Chapter 9 Lecture

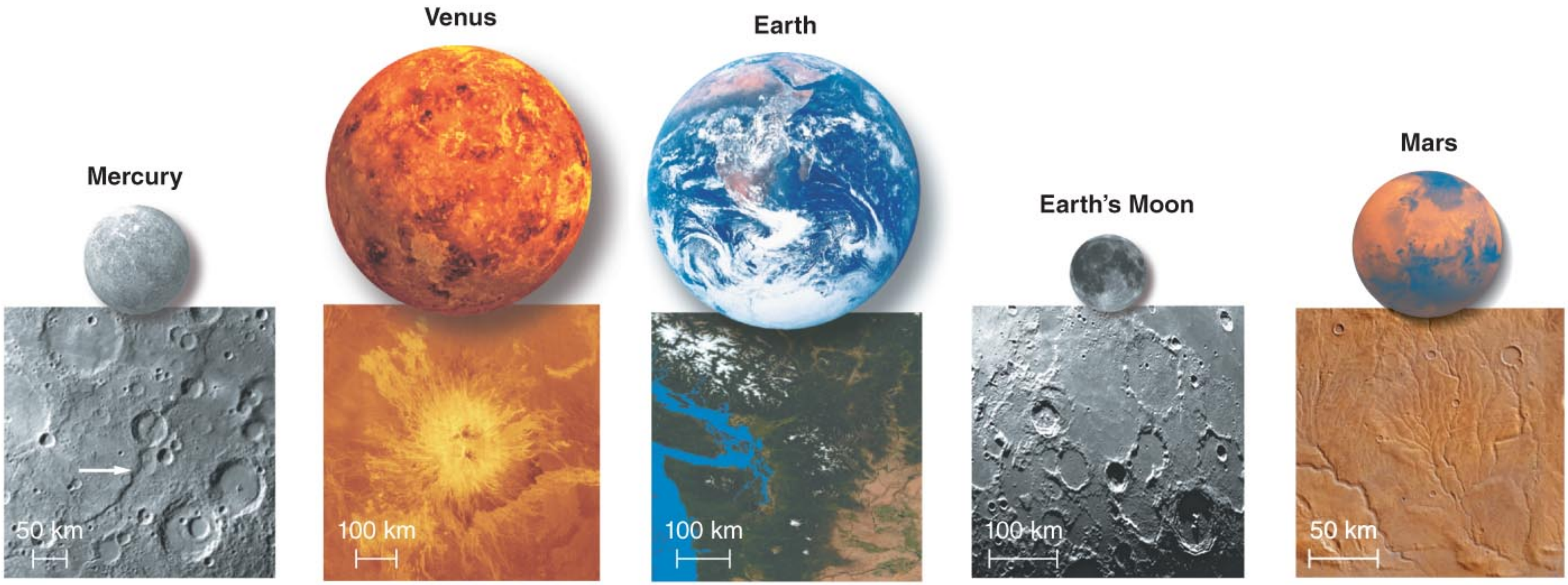
Chapter 9: Planetary Geology: Earth and the Other Terrestrial Worlds

Planetary Geology: Earth and the Other Terrestrial Worlds

9.1 Connecting Planetary Interiors and Surfaces

- Our goals for learning:
  - **What are terrestrial planets like on the inside?**
  - **What causes geological activity?**
  - **Why do some planetary interiors create magnetic fields?**

What are terrestrial planets like on the inside?



Heavily cratered Mercury has long steep cliffs (arrow).

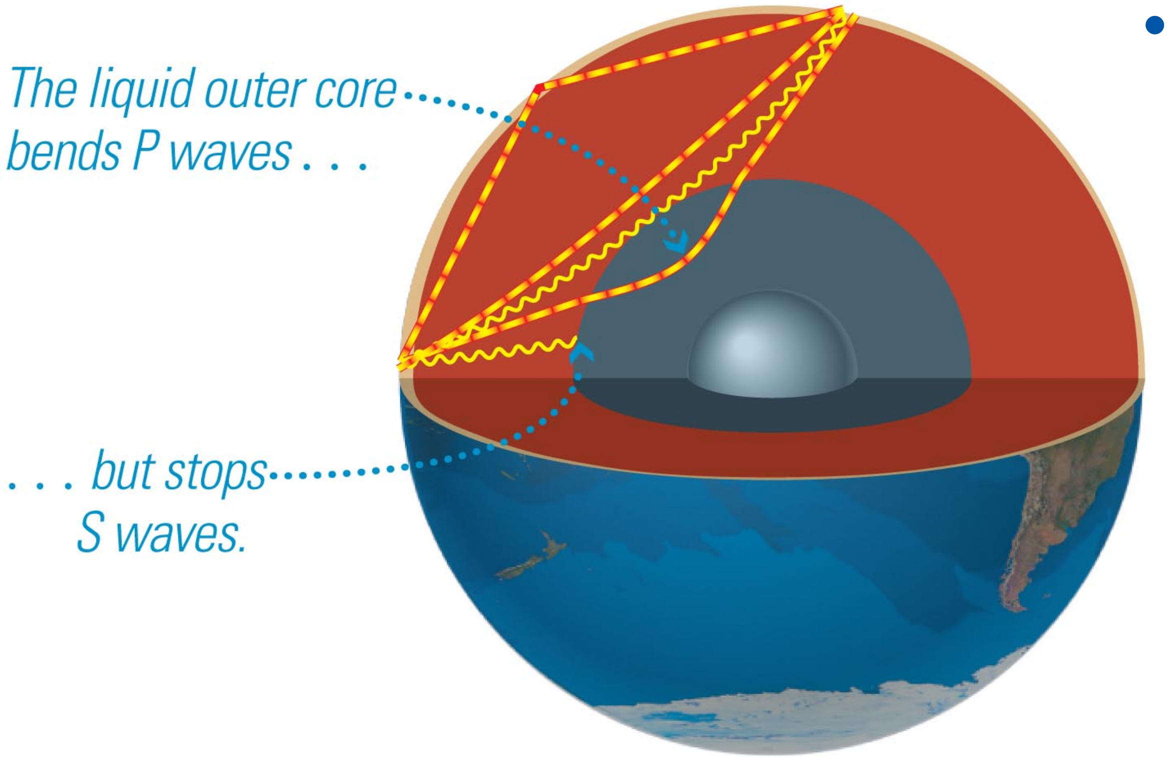
Cloud-penetrating radar revealed this twin-peaked volcano on Venus.

A portion of Earth's surface as it appears without clouds.

The Moon's surface is heavily cratered in most places.

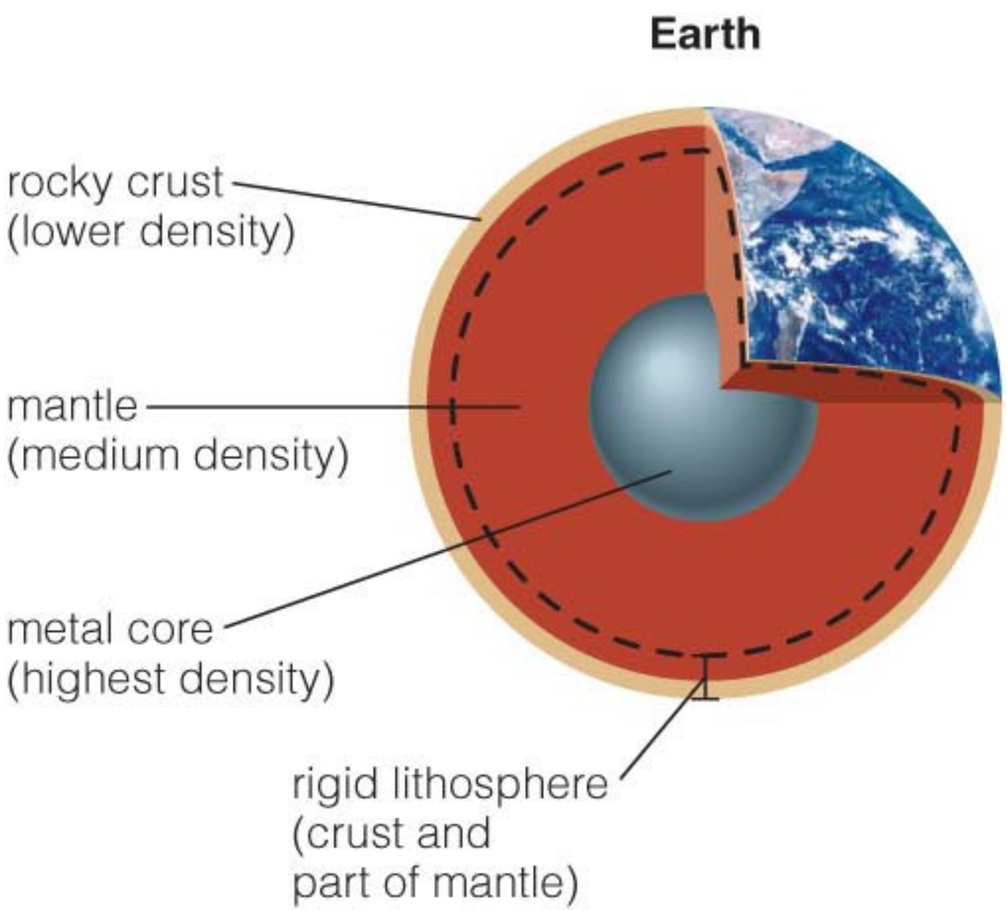
Mars has features that look like dry riverbeds; note the impact craters.

Seismic Waves



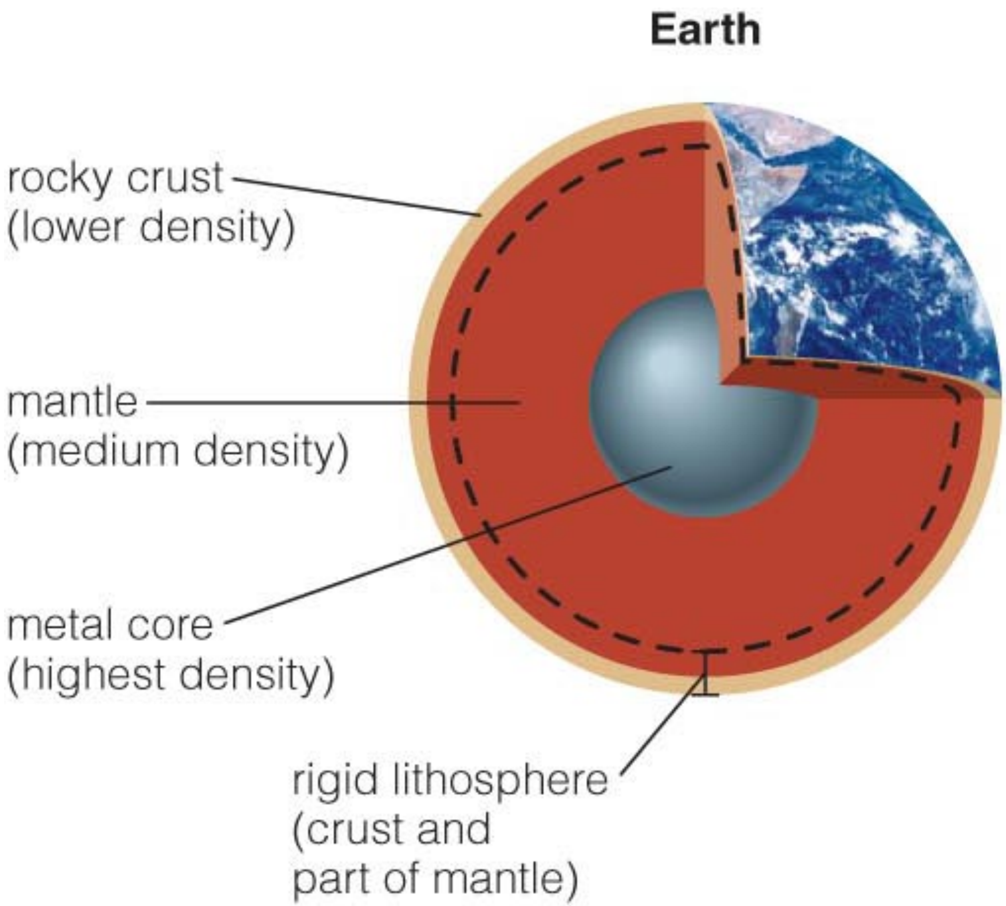
- Vibrations that travel through Earth's interior tell us what Earth is like on the inside.

Earth's Interior



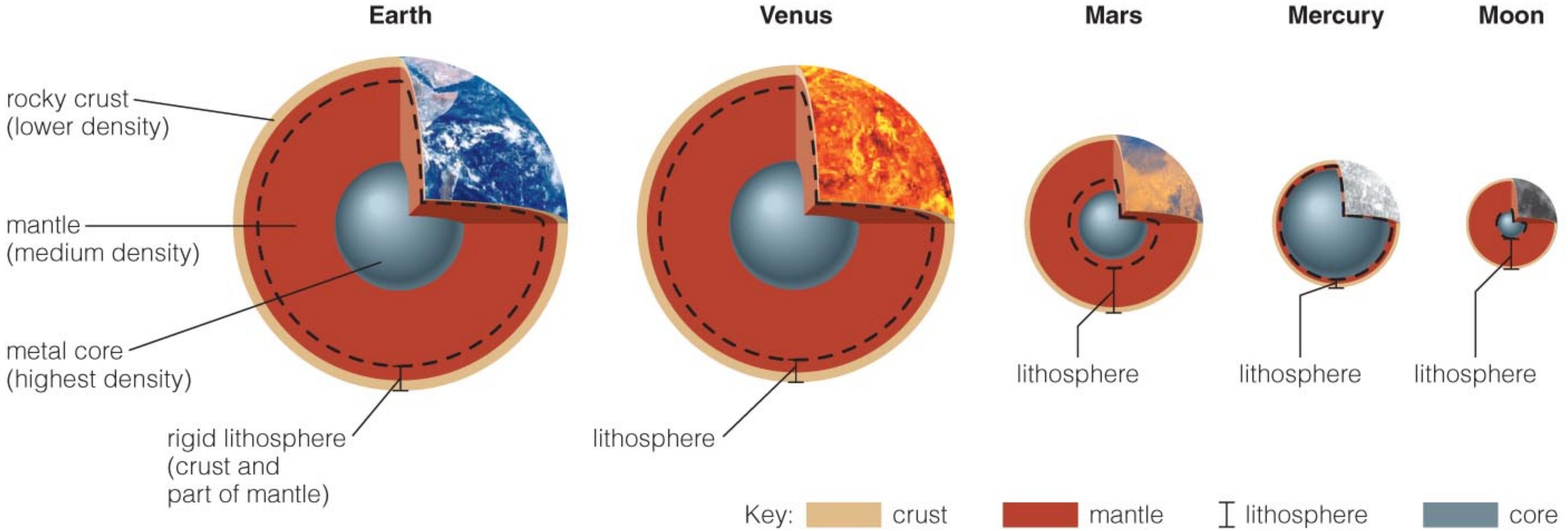
- **Core:** highest density; nickel and iron
- **Mantle:** moderate density; silicon, oxygen, etc.
- **Crust:** lowest density; granite, basalt, etc.

Differentiation



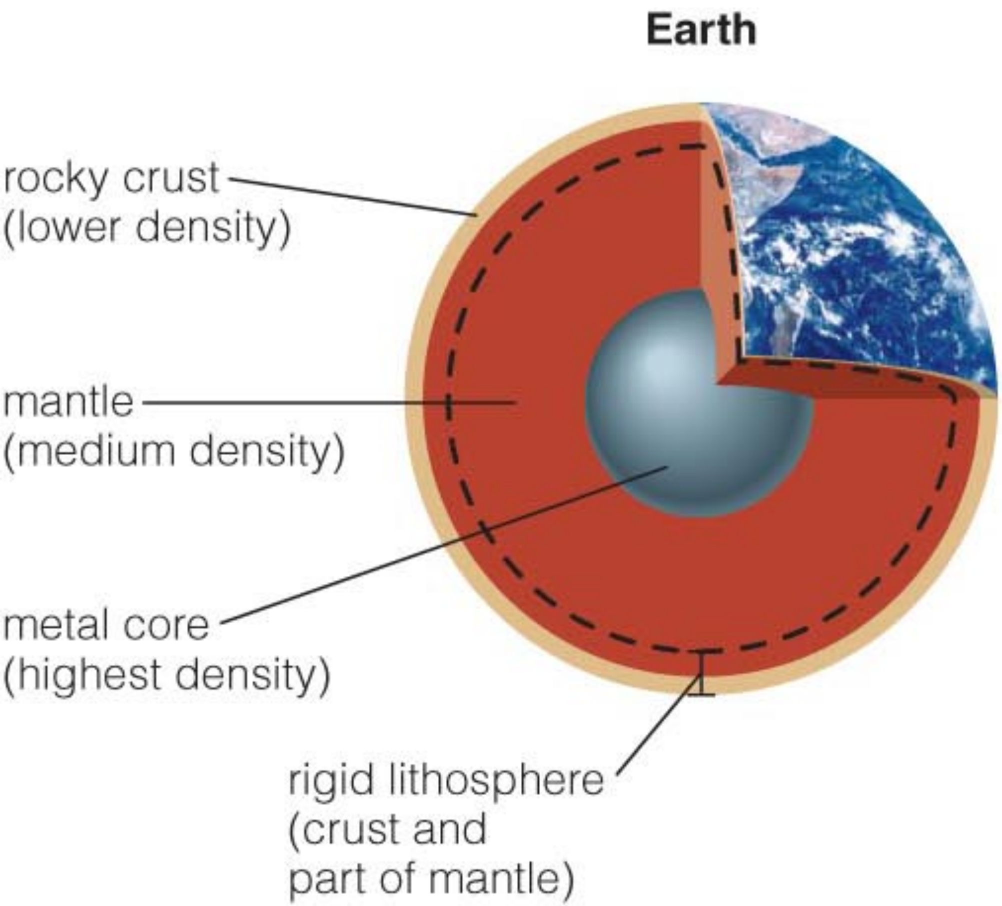
- Gravity pulls high-density material to center.
- Lower-density material rises to surface.
- Material ends up separated by density.

Terrestrial Planet Interiors



- Applying what we have learned about Earth's interior to other planets tells us what their interiors are probably like.

Lithosphere



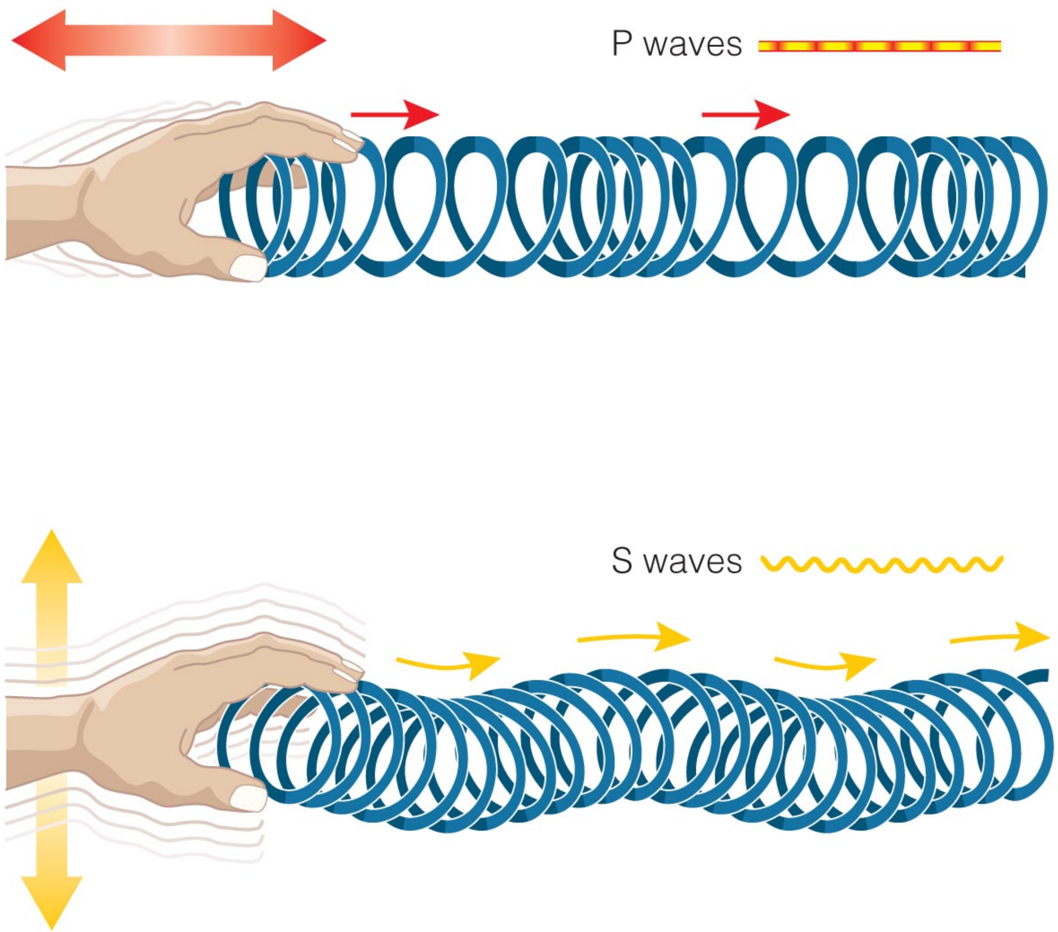
- A planet's outer layer of cool, rigid rock is called the *lithosphere*.
- It "floats" on the warmer, softer rock that lies beneath.

Strength of Rock

- Rock stretches when pulled slowly but breaks when pulled rapidly.
- The gravity of a large world pulls slowly on its rocky content, shaping the world into a sphere.

Special Topic:

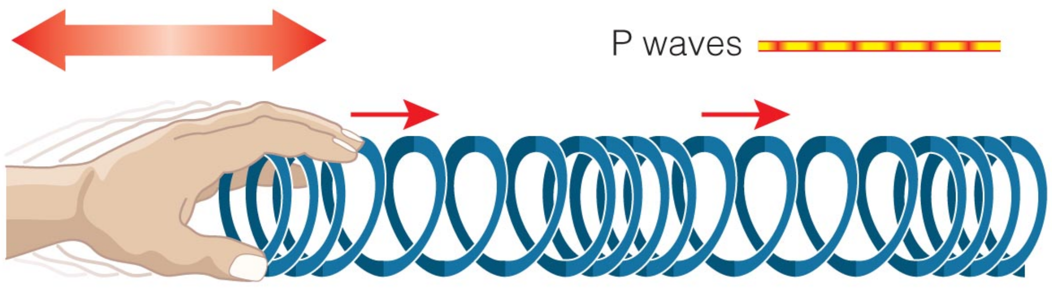
- How do we know what's inside Earth?



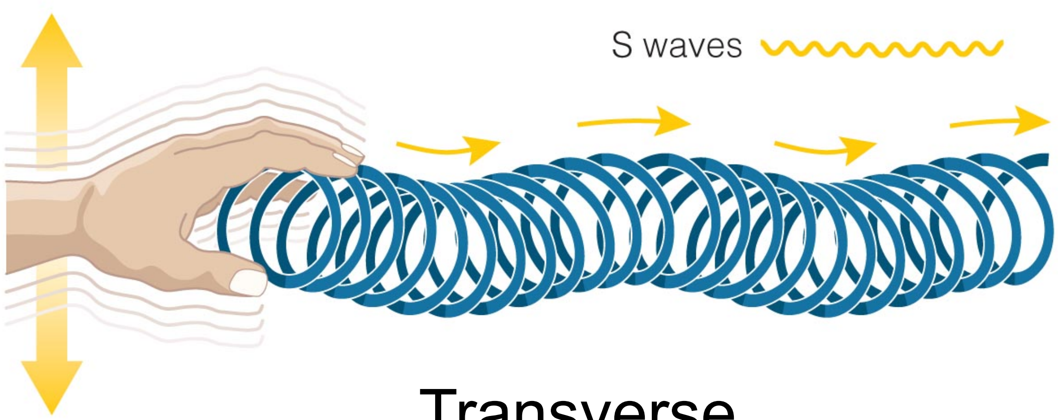
- P waves push matter back and forth.
- S waves shake matter side to side

Special Topic:

- How do we know what's inside Earth?



Longitudinal



Transverse

- P waves go through Earth's core, but S waves do not.
- We conclude that Earth's core must have a liquid outer layer.

Thought Question

- What is necessary for *differentiation* to occur in a planet?

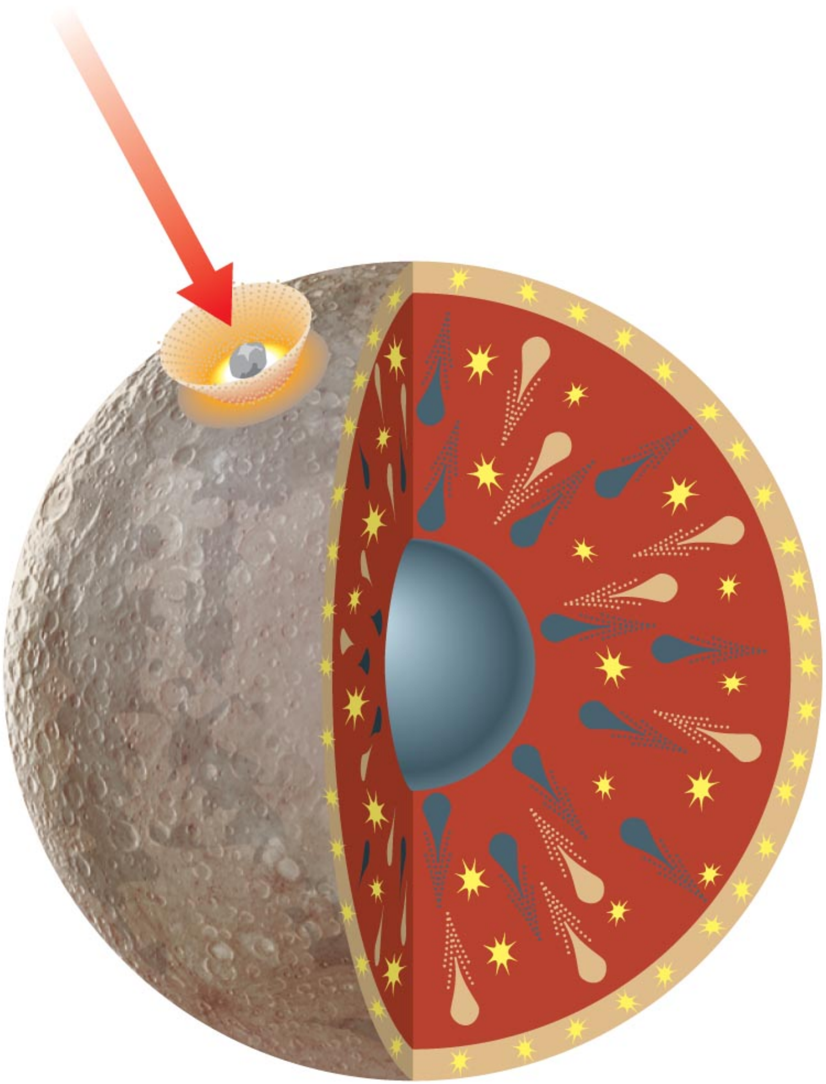
a) It must have metal and rock in it.
b) It must be a mix of materials of different density.
c) Material inside must be able to flow.
d) All of the above
e) b and c

Thought Question

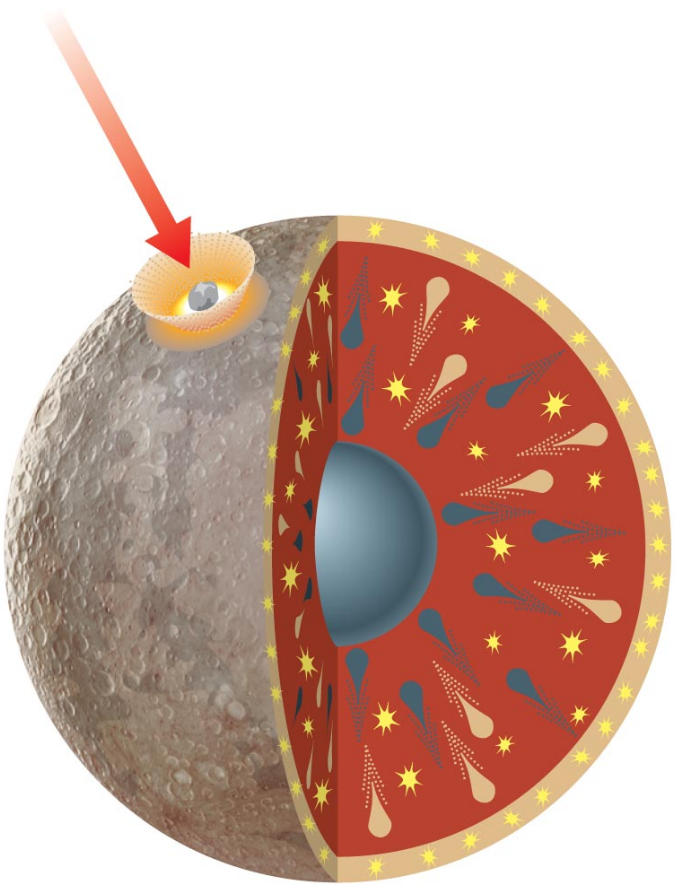
- What is necessary for *differentiation* to occur in a planet?

a) It must have metal and rock in it.
b) It must be a mix of materials of different density.
c) Material inside must be able to flow.
d) All of the above
e) b and c

What causes geological activity?

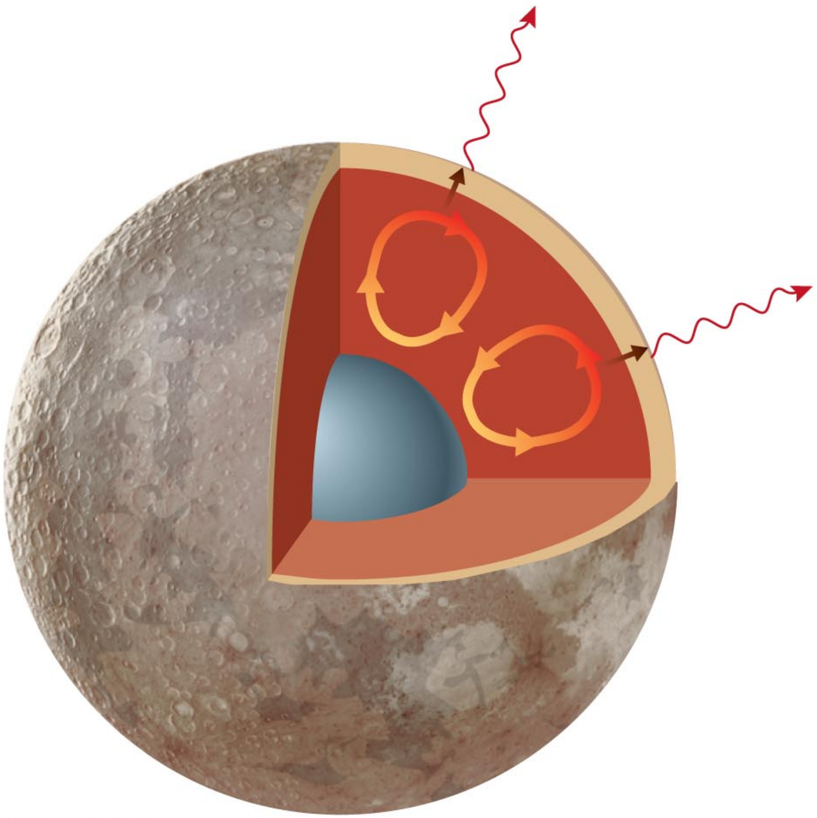


Heating of Planetary Interiors



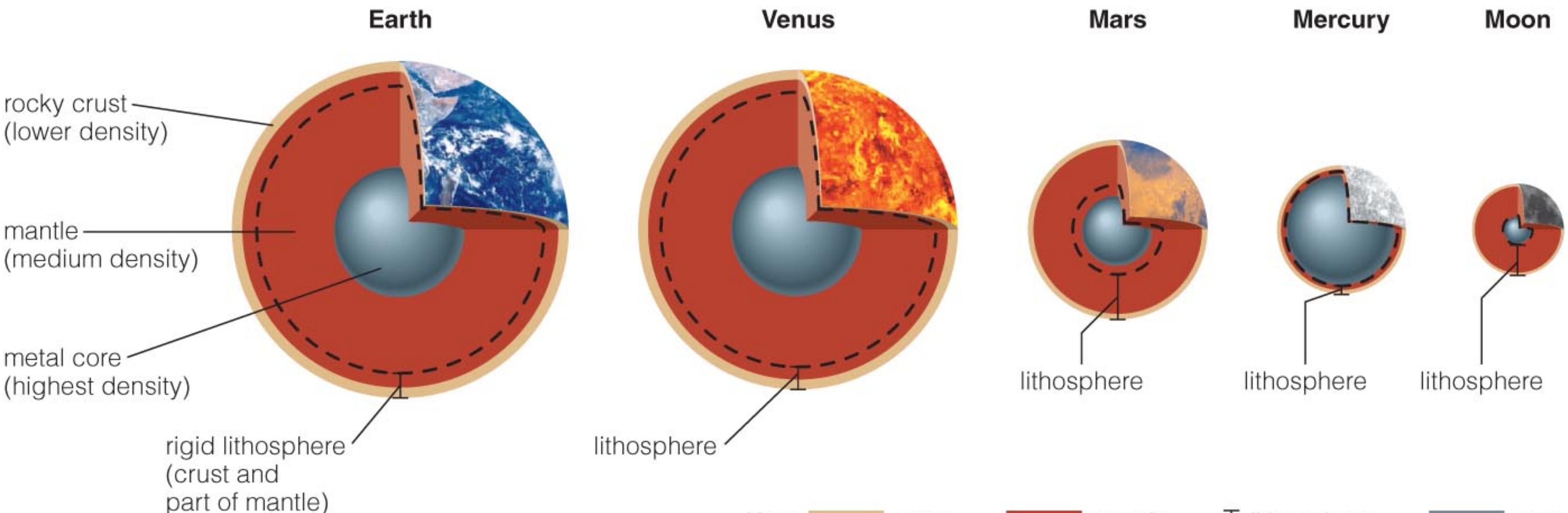
- Accretion and differentiation when planets were young
- Radioactive decay is most important heat source today.

Cooling of Planetary Interiors



- **Convection** transports heat as hot material rises and cool material falls.
- **Conduction** transfers heat from hot material to cool material.
- **Radiation** sends energy into space.

Role of Size



- Smaller worlds cool off faster and harden earlier.
- The Moon and Mercury are now geologically "dead."

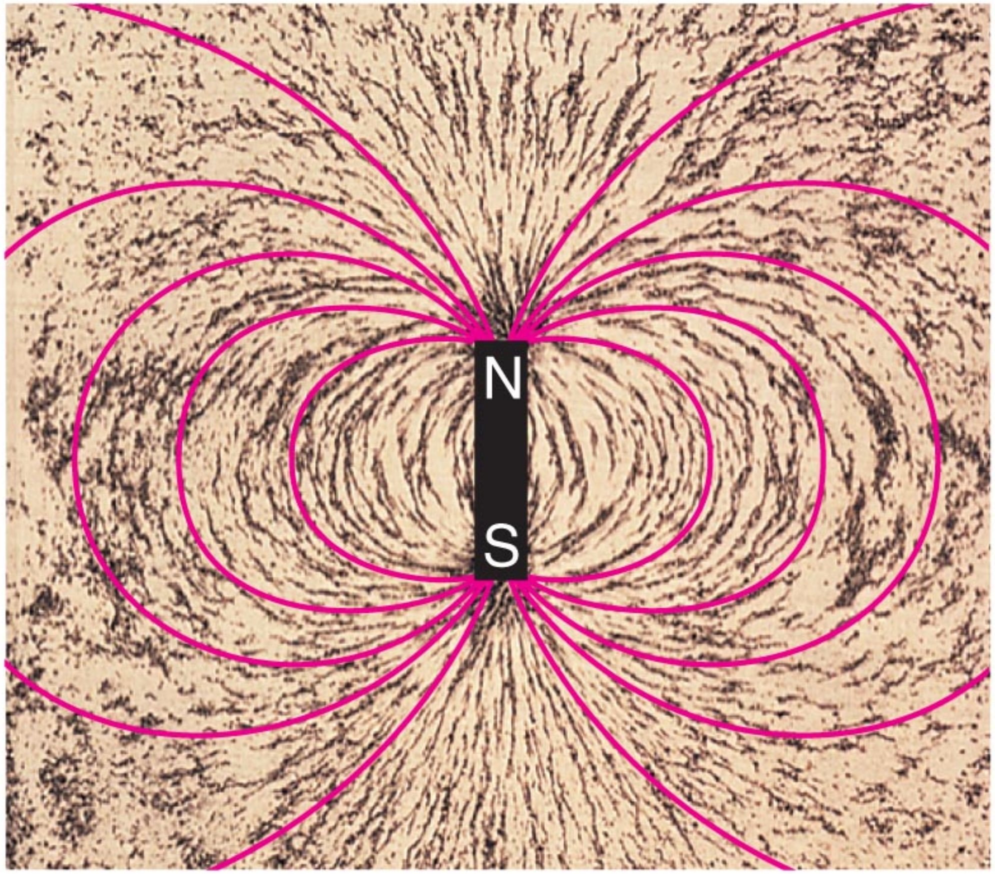
Surface Area–to–Volume Ratio

- Heat content depends on volume.
- Loss of heat through radiation depends on surface area.
- Time to cool depends on surface area divided by volume:

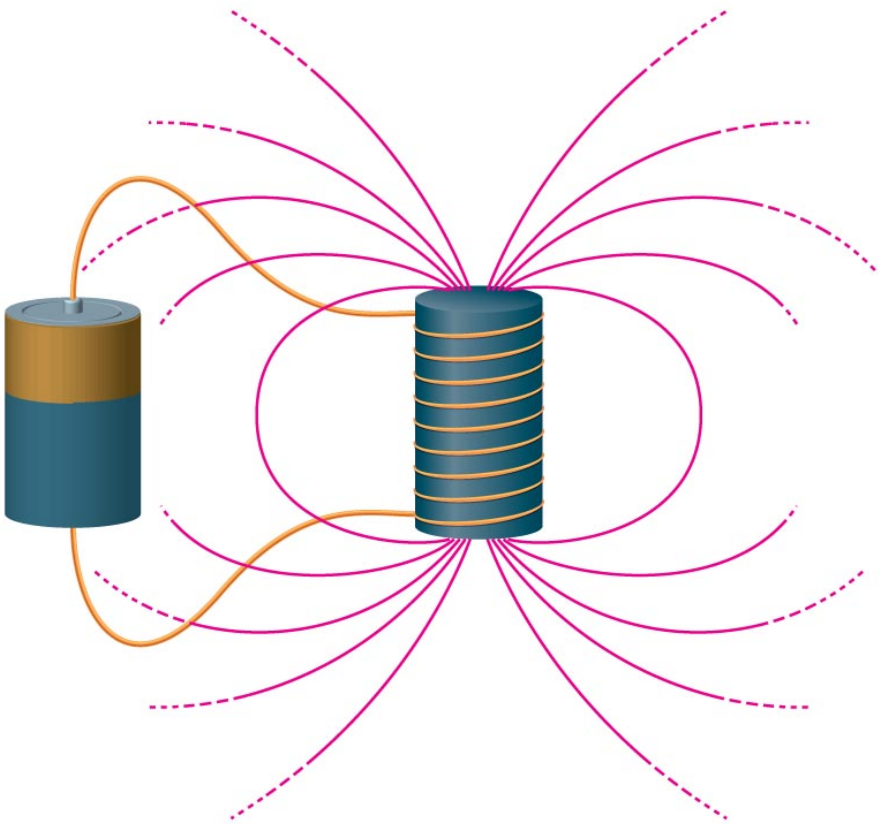
$$\text{surface area–to–volume ratio} = \frac{4\pi r^2}{\frac{4}{3}\pi r^3} = \frac{3}{r}$$

- Larger objects have a smaller ratio and cool more slowly.

Why do some planetary interiors create magnetic fields?

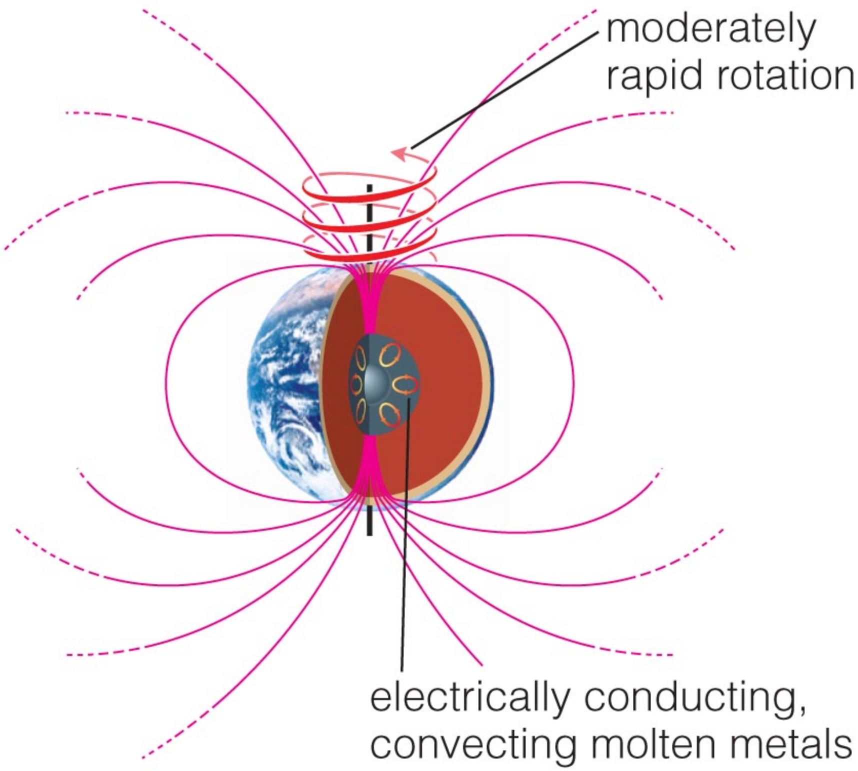


Sources of Magnetic Fields



- Motions of charged particles are what create magnetic fields.

Sources of Magnetic Fields



- A world can have a magnetic field if charged particles are moving inside.
- Three requirements:
  - Molten, electrically conducting interior
  - Convection
  - Moderately rapid rotation

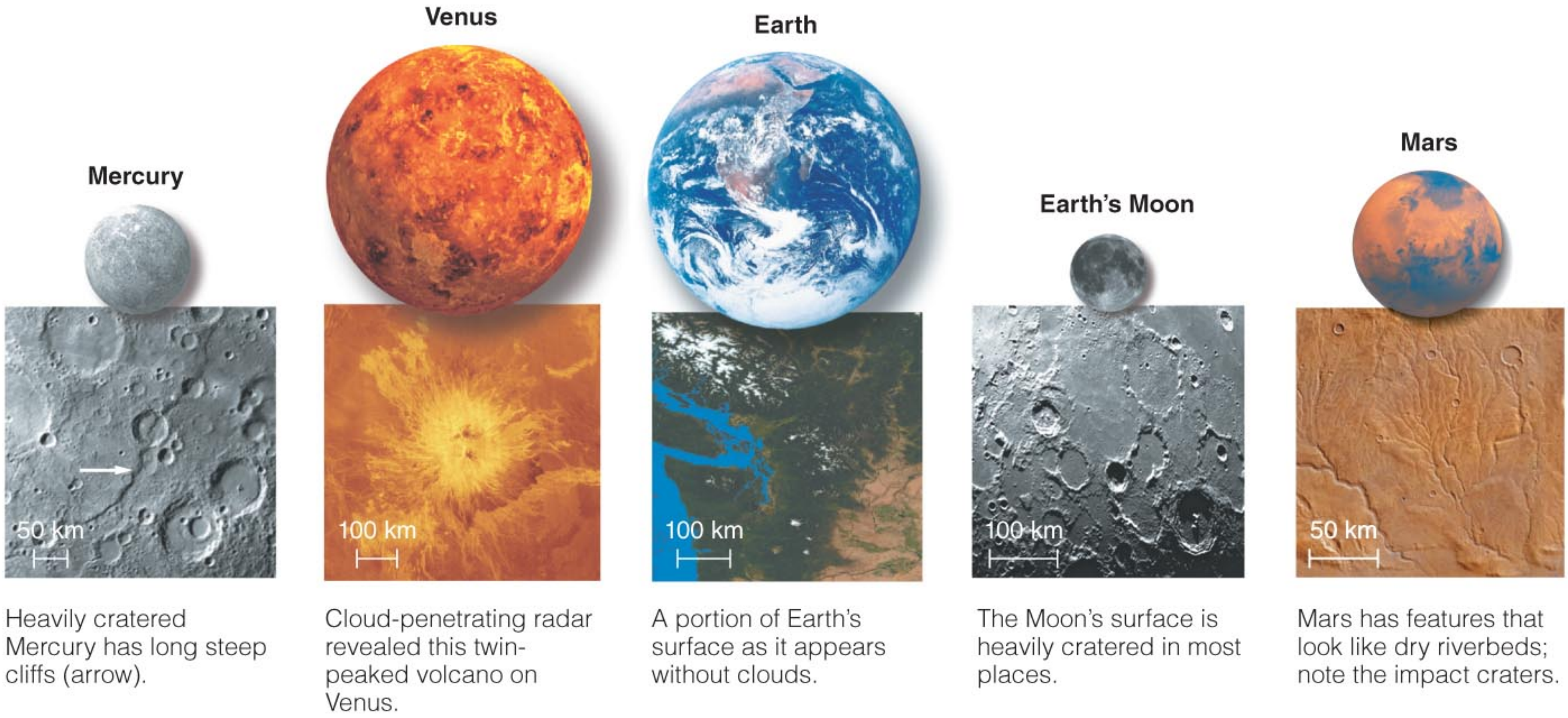
What have we learned?

- **What are terrestrial planets like on the inside?**
  - All terrestrial worlds have a core, mantle, and crust.
  - Denser material is found deeper inside.
- **What causes geological activity?**
  - Interior heat drives geological activity.
  - Radioactive decay is currently main heat source.
- **Why do some planetary interiors create magnetic fields?**
  - Requires motion of charged particles inside a planet

9.2 Shaping Planetary Surfaces

- Our goals for learning:
  - **What processes shape planetary surfaces?**
  - **How do impact craters reveal a surface's geological age?**
  - **Why do the terrestrial planets have different geological histories?**

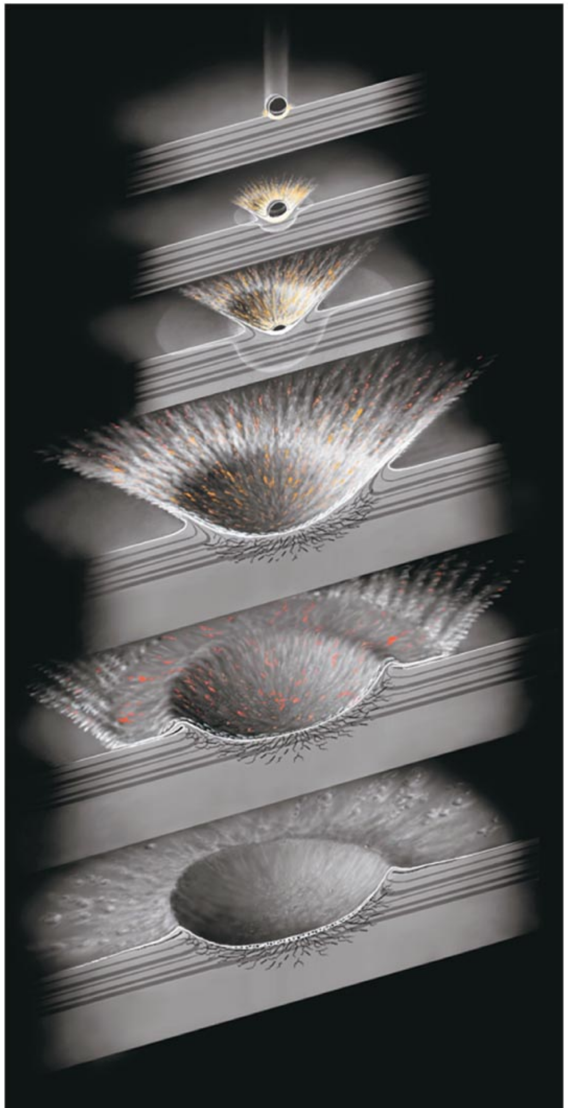
What processes shape planetary surfaces?



Processes That Shape Surfaces

- Impact cratering
  - Impacts by asteroids or comets
- Volcanism
  - Eruption of molten rock onto surface
- Tectonics
  - Disruption of a planet's surface by internal stresses
- Erosion
  - Surface changes made by wind, water, or ice

Impact Cratering



- Most cratering happened soon after the solar system formed.
- Craters are about 10 times wider than the object that made them.
- Small craters greatly outnumber large ones.

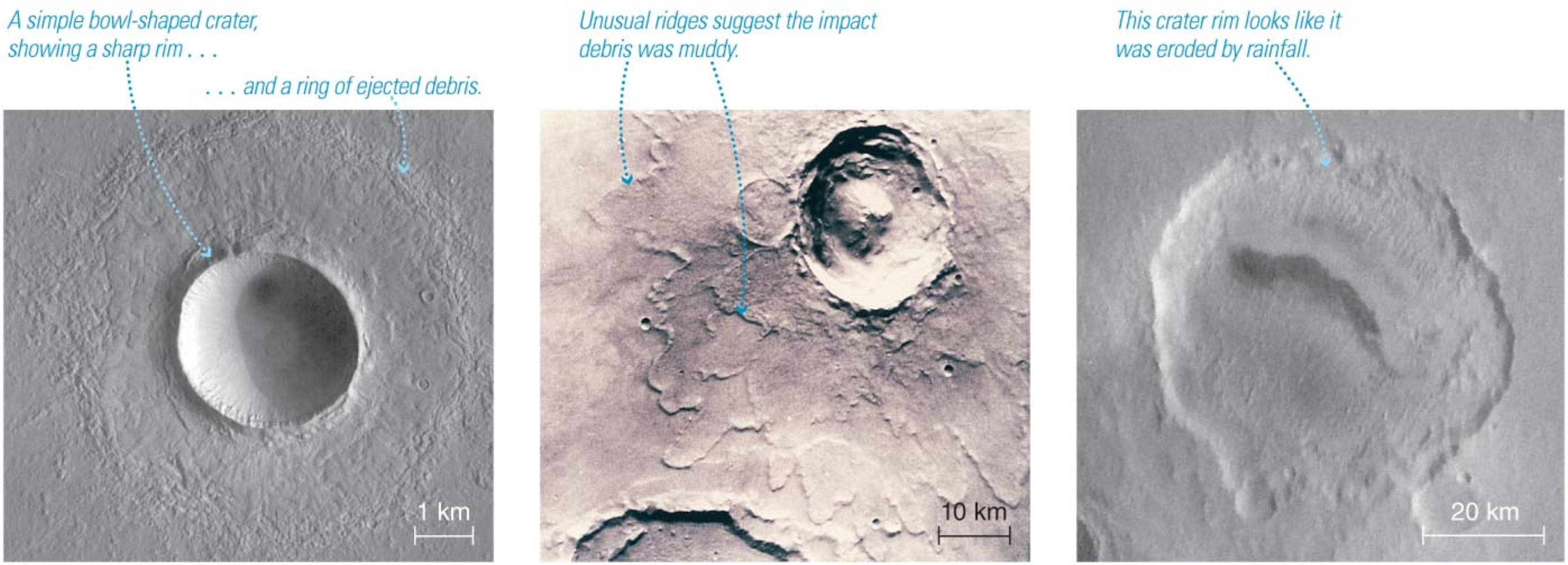
Impact Craters

a Meteor Crater in Arizona is more than a kilometer across and almost 200 meters deep. It was created around 50,000 years ago by the impact of a metallic asteroid about 50 meters across.

b This photo shows a crater, named Tycho, on the Moon. Note the classic shape and central peak.

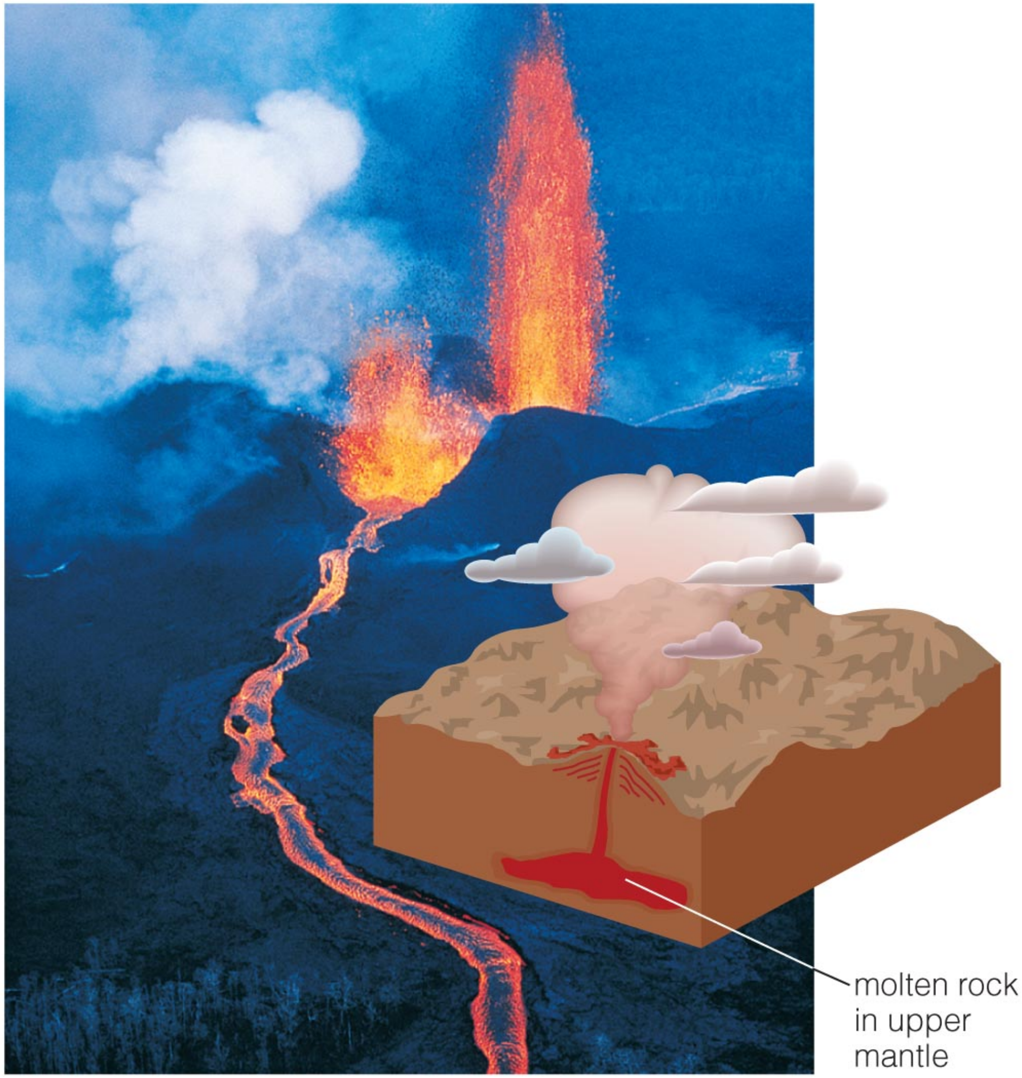
- Meteor Crater (Arizona)
- Tycho Crater (Moon)

Impact Craters on Mars



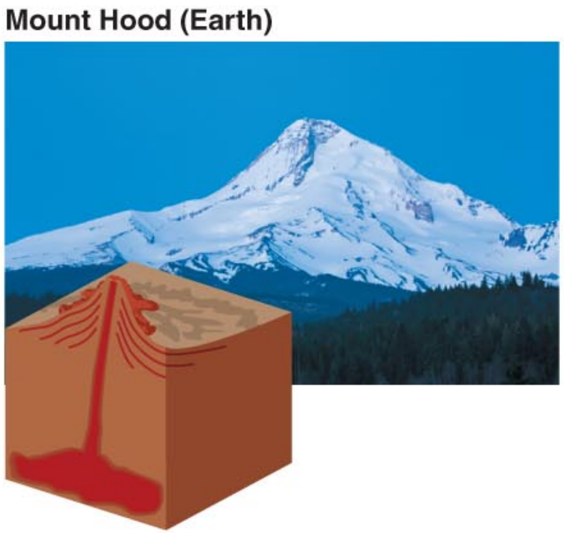
- "Standard" crater
- Impact into icy ground
- Eroded crater

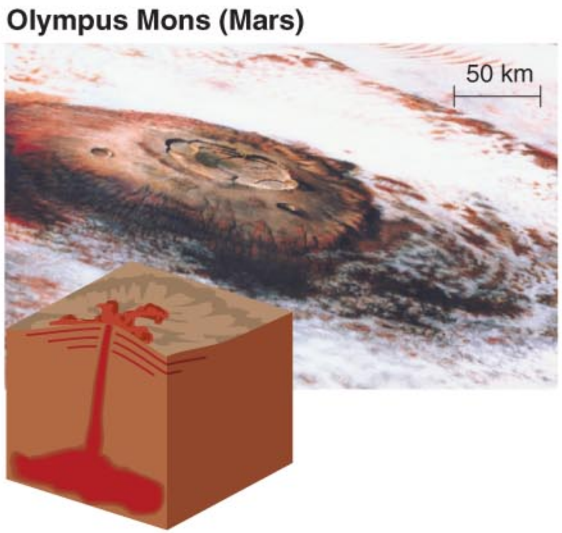
Volcanism

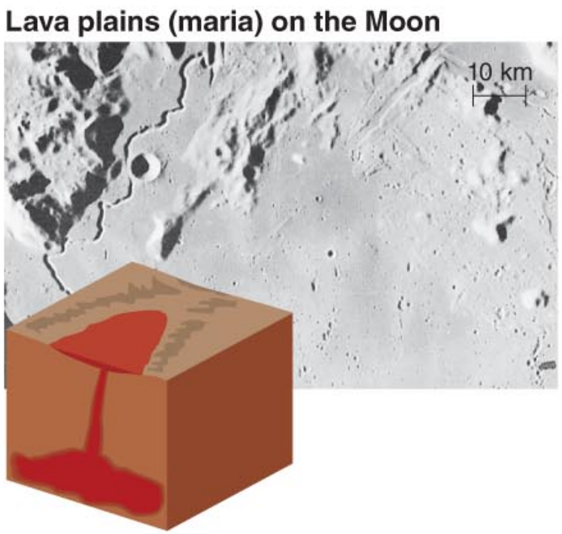


- Volcanism happens when molten rock (magma) finds a path through lithosphere to the surface.
- Molten rock is called *lava* after it reaches the surface.

Lava and Volcanoes







- Thickest lava makes steep *stratovolcanoes*.
- Slightly runnier lava makes broad *shield volcanoes*.
- Runny lava makes flat lava plains.

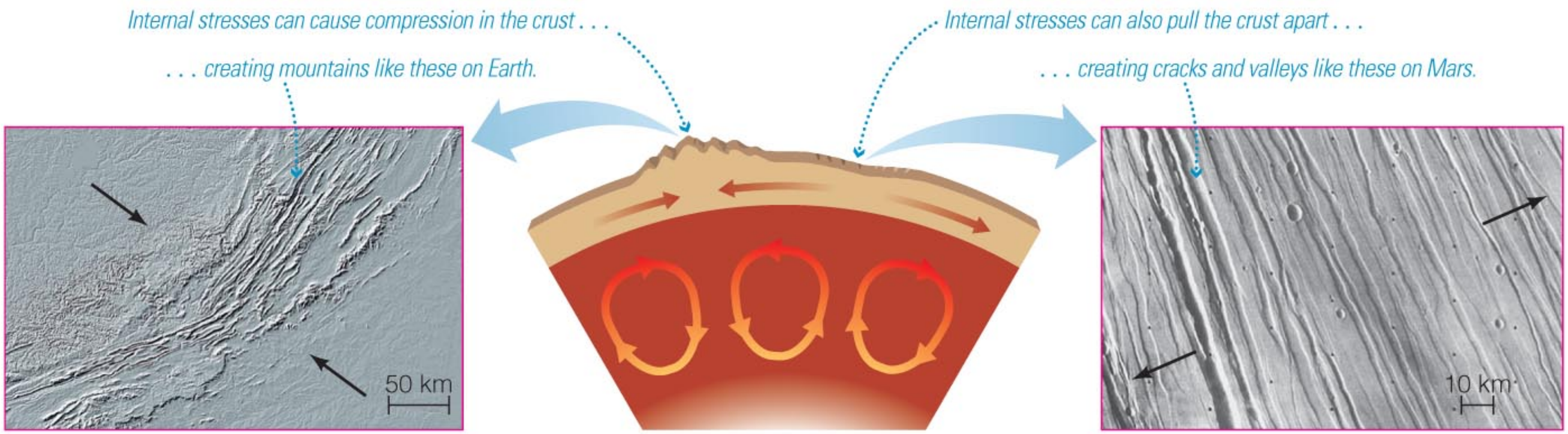
Outgassing

a The eruption of Mount St. Helens, May 18, 1980.

b More gradual outgassing from a volcanic vent in Volcanoes National Park, Hawaii.

- Volcanism also releases gases from Earth's interior into the atmosphere.

Tectonics



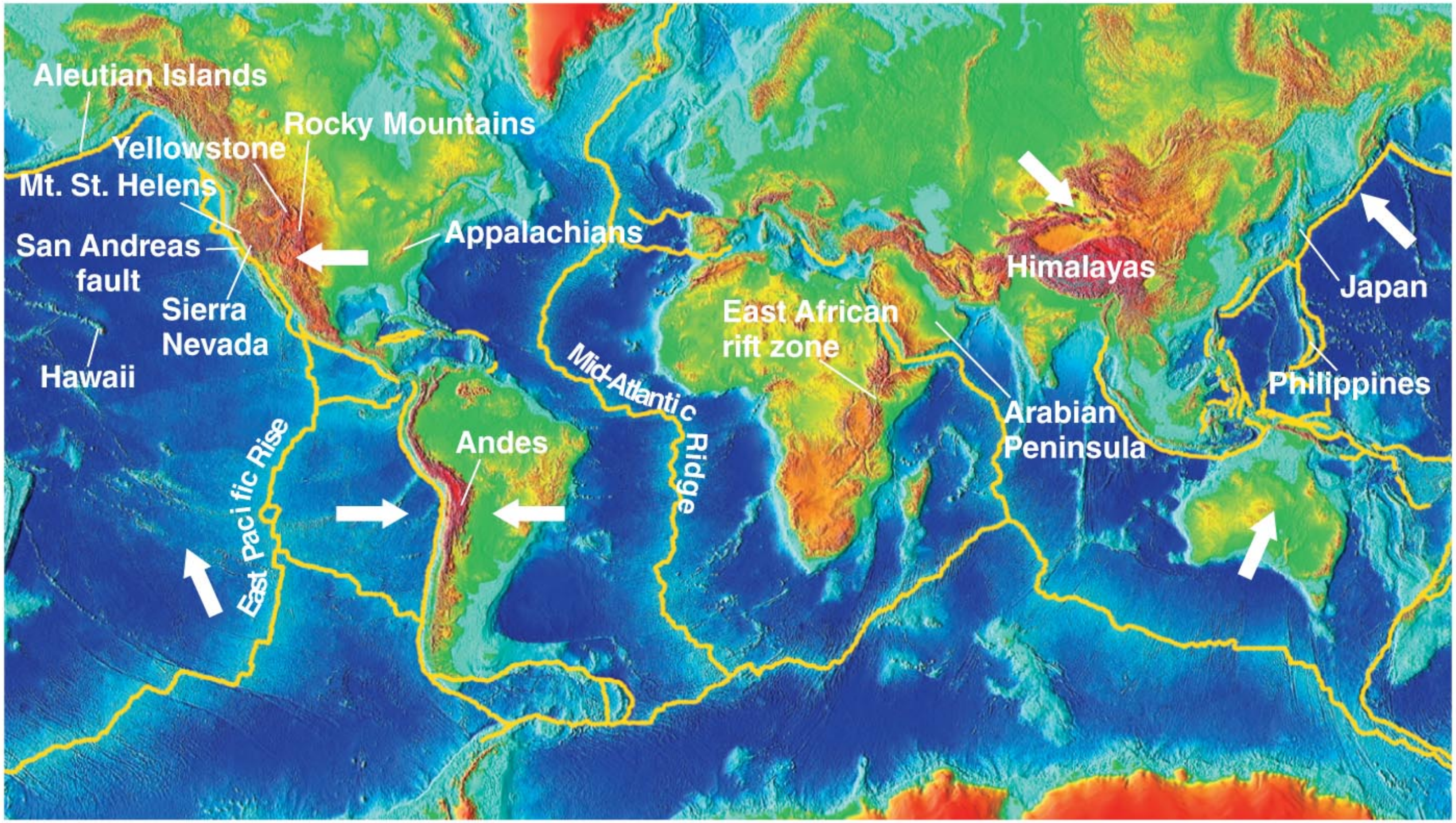
Appalachian Mountains in eastern United States

Ceraunius Valleys on Mars

- Convection of the mantle creates stresses in the crust called tectonic forces.
- Compression of crust creates mountain ranges.
- Valley can form where crust is pulled apart.

Plate Tectonics on Earth

- Earth's continents slide around on separate plates of crust.



Erosion

- Erosion is a blanket term for weather-driven processes that break down or transport rock.
- Processes that cause erosion include:
  - glaciers
  - rivers
  - wind

Erosion by Water

- The Colorado River continues to carve Grand Canyon.

Erosion by Ice

- Glaciers carved the Yosemite Valley.

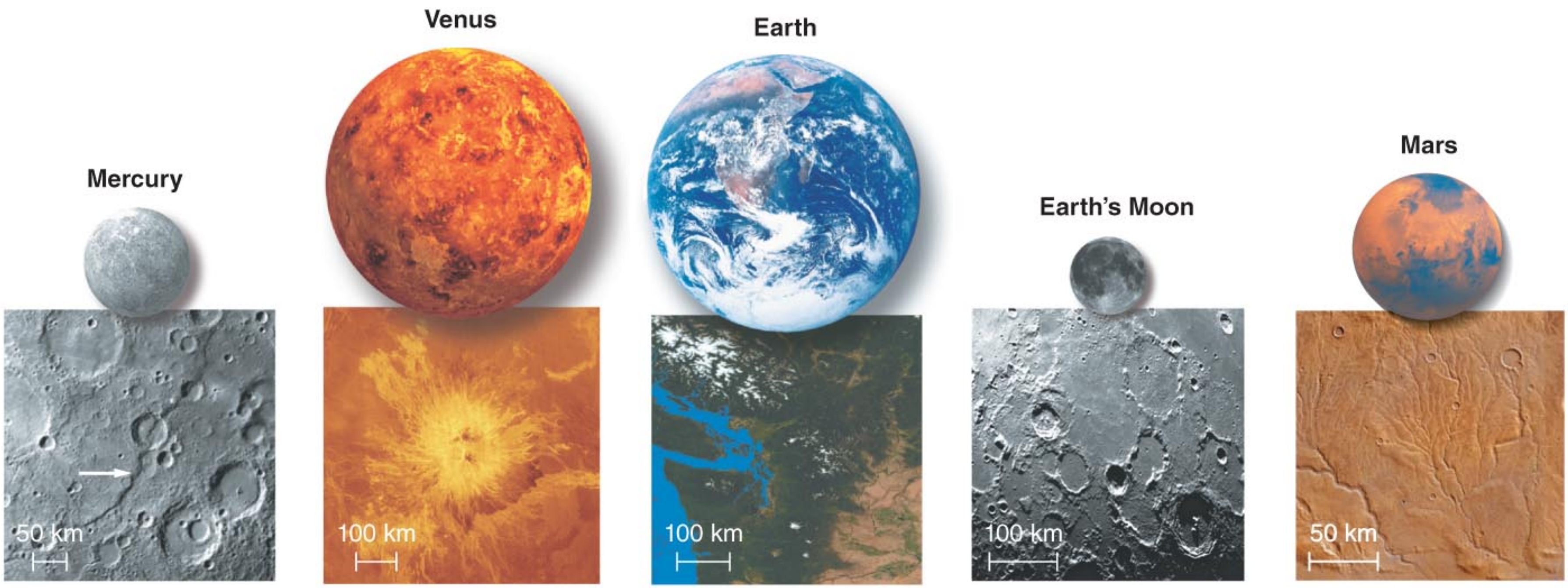
Erosion by Wind

- Wind wears away rock and builds up sand dunes.

Erosional Debris

- Erosion can create new features such as deltas by depositing debris.

How do impact craters reveal a surface's geological age?



Heavily cratered Mercury has long steep cliffs (arrow).

Cloud-penetrating radar revealed this twin-peaked volcano on Venus.

A portion of Earth's surface as it appears without clouds.

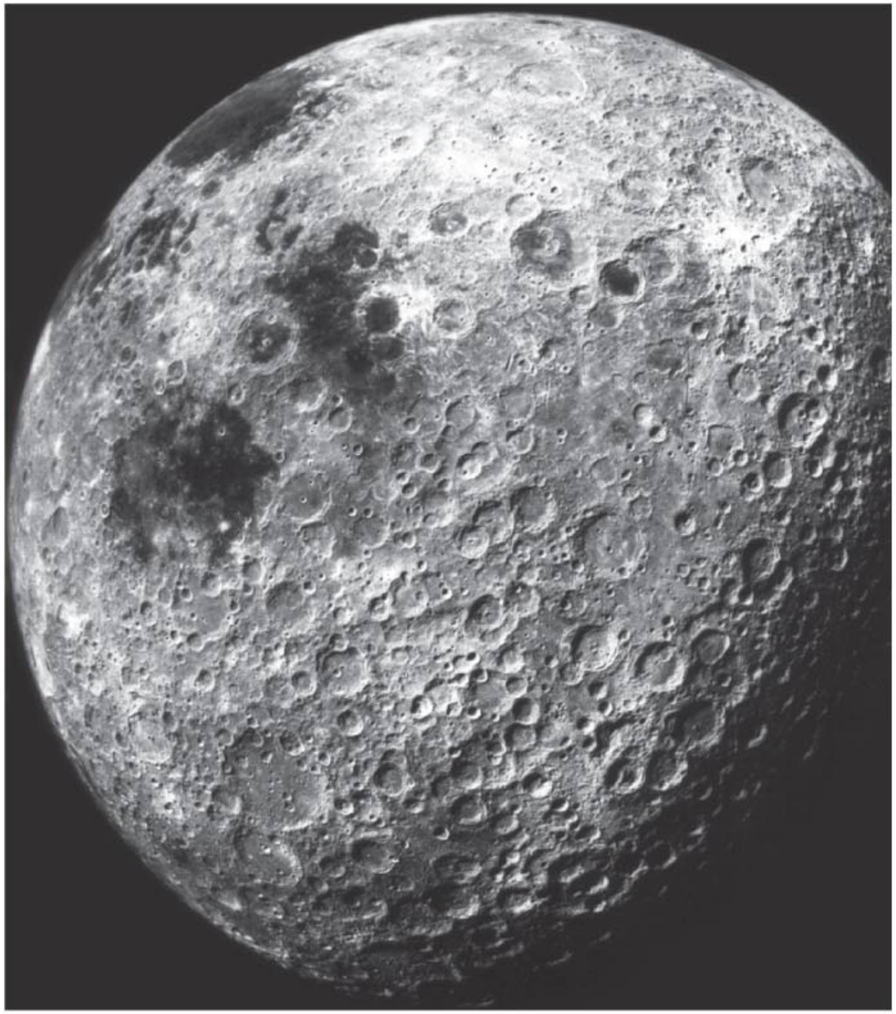
The Moon's surface is heavily cratered in most places.

Mars has features that look like dry riverbeds; note the impact craters.

History of Cratering

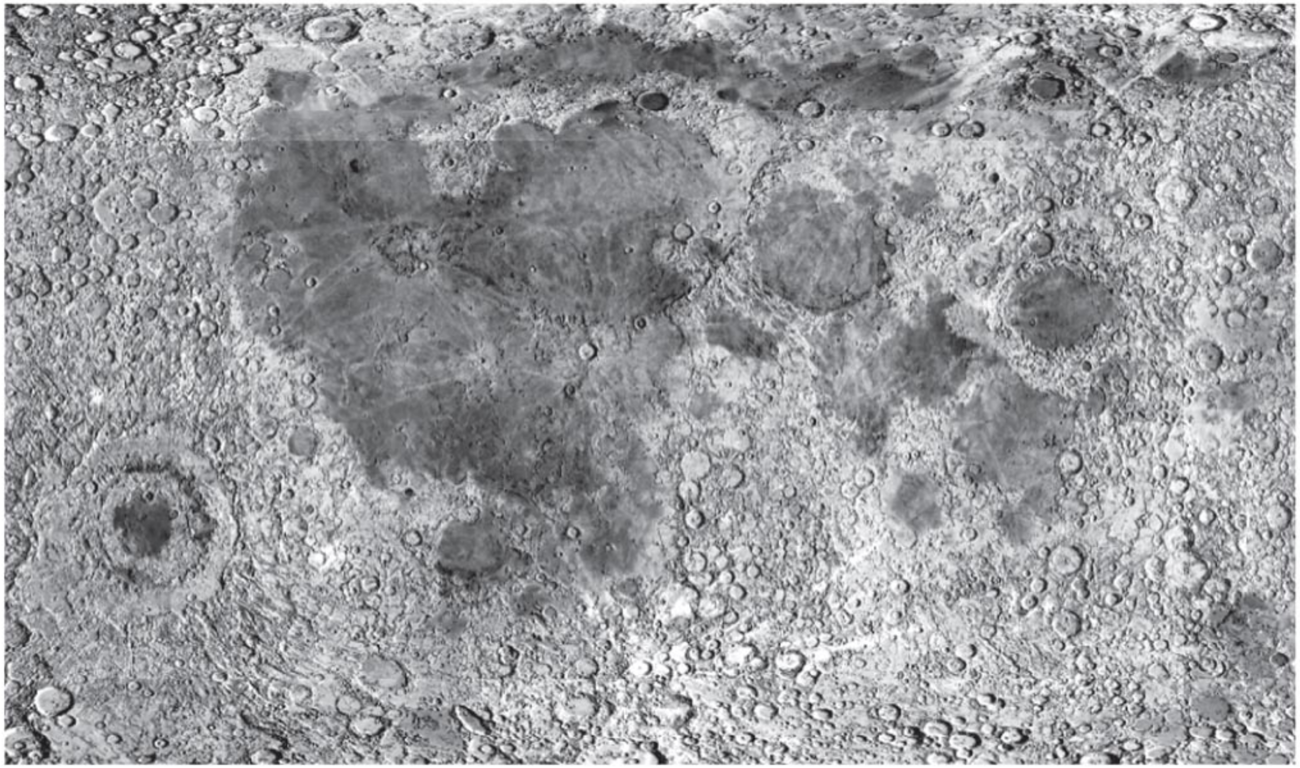
- Most cratering happened in the first billion years.
- A surface with many craters has not changed much in 3 billion years.

Cratering of Moon



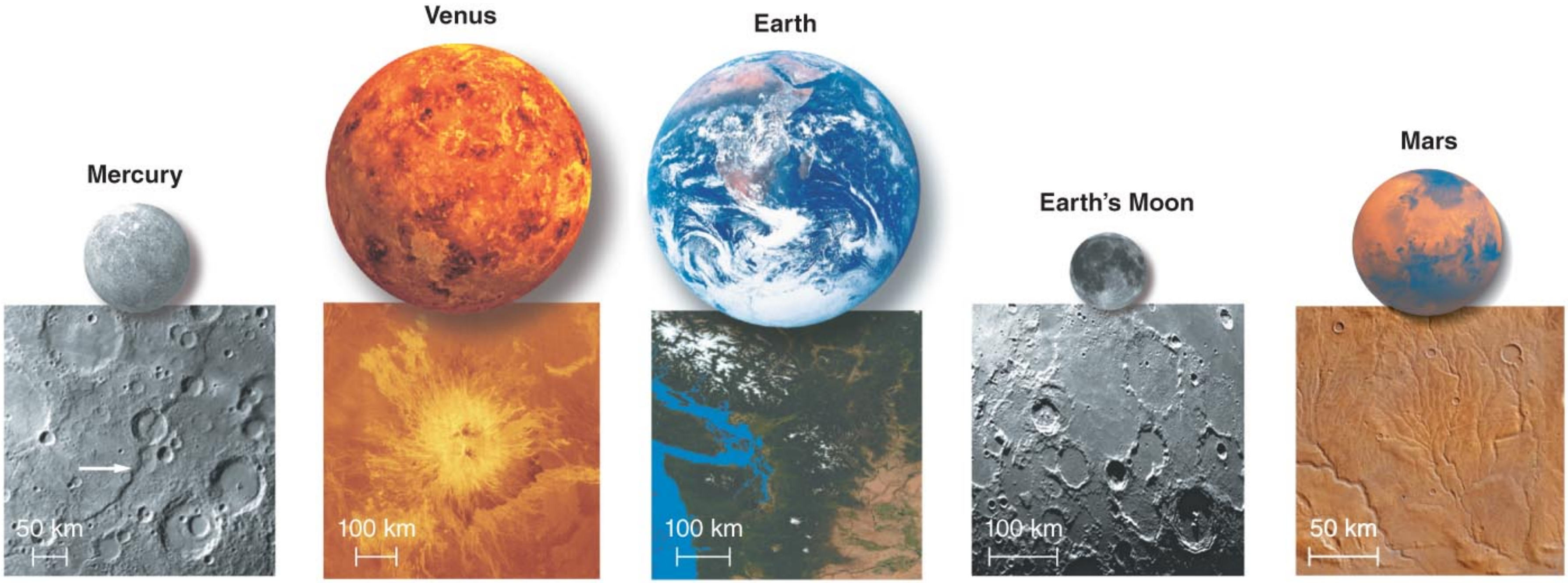
- Some areas of Moon are more heavily cratered than others.
- Younger regions were flooded by lava after most cratering.

Cratering of Moon



- Cratering map of the Moon's entire surface

Why do the terrestrial planets have different geological histories?



Heavily cratered Mercury has long steep cliffs (arrow).

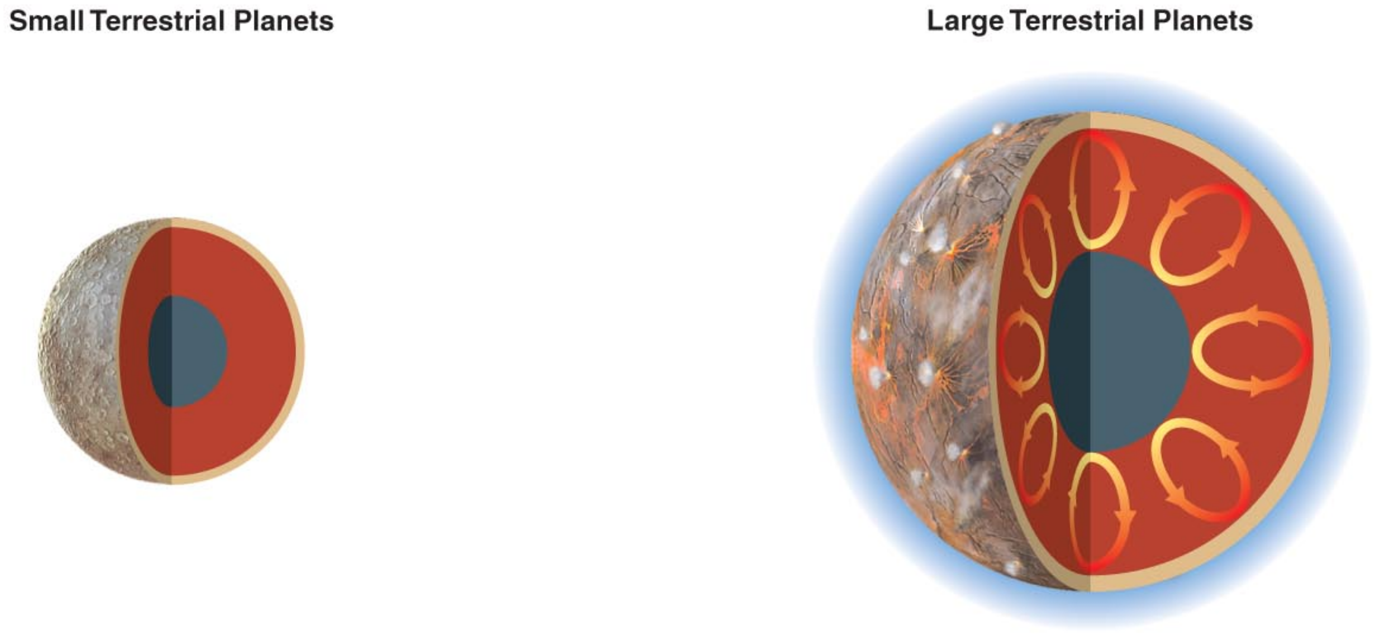
Cloud-penetrating radar revealed this twin-peaked volcano on Venus.

A portion of Earth's surface as it appears without clouds.

The Moon's surface is heavily cratered in most places.

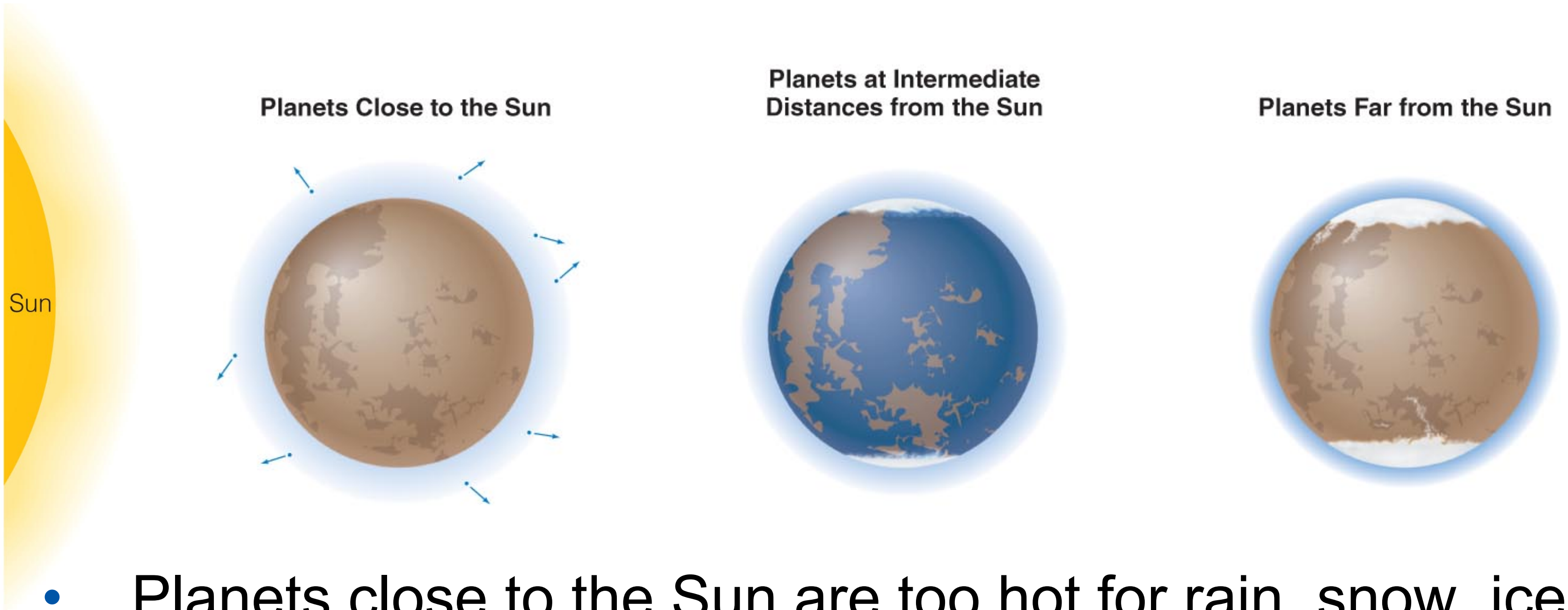
Mars has features that look like dry riverbeds; note the impact craters.

Role of Planetary Size



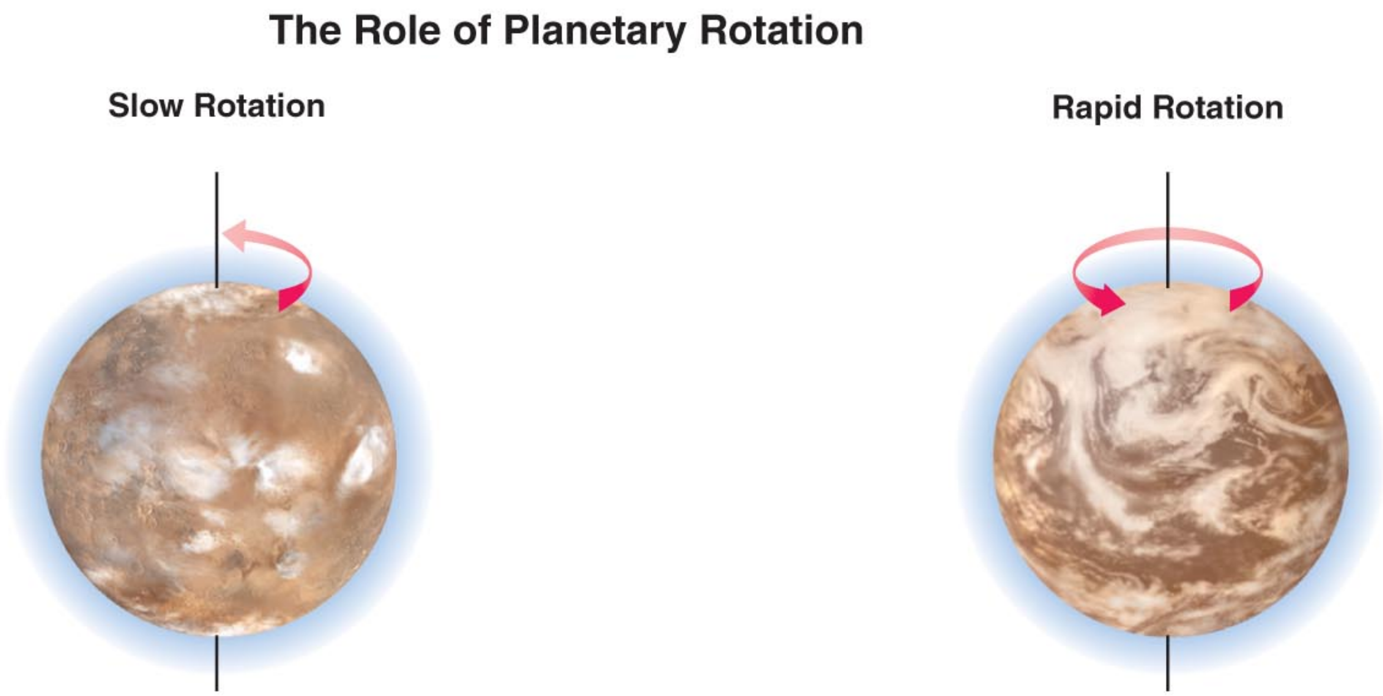
- Smaller worlds cool off faster and harden earlier.
- Larger worlds remain warm inside, promoting volcanism and tectonics.
- Larger worlds also have more erosion because their gravity retains an atmosphere.

Role of Distance from Sun



- Planets close to the Sun are too hot for rain, snow, ice have less erosion.
- Slowly rotating planets have less erosion.
- Planets far from the Sun are too cold for rain, limiting erosion.
- Planets with liquid water have the most erosion.

Role of Rotation



- Planets with slower rotation have less weather, less erosion, and a weak magnetic field.
- Planets with faster rotation have more weather, more erosion, and a stronger magnetic field.

Thought Question

- How does the cooling of planets and <u>potatoes</u> vary with size?

a) Larger size makes it harder for heat from inside to escape.
b) Larger size means a bigger ratio of volume to surface area.
c) Larger size takes longer to cool.
d) all of the above

Thought Question

- How does the cooling of planets and potatoes vary with size?

a) Larger size makes it harder for heat from inside to escape.
b) Larger size means a bigger ratio of volume to surface area.
c) Larger size takes longer to cool.
d) **all of the above**

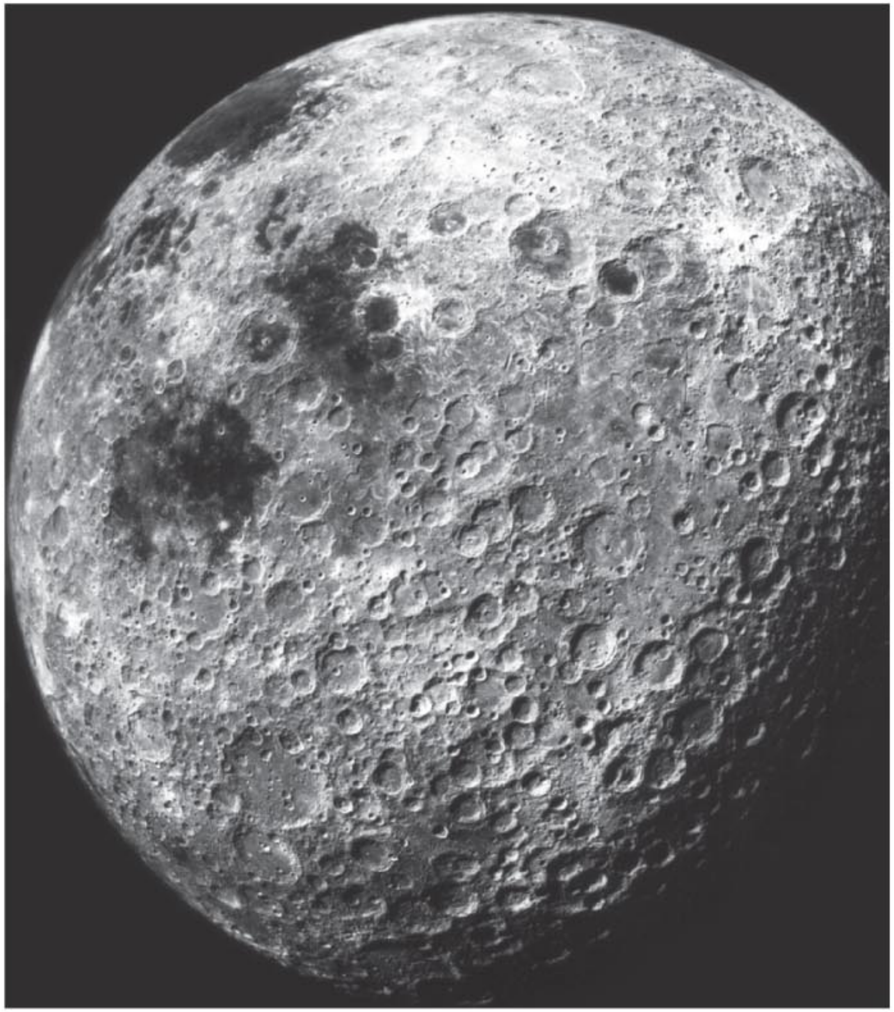
What have we learned?

- **What processes shape planetary surfaces?**
  - Cratering, volcanism, tectonics, erosion
- **How do impact craters reveal a surface's geological age?**
  - The amount of cratering tells us how long ago a surface formed.
- **Why do the terrestrial planets have different geological histories?**
  - Differences arise because of planetary size, distance from Sun, and rotation rate.

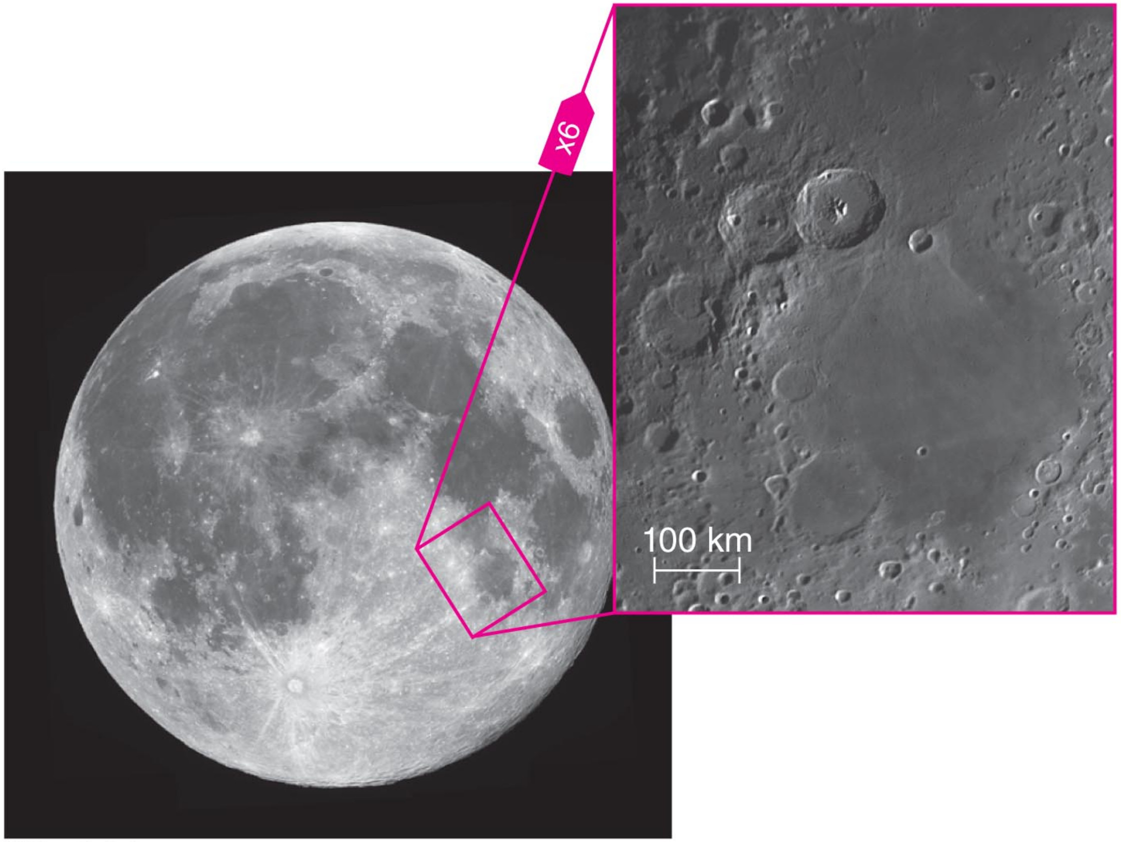
9.3 Geology of the Moon and Mercury

- Our goals for learning:
  - **What geological processes shaped our Moon?**
  - **What geological processes shaped Mercury?**

What geological processes shaped our Moon?

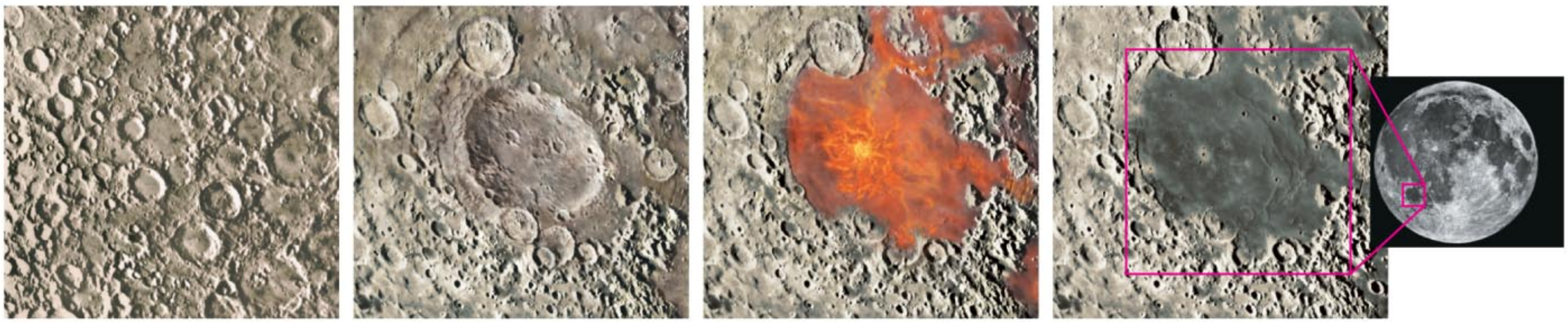


Lunar Maria



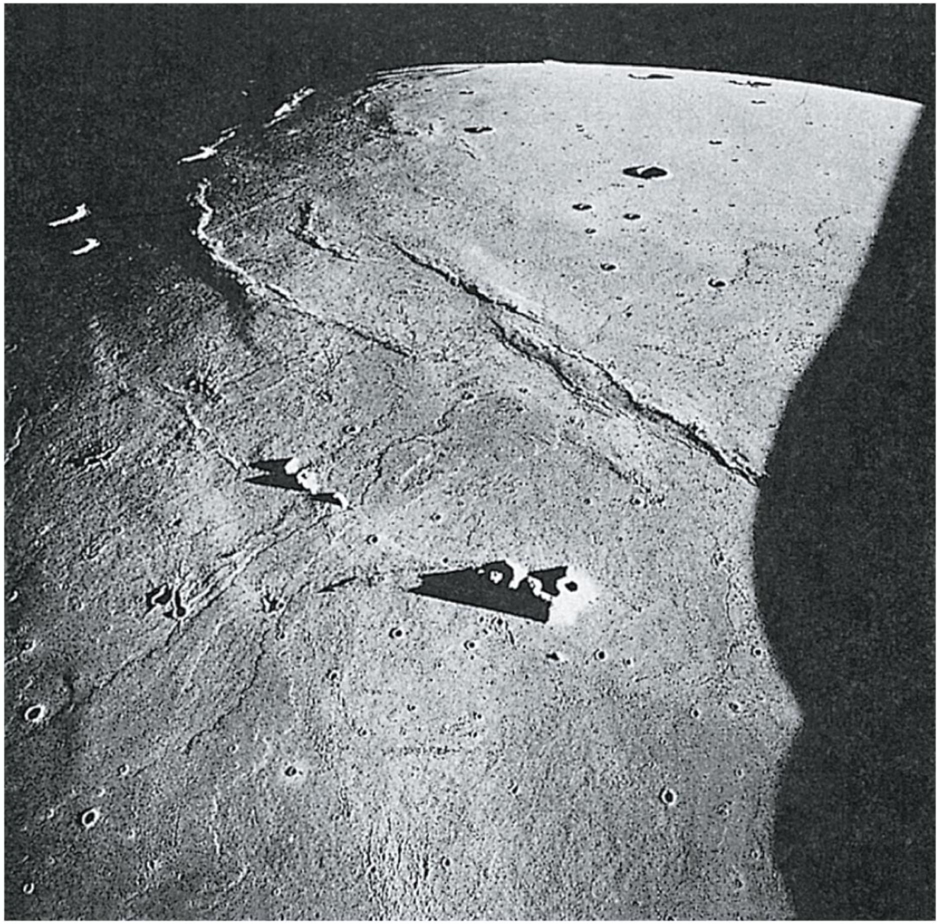
- Smooth, dark lunar maria are less heavily cratered than lunar highlands.
- Maria were made by floods of runny lava.

Formation of Lunar Maria



- Early surface is covered with craters.
- Large impact crater weakens crust.
- Heat build-up allows lava to well up to surface.
- Cooled lava is smoother and darker than surroundings.

Tectonic Features



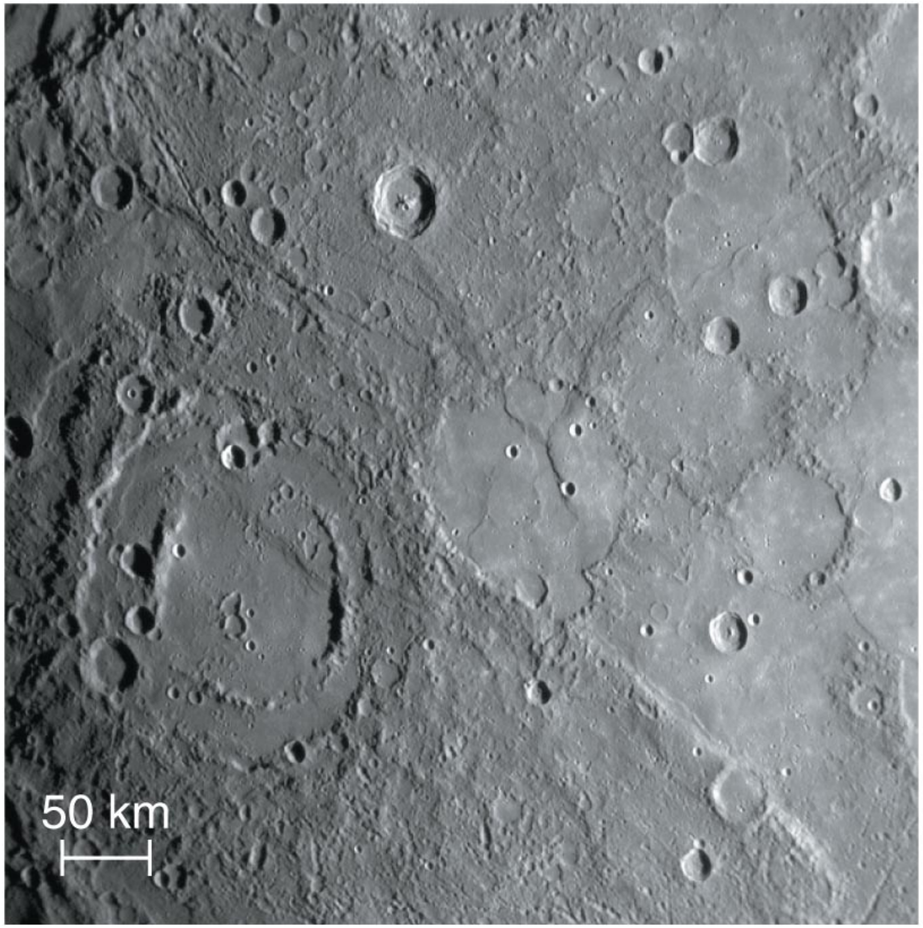
- Wrinkles arise from cooling and the contraction of a lava flood.

Geologically Dead

- Moon is considered geologically "dead" because geological processes have virtually stopped.

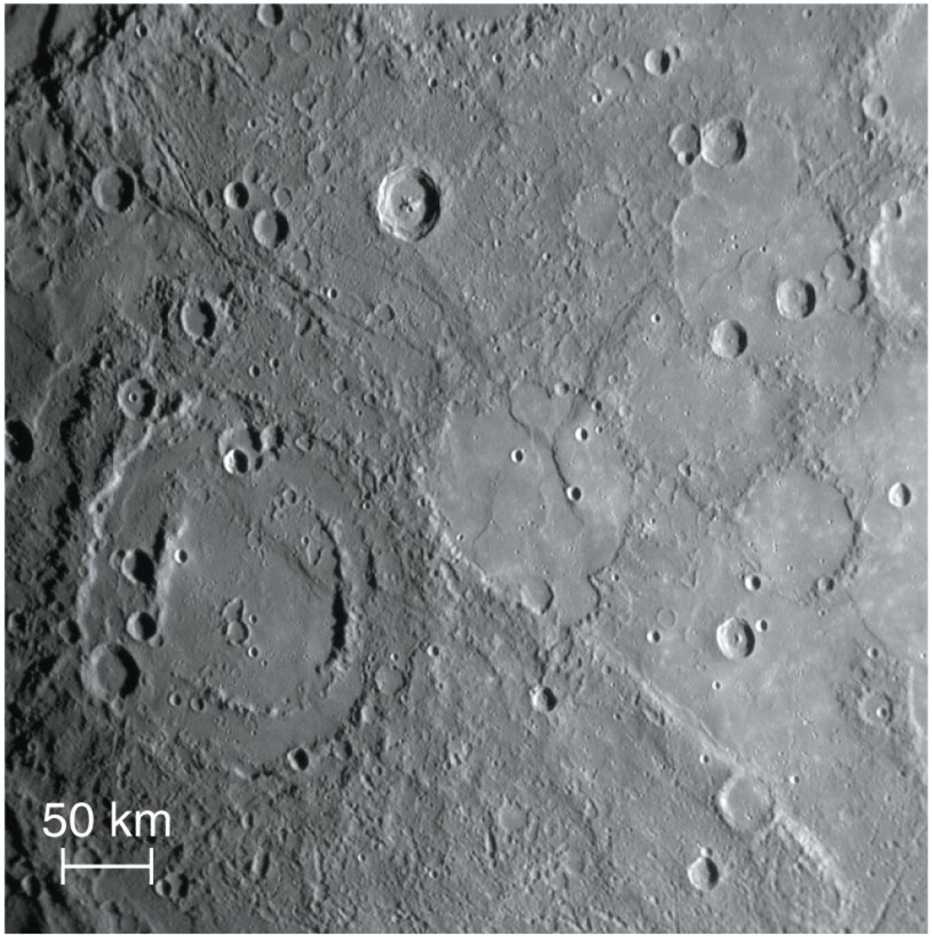
b The *Apollo* astronauts left footprints, like this one, in the Moon's powdery "soil." Micrometeorites will eventually erase the footprints, but not for millions of years.

What geological processes shaped Mercury?



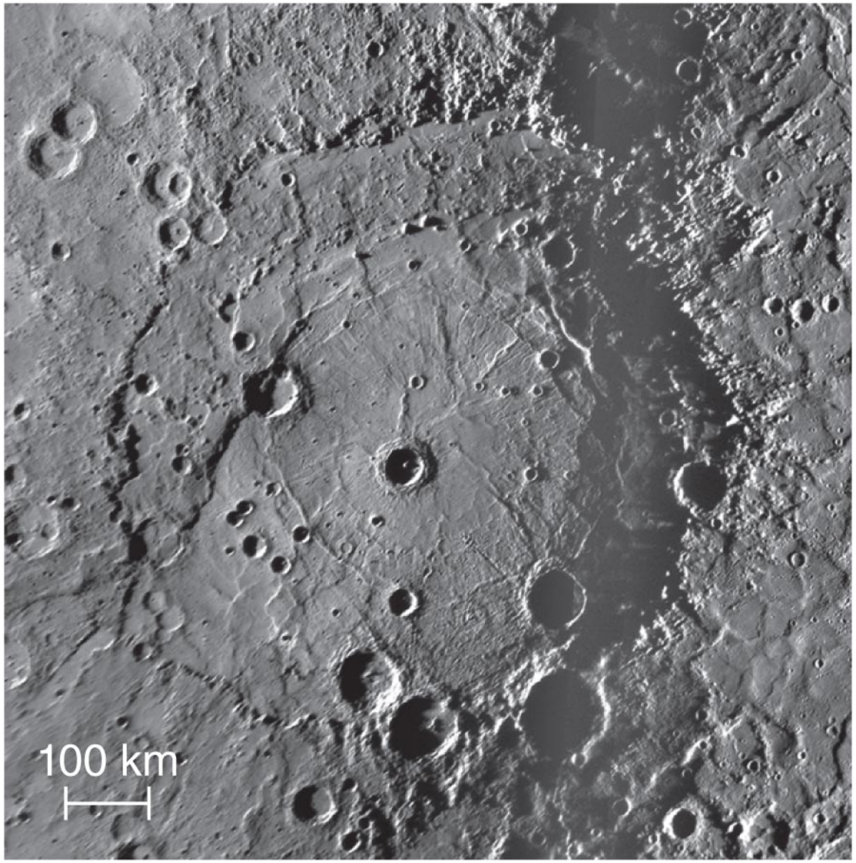
a A close-up view of Mercury's surface, showing impact craters and smooth regions where lava apparently covered up craters.

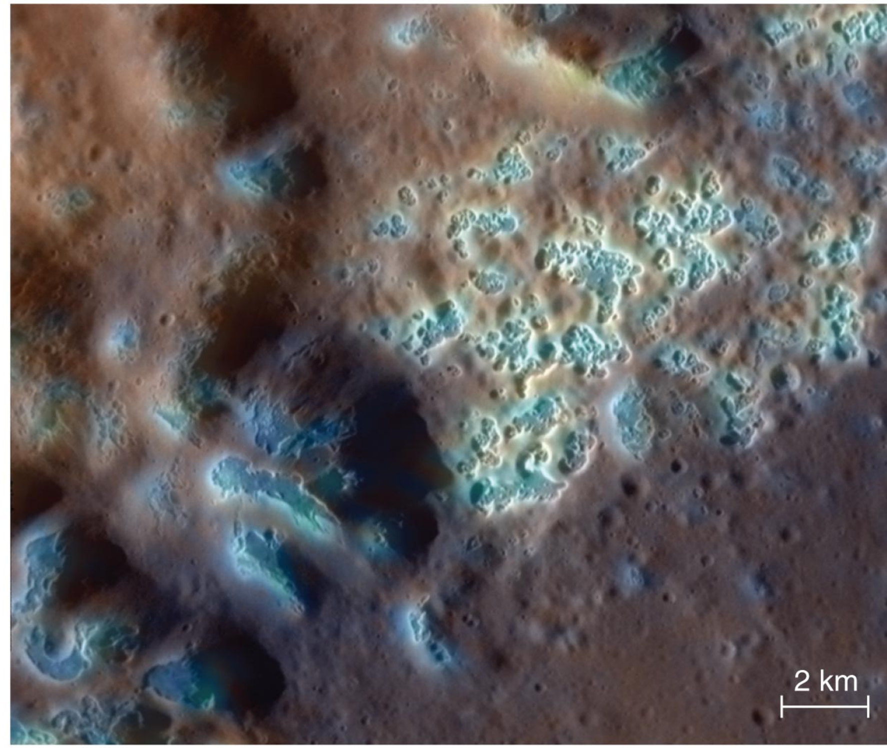
Cratering of Mercury



- Mercury has a mixture of heavily cratered and smooth regions like the Moon.
- Smooth regions are likely ancient lava flows.

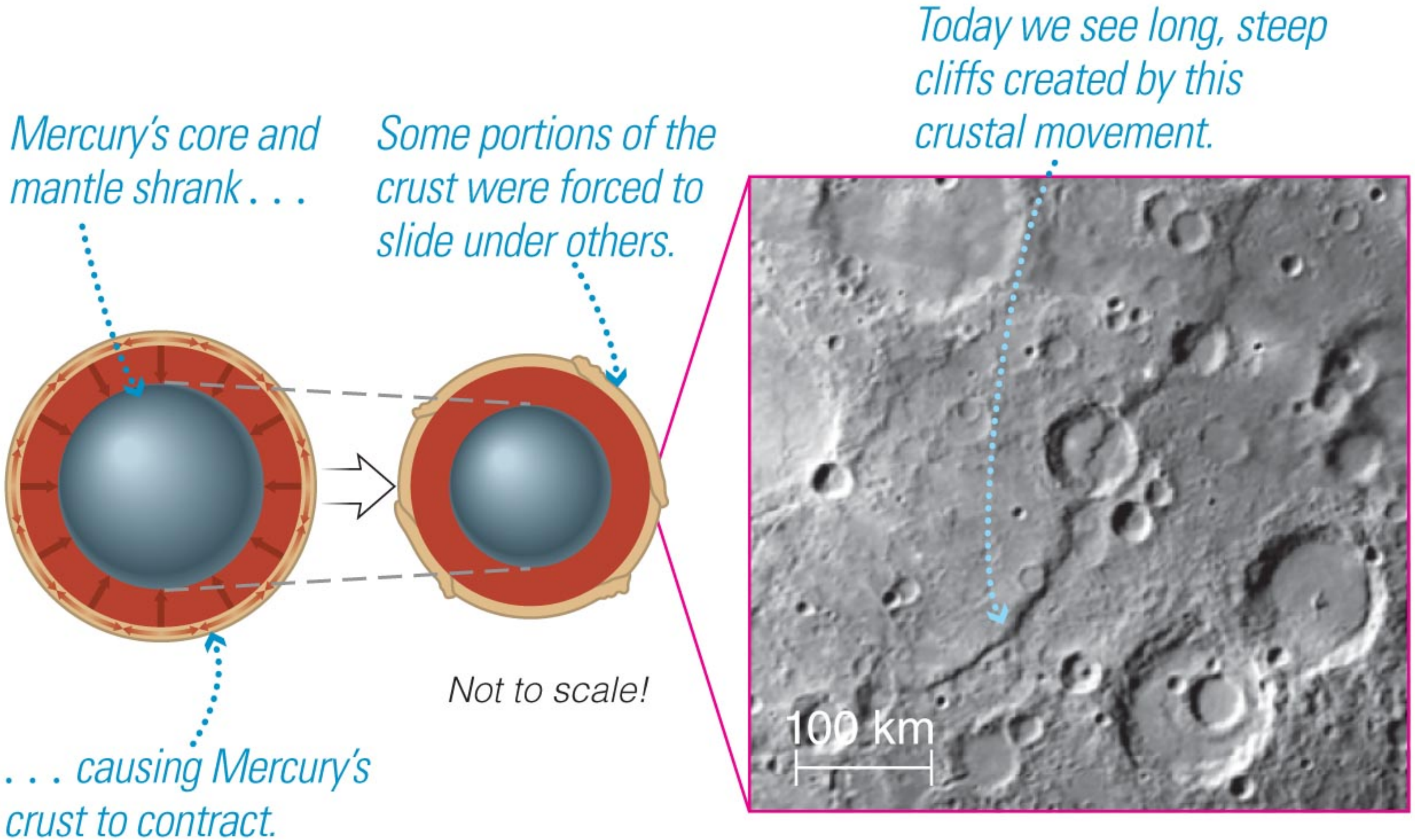
Cratering of Mercury





- The Rembrandt Basin is a large impact crater on Mercury.
- Hollows in a crater floor created by escaping gases.

Tectonics on Mercury



- Long cliffs indicate that Mercury shrank early in its history.

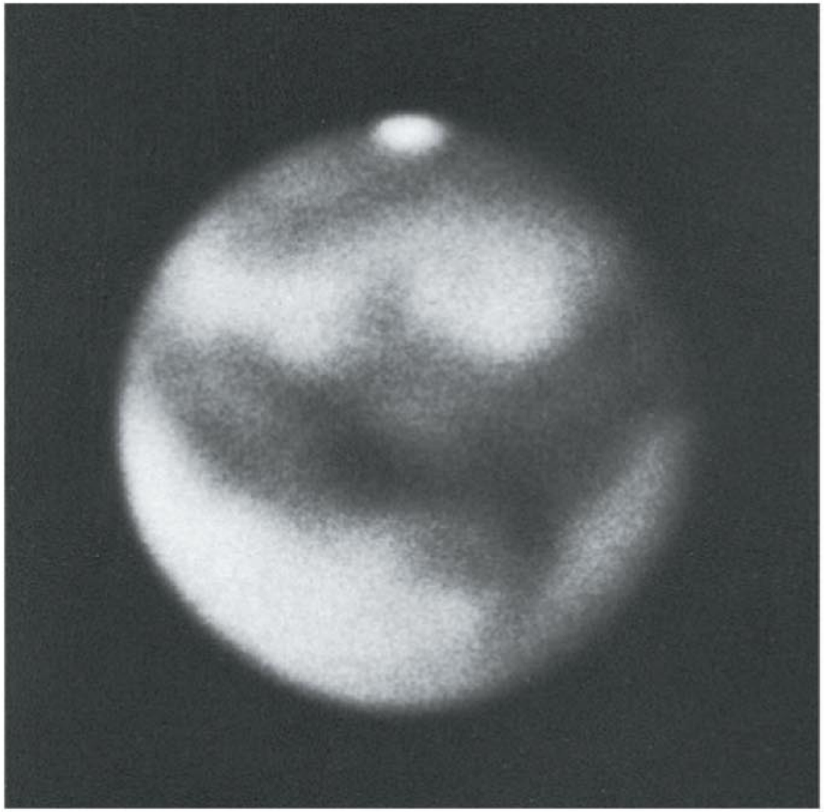
What have we learned?

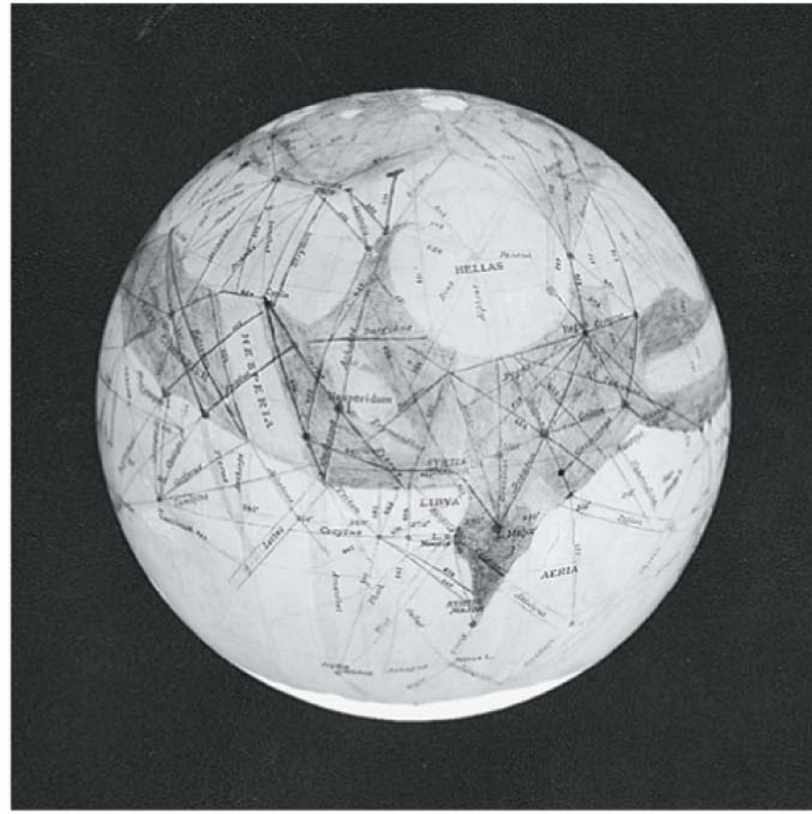
- **What geological processes shaped our Moon?**
  - Early cratering is still present.
  - Maria resulted from volcanism.
- **What geological processes shaped Mercury?**
  - Had cratering and volcanism similar to Moon
  - Tectonic features indicate early shrinkage.

9.4 Geology of Mars

- Our goals for learning:
  - **What geological processes have shaped Mars?**
  - **What geological evidence tells us that water once flowed on Mars?**

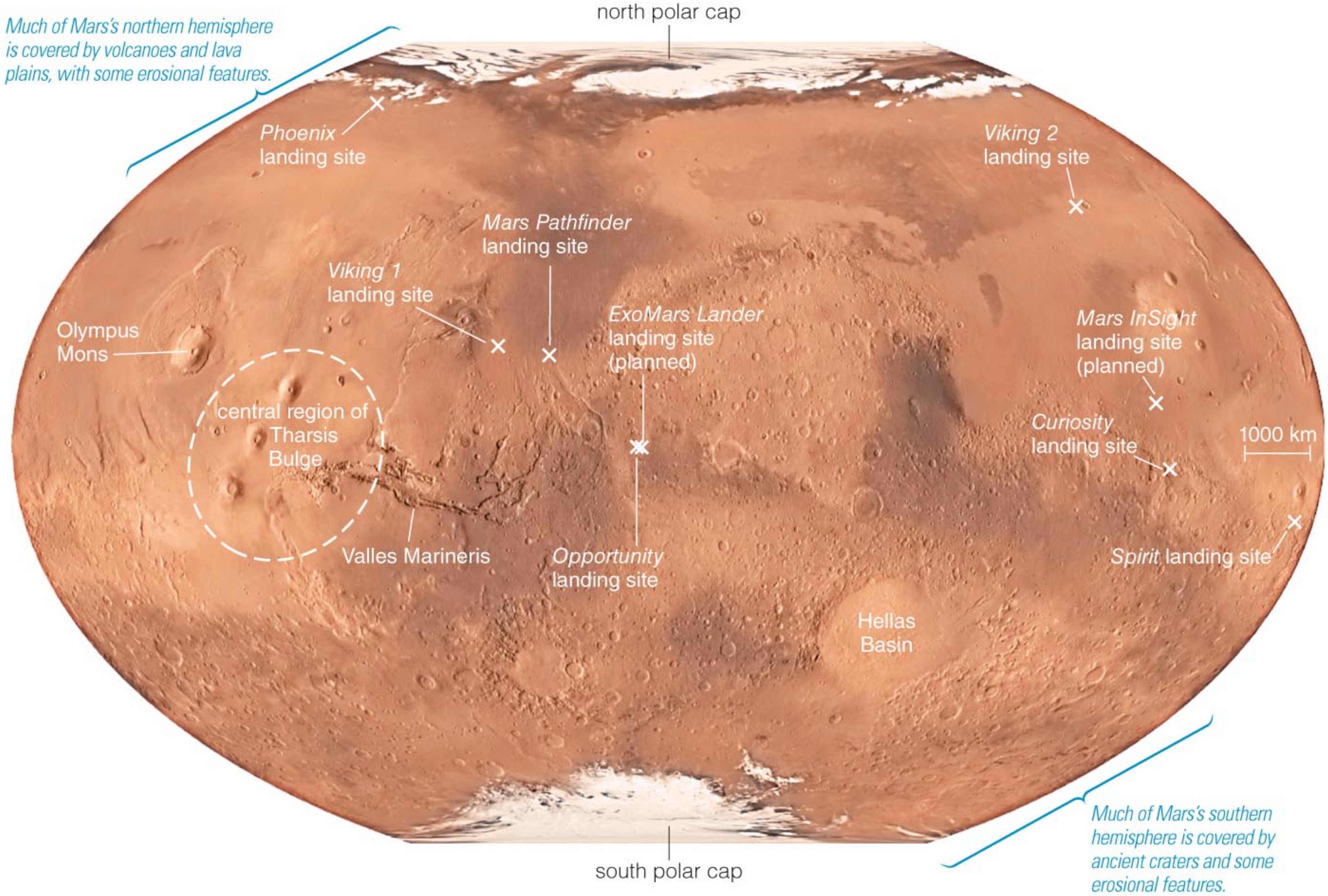
"Canals" on Mars



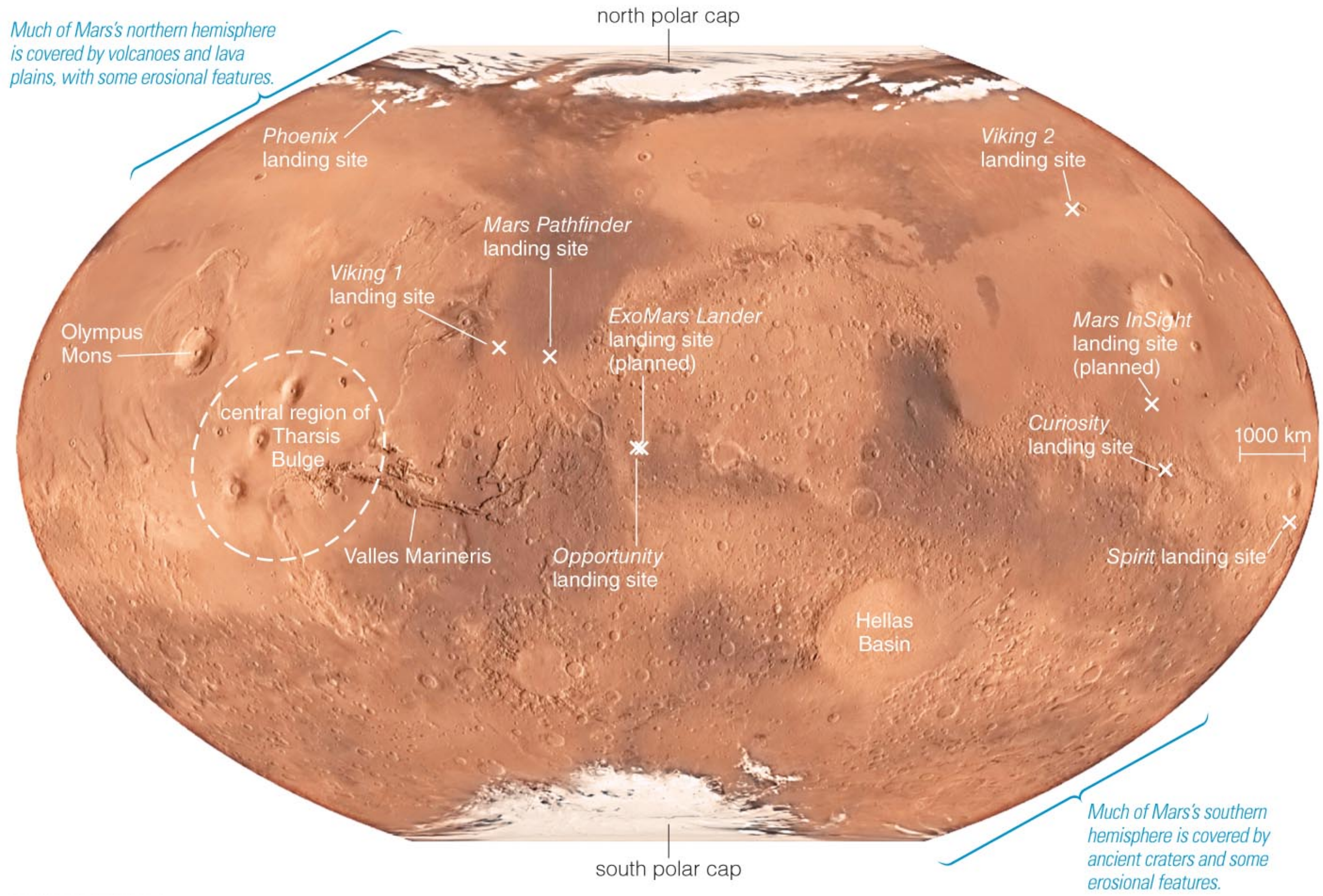


- Percival Lowell misinterpreted Giovanni Schiaparelli's observed surface features seen in telescopic images of Mars.

What geological processes have shaped Mars?

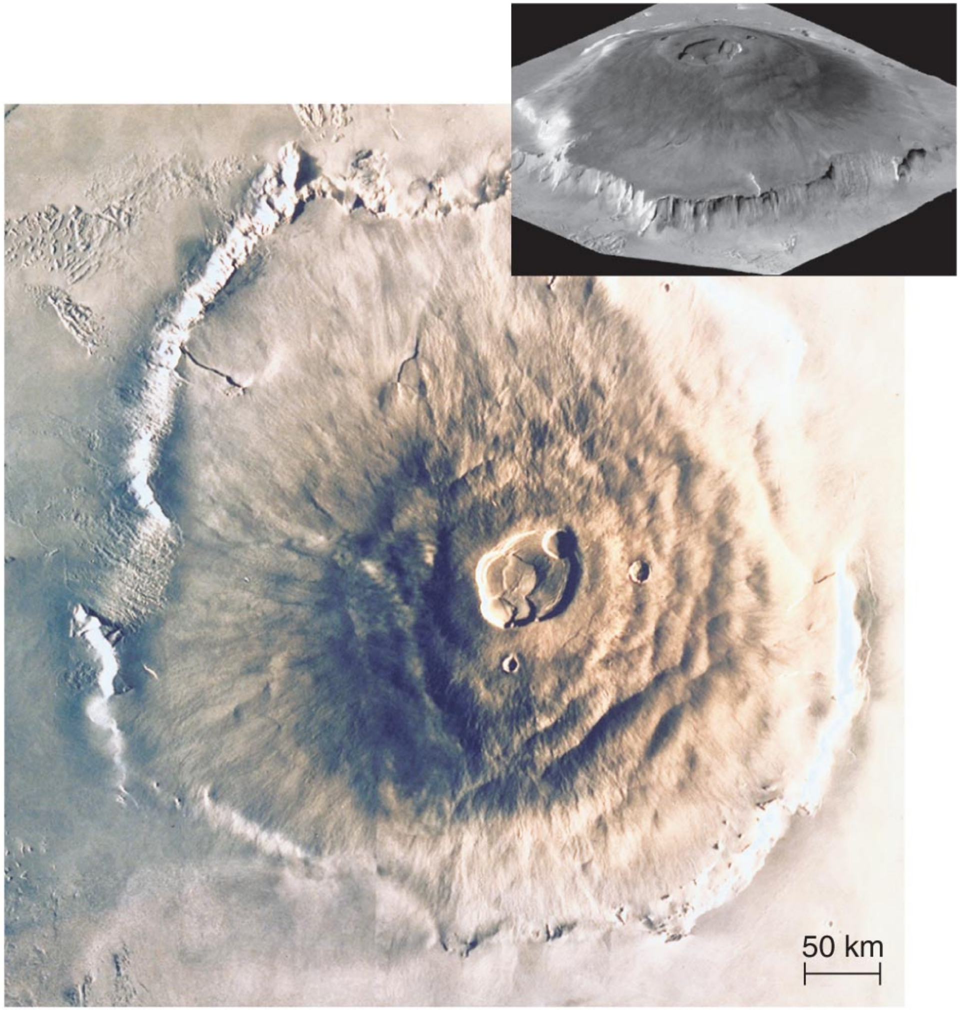


Cratering on Mars



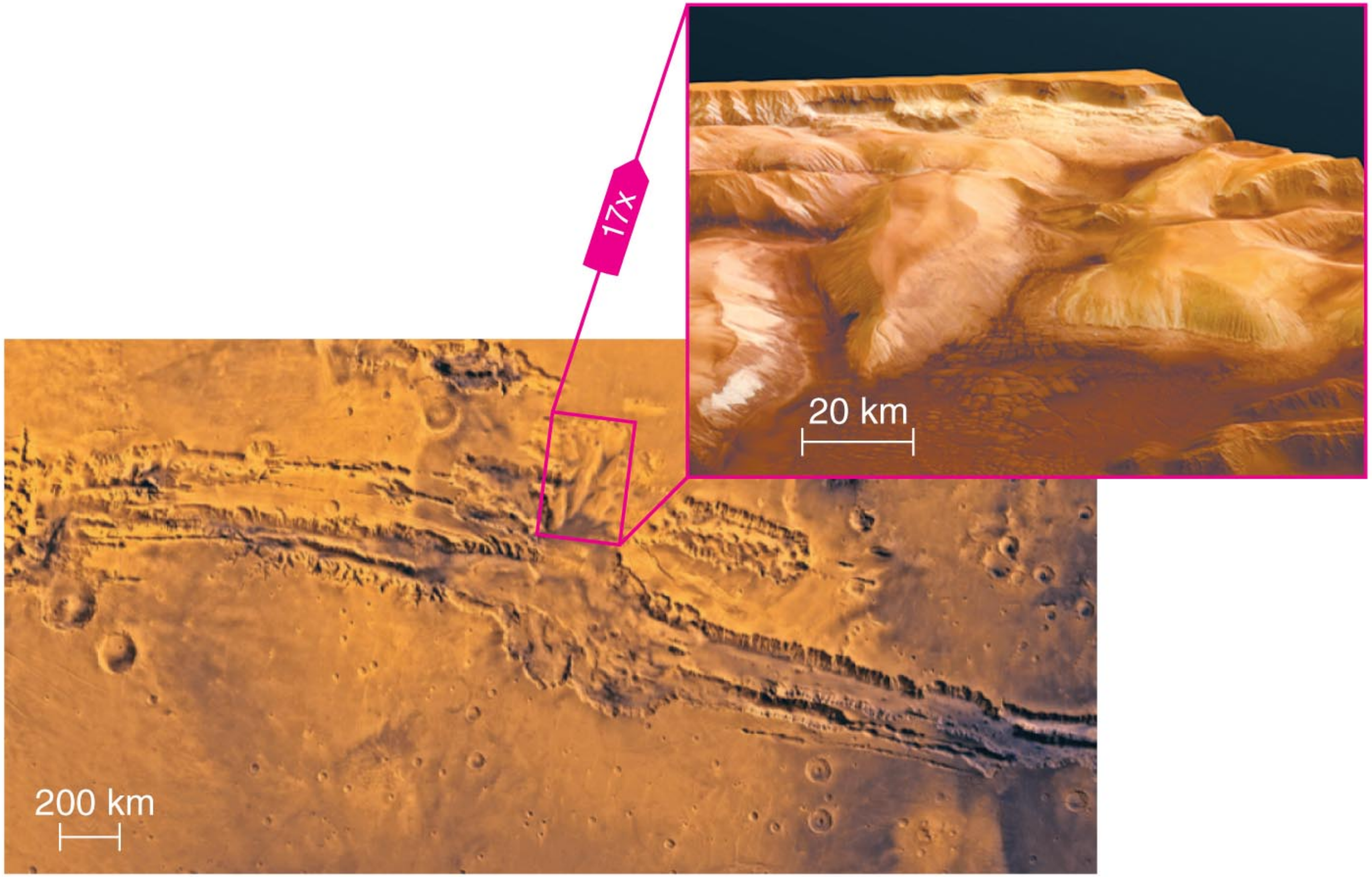
- The amount of cratering differs greatly across Mars's surface.
- Many early craters have been erased.

Volcanism on Mars



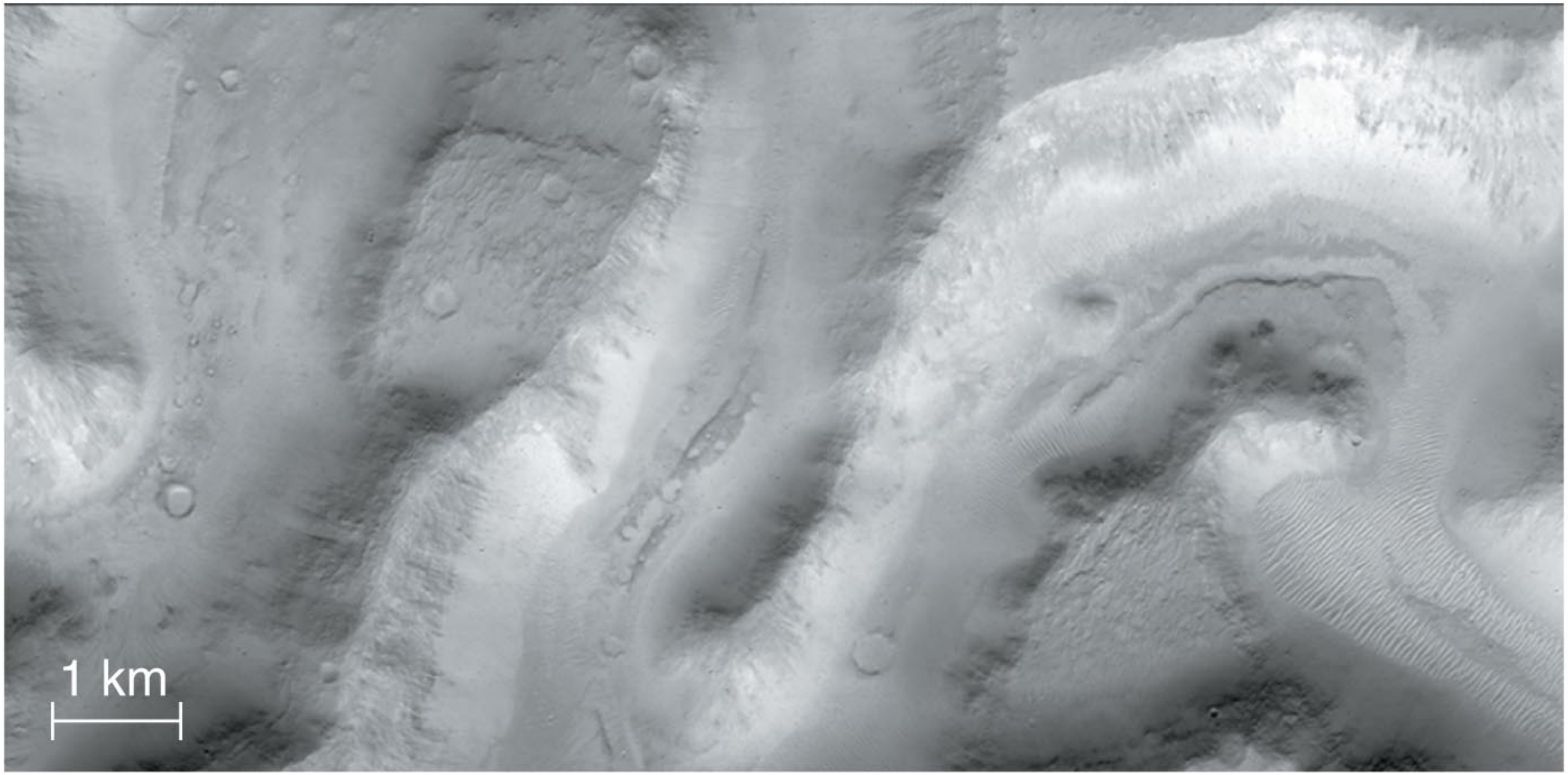
- Mars has many large shield volcanoes.
- Olympus Mons is largest volcano in solar system.

Tectonics on Mars

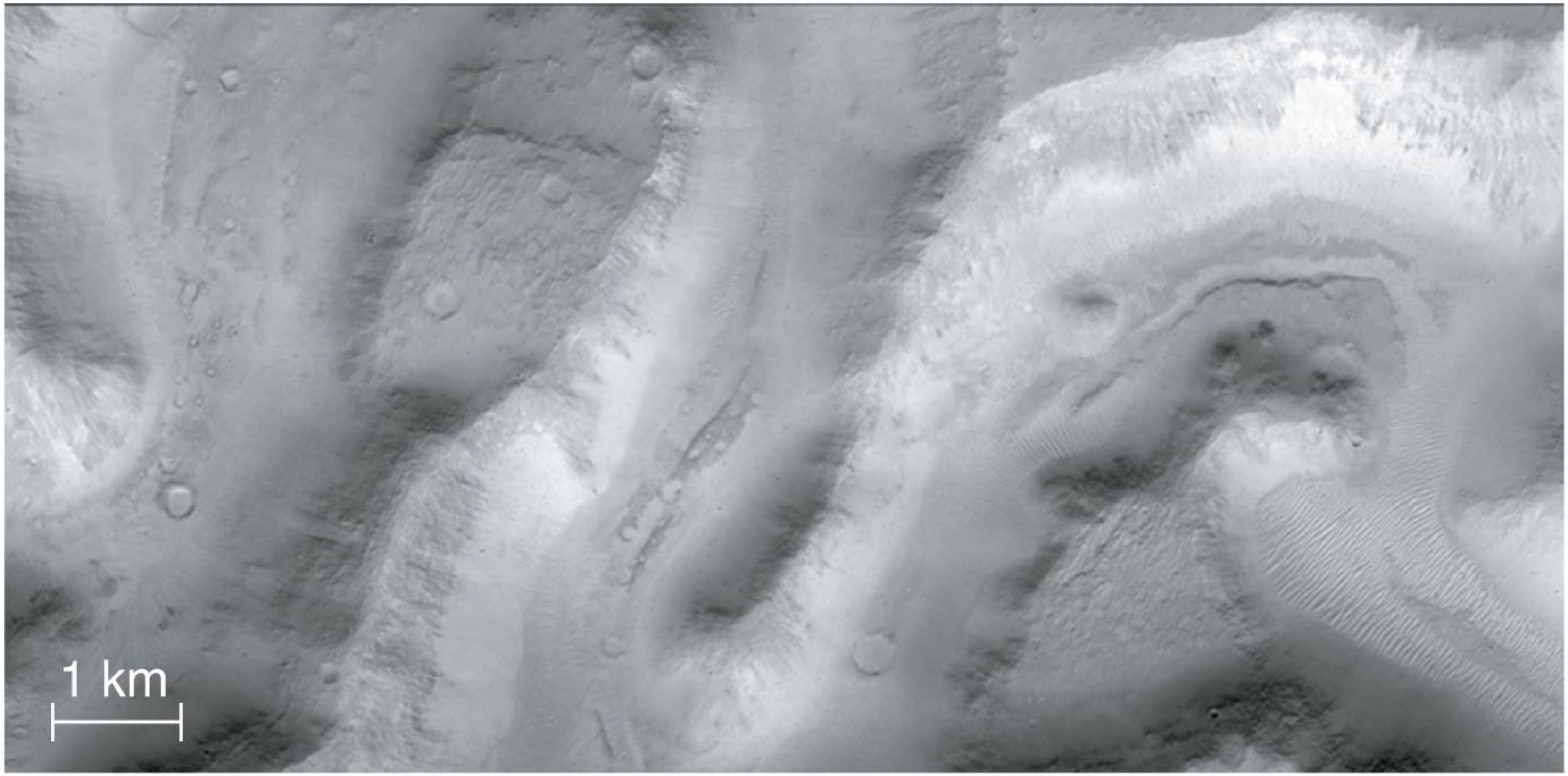


- The system of valleys known as Valles Marineris is thought to originate from tectonics.

What geological evidence tells us that water once flowed on Mars?



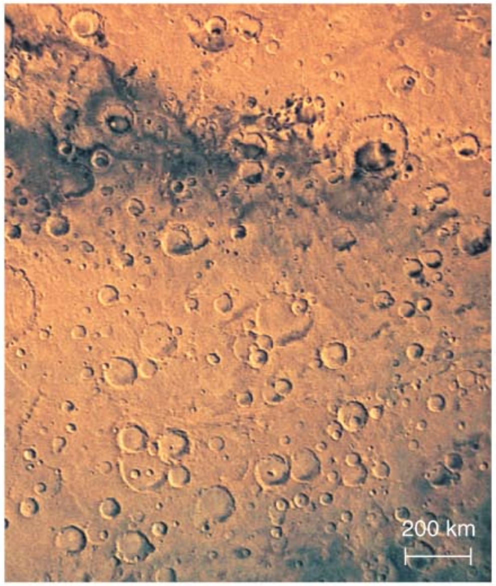
Dry Riverbeds?



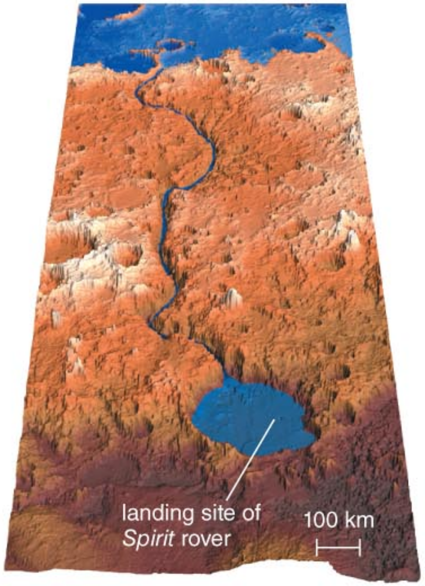
- Close-up photos of Mars show what appear to be dried-up riverbeds.

Erosion of Craters

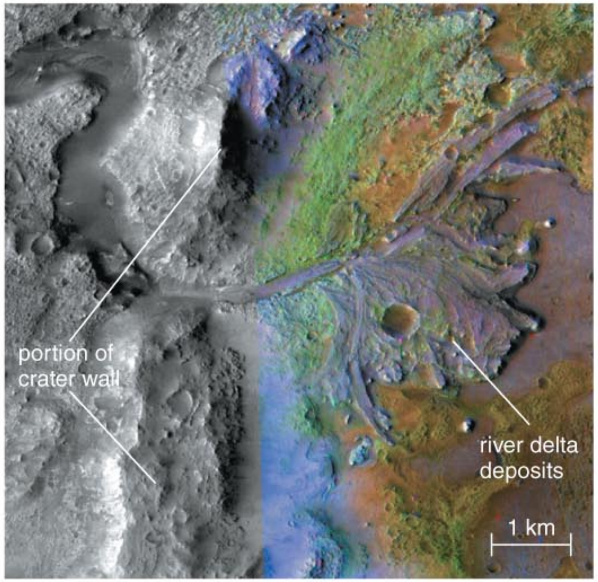
- Details of some craters suggest they were once filled with water.



a This photo shows a broad region of the southern highlands on Mars. The eroded rims of large craters and the relative lack of small craters suggest erosion by rainfall.

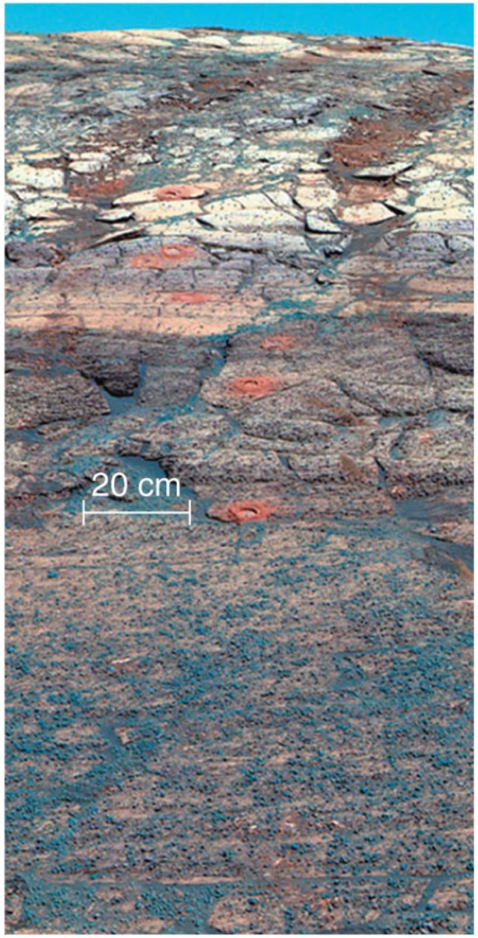


b This computer-generated perspective view shows how a Martian valley forms a natural passage between two possible ancient lakes (shaded blue). Vertical relief is exaggerated 14 times to reveal the topography.

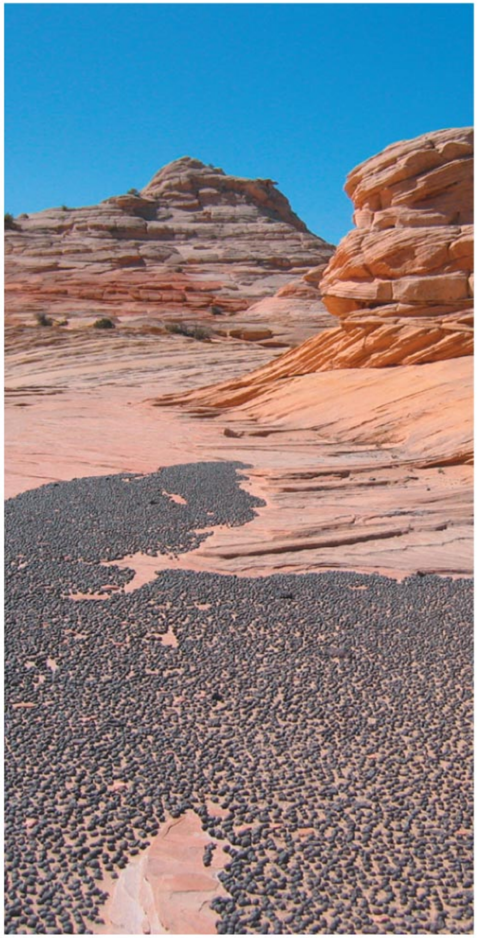


c Combined visible/infrared image of an ancient river delta that formed where water flowing down a valley emptied into a lake filling a large crater (portions of the crater wall are identified). Clay minerals are identified in green.

Martian Rocks



Mars (Endurance Crater)



Earth (Utah)

- Mars rovers have found rocks that appear to have formed in water.

Martian Rocks

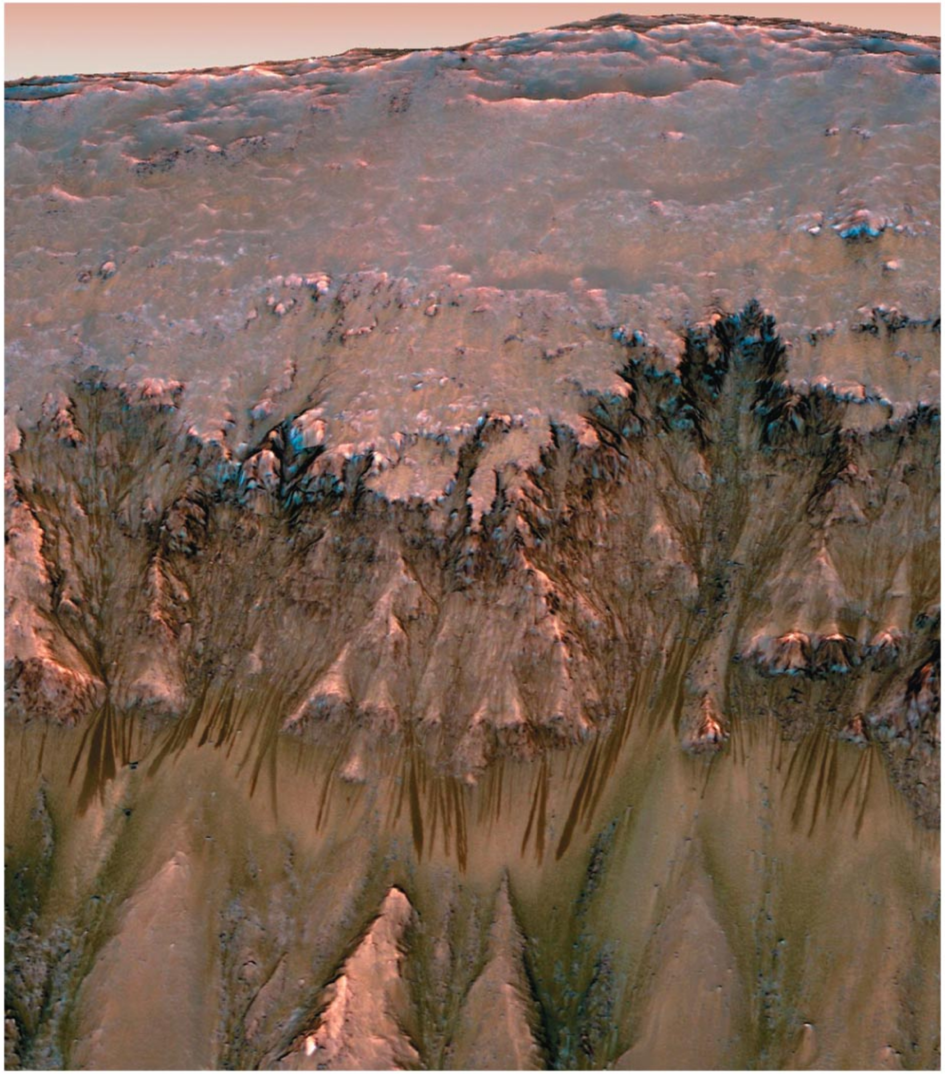
Mars

Earth

- Mars rovers have found rounded pebbles characteristic of those found in streams.

More Recent Water

- Dark streaks in this image may indicate salty water that seasonally melts.



What have we learned?

- **What are the major geological features of Mars?**
  - Differences in cratering across surface
  - Giant shield volcanoes
  - Evidence of tectonic activity

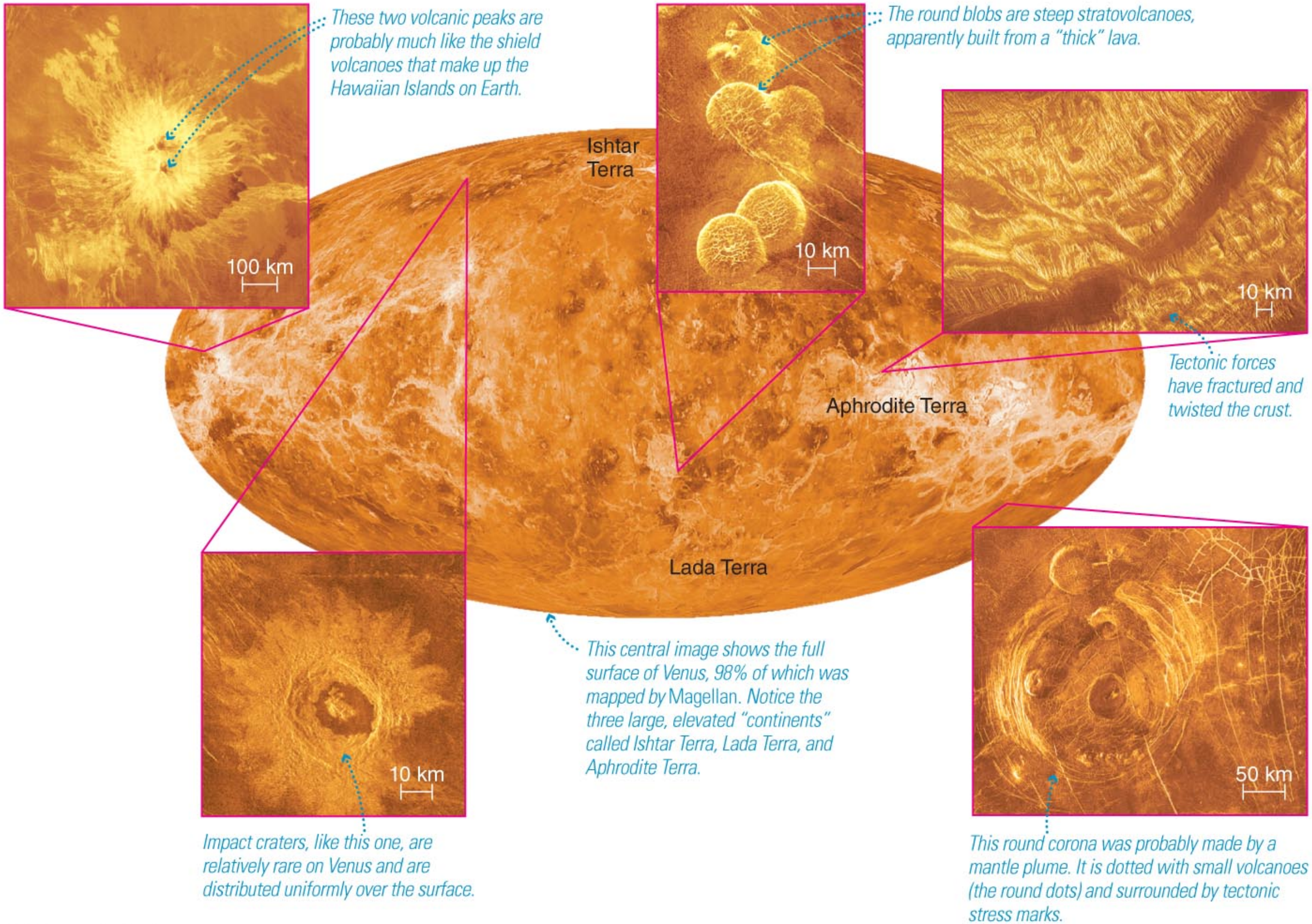
What have we learned?

- **What geological evidence tells us that water once flowed on Mars?**
  - Some surface features look like dry riverbeds.
  - Some craters appear to be eroded.
  - Rovers have found rocks that appear to have formed in water.
  - Gullies in crater walls may indicate recent water flows.

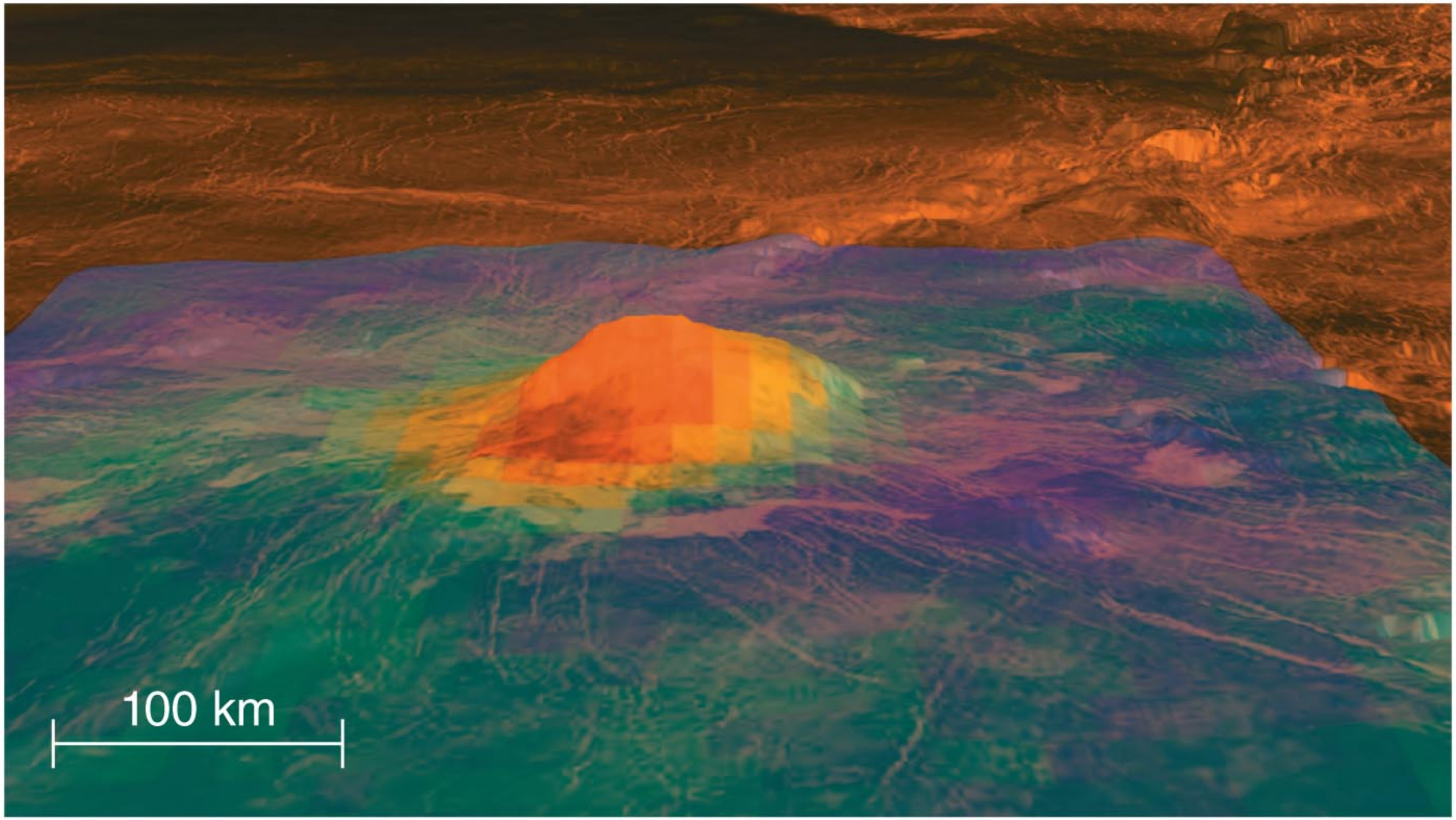
9.5 Geology of Venus

- Our goals for learning:
  - **What geological processes have shaped Venus?**
  - **Does Venus have plate tectonics?**

What geological processes have shaped Venus?

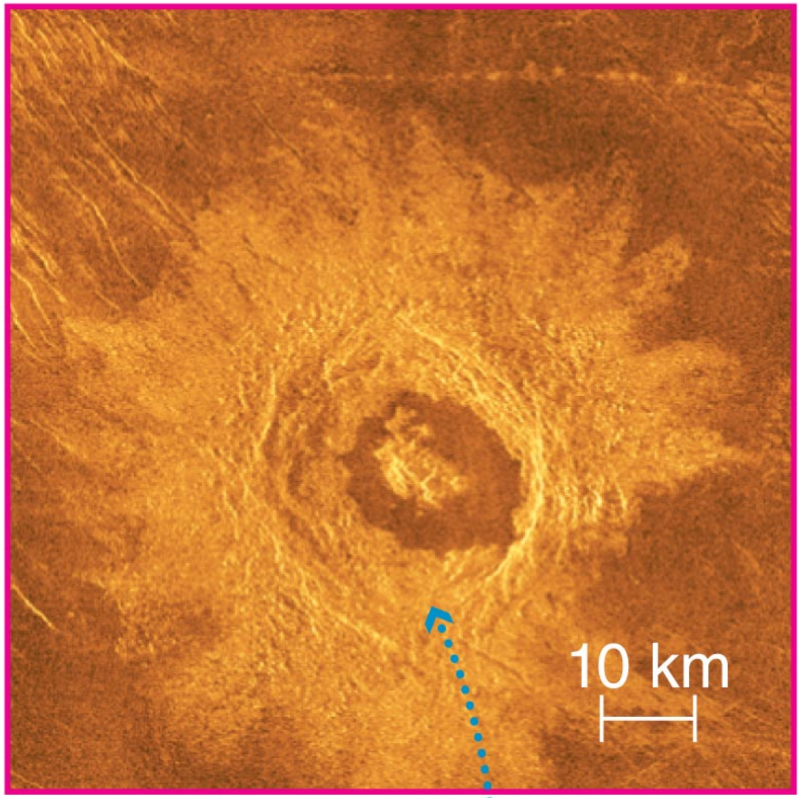


Radar Mapping



- Its thick atmosphere forces us to explore Venus's surface through radar mapping.

Cratering on Venus

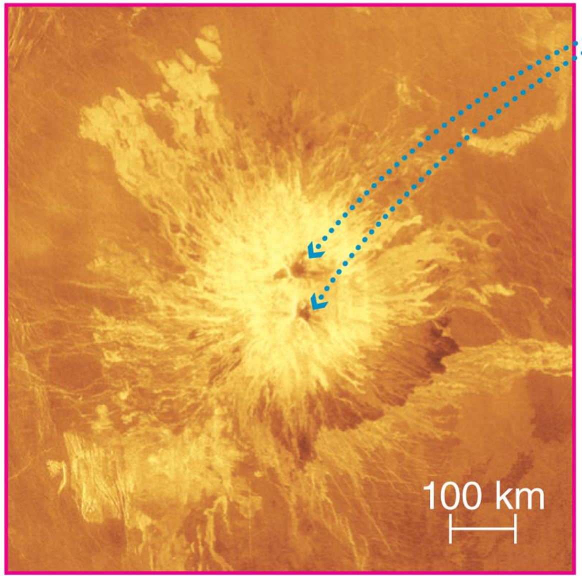


Impact craters, like this one, are relatively rare on Venus and are distributed uniformly over the surface.

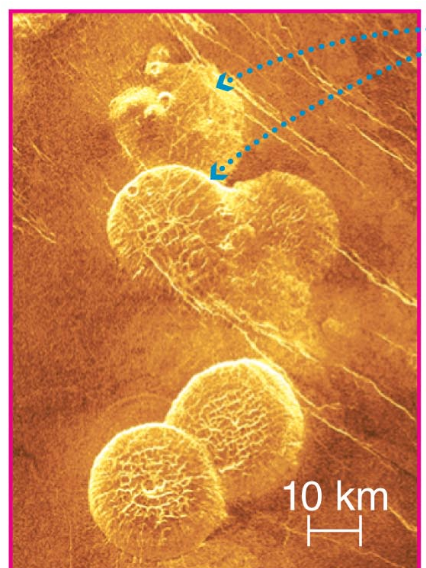
- Venus has impact craters, but fewer than the Moon, Mercury, or Mars.

Why, in your opinion?

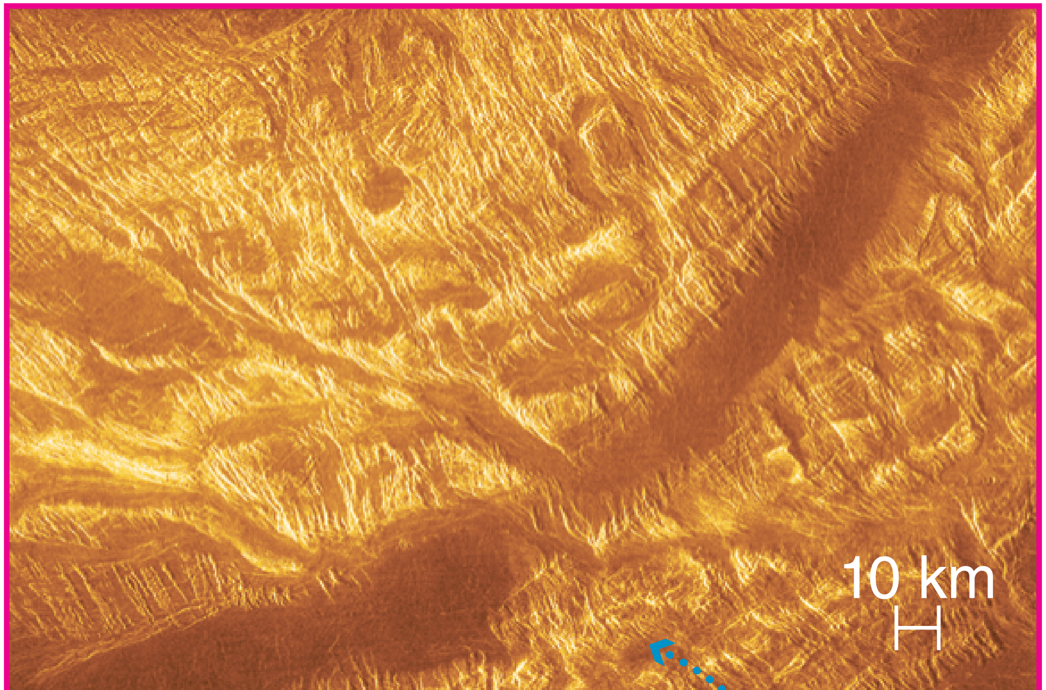
Cratering on Venus



- It has many volcanoes, including both shield volcanoes and stratovolcanoes.



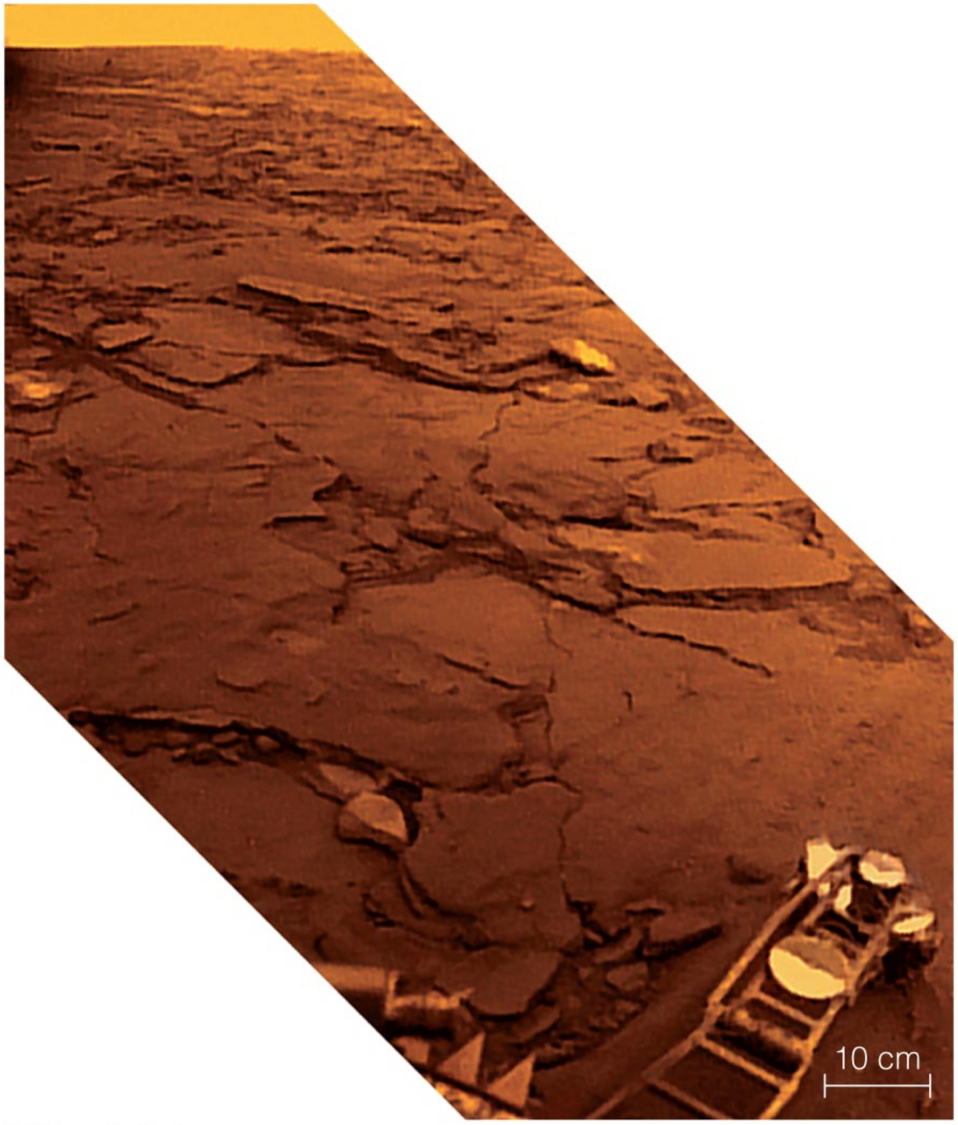
Tectonics on Venus



Tectonic forces have fractured and twisted the crust.

- The planet's fractured and contorted surface indicates tectonic stresses.

Erosion on Venus



- Photos of rocks taken by landers show little erosion.

Why, in your opinion?

Does Venus have plate tectonics?

- Venus does not appear to have plate tectonics, but entire surface seems to have been "repaved" 750 million years ago.
  - Weaker convection?
  - Thicker or more rigid lithosphere?

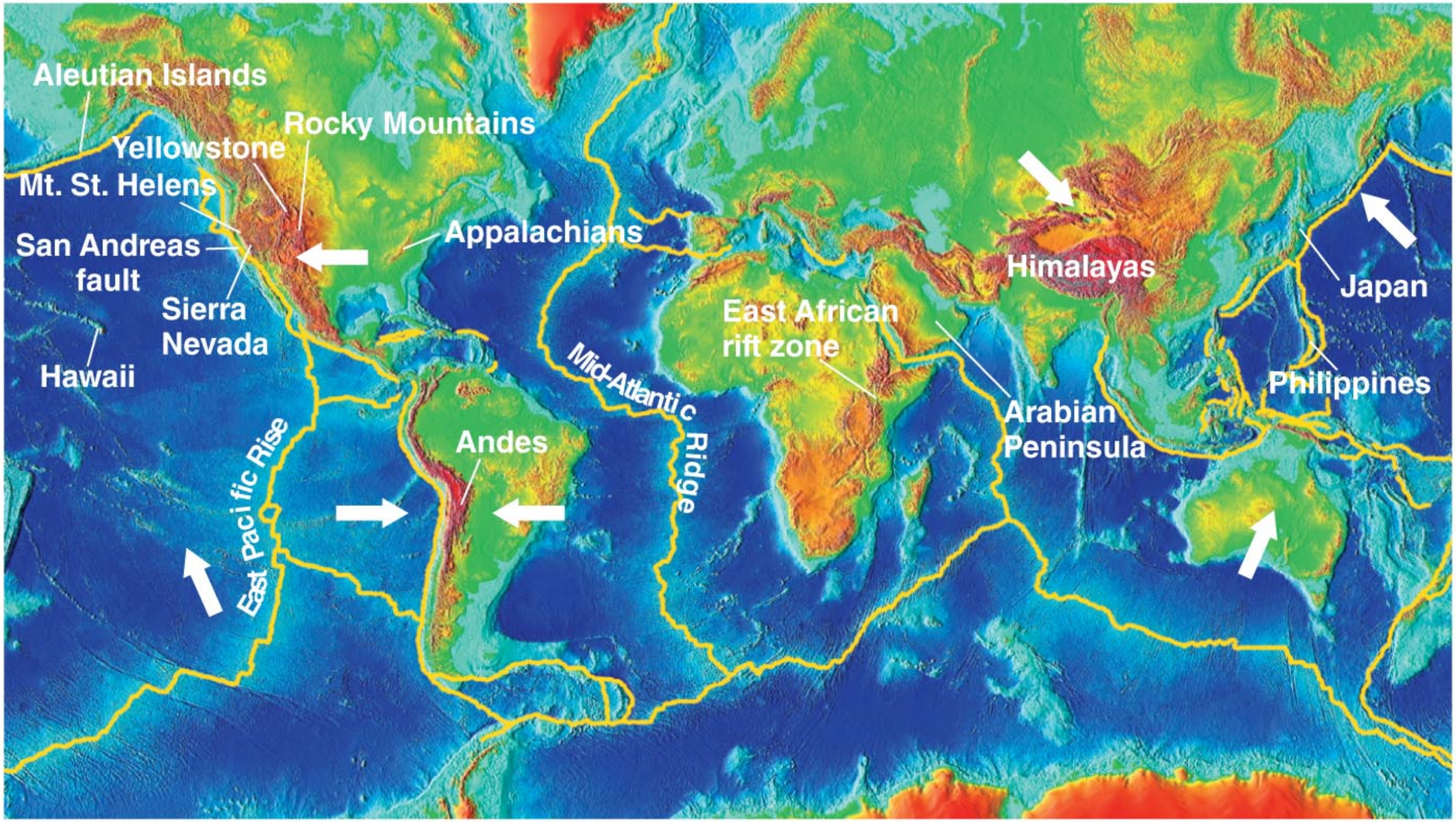
What have we learned?

- **What geological processes have shaped Venus?**
  - Venus has cratering, volcanism, and tectonics but not much erosion.
- **Does Venus have plate tectonics?**
  - The lack of plate tectonics on Venus is a mystery.

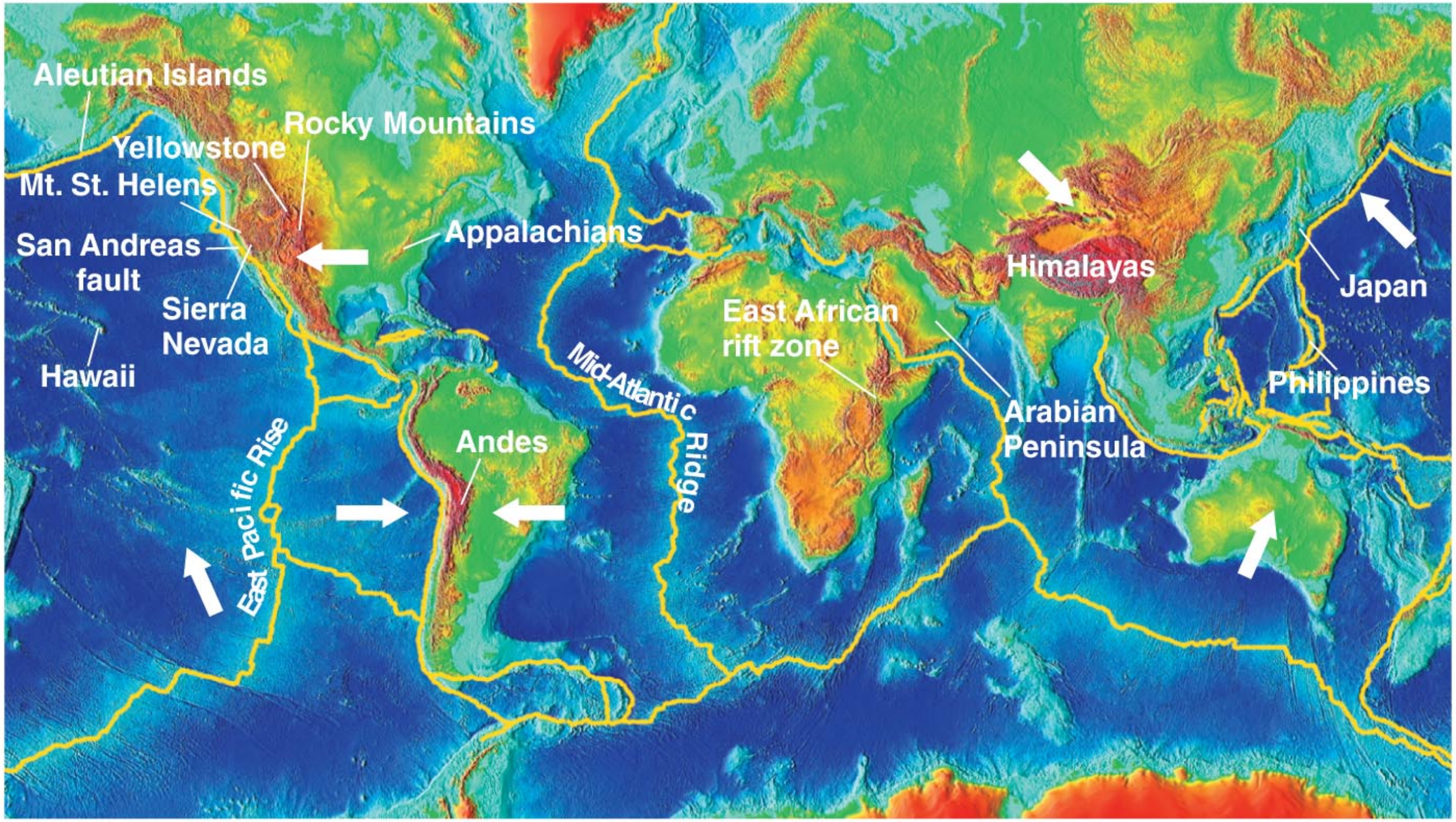
9.6 The Unique Geology of Earth

- Our goals for learning:
  - **How is Earth's surface shaped by plate tectonics?**
  - **Was Earth's geology destined from birth?**

How is Earth's surface shaped by plate tectonics?



Continental Motion

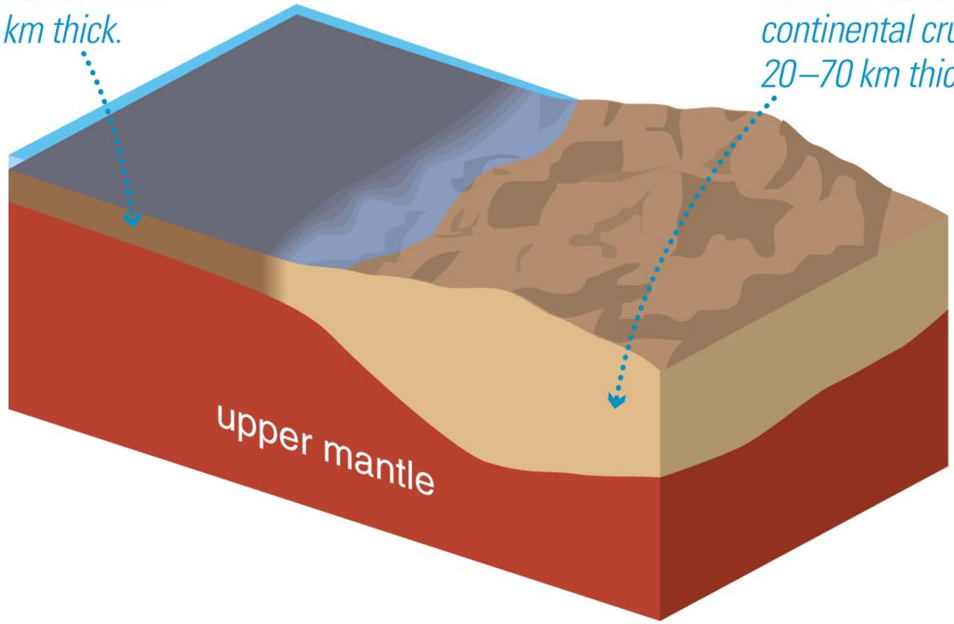


- Motion of the continents can be measured with GPS.

Continental Motion

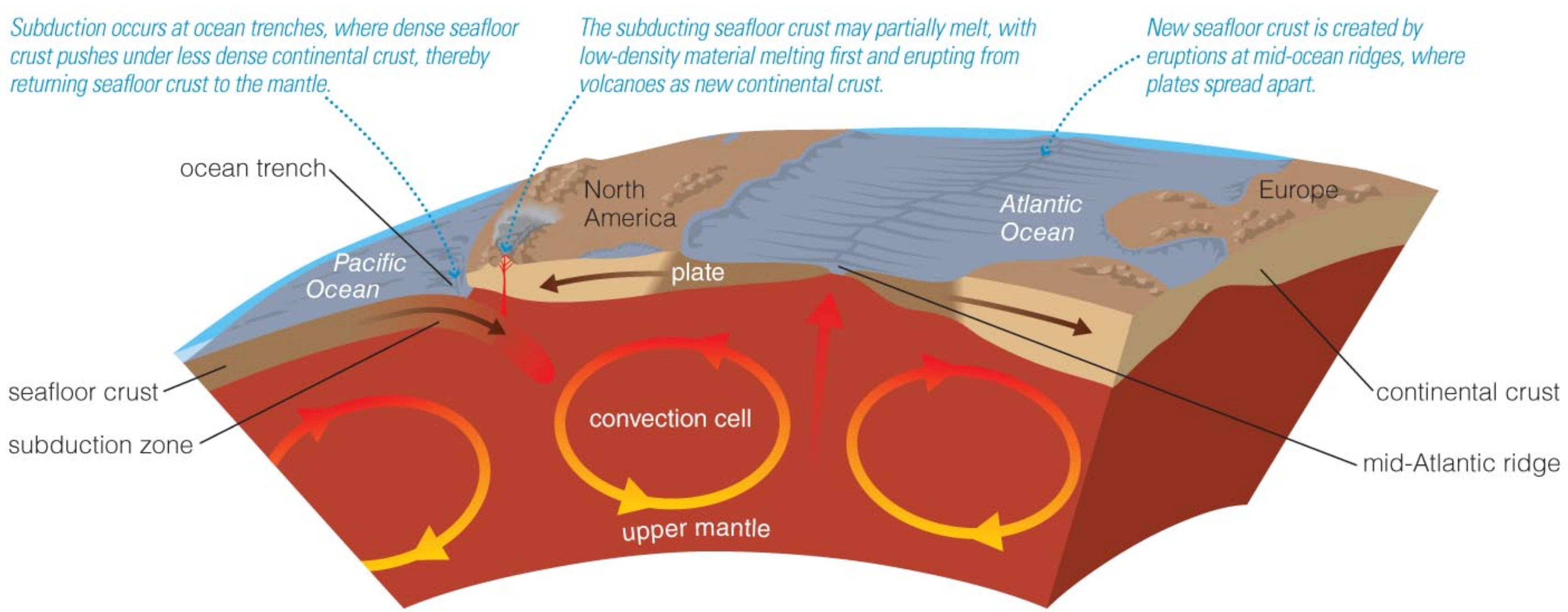
- The idea of continental drift was inspired by the puzzle-like fit of the continents.
- Mantle material erupts where the seafloor spreads.

Seafloor Crust



- Thin seafloor crust differs from thick continental crust.
- Dating of the seafloor shows that it is usually quite young.

Seafloor Recycling

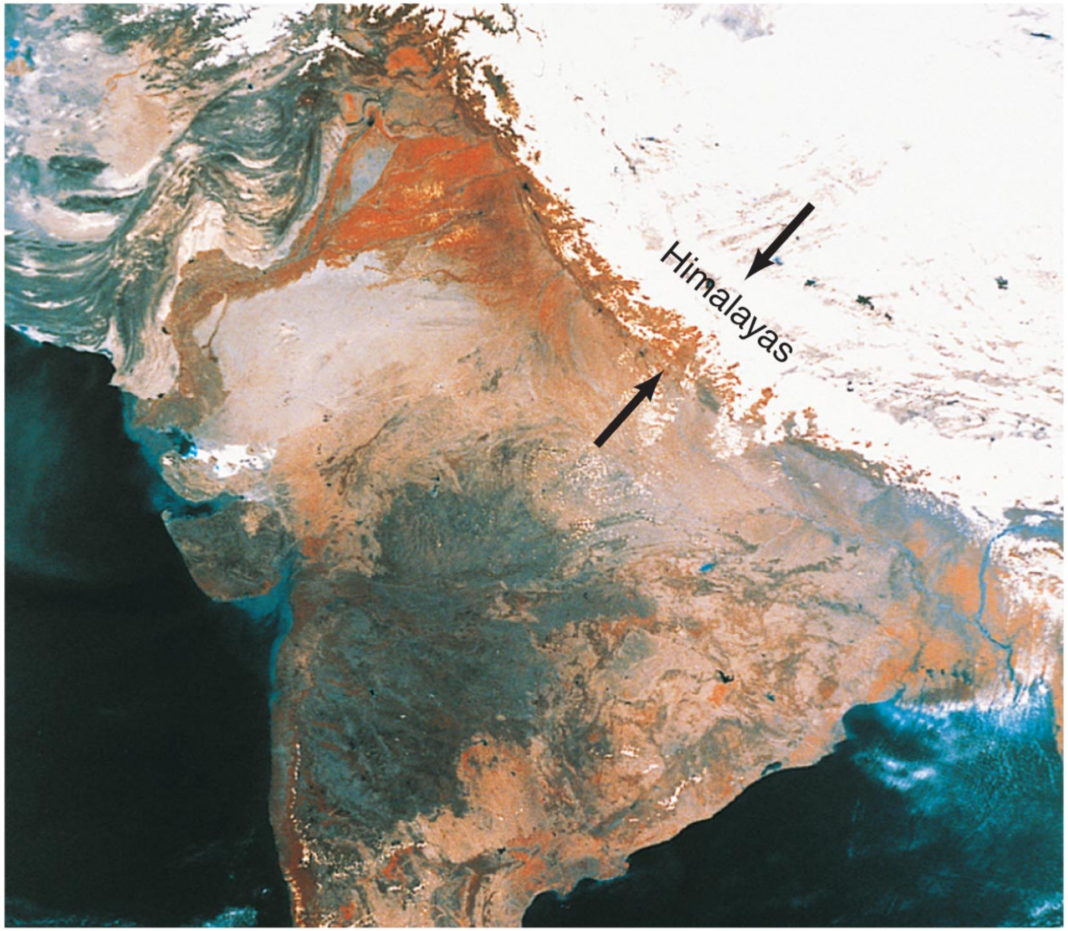


- Seafloor is recycled through a process known as subduction.

Surface Features

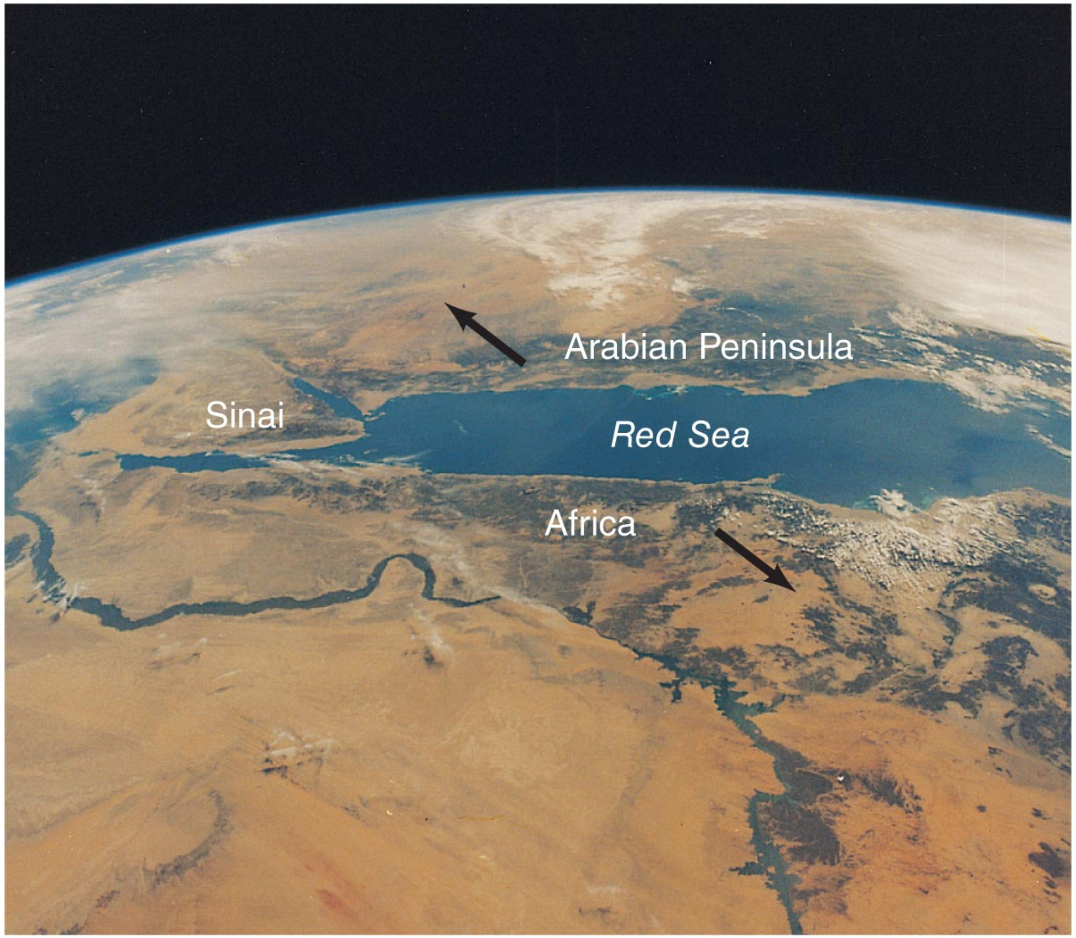
- Major geological features of North America record the history of plate tectonics.

Surface Features



- The Himalayas formed from a collision between plates.

Surface Features



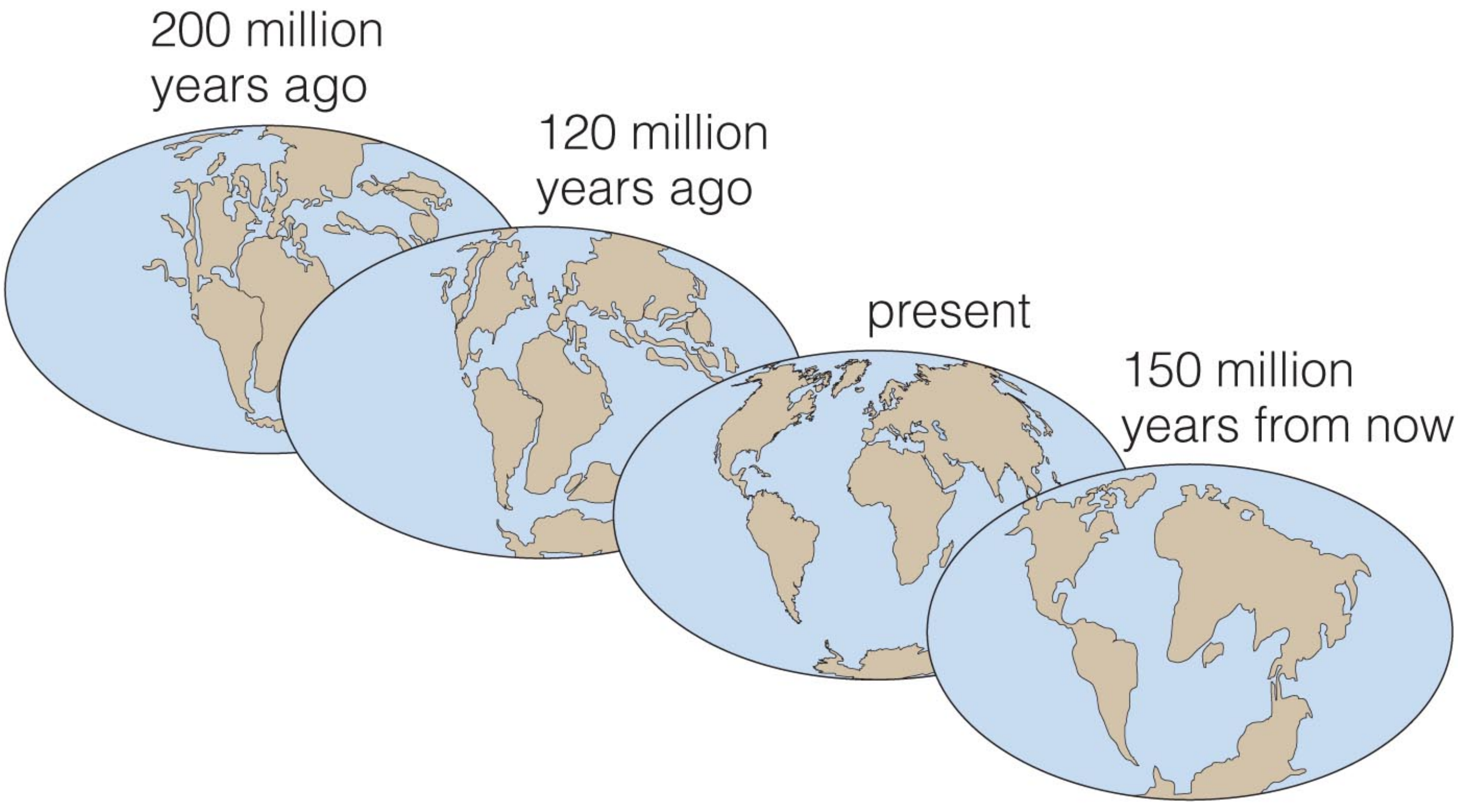
- The Red Sea is formed where plates are pulling apart.

Rifts, Faults, Earthquakes

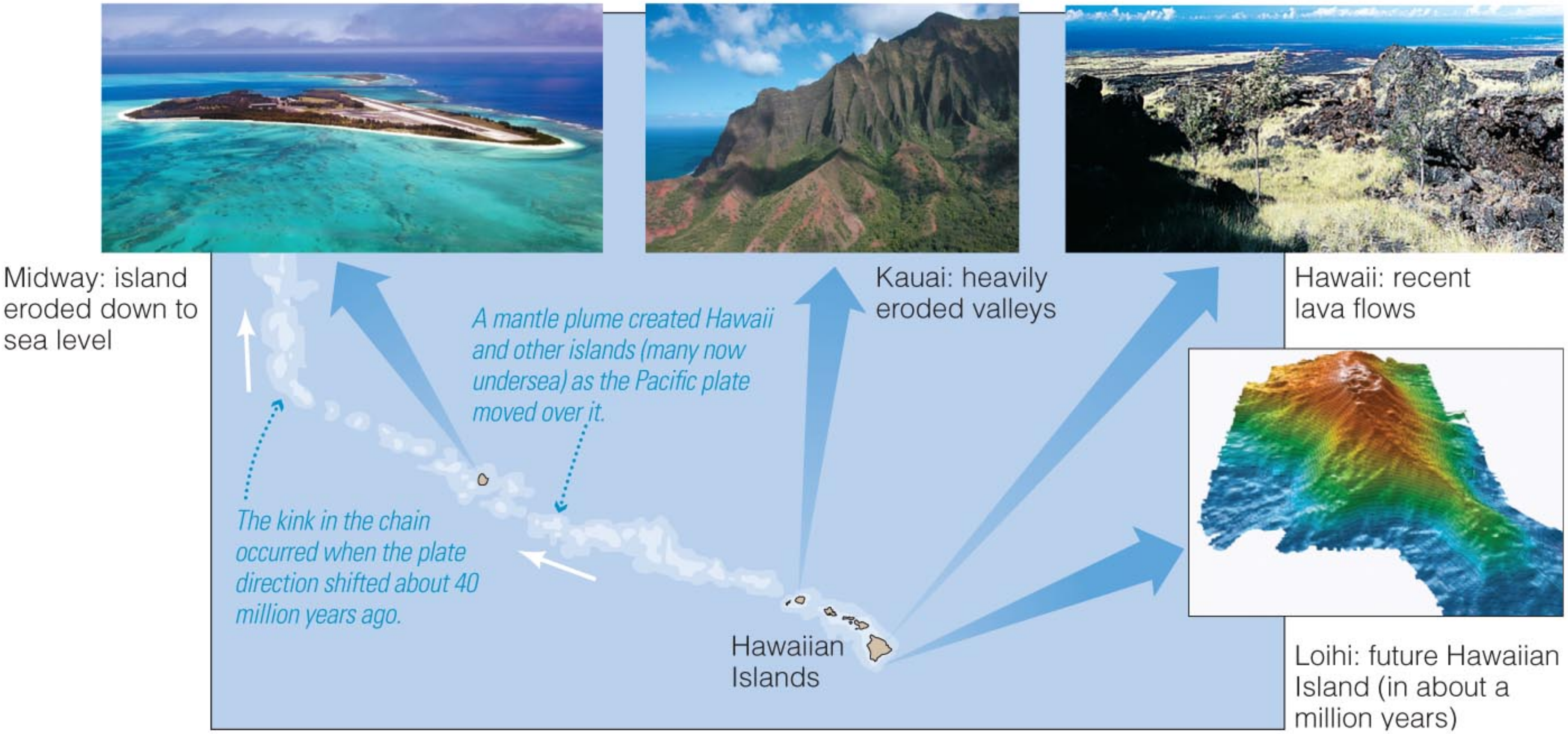
- The San Andreas fault in California is a plate boundary.
- Motion of plates can cause earthquakes.

Plate Motions

- Measurements of plate motions tell us past and future layout of the continents.

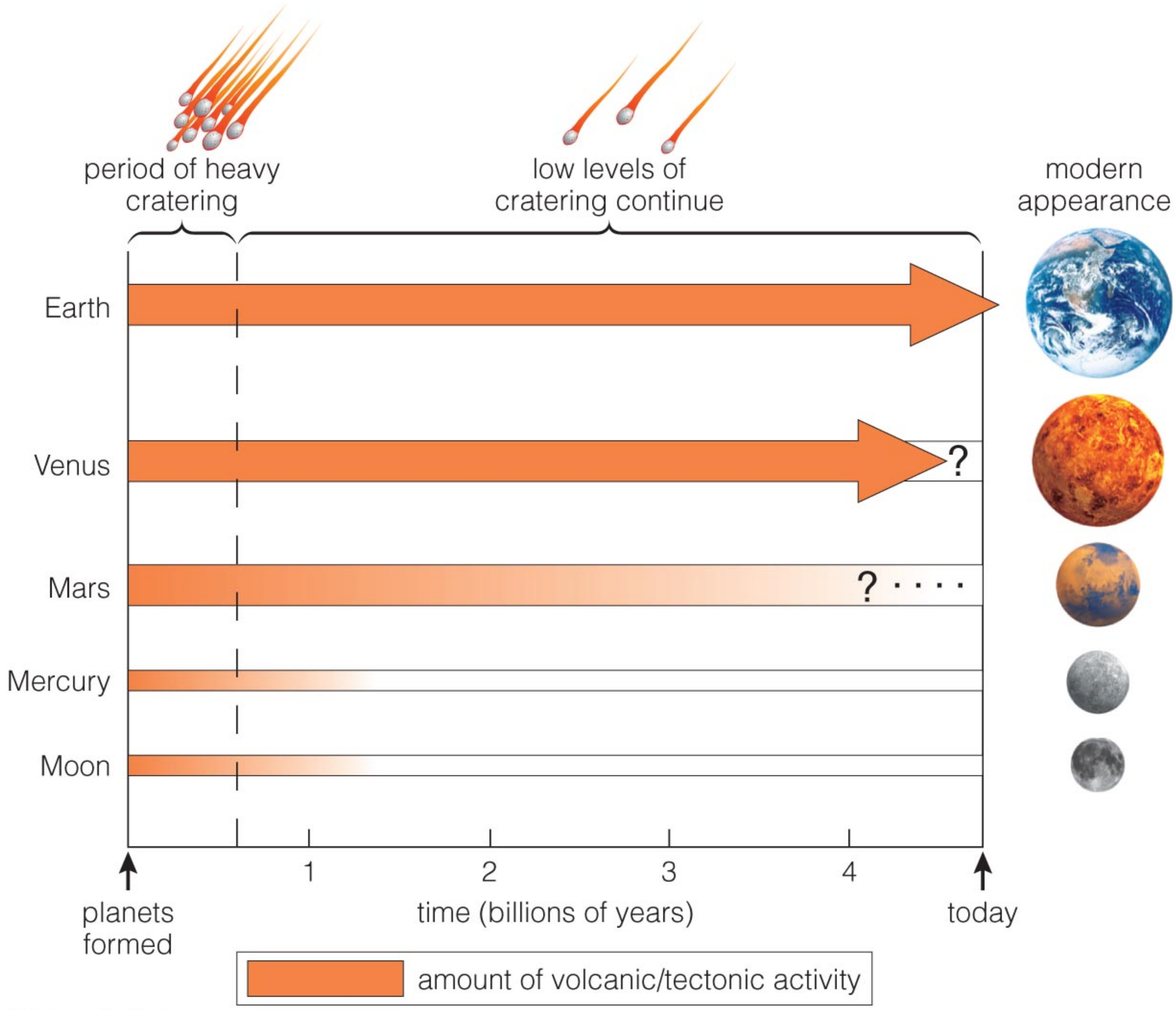


Hot Spots

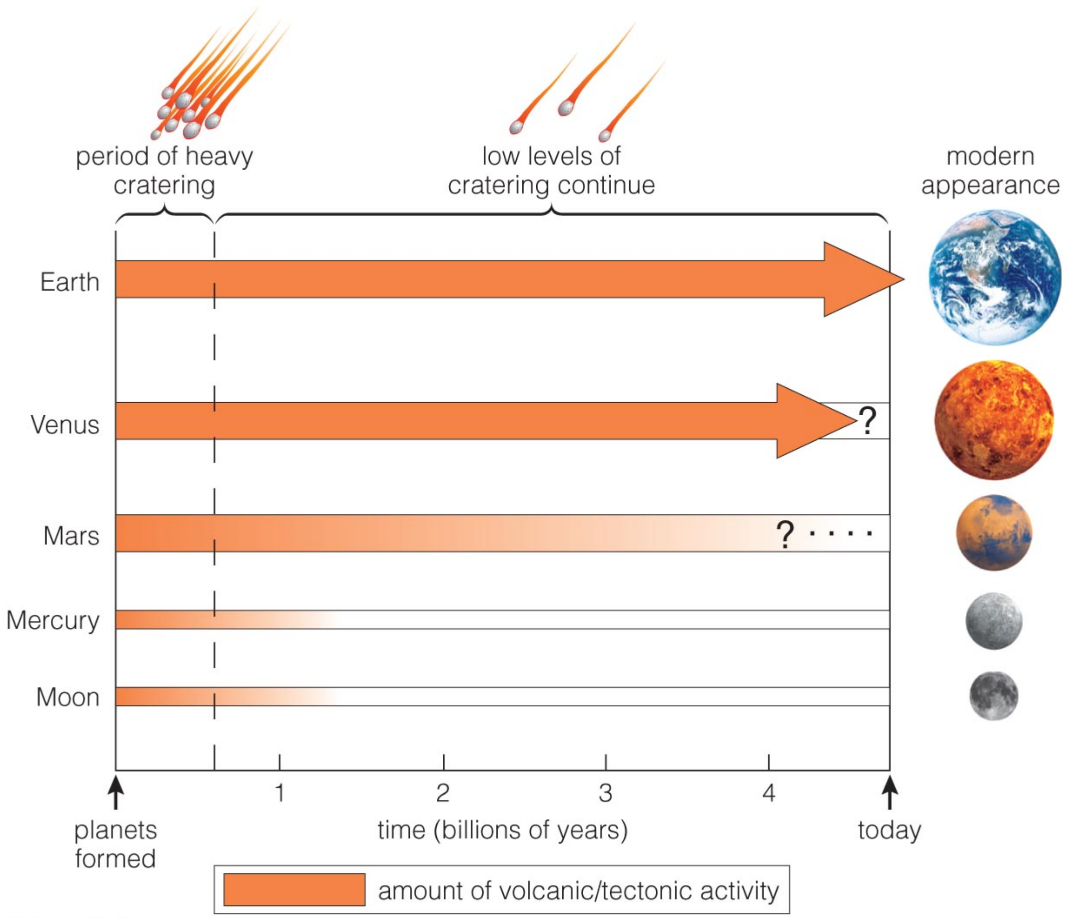


- The Hawaiian islands have formed where a plate is moving over a volcanic hot spot.

Was Earth's geology destined from birth?



Earth's Destiny



- Many of Earth's features are determined by its size, rotation, and distance from Sun.
- The reason for plate tectonics is not yet clear.

What have we learned?

- **How is Earth's surface shaped by plate tectonics?**
  - Measurements of plate motions confirm the idea of continental drift.
  - Plate tectonics is responsible for subduction, seafloor spreading, mountains, rifts, and earthquakes.

What have we learned?

- **Was Earth's geology destined from birth?**
  - Many of Earth's features are determined by its size, distance from Sun, and rotation rate.
  - The reason for plate tectonics is still a mystery.

A theory of plate tectonics: Pangaea

235 million years to date

Michael Klaas @ YouTube