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Chapter 6
The Terrestrial Planets

- The comparison of one planet with another is called comparative planetology.
  - It is one of the best ways to analyze the worlds in our solar system.
  - You will learn much more by comparing planets than you could by studying them individually.

A Travel Guide to the Terrestrial Planets

- In this chapter, you will visit five Earthlike worlds.
  - This preliminary section will be your guide to important features and comparisons.

Five Worlds

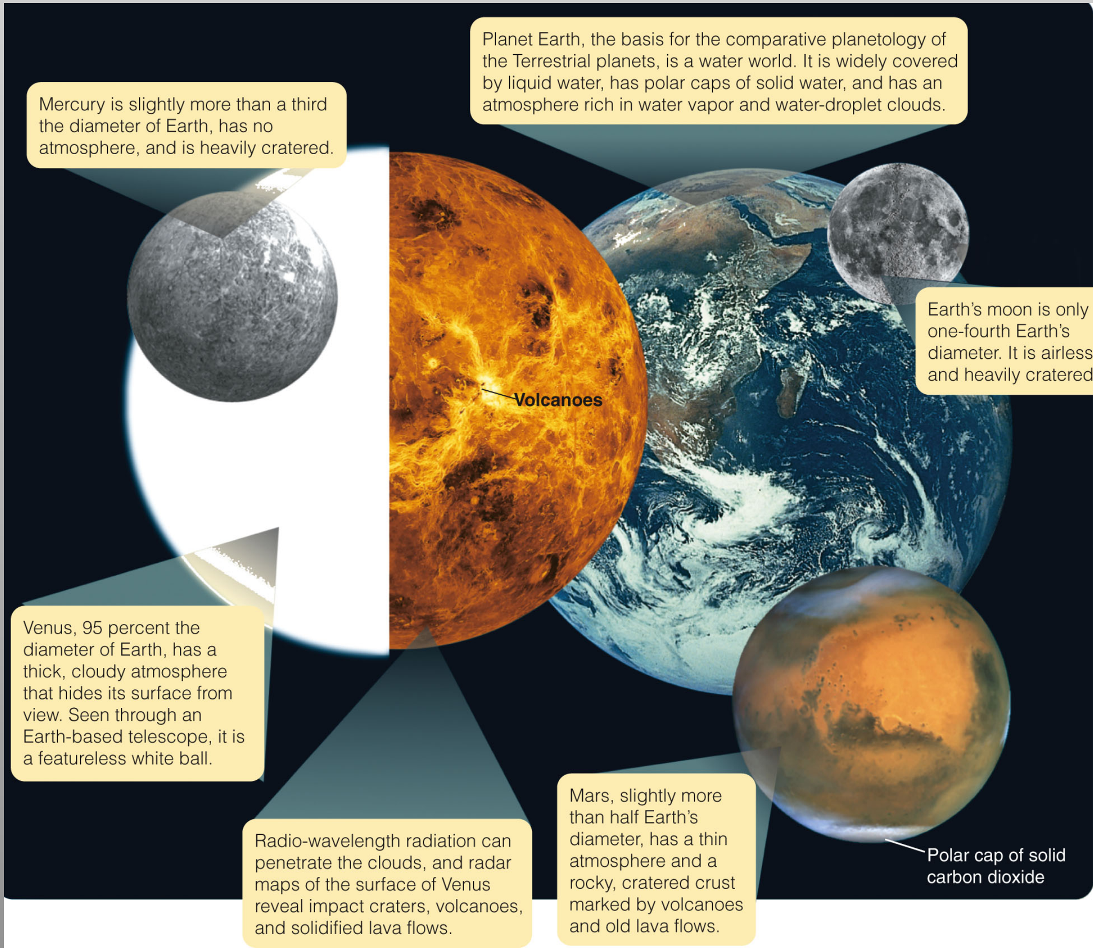
- You are about to visit Earth, Earth’s moon, Mercury, Venus, and Mars.
  - It may surprise you that the moon is on your itinerary.
  - After all, it is just a natural satellite orbiting Earth and isn’t one of the planets.

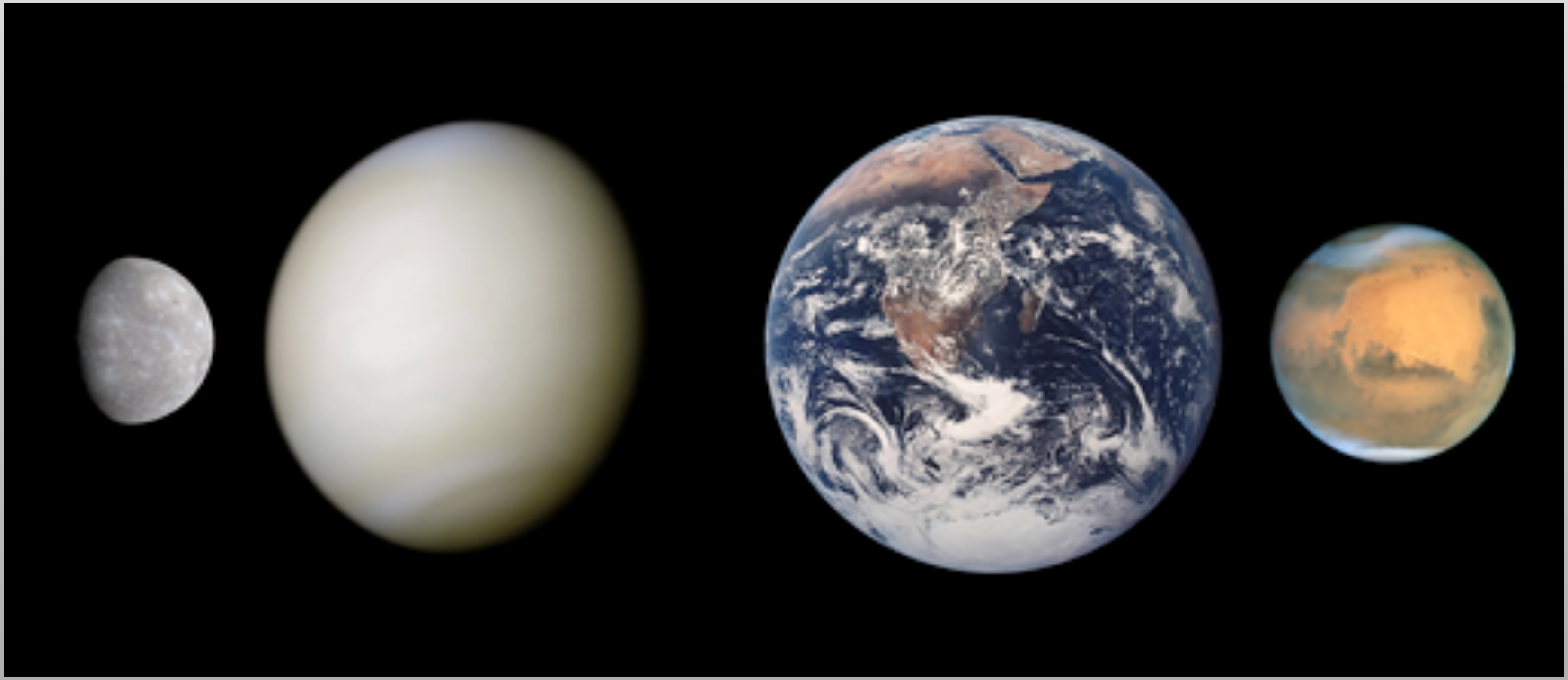
Five Worlds

- The moon is a fascinating world of its own.
  - It is a planetlike object two-thirds the size of Mercury.
  - It makes a striking comparison with the other worlds on your list.

Five Worlds

- The figure compares the five worlds you are about to study.

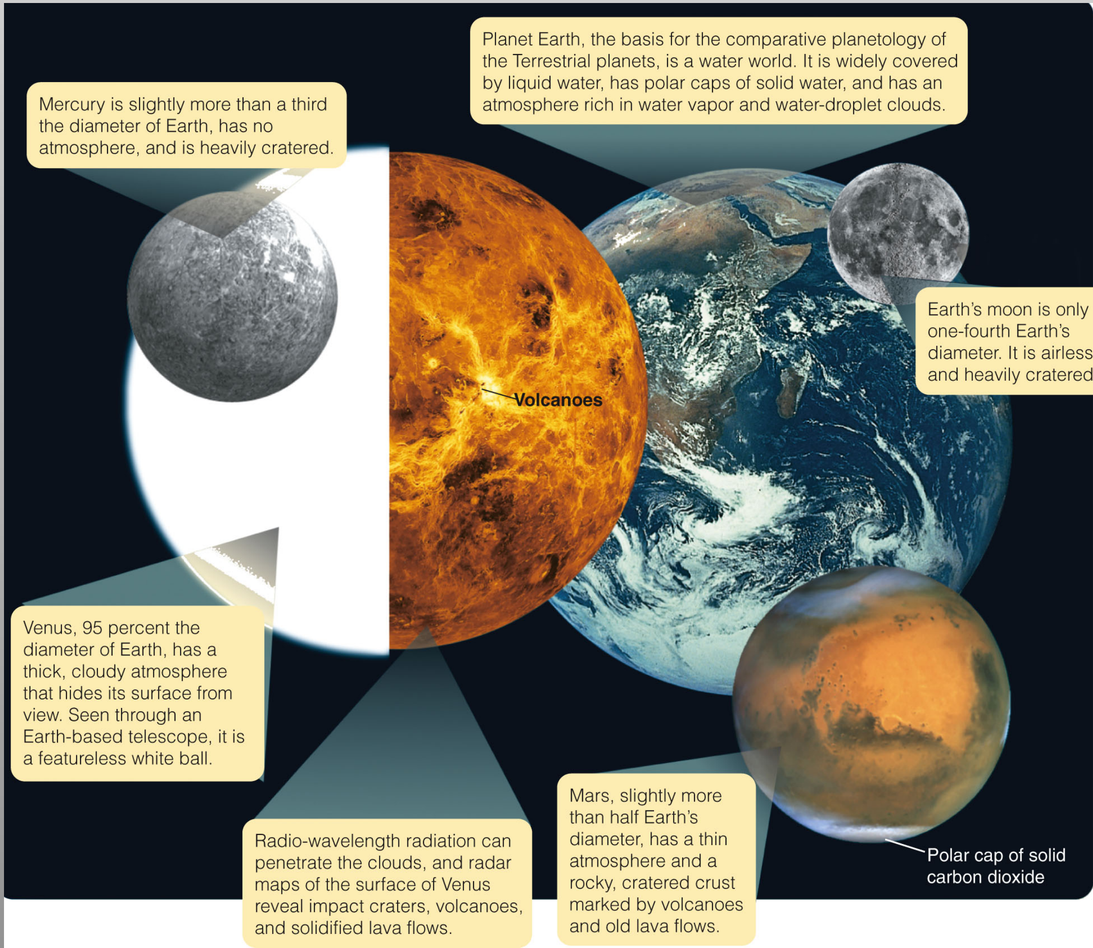




The terrestrial planets Mercury, Venus, Earth and Mars in true colors, sizes to scale

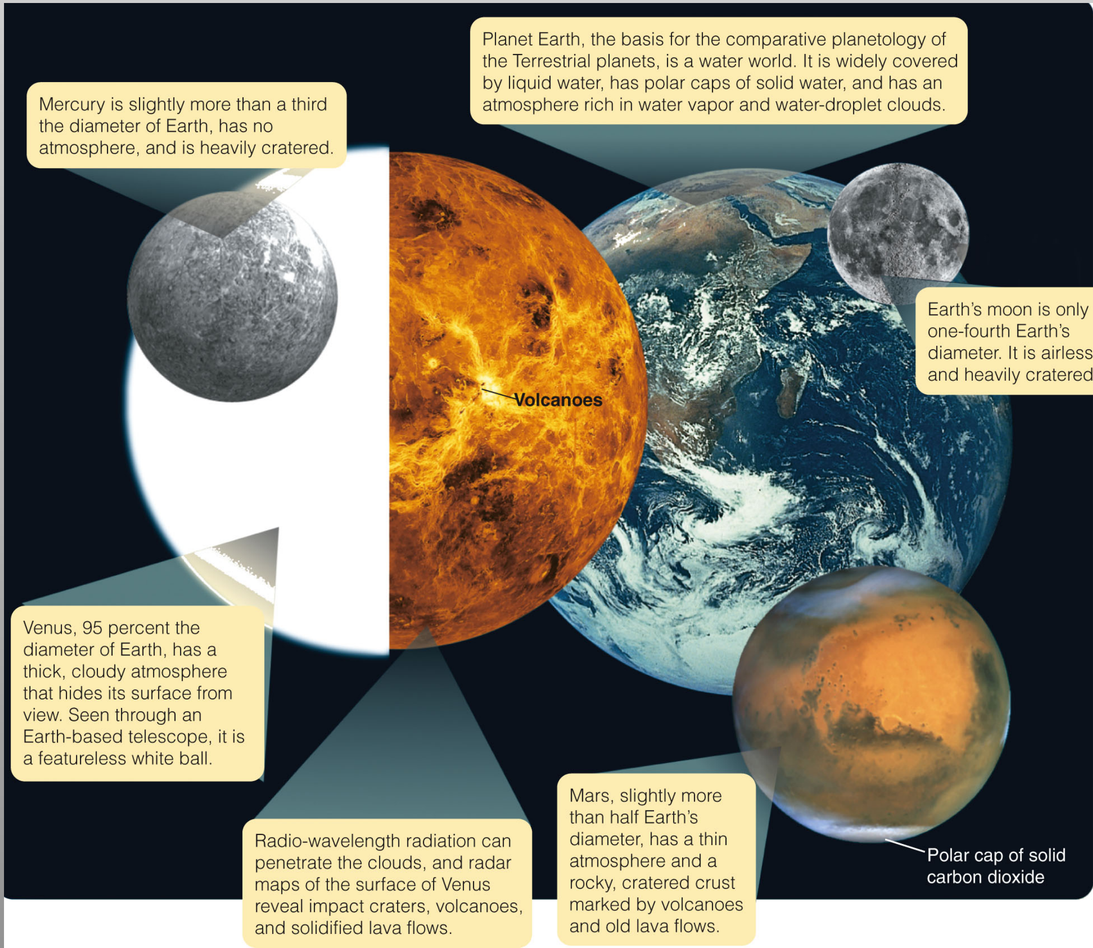
Five Worlds

- The first feature to notice is diameter.



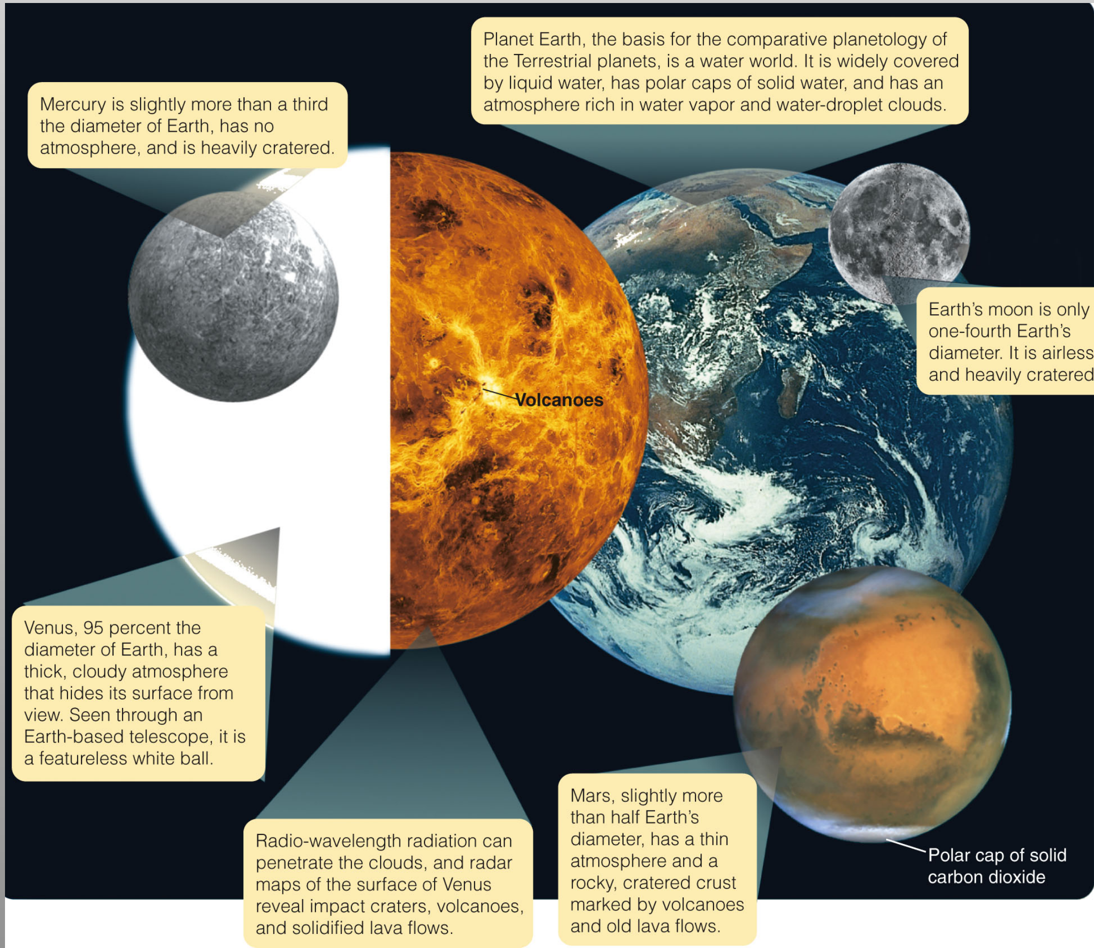
Five Worlds

- The moon is small.
- Mercury is not much bigger.



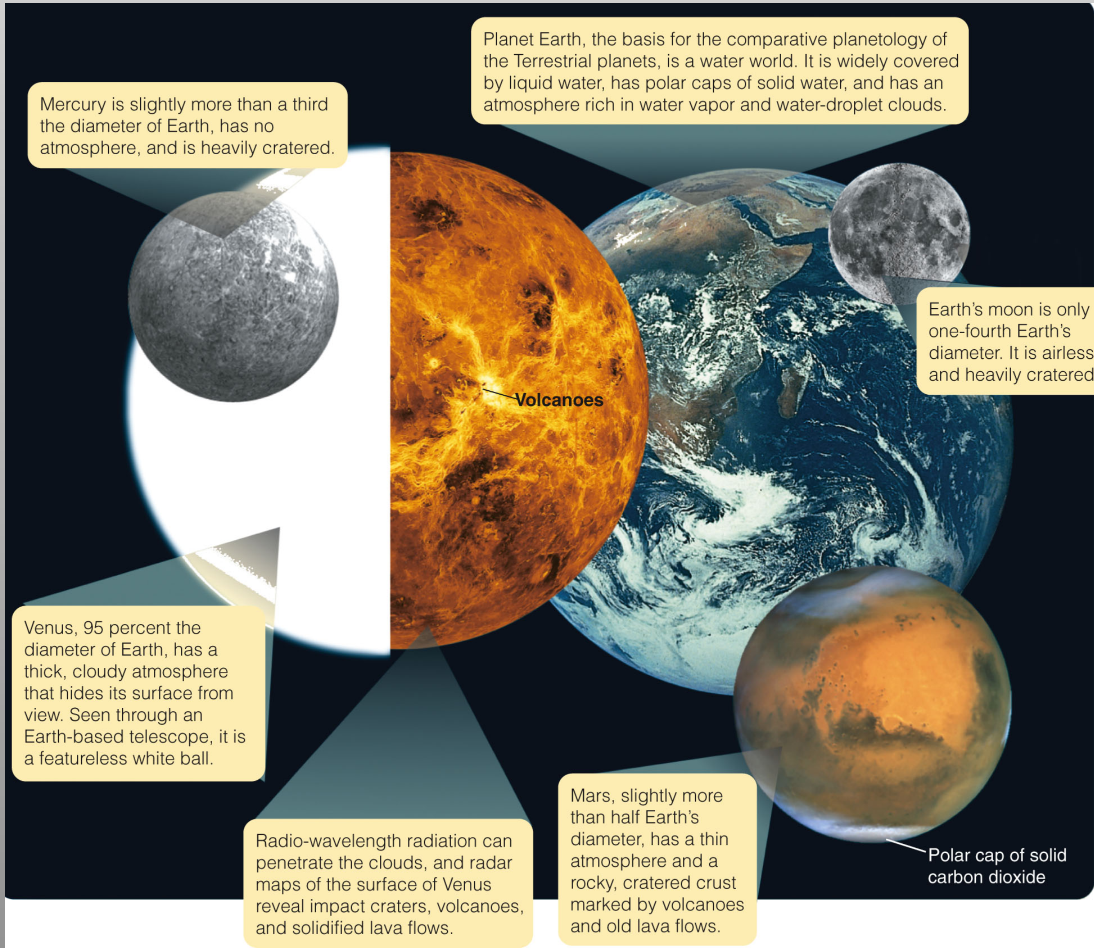
Five Worlds

- Earth and Venus are large and similar in size to each other.



Five Worlds

- Mars, though, is a medium-sized world.



Five Worlds

- You will discover that size is a critical factor in determining a world’s personality.
  - Small worlds tend to be internally cold and geologically dead.
  - However, larger worlds can be geologically active.

All terrestrial planets have approximately the same type of structure: a central metallic core, mostly iron, with a surrounding silicate mantle. The Moon is similar, but has a much smaller iron core. Io and Europa are other satellites that have internal structure similar to terrestrial planets. Terrestrial planets can have canyons, craters, mountains, volcanoes, and other surface structures. Terrestrial planets possess secondary atmospheres, generated through internal volcanism or comet impacts, in contrast to the gas giants, whose atmospheres are primary, captured directly from the original solar nebula

Core, Mantle, and Crust

- The terrestrial worlds are made up of rock and metal.
- They are all differentiated:
  - Rocky, low-density crusts
  - High-density metal cores
  - Mantles composed of dense rock between the cores and crusts

Core, Mantle, and Crust

- As you have learned, when the planets formed, their surfaces were subjected to heavy bombardment by leftover planetesimals and fragments.
  - The cratering rate then was as much as 10,000 times what it is at present.
  - You will see lots of craters on these worlds—especially on Mercury and the moon.

Core, Mantle, and Crust

- Notice that cratered surfaces are old.
  - For example, if a lava flow covered up some cratered landscape to make a new surface after the end of the heavy bombardment, few craters could be formed afterward on that surface.
  - This is because most of the debris in the solar system was gone.
  - So, when you see a smooth plain on a planet, you can guess that the surface is younger than the cratered areas.

Core, Mantle, and Crust

- One important way you can study a planet is by following the energy.
  - The heat in the interior of a planet may be left over from the formation of the planet.
  - It may also be heat generated by radioactive decay.
  - In any case, it must flow outward toward the cooler surface where it is radiated into space.

Core, Mantle, and Crust

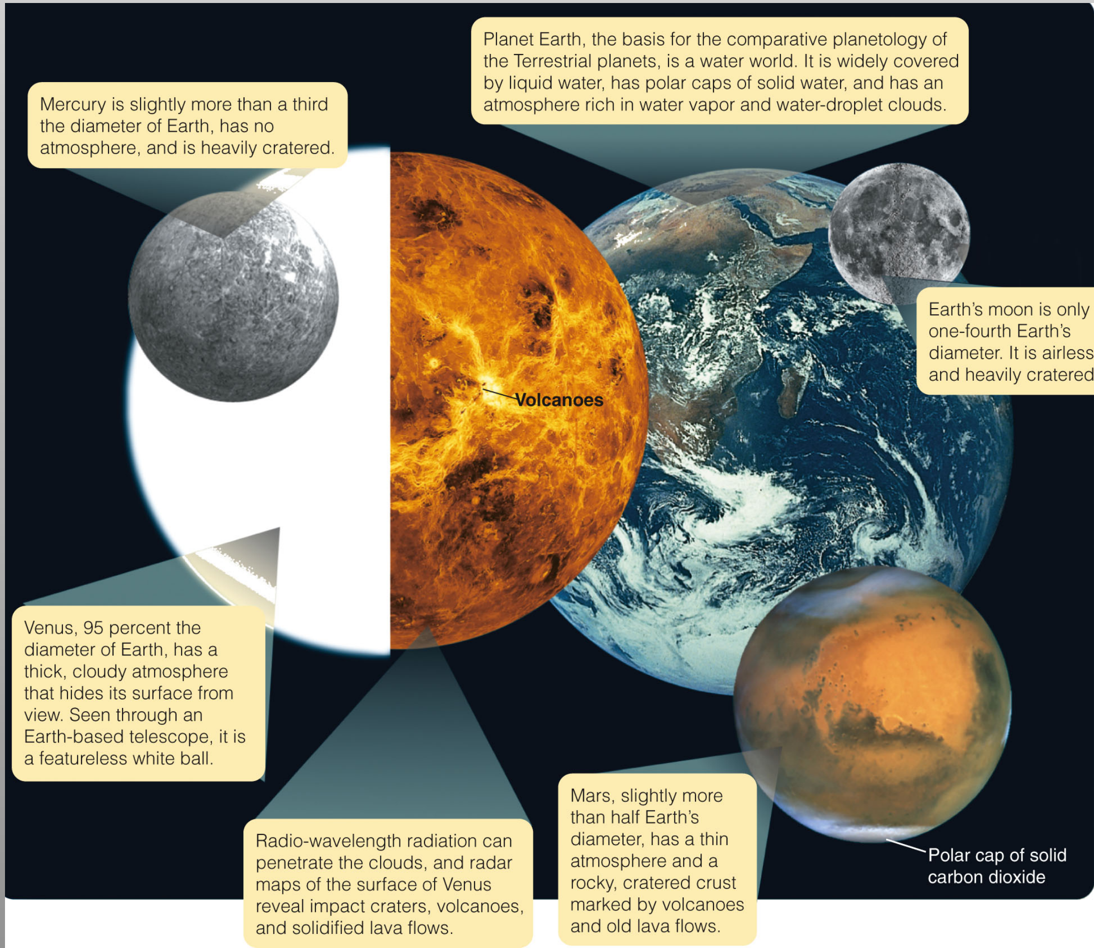
- In flowing outward, the heat can cause phenomena such as:
  - Convection currents in the mantle
  - Magnetic fields
  - Plate motions
  - Quakes
  - Faults
  - Volcanism
  - Mountain building

Core, Mantle, and Crust

- Heat flowing upward through the cooler crust makes a large world like Earth geologically active.
- In contrast, the moon and Mercury—both worlds—cooled fast.
  - So, they have little heat flowing outward now and are relatively inactive.

Atmospheres

- When you look at Mercury and the moon, you can see their craters, plains, and mountains.



The atmospheres of at least the inner planets has evolved since they formed. This is clearest for the Earth. The Earth’s original atmosphere was probably similar to Venus in composition, consisting of carbon dioxide and nitrogen. The evolution of photosynthesis converted carbon dioxide in the Earth’s atmosphere to oxygen, increasing the amount of O2 in it from an initial 0.01% to its current 22% level.

Each of the planets has a different atmosphere, although there are clear similarities between the atmospheres of the four terrestrial planets and the four gas giant planets. The terrestrial planets are rich in heavier gases and gaseous compounds, such as carbon dioxide, nitrogen, oxygen, ozone, and argon. In contrast, the gas giant atmospheres are composed mostly of hydrogen and helium.

Here is basic information on the atmosphere of each planet. Mercury has a very thin, almost undetectable atmosphere composed of sodium and potassium gas. These elements were likely blown from the surface of Mercury by the solar wind.

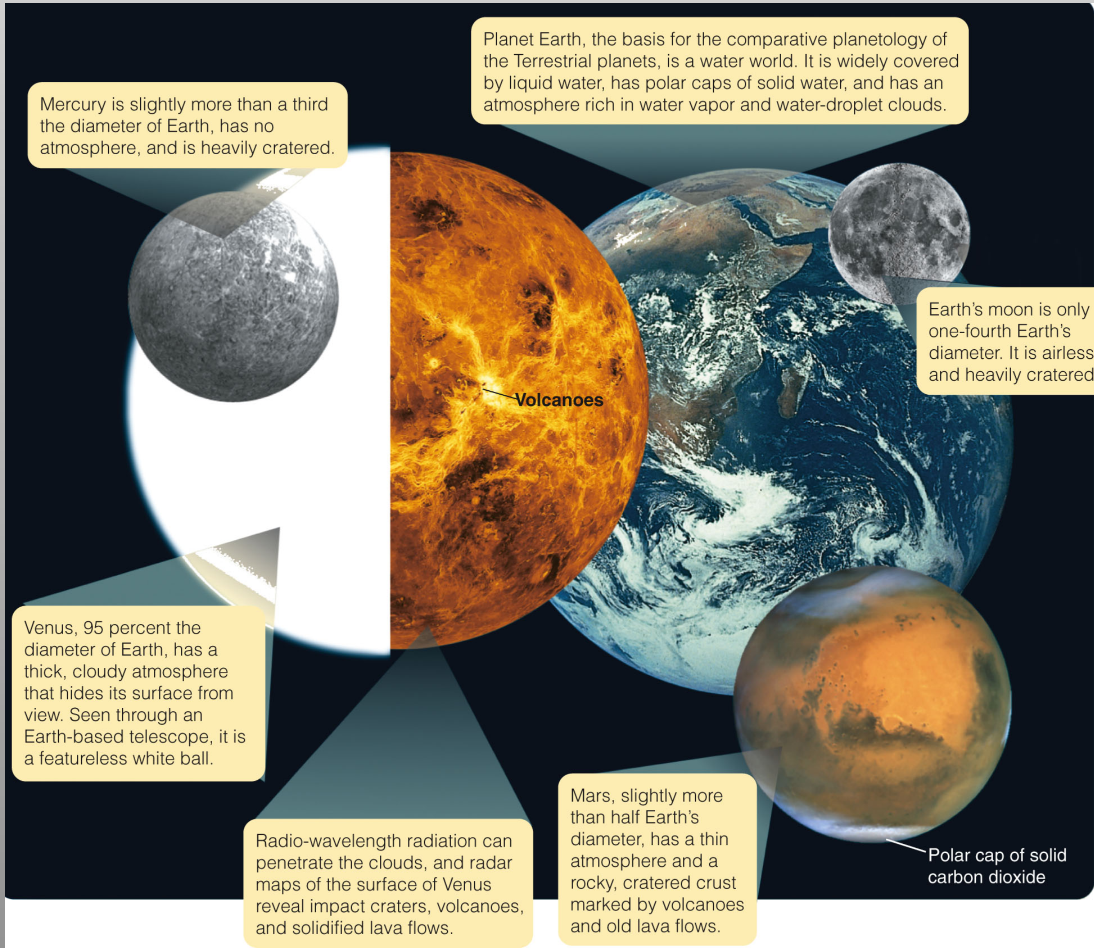
The atmosphere of Venus is composed mainly of carbon dioxide with minor amounts of nitrogen and trace amounts of nitrogen, helium, neon, and argon.

The Earth's atmosphere primarily composed of nitrogen and oxygen. Minor gases include and carbon dioxide, ozone, argon, and helium.

Mars' atmosphere is a thin layer composed mainly of carbon dioxide. Nitrogen, argon, and small traces of oxygen and water vapor are also present.

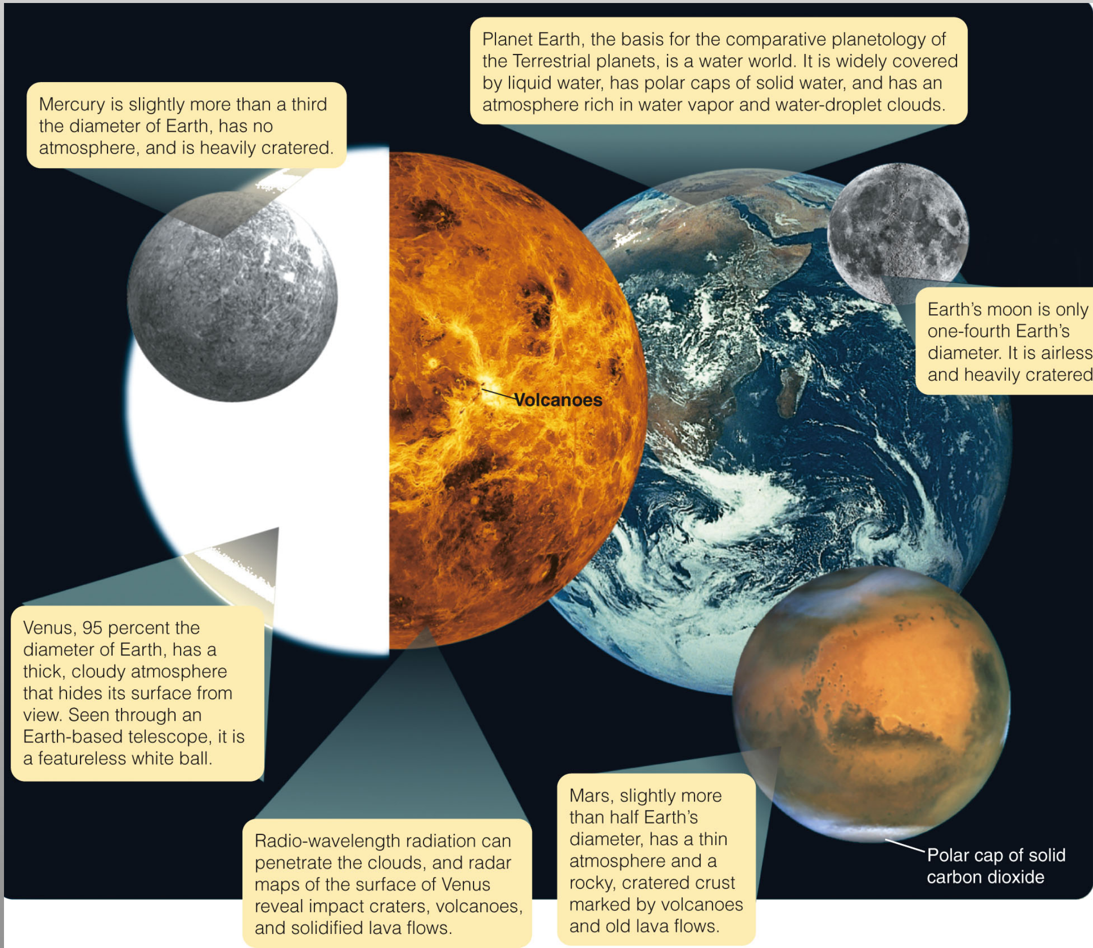
Atmospheres

- The surface of Venus, though, is completely hidden by a cloudy atmosphere even thicker than Earth's.



Atmospheres

- Mars, the medium-sized terrestrial planet, has a relatively thin atmosphere.



Atmospheres

- You might ponder two questions.
- One, why do some worlds have atmospheres while others do not?
  - You will discover that both size and temperature are important.

Atmospheres

- The second question is more complex.
- Where did these atmospheres come from?
  - To answer the question, you will have to study the geological history of these worlds.

Earth: Planet of Extremes

- Earth will be the basis for your comparative study of the terrestrial planets.
  - So, you should pretend to visit it as if you didn’t live here.

Earth: Planet of Extremes

- Earth is an active planet.
  - It has a molten interior and heat flowing outward to power volcanism, earthquakes, and an active crust.
  - Almost 75 percent of its surface is covered by liquid water.
  - The atmosphere contains a significant amount of oxygen.

Earth's Interior

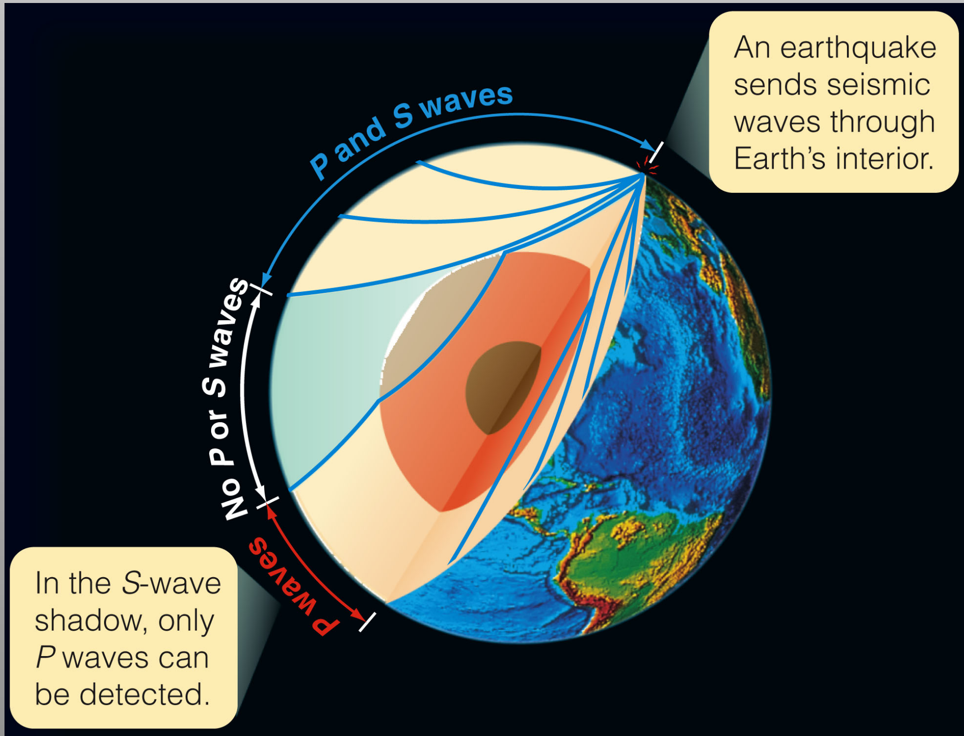
- From what you know of the formation of Earth, you would expect it to have differentiated.
- In science, though, evidence rules.
  - What does the evidence reveal about Earth's interior?

Earth's Interior

- Earth's mass divided by its volume gives you its average density—about 5.5 g/cm^3.
- However, the density of Earth's rocky crust is only about half that.
  - Clearly, a large part of Earth's interior must be made of material denser than rock.

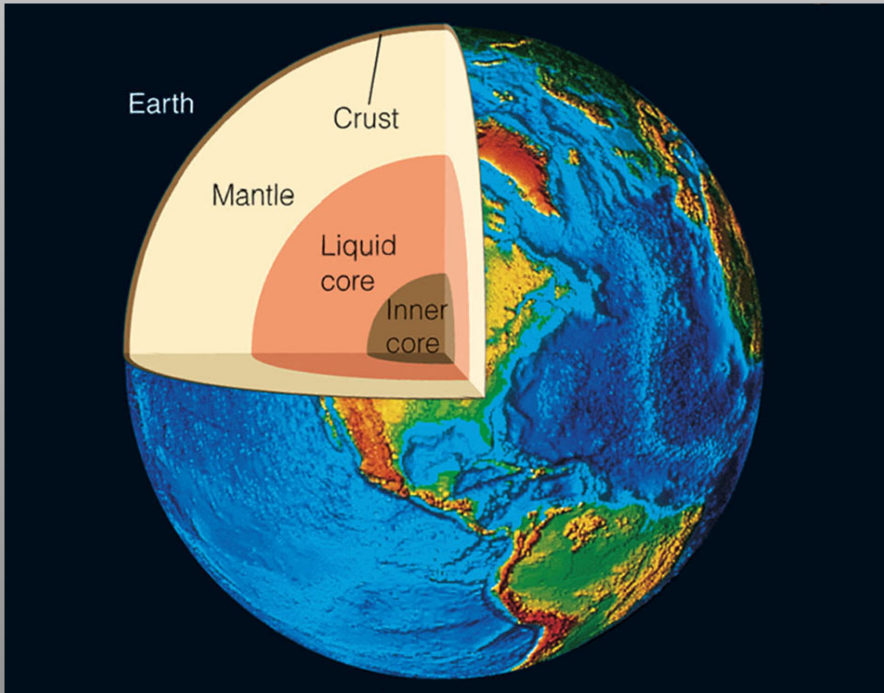
Earth's Interior

- Each time an earthquake occurs, seismic waves travel through the interior and register on seismographs all over the world.



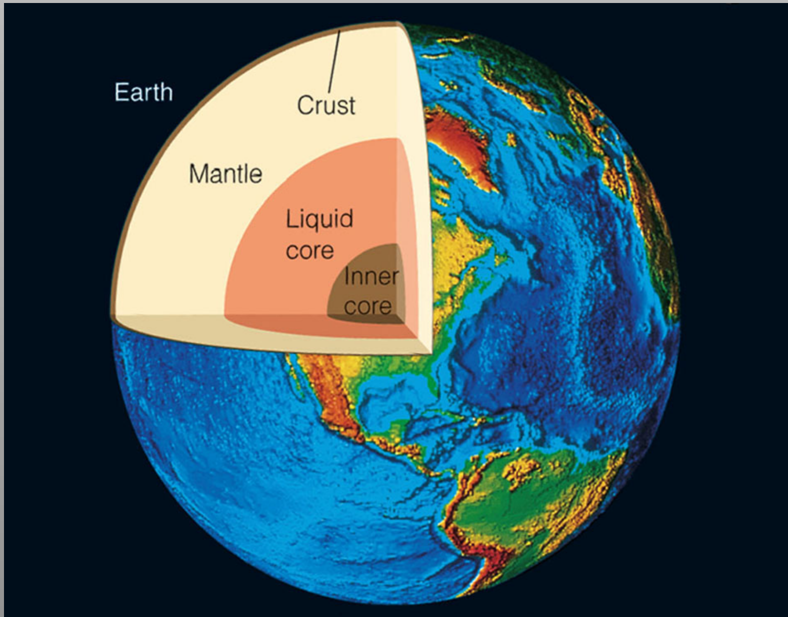
Earth's Interior

- Analysis of these waves shows that Earth's interior is divided into:
  - A metallic core
  - A dense rocky mantle
  - A thin, low-density crust



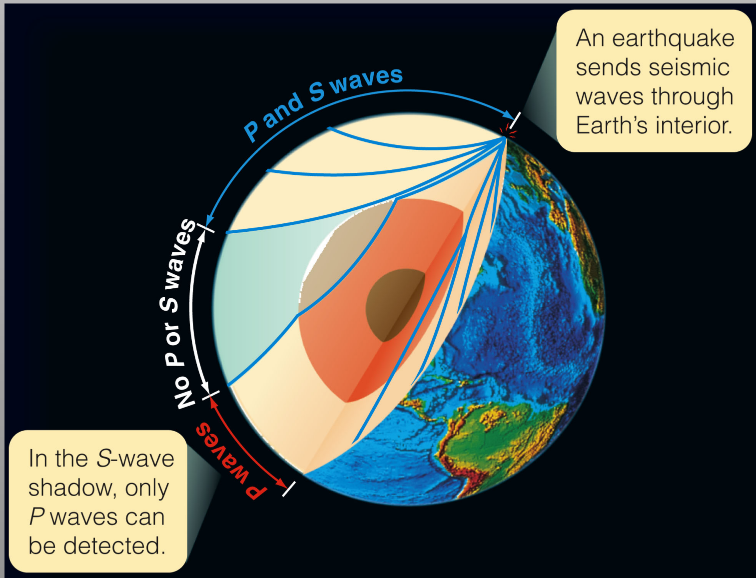
Earth's Interior

- The core has a density of 14 g/cm^3, greater than lead.
- Models indicate it is composed of iron and nickel at a temperature of roughly 6,000 K.
  - The core is as hot as the surface of the sun.
  - However, high pressure keeps the metal a solid near the middle of the core and a liquid in its outer parts.



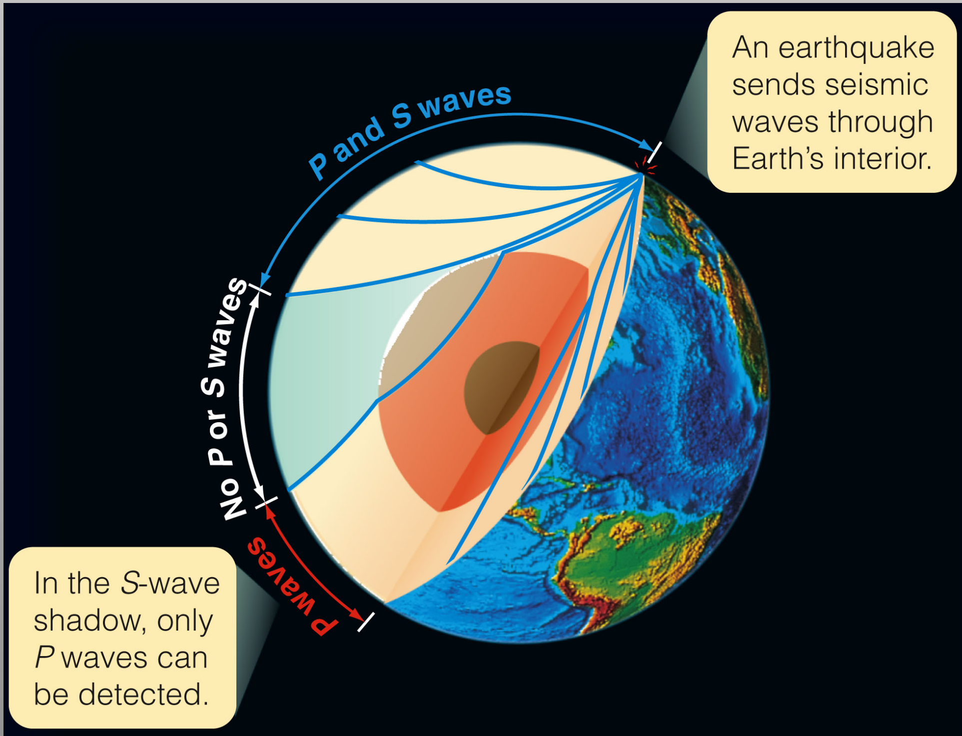
Earth's Interior

- Two kinds of seismic waves show that the outer core is liquid.
  - *P* waves travel like sound waves, and they can penetrate a liquid.
  - *S* waves travel as a side-to-side vibration that can travel along the surface of a liquid but not through it.



Earth's Interior

- So, Earth scientists can deduce the size of the liquid core—by observing where *S* waves get through and where they don't.

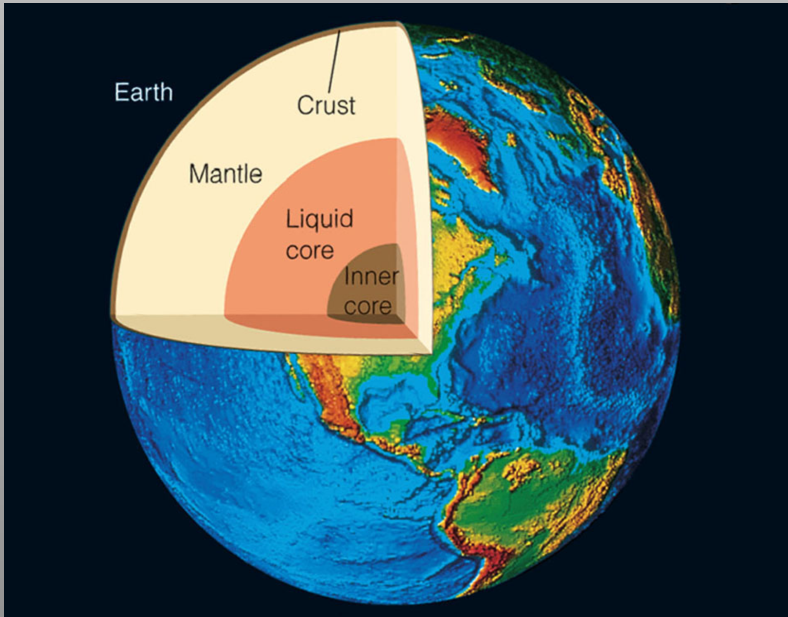


Earth's Interior

- Earth's magnetism gives you further clues about the core.
  - The presence of a magnetic field is evidence that part of Earth's core must be a liquid metal.
  - Convection currents stir the molten liquid.
  - As the liquid is a very good conductor of electricity and is rotating as Earth rotates, it generates a magnetic field through the dynamo effect.
  - This is a different version of the process that creates the sun's magnetic field.

Earth’s Interior

- Earth’s mantle is a deep layer of dense rock between the molten core and the solid crust.

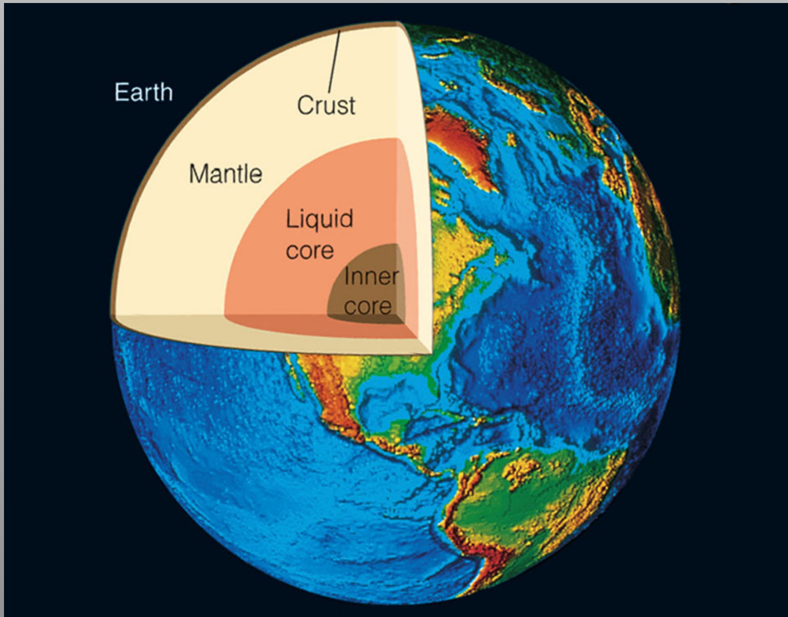


Earth's Interior

- Models indicate the mantle material has the properties of a solid but is capable of flowing slowly.
  - It is like asphalt used in paving roads—which shatters if struck with a sledgehammer, but bends under the weight of a truck.
  - Just below Earth's crust, where the pressure is less than at greater depths, the mantle flows most easily.

Earth's Interior

- Earth's rocky crust is made up of low-density rocks.
  - It is thickest under the continents—up to 60 km (35 mi) thick.
  - It is thinnest under the oceans—only about 10 km (6 mi) thick.



Earth's Active Crust

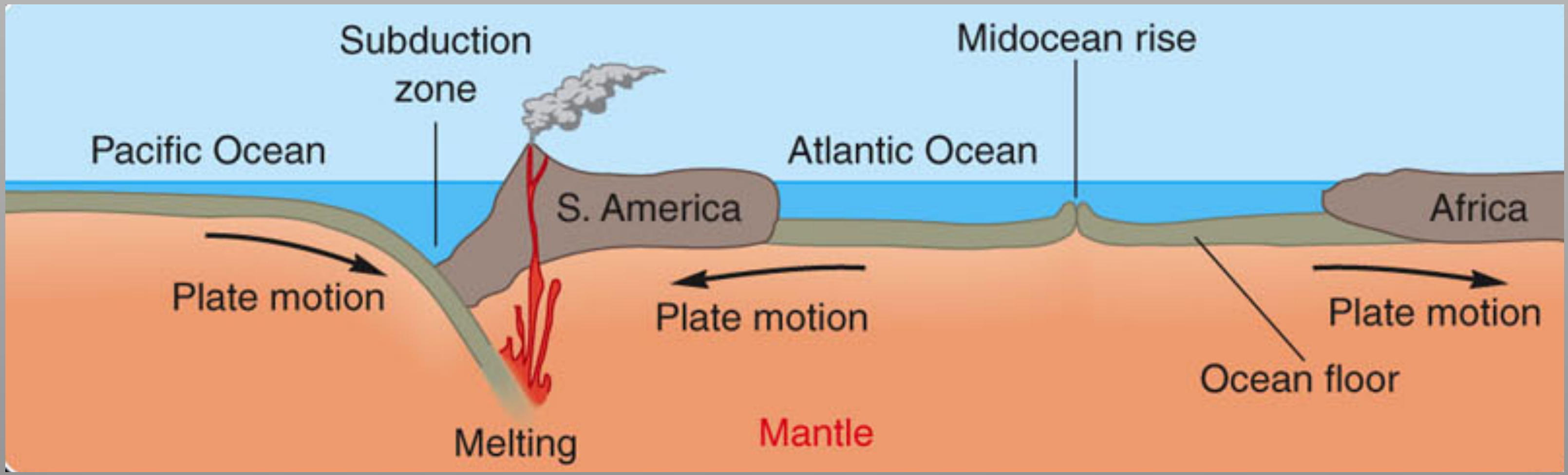
- Earth's crust is composed of lower-density rock that floats on the mantle.
  - The image of rock floating may seem odd.
  - However, the mantle rock is denser than crust rocks.
  - Also, just below the crust, the mantle rock tends to be more fluid.
  - So, sections of low-density crust do indeed float on the mantle—like great lily pads floating on a pond.

Earth's Active Crust

- The motion of the crust and the erosive action of water make Earth's crust highly active and changeable.
- There are three important points to note about the active Earth.

Earth's Active Crust

- One, the motion of crust plates produces much of the geological activity on Earth.
  - Earthquakes, volcanism, and mountain building are linked to motions of the crust and the location of plate boundaries.



Earth’s Active Crust

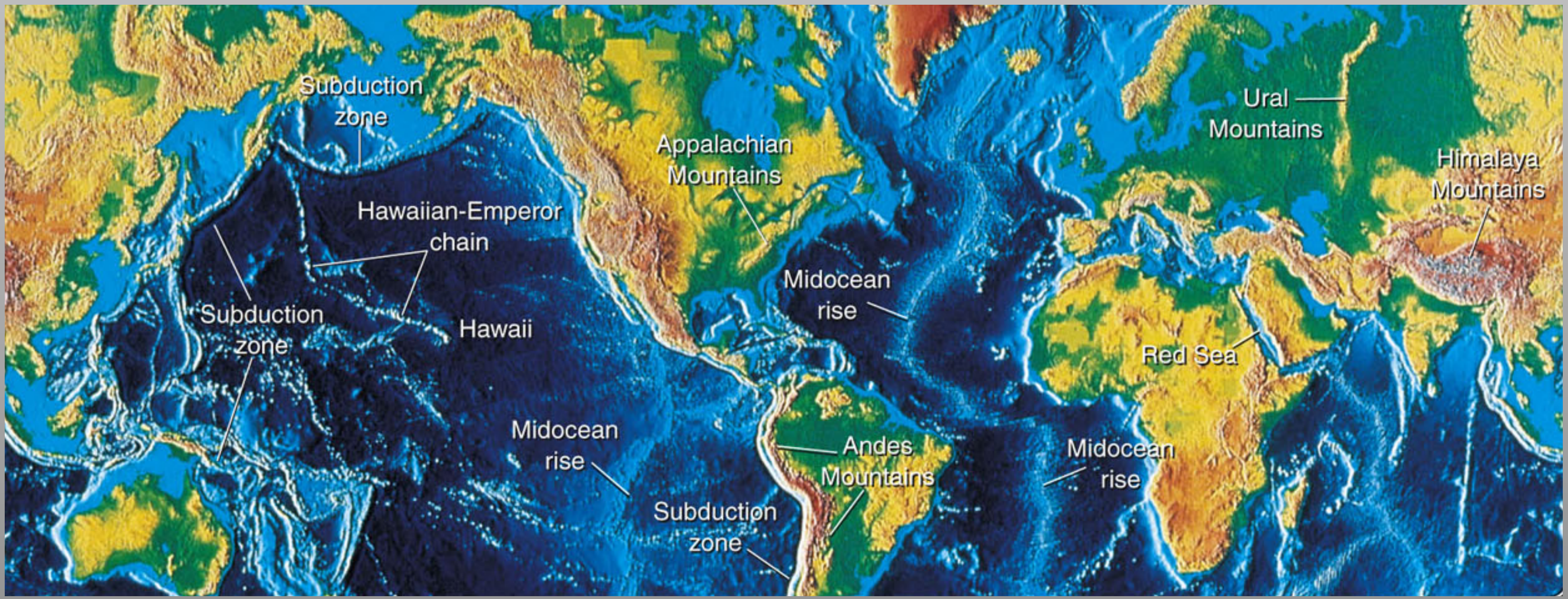
- While you are thinking about volcanoes, you can correct a common misconception.
  - The molten rock that emerges from volcanoes comes from pockets of melted rock in the upper mantle and lower crust—not from the molten core.

Earth's Active Crust

- Two, the continents on Earth's surface have moved and changed over periods of hundreds of millions of years.
  - A hundred million years is only 0.1 billion years, 1⁄45 of the age of Earth.
  - So, sections of Earth's crust are in geological rapid motion.

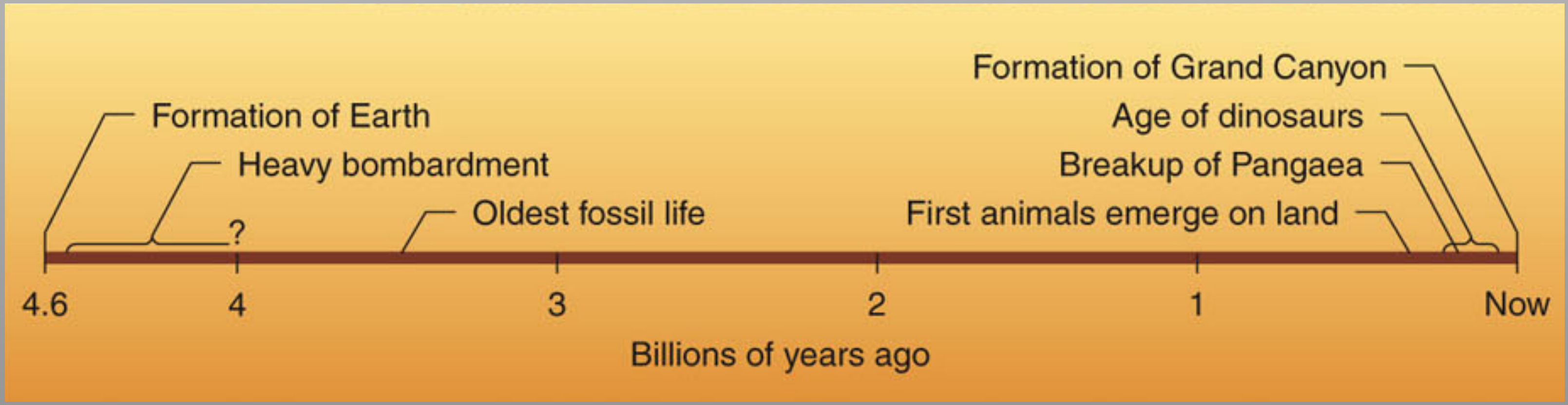
Earth’s Active Crust

- Three, most of the geological features you know—mountain ranges, the Grand Canyon, and even the outline of the continents—are recent products of Earth’s active surface.



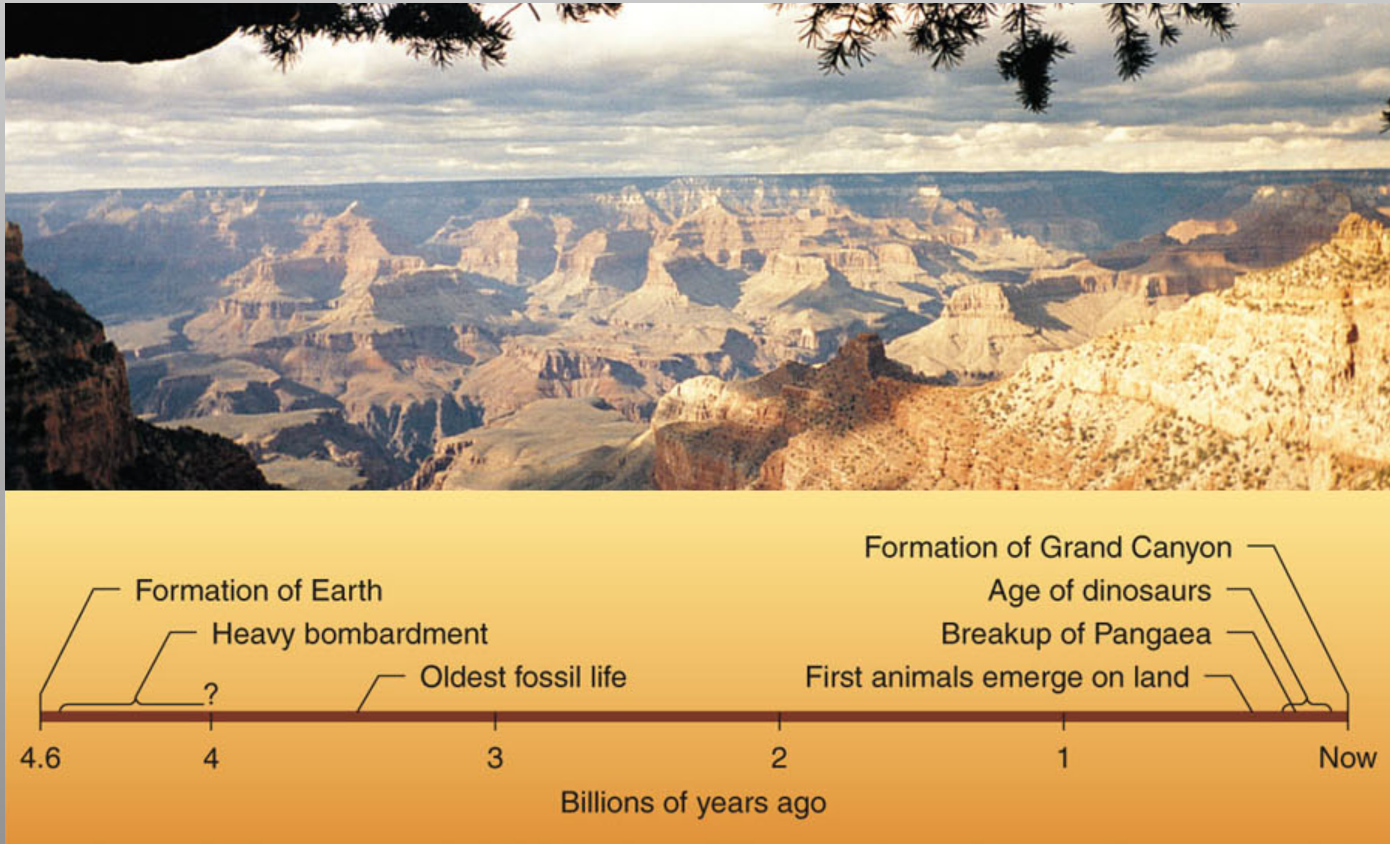
Earth’s Active Crust

- Earth’s surface is constantly renewed.
  - The oldest Earth materials known are small crystals called zircons from western Australia.
  - These are 4.3 billion years old.
  - Most of the crust is much younger than that.



Earth's Active Crust

- The mountains and valleys around you are probably no more than a few tens or hundreds of millions of years old.



Earth's Atmosphere

- When you think about Earth's atmosphere, you should consider three questions.
  - How did it form?
  - How has it evolved?
  - How are we changing it?

Earth's Atmosphere

- Answering these questions will help you understand other planets as well as our own.

Earth's Atmosphere

- Earth's first atmosphere—its primary atmosphere—was once thought to contain gases from the solar nebula, such as hydrogen and methane.
  - Modern studies, however, indicate that the planets formed hot.
  - So, gases such as carbon dioxide, nitrogen, and water vapor would have been cooked out of (been outgassed from) the rock and metal.

Earth’s Atmosphere

- Also, the final stages of planet building may have seen Earth and other planets accreting planetesimals rich in volatile materials—such as water, ammonia, and carbon dioxide.
  - Thus, the primary atmosphere must have been rich in carbon dioxide, nitrogen, and water vapor.
  - The atmosphere you breathe today is a secondary atmosphere produced later in Earth’s history.

Earth's Atmosphere

- Soon after Earth formed, it began to cool.
  - Once it cooled enough, oceans began to form, and carbon dioxide began to dissolve in the water.
  - Carbon dioxide is highly soluble in water—which explains the easy manufacture of carbonated beverages.

Earth’s Atmosphere

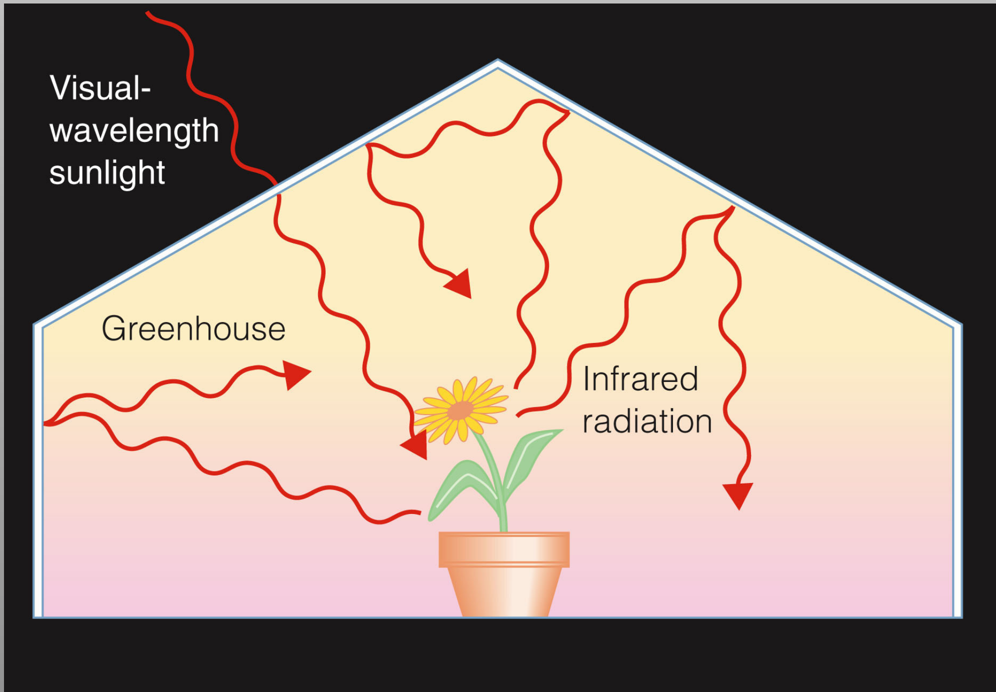
- As the oceans removed carbon dioxide from the atmosphere, it reacted with dissolved compounds in the ocean water—to form silicon dioxide, limestone, and other mineral sediments.
  - Thus, the oceans transferred the carbon dioxide from the atmosphere to the seafloor and left air richer in other gases, especially nitrogen.

Earth's Atmosphere

- This removal of carbon dioxide is critical to Earth's history.
  - This is because an atmosphere rich in carbon dioxide can trap heat—by the greenhouse effect.

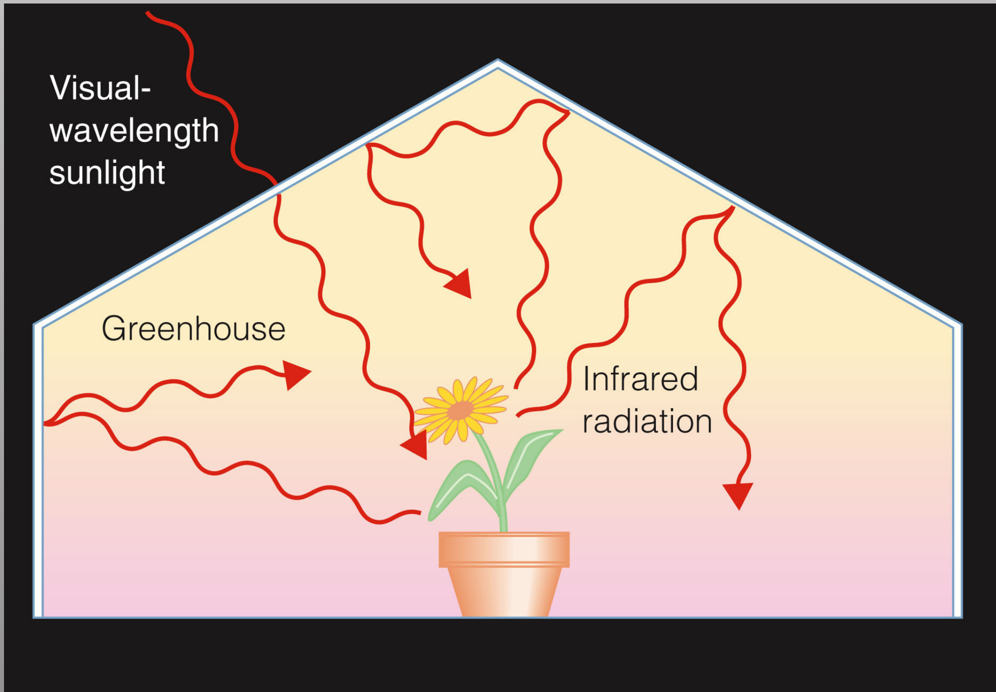
Earth’s Atmosphere

- When visible-wavelength sunlight shines through the glass roof of a greenhouse, it heats the interior.
  - Infrared radiation from the warm interior can’t get out through the glass.
  - Heat is trapped in the greenhouse.



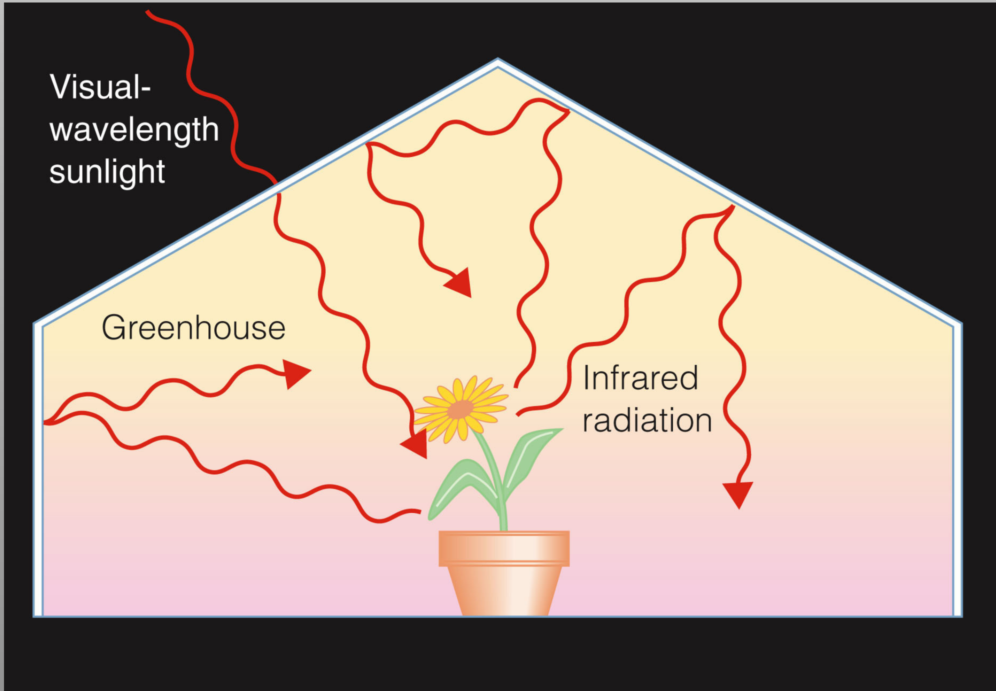
Earth’s Atmosphere

- The temperature climbs until the glass itself grows warm enough to radiate heat away as fast as sunlight enters.



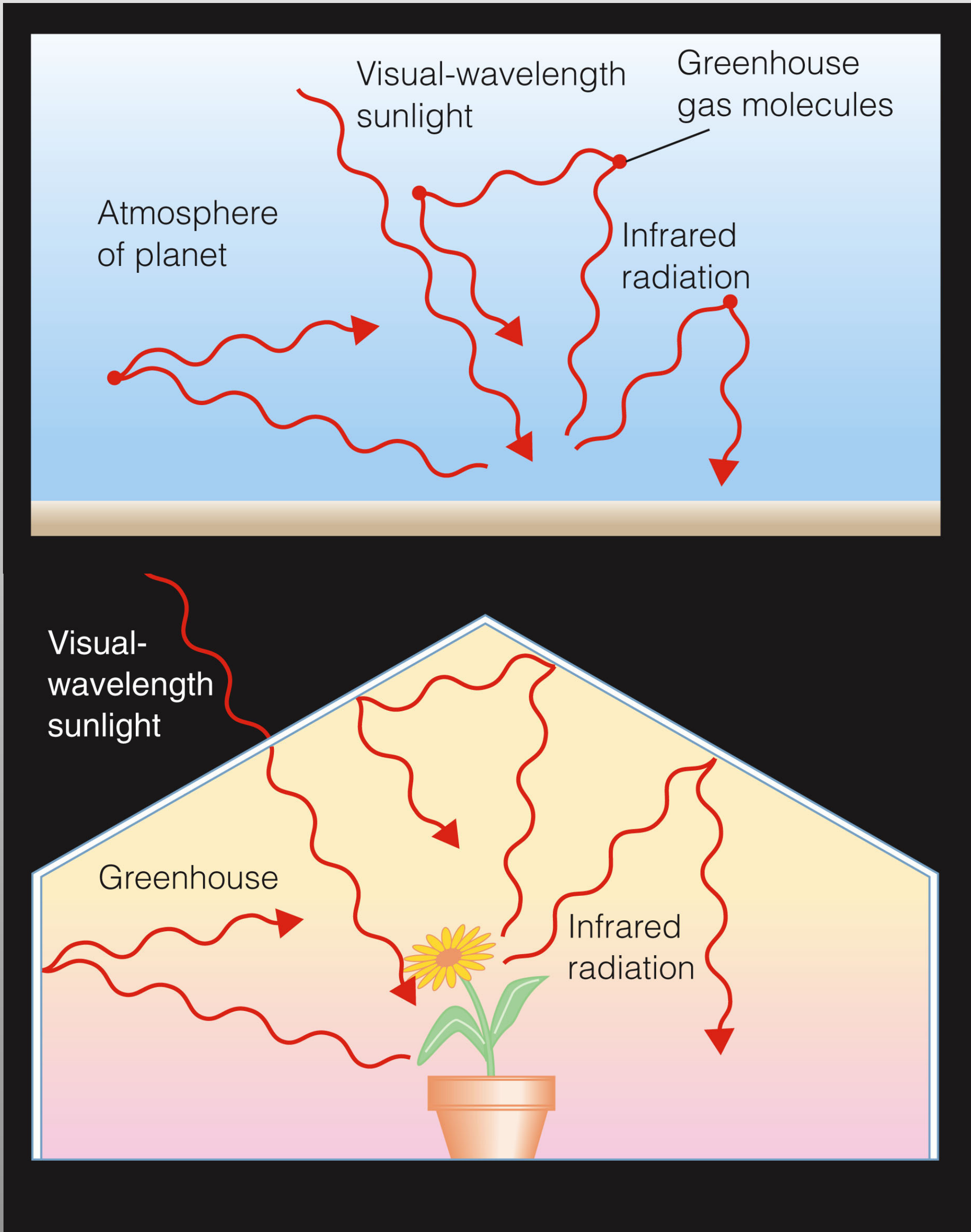
Earth’s Atmosphere

- Of course, a real greenhouse also retains its heat because the walls prevent the warm air from mixing with the cooler air outside.
  - This is also called the ‘parked car effect’—for obvious reasons.



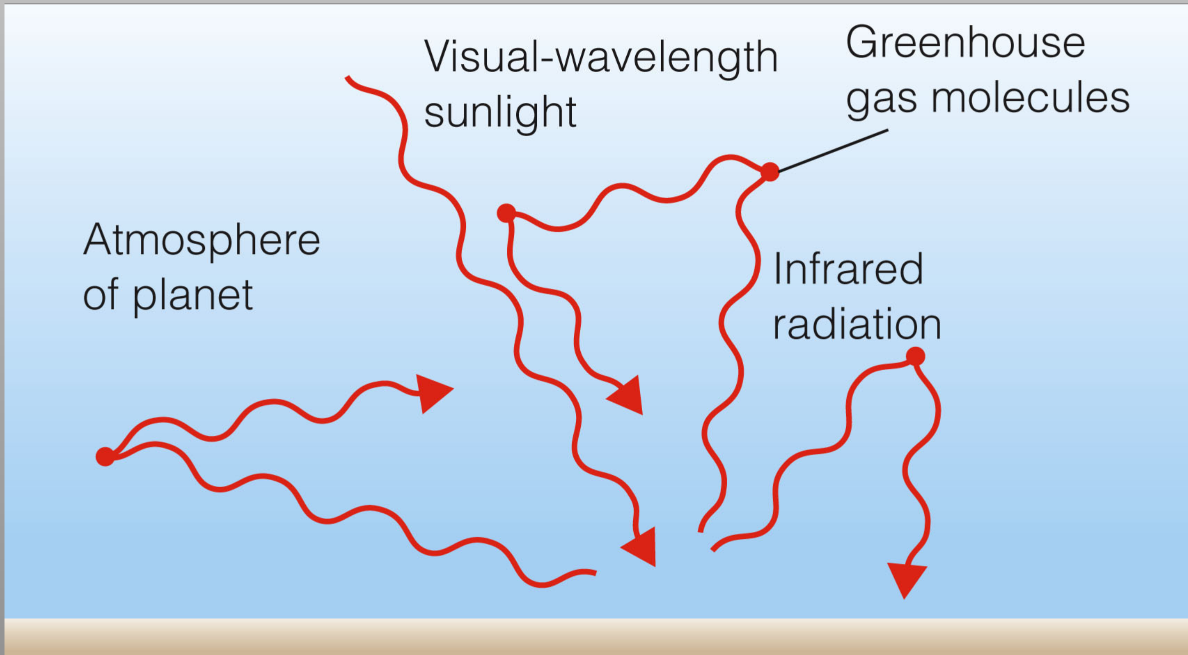
Earth’s Atmosphere

- Like the glass roof of a greenhouse, a planet’s atmosphere can allow sunlight to enter and warm the surface.



Earth's Atmosphere

- Carbon dioxide and other greenhouse gases such as water vapor and methane are opaque to infrared radiation.
  - So, an atmosphere containing enough of these gases can trap heat and raise the temperature of a planet's surface.



Earth’s Atmosphere

- It is a common misconception that the greenhouse effect is always bad.
  - However, without the effect, Earth would be colder by at least 30 K (54 F).
  - The planetwide average temperature would be far below freezing.

Earth’s Atmosphere

- The problem is that human civilization is adding greenhouse gases to those that are already in the atmosphere.

Earth's Atmosphere

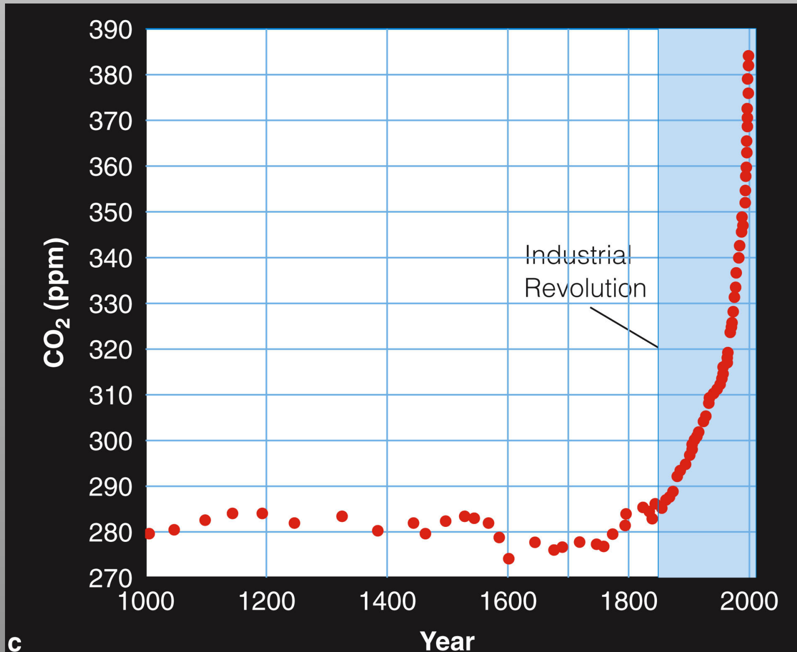
- For 4 billion years, Earth's oceans and plant life have been absorbing carbon dioxide and burying it—in the form of carbonates such as limestone and in carbon-rich deposits of coal, oil, and natural gas.

Earth's Atmosphere

- However, in the last century or so, human civilization has been:
  - Digging up those fuels
  - Burning them for energy
  - Releasing the carbon back into the atmosphere as carbon dioxide

Earth's Atmosphere

- This process is steadily increasing the carbon dioxide concentration in the atmosphere and warming Earth's climate.
  - This is known as global warming.



Earth's Atmosphere

- Global warming is a critical issue.
  - This is not just because it affects agriculture.
  - It is also changing climate patterns that will warm some areas and cool other areas.
  - In addition, the warming is melting what had been permanently frozen ices in the polar caps—causing sea levels to rise.
  - A rise of just a few feet will flood major land areas.

Earth’s Atmosphere

- When you visit Venus, you will see a planet dominated by the greenhouse effect.

Oxygen in Earth's Atmosphere

- When Earth was young, its atmosphere had no free oxygen.
  - Oxygen is very reactive and quickly forms oxides in the soil.
  - So, plant life is needed to keep a steady supply of oxygen in the atmosphere.

Oxygen in Earth’s Atmosphere

- Photosynthesis makes energy for the plant—by absorbing carbon dioxide and releasing free oxygen.

Oxygen in Earth's Atmosphere

- Ocean plants began to manufacture oxygen faster than chemical reactions could remove it about 2 to 2.5 billion years ago.
  - Atmospheric oxygen then increased rapidly.

Oxygen in Earth's Atmosphere

- As there is oxygen in the atmosphere now, there is also a layer of ozone (O_3) at altitudes of 15 to 30 km.

Oxygen in Earth’s Atmosphere

- Many people hold the common misconception that ozone is bad—because they hear it mentioned as part of smog.
  - Indeed, breathing ozone is bad for you.
  - However, the ozone layer is needed in the upper atmosphere.
  - This layer protects you from harmful UV photons.

Oxygen in Earth's Atmosphere

- However, certain compounds called chlorofluorocarbons (CFCs), used in refrigeration and industry, can destroy ozone when they leak into the atmosphere.
  - Since the late 1970s, the ozone concentration has been falling.
  - The intensity of harmful ultraviolet radiation at Earth's surface has been increasing year by year.

Oxygen in Earth's Atmosphere

- Note that ozone depletion is an Earth environmental issue that is separate from global warming.
- This poses an immediate problem for public health on Earth.
- However, it is also of interest astronomically.
  - When you visit Mars, you will see the effects of an atmosphere without ozone.

A Short Geological History of Earth

- As Earth formed in the inner solar nebula, it passed through three stages.
  - These stages also describe the histories of the other terrestrial planets to varying extents.

A Short Geological History of Earth

- When you try to tell the story of each planet in our solar system, you pull together all the known facts as well as hypotheses.
- Then, you try to make them into a logical history of how the planet got to be the way it is.

Earth had already passed through its 4 stages:

1. Differentiation - the separation of material according to density.

- For Earth, the heavy iron and nickel settles in the center, producing a dense metallic core. Silicates have went outward to form a thin, fragile crust. It is from the densest (core), less dense (mantle) to the low-densest (crust), where the densest materials were able to sink to the core because Earth's interior was melted.
- This differentiation had occurred due to the melting of Earth's interior caused by heat from the combination of radioactive decay plus energy released by in-falling matter during the planet's formation. Once the interior of Earth melted, the densest materials sank to the core.

2. Cratering - when the crust formed

- Earth was heavily bombarded by craters in the debris-filled early solar system.

3. Flooding - the flooding of the crater basins by lava, water, or both.

4. Slow Surface Evolution : caused by wind erosion And plate tectonics.

That Earth _____ , evidence that Earth differentiated

- Because of its density
- Very high density of the core.
- Lower density in the mantle, and even lower density in the crust.

A Short Geological History of Earth

- Earth's surface is constantly changing—as sections of crust:
  - Slide over and past each other
  - Push up mountains
  - Shift continents

- .

Dynamo Effect (how Earth's magnetic field is created)

the theory that Earth's magnetic field is generated by the currents in its melting core.

- It is said that the liquid core is stirred by convection.

- Earth's rotation brings this motion closer that circulates in a way that generates electric currents throughout the core.

- Plate Tectonics ("The Builder of Earth's Surface")
- the constant destruction and renewal of Earth's surface by the motion of sections of crust.

Because Earth's surface is active, large sections of its crust come and go as interactions between plates destroy old terrain, push up mountains, and create new crusts.

- Where plates spread apart, lava comes up to form new crust; where plates push against each other, they crumple the crust to form mountains; where one plate slides over another, volcanism occurs.

A Short Geological History of Earth

- In addition, moving air and water erode the surface and wear away geological features.
  - Almost all traces of the first billion years of Earth's geology have been destroyed by the active crust and erosion.

A Short Geological History of Earth

- Terrestrial planets pass through these stages.
  - However, differences in masses, temperature, and composition emphasize some stages over others—producing surprisingly different worlds.

- .

Eccentricity (e)

a number between 1 and 0 that describes the shape of an ellipse, the distance from one focus to the center of the ellipse divided by the semimajor axis.

- Oblate
- the flattening of a spherical body/planet at the poles, usually caused by rotation.

- Albedo
- the ratio of the light reflected from an object to the light that hits the object.

  0 = perfectly black
  1 = perfectly white

Moon's Characteristics

- Equatorial diameter: 3.48×10^3 km (2162.4 miles)
  Mass: 7.35×10^{22} kg
  Average density: 3.36 g/cm^3 [3.3 g/cm^3 uncompressed]
  Surface gravity: 0.17 Earth gravity
  Escape velocity: 2.4 km/s
  Surface temperature: -170^0 to 130^0 C (-275^0 to 265^0 F)
  Average albedo: 0.07

- The Moon
- Impact Cratering:

1. Impact craters have certain distinguishing characteristics, such as their shape and the way the impacts ejected material across the lunar surface.

2. There s a great range of sizes from giant basins to microscopic pits.

3. Most of the craters on the moon are old; they were formed long ago when the solar system was young.

- Lunar Maria
- large, dark plains of the lunar lowlands (rhe dark gray areas visible from Earth by naked eye) formed by volcanic eruptions of dark lava. Latin for "seas," early astronomers thought these dark areas on the moon were filled with water. 16% of the moon's surface is covered in maria.

  The lunar Maria is one of the moon's terrains.

- Impact Cratering of the Moon (what caused the craters on the moon)
- The craters on the moon were formed by the impact of meteorites striking the moon traveling about 10 to 70 km/s, and can hit with the energy of many nuclear bombs.

  1. Craters have certain distinguishing characteristics, such as shape and the ejecta, rays, and secondary craters around them.

- - ejecta - Pulverized rock scattered by meteorite impacts on a planetary surface.

  2. Lunar impact craters range from tiny pits formed by micrometeorites (small meteorites) to giant multiringed basins (the larges craters one or more inner rings concentric with the outer rim).

  3. Most of the craters on the moon are old; they were formed long ago when the solar system was young.

The Origin of the Moon

- Astronomers had come up with 3 different hypothesis for the origin of the moon:

  1. Fission hypothesis - the moon broke from a rapidly spinning young Earth.
  2. Condensation hypothesis - Earth and its moon condensed from the same cloud of matter in the solar nebula.

- 3. Capture hypothesis - the moon formed elsewhere in the solar nebula and was later captured by Earth.

  Later in the 1970s, a new theory about the origin of the moon was proposed:
  - Large-Impact hypothesis.

Large-Impact Hypothesis

- origin of the moon. A LARGE body the size of mars smashed into the earth and effected DEBRIS into a disk around the earth where it formed out moon

  The theory that the moon formed from debris ejected during a collision between Earth and a large planetesimal.

Mercury's Characteristics

- Equatorial diameter 4.89 x 10^3 km
  Mass 3.31 x 10^{23} kg
  Average density: 5.44 g/cm^3 [5.4 g/cm^3 uncompressed]
  Surface gravity: 0.38 Earth gravity
  Escape velocity: 4.3 km/s
  Surface temperature: -170^0 to 430^0 C (-275^0 to 800^0F)
  Average albedo: 0.1
  Oblateness: 0

The Moon

- You will need a good spacesuit to visit the moon.
  - There is no air.
  - The temperature difference from sunshine to shade is extreme.

Lunar Geology

- You could visit two kinds of terrain on the moon.
  - The dark gray areas visible from Earth are the smooth lunar lowlands—which, drawing on the Latin word for *seas*, earlier astronomers named maria.
  - You could also visit the lighter-colored mountainous lunar highlands.

Lunar Geology

- The moon looks quite bright in the night sky seen from Earth.
  - In fact, the albedo of the moon is only 0.06—that is, it reflects only 6 percent of the light that hits it.
  - The moon looks bright only in contrast to the night sky.
  - It is, in reality, a dark gray world.

Lunar Geology

- Wherever you go on the moon, you will find craters.
  - The highlands are marked heavily by craters.
  - In contrast, the smooth lowlands contain few craters.

Lunar Geology

- The evidence that craters on the moon were formed by impacts is:
  - Their distinguishing characteristics such as shape and the material (ejecta) they have spread across the moon's surface

Lunar Geology

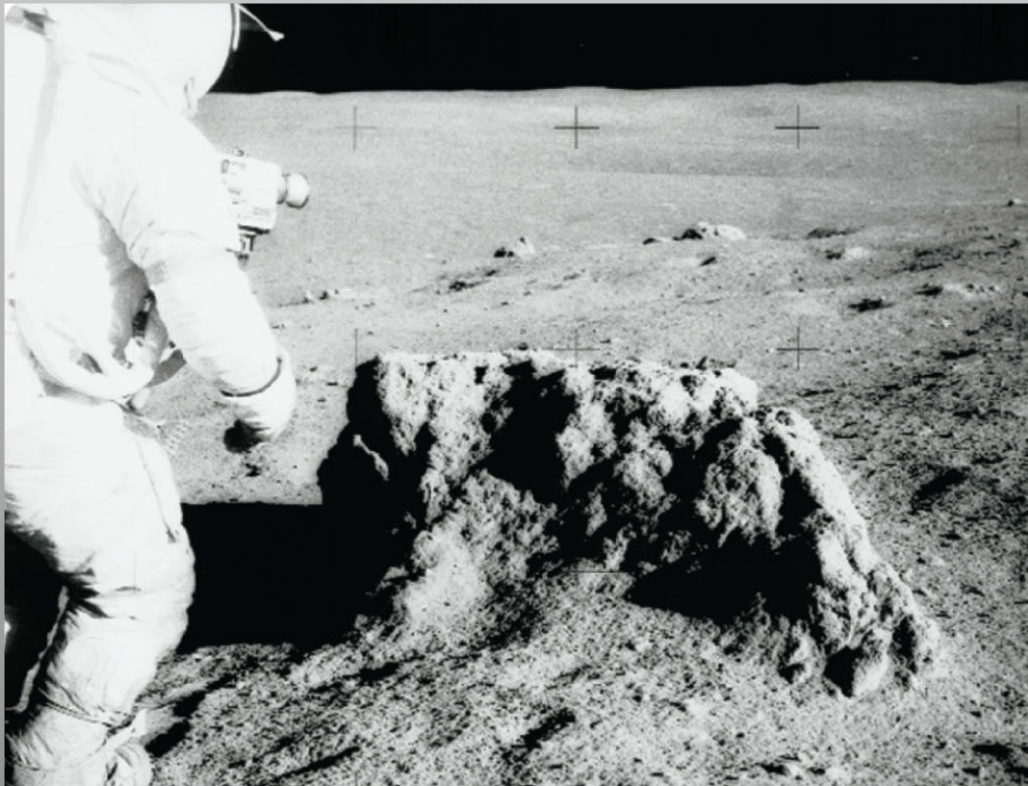
- Craters range in size from giant basins hundreds of kilometers across to microscopic pits found in moon rocks.

Lunar Geology

- Most of the craters are old.
  - They were formed long ago—when the solar system was young.
  - This is clear from comparison of ages of moon rocks collected from the heavily cratered highlands and the somewhat younger, less heavily cratered maria.

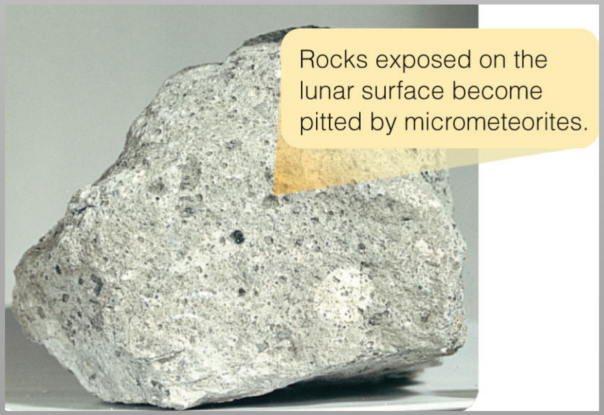
Lunar Geology

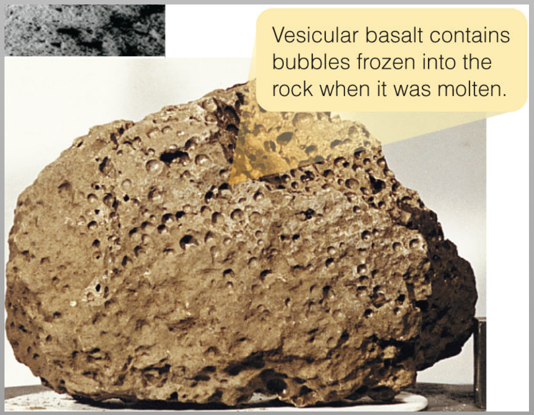
- Twelve Apollo astronauts visited both the moon’s maria and highlands in six expeditions between 1969 and 1972.

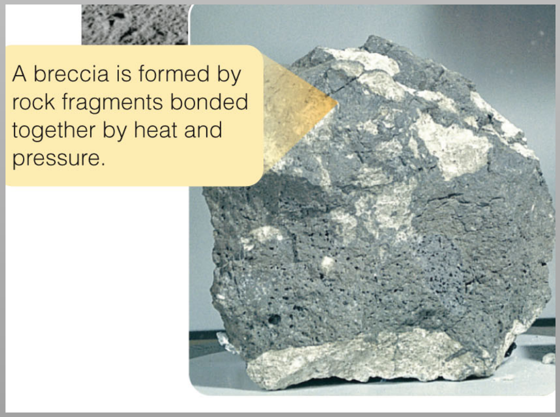


Lunar Geology

- Most rocks they found, both in the highlands and the maria, were typical of hardened lava.

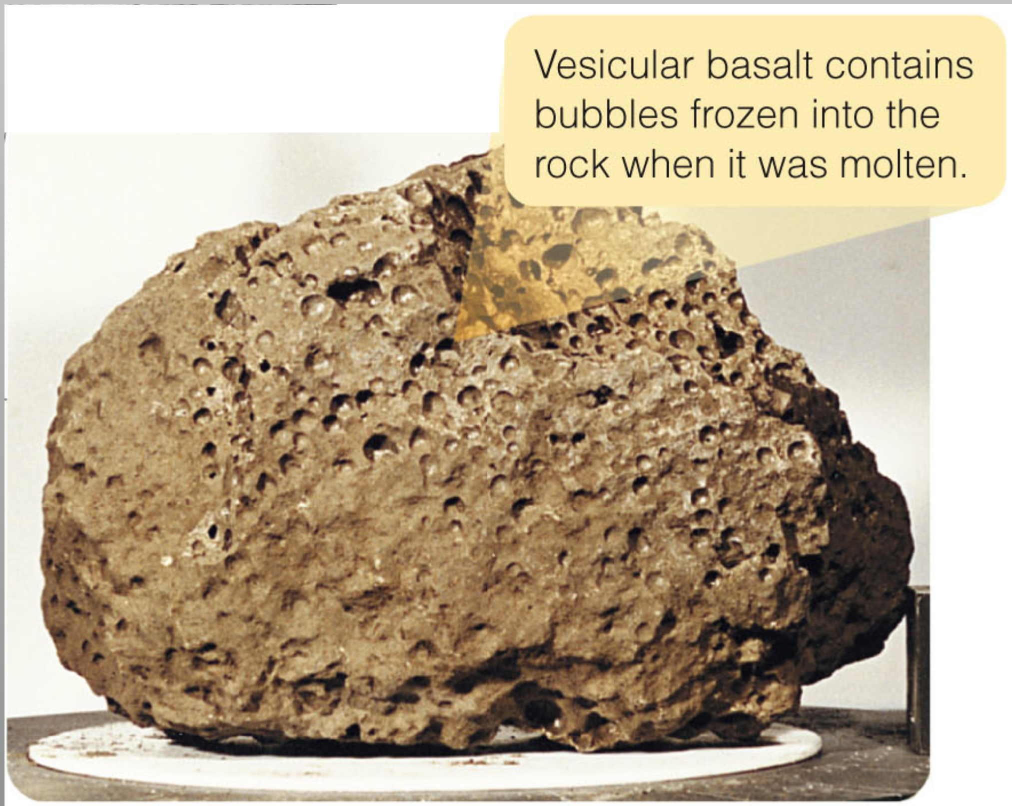






Lunar Geology

- The maria are actually ancient basalt lava flows.

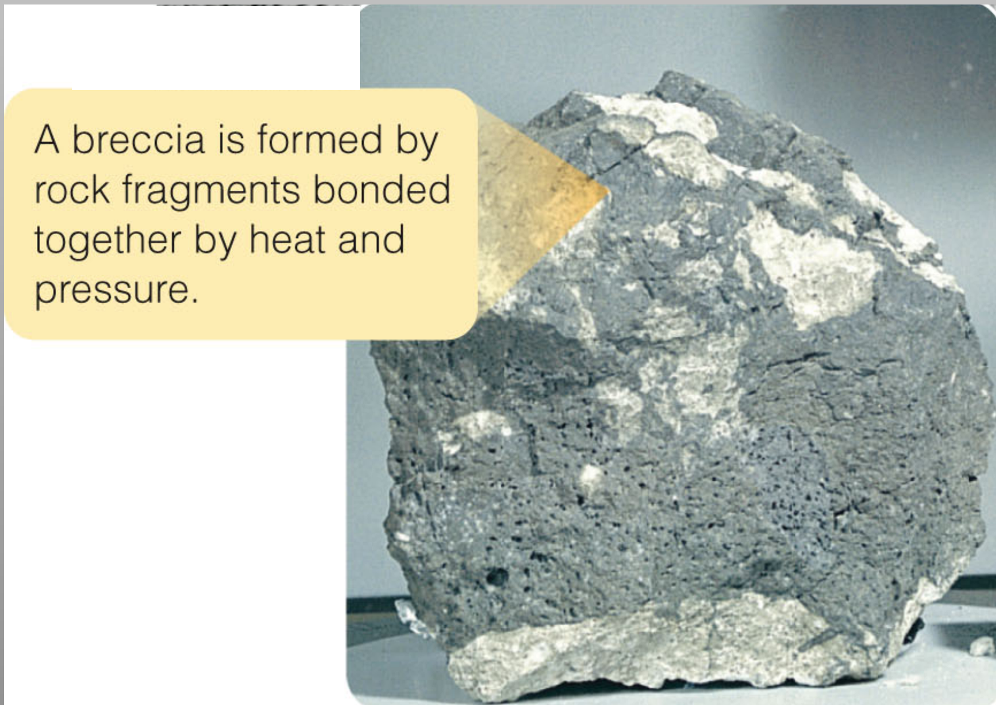


Lunar Geology

- The highlands, in contrast, are composed of low-density rock containing minerals.
  - For example, anorthosite—a light-colored rock that contributes to the highlands' bright contrast with the dark maria—would be among the first material to solidify and float to the top of molten rock.

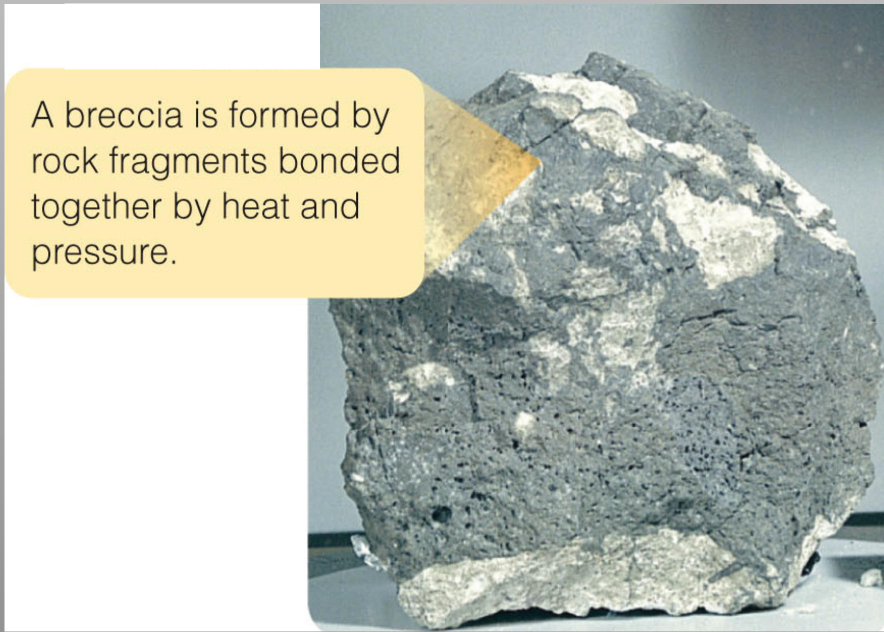
Lunar Geology

- Many rocks found on the moon are breccias.
  - These are made up of fragments of broken rock cemented together under pressure.



Lunar Geology

- The breccias show how extensively the moon's surface has been shattered by meteorites.
  - So does the surface layer of powdery dust kicked up by an astronaut's boots.



The Origin of Earth’s Moon

- Over the last two centuries, astronomers have developed three different hypotheses for the origin of Earth’s moon.

The Origin of Earth's Moon

- The fission hypothesis proposed:
  - The moon broke from a rapidly spinning proto-Earth.

The Origin of Earth's Moon

- The condensation hypothesis suggested:
  - Earth and its moon condensed from the same cloud of matter in the solar nebula.

The Origin of Earth's Moon

- The capture hypothesis suggested:
  - The moon formed elsewhere in the solar nebula and was later captured by Earth.

The Origin of Earth's Moon

- Each of these traditional ideas had problems.
  - Consequently, they failed to survive comparison with all the evidence.

The Origin of Earth's Moon

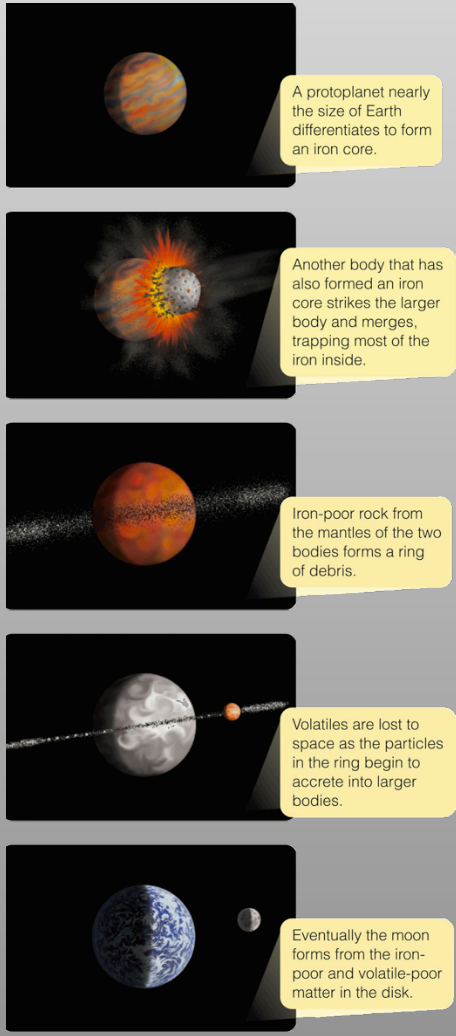
- In the 1970s, a new hypothesis was proposed.
  - It combined some aspects of the traditional hypotheses.

The Origin of Earth's Moon

- The large-impact hypothesis proposes:
  - The moon formed when a planetesimal estimated to have been at least as large as Mars smashed into the proto-Earth.

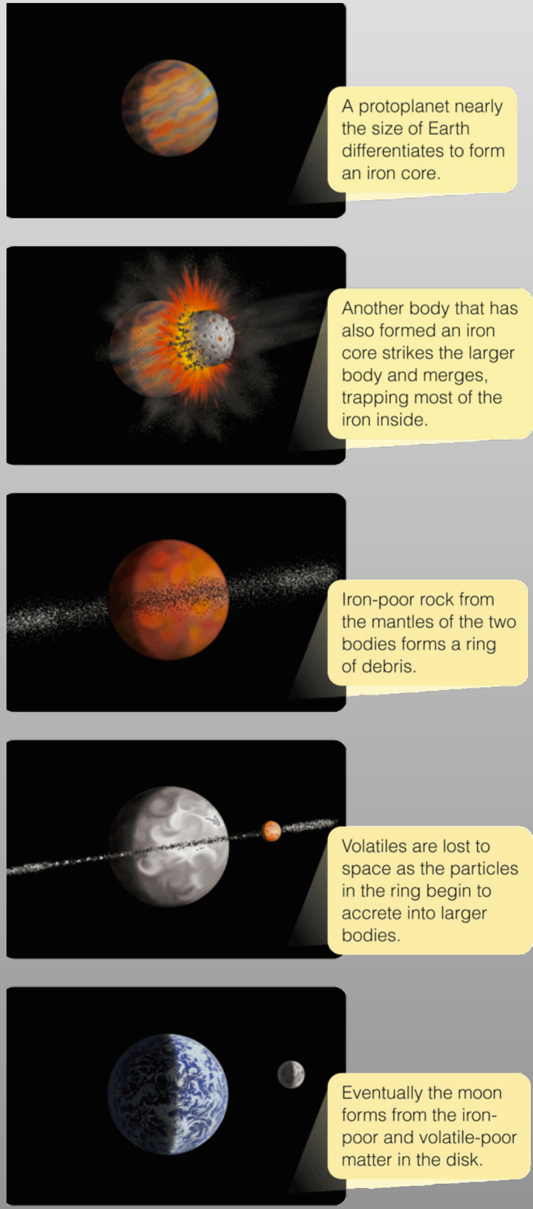
The Origin of Earth's Moon

- Model calculations indicate that this collision would have ejected a disk of debris into orbit around Earth that would have quickly formed the moon.



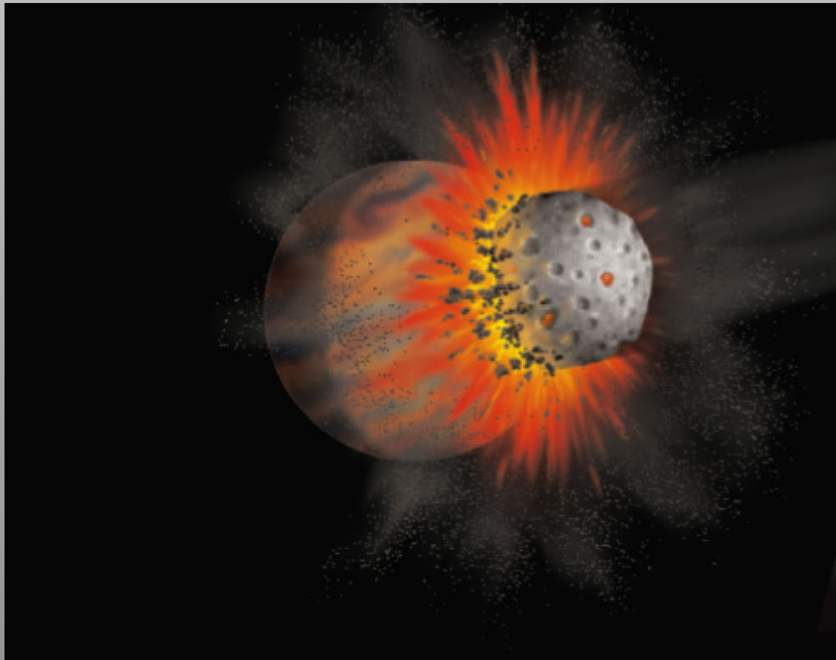
The Origin of Earth’s Moon

- This would explain a number of phenomena.



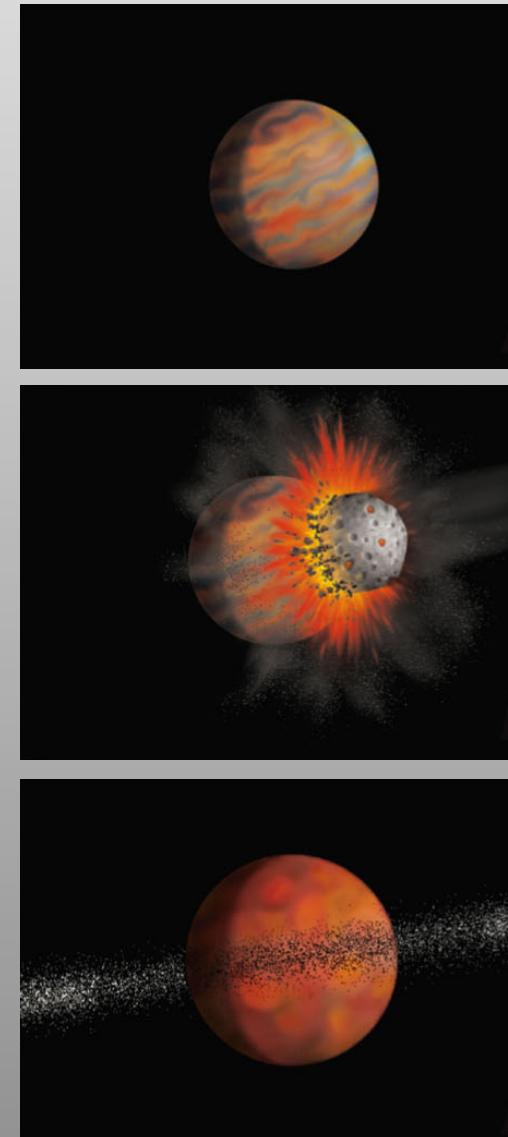
The Origin of Earth's Moon

- If the collision had occurred off-center, it would have spun the Earth–moon system rapidly.
  - This would explain the present high angular momentum.



The Origin of Earth’s Moon

- If the proto-Earth and impactor had already differentiated, the ejected proto-Earth, and the material falling together to form the moon would have been hot enough to melt.
  - This fits evidence the the highland anorthosite in the moon’s oldest rocks formed by differentiation of large quantities of molten material.



The Origin of Earth’s Moon

- The large impact hypothesis passes tests of comparison with the known evidence and is now considered likely to be correct.

The History of Earth's Moon

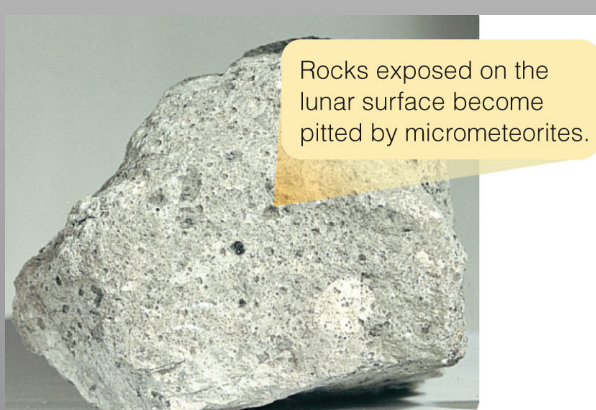
- The history of Earth's moon since its formation is dominated by a single fact—it is small.
  - It is only one-quarter the diameter of Earth.

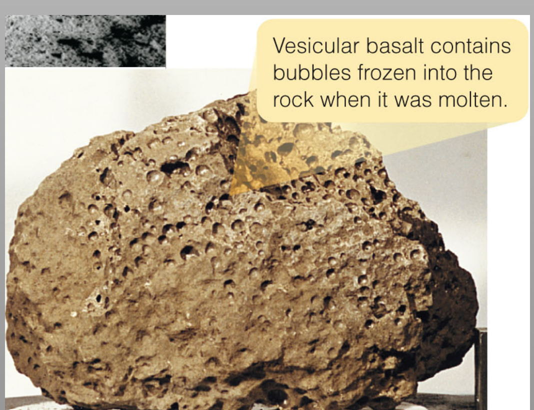
The History of Earth’s Moon

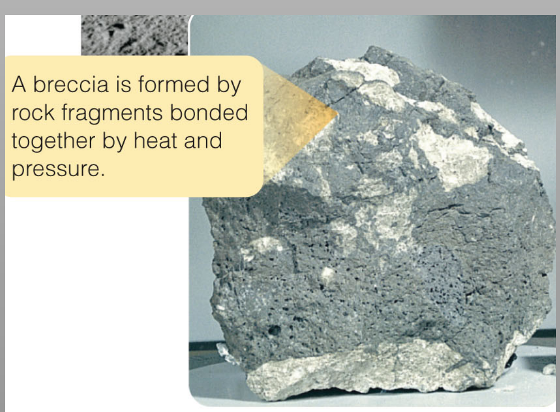
- The escape velocity is low.
- So, it has been unable to hold any atmosphere.
  - It cooled rapidly as its internal heat flowed outward into space.

The History of Earth’s Moon

- The Apollo moon rocks are the source of information about the timing of events during the moon’s history.
  - For example, they show that the moon must have formed in a mostly molten state.





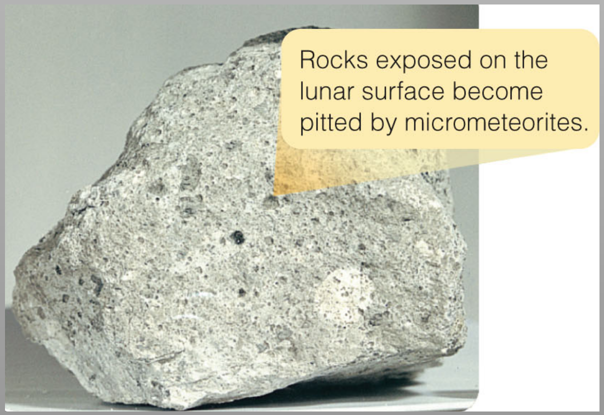


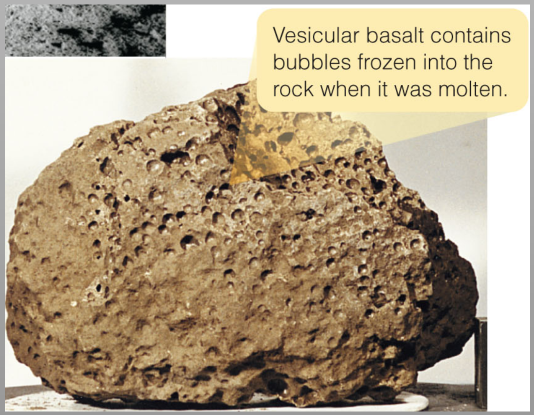
The History of Earth's Moon

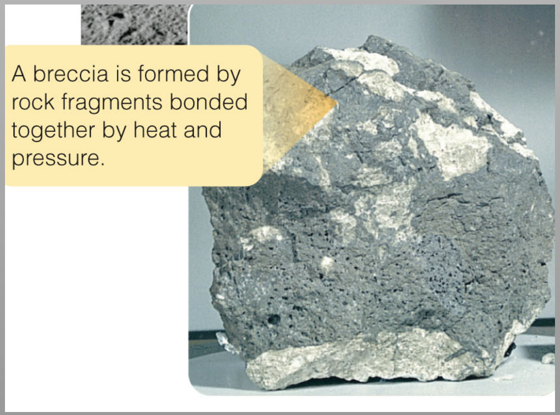
- Planetary geologists now refer to the exterior of the newborn moon as a magma ocean.
  - Denser materials sank towards the centre.
  - Low-density minerals floated to the top—to form a low-density crust.
  - In this way, the moon partly differentiated.

The History of Earth's Moon

- The radioactive ages of the moon rocks show that the surface solidified about 4.4 billion years ago.





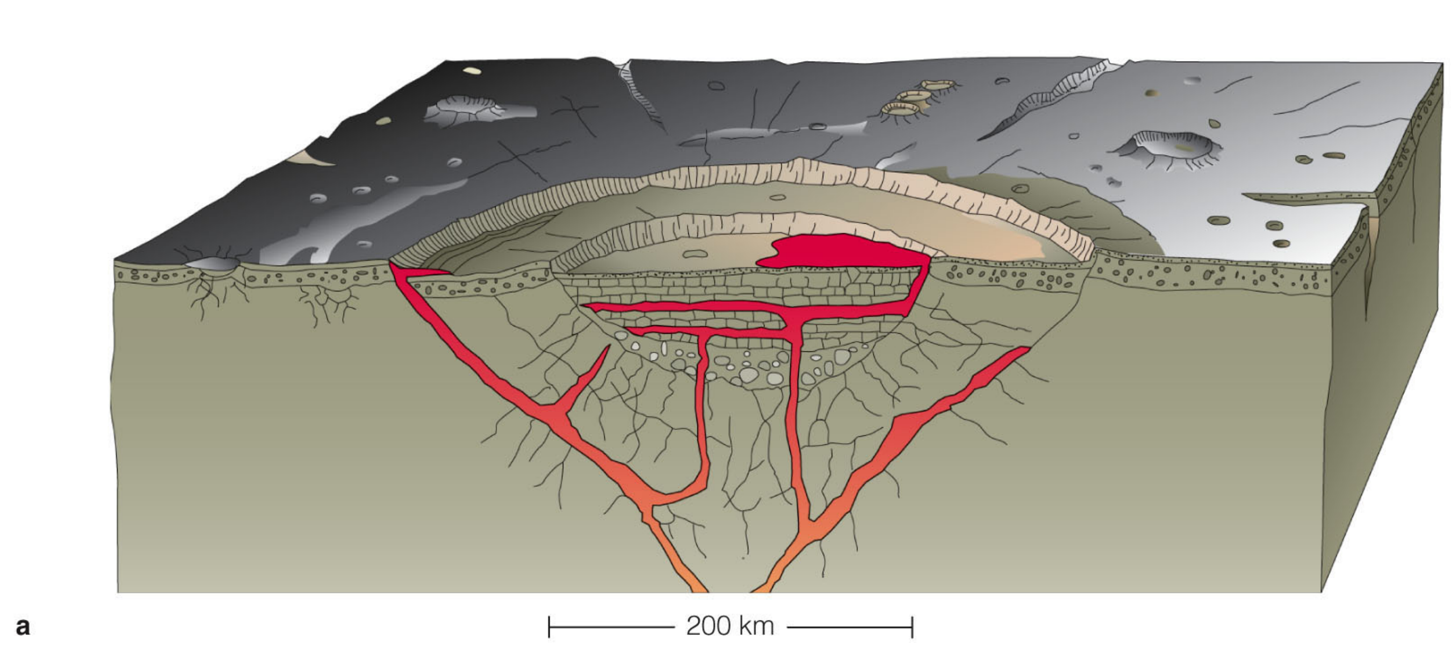


The History of Earth's Moon

- The second stage, cratering and basin formation, began as soon as the crust solidified.
  - The older highlands show that the cratering was intense during the first 0.5 billion years—during the heavy bombardment at the end of the solar system's period of planet building.

The History of Earth's Moon

- The moon's crust was shattered.
- The largest impacts formed giant multiringed basins hundreds of kilometers in diameter.



The History of Earth's Moon

- There is some evidence indicating that, about 4 billion years ago, there was a sudden temporary increase in the cratering rate.
  - Astronomers refer to this as the late heavy bombardment.

The History of Earth’s Moon

- Astronomers hypothesize that the bombardment could have been caused by the final accretion and migration of Uranus and Neptune.
  - This scattered remnant planetesimals across the solar system to collide with the moon and planets.

The History of Earth's Moon

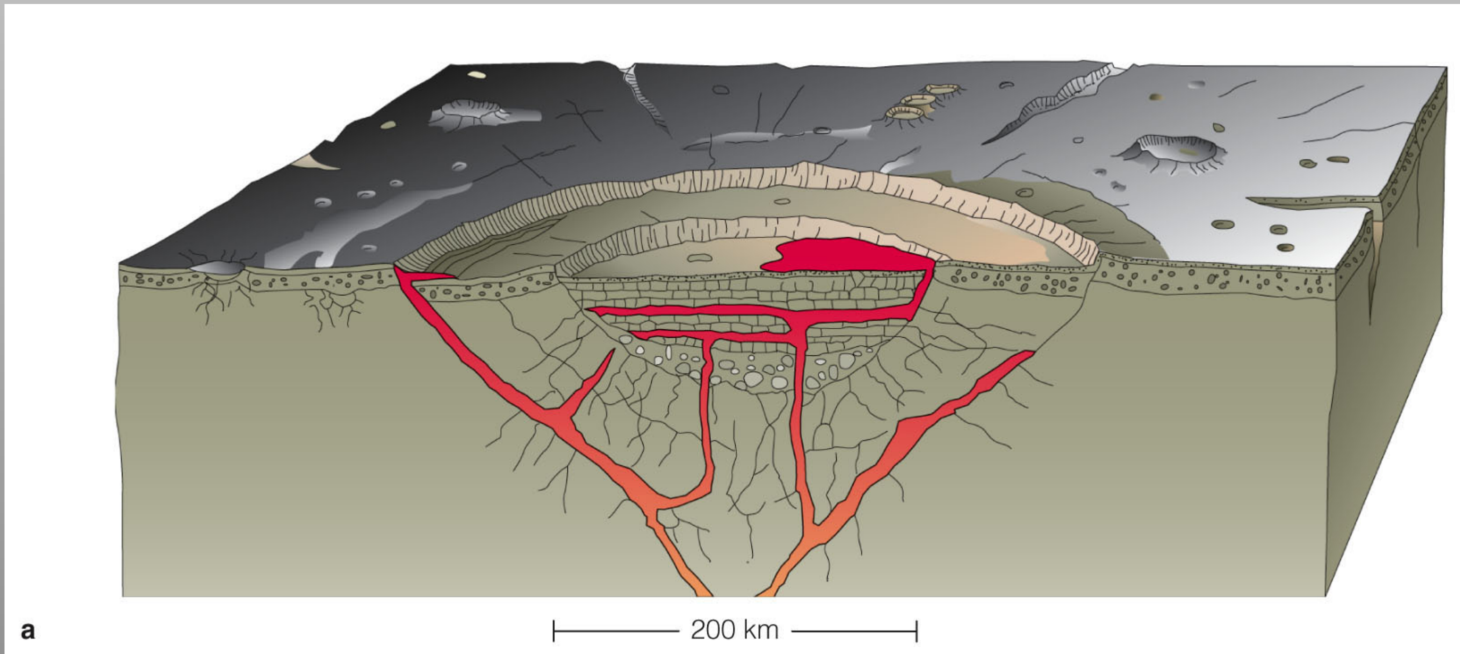
- After about 3.8 billion years ago, the cratering rate fell rapidly to the current low rate.

The History of Earth’s Moon

- The tremendous impacts that formed the lunar basins cracked the crust as deep as 10 kilometers and led to flooding by lava.

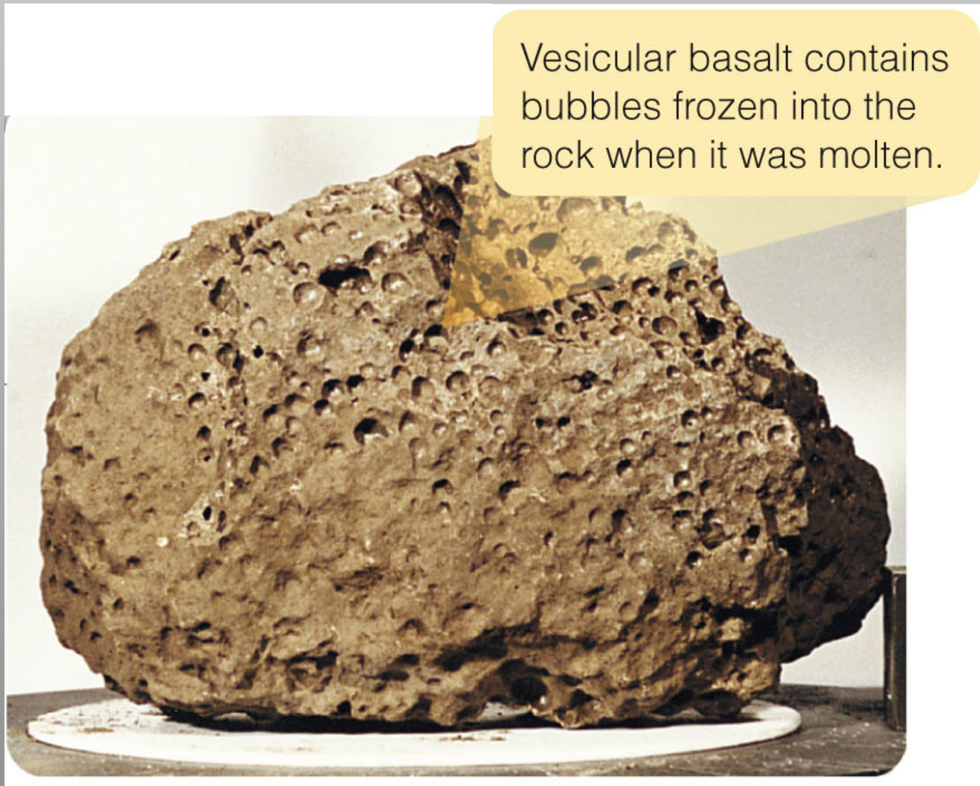
The History of Earth's Moon

- Though Earth's moon cooled rapidly after its formation, radioactive decay heated the subsurface material.
  - Part of it melted—producing lava that followed the cracks up into the giant basins.



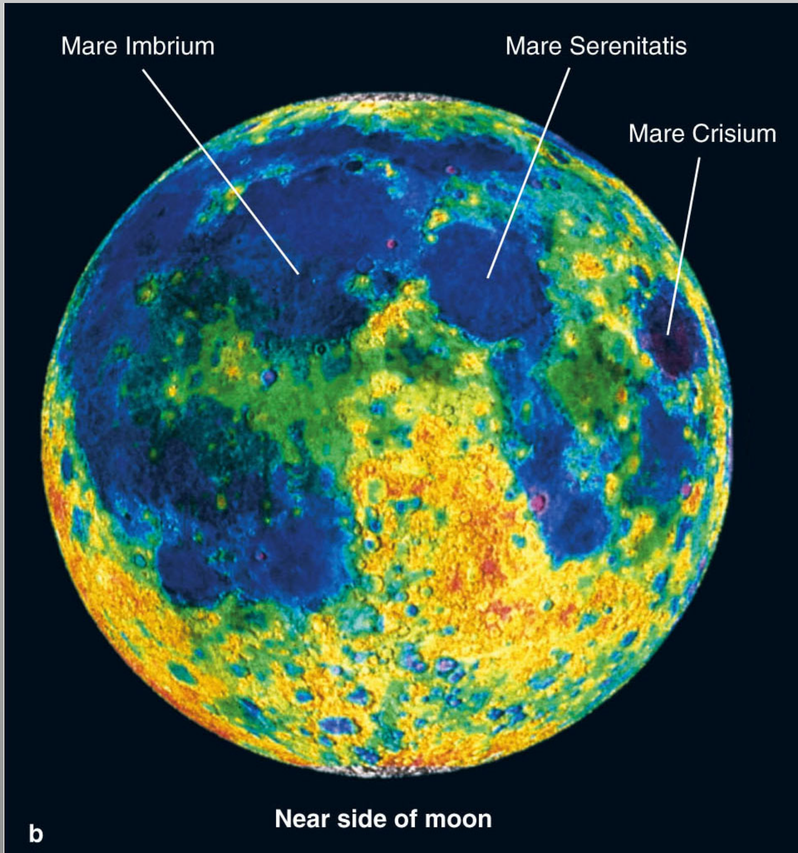
The History of Earth’s Moon

- Studies of the Apollo moon rocks show that the basins were flooded by successive lava flows of dark basalts.



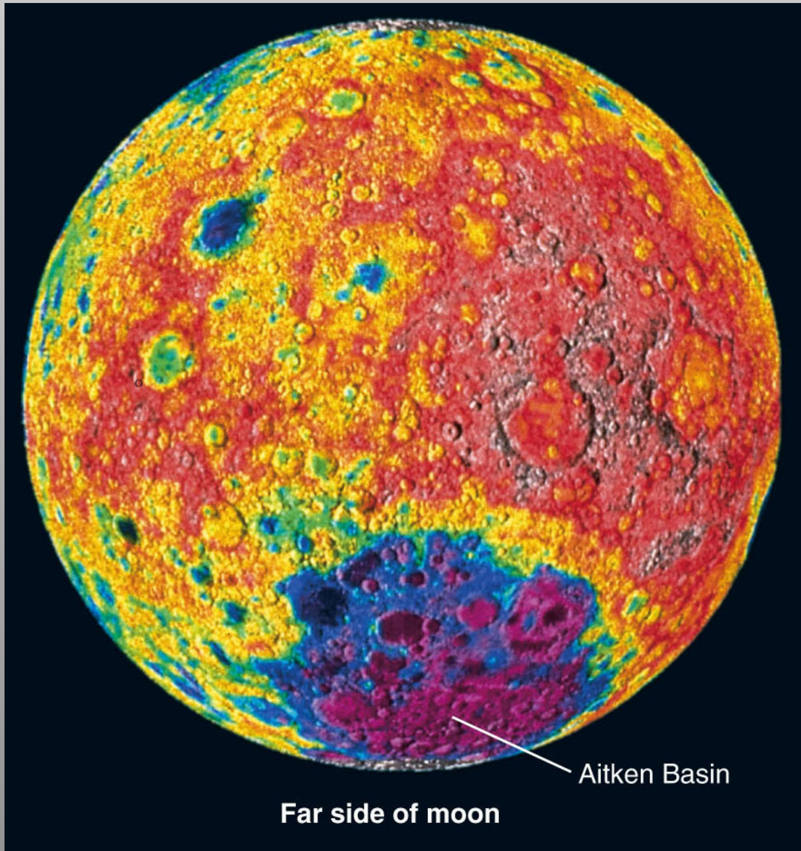
The History of Earth's Moon

- That formed the maria—from roughly 4 to 2 billion years ago.



The History of Earth's Moon

- The moon's crust is thinner on the side toward Earth—perhaps due to tidal effects.
  - So, while lava flooded the basins on the Earth-facing side, it was unable to rise through the thicker crust to flood the lowlands on the far side.



The History of Earth's Moon

- The third stage, slow surface evolution, was limited for two reasons.
  - The moon cooled rapidly.
  - The moon lacks water.

The History of Earth's Moon

- The moon has never had an atmosphere.
- Thus, it has never had liquid water.
  - With no air and no water, erosion is limited to the constant bombardment of micrometeorites and rare larger impacts.
  - Indeed, a few meteorites found on Earth have been identified as moon rocks ejected from the moon by major impacts within the last few million years.

The History of Earth's Moon

- As the moon lost its internal heat, volcanism died down.
- Geologically, the moon became dead.
  - Its crust never divided into moving plates—there are no folded mountain ranges.
  - It is now a "one-plate" planet.

Mercury

- Like Earth's moon, Mercury is small and nearly airless.
- You will find it is a cratered, dead world too.
    - This is because it cooled too quickly to develop plate tectonics.

Spacecraft at Mercury

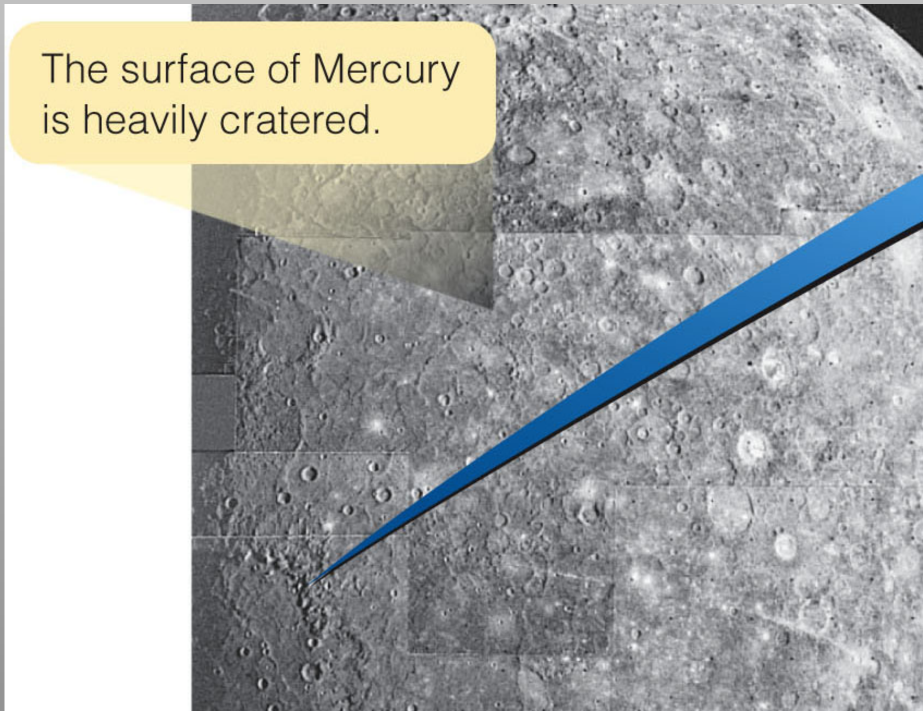
- Mercury orbits so close to the sun that it is difficult to observe from Earth.
    - So, little was known about the planet.

Spacecraft at Mercury

- In 1974-1975, the Mariner 10 spacecraft flew past Mercury three times.

Spacecraft at Mercury

- It revealed a planet with a heavily cratered surface—much like that of Earth's moon.

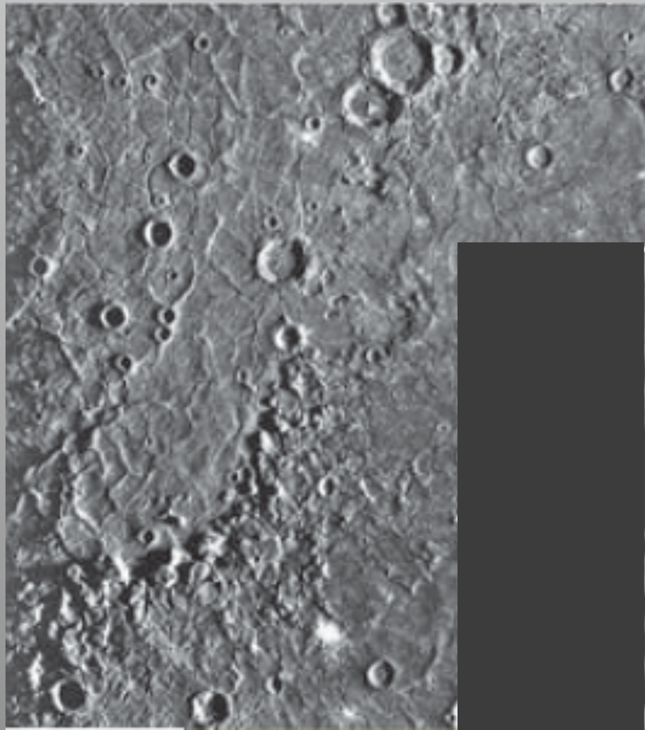


Spacecraft at Mercury

- A new spacecraft called MESSENGER made three flybys of Mercury in 2008 and 2009.
  - It took impressively high-resolution images and measurements of the parts of the planet not covered by Mariner 10's cameras.
- MESSENGER is scheduled to go into orbit around Mercury in 2011 and begin a yearlong closeup study.

Spacecraft at Mercury

- Analysis shows that large areas have been flooded by lava and then cratered.
- The largest impact feature on Mercury is the Caloris Basin.
  - This is a multiringed area 1,300 km (800 miles) in diameter.

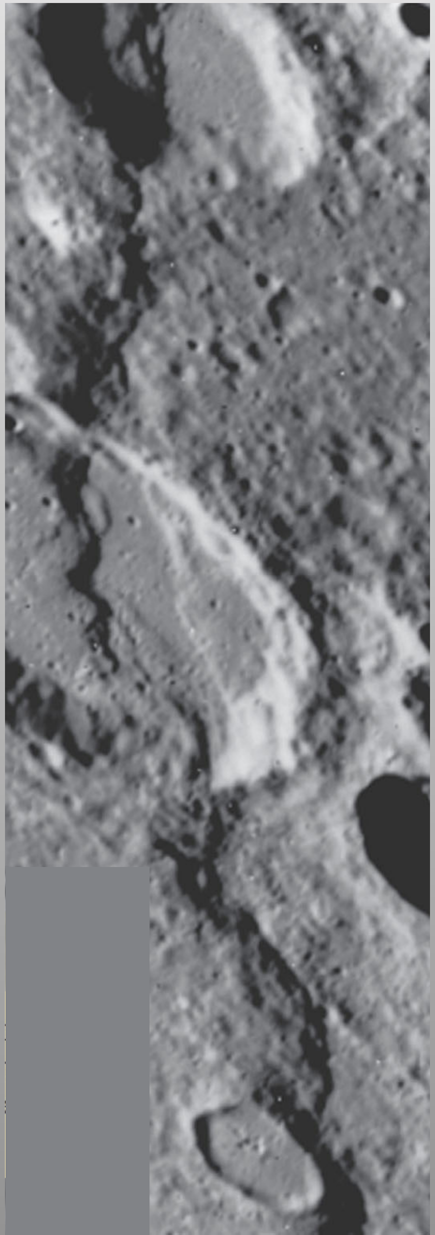


Spacecraft at Mercury

- Mercury is quite dense.
  - Models indicate that it must have a large metallic core.
  - In fact, the metallic core occupies about 70 percent of the radius of the planet.
  - Essentially, Mercury is a metal planet with a thin rock mantle.

Spacecraft at Mercury

- Mariner 10 photos revealed long, curving ridges up to 3 km (2 mi) high and 500 km (300 mi) long.
  - The ridges even cut through craters—indicating that they formed after most of the heavy bombardment.
  - Planetary scientists understand these ridges as evidence that the entire crust of Mercury compressed and shrank long ago.



A History of Mercury

- Like Earth's moon, Mercury is small.
- This has determined much of its history.
  - It is too small to retain an atmosphere.
  - It has also lost much of its internal heat.
  - Thus, it is not geologically active.

A History of Mercury

- In the first stage, Mercury differentiated to form a metallic core and a rocky mantle.
  - Mariner 10 discovered a weak magnetic field about 10^{-4} times that of Earth—further evidence of a metallic core.

A History of Mercury

- You have learned that the condensation sequence could explain the abundance of metals in Mercury.
  - However, careful model calculations show that Mercury contains even more iron than would be expected from its position in the solar system.

Table 12.2 The Condensation Sequence

Temperature (K)	Condensate	Object (Estimated Temperature of Formation; K)
1,500	Metal oxides	Mercury (1,400)
1,300	Metallic iron and nickel	
1,200	Silicates	
1,000	Feldspars	Venus (900)
680	Troilite (FeS)	Earth (600) Mars (450)
175	H_2O ice	Jovian (175)
150	Ammonia–water ice	
120	Methane–water ice	
65	Argon–neon ice	Pluto (65)

A History of Mercury

- Drawing on the large-impact hypothesis for the origin of Earth's moon, scientists have proposed that Mercury suffered a major impact soon after it differentiated.
  - This impact was so large it ejected much of the rocky mantle into space.

A History of Mercury

- Such catastrophic events are rare in nature.
- However, they do occur.
  - So, astronomers must be prepared to consider such hypotheses.

A History of Mercury

- In the second stage of planet formation, cratering battered the crust, and lava flows welled up to fill the lowlands—as they did on the moon.
  - As the small world lost internal heat, its large metal core contracted and its crust was compressed.
  - Eventually, the crust broke to form the long ridges—much as the peel of a drying apple wrinkles.

A History of Mercury

- Lacking an atmosphere to erode it, Mercury has changed little since the last lava hardened.
  - Now, it is a “one-plate” planet—like Earth’s moon.

Venus

- You might expect Venus to be much like Earth.
  - It is 95 percent Earth's diameter.
  - It has a similar average density.
  - It is only 30 percent closer to the sun.

Venus

- Unfortunately, the surface of Venus is perpetually hidden below thick clouds.

Venus

- Only in the last few decades have planetary scientists discovered that Venus is a hot desert world of volcanoes, lava flows, and impact craters lying at the bottom of a deep hot atmosphere.
  - No spacesuit will allow you to visit the surface of Venus.

The Atmosphere of Venus

- In composition, temperature, and density, the atmosphere of Venus is more Hades than Heaven.
  - The air is unbreathable, very hot, and very dense.

The Atmosphere of Venus

- How do planetary scientists know this?
  - U.S. and Soviet space probes have descended into the atmosphere.
  - In some cases, they have even landed on the surface.

The Atmosphere of Venus

- The atmosphere is roughly 96 percent carbon dioxide.
- The rest is mostly nitrogen, with some argon, sulfur dioxide, and small amounts of sulfuric acid, hydrochloric acid, and hydrofluoric acid.
- There is only a tiny amount of water vapor.
  - On the whole, the composition is deadly unpleasant and most certainly smells bad too.

The Atmosphere of Venus

- Spectra show that the impenetrable clouds that hide the surface are made up of droplets of sulfuric acid and microscopic crystals of sulfur.

The Atmosphere of Venus

- This unbreathable atmosphere is 90 times denser than Earth's.
  - The air you breathe is 1,000 times less dense than water.
  - If you could survive the unpleasant composition and intense heat, you could strap wings on your arms and fly.

The Atmosphere of Venus

- The surface temperature is hot enough to melt lead.
  - You can understand that because the thick atmosphere creates a severe greenhouse effect.
  - Sunlight filters down through the clouds and warms the surface.
  - Infrared radiation cannot escape because the carbon dioxide gas is opaque to infrared.

The Atmosphere of Venus

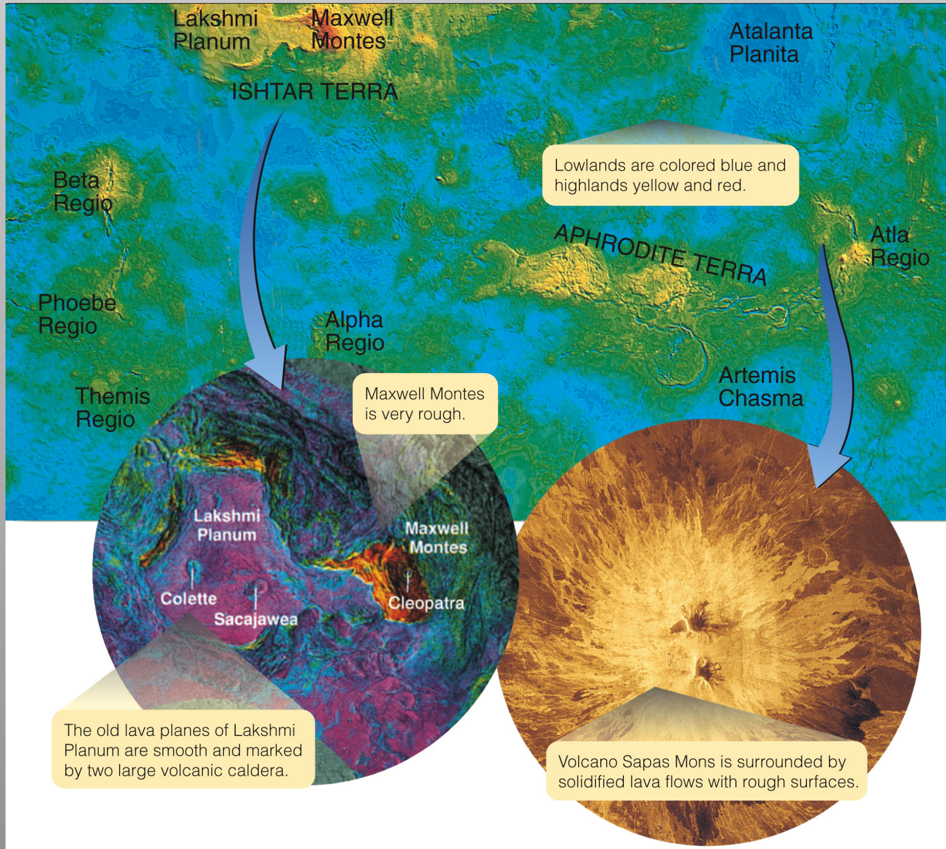
- The overwhelming abundance of carbon dioxide makes the greenhouse effect on Venus much more severe than on Earth.

The Surface of Venus

- Although the thick clouds on Venus are opaque to visible and infrared light, they are transparent to radio waves.
  - Orbiting spacecraft mapped Venus by radar.

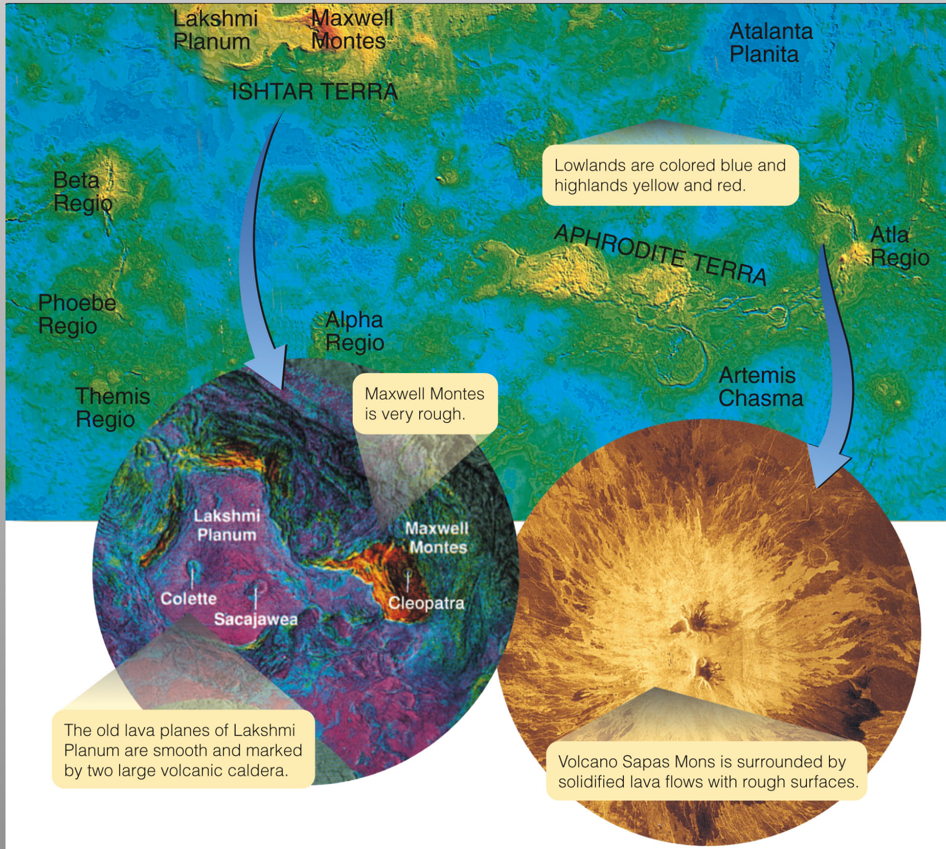
The Surface of Venus

- This revealed details as small as 100 meters in diameter.



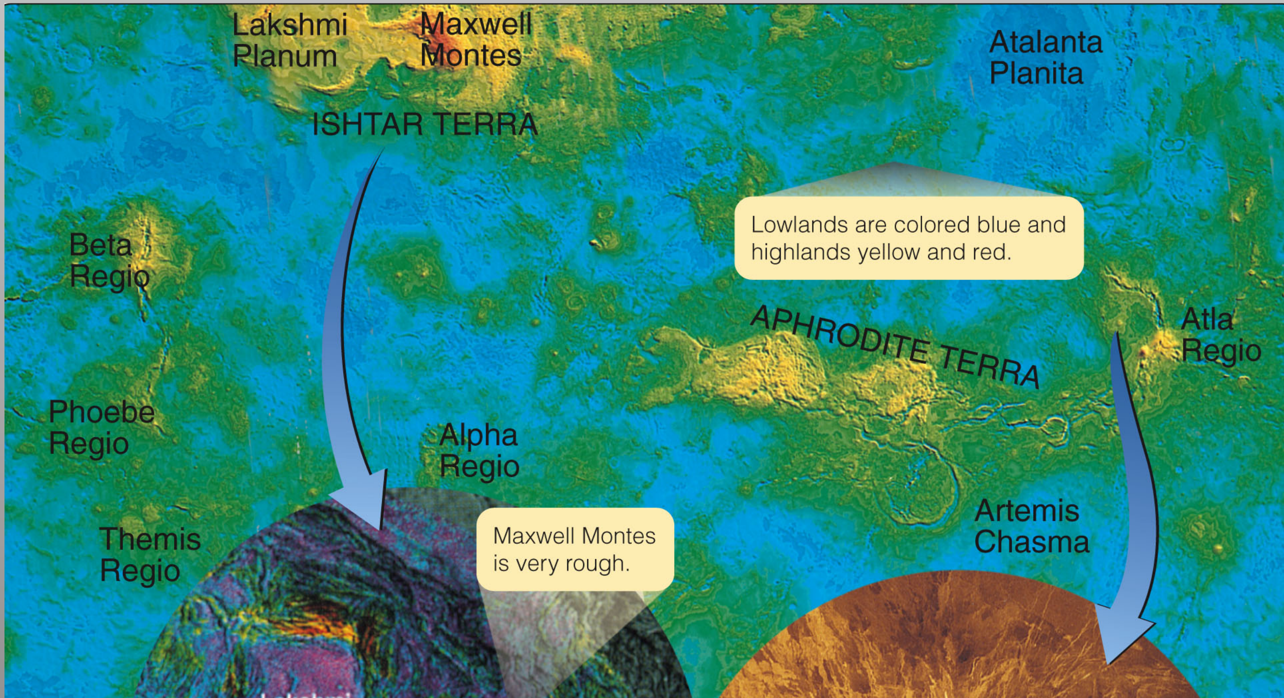
The Surface of Venus

- Radar maps of Venus are reproduced using arbitrary colors.



The Surface of Venus

- In some maps, lowlands are colored blue.
  - In a sense, this is misleading—because there are no oceans on Venus.



The Surface of Venus

- In some maps, the scientists have chosen to give Venus an overall orange tint.
  - This is because sunlight filtering down through the clouds bathes the landscape in a perpetual sunset glow.

The Surface of Venus

- Some maps are shown in gray.
  - This is due to the natural color of the rocks.

The Surface of Venus

- Radar maps show that Venus is similar to Earth in one way, but strangely different in other ways.

The Surface of Venus

- Nearly 75 percent of Earth's surface is covered by low-lying, basaltic seafloors.
- 85 percent of Venus is covered by basaltic lowlands.

The Surface of Venus

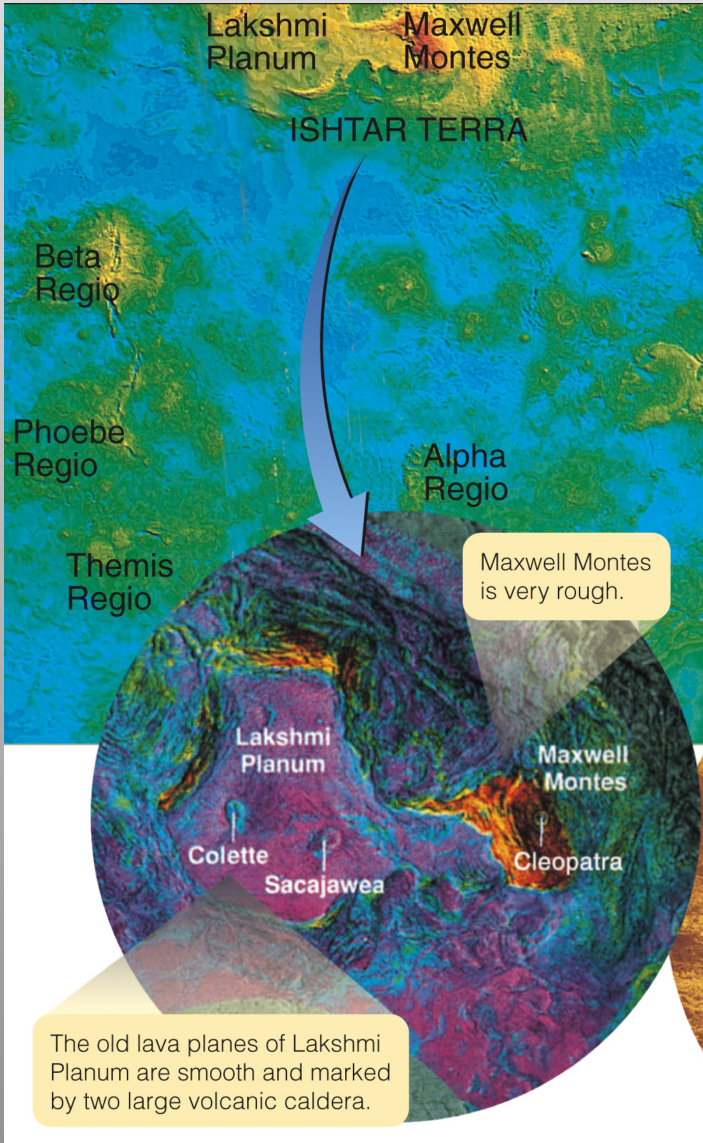
- Of course, on Venus, the lowlands are not seafloors.
- Also, the remaining highlands are not the well-defined continents you see on Earth.

The Surface of Venus

- Earth is dominated by plate tectonics.
- Something different is happening on Venus.

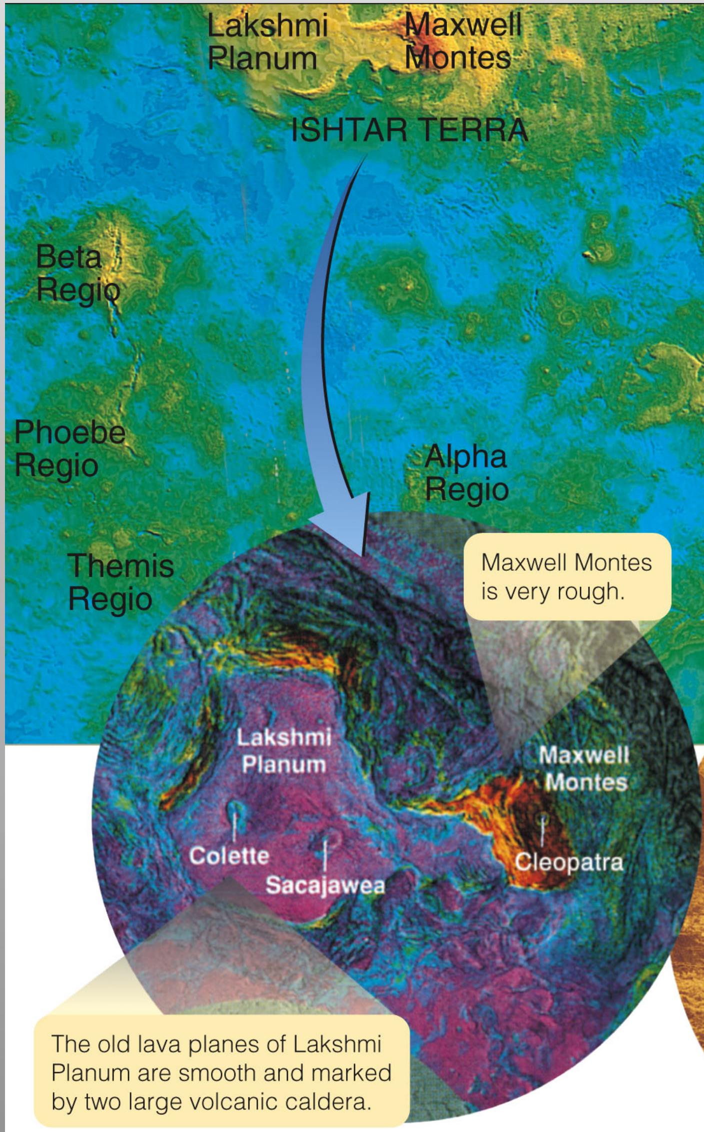
The Surface of Venus

- The highland area Ishtar Terra (named for the Babylonian goddess of love) is about the size of Australia.
  - At its eastern edge, the mountain Maxwell Montes thrusts up 12 km (Everest is 8.8 km high).



The Surface of Venus

- The mountains bounding Ishtar Terra, including Maxwell, resemble folded mountain ranges.
  - This suggests that some horizontal motion in the crust as well as volcanism has helped form the highlands.



The Surface of Venus

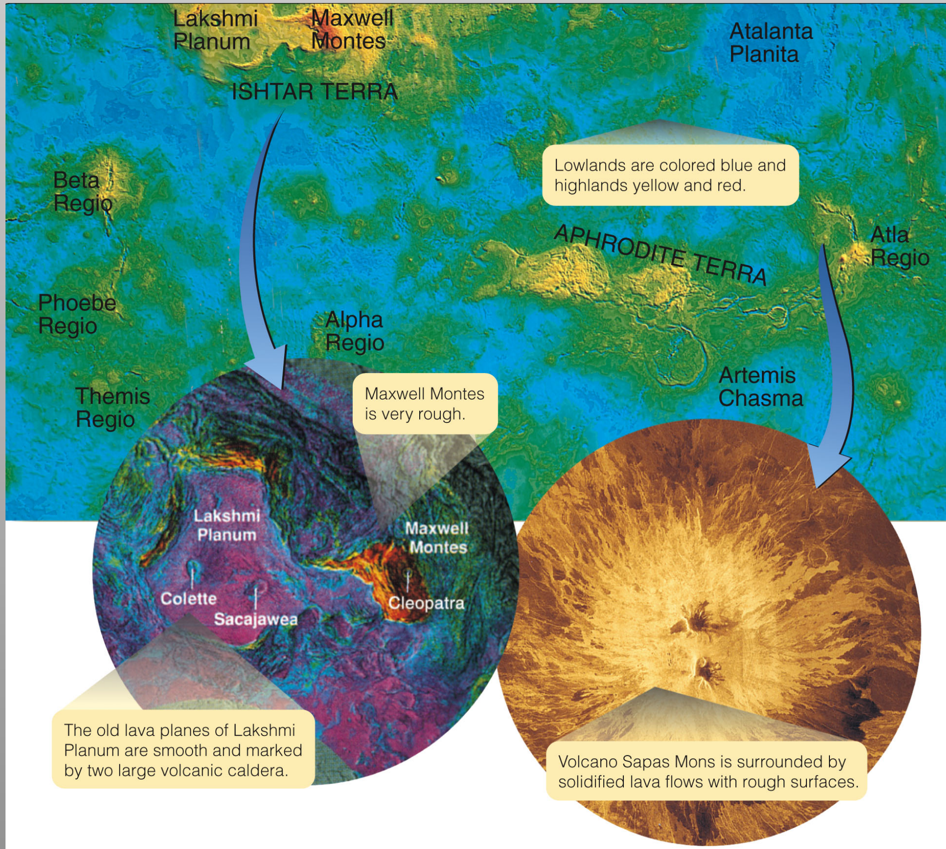
- Many features on the planet testify to its volcanic history.

The Surface of Venus

- There are long, narrow lava channels that meander for thousands of kilometers.

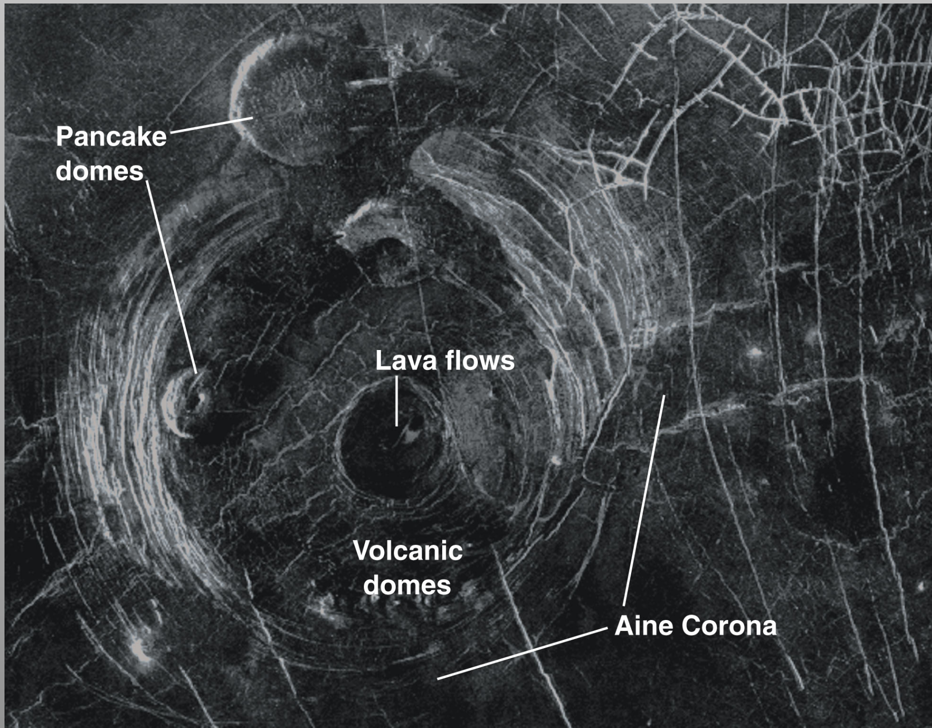
The Surface of Venus

- Radar maps reveal many smaller volcanoes, faults, and sunken regions produced when magma below the surface drained away.



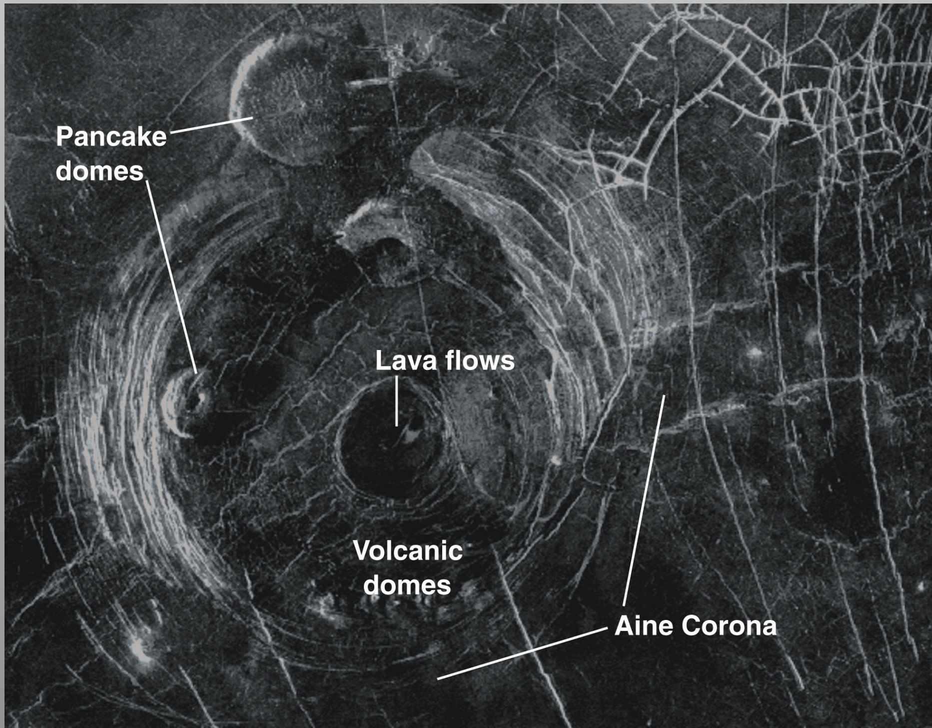
The Surface of Venus

- Other volcanic features include the coronae.
  - These are circular bulges up to 2,100 km (13,000 mi) in diameter bordered by fractures, volcanoes, and lava flows.



The Surface of Venus

- These appear to be produced by rising convection currents of molten magma that push up under the crust.
  - When the magma withdraws, the crust sinks back.
  - However, the circular fractures remain and mark the edge of the original upwelling.



The Surface of Venus

- Radar images also show that Venus is marked by numerous craters.
  - Meteorites big enough to make craters larger than 3 km in diameter have no trouble penetrating the thick atmosphere.
  - However, they have formed only about 10 percent as many craters on Venus as on the maria of Earth's moon.

The Surface of Venus

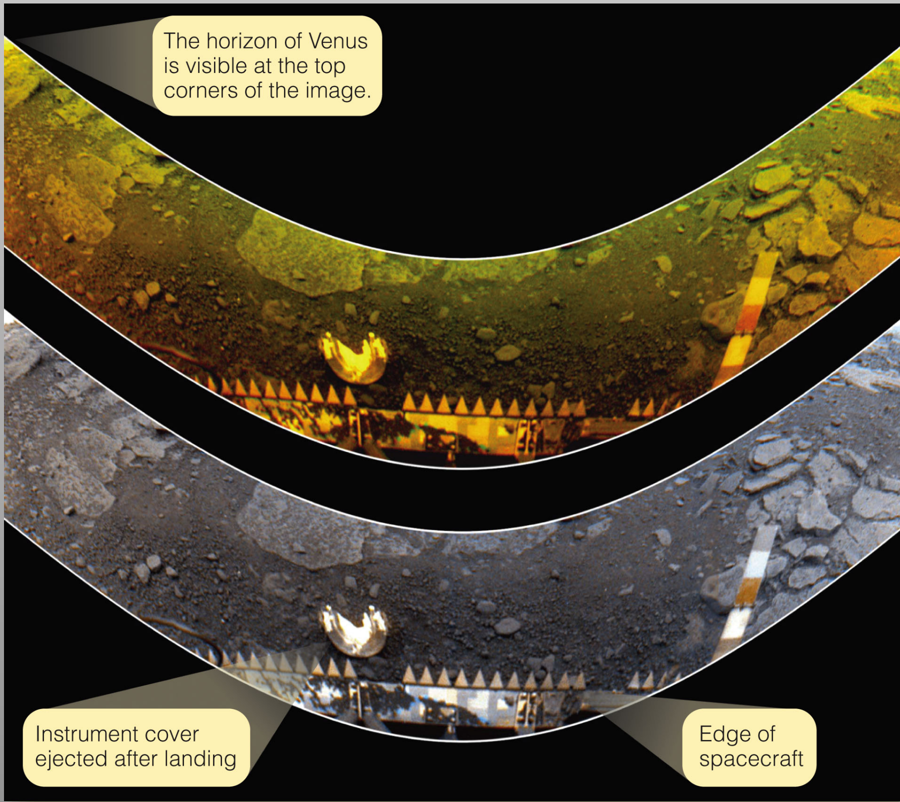
- The number of craters shows that the crust is not as ancient as the lunar maria but not as young as Earth’s active surface.
  - The average age of the surface of Venus is estimated to be roughly half a billion years.
  - Clearly, geological processes cannot be renewing the surface as rapidly as they do on Earth.

The Surface of Venus

- Ten robot probes landed successfully on the surface of Venus in the 1970s and 80s and managed to survive the heat and pressure for a few hours.
  - Some of those spacecraft analyzed the rock and snapped a few photographs.

The Surface of Venus

- The surface rocks on Venus are dark gray basalts—much like those in Earth's ocean floors.
  - This evidence confirms that volcanism is important.



The History of Venus

- To tell the story of Venus, you must draw together all the evidence and find hypotheses to explain two things:
  - The thick carbon dioxide atmosphere
  - The peculiar geology

The History of Venus

- Calculations show that Venus and Earth have outgassed about the same amount of carbon dioxide.
  - Earth’s oceans, though, have dissolved it and converted it to sediments such as limestone.

The History of Venus

- If all the carbon in Earth's sediments and crust were dug up and converted back to carbon dioxide, our atmosphere would be about as dense as the air on Venus.
  - This suggests that the main difference between Earth and Venus is the lack of water on Venus.

The History of Venus

- Venus may have had small oceans when it was young and much more Earthlike conditions than at present.
  - However, being closer to the sun, it was warmer, and the carbon dioxide in the atmosphere created a greenhouse effect that made the planet even warmer.

The History of Venus

- That process could have dried up any oceans that did exist and prevented Venus from purging its atmosphere of carbon dioxide.
  - In fact, evidence from the composition of Venus's atmosphere indicates that an ocean's worth of water has been vaporized and lost.

The History of Venus

- As carbon dioxide continued to be outgassed, the greenhouse effect grew even more severe.
  - Thus, planetary scientists conclude that Venus was trapped in a runaway greenhouse effect.

The History of Venus

- The intense heat at the surface may have affected the geology of Venus.
  - It may have made the crust drier and more flexible—so that it was unable to break into moving plates as on Earth.

The History of Venus

- There is no sign of plate tectonics.
- However, there is evidence that convection currents below the crust are deforming the crust to:
  - Make coronae
  - Push up mountains such as Maxwell
  - Create some folded mountains—like those around Ishtar Terra—by minor horizontal crust motions

The History of Venus

- The small number of craters on the surface hints that the entire crust has been replaced within the last half-billion years or so.
  - This may have occurred in a planetwide overturning—as the old crust broke up and sank and lava flows created a new crust.

The History of Venus

- Comparing Earth to Venus may eventually reveal more about how our own world's volcanism and tectonics work.

Mars

- If you ever visit another world, Mars may be your best choice.
  - You will need a heated, pressurized spacesuit, but Mars is not as inhospitable as the moon.
  - It is also more interesting—with weather, complex geology, craters, volcanoes, and signs that water once flowed over its surface.

The Atmosphere of Mars

- The Martian air contains:
  - 95 percent carbon dioxide
  - 3 percent nitrogen
  - 2 percent argon

The Atmosphere of Mars

- That is similar to the composition of air on Venus.
- However, the Martian atmosphere is very thin.
  - It is less than 1 percent as dense as Earth's atmosphere.
  - It is 1/10,000 as dense as Venus's.

The Atmosphere of Mars

- There is very little water in the Martian atmosphere.
  - Liquid water cannot survive on the surface of Mars because the air pressure is too low.
  - Any liquid water would immediately boil away.

The Atmosphere of Mars

- The polar caps appear to be composed of frozen water ice coated over by carbon dioxide (dry ice).
  - Whatever water is present on Mars is frozen either within the polar caps or as permafrost in the soil.

The Atmosphere of Mars

- Although the present atmosphere of Mars is very thin, you will see evidence that the climate once permitted liquid water to flow over the surface.
  - So, it must have had a thicker atmosphere.

The Atmosphere of Mars

- Being a terrestrial planet, it should have outgassed significant amounts of carbon dioxide, nitrogen, and water vapor.
- As it was small, however, it could not hold onto its atmosphere.
  - There are various reasons for this.

The Atmosphere of Mars

- The escape velocity on Mars is only 5 km/s—less than half of Earth’s.
  - So, it was easier for rapidly moving gas molecules to escape into space.

The Atmosphere of Mars

- Another factor is the temperature of a planet.
  - If Mars had been colder, the gas molecules in its atmosphere would have been traveling more slowly.
  - Thus, they would not have escaped as easily.

The Atmosphere of Mars

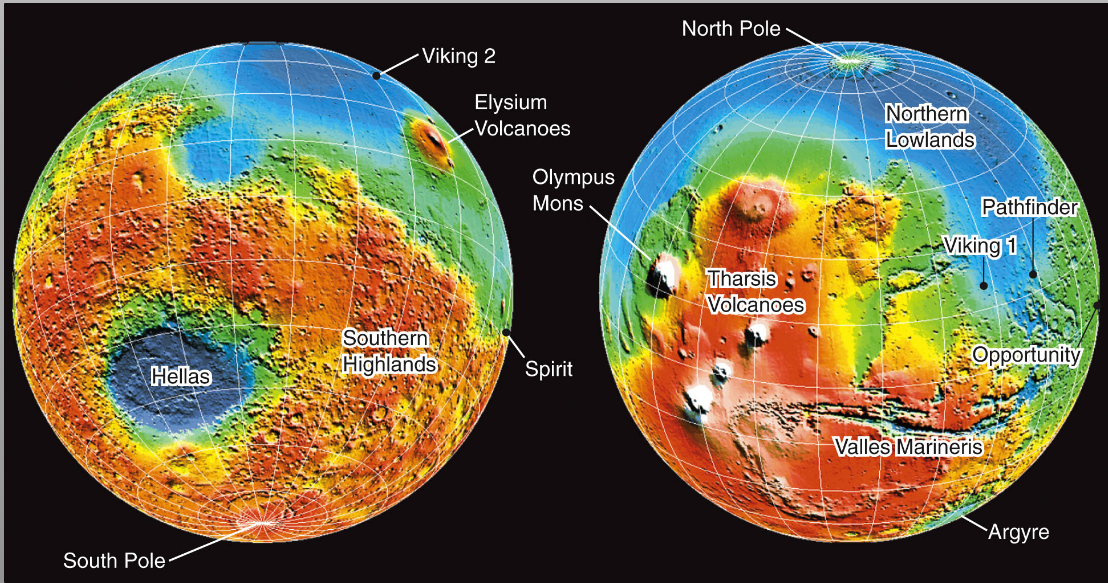
- Another factor is the planet's lack of an ozone layer to screen out UV radiation.
  - Sunlight UV photons can break atmospheric molecules up into smaller fragments.
  - For example, can be broken by UV into hydrogen and oxygen.
  - The hydrogen then easily escapes into space.
  - The oxygen easily combines chemically with rocks and soil.

The Atmosphere of Mars

- Mars may have had a substantial atmosphere when it was young.
- However, it gradually lost much of that—by both direct escape and UV destruction.
  - With a thin atmosphere that does not provide much greenhouse warming nor permit liquid water to persist on the surface, Mars is now a cold, dry world.

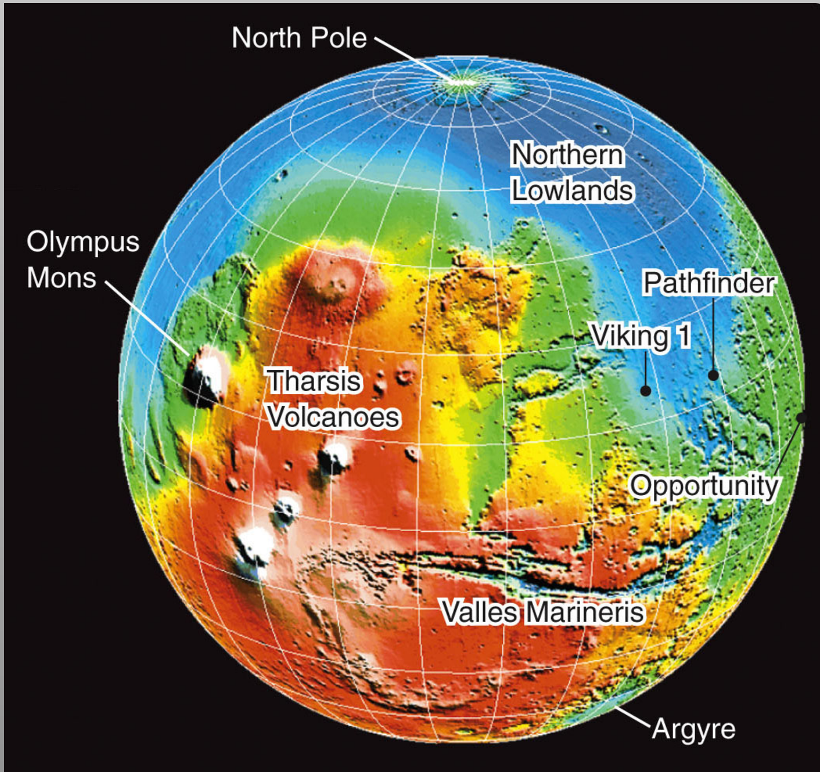
Exploring the Surface of Mars

- Data recorded by orbiting satellites show:
  - The southern hemisphere is a heavily cratered highland region up to 4 billion years old.
  - The northern hemisphere is mostly a much younger lowland plain with few craters.



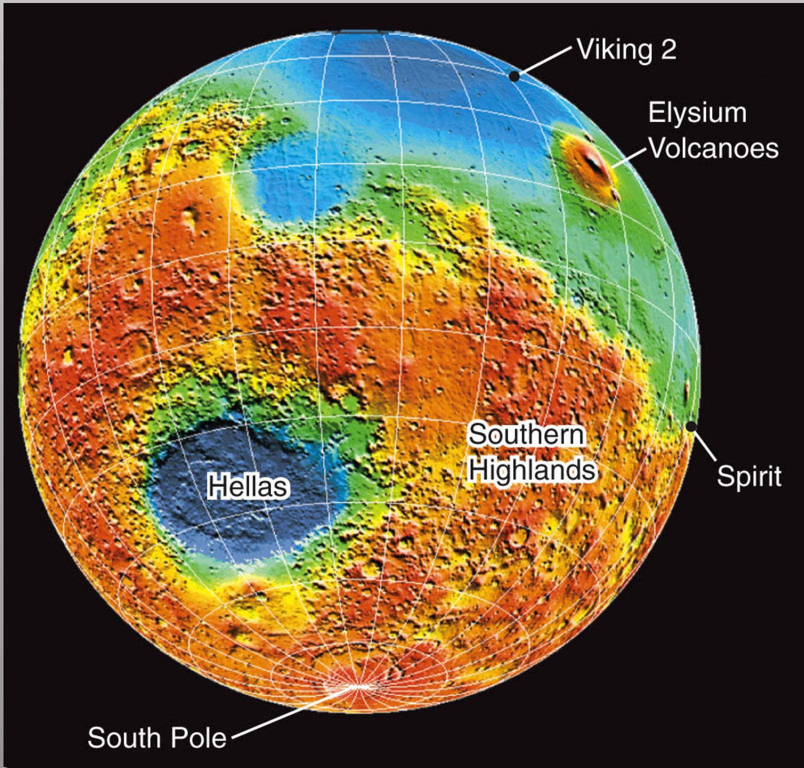
Exploring the Surface of Mars

- Volcanism is dramatically evident in the Tharsis region.
  - This is a highland region of volcanoes and lava flows bulging 10 km (6 mi) above the surrounding surface.



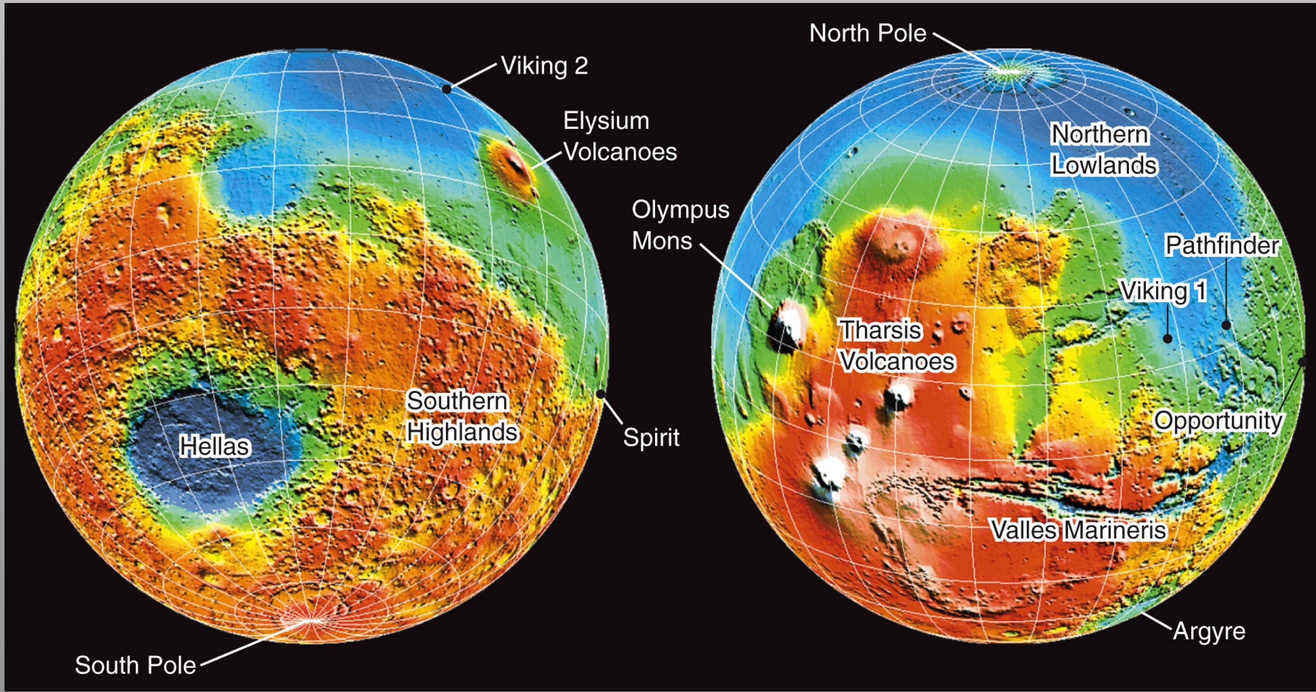
Exploring the Surface of Mars

- A similar uplifted volcanic plain is the Elysium region.
  - It is more heavily cratered and eroded.
  - Also, it appears to be older than the Tharsis bulge.



Exploring the Surface of Mars

- The lack of many impact craters suggests that some volcanoes have been active within the last few hundred million years and maybe even more recently.



Exploring the Surface of Mars

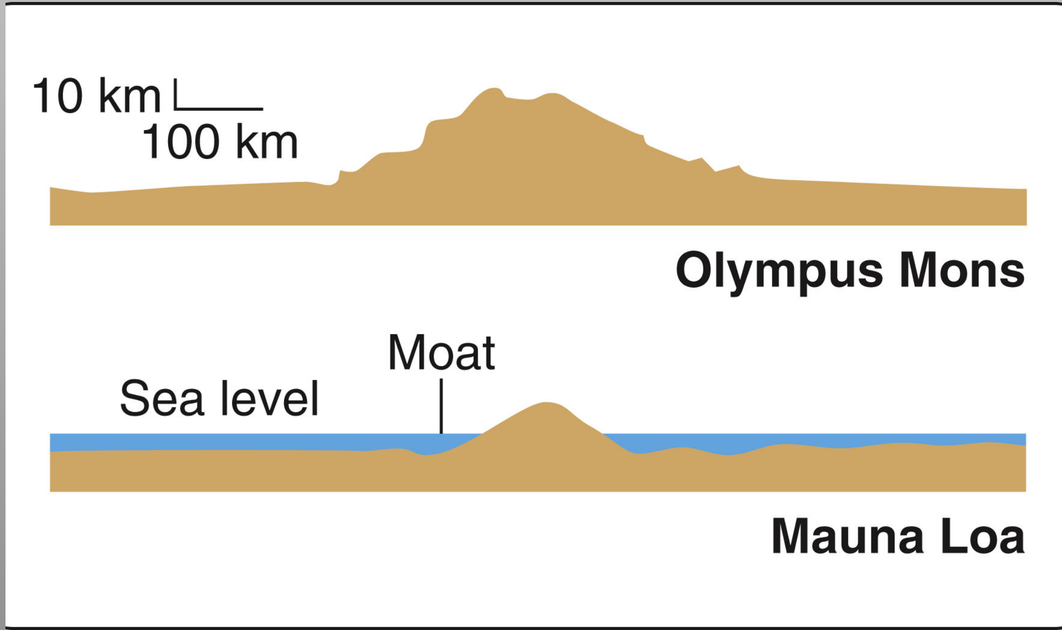
- All the volcanoes on Mars are shield volcanoes.
  - These are very broad mountains with gentle slopes.
  - On Earth, they are produced by hot spots penetrating upward through the crust.

Exploring the Surface of Mars

- Shield volcanoes are not related to plate tectonics.
  - In fact, the large shield volcanoes on Mars provide evidence that plate tectonics has not been significant on that planet.

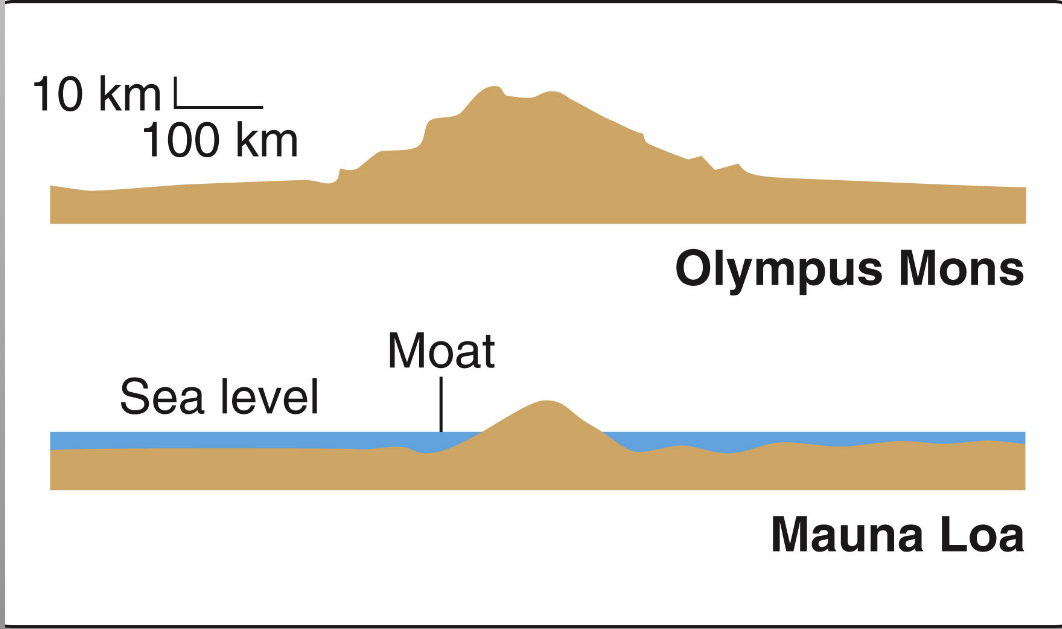
Exploring the Surface of Mars

- The largest shield volcano on Mars is Olympus Mons.
  - It is 600 km (almost 400 mi) in diameter at its base.
  - It rises 21 km (13 mi) high.



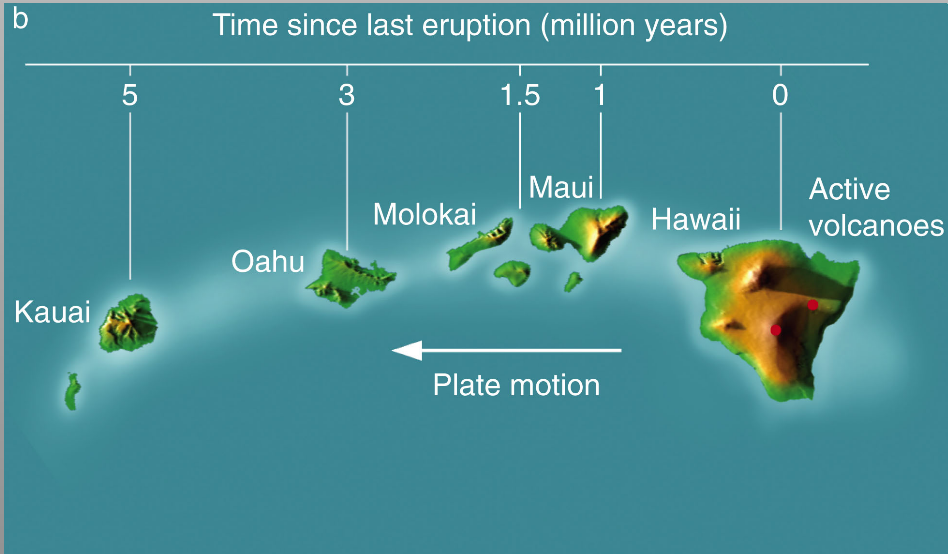
Exploring the Surface of Mars

- In comparison, the largest volcano on Earth—also a shield volcano—is Mauna Loa in Hawaii.
  - It rises only 10 km (6 mi) above its base on the seafloor.



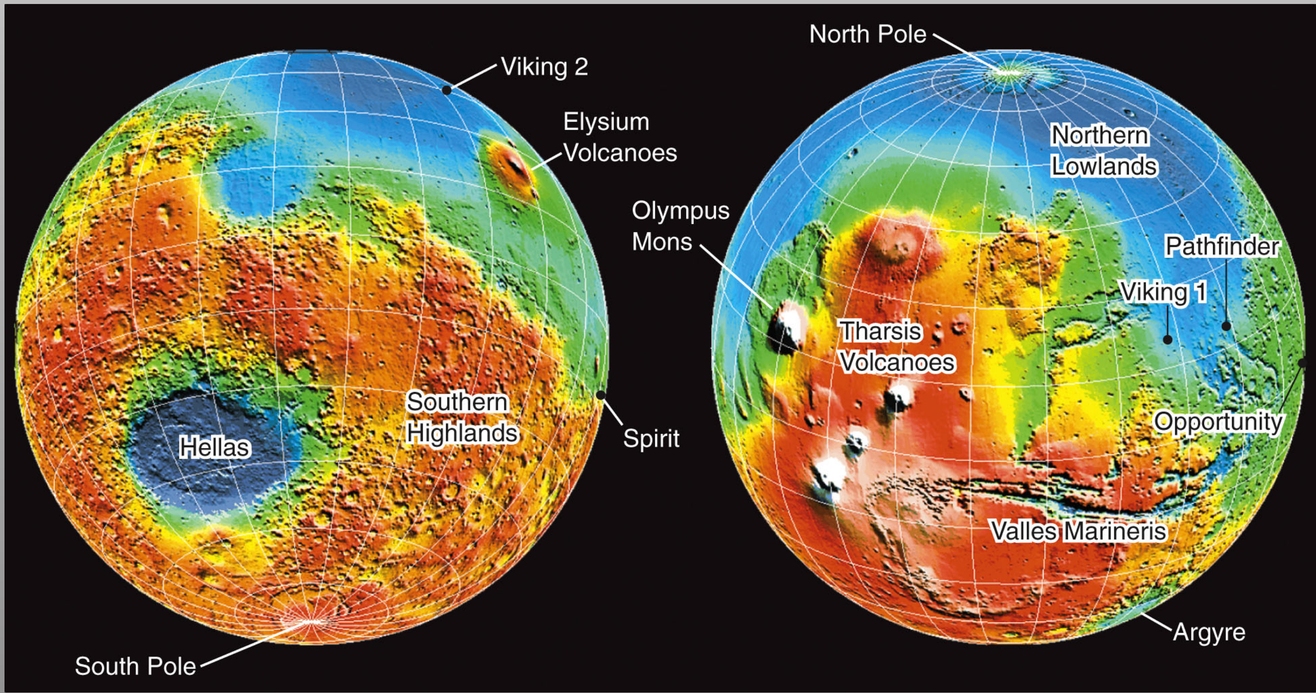
Exploring the Surface of Mars

- On Earth, volcanoes like those that formed the Hawaiian Islands occur over rising currents of hot material in the mantle.
  - The crust plate moves horizontally.
  - So, a chain of volcanoes is formed—instead of a single large feature.



Exploring the Surface of Mars

- A lack of plate motion on Mars has allowed rising currents of magma to heat the crust repeatedly in the same places.
  - This has built Olympus Mons plus other very large volcanic shields—especially in the Tharsis region.

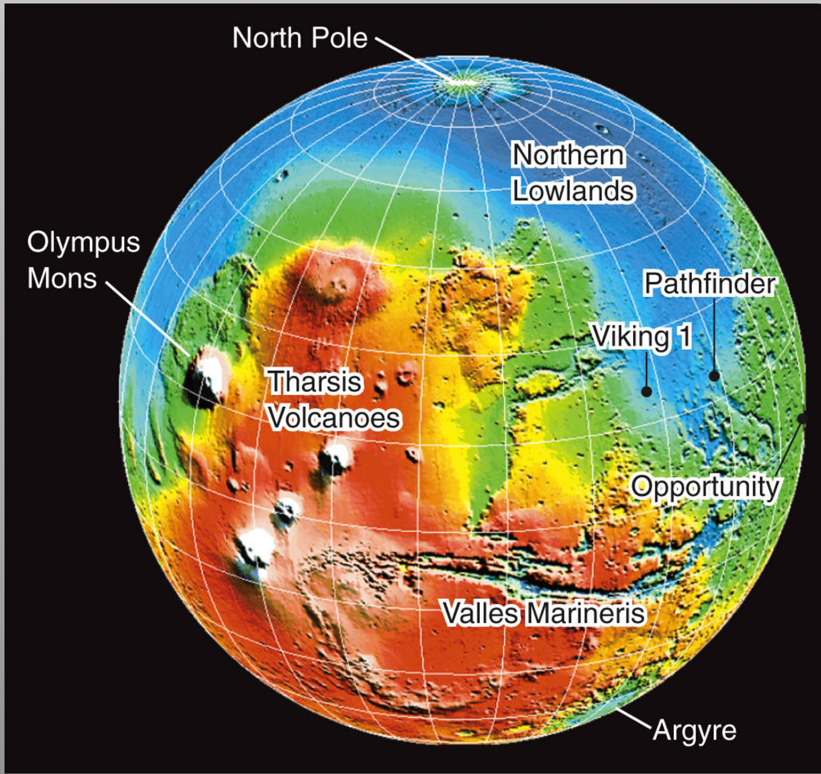


Exploring the Surface of Mars

- When the crust of a planet is strained, it may break—producing faults and rift valleys.

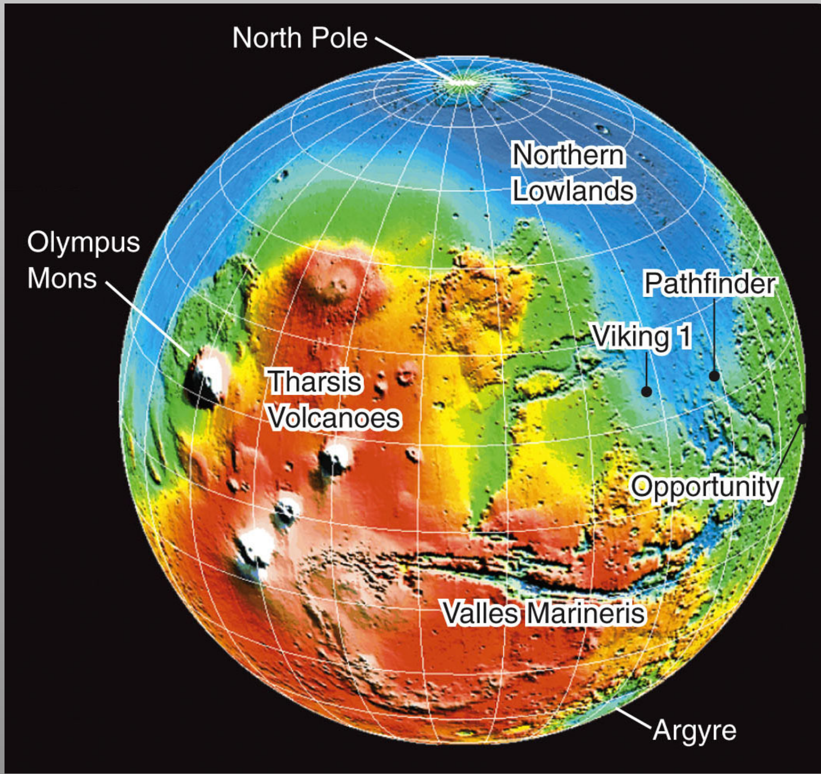
Exploring the Surface of Mars

- Near the Tharsis region is a great valley—Valles Marineris.
  - It is named after the Mariner spacecraft that first photographed it.
  - The valley is a block of crust that has dropped downward along parallel faults.



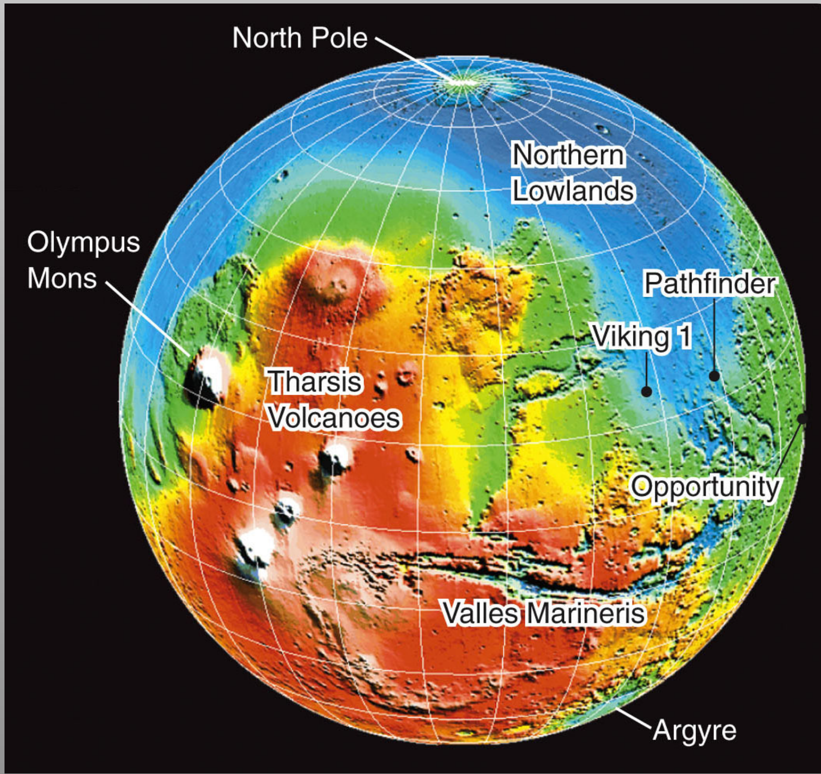
Exploring the Surface of Mars

- Erosion and landslides have further modified the valley into a great canyon.
  - It is four times deeper, nearly 10 times wider, and over 10 times longer than the Grand Canyon.



Exploring the Surface of Mars

- The number of craters indicates that it is 1 to 2 billion years old.
  - This places its origin sometime before the end of volcanism in the Tharsis region.



Searching for Water on Mars

- Before you can tell the story of Mars, you must consider a difficult issue—water.
  - How much water has Mars had?
  - How much has been lost?
  - How much remains?

Searching for Water on Mars

- You cannot expect surface water on Mars now.
  - This is because of its low atmospheric pressure and low temperature.

Searching for Water on Mars

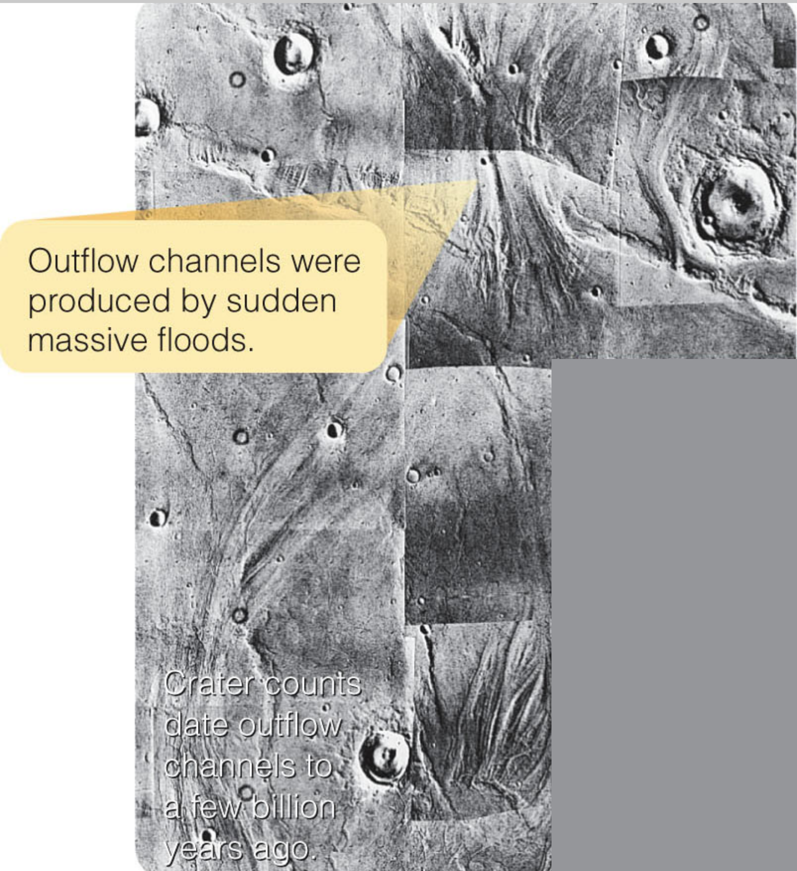
- However, observations from orbiting spacecraft have revealed landforms that suggest the effects of flowing water.
- Rovers on the surface have turned up proof positive of surface water.

Searching for Water on Mars

- In 1976, the two Viking spacecraft reached orbit around Mars and photographed its surface.
- The photos revealed two water-related features.

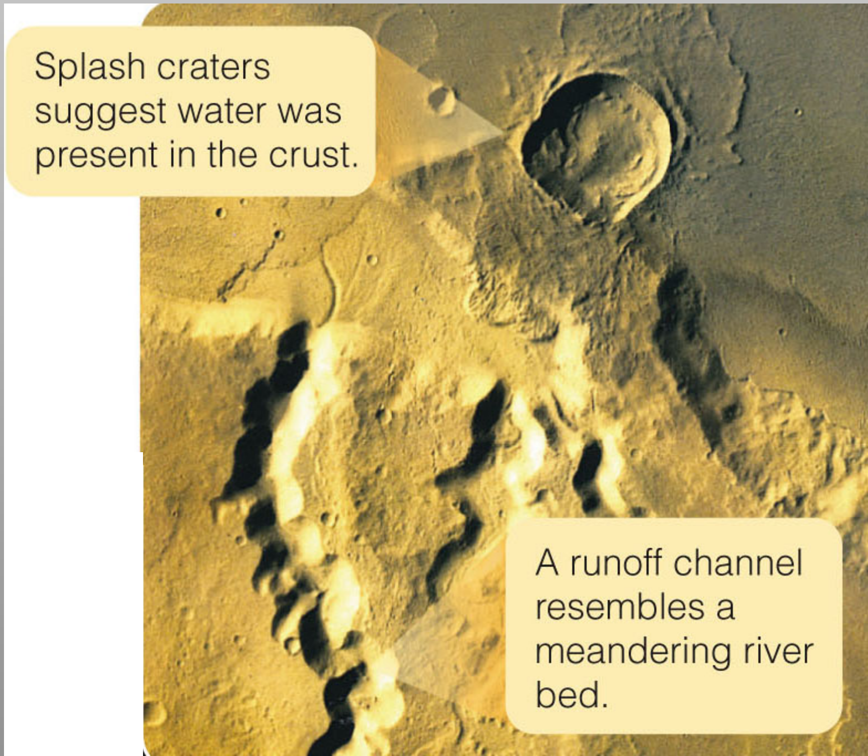
Searching for Water on Mars

- Outflow channels appear to have been cut by massive floods carrying as much as 10,000 times the water flowing down the Mississippi River.
  - In a matter of hours or days, such floods swept away geological features and left scarred land.



Searching for Water on Mars

- In contrast, valley networks look like meandering riverbeds with sandbars, deltas, and tributaries typical of streams that flowed for extended periods of time.



Searching for Water on Mars

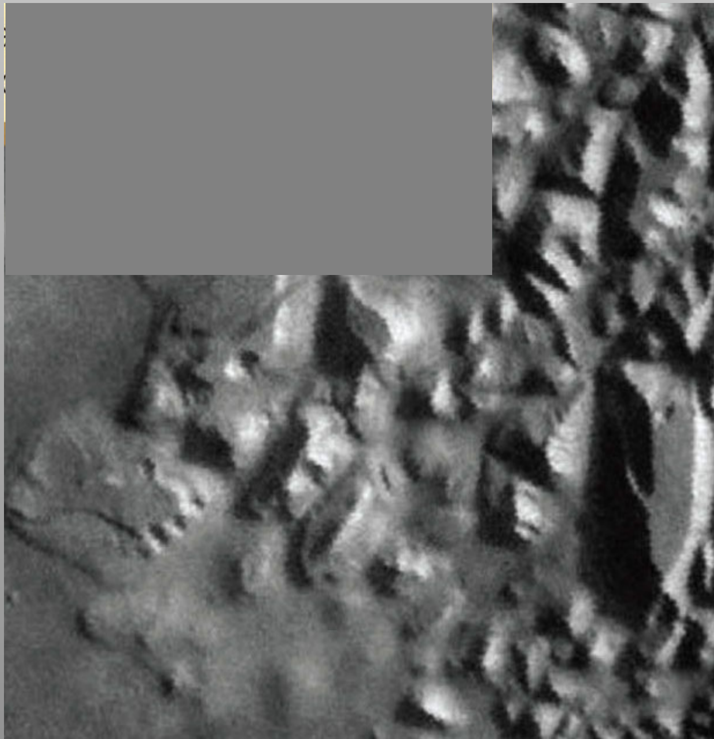
- The number of craters on top of these features reveals that they are quite old.

Searching for Water on Mars

- Spacecraft in orbit around Mars have used remote instruments to detect large amounts of water frozen in the soil.
- A radar study has found frozen water extending at least a kilometer beneath both polar caps.

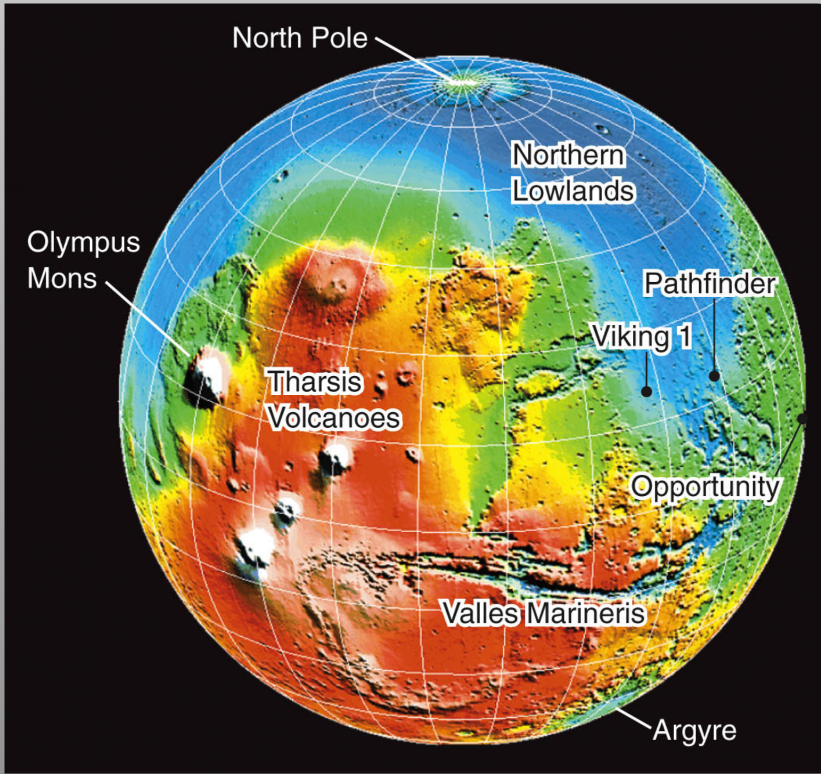
Searching for Water on Mars

- Images made from orbit also show regions of jumbled terrain and gullies leading down slopes.
  - This suggests that water has flowed onto the surface from underground sources, perhaps melting of subsurface ice.



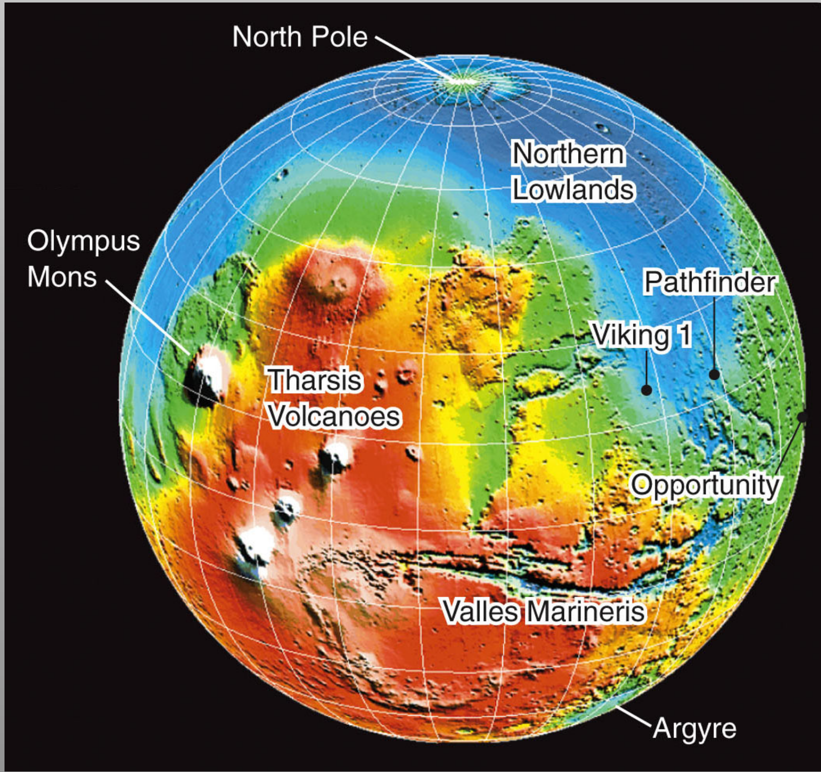
Searching for Water on Mars

- The terrain at the edges of the northern lowlands has been compared to shorelines.
- Some scientists suspect that the lowlands were filled with an ocean roughly 3 billion years ago.



Searching for Water on Mars

- The lowlands have been color-coded blue.
- Notice the major outflow channels leading from highlands into lowlands, like rivers flowing into an ocean.

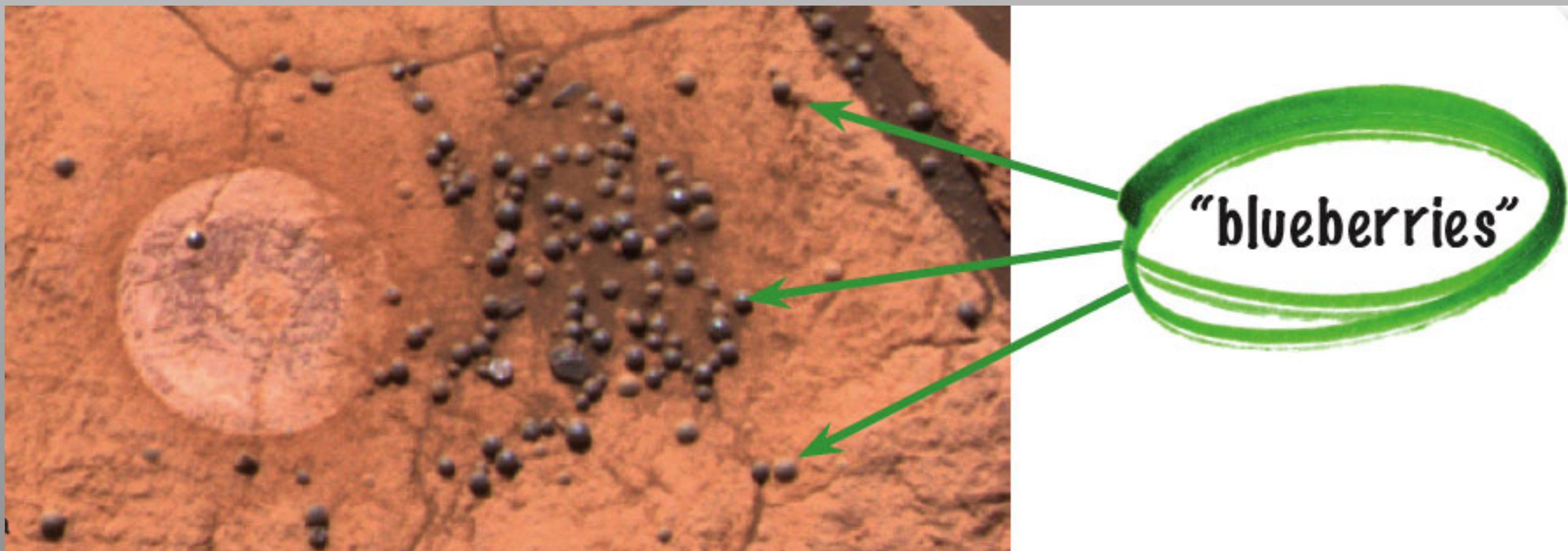


Searching for Water on Mars

- Rovers named Spirit and Opportunity landed in January 2004.
  - They carried sophisticated instruments to explore the rocky surface.
  - Both rovers landed in areas suspected of having had water on their surfaces.
  - Both made exciting discoveries.

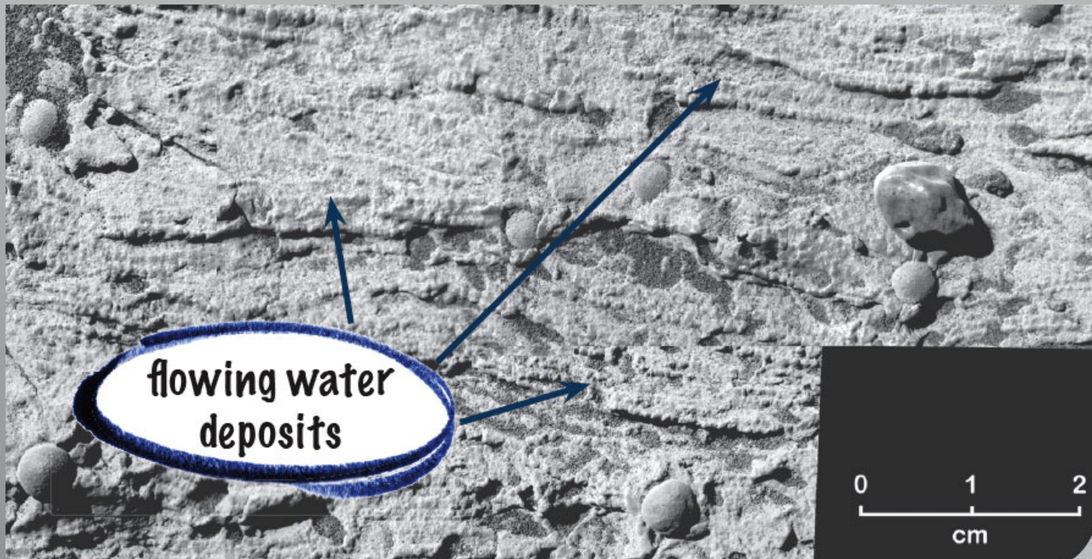
Searching for Water on Mars

- Using close-up cameras, they found small spherical concretions of hematite—dubbed 'blueberries.'
  - These must have formed in water.



Searching for Water on Mars

- In other places, they found layers of sediments with ripple marks and crossed layers showing deposits.
  - The deposits must have formed in moving water.
  - Chemical analysis revealed minerals in the soil such as sulfates that are left behind when standing water evaporates.



Searching for Water on Mars

- In 2008, the space probe Phoenix landed in the north polar region of Mars.
  - It used its robotic arm to uncover water ice frozen in the Martian soil.
- Detailed chemical analysis of soil samples were completed confirming the presence of water and minerals necessary for any life that might exist there.

The History of Mars

- The history of Mars is a case of arrested development.

The History of Mars

- The planet began by differentiating into a crust, mantle, and core.
  - Studies of its rotation reveal that it has a dense core but no planetwide magnetic field.
  - The core must have cooled quickly and shut off the dynamo effect that would have produced a field.

The History of Mars

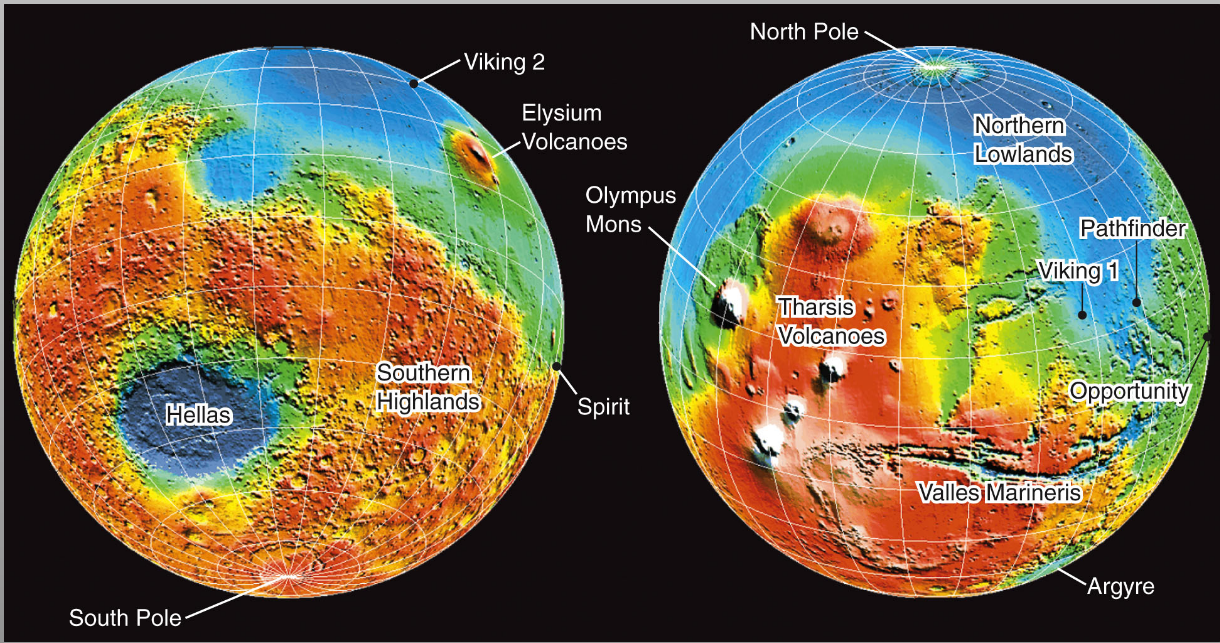
- The crust of Mars is now quite thick—as revealed by the mass of Olympus Mons volcano.
  - It was thinner in the past, though.

The History of Mars

- Cratering may have broken or at least weakened the crust—triggering lava flows that flooded some basins.

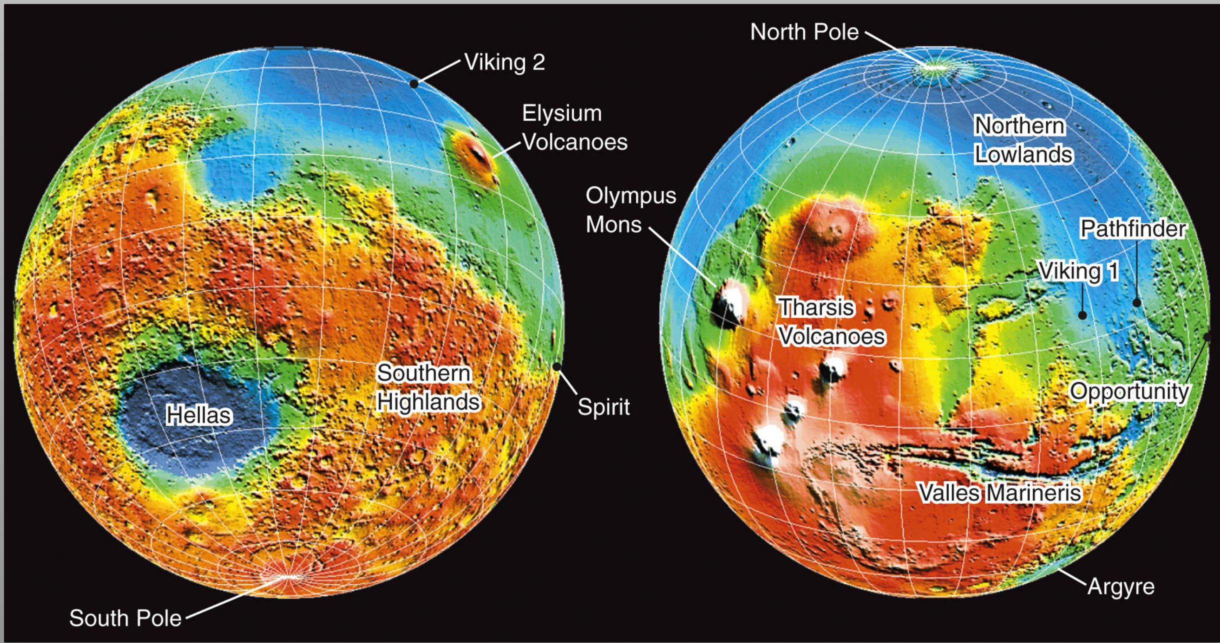
The History of Mars

- Mantle convection may have pushed up the Tharsis and Elysium volcanic regions and broken the crust to form Valles Marineris.



The History of Mars

- Moving crustal plates, though, never dominated Mars.
  - There are no folded mountain ranges and no sign of plate boundaries.



The History of Mars

- The small planet cooled rapidly, and the crust grew thick and immobile.

The History of Mars

- The last stage of planetary development has been one of slow decline.
  - Volcanoes may still occasionally erupt.
  - However, the little planet has lost much of its internal heat—and most volcanism occurred long ago.
  - At some point in its history, water was abundant enough to flow over the surface in great floods and may have filled an ocean.
  - However, the age of liquid water must have ended over 3 billion years ago.

The History of Mars

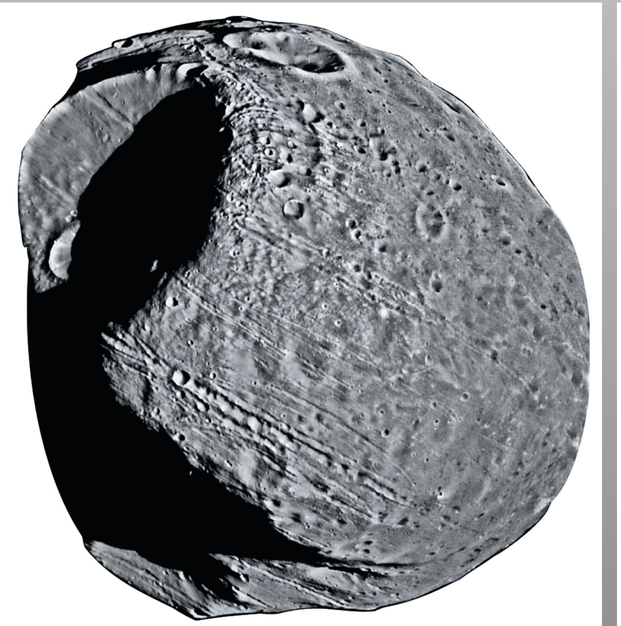
- The climate on Mars has changed as the atmosphere gradually became thinner.
  - Atmospheric gases and water were lost to space.
  - The volcanic activity that could have replaced them had nearly stopped.

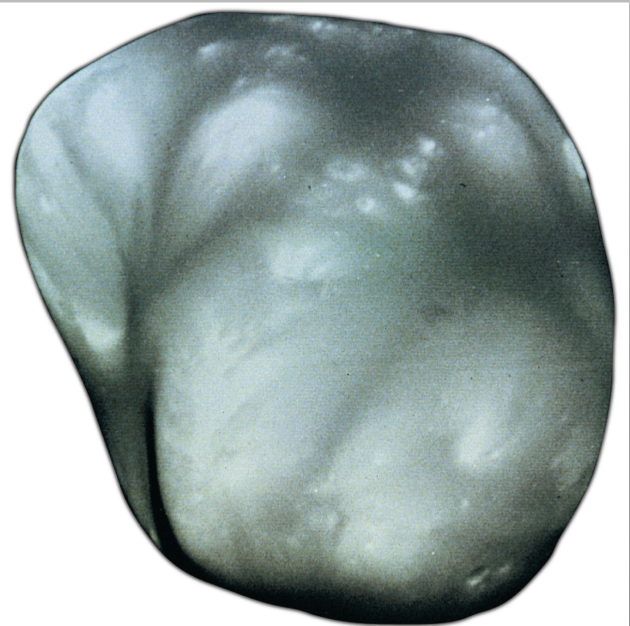
The History of Mars

- The water remaining on Mars today is frozen in the polar caps or in the soil.
- However, water being the first necessity of life, its presence long ago is exciting.
  - Someday, an astronaut may scramble down an ancient Martian streambed, turn over a rock, and find a fossil.

The Moons of Mars

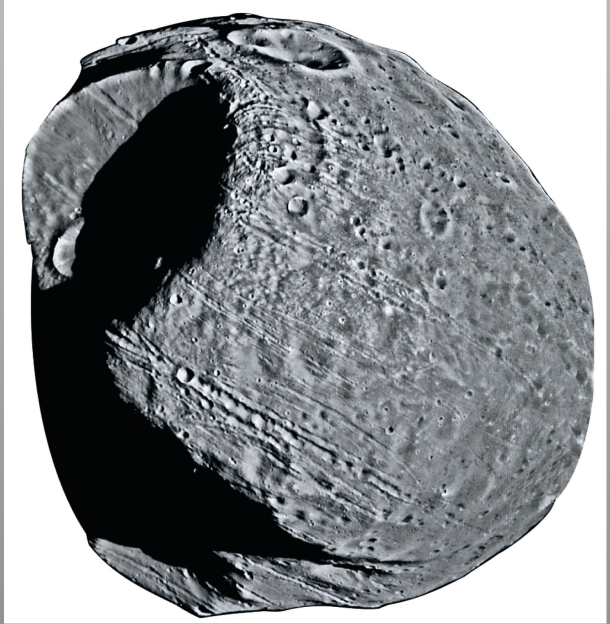
- Unlike Mercury or Venus, Mars has moons.
  - Phobos is 28 x 23 x 20 km in diameter.
  - Deimos is 16 x 12 x 10 km in diameter.

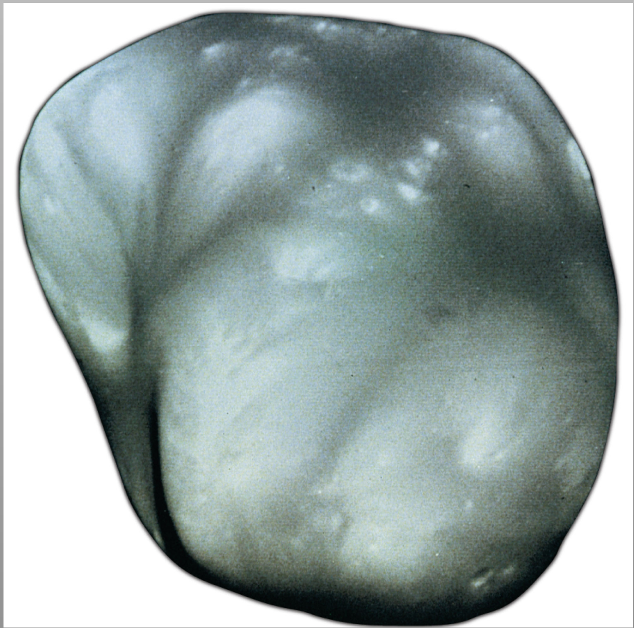




The Moons of Mars

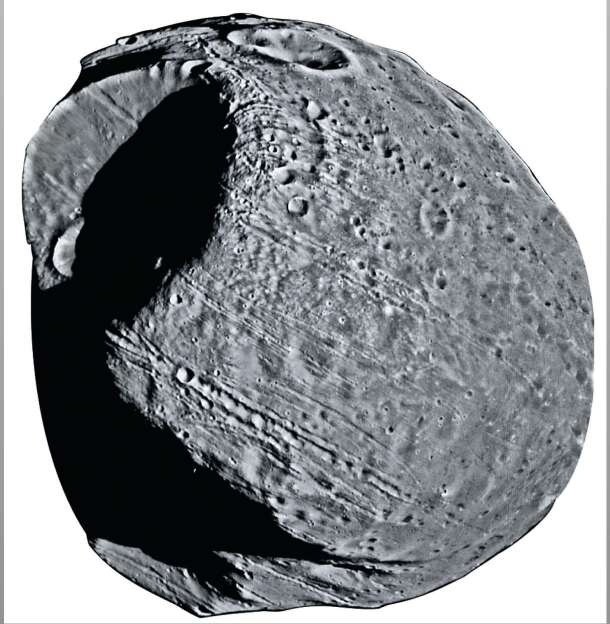
- Small and irregular in shape, they are almost certainly captured asteroids.

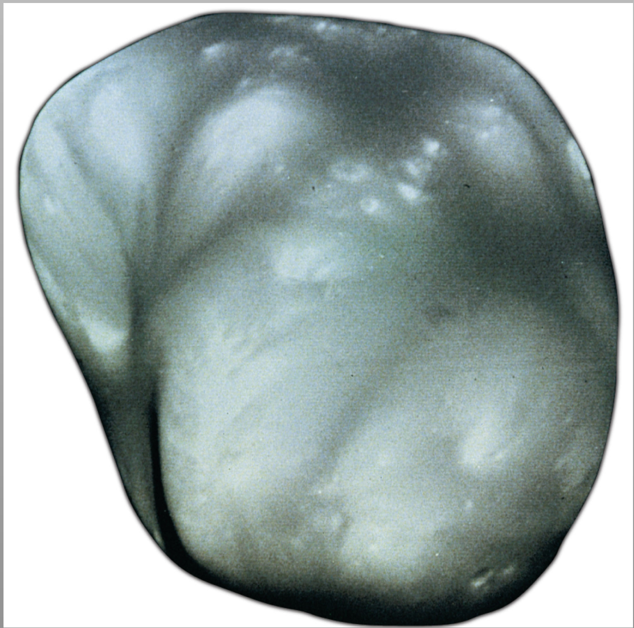




The Moons of Mars

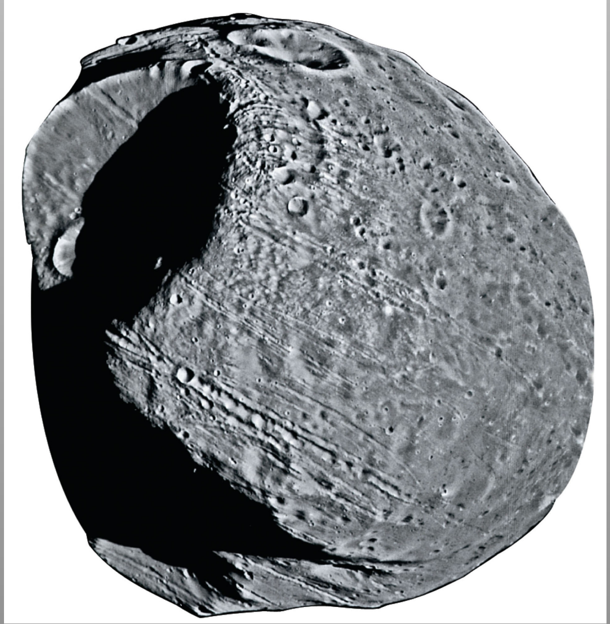
- In fact, they are not just small—they are tiny.
  - An athletic astronaut who could jump 2 m (6 ft) high on Earth could jump almost 3 km (2 miles) on Phobos.

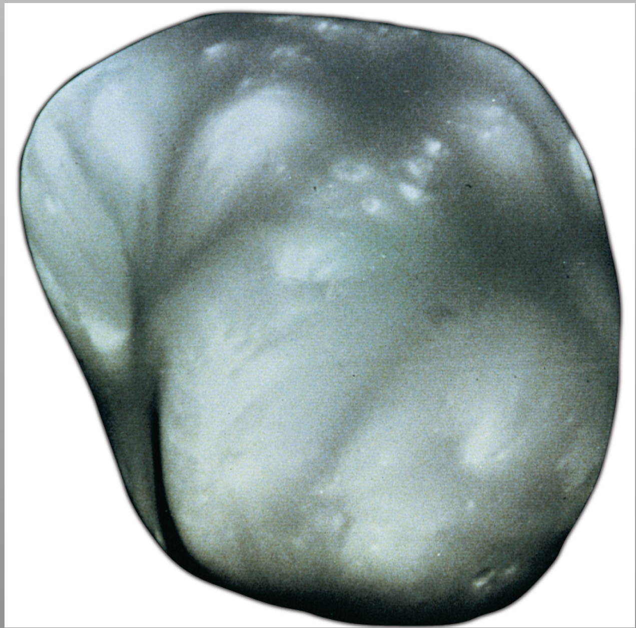




The Moons of Mars

- However they formed, they are so small that any interior heat would have leaked away very quickly.
- Also, there is no evidence of any internally driven geologic activity on either object.





The Moons of Mars

- Some futurists suggest that the first human missions to Mars may not land on the planet's surface.
- Instead, they could build a colony on Phobos or Deimos.
  - These plans involve speculation that these moon and other asteroids may have water in deep interior rocks that colonists could use.