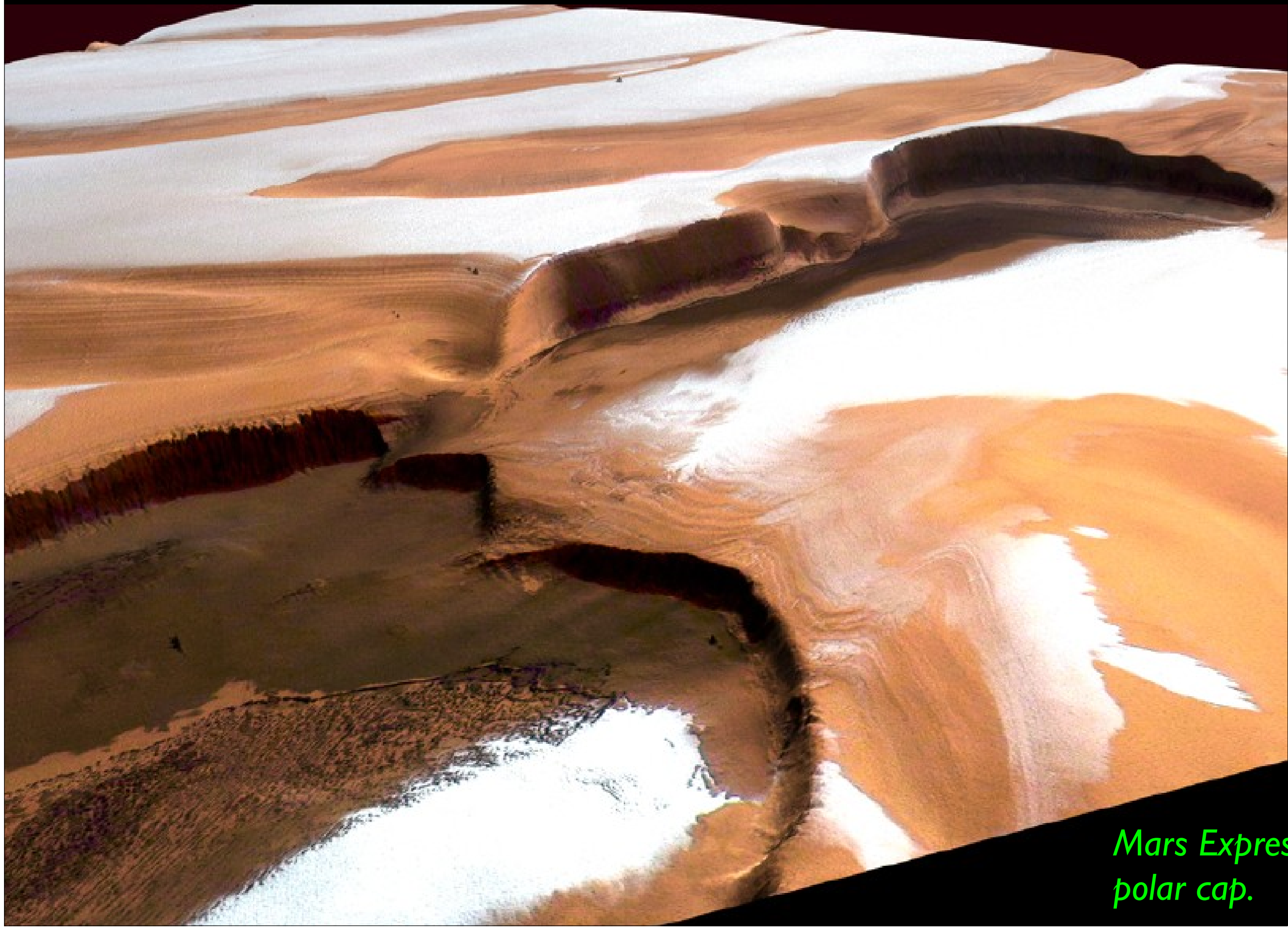
At the poles, water is permanently frozen. In winter, the temperature drops below the freezing point for carbon dioxide, which condenses out to form a seasonal polar cap of dry ice.





The southern (left) and northern (right) ice caps during summer, at their minimum sizes of about 420 km and 1100 km respectively.

In winter the ice extends to a latitude of about 60°. In summer, the ice sublimes, leaving dust behind: this produces a layering of dust and ice.

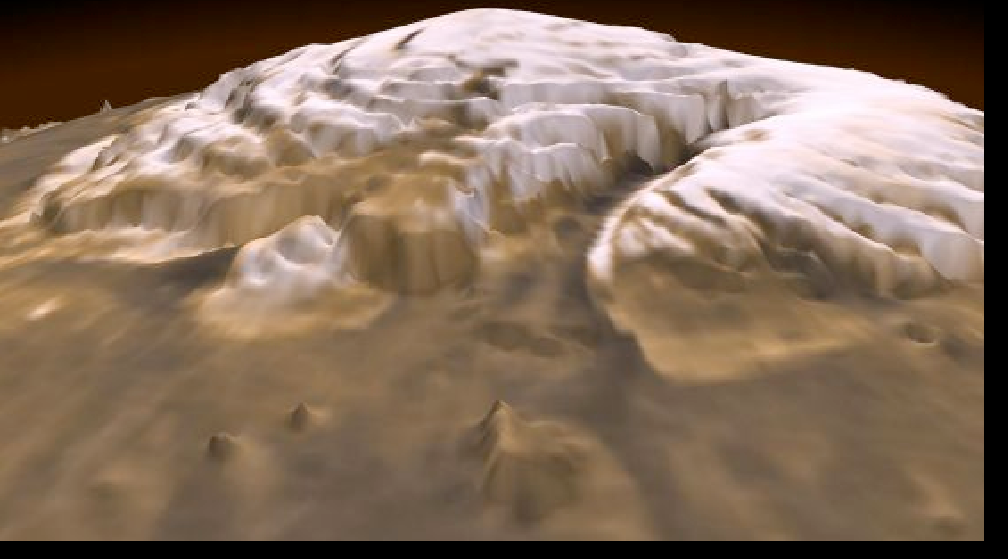


Mars Express picture of the north polar cap.

In the north, the CO_2 sublimes away completely during summer, leaving a permanent ice cap of water-ice about 1000 km in diameter. In the south, the CO_2 never completely sublimates away, leaving a permanent cap of ice about 350 km in diameter. The OMEGA spectrometer on Mars Express recently found that the ice at the south pole has only a thin veneer of CO_2, which covers huge deposits of water ice.

Images of Mars' North Pole, created by assembling mosaics of three sets of images taken by HST in October, 1996 and in January and March, 1997. They show the ice cap in early spring, mid-spring, and early summer.

Laser altimeter measurements from Global Surveyor show that the north polar cap is up to 3 km thick and is cut by canyons up to 1 km deep.



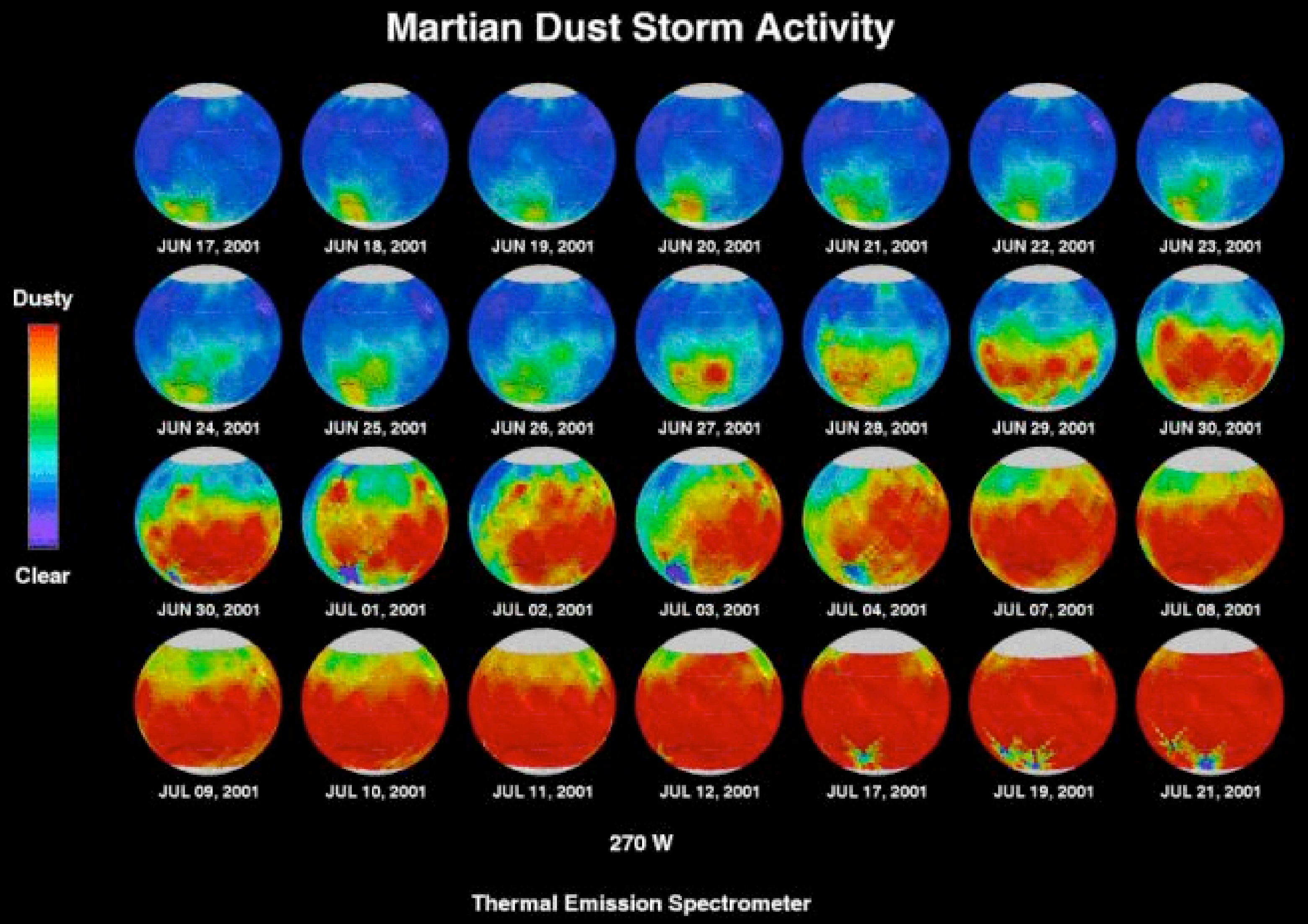
3-D visualisation of Mars' north pole based on elevation measurements made by an orbiting laser.

Atmosphere

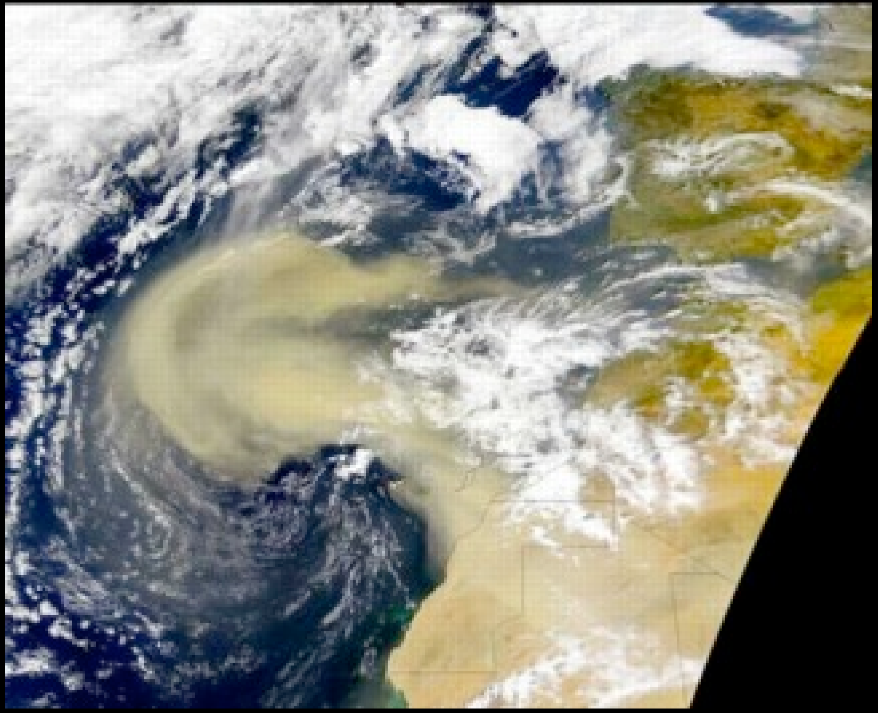
The Martian atmosphere is 95% CO_2, 2% nitrogen, and 1–2% argon. The atmospheric pressure is about 6 millibar (about 1/150th of Earth's). There is a seasonal variation in pressure of about 20%, due mostly to the extra carbon dioxide which freezes out of the atmosphere.

An oblique view of Mars taken by the Viking Orbiter, showing the Martian atmosphere over the Argyre impact basin.

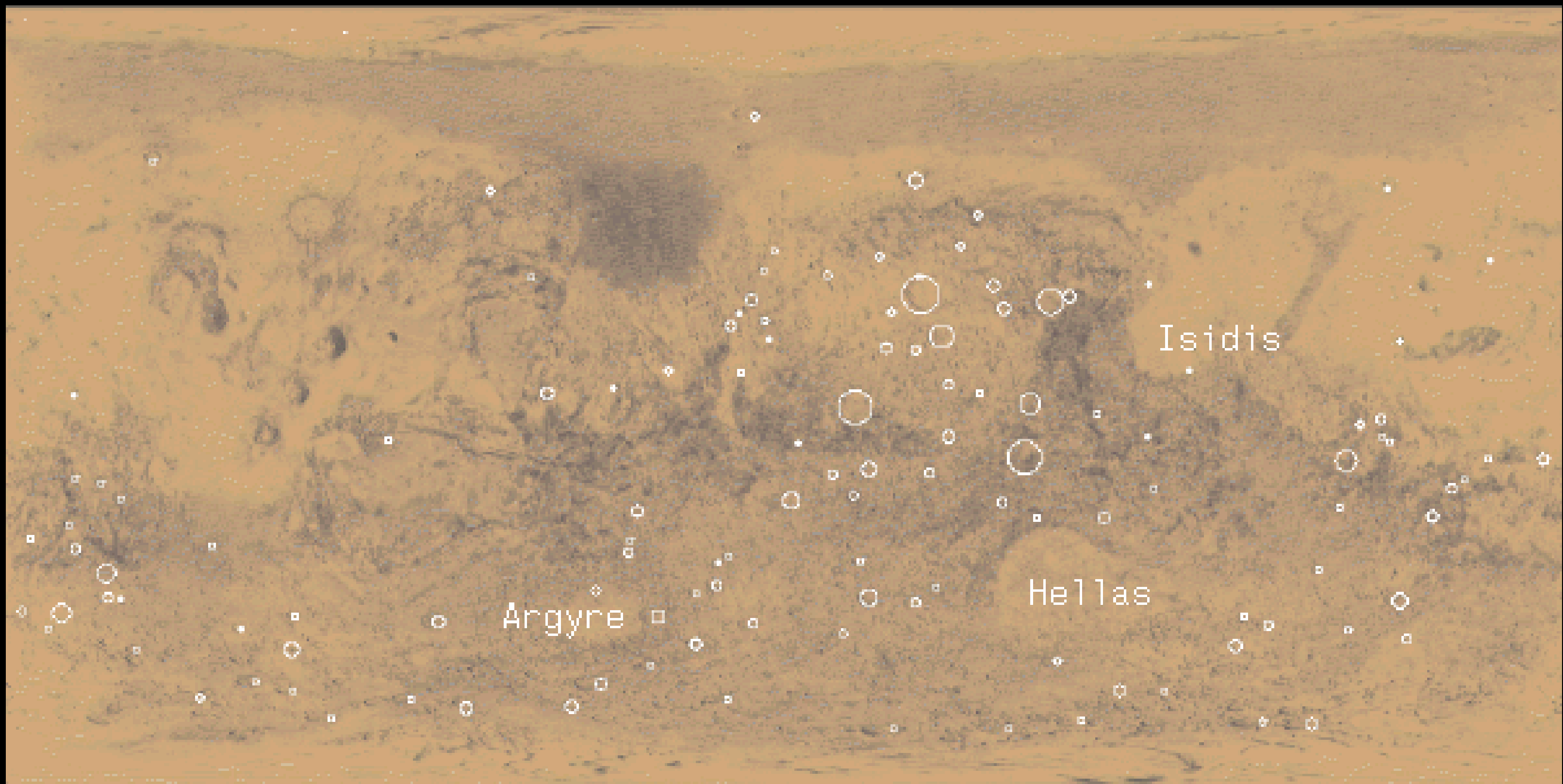
The Martian spring is the time for giant, planet-wide dust storms.



Dust eroded from low latitudes is carried in dust storms to the poles, where it is deposited. These giant dust storms can lead to large-scale changes in the appearance of the planet – which in the 1800s led to theories of seasonal vegetation coverage.

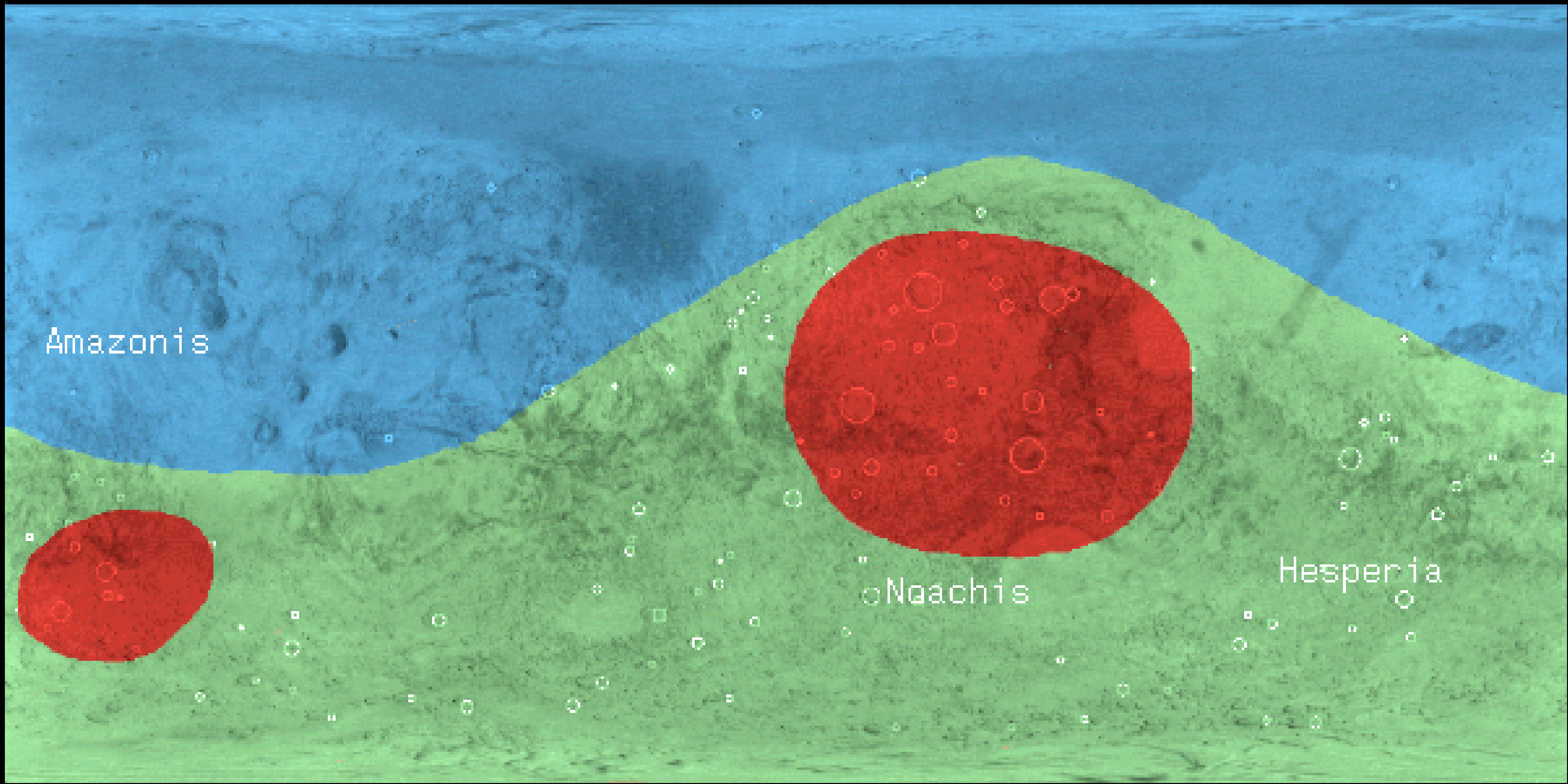


How did the surface of Mars evolve? We can get some clues by looking at the position of all craters larger than 100 km in diameter. Their distribution is not at all uniform:

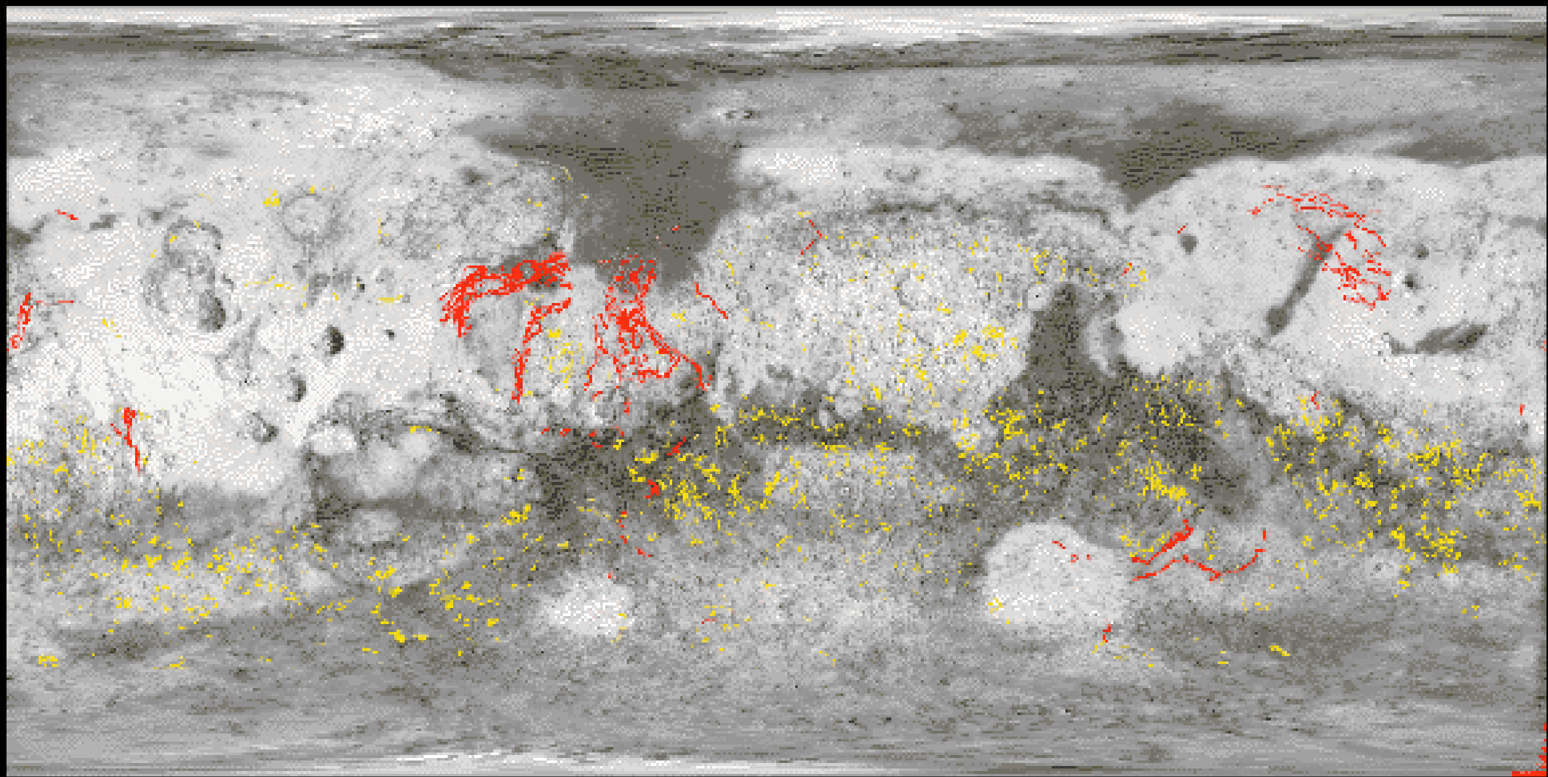


We can colour-code these regions: red for heavily cratered areas, green for intermediate, and blue for least cratered.

Roughly speaking, these represent the ages of the surfaces on Mars.



If we look at where the river-like networks (yellow) and outflow channels (red) are, the networks are found in the old regions, and the outflow channels in the youngest regions.



These three phases are given the names of regions which approximate these ages. The absolute ages are very uncertain:

1. the *Noachian* period (4.5 Gy–3.8 Gy): Heavy bombardment, producing a lunar-like, heavily cratered terrain, though more degraded than on the Moon. Plate tectonics appear to have been active, and liquid water appears to have been on the surface for at least some of the time.

2. the *Hesperian* period (3.8 Gy–3.5 Gy): Rate of bombardment lessened. Extensive lava flooding, beginning of Tharsis uplift and Valles Marineris canyon system.

3. the *Amazonian* period (3.5 G– present): Northern plains fill; very low impact flux. Volcanoes form. Outflow channels from Valles Marineris.

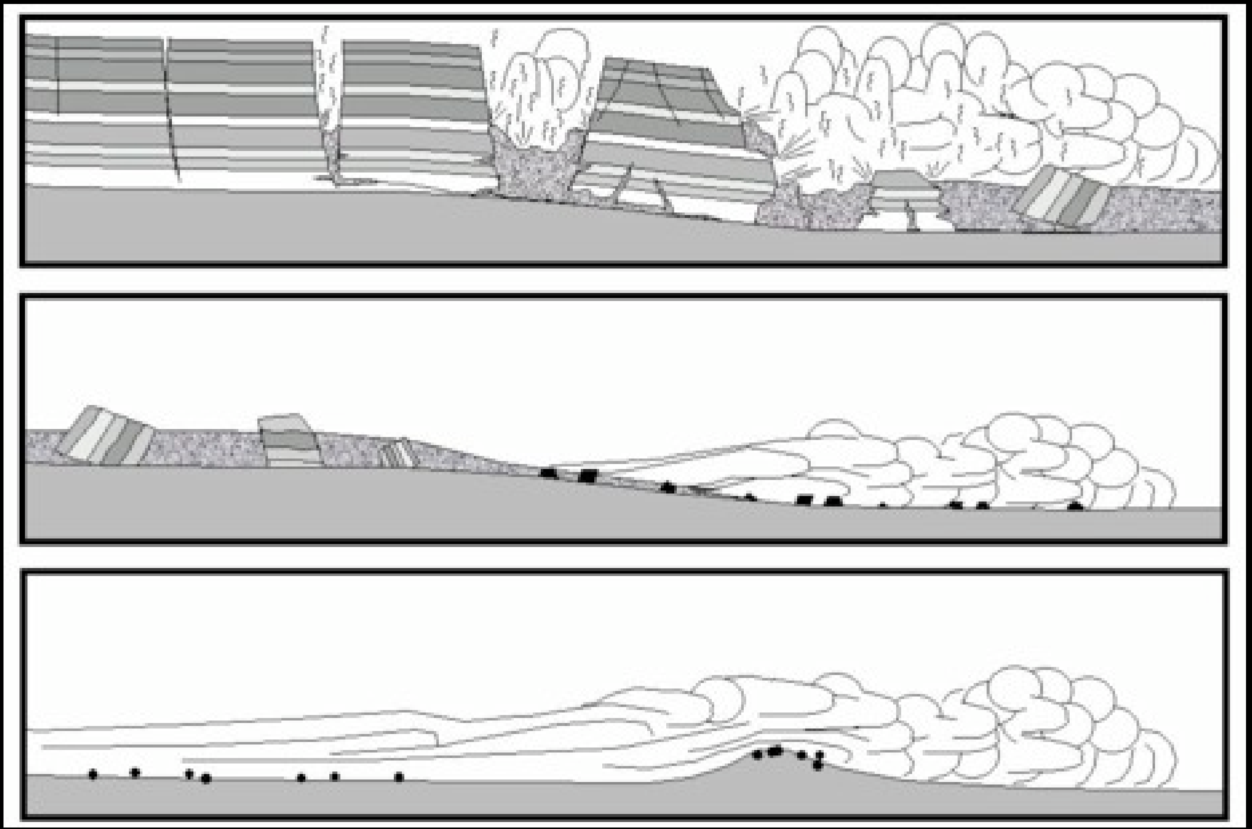
Some outstanding issues:

1. *Where did the crustal dichotomy come from?*
   Impact basin? Plate tectonics? Was it ever filled with water?

2. *What caused the Tharsis rise?*
   Was it related with the Hellas Basin impact? The mantle plume under the rise must have been fixed for a very long time.

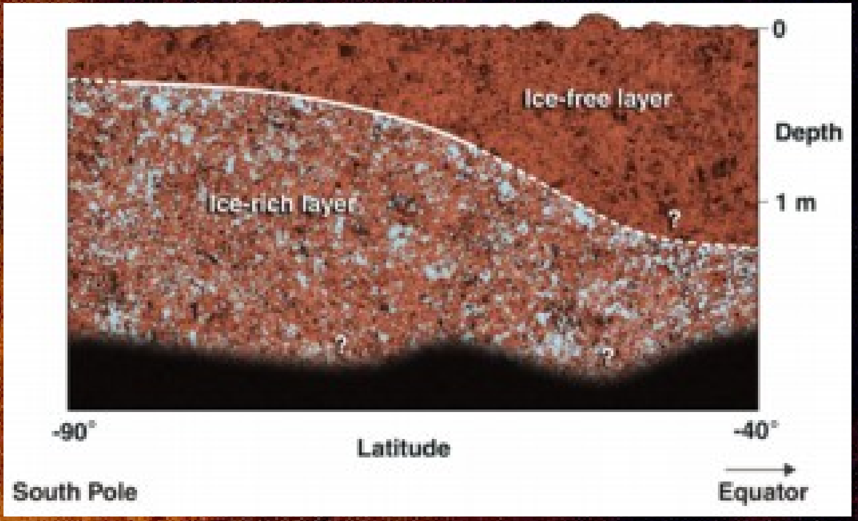
3. *Was water ever liquid on the surface of Mars?*
   So many surface features suggest so: but liquid water cannot exist in Mars' present atmosphere. Perhaps greenhouse gases kept the surface warm and atmospheric pressure higher; possibly there were many cycles of wet and dry Mars. But why are there no carbonate minerals on Mars?

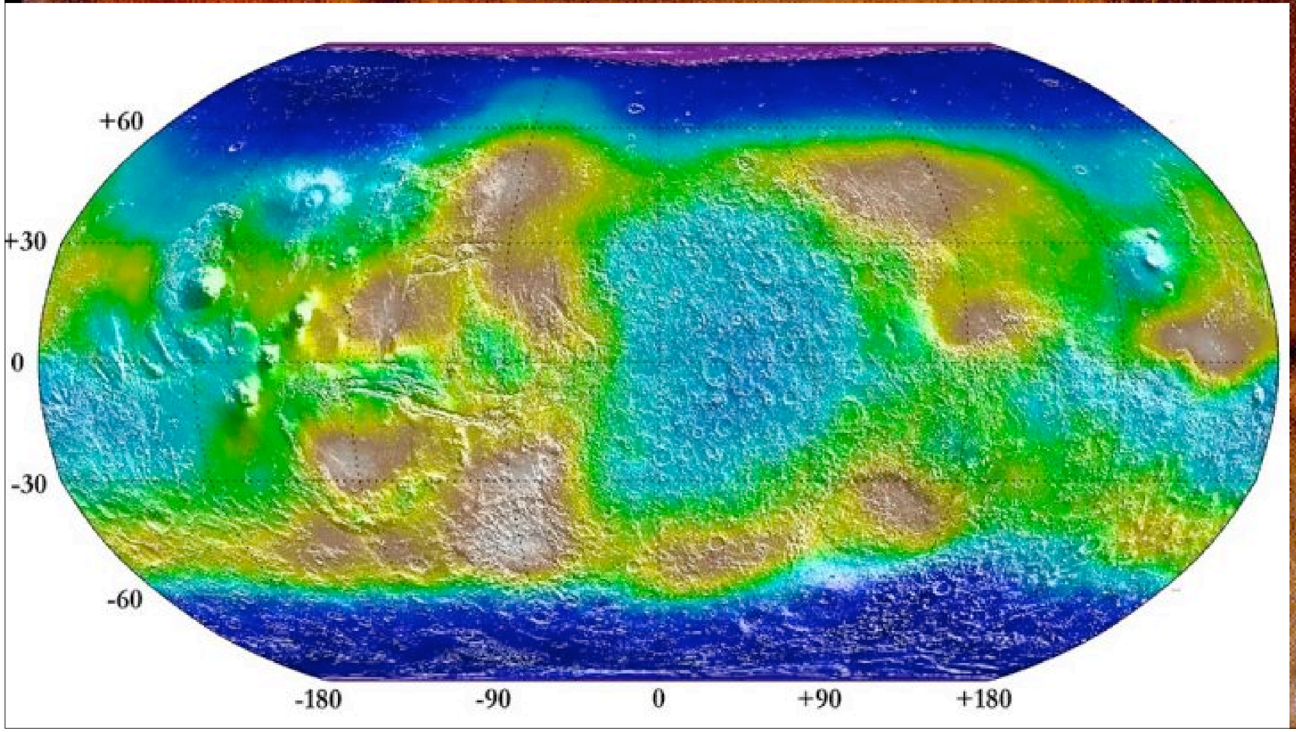
Some authors have suggested that there was never liquid water on Mars, and that the flow features were formed by carbon dioxide instead of water: cold and dry avalanches instead of warm and wet floods.



The "White Mars" model: layers of solid CO_2 ("dry ice") embedded in layers in rock, are released during a quake. Exposed to low pressure, the CO_2 fizzes and floods over the lowlands.

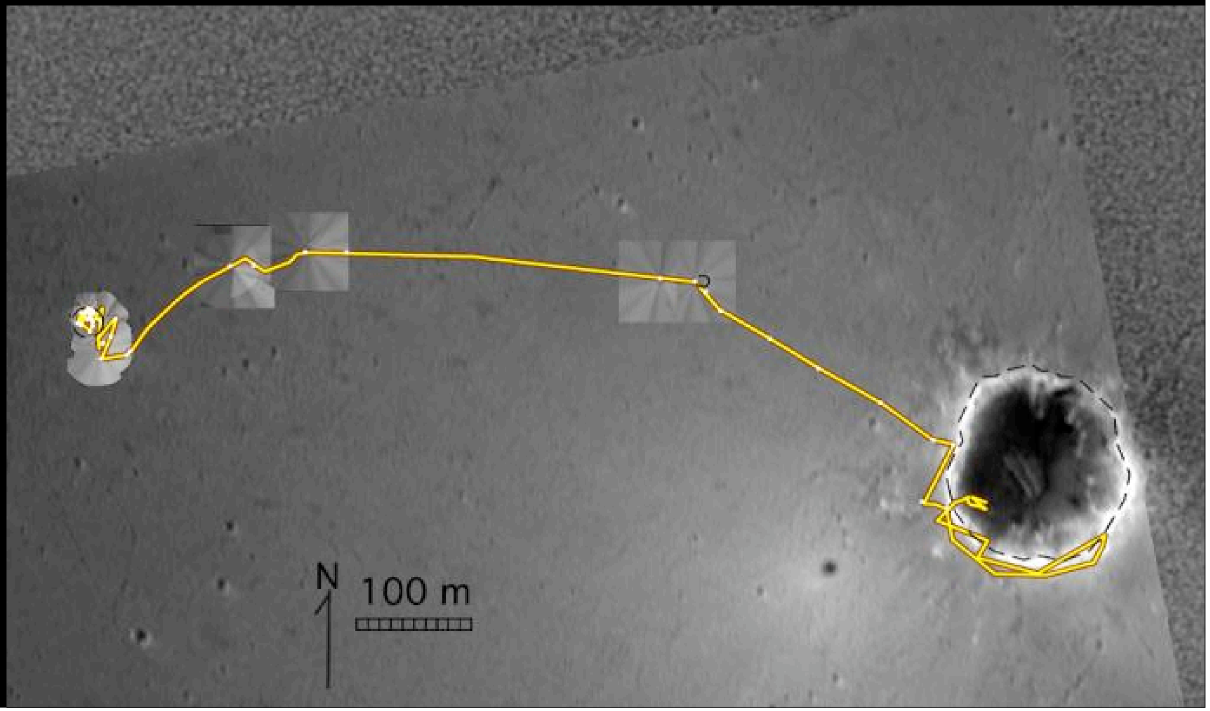
However, Mars Odyssey has found evidence for large quantities of water ice in Martian soil. The ice is mainly at the poles, but there are also substantial amounts in a band near the equator.





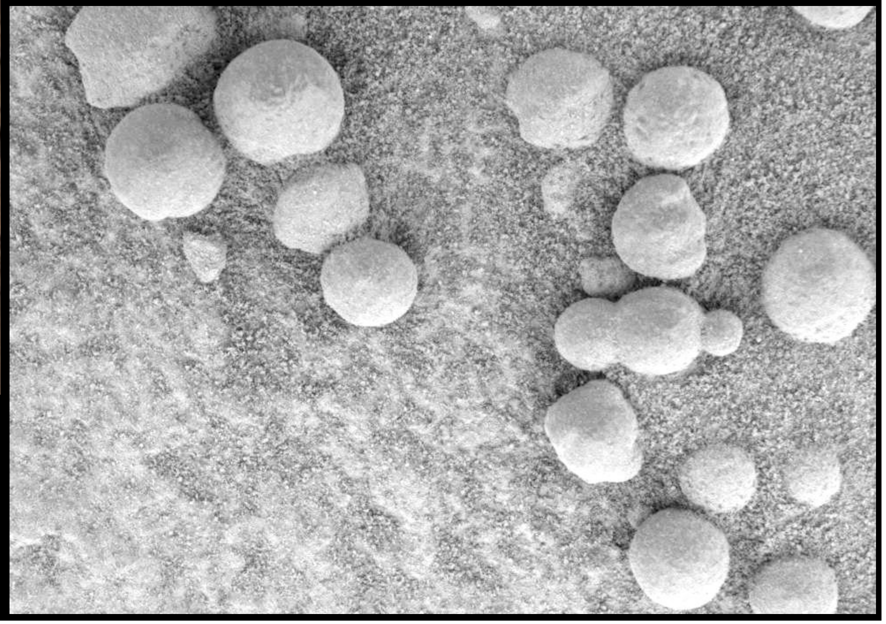
The Martian rovers *Spirit* and *Opportunity* have now been on Mars for just over one Earth year. They have found abundant evidence for water on Mars, at least in the past.

Spirit landed at Gusev Crater, which had appeared to be an ancient lake bed, while *Opportunity* landed at Meridiani Planum, which had showed an unusual concentration of haematite, a form of iron oxide which (on Earth) usually forms in water.



Opportunity's traverse through the rover's 205th sol (Aug. 21, 2004). Opportunity began its exploration inside "Eagle" crater, then traversed eastward to a small crater ("Fram" crater) before driving southeastward to the rim of "Endurance" crater.

Inside the Endurance crater, *Opportunity* found tiny spherules, dubbed "*blueberries*", which contain a large proportion of the iron mineral haematite. They appear to have formed in liquid water.

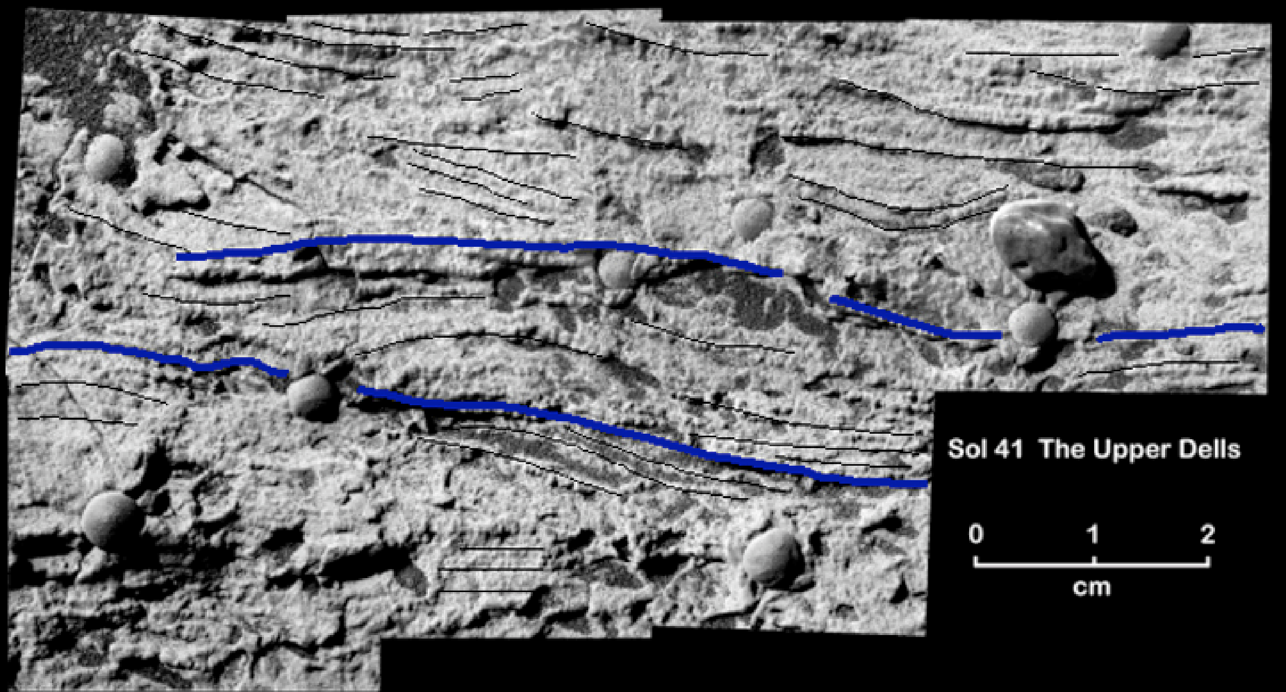


TIny spherules of haematite, shown in close-up (right).

False colour image of sand dunes at the bottom of Endurance Crater. The blue colour results from the presence of "blueberries".

Curves and layers in a rock called "Upper Dells" showed evidence of having been laid down in standing water. Chemical signatures in the rock indicate salty water: this area of Mars must once have been a salty sea.

Upper Dells MI Mosaic

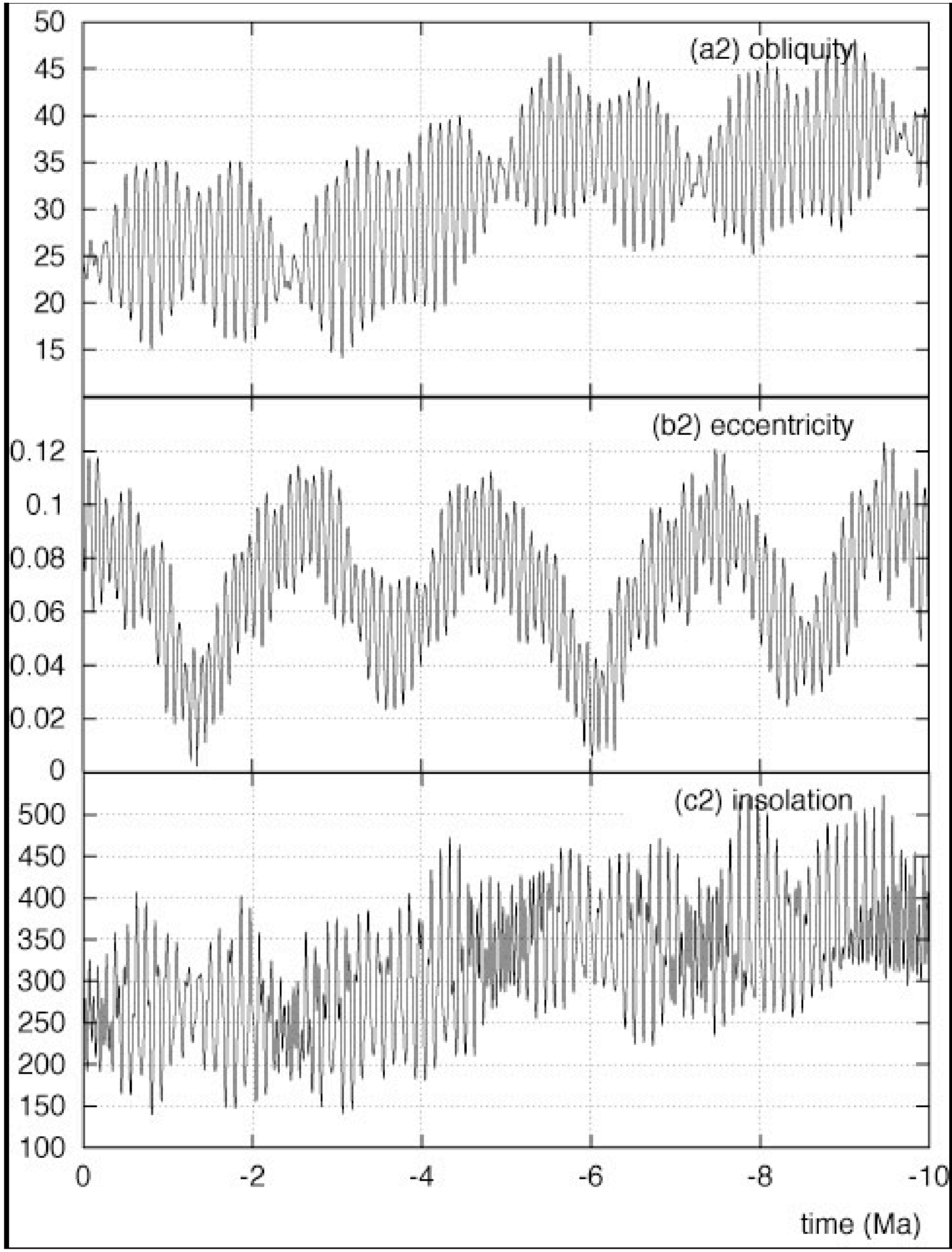


Climate variation

Why would Mars' climate have been radically different in the past?

One possibility is that changes in Mars' orbit could result in large climate changes.

Mars axial tilt (its *obliquity*) is strongly chaotic: over millions of years it varies between 15° and 35° over roughly 125,000 years, and has probably tilted as far as 0° and 60° over the past few tens of millions of years.



Variations of Mars' obliquity (angle between the planet's equator and orbital plane), eccentricty, and summer insolation at the north pole surface, computed over 10 million years. These variations result from the gravitational planetary perturbations exerted by the other planets of the solar system. (From Laskar et al. 2002)

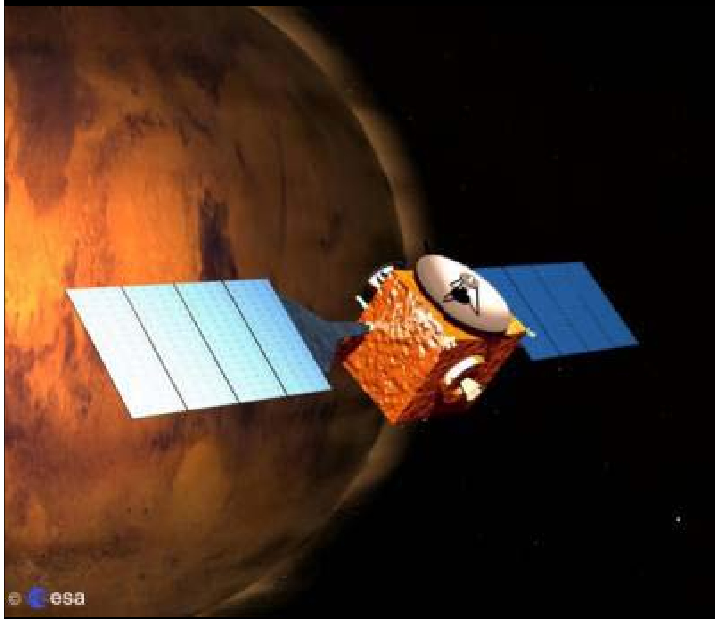
According to some theories, as Mars' axis tilts further, increased sunlight at the poles warms the poles significantly. This thaws the polar CO_2, releasing it into the air, so Mars' air pressure increases significantly.

This still leaves its air pressure only a tiny fraction of Earth's (at most, about 4%) – but it produces enough of a greenhouse effect to warm Mars by another 10° C. And it also raises Mars' air pressure enough that liquid water can exist on its surface.

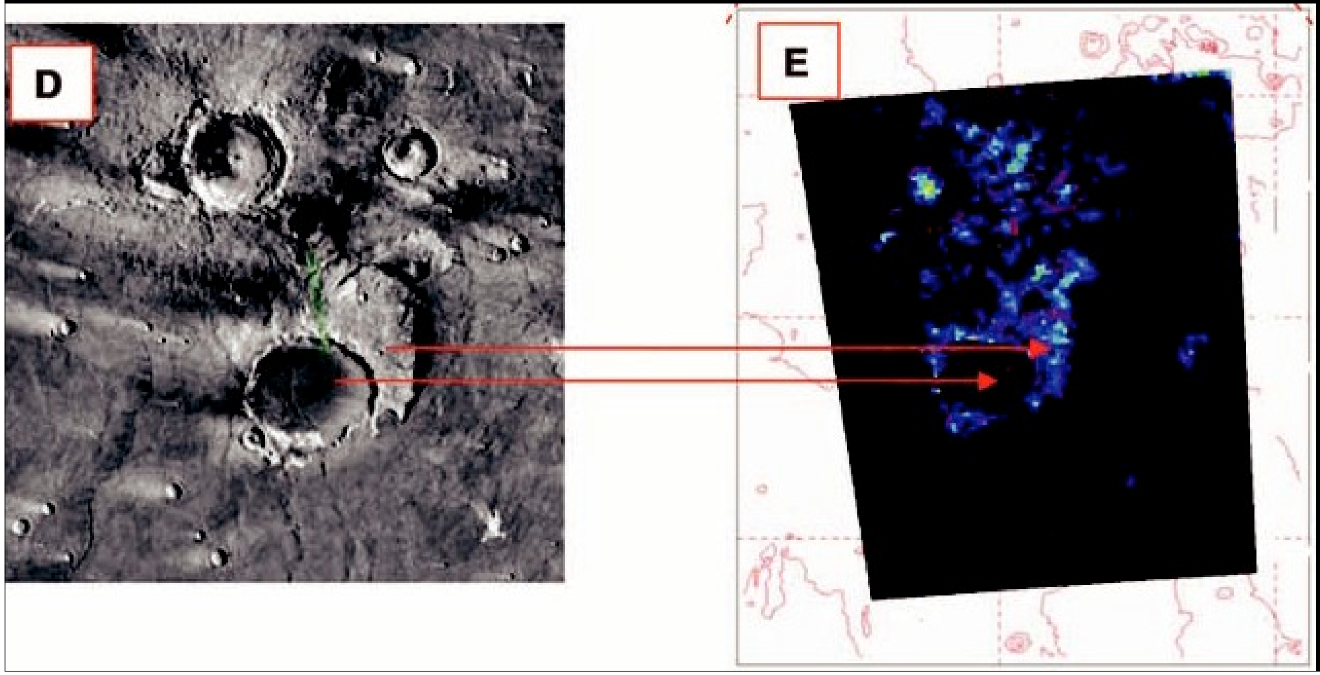
As the axial tilt reduces again in its long cycle, the CO_2 freezes out again, returning Mars to its current state.

Late breaking news

Very recent results from the OMEGA spectrometer on board Mars Express cast doubt on this theory. OMEGA is an imaging spectrometer, designed to examine the global distribution of minerals and chemicals on the surface of Mars by looking at their spectral signatures.



Mineral evidence for past water activity was detected all over the planet, but only in the oldest areas. This would indicate that all the signs of alteration of the surface by water could date from the most ancient times (beginning of Noachian era). No permanent liquid has existed for the past 3 billion years.



Omega map of hydrated minerals around a crater in Syrtis Major. The ancient crater ejecta show hydrated minerals, whereas the more recent lava flows are essentially free of them. (From Bibring et al. 2005.

Further, the OMEGA found no sign of carbonate minerals. If Mars had ever had a thick carbon dioxide atmosphere, enough to raise the temperature enough to melt ice, carbonate minerals should have formed.

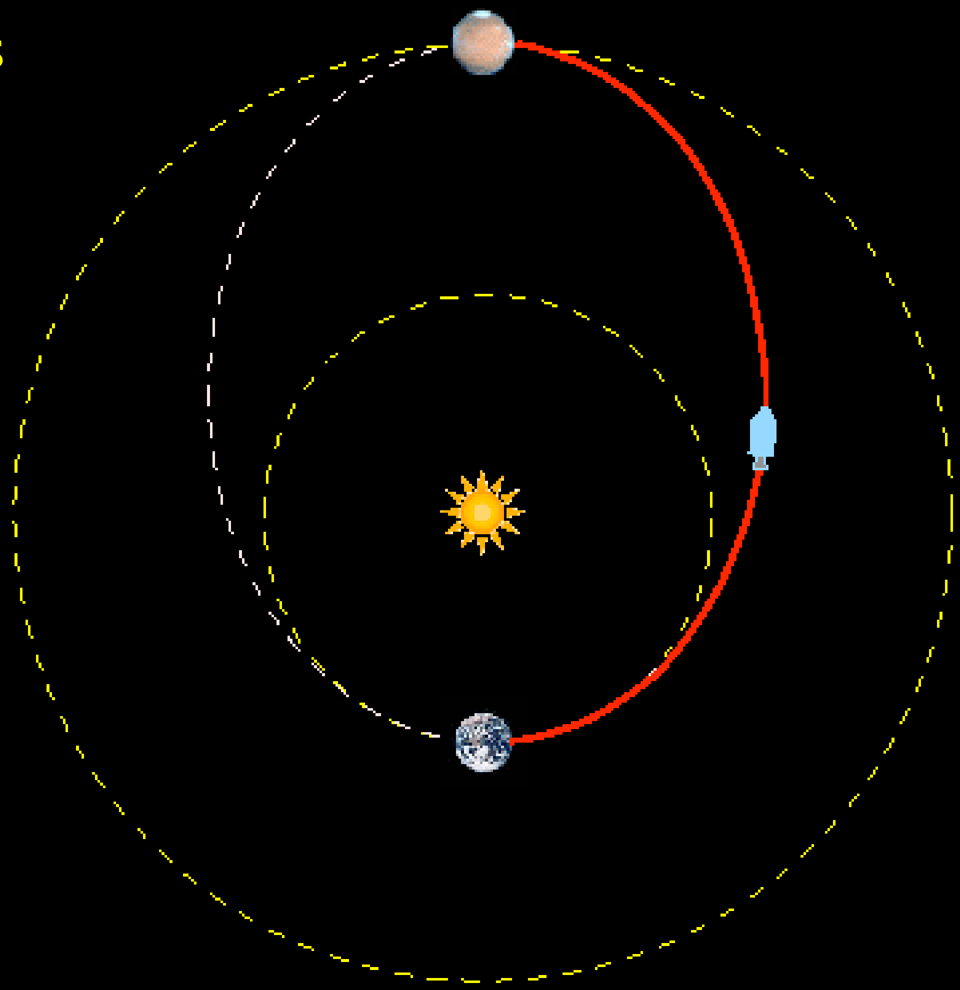
The absence of these minerals means that the atmosphere of Mars must have been massively lost in the early history of the planet, meaning that Mars probably never experienced long-term green-house warming.

Mars Settlement

What are the prospects for manned settlement of Mars? Many people have spent much time thinking bout possible scenarios.

One of the best developed is the "Mars Direct" mission, first proposed by Robert Zubrin. This is based on the idea that the astronauts need to "live off the land" as much as possible: create their own return fuel on the surface of Mars.

Recall from the Spaceflight lecture that we'd like to do a Hohmann transfer to save fuel; but this requires that we take half a year to get there, since it means arriving at Mars exactly half an orbit away from where we left it.



Stage 1: Unmanned 45 metric ton payload sent to Mars, containing the Earth Return Vehicle, a nuclear reactor, and 6 tons of liquid hydrogen.

8 month trip to Mars: lands using aerobraking. H_2 combines with atmospheric CO_2 to produce water and methane. Water is electrolysed to produce hydrogen and oxygen: O_2 stored, H_2 recycled.

Stage 2: 2 years later: second unmanned cargo leaves with a second ERV as backup.

At the same time, a craft with a crew of four with supplies for 3 years leaves Earth and lands near the first ERV. The crew remains on the surface for 18 months, exploring with a rover brought with them and fueled using methane produced by the initial ERV.

Stage 3: Every two years, a new manned and unmanned craft is launched to Mars, with a new crew to replace the one which is now returning home, leaving the habitation module behind.

A group called the Haughton-Mars Project has been simulating life on Mars by living in a habitation module similar to the one envisioned for Mars, in a polar desert in Haughton Crater in the Canadian high arctic. A group of volunteers is studying a landscape similar to Mars, while testing out technologies and living conditions similar to those envisioned on a voyage to Mars.


Next week...
... we'll look at rocks in space:
asteroids, comets and meteors.

Further reading

There are an enormous number of books on Mars out there, but most of them are organised around the various missions to Mars instead of the planet itself, and a great many tend towards a decidedly breathless style! At least they all have great pictures in them. Of course, the books that include information about the discoveries of the past year aren't out yet, though doubtless they will start appearing in the next year or so. With that caveat, here are a few recommendations.

- By far the best one I found is **"A Traveler's Guide to Mars"** by William K. Hartmann (Workman Publishing, 2003). The author is a scientist with Global Surveyor, so the book is extremely up-to-date as well as very readable. One of the best planet books I've read this year.

- **"Uncovering the Secrets of the Red Planet Mars"** by Paul Raeburn (National Geographic Society, 1998) tells the stories of the various Mars missions

- **"To Rise from Earth"** by Wayne Lee (Blandford, 1995), referenced in Lecture 2 about Spaceflight, has a very nice final section about the challenges of sending a manned mission to Mars from the spacecraft engineer's perspective.

- **"The Case for Mars"** by Robert Zubrin with Richard Wagner (Touchstone, 1997) is the blueprint for the "Mars Direct" mission. It's a bit of a polemic, but makes for interesting reading, including a bit about the "Mars Underground" that I liked. (You can even join, if you want!)

There are an unbelievable number of websites out there devoted to Mars and Mars colonisation. Here are a few I found useful as starting-out points:

- There is an excellent interactive map of Mars at "The Solar System in Pictures – The Planet Mars" by Alwyn Botha: http://www.the-planet-mars.com/map-of-mars/map-mars.html
- If you need to find out what all that Latin means in Martian place names, take a look at the USGS "Gazetteer of Planetary Nomenclature", Appendix 5: Descriptor Terms http://planetarynames.wr.usgs.gov/append5.html
- There's a very nice series of articles about the Martian terrain, written for students and teachers, by one of the scientists for the Mars Global Surveyor team, at "Essays Written for the Planetary Society Marslink Project" by Mike Caplinger, http://www.msss.com/http/ps/intro.htm
- The 15 January 2005 issue of New Scientist had a nice summary of "An amazing year on Mars", summarising the results found by the Mars Rovers, as did the March 2005 issue of Sky and Telescope.
- A discussion of the Mars Direct plan can be found at "Mars Direct: Headquarters for the Mars Direct Manned Mars Mission" http://www.nw.net/mars/
  There is also a Scentific American article by Robert Zubrin in the March 2000 issue: "The Mars Direct Plan" http://www.sciam.com/article.cfm?articleID=00087E38-5B46-1C75-9B81809EC588EF21

Sources for images used:

- Background image: Image of the "grand canal" (Valles Marineris) of mars from “Pictures of Mars and its Satellites” in “The Nine Planets: A Multimedia Tour of the Solar System” by Bill Arnett http://seds.lpl.arizona.edu/nineplanets/nineplanets/pxmars.html
- Missions to Mars: A complete list can be found at http://solarsystem.nasa.gov/missions/mars_missns/mars-mod.html. The pictures of the various missions come from this page or links therein.
- Mars/Earth comparison: from Mars Exploration Rover Mission: Classroom, poster comparing Earth and Mars, http://marsrovers.jpl.nasa.gov/classroom/
- Mars relief map: from MOLA High Resolution Shaded Relief Maps, http://ltpwww.gsfc.nasa.gov/tharsis/shademap.html
- Topographic image of Mars: taken by the Mars Global Surveyor. From the NASA Planetary Photojournal http://photojournal.jpl.nasa.gov/targetFamily/Mars, image PIA02031: Maps of Mars Global Topography.
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- Image of the crater Yuty: NASA/Viking Orbiter image 3A07. Colour version from http://www.nirgal.net/crater.html
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- Network of streams: from “Views of the Solar System” by Calvin Hamilton, http://www.solarviews.com/cap/mars/network.htm
- Flow channel: MOC image 8704, from “Views of the Solar System” by Calvin Hamilton, http://www.solarviews.com/cap/mgs/canyon.htm
- Islands: from “Views of the Solar System” by Calvin Hamilton, http://www.solarviews.com/cap/mars/islands.htm

- Tiu Vallis: from "Channels and Valleys" by Mike Caplinger http://www.msss.com/http/ps/channels/channels.html
- "Frozen sea": image from Mars Express press release 23 February 2005, http://www.esa.int/SPECIALS/Mars_Express/SEMCHPYEM4E_0.html
- Water pressure-temperature diagram: from Mars Polar Lander: Volatiles, http://mars.jpl.nasa.gov/msp98/mvacs/overview/volatiles.html
- Mars panorama: from Astronomy Picture of the Day 2000 May 14 http://antwrp.gsfc.nasa.gov/apod/ap000514.html
- Yogi rock: from Astronomy Picture of the Day August 14, 1997 http://antwrp.gsfc.nasa.gov/apod/ap970814.html
- South polar ice cap: from Views of the Solar System: South Polar Cap http://www.solarviews.com/cap/mars/southpol.htm
- Layers at the pole: from Views of the Solar System: Polar Laminated Terrain http://www.solarviews.com/cap/mars/layers.htm
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- Water map of Mars: from Astronomy Picture of the Day, 2004 September 4, http://antwrp.gsfc.nasa.gov/apod/ap040904.html
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- Mars obliquity variations: from Laskar et al., Paleoclimats martien, http://www.obspm.fr/actual/nouvelle/oct02/mars.en.shtml
- Mars Express image: from The Planetary Society, http://www.planetary.org/mars/mex-inst-omega.html
- OMEGA mineral map: from Bibring et al. 2005, Science 307, 1576–1581
- Images of the Mars Direct mission: from "Mars Direct Manned Mars Mission Image Gallery" http://www.nw.net/mars/gallery.html
- Haughton Crater: The Haughton-Mars Project: http://www.marsonearth.org/