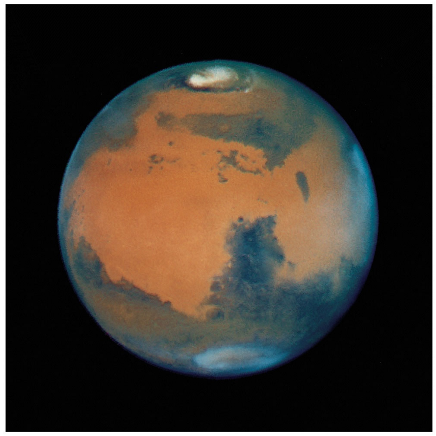
Mars



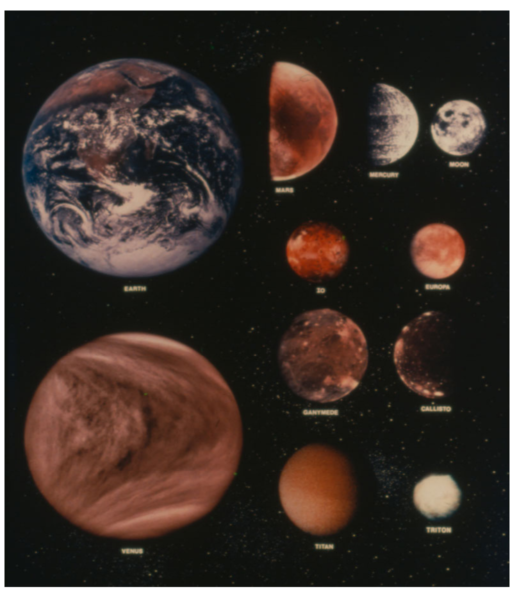
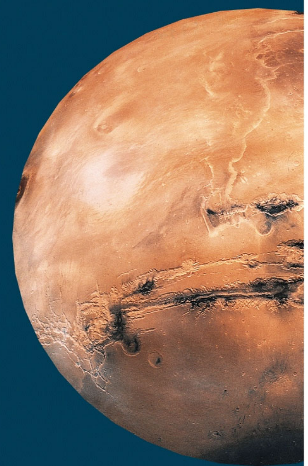

MARS
MERCURY
MOON
EARTH
IO
EUROPA
GANYMEDE
CALLISTO
VENUS
TITAN
TRITON

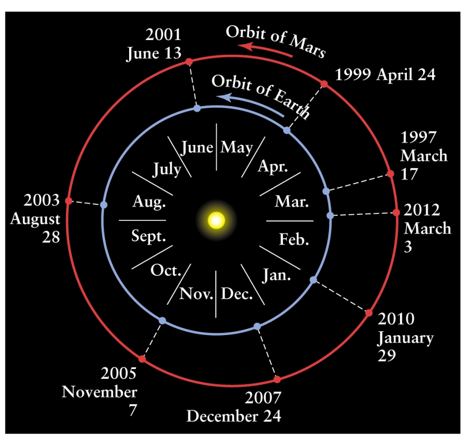
Table 12-1 Mars Data

Average distance from Sun:	1.524 AU = 2.279×10^8 km
Maximum distance from Sun:	1.666 AU = 2.492×10^8 km
Minimum distance from Sun:	1.381 AU = 2.067×10^8 km
Eccentricity of orbit:	0.093
Average orbital speed:	24.1 km/s
Orbital period:	686.98 days = 1.88 years
Rotation period:	$24^h\ 37^m\ 22^s$
Inclination of equator to orbit:	25.19°
Inclination of orbit to ecliptic:	1.85°
Diameter (equatorial):	6794 km = 0.533 Earth diameter
Mass:	6.418×10^{23} kg = 0.107 Earth mass
Average density:	3934 kg/m^3
Escape speed:	5.0 km/s
Surface gravity (Earth = 1):	0.38
Albedo:	0.15
Surface temperatures:	Maximum: 20°C = 70°F = 293 K
	Mean = −53°C = −63°F = 220 K
	Minimum: −140°C = −220°F = 133 K

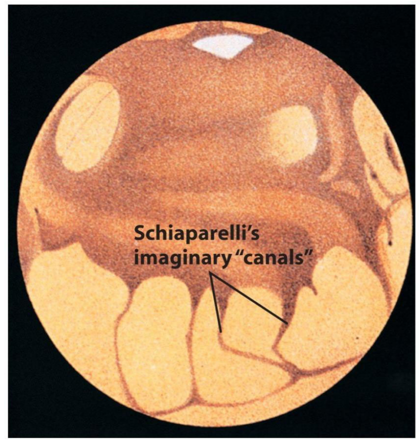


(NASA, USGS)

Orbit of Mars



Early Observations

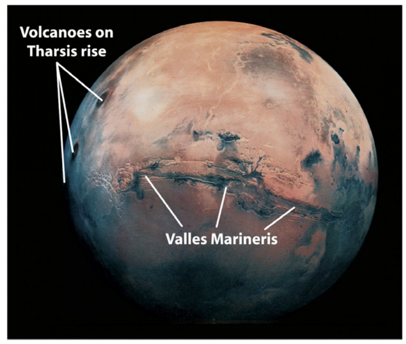


Universe by Freedman, Geller, and Kaufmann

Earth and Spacecraft Views

Exploration of Mars

First visits were by Mariners 4, 6, and 7. A major step forward was achieved in 1971, when **Mariner 9** became the first spacecraft to orbit another planet. The Mariner 9 orbiter mapped the entire planet at a resolution of about 1 km and discovered a great variety of features missed by the previous flybys, including volcanoes, huge tectonic canyons, intricate layers on the polar caps, and channels that appeared to have been cut by running water.



Universe by Freedman, Geller, and Kaufmann

Exploration of Mars – Orbiters

Viking Orbiters (2)	1976 – 1980	
Phobos 2 (Soviet)	1989	
Mars Global Surveyor	1997 – 2006	mars.jpl.nasa.gov/mgs/
Mars Odyssey	2001 – present	mars.jpl.nasa.gov/odyssey/
Mars Express	2003 – present	mars.jpl.nasa.gov/express/
Reconnaissance Orbiter	2006 – present	mars.jpl.nasa.gov/mro/
MAVEN	2014 – present	mars.nasa.gov/maven/
Mars Orbiter Mission	2014 – present	isro.gov.in/
ExoMars Trace Gas Orbiter	2016 – present	
Emirates Mars Mission (Hope)	2020 –	
Tianwen 1 (China)	2020 –	

Global Properties

Mars has a diameter of 6787 km, just over half that of the Earth. Its mass is 11% of the Earth's, and its uncompressed density is 3.8 gm/cm^3, about midway between that of the Earth (4.5) and that of the Moon (3.2).

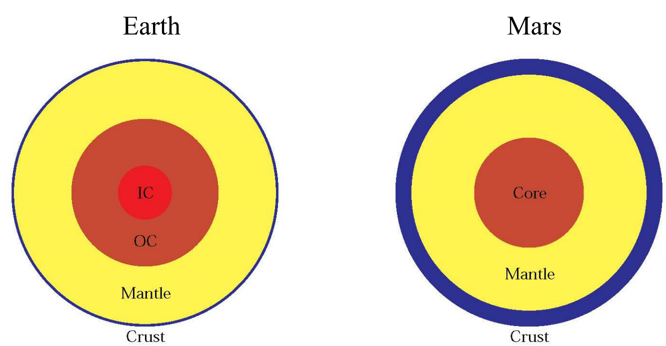
Thus Mars apparently has a composition between that of the Earth and that of the Moon, consisting primarily of silicates but with the possibility of a substantial metal core. This core is estimated to consist primarily of iron sulfide (FeS) and to have a diameter of about 2400 km.

The planet has **no detectable magnetic field**, suggesting that the core is not liquid.

Global Properties

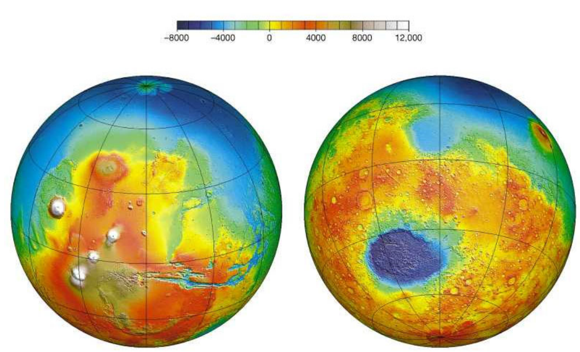
For its size, it is clear that Mars (like Earth, Moon, and Mercury) is a differentiated planet. Any scenario for its origin would have permitted it to heat sufficiently to separate into a core, mantle, and crust. However, since no seismic studies have been carried out, any conclusions about the exact interior structure of Mars are some what speculative.

Comparison of Mars



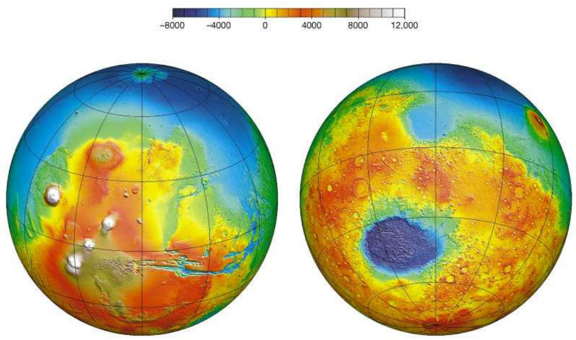
Global Properties

The surface of Mars divides into two major terrains. Approximately half the planet, lying primarily in the southern hemisphere, consists of ancient cratered terrain.



Global Properties

The other half, which is primarily in the north, contains young volcanic plains. These plains, like the terrestrial ocean basins or the lunar maria, are at an average elevation several km lower than the older southern uplands.



Global Properties

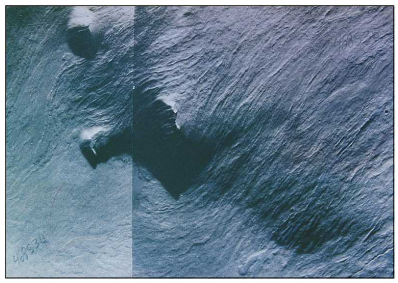
In many places the boundary between the two terrains is relatively abrupt, with the surface sloping down 4 or 5 km in a span of a few hundred km.

There are no mountain rings to mark the borders of the lowlands. They did not originate, like the lunar mare basins, in catastrophic impacts.

Some other process, still unknown, *destroyed the ancient crust* over half the planet and lowered the surface levels by about 5 km on the average.

Volcanic Plains

The northern hemisphere is characterized by rolling, volcanic plains that lie several km lower in elevation than the uplands. (1) These plains look very much like the lunar maria, and they have about the same numbers of impact craters; hence, they are probably 3 to 4 billion years old. (2) Mars experienced extensive volcanic activity at about the same time the Moon did. (3) The martian plains have been modified by erosion and sedimentation.

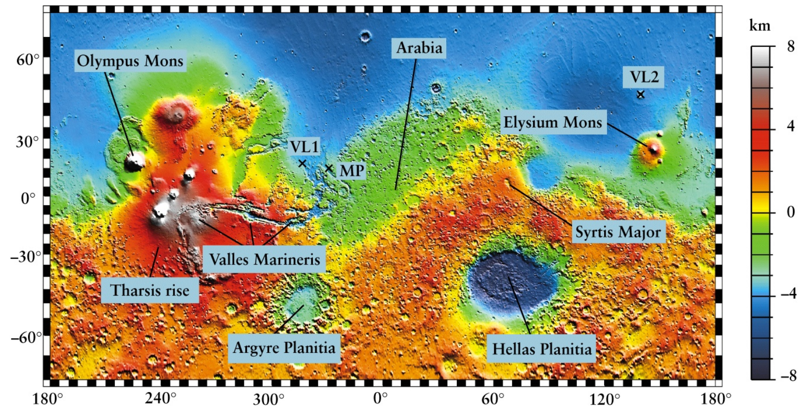


Cratered Uplands

Most of the martian southern hemisphere consists of cratered uplands. The martian craters are clearly of impact origin, although they have been modified more than lunar craters by subsequent erosion. There are no rays, and most craters have also lost their ejecta blanket. Some of the oldest craters appear to have been partially filled in, perhaps by windblown dust.

Global Properties

Mars does have impact basins, but they lie in the old southern uplands. Two largest basins are surrounded by mountains formed from the impacts.



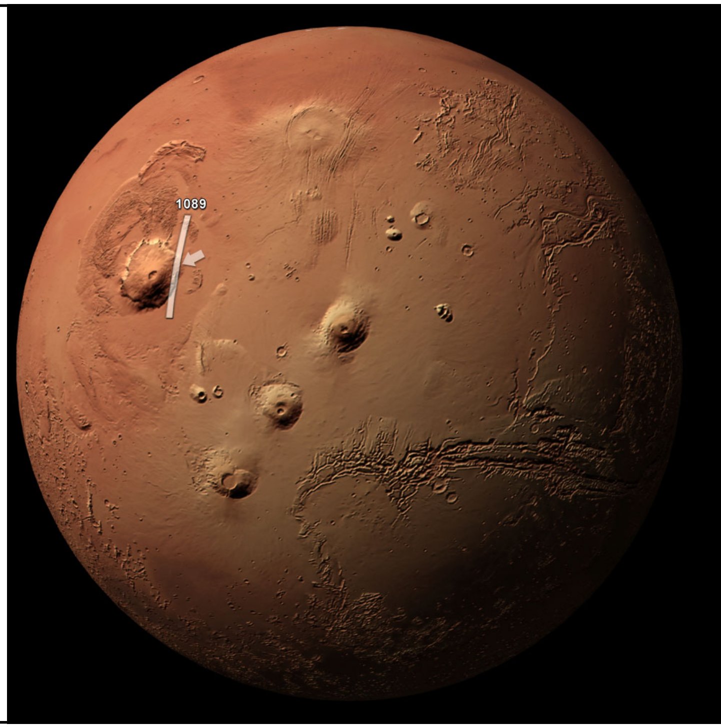
Universe by Freedman, Geller, and Kaufmann

Global Properties

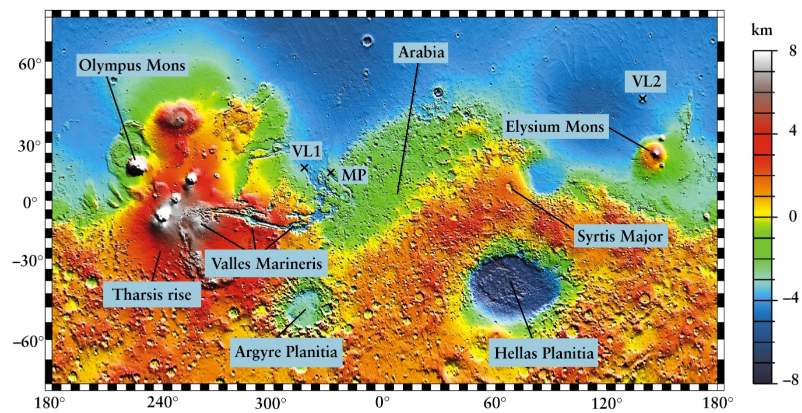
In addition to the north-south division of old uplands and young volcanic plains, Mars displays an impressive east-west asymmetry.

On one side of the planet, straddling the boundary between uplands and plains, is an immense bulge the size of North America that rises nearly 10 km above its surroundings. This is the **Tharsis Bulge**, a volcanically active region crowned by four great volcanoes that rise another 15 km.

The total range in elevation on Mars is 30 km; on the Earth it is 17 km.



Map of Topography



Universe by Freedman, Geller, and Kaufmann

Surface Features

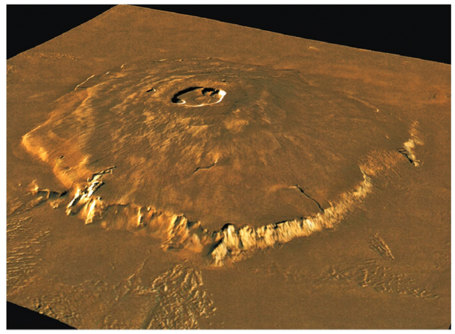
Volcanoes
Canyons
Craters
Runoff Channels

Tectonic Features

The **Tharsis Bulge** is primarily tectonic (but not plate tectonics) in origin. There is the single feature of Tharsis, forced upward but not induced to shift sideways. It is as if crustal forces began to act but then subsided before full-scale plate tectonics could begin.

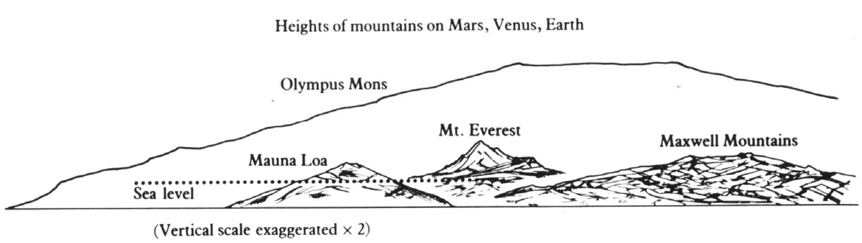
Shield Volcanoes

There are about a dozen volcanoes, and most are associated with the Tharsis bulge. Each is about 400 km in diameter, and all rise to the same height. **Olympus Mons** is more than 500 km in diameter, with a summit 25 km above the surrounding plains. Its volume is 100 times that of Mauna Loa.

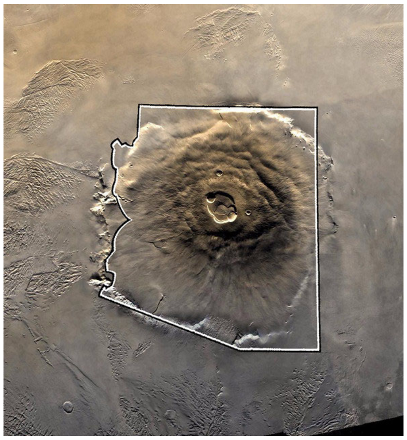


Shield Volcanoes

The volcanoes consist of many overlapping flows of fluid basaltic lavas. The summits of shield volcanoes are marked by **calderas**, which are broad, flat-floored collapse craters. The caldera of Olympus Mons is 80 km across; that of Arsia Mons is 120 km.

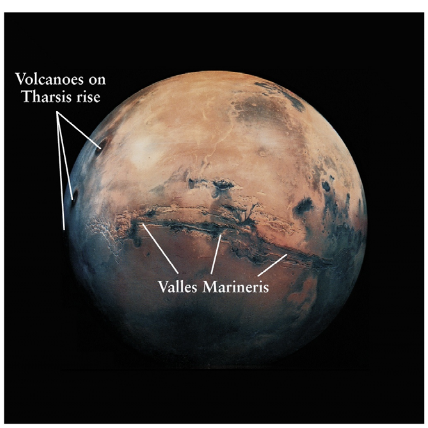


Shield Volcanoes



Many of the volcanoes show a fair number of impact craters, suggesting that they ceased activity a billion years or more ago. However, Olympus Mons has very, very few craters. Its present surface cannot be more than hundred million years old, and it could be much younger.

Valles Marineris

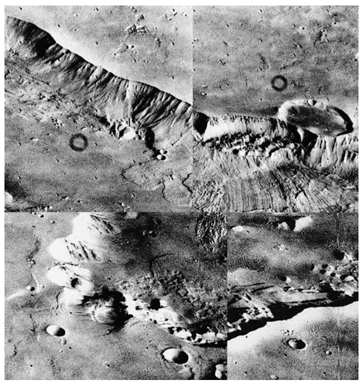


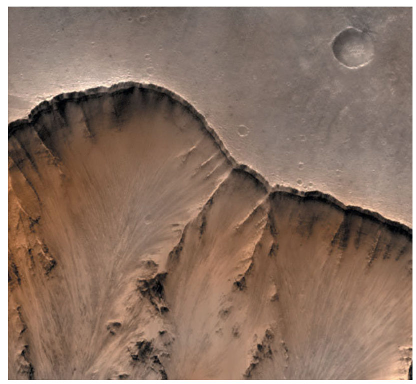
Universe by Freedman, Geller, and Kaufmann

The **Valles Marineris** canyon extends for 5000 km along the slopes of the Tharsis Bulge. The main canyon is about 7 km deep and up to 100 km wide.

It is NOT due to flooding. It is believed that a hard crust formed first, then part of the core and the mantle became liquid and **expanded**. Valles Marineris was produced as a result, basically being a giant tectonic crack.

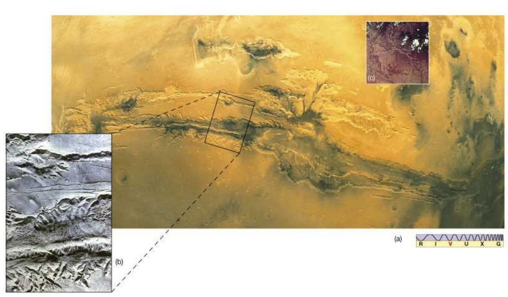
Valles Marineris





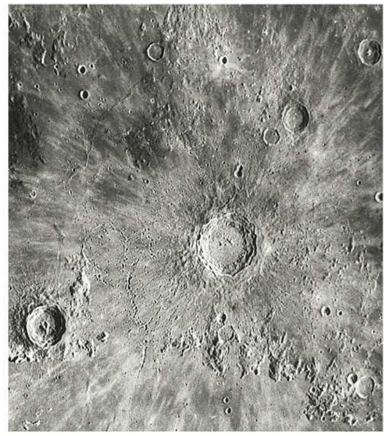
Canyons

The term canyon is somewhat misleading, because the Valles Marineris canyons were not cut by running water. They have no outlets. They are basically cracks, produced by the same crustal tensions that caused the Tharsis uplift. However, water is believed to have played a later role in shaping the canyons, primarily through the undercutting of cliffs by seepage from deep springs. This under-cutting led to landslides, gradually widening the cracks into great valleys.



Lunar Craters

This is the large *lunar* crater Copernicus. Its ejecta blanket appears to be composed of dry, powdery material.



Splosh Craters

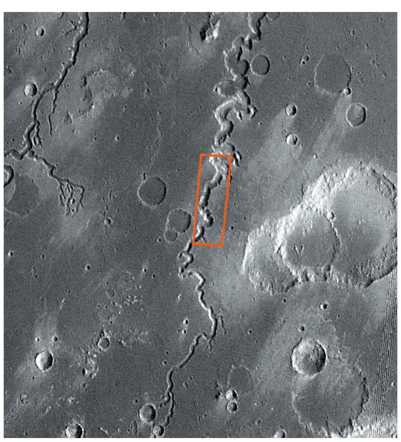
The ejecta from Mars' Yuty crater was liquid in nature.

Runoff Channel

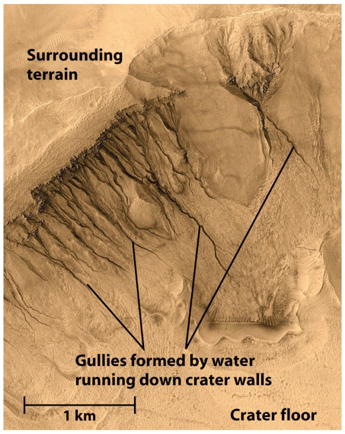
Numerous **runoff channels** appear to have been created by *rainfall*.

These are found in the old, southern cratered areas.

Ancient Riverbeds



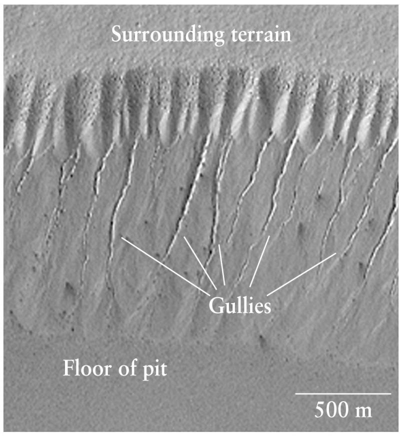
Gullies



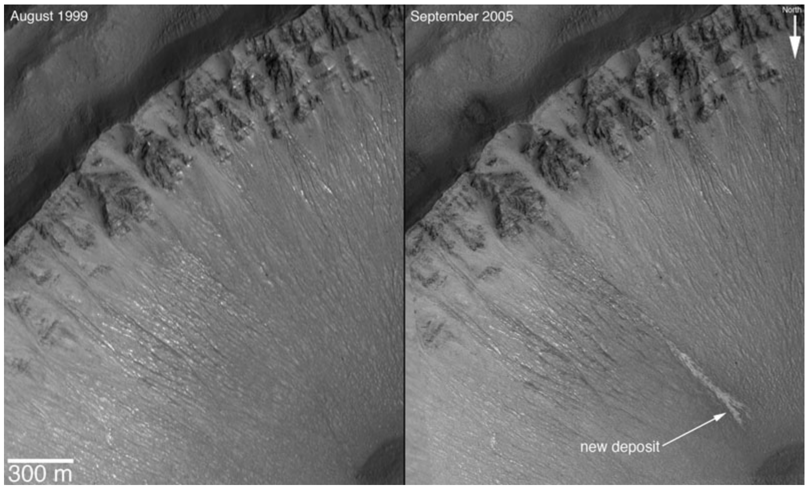
Universe by Freedman, Geller, and Kaufmann

Formed by running water?

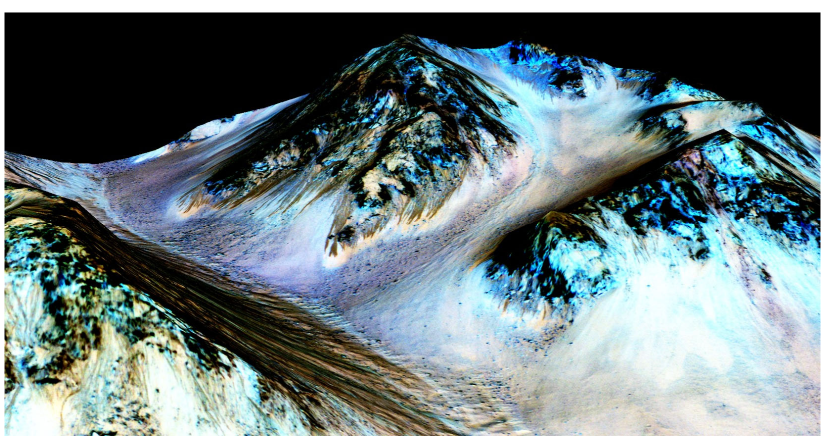
Gullies



These gullies along the pit of a wall appear to have been formed when subsurface water seeped out to the surface.



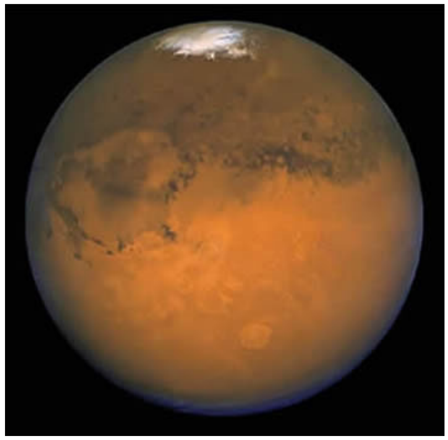
Flowing Water



Flowing Water 2015

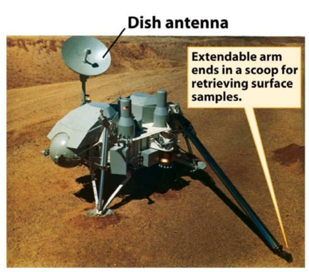
Using an imaging spectrometer on the Mars Reconnaissance Orbiter, **Georgia Tech** researchers detected signatures of hydrated minerals on slopes where mysterious streaks are seen. These darkish streaks appear to ebb and flow over time. They darken and appear to flow down steep slopes during warm seasons, and then fade in cooler seasons. They appear in several locations on Mars when temperatures are above -10 F (-23 C), and disappear at colder times.

The Surface of Mars



Exploration of Mars

The Viking missions (1976) consisted of two orbiters and two landers. The orbiters surveyed the planet at higher resolution than Mariner 9. After an exciting and often frustrating search for a safe landing spot, Viking 1 touched down on the surface of Chryse Planitia (the Plains of Gold) on July 20, 1976. Two months later Viking 2 landed with equal success in another plain farther north, called Utopia.



Surface Images – Viking

Universe by Freedman, Geller, and Kaufmann

Surface Images – Viking

The Search For Life

The present status of life on Earth demonstrates that microscopic organisms far outnumber large ones and are far more versatile in their adaptations to various environments. The fossil record shows that microbial life was the only kind of life on Earth for billions of years, far longer than larger creatures have existed.

There is no reason to expect another planet with life to differ from Earth in the overall development of living systems, and this is why the Viking project emphasized the search for martian microbes.

The major difficulty was trying to guess what the alien organisms would eat and drink and what effect they might have on their environment.

Viking Life Experiments

In addition to searching the landscape for large life-forms with the Lander cameras, four types of experiments were carried out to determine whether the Martian soil contains any form of microscopic life.

The Landers performed each of these experiments repeatedly on different samples of soil using the **Viking Lander soil sampler**.

No conclusive evidence for life on Mars was found during the Viking missions.

Gas Exchange Experiment

The first of the biology experiments, the **Gas Exchange Experiment**, was designed to test whether minute organisms lying dormant in the soil would come to life after addition of water or organic compounds.

Both oxygen and carbon dioxide were given off after addition of water, but their release could have been caused by decomposition of the soil.

Carbon Assimilation Experiment

The second experiment, the **Carbon Assimilation Experiment**, assumed that organisms would thrive in the carbon dioxide-rich atmosphere of Mars, and would incorporate or assimilate carbon from the atmosphere in their life processes.

Although some carbon compounds were produced during this experiment, they could also have been caused by chemical reactions in the soil.

Labeled Release Experiment

The third experiment, the **Labeled Release Experiment**, tested whether life processes were present by monitoring the release of radioactive gas introduced to the sample in the form of nutrients.

A rapid release of carbon dioxide did occur after the first addition of nutrients, consistent with biological activity. However, the amount of carbon dioxide soon diminished, suggesting that Martian organisms were not responsible.

Gas Chromatograph – Mass Spectrometer

The **Gas Chromatograph – Mass Spectrometer Experiment (GCMS)** also heated a soil sample and revealed an unexpected amount of water but failed to detect organic compounds.

This absence was so absolute that it seems there must be some mechanism actually *destroying* carbon compounds on the surface.

Mars' Red Dust

Mars is covered with vast expanses of sand and dust, and its surface is littered with rocks and boulders. The dust is very fine, and enough remains suspended in the atmosphere to give the sky a reddish hue. This hue is due to ***rusting iron*** minerals presumably formed a few billion years ago when Mars was warm and wet. But now that it is cold and dry, modern rusting may be due to a super-oxide that forms on minerals exposed to ultraviolet rays in sunlight.

Life on Mars?

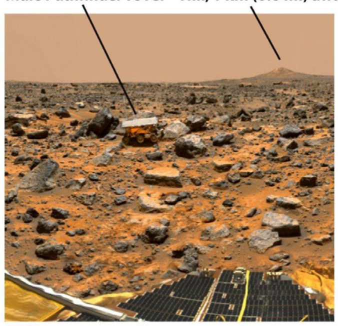
Is there life on Mars? Two planetary scientists recently speculated that there are *extremophile microbes* which utilize a mixture of hydrogen peroxide (H_2O_2) and water (H_2O). These microbes might well be able survive the thin, cold, dry atmosphere on Mars.

Life that involves hydrogen peroxide does exist here on Earth, they note, and such life would be better able to absorb water on Mars.

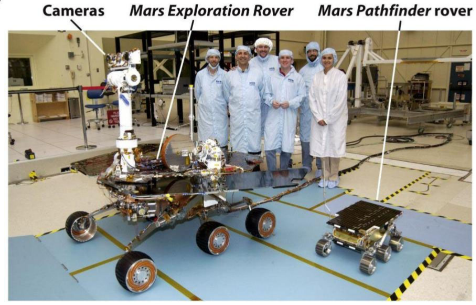
They also claim that such life would be consistent with the ambiguous results coming out from the life-detecting experiments aboard the old Viking Landers.

Exploration of Mars – Landers

Mars Pathfinder (*Sojourner*)	1997
Mars Exploration Rovers	2004 – 2010 (Spirit) ;
(*Spirit* and *Opportunity*)	2004 – 2018 (Opportunity)



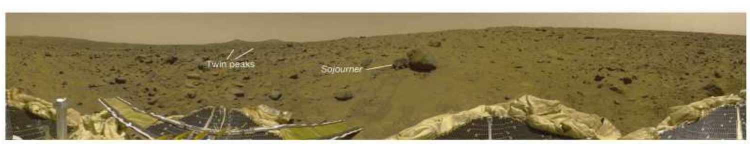
(a) A rover on Mars



Two generations of rovers

Universe by Freedman, Geller, and Kaufmann

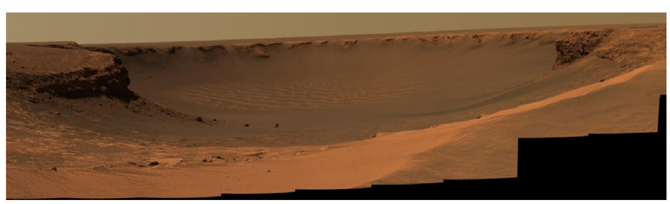
Surface Images – Pathfinder



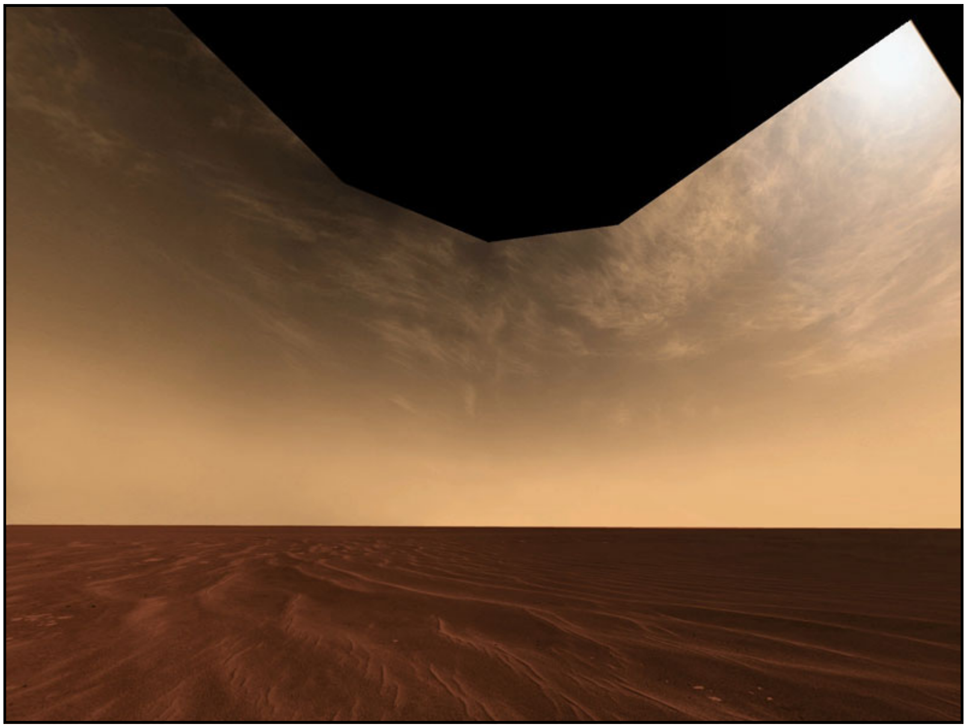
Surface Images – Pathfinder

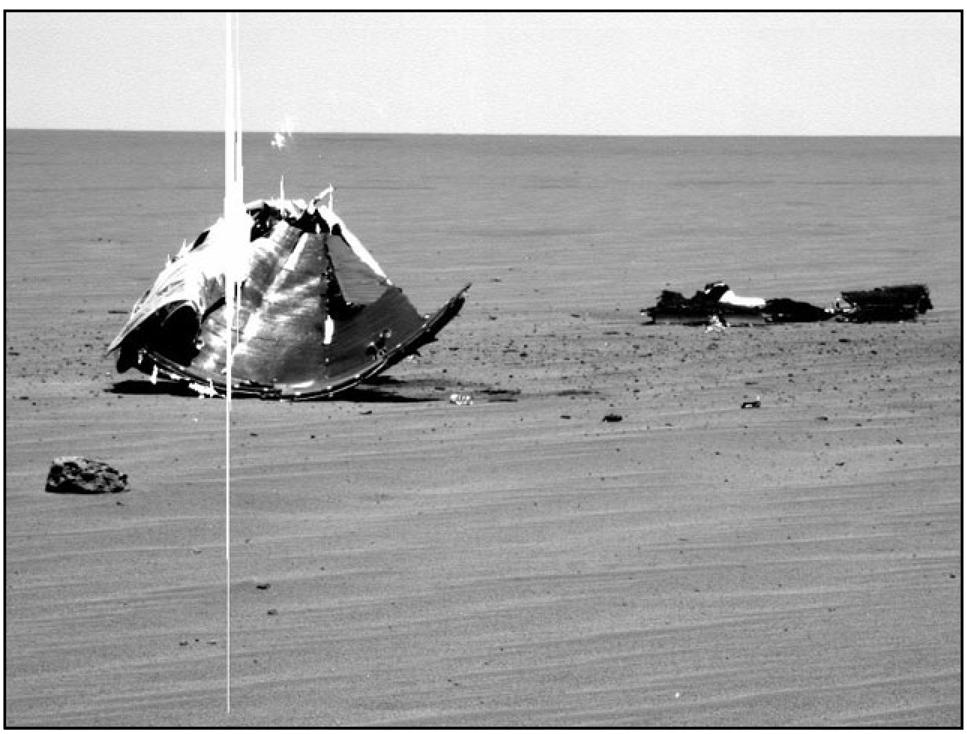
Universe by Freedman, Geller, and Kaufmann

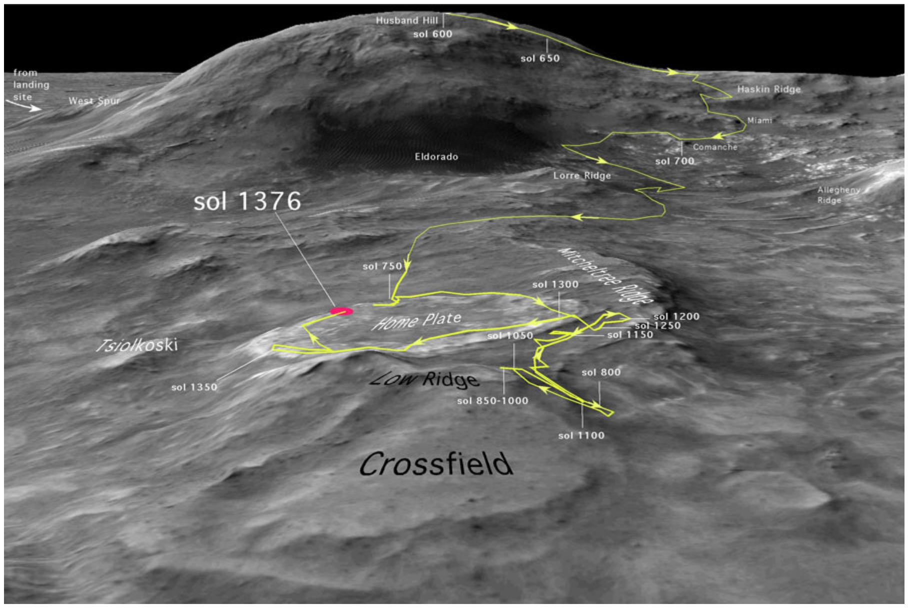
Surface Images – Rovers

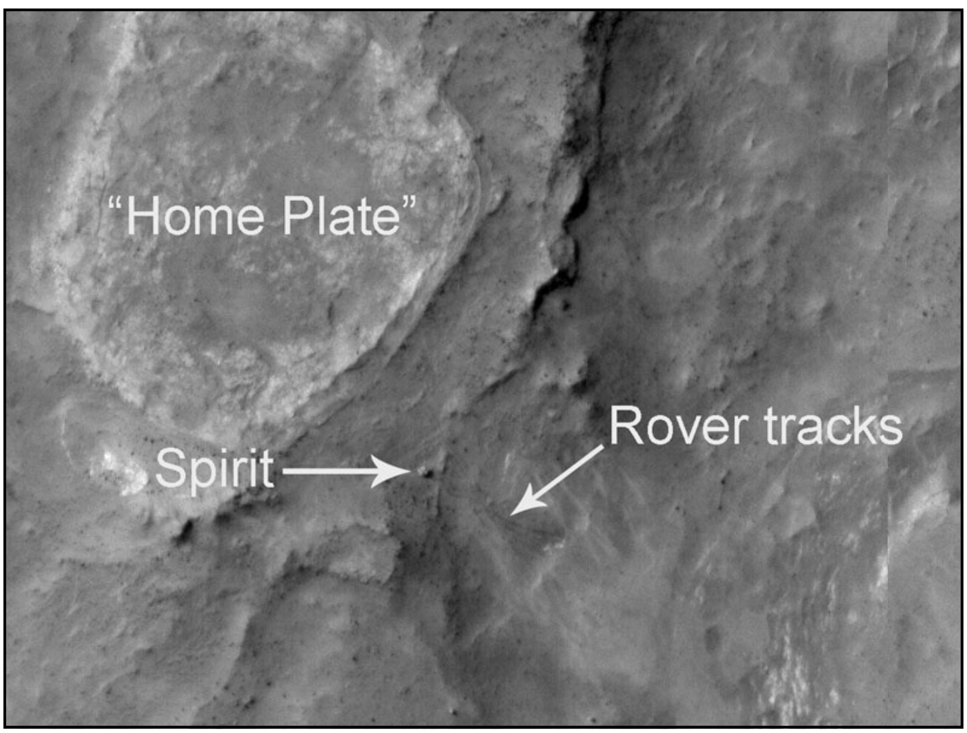


Universe by Freedman, Geller, and Kaufmann






Husband Hill
sol 600
sol 650
from landing site
West Spur
Haskin Ridge
Miami
Comanche
Eldorado
sol 700
Lorre Ridge
Allegheny Ridge
sol 1376
sol 750
Mitcheltree Ridge
sol 1300
sol 1200
sol 1250
sol 1150
Home Plate
sol 1050
Tsiolkoski
sol 1350
Low Ridge
sol 800
sol 850-1000
sol 1100
Crossfield


"Home Plate"
Spirit
Rover tracks

Rover Locations

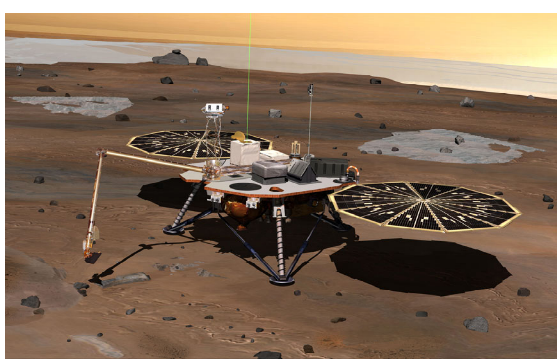
Where are the Rovers and Curiosity?

http://marsrovers.jpl.nasa.gov/mission/traverse_maps.html

http://mars.jpl.nasa.gov/msl/multimedia/videos/

Exploration of Mars – Landers

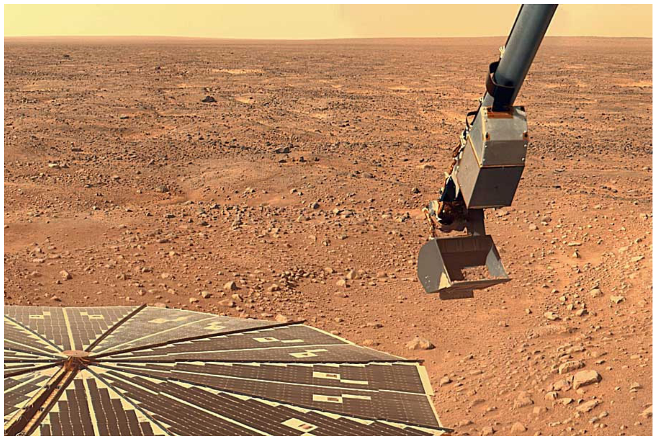
Phoenix 2008 – 2010 phoenix.lpl.arizona.edu/



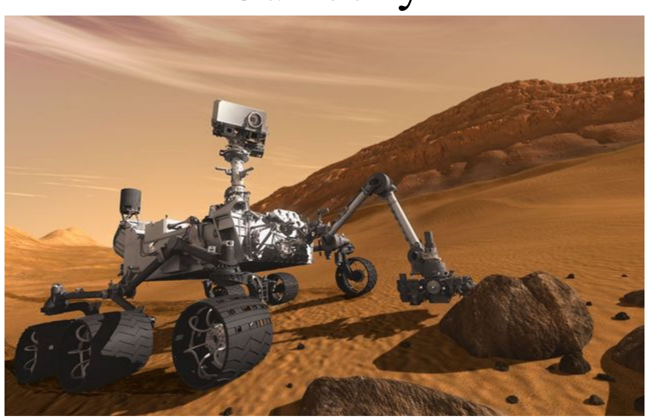
Surface Images – Phoenix

Surface Images – Phoenix

Surface Images – Phoenix



Curiosity



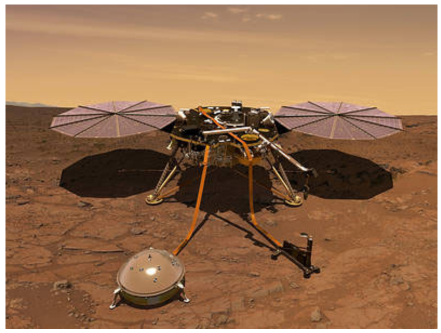
Curiosity Status

Exploration of Mars – Landers

Curiosity 2012 – present http://mars.jpl.nasa.gov/msl/

Exploration of Mars – Landers

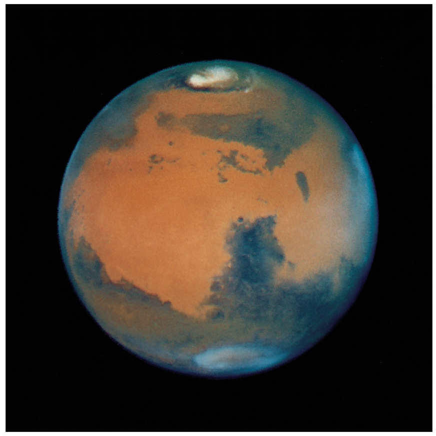
InSight 2018 – present /www.nasa.gov/mission_pages/insight



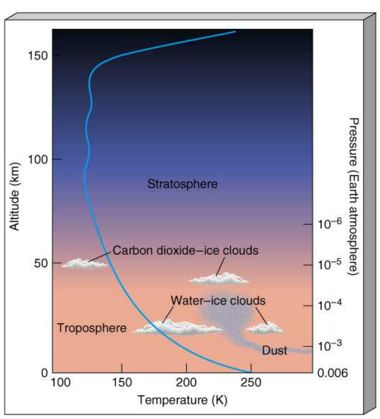
Exploration of Mars – Landers

Perseverence 2021 – present https://www.nasa.gov/perseverance

Mars



Martian Atmosphere

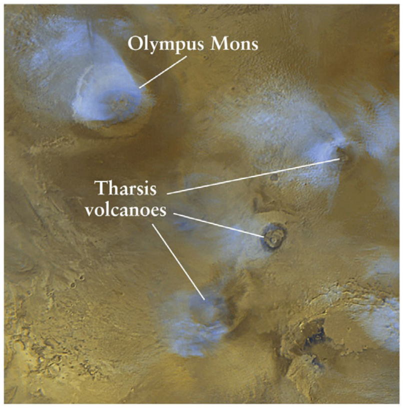


The atmosphere of Mars is composed primarily of **carbon dioxide** (95%), with about 3% **nitrogen** and 2% **argon**.

The preponderance of carbon dioxide over nitrogen is not too surprising when you remember that the Earth's atmosphere would also be mostly CO_2 if the CO_2 were not locked up in marine sediments.

Mars has a troposphere, in which convection takes place, and above it a more stable stratosphere.

Martian Clouds

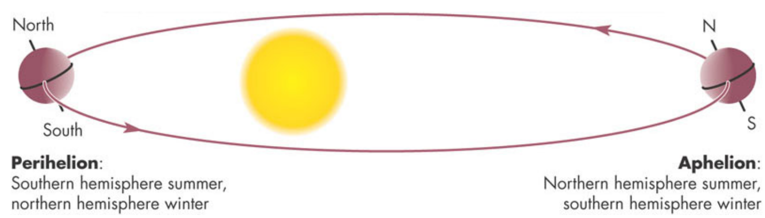


Universe by Freedman, Geller, and Kaufmann

Several types of clouds can form in the atmosphere. There are dust clouds, H_2O ice clouds (similar to cirrus clouds on Earth), and CO_2 "dry ice" crystal clouds at high altitudes.

Fogs can also appear in deep craters and canyons during the early morning.

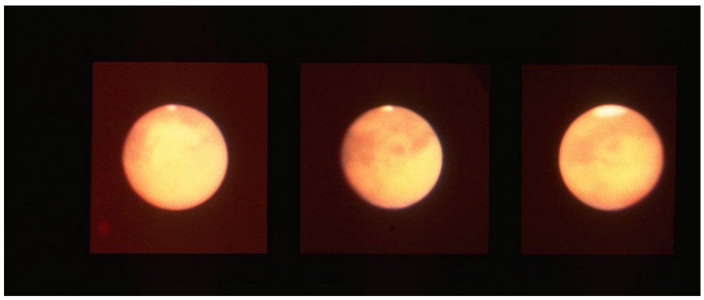
Eccentricity Effects Seasons



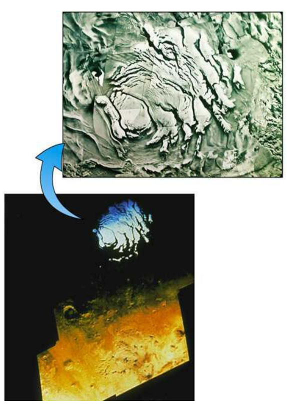
Mars is nearest the Sun in southern summer and farthest from the Sun in southern winter. Thus, the **southern seasonal** variations **are greater** than those in the northern hemisphere.

Seasonal Polar Caps

The seasonal caps on Mars are composed of frozen CO_2. These deposits condense directly from the atmosphere when the surface temperature drops below about 150 K. The caps develop during the cold Martian winters, extending down to about 55° latitude in the south and to 65° in the north. When the seasons warm, the CO_2 sublimates into the atmosphere.



Permanent Polar Caps



What is left during the summers?

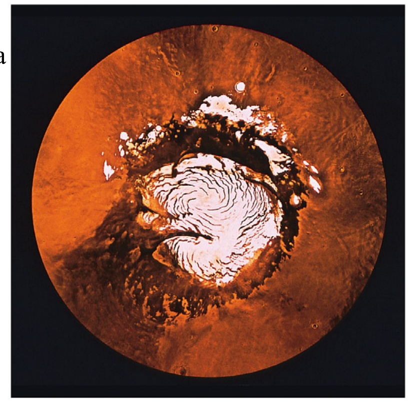
Quite distinct from the thin seasonal caps of CO_2 are the **permanent caps**. The southern permanent cap has a diameter of 350 km and is composed of thick deposits of frozen CO_2 (probably on top of some H_2O).

Throughout the southern summer, the cap remains at the freezing point of CO_2, 150 K, and this cold reservoir is thick enough to survive the summer heat intact, even though the surrounding temperature should be able to melt the "dry ice" cap.

Permanent Polar Caps

The permanent northern cap is different. It is much larger, never shrinking below a diameter of 1000 km, and it is composed of ordinary water ice.

Summer temperatures here are also too high for CO_2 to be retained. We do not know the thickness of the water ice cap, but it may be as much as several km. This cap represents a huge reservoir of H_2O, in comparison with the very small amounts of water vapor in the atmosphere.

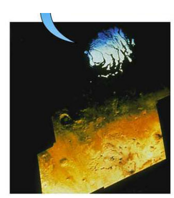


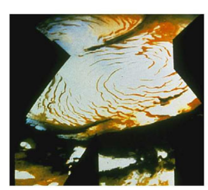
Differences in the Polar Caps

The explanation for the different composition of the two permanent polar caps is complex, since the southern summers are hotter than the northern ones, yet it is in the warmer south that CO_2 survives.

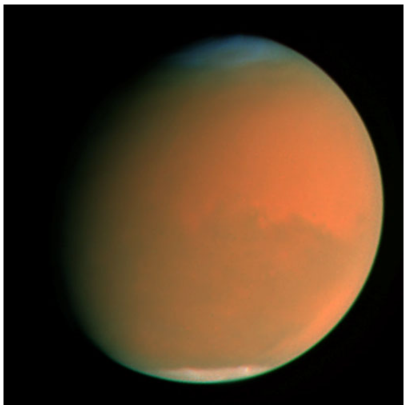
Probably the explanation is associated with the major **dust storms** which always take place during the northern winters (southern summers).

The northern cap becomes dusty and dark, so that it absorbs more sunlight and heats more rapidly when spring arrives, evaporating the CO_2 and retaining only H_2O.





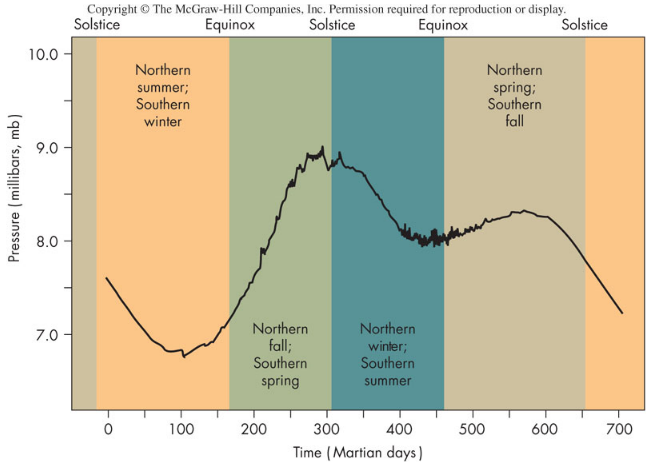
Dust Storms



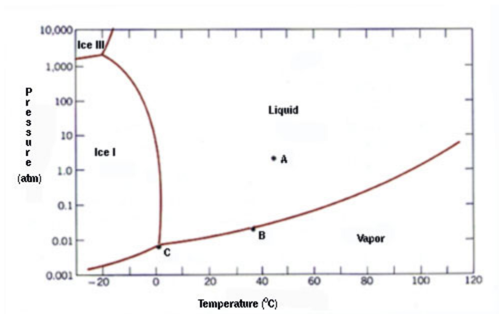
Periodically, global dust storms occur. Only very small dust particles can be carried aloft and deposited over the surface by the weak winds in the thin Martian atmosphere. For example, a 100-km/hr wind is only as strong as a 10-km/hr breeze on the Earth.

The dust storms are the cause for the changing color patterns seen by visual astronomers. It also gives the Martian sky a pinkish hue.

Change in Atmospheric Pressure

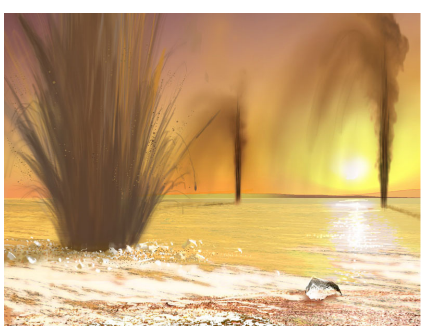


Why No Liquid Water?



The surface pressure is always less than 0.01 atm. The temperature is rarely above freezing. The vapor **condenses** to ice; the ice **sublimates** to vapor.

Geysers

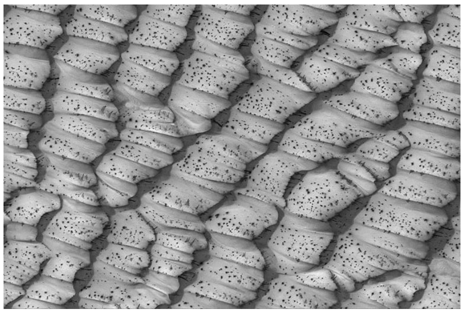


Artist's impression

Mars Odyssey has spotted jets of CO_2 erupting from the south pole. The gas geysers are quite unlike anything on Earth and carry debris hundreds of meters above the surface.

Possibly the south polar cap is composed of water ice mixed with layers of dust and sand. On top of this is the CO_2 ice layer. Heating causes the trapped gas to explosively vent through the top layers

Geysers



The black "dots" are ~100 feet across.

Dark spots mark the presence of CO_2. When spring begins and the sunlight warms the pole again, the CO_2 frost sublimates. Eventually pressure builds up and the gas bursts through weak spots in the overlying slab, jetting out at about 150 km an hour.

Images show dark spots and spider-shaped markings where the jet erodes the surrounding terrain. The gas geysers last for several months until the overlying slab completely sublimates away.

Catastrophic Floods

The martian **outflow channels** were formed by sudden floods. The source regions contained abundant water frozen in the soil as **permafrost**.

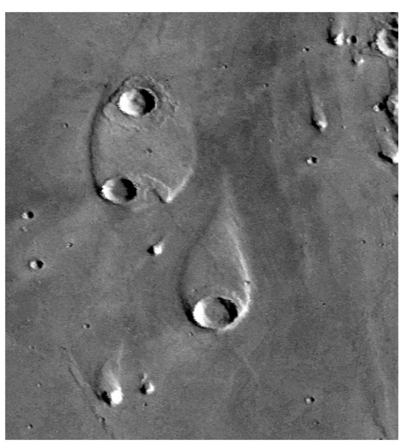
Most of the subsurface of Mars remains below freezing temperatures at all times, so that permafrost is stable indefinitely.

These could have been caused during the formation of the volcanic plains.

Outflow Channels

Outflow channels drain from the uplands into the northern volcanic plains. These channels are much larger than the older runoff channels. The largest are 10 km or more in width and hundreds of km long.

Catastrophic Floods



Universe by Freedman, Geller, and Kaufmann

Many features have convinced geologists that they were carved by huge volumes of running water. Such floods could not have been sustained by rainfall, but most have some other source.

The Pathfinder probe landed near here. The flash flood had brought and deposited a wide variety of rock types, so Pathfinder did not have to travel far to see a great differences.

Catastrophic Floods

The two kinds of martian channels thus provide evidence of two periods in the past when water was present in liquid form.

The first, about 4 billion years ago, was a time when rain fell and the atmosphere was probably much thicker and warmer than it is at present. **[Runoff Channels]**

The second, perhaps a billion years later, represented the release of frozen groundwater by volcanic heating. **[Outflow Channels]**

Since then, the planet has probably been as cold and dry as we see it today, although occasional shorter periods of warmer and wetter climate are not impossible in more recent times.

Climatic Change

The layering in polar regions suggests climatic changes similar to our ice ages, with time scales of tens of thousands of years. In addition, there are longer-term trends. Billions of years ago, the Martian temperatures were warmer, rain fell, and the atmosphere must have been much more substantial.

The long-term cooling of Mars and loss of its atmosphere are a result of both its small size (and low escape velocity) and its greater distance from the Sun. Presumably, Mars formed with a much thicker atmosphere, and it maintained a higher surface temperature because of the greenhouse effect.

Rainwater took CO_2 out of the atmosphere, and this gradually lowered the temperature. Eventually, it became so cold that the water froze out, further reducing the atmosphere's ability to retain heat.

Climatic Change

On Mars there was no plate tectonic activity, so the rocks – that contain the CO_2 – were not recycled. It is possible that a greenhouse effect occurred for about 500 million years.

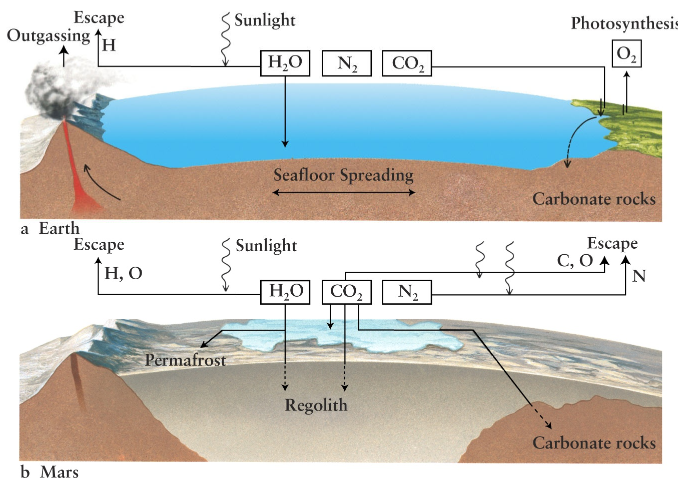
But then rainfall removed H_2O and CO_2 from the atmosphere, causing the temperature to decline.

Then UV radiation from the Sun destroyed N_2, which subsequently escaped. Also, the H_2O was fractionated.

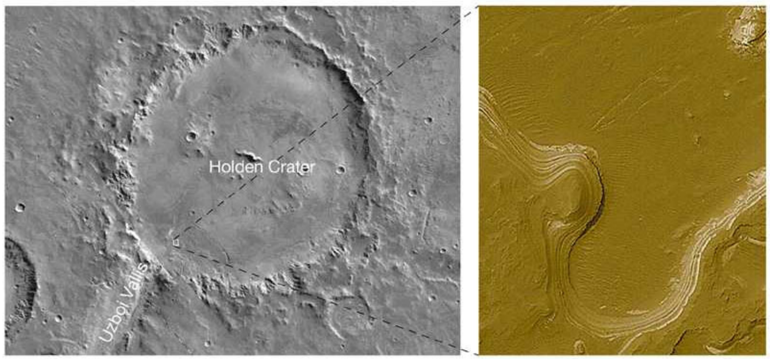
The released O_2 later combined into the rocks.

So it was a combination of (a) **rainfall**, (b) **losses to space**, and (c) **chemical reactions** that changed the atmosphere.

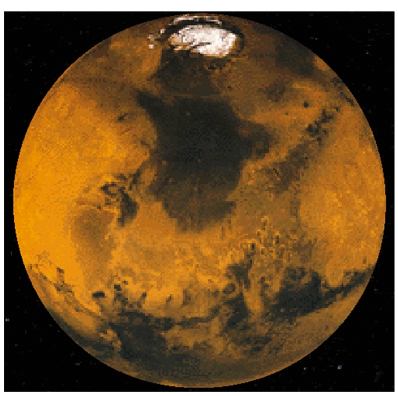
Atmospheres of Earth and Mars

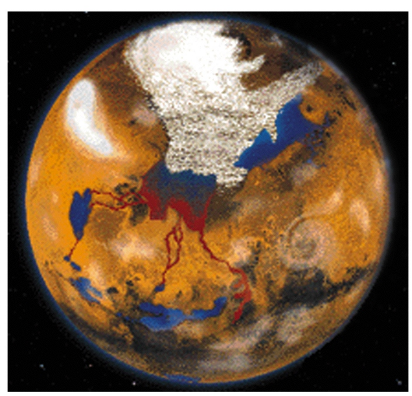


Ancient Oceans

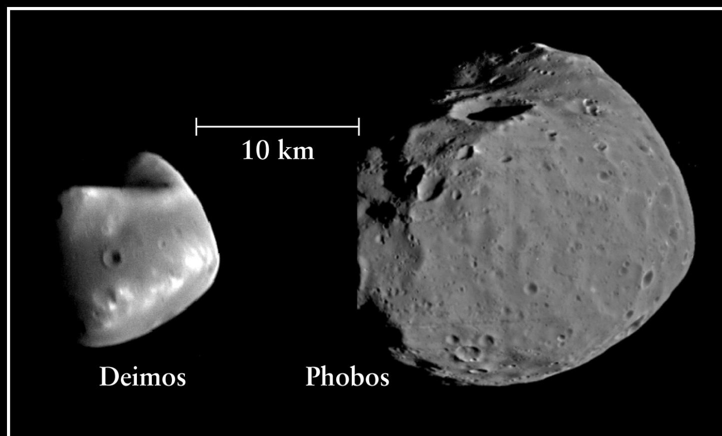


Ancient Oceans

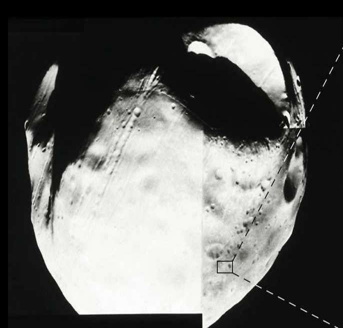




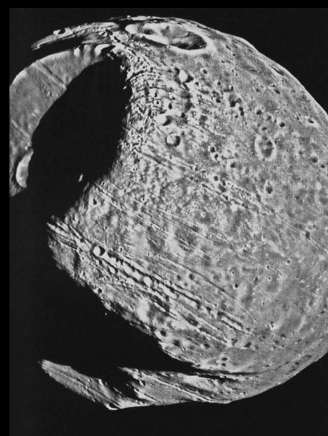
Phobos and Deimos



Phobos



Phobos



Phobos

N - North pole

Deimos

Deimos