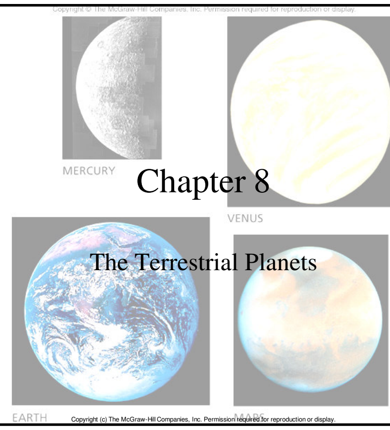
October 30, 2008

- Reminder:
  - Online quizzes due by test date
  - Observation tonight, weather permitting, dress warmly!
- Chapter 8
- Planetary distances Exercise



Chapter 8

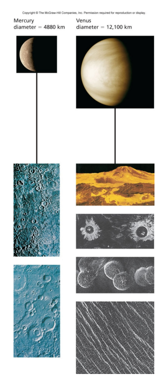
The Terrestrial Planets

The Terrestrial Planets

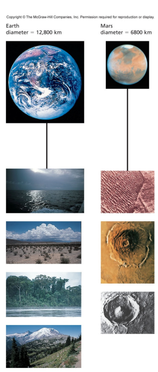
- The four terrestrial planets – Mercury, Venus, Earth, and Mars – have similar sizes and structure
- These rocky worlds orbit in the inner part of the Solar System, too small and too warm to have captured massive hydrogen atmospheres like the Jovian giants
- They have very few possessions – the Earth has the relatively large Moon and Mars has two small captured asteroids as moons

Terrestrial Planet Overview

- Mercury – smallest terrestrial planet, looks like Moon (gray, bare, cratered), essentially no atmosphere
- Venus – covered with deep sulfuric acid clouds in a dense CO_2 atmosphere, hottest planet, immense volcanic peaks tower over desolate plains

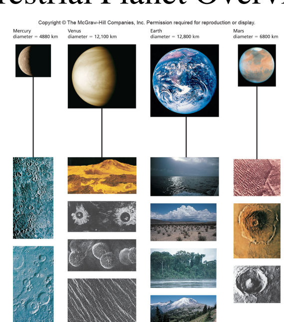


Terrestrial Planet Overview



- Mars – polar caps of ice and CO_2, vast red deserts with craters and dunes, canyons, and dry river beds, ancient volcanoes, thin CO_2 atmosphere
- Earth – blue seas, white clouds and ice caps, red deserts, green jungles, mountains

Terrestrial Planet Overview

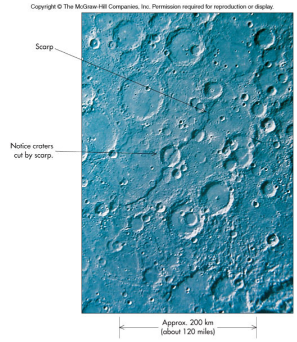


- Planetary size coupled with distance from Sun is the cause for these differences!

Mercury

- Mercury's radius is 1/3 and its mass 1/20 that of Earth
- Circular craters cover the surface with the largest one being Caloris Basin with a diameter of 1300 km
- Unlike the Moon where they are found almost exclusively in maria, congealed lava flows are found in many of Mercury's old craters and pave much of its surface

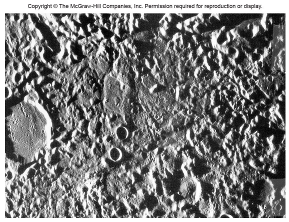
Scarps



- Enormous ***scarps*** (cliffs), formed as Mercury cooled, and shrank, wrinkling like a dried apple

"Weird" Terrain

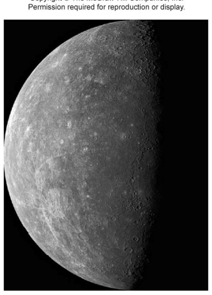
- "Weird terrain" feature opposite side of planet from Caloris Basin possibly caused by seismic waves generated by impact that created Caloris



Mercury's Temperature

- Mercury's noon temperature at the equator (about 700 K = 800° F) and nighttime temperature (100 K = -280° F) are near the Solar System's surface extremes
- These extremes result from Mercury's proximity to the Sun and its lack of atmosphere

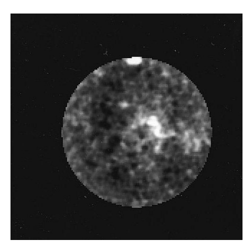
Mercury's Atmosphere?



- Its low mass and proximity to the Sun do not allow Mercury to retain an atmosphere of any significance
- Its lack of volcanoes suggests that Mercury never had a significant atmosphere

Ice at the Poles?

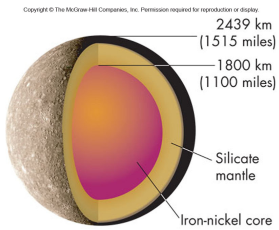
- Mercury's poles are always very cold, enough so that small ice caps exist there - perhaps the result of a comet impact that created gaseous water that drifted to the poles and froze out



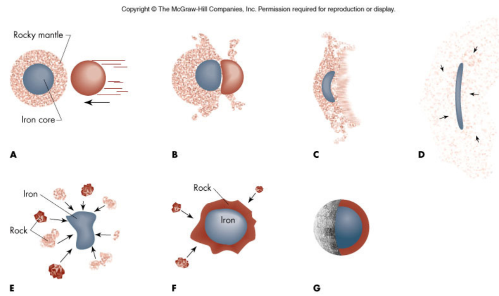
Note to editor: This image is From 3rd ed. Newer images Are available in the literature

Mercury's Interior

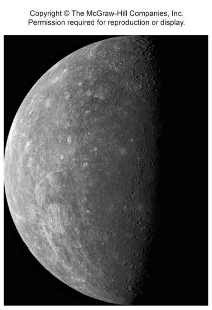
- Mercury's very high average density suggests that its interior is iron-rich with only a thin rock (silicate) mantle
- Two possible reasons for a thin silicate surface:
  - Silicates did not condense as easily as iron in the hot inner solar nebula where Mercury formed
  - Rocky crust was blasted off by an enormous impact



Another Large Impact Hypothesis



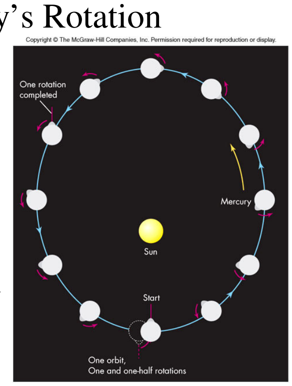
Mercury's Magnetic Field



- Mercury's very weak magnetic field probably due to:
  - Small molten core
  - Slow rotation rate
  - The field may be simply that its solid iron-nickel core is a huge permanent magnet, but one weaker than the dynamo-created magnetic field of Earth

Mercury's Rotation

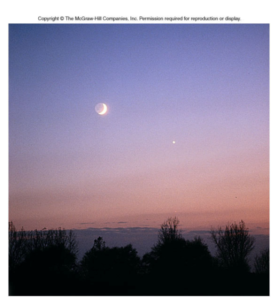
- Mercury spins very slowly with a sidereal rotation period of 58.646 Earth days, exactly 2/3 its orbital period around the Sun of 87.969 Earth days
- Consequently, Mercury spins 3 times for every 2 trips around the Sun



Mercury's Rotation

- Such a ratio of periods is called a ***resonance***
  - Mercury's resonance is the result of the Sun's tidal force on Mercury and its very elliptical orbit – the Sun cannot lock Mercury into a synchronous 1:1 rotation because of the high eccentricity of Mercury
- Mercury's solar day is 176 Earth days, longer than its year!
- Because of Mercury's slow rotation, near perihelion the Sun will briefly reverse direction in the Hermean sky

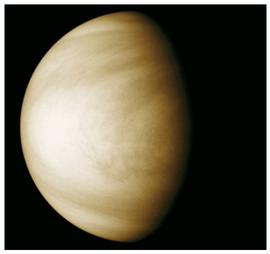
Venus



- Venus has a mass and diameter very close to that of Earth
- However, the two planets have radically different surfaces and atmospheres

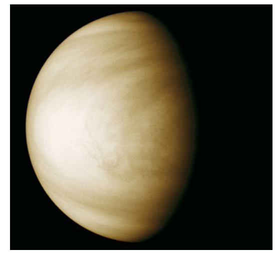
The Atmosphere of Venus

- Reflected spectra and spacecraft measurements show the Venusian atmosphere is 96% CO_2, 3.5% N_2, and small amounts of H_2O and other gases



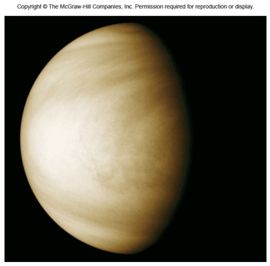
The Atmosphere of Venus

- The clouds of Venus are sulfuric acid droplets with traces of water
  - The clouds are very high and thick, ranging from 30 km to 60 km above the surface
  - Surface cannot be seen through clouds
  - Some sunlight penetrates to surface and appears as tinged orange due to clouds absorbing blue wavelengths



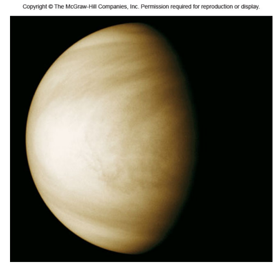
The Atmosphere of Venus

- The atmosphere is extremely dense, reaching pressures about 100 times that of Earth’s
- The lower atmosphere is very hot with temperatures of 750 K (900° F) at the surface, enough to melt lead
- Spacecraft have landed on Venus, but do not survive long



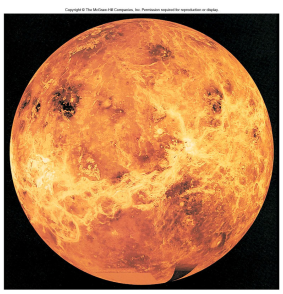
The Greenhouse Effect on Venus

- Large amounts of CO_2 in the Venusian atmosphere create an extremely strong greenhouse effect
- The effect is so strong Venus’s surface is hotter than Mercury’s although Venus is farther from the Sun
- The high temperature and density of Venus then create the high Venusian atmospheric pressure



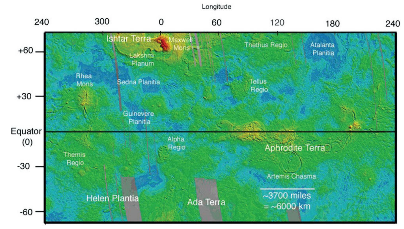
The Surface of Venus

- Ground features can be mapped with radar from Earth and spacecraft orbiting Venus since radar can penetrate the Venusian clouds
- Venus’s surface is less mountainous and rugged than Earth, with most of its surface low, gently rolling plains



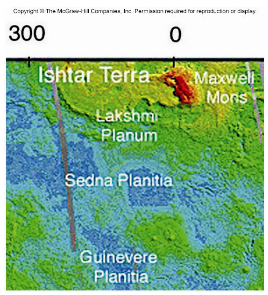
The Surface of Venus

- Only two major highlands, Ishtar Terra and Aphrodite Terra and about 8% of the surface, rise above the plains to form land masses similar to terrestrial continents



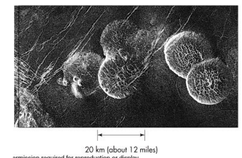
The Surface of Venus

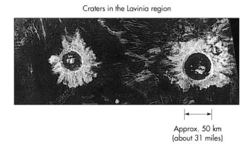
- Ishtar Terra is about the size of Greenland and is studded with volcanic peaks – Maxwell Montes, the highest, is at 11 km above the average level of the planet (the equivalent "sea level" reference)



Surface Features

- Radar maps have shown many puzzling surface features (or lack thereof)
  - Few plate tectonic features: continental blocks, crustal rifts, trenches at plate boundaries
  - A few distorted impact craters and crumbled mountains
  - Volcanic landforms dominate: peaks with immense lava flows, "blisters of uplifted rock, grids of long narrow faults, peculiar lumpy terrain



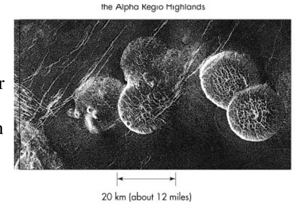


Surface Features

- These features indicate a young and active surface
  - Venus's original surface has been destroyed by volcanic activity
  - The current surface is not more than 500 million years old (much younger than Earth's) with some regions less than 10 million

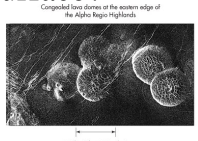
Active Surface?

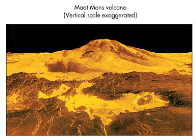
- Volcanic eruptions have not been directly observed
  - Some lava flows appear fresh
  - Electrical discharges on Venus indicative of eruptions
  - Brief increases in atmospheric sulfur content also indicative of eruptions



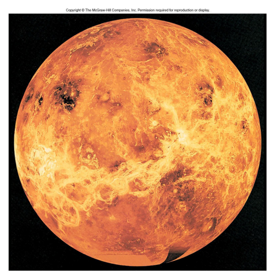
Active Surface?

- Numerous volcanic peaks, domes, and uplifted regions suggest that heat flows less uniformly within Venus than Earth – "hot spot" generation of volcanoes dominate on Venus, which is not the case on Earth





Venus is not Earth's twin!



Interior of Venus probably very similar to Earth – iron core and rock mantle

- Venus still evolving into the smooth heat flow patterns found on Earth
- Earth rocks have more trapped water in them, making Earth rocks "runnier" than Venusian rocks and the Earth crust thinner (which will allow easier cracking of the crust into plates for tectonic movement)

First Image from Venus

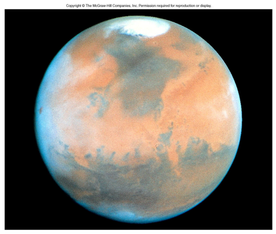
- Pictures from the Russian *Venera* landers show a barren surface covered with flat, broken rocks lit by the pale orange sunlight – sampling also indicated the rocks are volcanic

Rotation of Venus

- Radar measurements show Venus is the slowest rotating planet, taking 243 Earth days to rotate once, and its spin is retrograde ("backward")
- Two possible causes of this slow retrograde rotation:
  - Venus was struck shortly after its birth by a huge planetesimal
  - Tidal forces from the Sun and perhaps Earth may have shifted its spin axis over time
- Solar day on Venus is 117 Earth days
- Venus rotates too slowly to generate a magnetic field

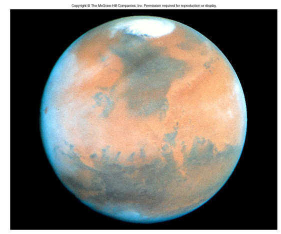
Mars

- Although its diameter is 1/2 and its mass 1/10 that of Earth, Mars is the planet that most resembles the Earth
- Mars extensively photographed by the *Mariner, Viking,* and *Mars Global Surveyor* spacecraft



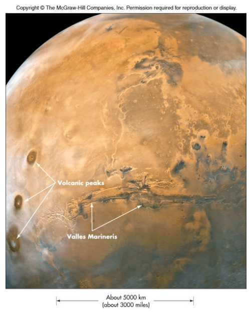
Mars

- On a warm day, the temperature hits about 50° F (10° C)
- Winds sweep dust and patchy ice crystal clouds through a sky that generally is clear enough for its surface to be seen from Earth
- Sparkling white polar caps contrast with the reddish color of most of the planet

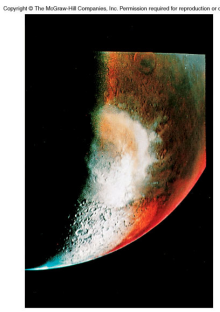


Vallis Marineris

- A rift running along the equator stretching 1000 km long, 100 km wide, and 10 km deep
- This canyon, named after *Mariner,* dwarfs the Grand Canyon and would span the U.S.



Polar Ice Caps



B

- Change in size with seasons (Mars tilt similar to Earth's)
- Thin atmosphere creates more severe extremes in the seasons leading to large ice cap size variations
- Southern cap is frozen CO_2 (dry ice) and its diameter varies from 5900 km in winter to 350 km in summer

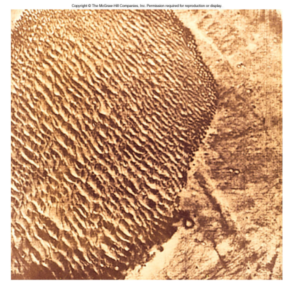
Polar Ice Caps

A

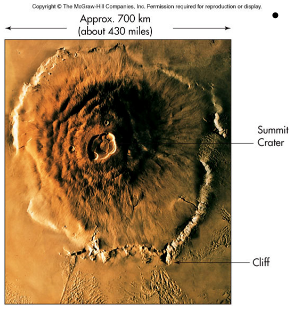
- Northern cap shrinks to about 1000 km, has surface layer of CO_2, but is primarily water ice and has separate layers indicative of climate cycles (including "ice ages")
- Water contained in Mars caps is far less than that in Earth's caps

Dune Fields

- Martian poles are bordered by immense deserts with dunes blown by winds into parallel ridges



The Tharsis Bulge

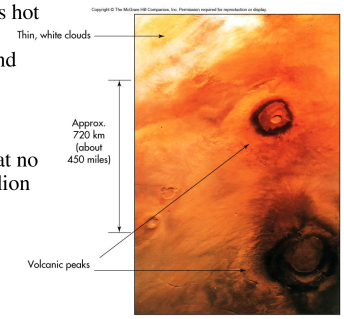


B

- At midlatitudes, there is the huge uplands called the Tharsis bulge
  - Dotted with volcanic peaks including Olympus Mons, which rises 25 km above its surroundings (3 times higher than Mt. Everest on Earth)

The Tharsis Bulge

- Believed formed as hot material rose from the deep interior and forced the surface upward
- Scarcity of impact craters put its age at no older than 250 million years
- May have created gigantic Valles Marineris



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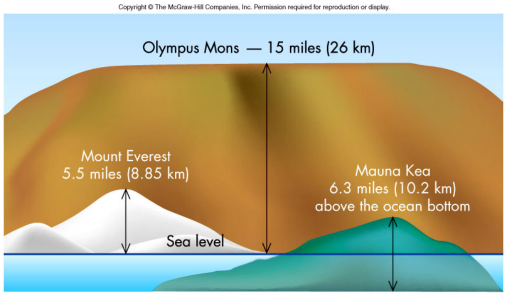
Largest Mountain in the Solar System

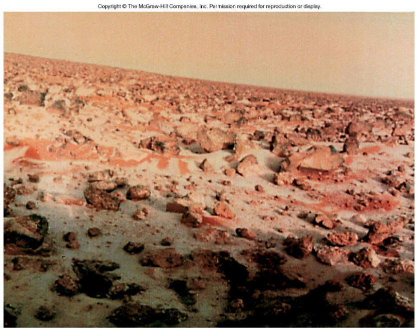


Height scale is exaggerated by ~ factor of two.

Water on Ancient Mars

- From winding nature of features that often contain "islands", it is inferred that water once flowed on Mars
- No surface liquid is now present
- Huge lakes and small oceans thought to have once existed – evidence comes from smooth traces that look like old beaches around edges of craters and basins

Morning Frost



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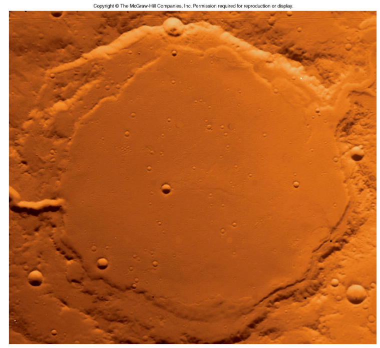
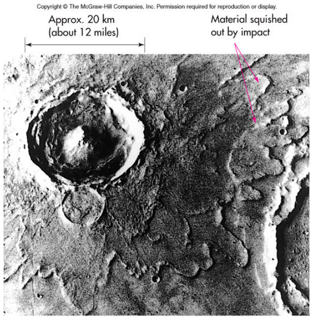
Ancient Lake?



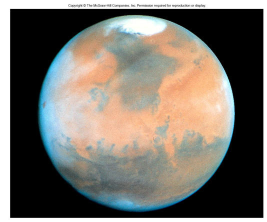
Splash Craters



B

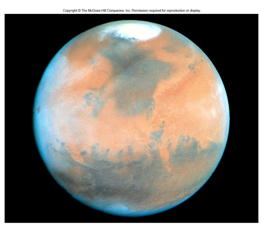
The Atmosphere of Mars

- Clouds and wind blown dust are visible evidence that Mars has an atmosphere
- Spectra show the atmosphere is mainly CO_2 (95%) with traces of N_2 (3%), oxygen and water
- The atmosphere's density is about 1% that of the Earth's



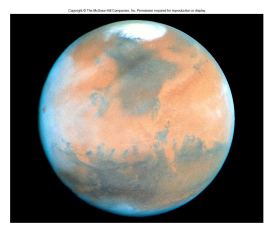
The Atmosphere of Mars

- The lack of atmospheric density and Mars distance from the Sun make the planet very cold
  - Noon temperatures at the equator reach a bit above the freezing point of water
  - Night temperatures drop to a frigid 218 K (-67° F)
  - Thus, most water is frozen, locked up either below the surface as permafrost or in the polar caps as solid ice

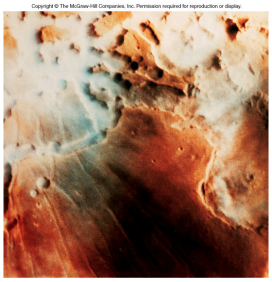


The Atmosphere of Mars

- Clouds, generally made of dry ice and water-ice crystals, are carried by the winds
- As on Earth, the winds arise from warm air that rises at the equator, moves toward the poles, and is deflected by the Coriolis effect
- Winds are generally gentle, but can strengthen and carry lots of dust!



Not a drop of rain…

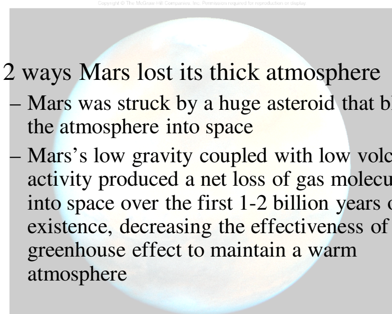

A

- No rain falls, despite clouds
  - Atmosphere is too cold and dry
  - Fog seen in valleys and ground frost has been observed
  - CO_2 "snow" falls on poles during winter

Ancient Atmosphere of Mars

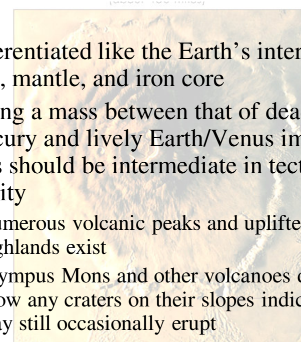
- Dry river beds indicate liquid water flowed in Mars's past
- This implies that Mars had to have a denser atmosphere (higher pressure) to prevent the fast vaporization of surface water into the atmosphere
- Cratering indicates that this thicker atmosphere disappeared about 3 billion years ago

Where did the atmosphere go?



- 2 ways Mars lost its thick atmosphere
  - Mars was struck by a huge asteroid that blasted the atmosphere into space
  - Mars's low gravity coupled with low volcanic activity produced a net loss of gas molecules into space over the first 1-2 billion years of its existence, decreasing the effectiveness of the greenhouse effect to maintain a warm atmosphere

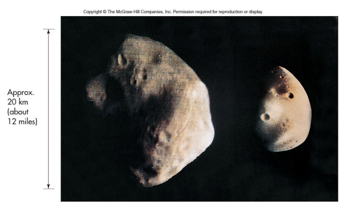
The Martian Interior



- Differentiated like the Earth's interior into a crust, mantle, and iron core
- Having a mass between that of dead Mercury and lively Earth/Venus implies Mars should be intermediate in tectonic activity
  - Numerous volcanic peaks and uplifted highlands exist
  - Olympus Mons and other volcanoes do not show any craters on their slopes indicating they may still occasionally erupt

The Martian Moons

- Phobos and Deimos are about 20 km across and are probably captured asteroids
- Their small size prevents gravity from pulling them into spherical shapes
- Both are cratered, implying bombardment by smaller objects

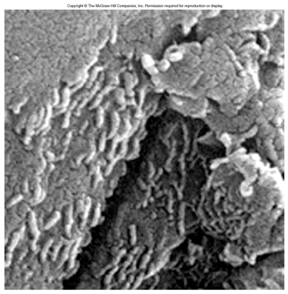


Life on Mars?

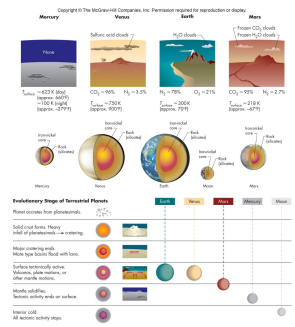
- Interest in life on Mars grew enormously with the misinterpretation of observations made by astronomer Giovonni Schiaparelli in 1877, who called certain straight-line features on Mars "canalli" meaning "channels"
  - English-speaking countries interpreted this as "canals" and the search for intelligent life on Mars began
  - Spacecraft photos later revealed features on Mars to be natural land structures

Life on Mars?

- Viking spacecraft landed on Mars to search for life up closer – no evidence found
- In 1996, a meteorite was found on Earth with a Mars origin
  - Certain meteorite structures suggested Martian bacteria
  - Most scientists today are unconvinced



Why Are the Terrestrial Planets So Different?



Role of Mass and Radius

- Mass and radius affect interior temperature
- This in turn determines the level of tectonic activity
- Low-mass, small-radius planets will be cooler inside and hence less active than larger planets
- This relationship is in fact observed with Mercury (the least active), then Mars, then Venus/Earth

Role of Internal Activity

- Internal activity also affects a planet's atmosphere since volcanic gases are the most likely source of materials
- Low mass Mercury and Mars will have a smaller source of age than Venus/Earth and the low surface gravity of these small planets also means they will have trouble retaining the gases they receive
- Mars, Venus, and Earth all probably started with CO_2 atmospheres with traces of N_2 and H_2O, but were then modified by sunlight, tectonic activity, and, in the case of the Earth, life

Role of Sunlight

- Sunlight warms a planet in a manner that depends on the planet's distance from the Sun – the closer the warmer
- Amount of warming depends on the amount and makeup of the atmospheric gases present
- Solar warming and atmospheric chemistry will also determine the structure of the atmosphere, which may "feed back" into the amount of warming that occurs
- For example, warmer Venus lifts water vapor to great heights in its atmosphere, whereas at cooler Earth, water condenses out at lower heights and the upper atmosphere is almost totally devoid of water

Role of Water Content

- Great differences in water content of upper atmospheres of Earth and Venus has lead to a drastic difference between their atmospheres at lower levels
- Water at high altitudes in Venusian atmosphere is lost to ***photodissociation*** as solar ultraviolet light breaks H_2O apart with the H escaping into space
- Venus, as a result, has lost most of its water, whereas Earth, with its water protected at lower altitudes, has not
- The water near Earth's surface then makes possible many chemical reactions not found on Venus – for example, CO_2 (a greenhouse gas) is removed from the atmosphere by dissolving in water

Role of Biological Processes

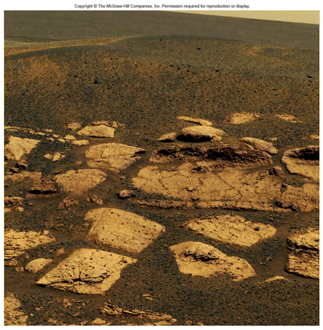
- Biological processes also remove CO_2 from the atmosphere
  - Dissolved CO_2 in ocean water is used by sea creatures to make shells of calcium carbonate
  - When these creatures die, their shells fall to ocean bottom forming a sediment
  - The sediment eventually changes to rock, thus tying up CO_2 for long periods of time
  - With CO_2 so readily removed from our atmosphere, mostly N_2 is left
  - Some CO_2 can be recycled back into the atmosphere by tectonic activity
- Green plants breaking down H_2O during photosynthesis is very likely the reason Earth's atmosphere has a high oxygen content

Exploring Mars

- Twin rovers, *Spirit* and *Opportunity,* have landed on the surface of Mars and have returned an amazing amount of data!

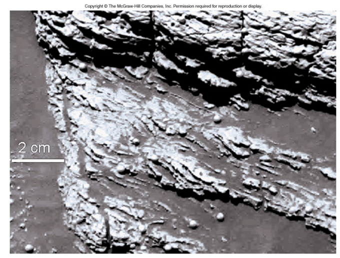
Exploring Mars

- Rock outcropping at the *Opportunity* landing site. Thought to be material deposited at the bottom of an ancient ocean



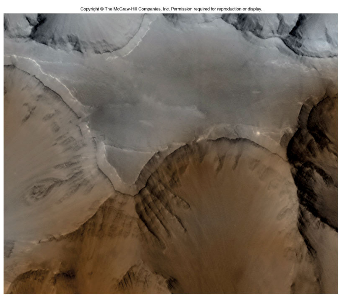
Exploring Mars

- Closeup image of rock at the *Opportunity* landing site
- Possibly formed from sediment in flowing water



Exploring Mars

- Image from *Mars Global Surveyor,* a Mars orbiter that ended its mission in 2007
- A flat-topped mesa



Exploring Mars

- A view of what appears to be a dried-up river delta