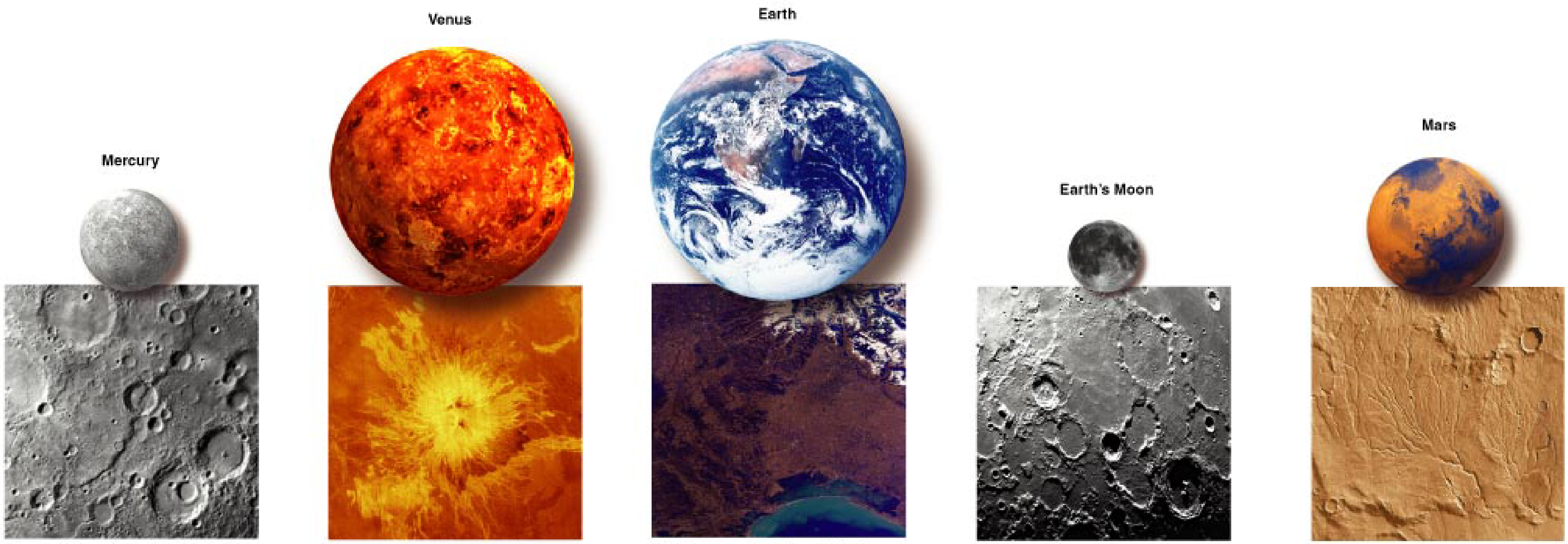
Chapter 9
Planetary Geology:
Earth and the Other Terrestrial Worlds

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?

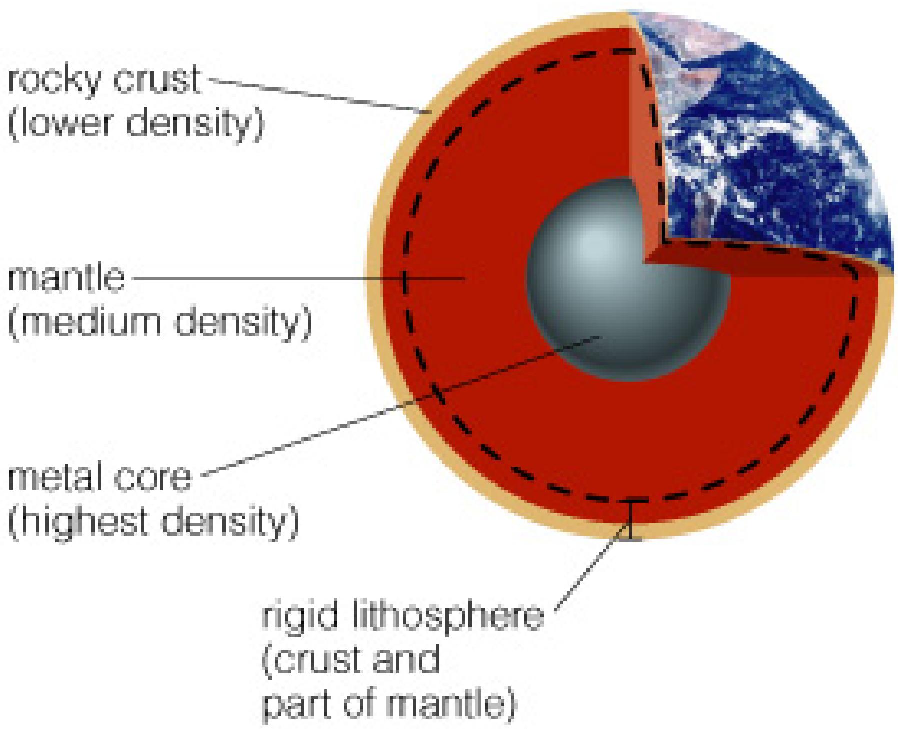
What are terrestrial planets like on the inside?



Seismic Waves

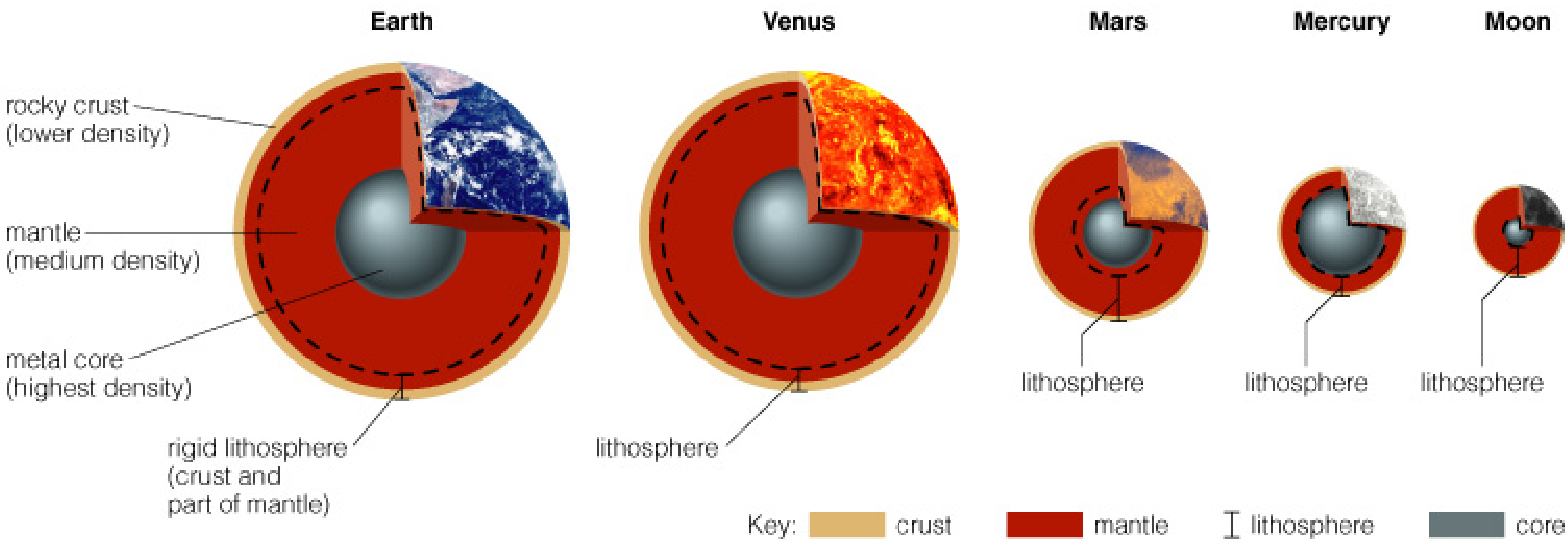
- Vibrations that travel through Earth’s interior tell us what Earth is like on the inside

Earth's Interior



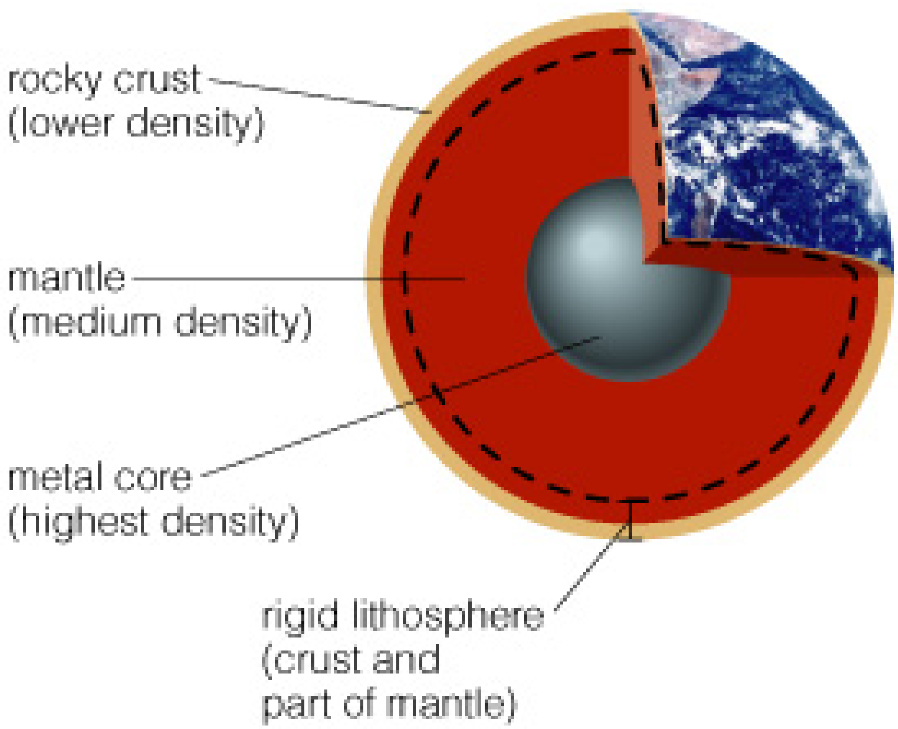
- **Core:** Highest density; nickel and iron
- **Mantle:** Moderate density; silicon, oxygen, etc.
- **Crust:** Lowest density; granite, basalt, etc.

Terrestrial Planet Interiors



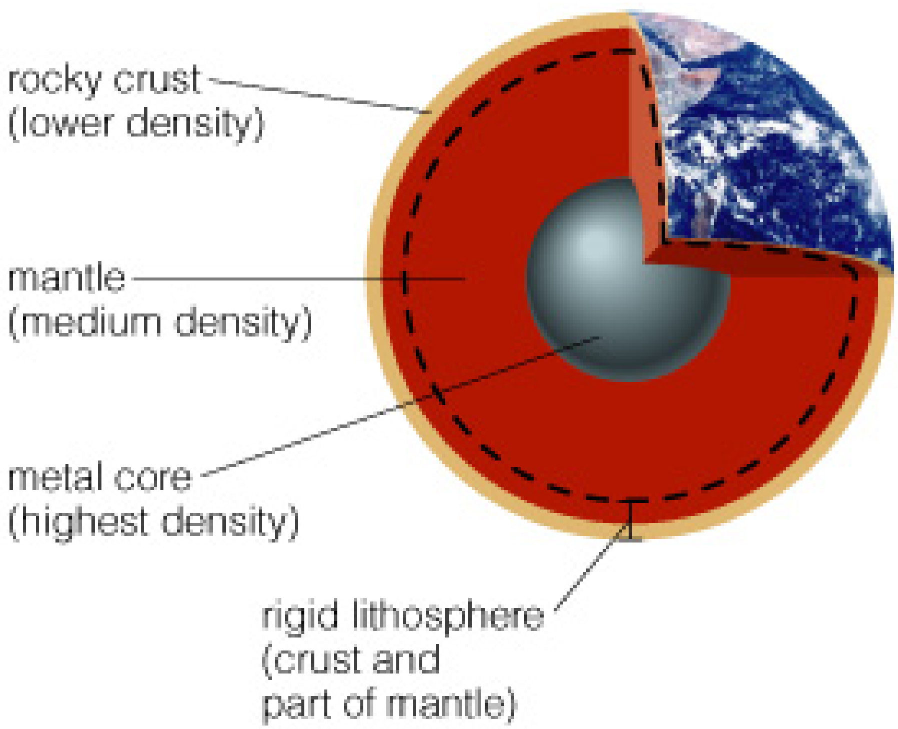
- Applying what we have learned about Earth's interior to other planets tells us what their interiors are probably like

Differentiation



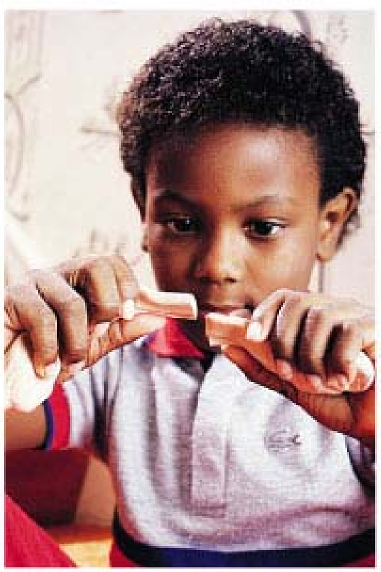
- Gravity pulls high-density material to center
- Lower-density material rises to surface
- Material ends up separated by density

Lithosphere



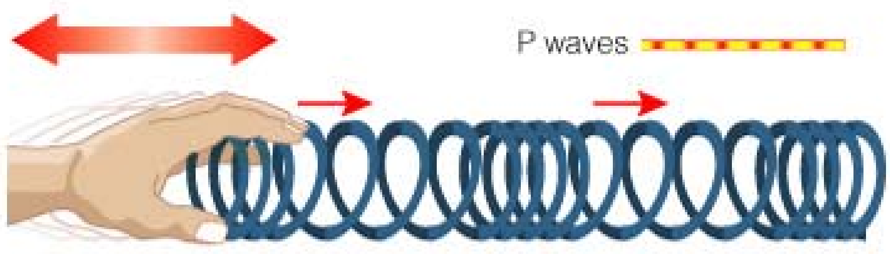
- A planet's outer layer of cool, rigid rock is called the lithosphere
- It "floats" on the warmer, softer rock that lies beneath

Strength of Rock

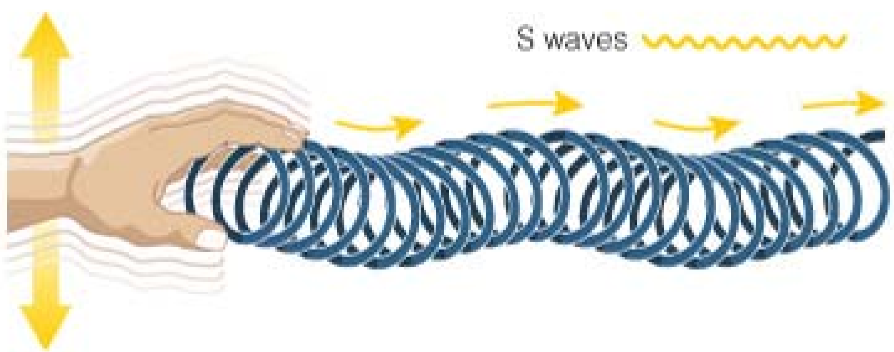


- Rock stretches when pulled slowly but breaks when pulled rapidly
- The gravity of a large world pulls slowly on its rocky content, shaping the world into a sphere

Special Topic:
How do we know what's inside a planet?



- P waves push matter back and forth

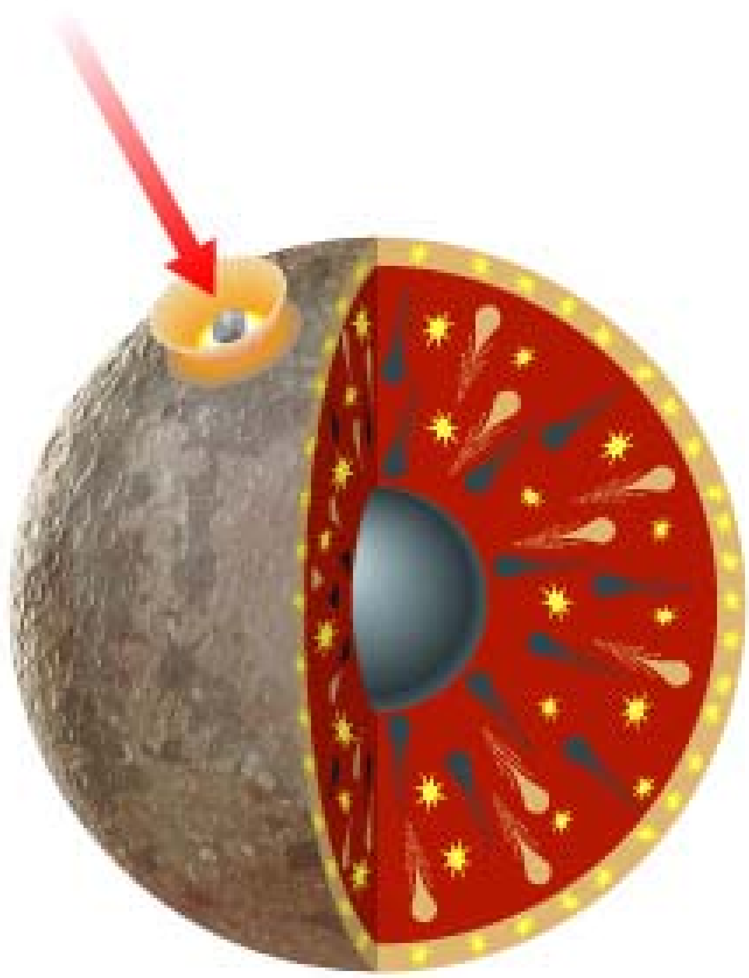


- S waves shake matter side to side

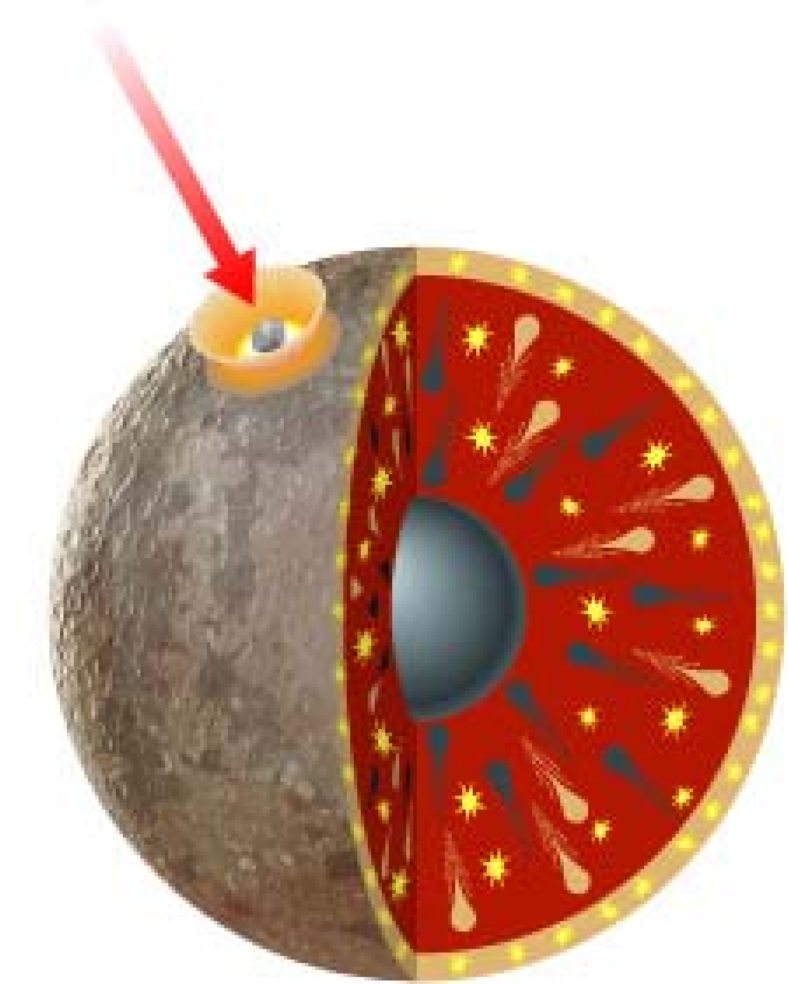
Special Topic:
How do we know what's inside a planet?

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

What causes geological activity?

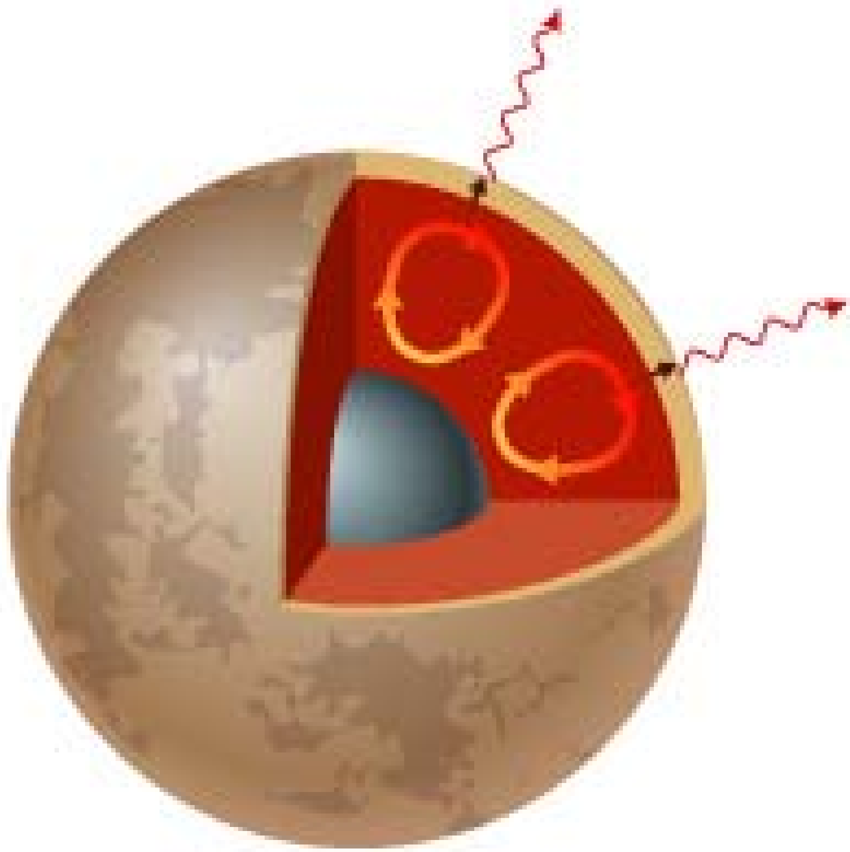


Heating of Interior



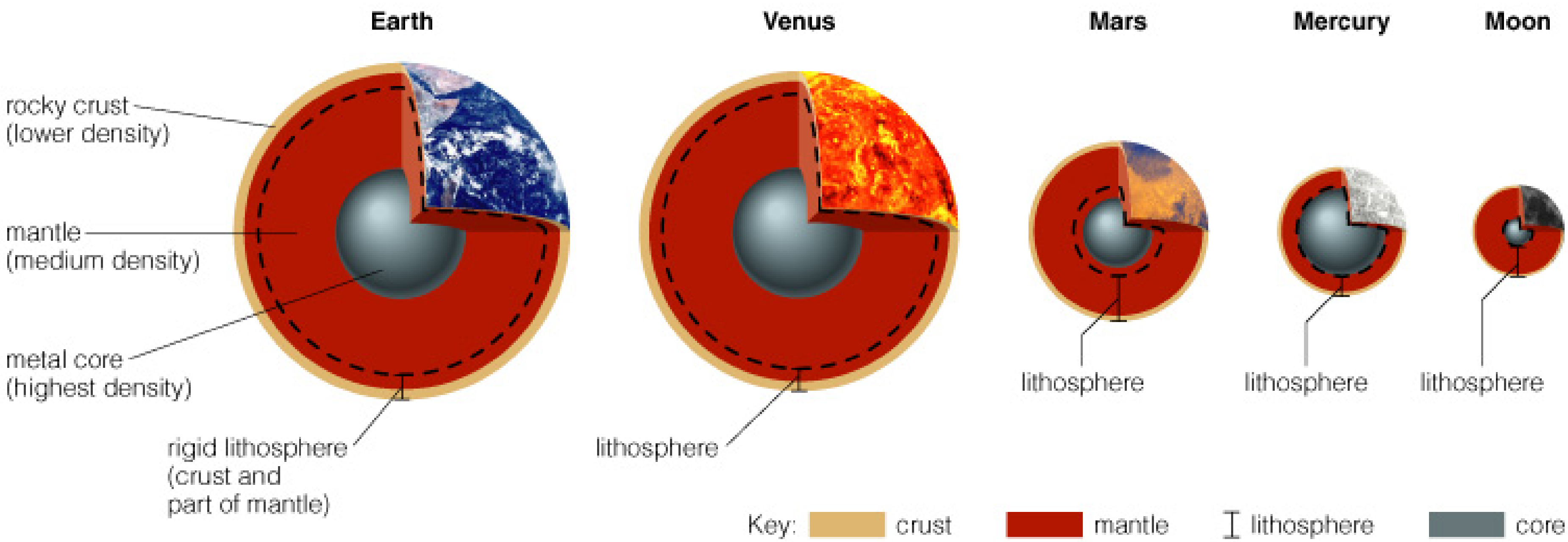
- Accretion and differentiation when planets were young
- Radioactive decay is most important heat source today

Cooling of Interior



- **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
- Moon and Mercury are now geologically “dead”

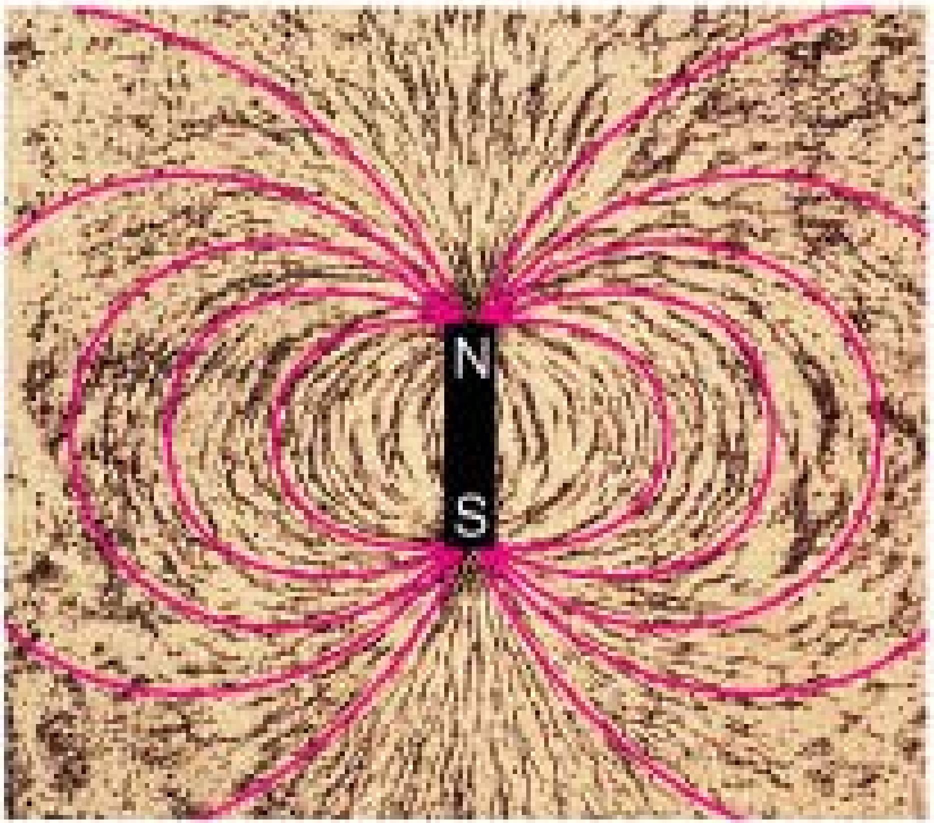
Surface Area to Volume Ratio

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

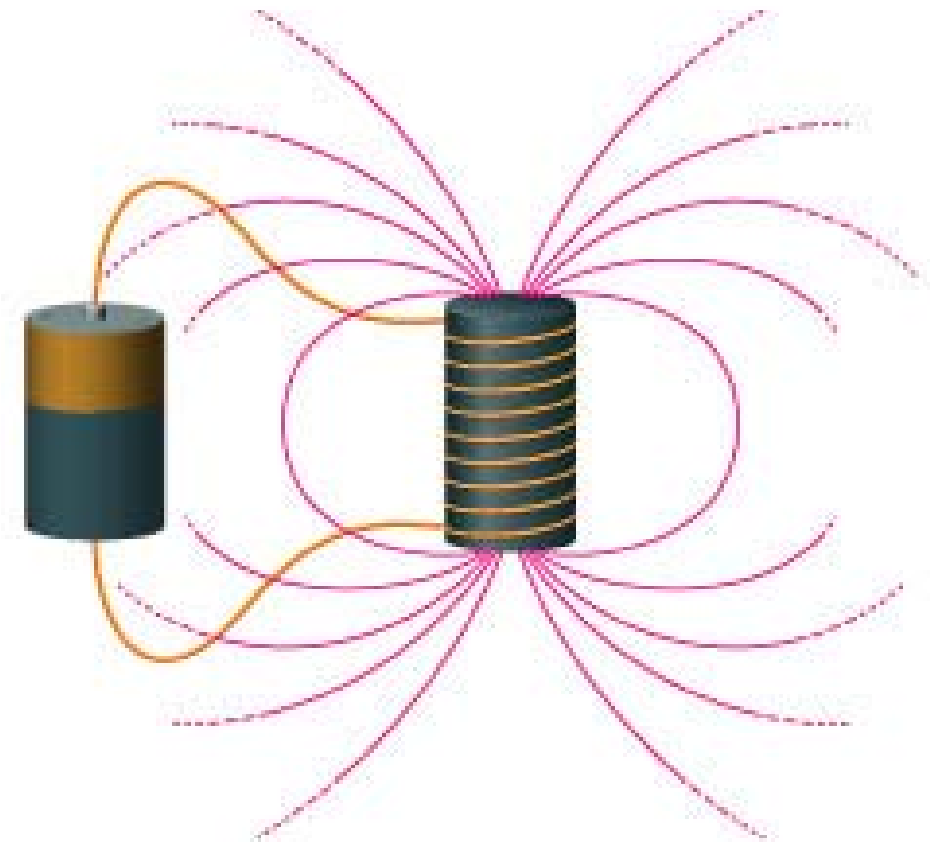
$$\text{surface area to volume ratio} = \frac{4\pi r^2}{\frac{4}{3}\pi r^3} = \frac{3}{r}$$

- Larger objects have smaller ratio and cool more slowly

Why do some planetary interiors create magnetic fields?

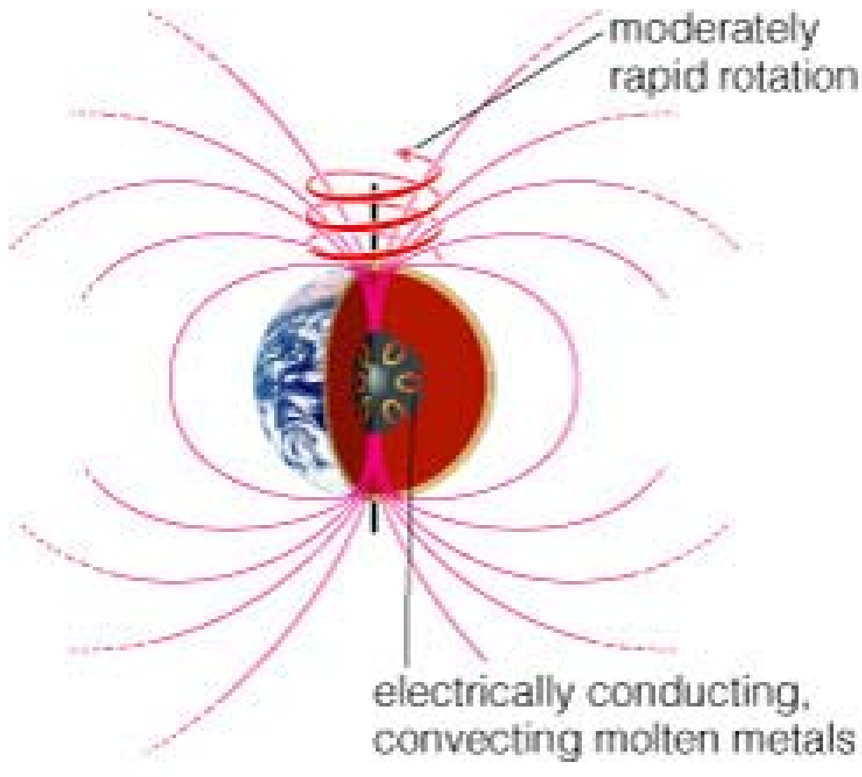


Sources of Magnetic Fields



- 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
- 3 requirements:
  - Molten interior
  - Convection
  - Moderately rapid rotation

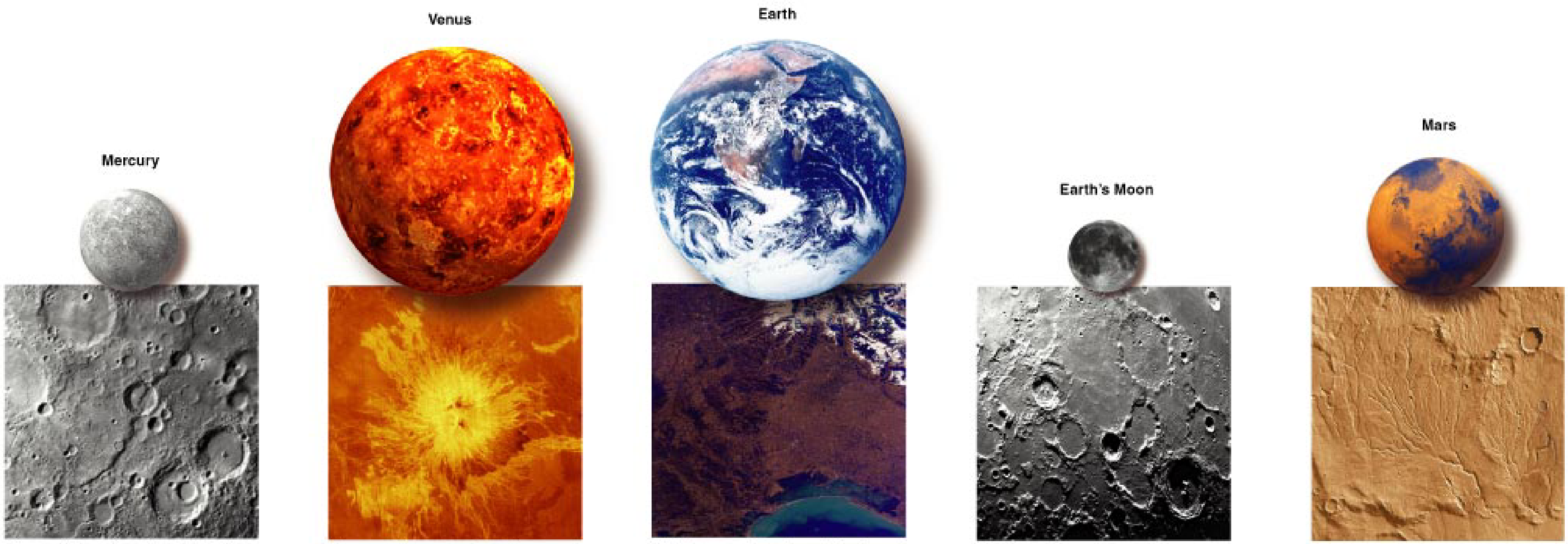
What have we learned?

- What are terrestrial planets like on the inside?
  - Core, mantle, crust structure
  - 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 planet

9.2 Shaping Planetary Surfaces

- Our goals for learning
- What processes shape planetary surfaces?
- Why do the terrestrial planets have different geological histories?
- How does a planet's surface reveal its geological age?

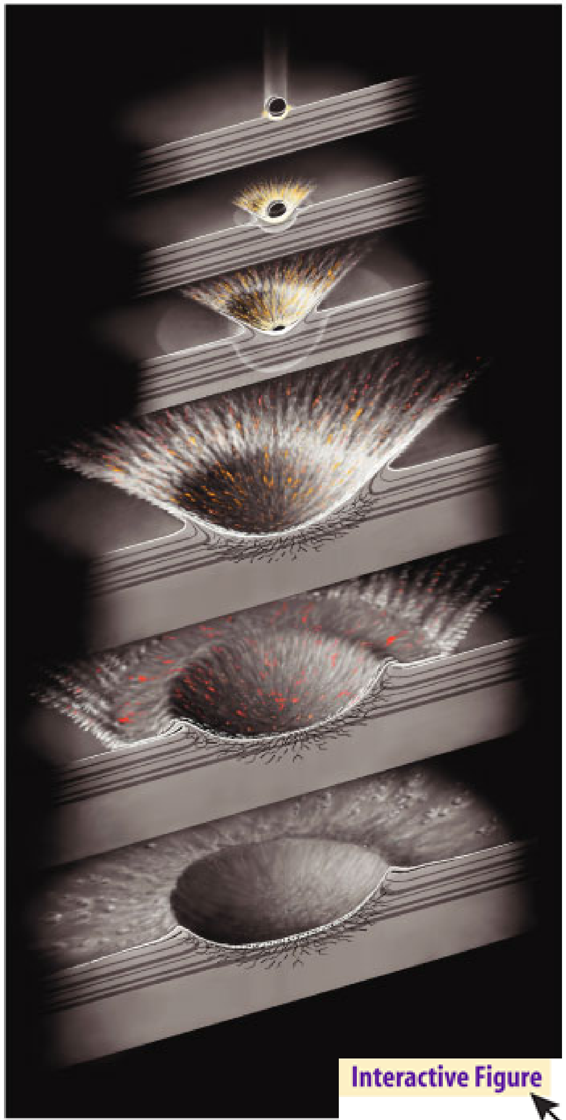
What processes shape planetary surfaces?



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

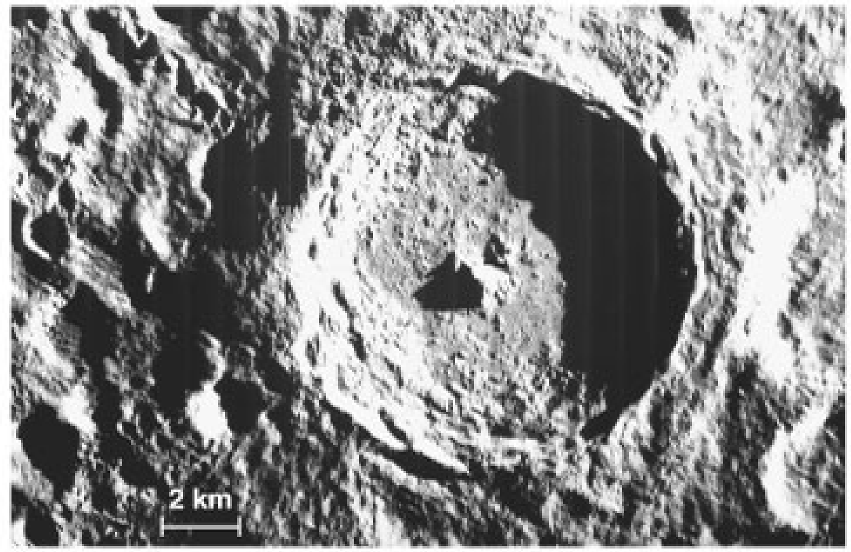
Impact Cratering



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

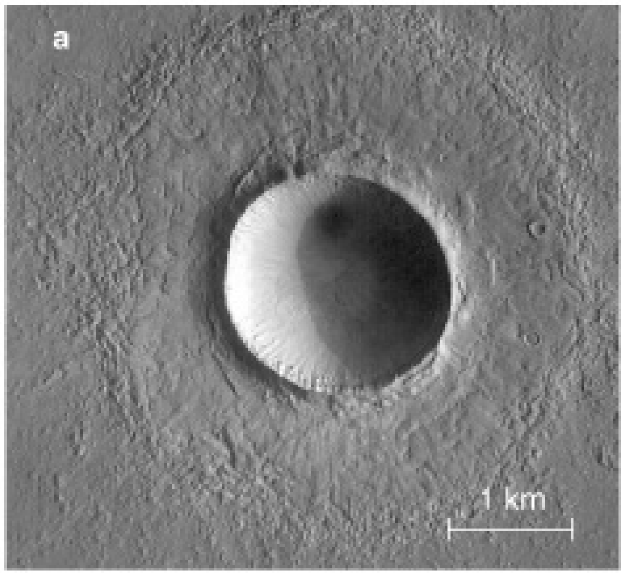
Impact Craters

Meteor Crater (Arizona)

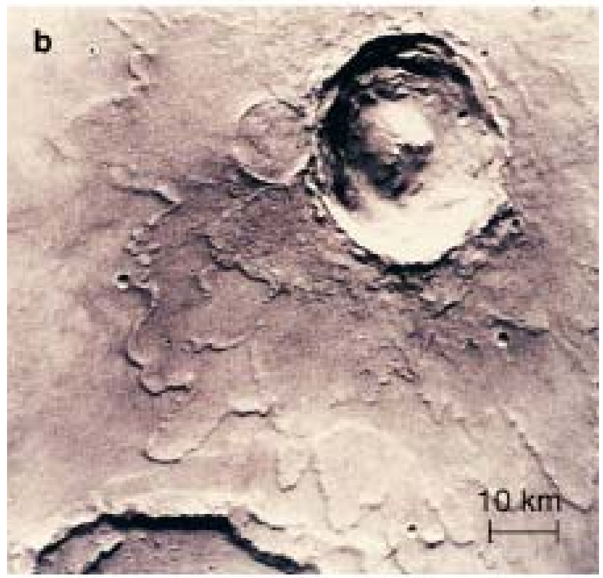


Tycho (Moon)

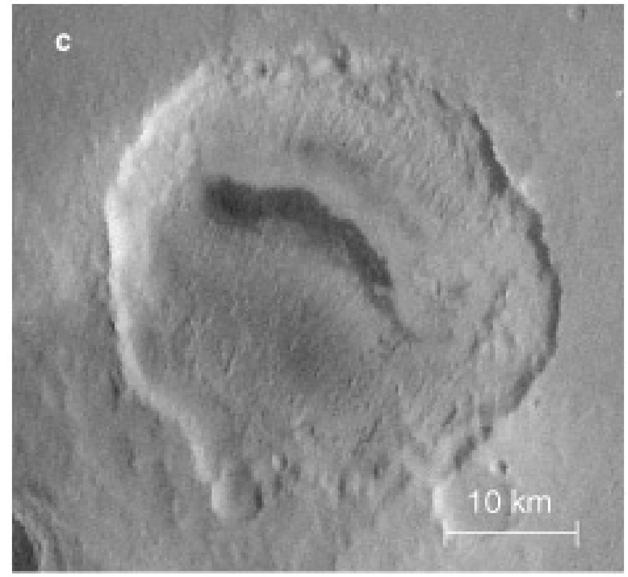
Impact Craters on Mars



“standard” crater

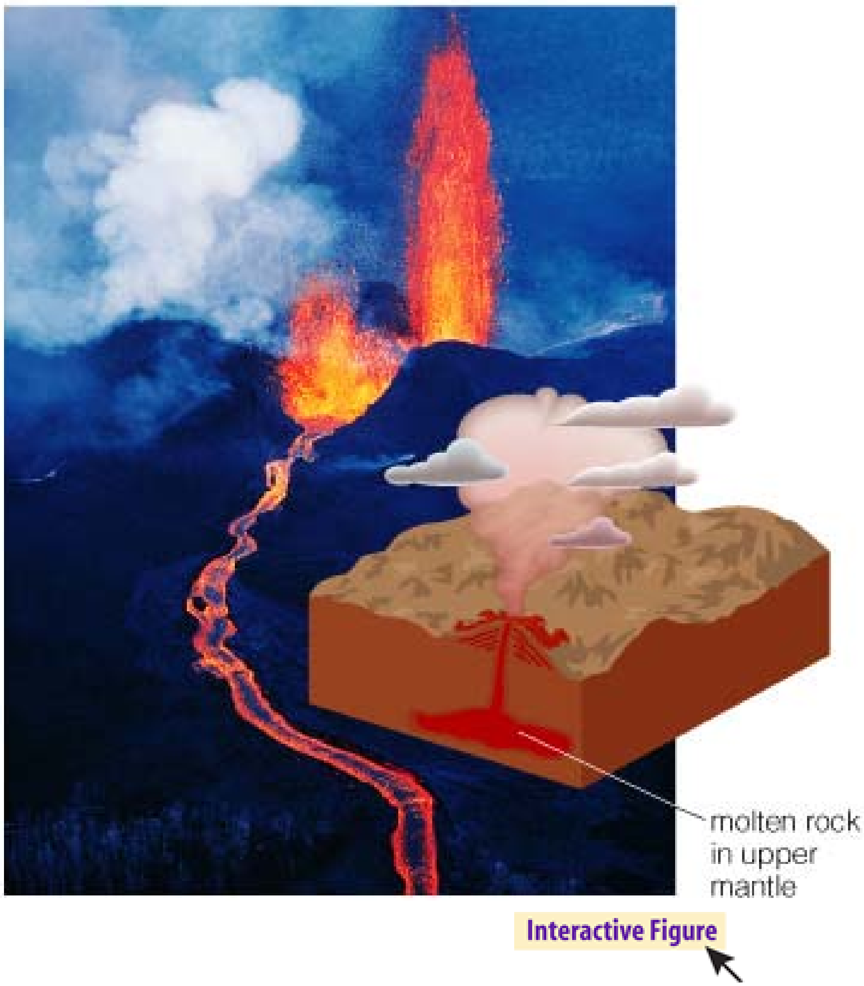


impact into icy ground



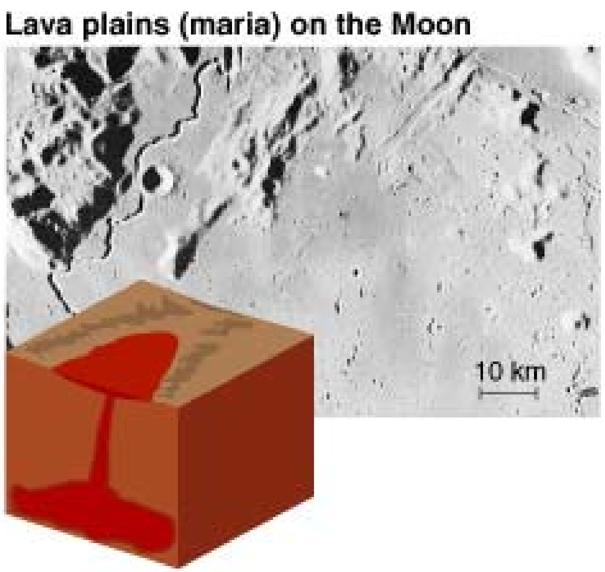
eroded crater

Volcanism

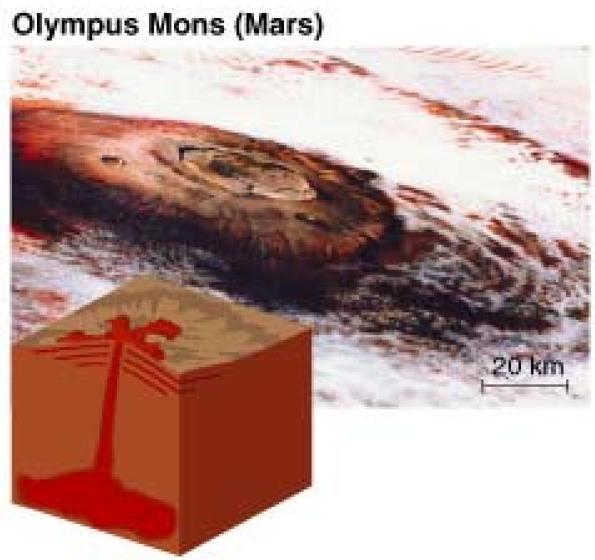


- Volcanism happens when molten rock (magma) finds a path through lithosphere to the surface
- Molten rock is called *lava* after it reaches the surface

Lava and Volcanoes



Runny lava makes flat lava plains



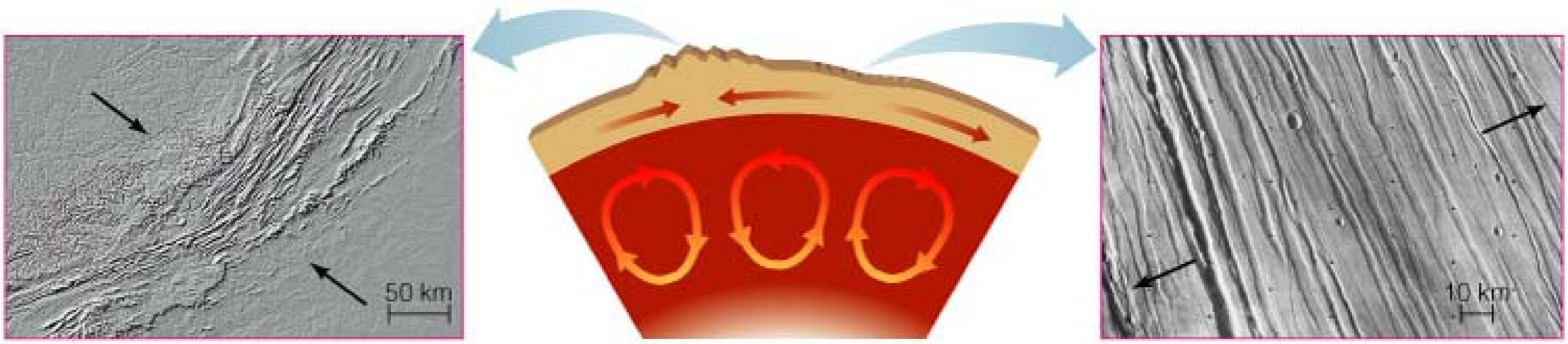
Slightly thicker lava makes broad *shield volcanoes*

Thickest lava makes steep *stratovolcanoes*

Outgassing

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

Tectonics



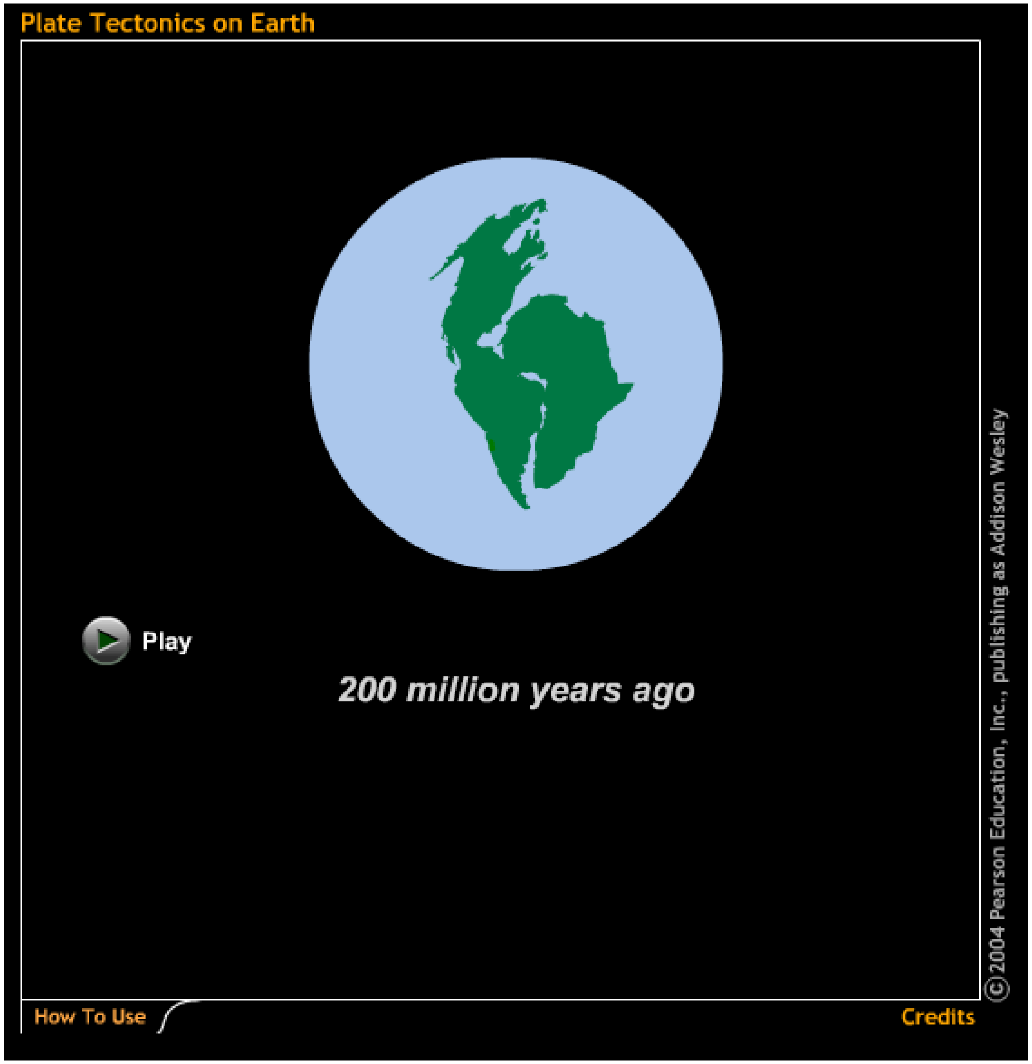
Appalachian Mountains in eastern United States

Interactive Figure

Ceraunius Valleys on Mars

- Convection of the mantle creates stresses in the crust called tectonic forces
- Compression forces make 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

- Colorado River continues to carve Grand Canyon

Erosion by Ice

- Glaciers carved the Yosemite Valley

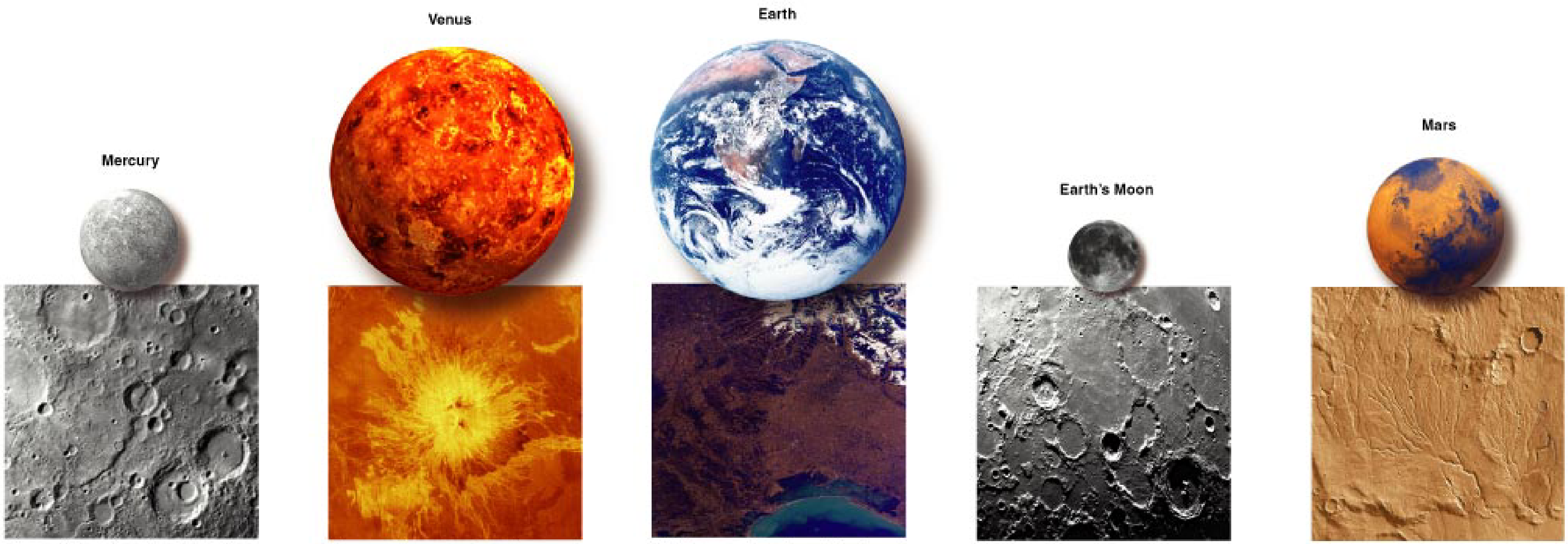
Erosion by Wind

- Wind wears away rock and builds up sand dunes

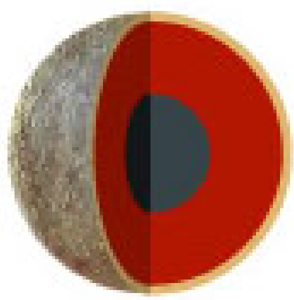
Erosional Debris

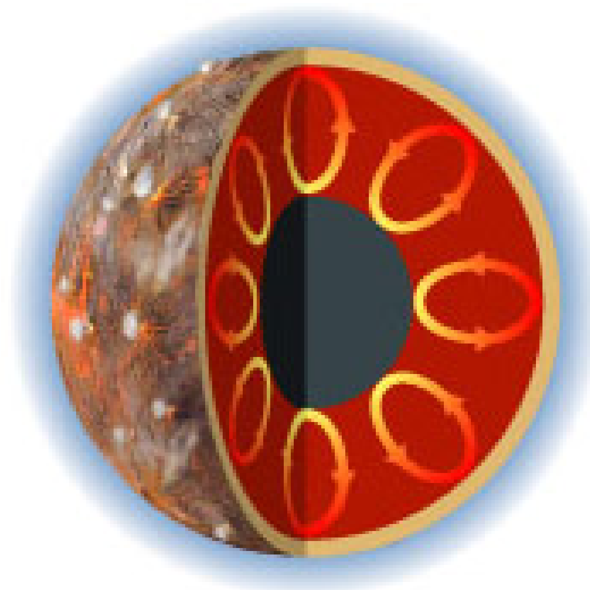
- Erosion can create new features by depositing debris

Why do the terrestrial planets have different geological histories?



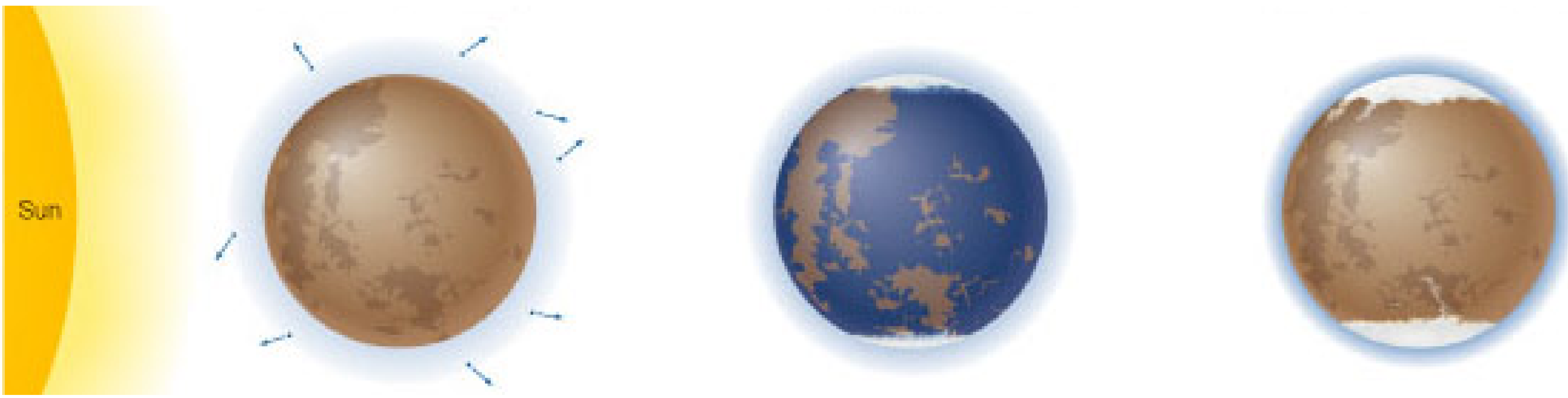
Role of Planetary Size





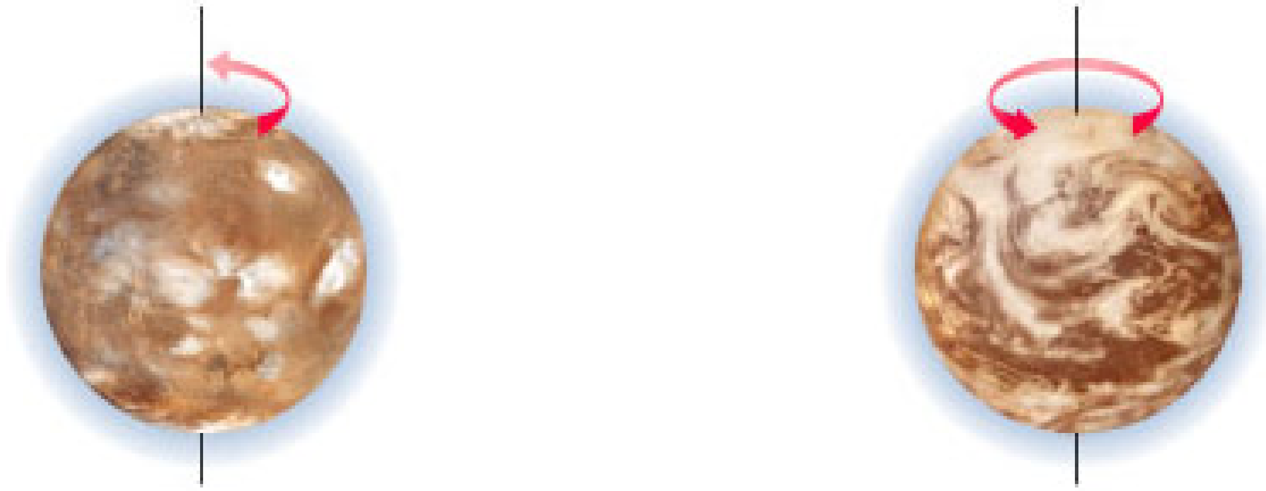
- Smaller worlds cool off faster and harden earlier
- Larger worlds remain warm inside, promoting volcanism and tectonics
- Larger worlds also have more erosion because their gravity retains an atmosphere

Role of Distance from Sun



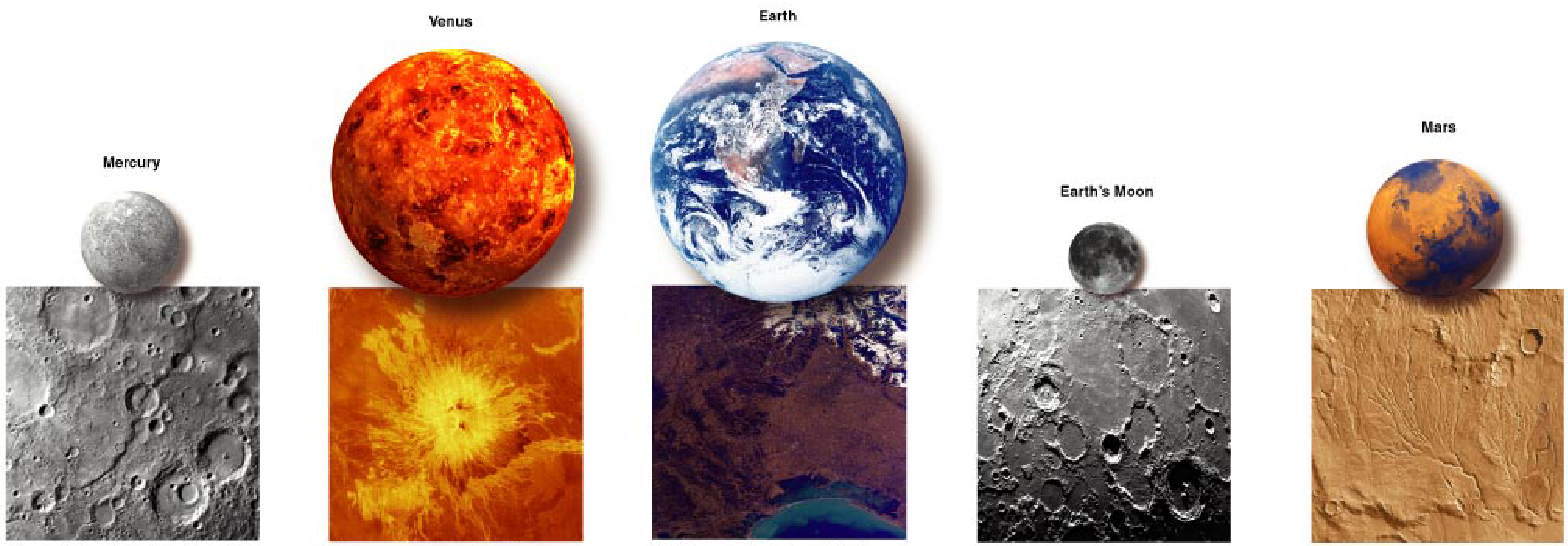
- Planets close to Sun are too hot for rain, snow, ice and so have less erosion
- More difficult for hot planet to retain atmosphere
- Planets far from Sun are too cold for rain, limiting erosion
- Planets with liquid water have most erosion

Role of Rotation

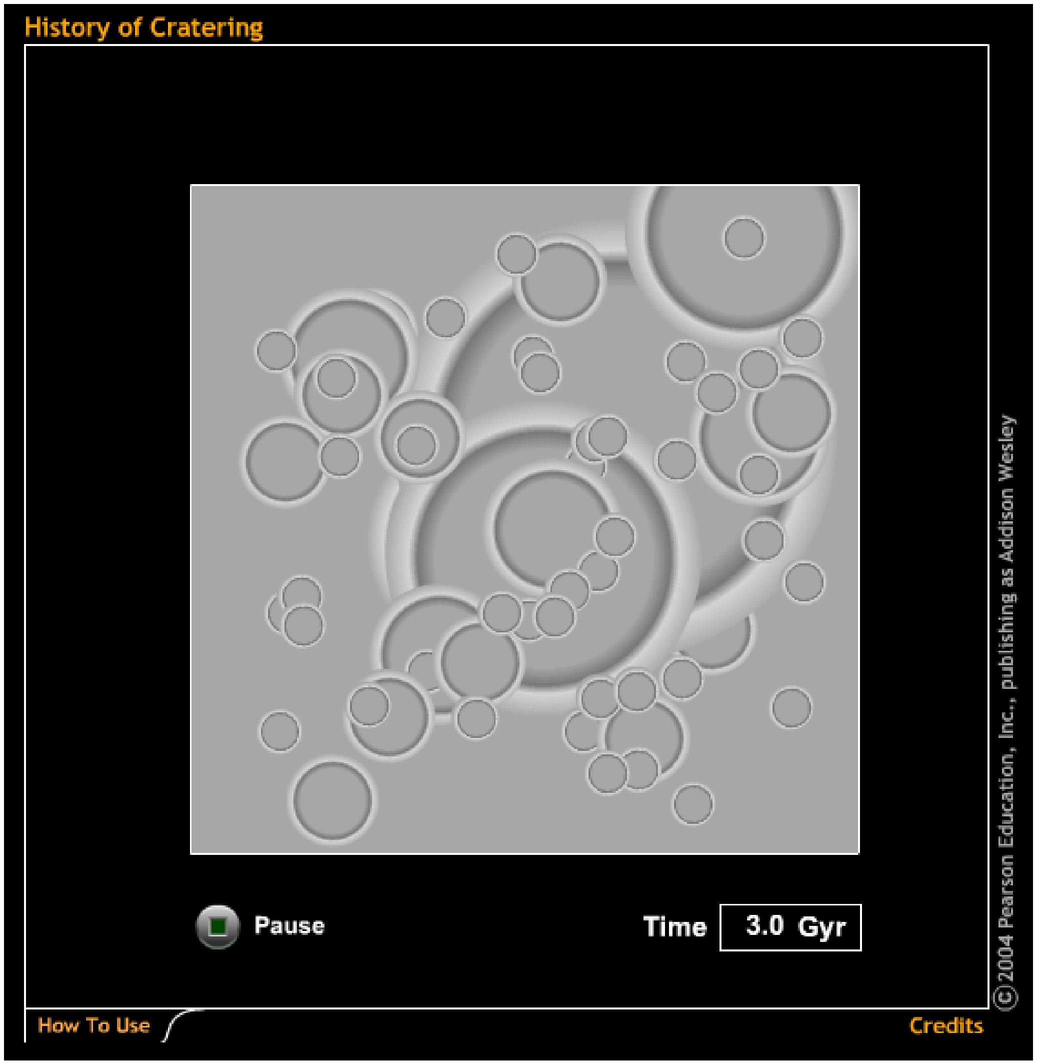


- Planets with slower rotation have less weather and less erosion and a weak magnetic field
- Planets with faster rotation have more weather and more erosion and a stronger magnetic field

How does a planet's surface reveal its geological age?

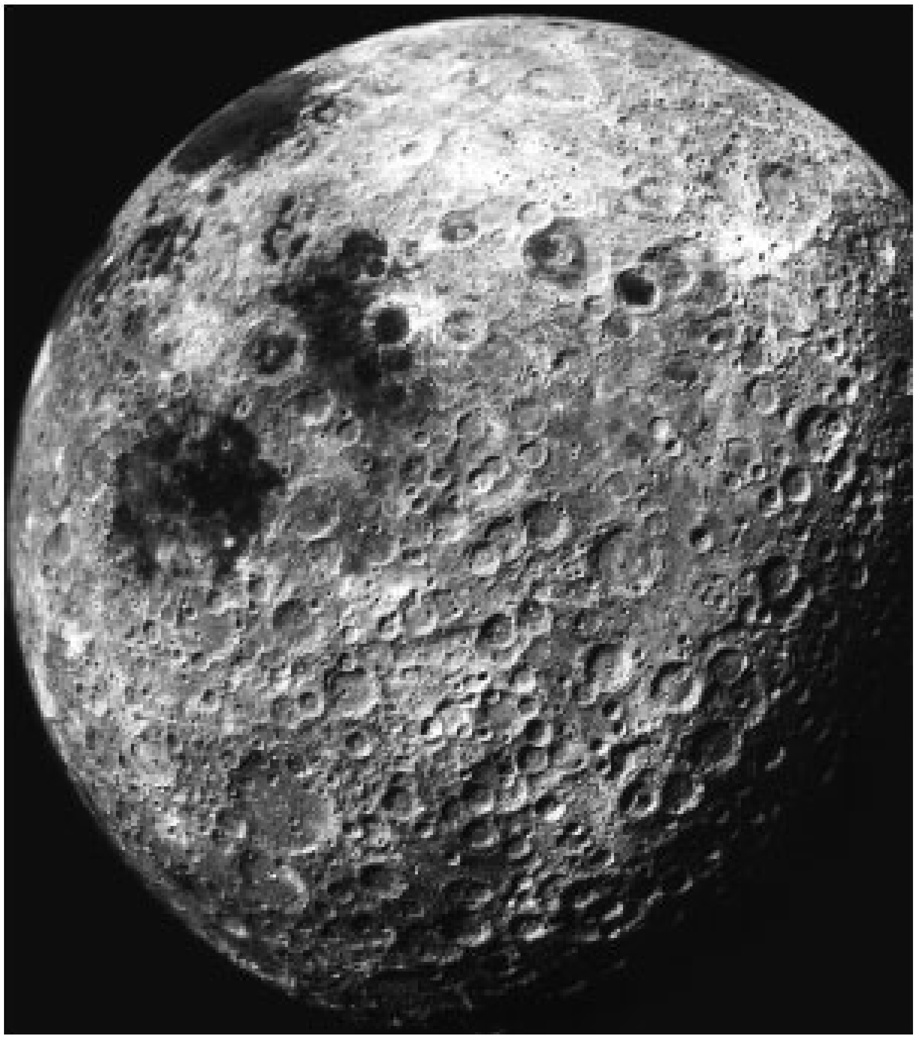


History of Cratering



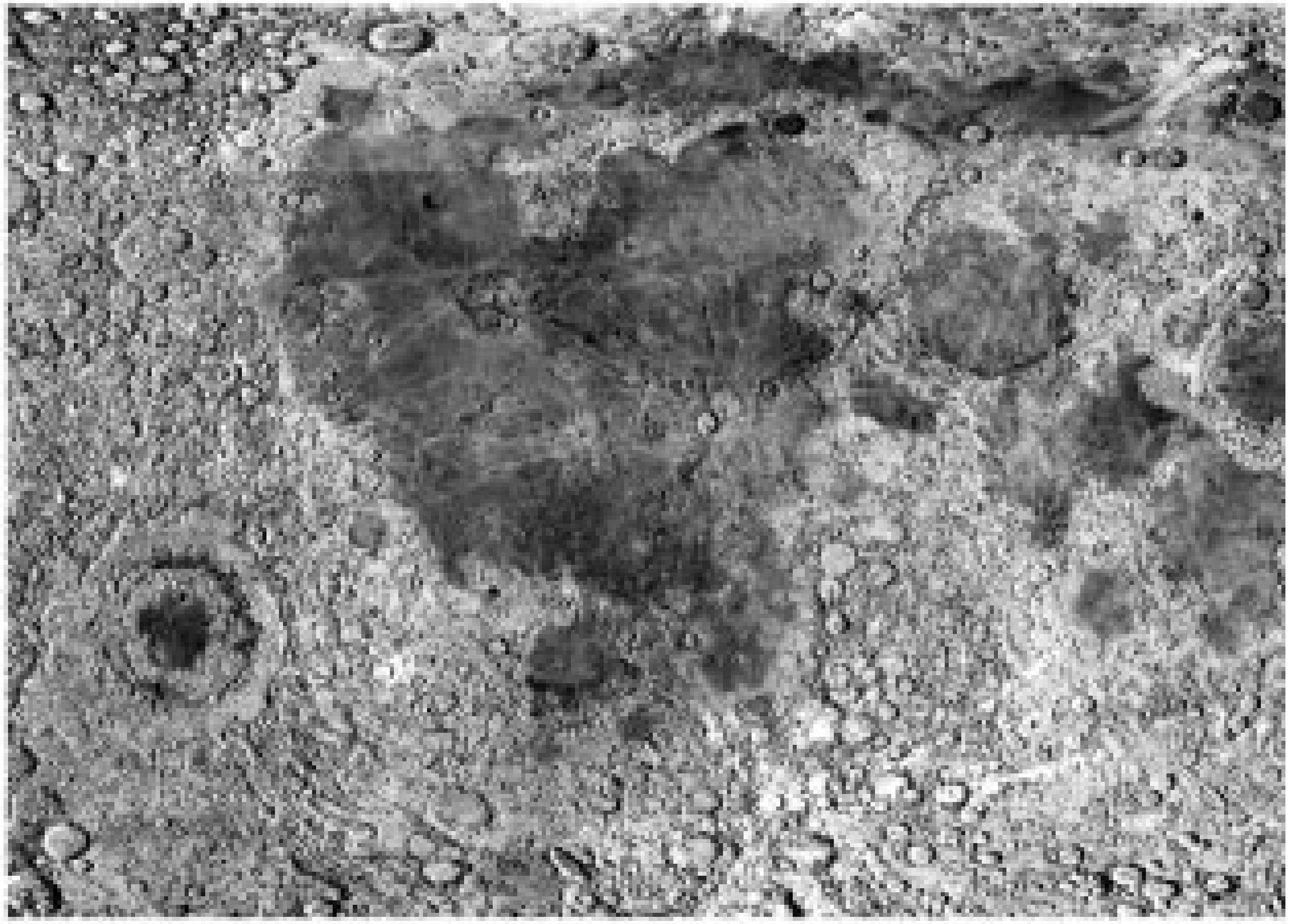
- Most cratering happened in first billion years
- A surface with many craters has not changed much in 3 billion years

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 Moon’s entire surface

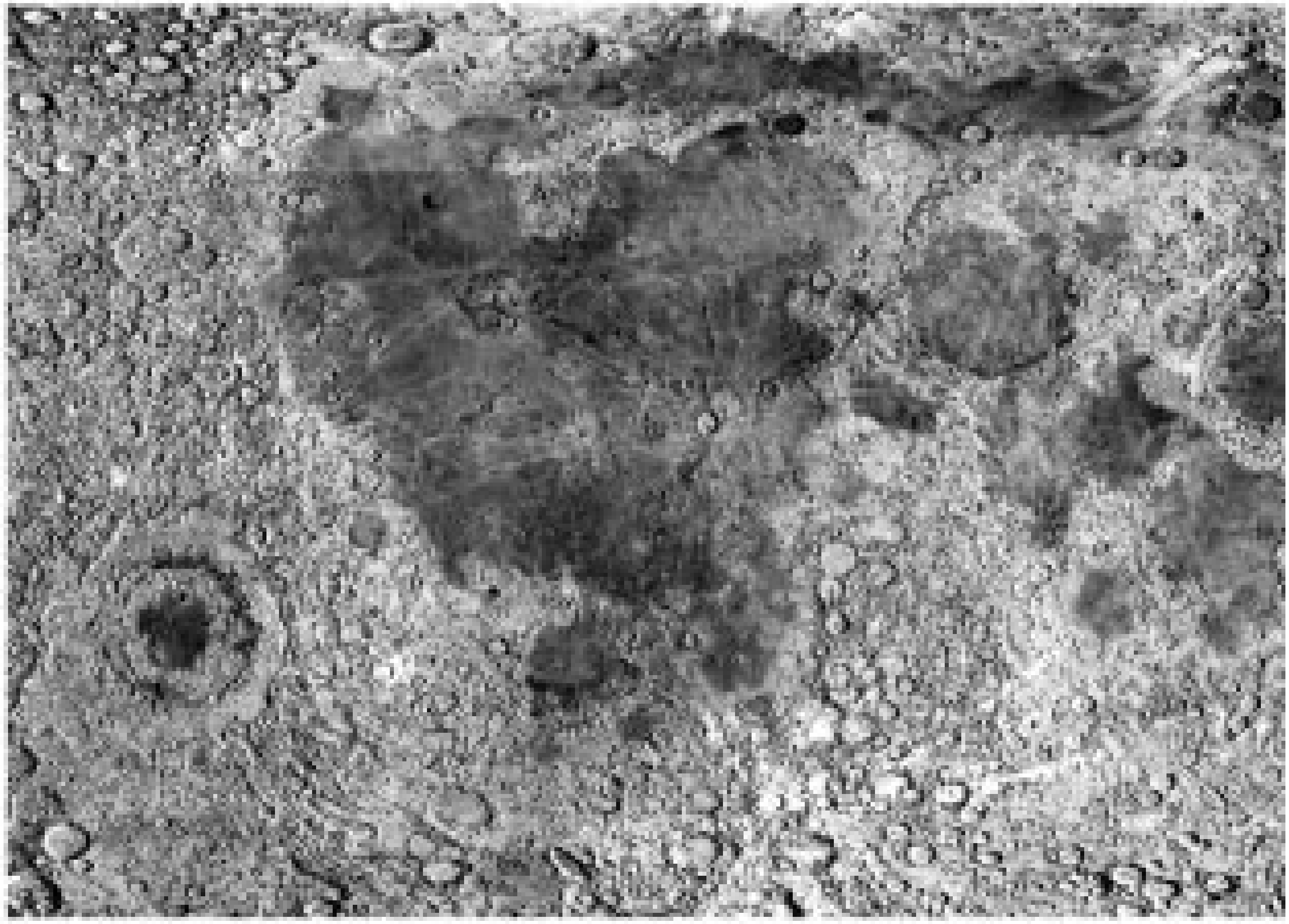
What have we learned?

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

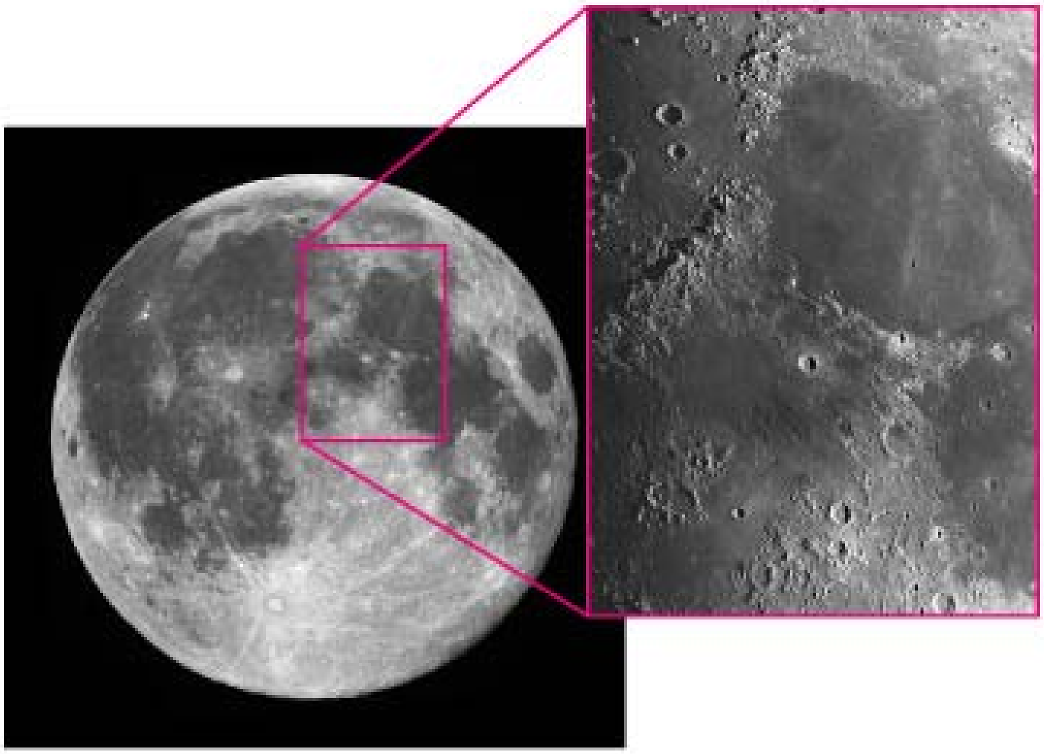
9.3 Geology of the Moon and Mercury

- 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 flood of runny lava

Formation of Lunar Maria

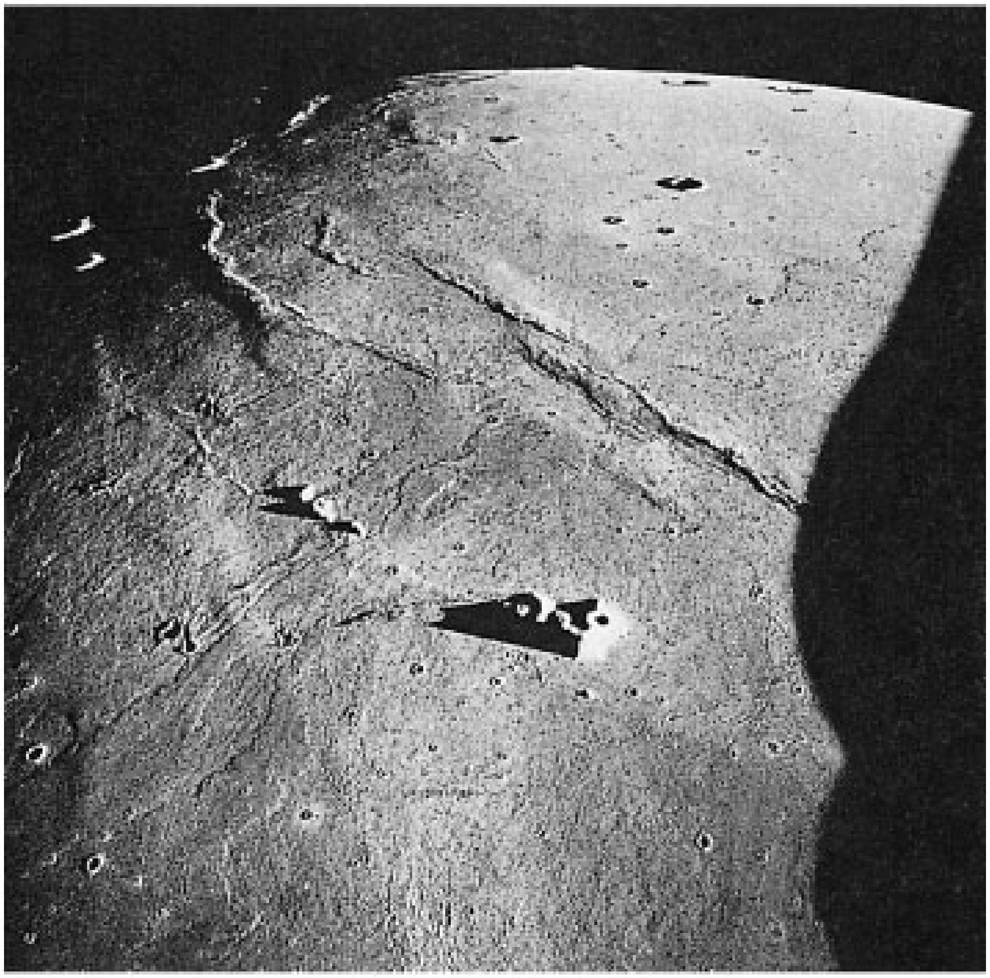
Early surface covered with craters

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

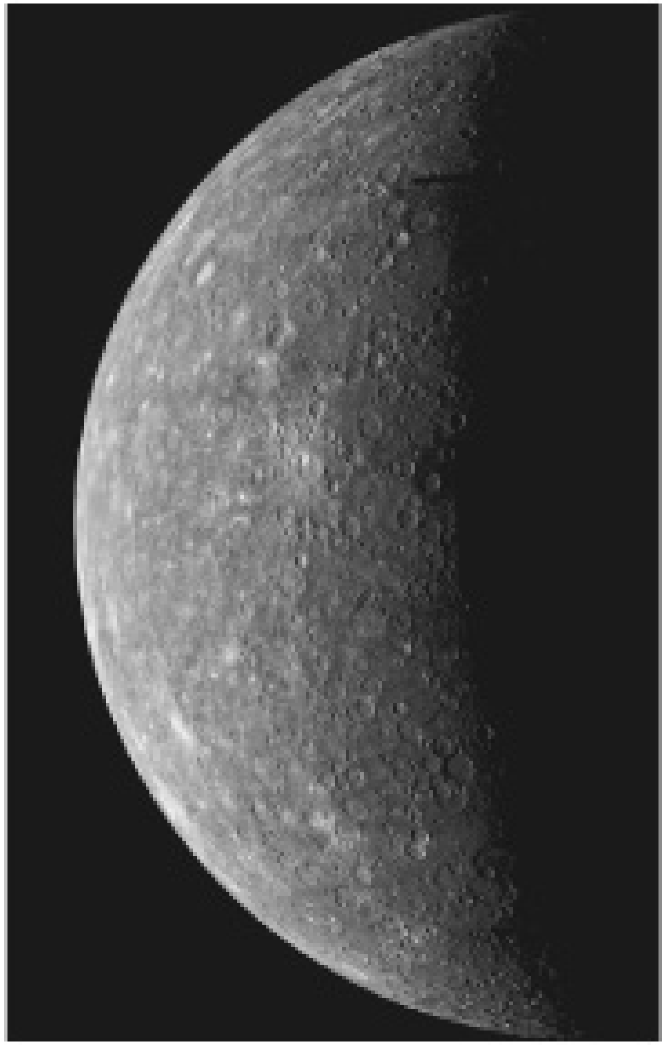


- Wrinkles arise from cooling and contraction of lava flood

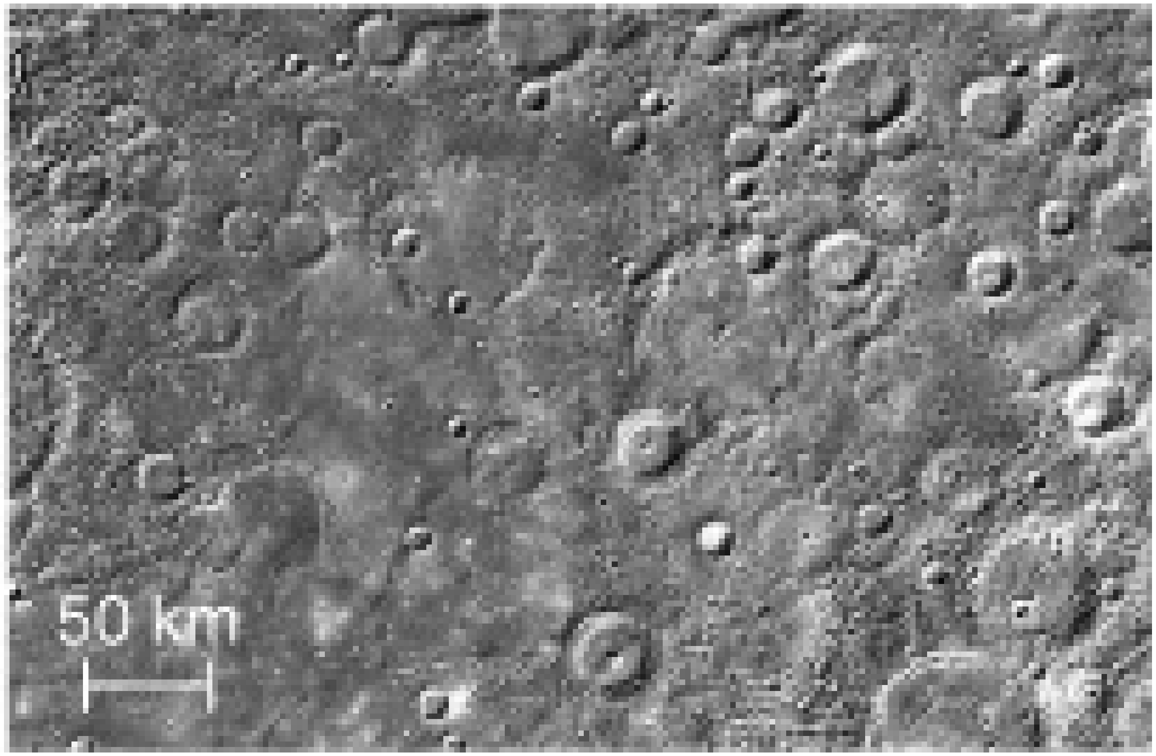
Geologically Dead

- Moon is considered geologically “dead” because geological processes have virtually stopped

What geological processes shaped Mercury?

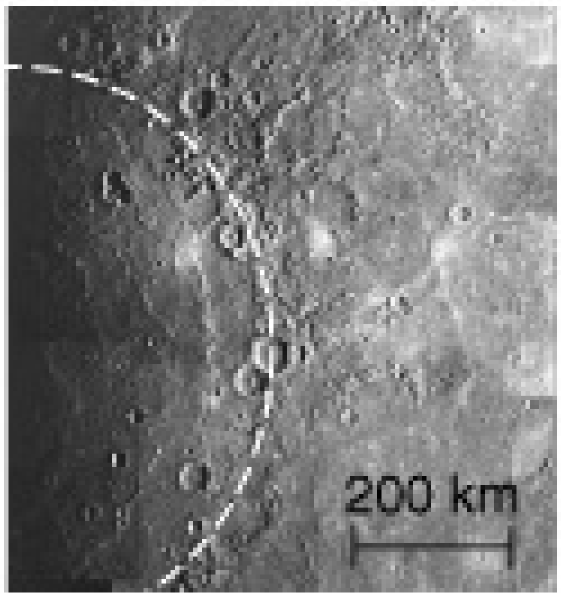


Cratering of Mercury

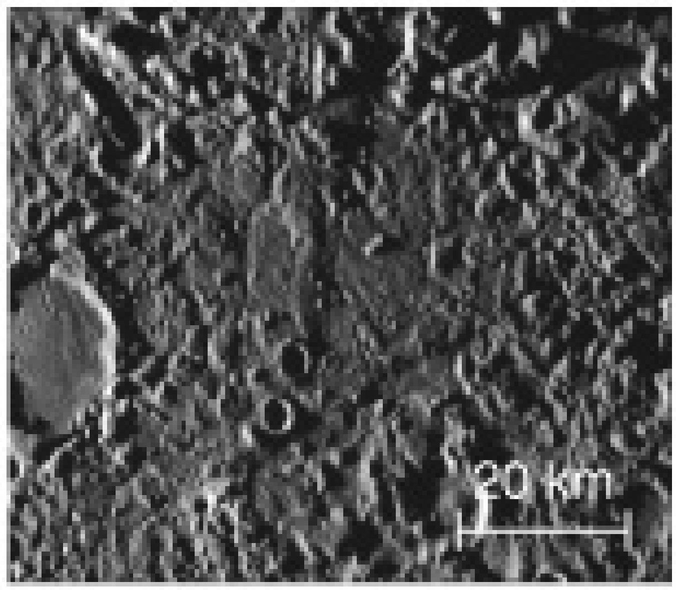


- A mixture of heavily cratered and smooth regions like the Moon
- Smooth regions are likely ancient lava flows

Cratering of Mercury

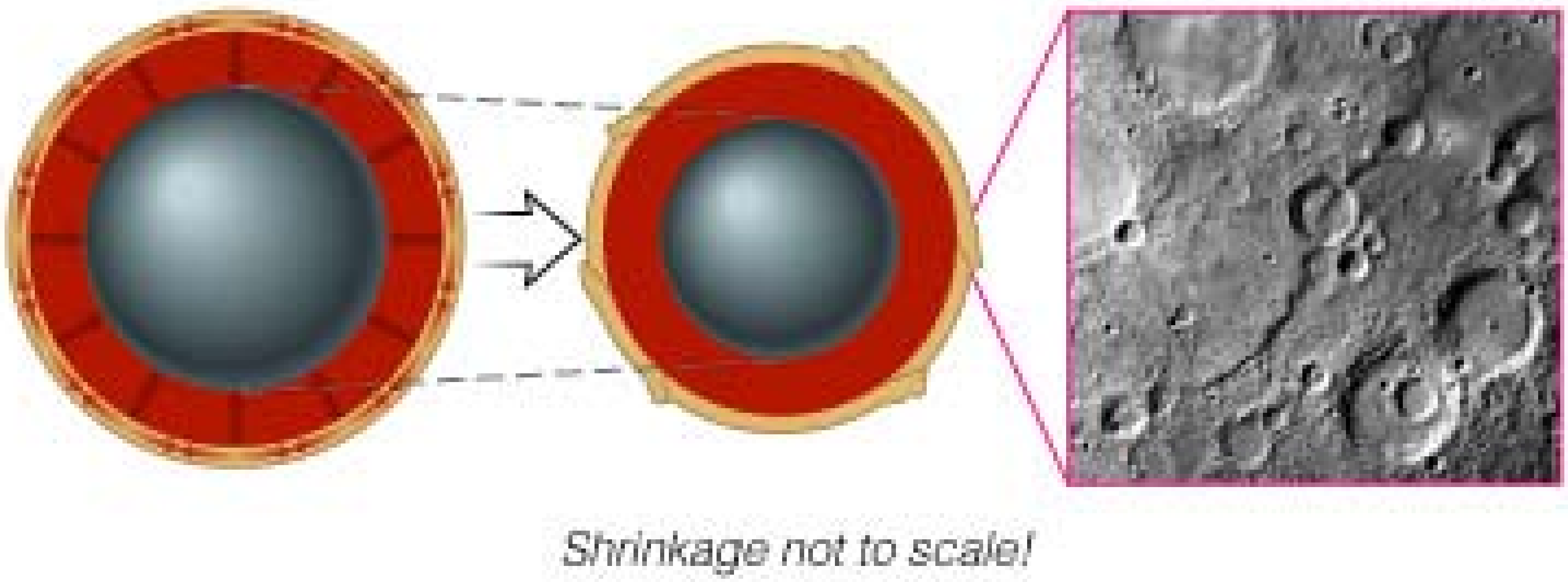


Caloris basin is largest impact crater on Mercury



Region opposite Caloris Basin is jumbled from seismic energy of impact

Tectonics on Mercury



- Long cliffs indicate that Mercury shrank early in its history

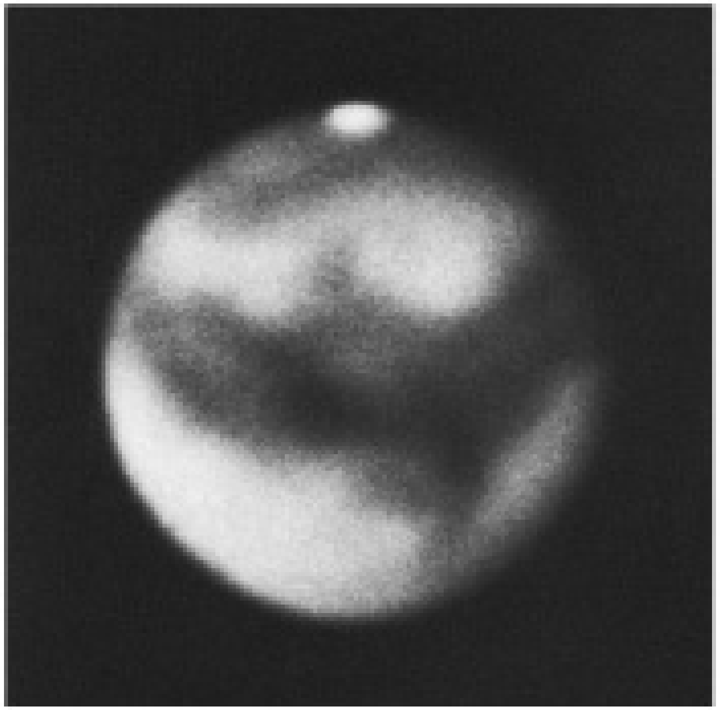
What have we learned?

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

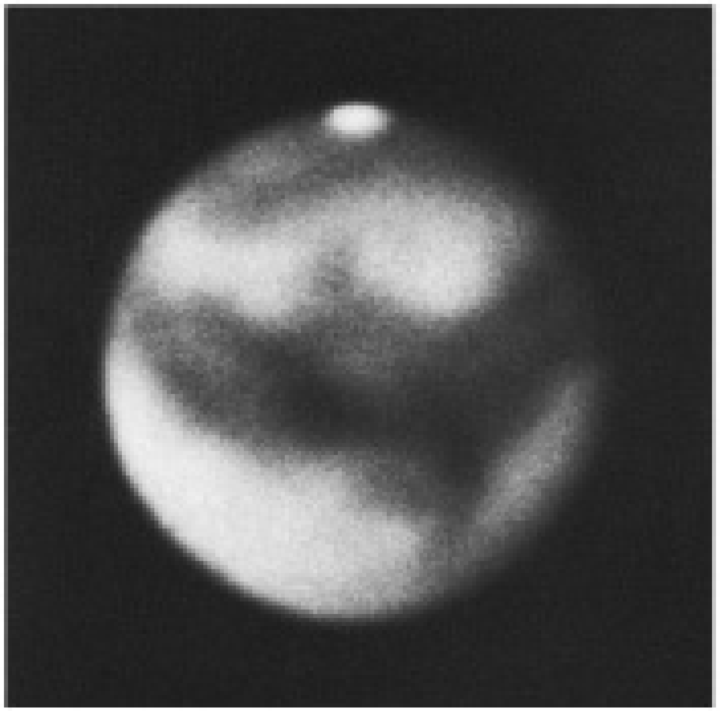
9.4 Geology of Mars

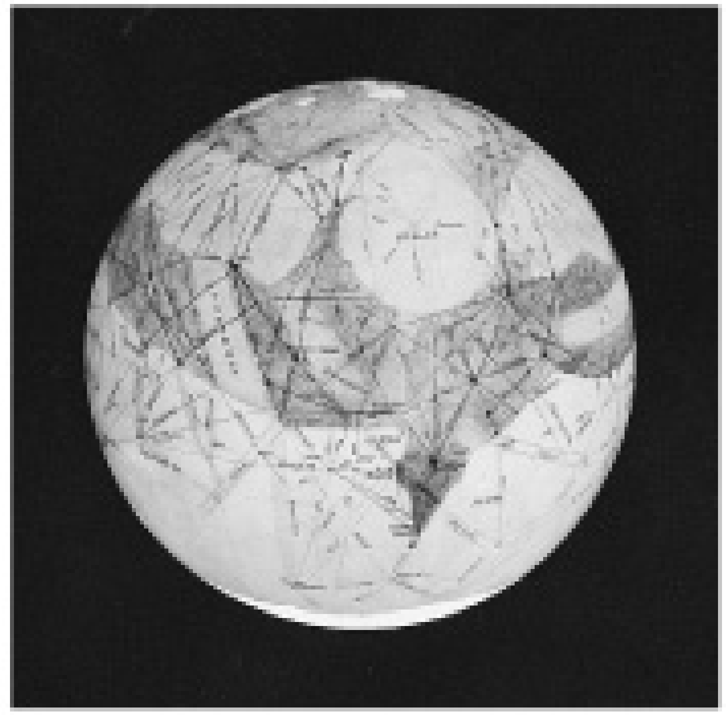
- Our goals for learning
- How did Martians invade popular culture?
- What are the major geological features of Mars?
- What geological evidence tells us that water once flowed on Mars?

How did Martians invade popular culture?



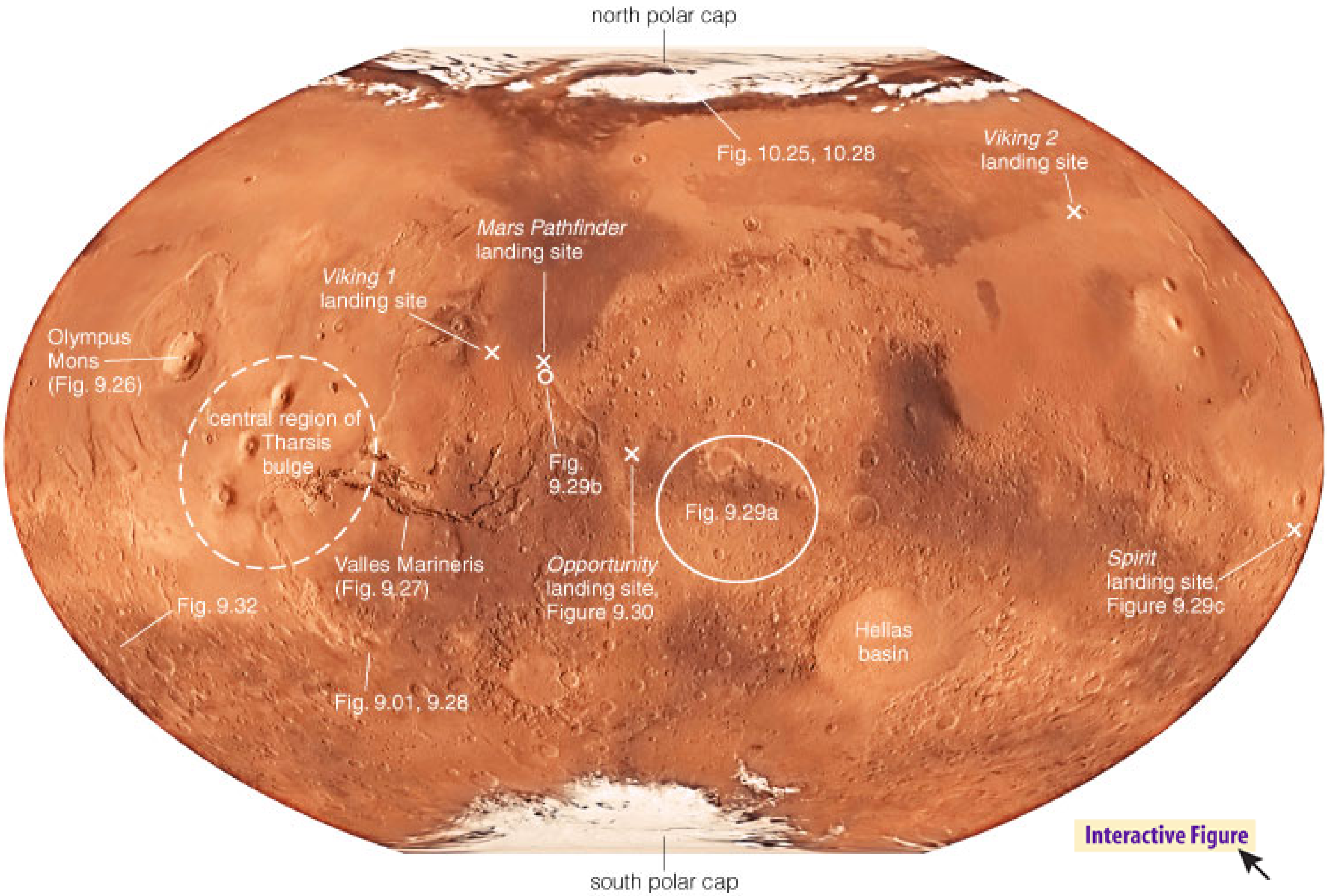
“Canals” on Mars



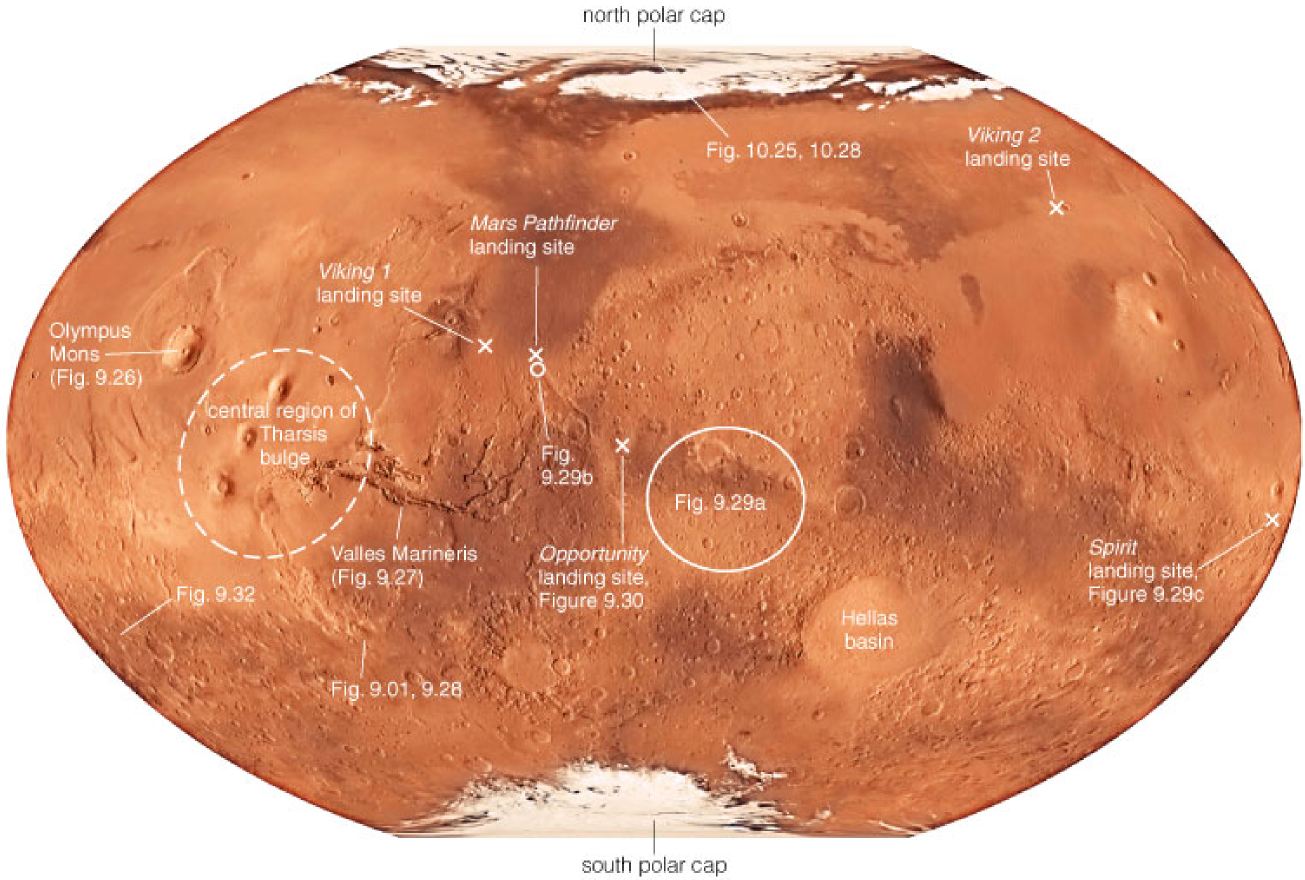


- Percival Lowell misinterpreted surface features seen in telescopic images of Mars

What are the major geological features of Mars?

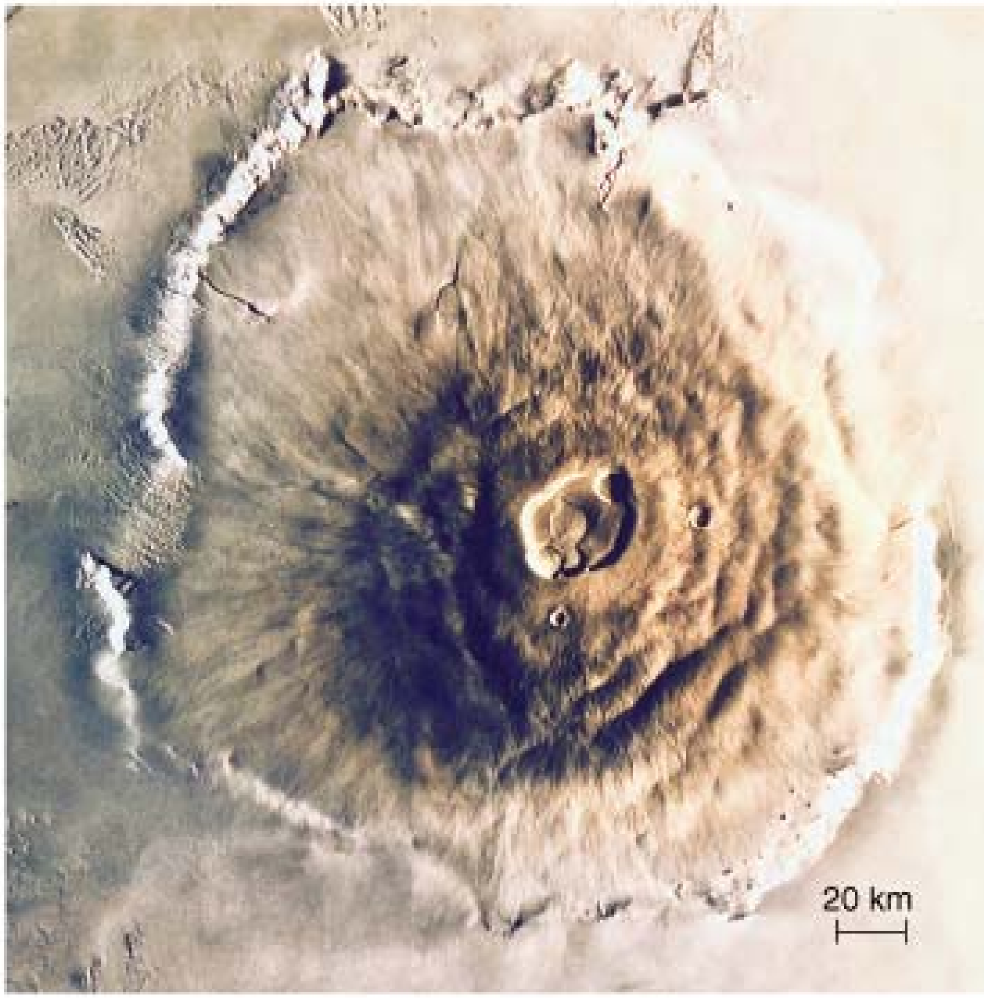


Cratering on Mars



- Amount of cratering differs greatly across surface
- Many early craters have been erased

Volcanism on Mars

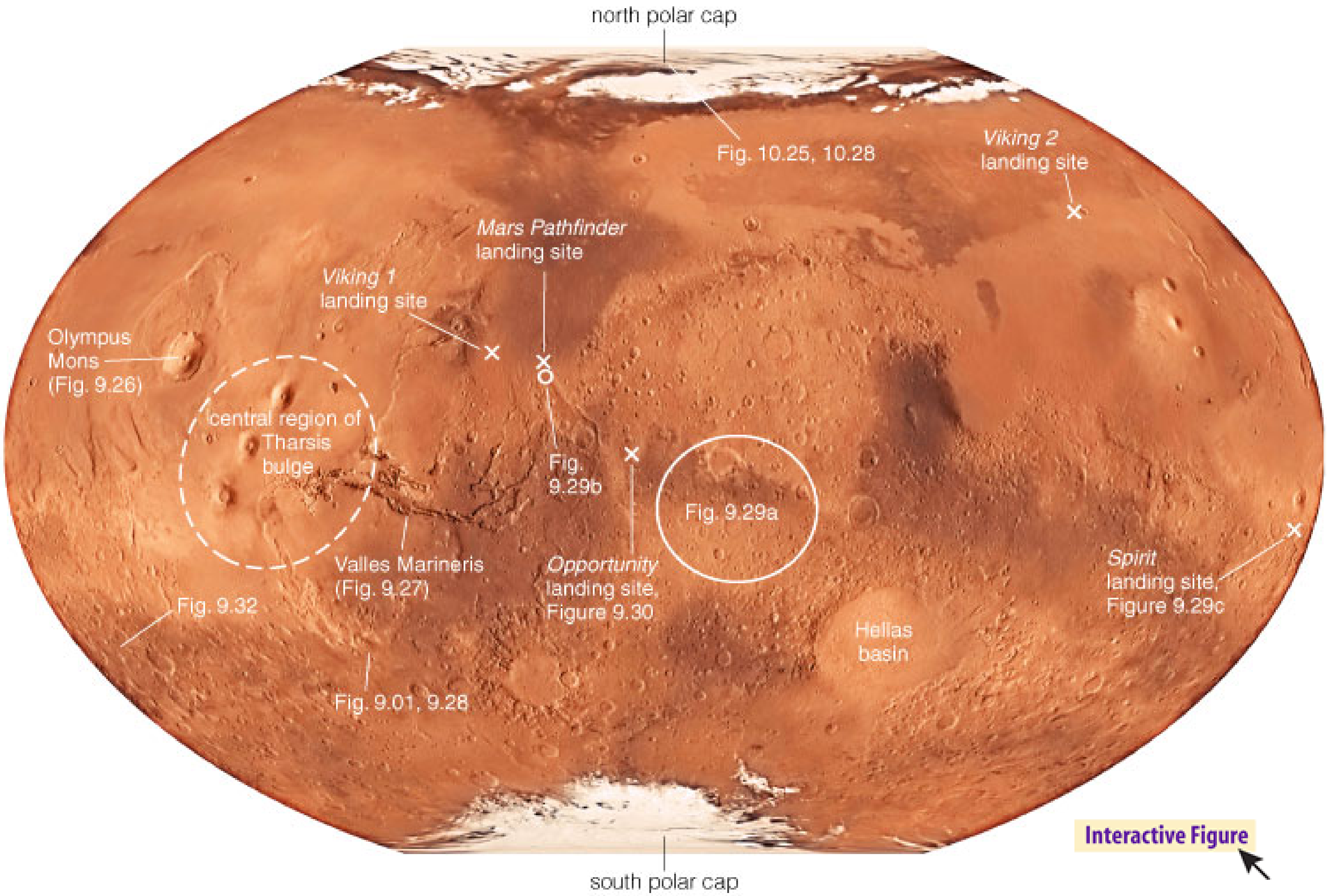


- Mars has many large shield volcanoes
- Olympus Mons is largest volcano in solar system

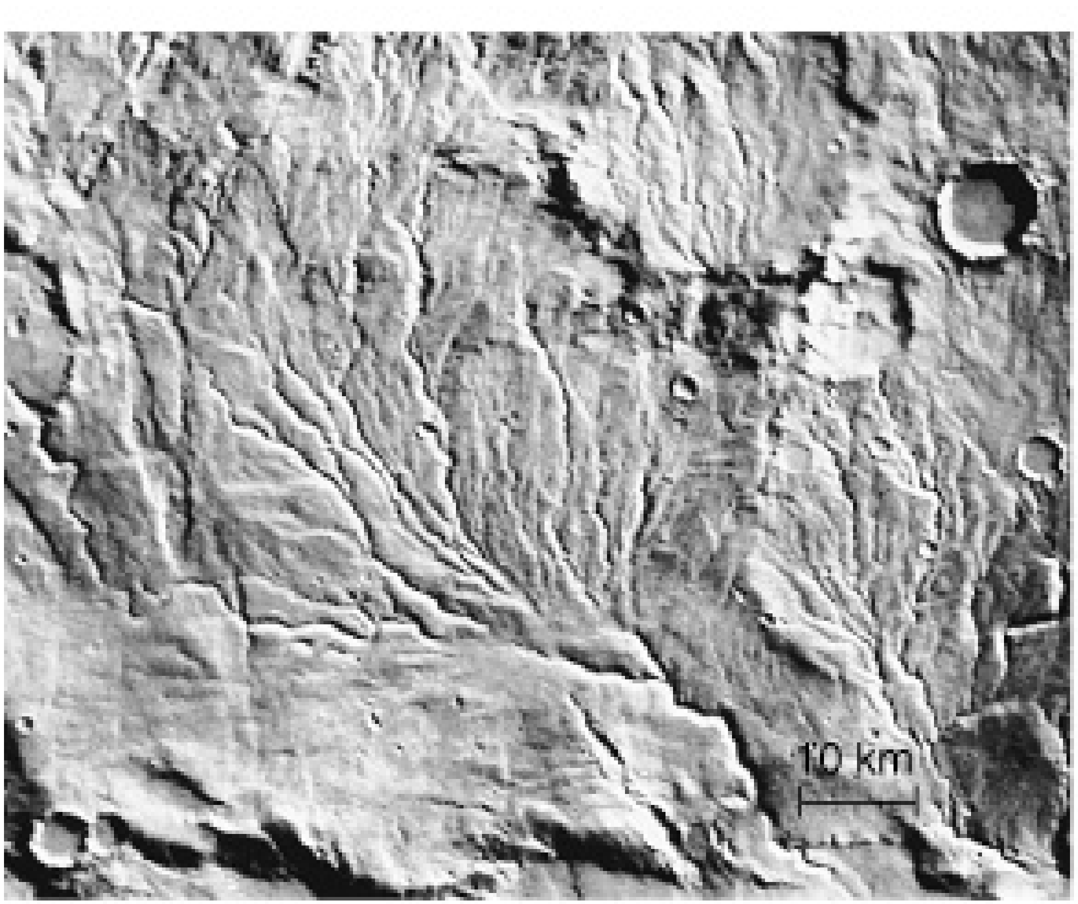
Tectonics on Mars

- System of valleys known as Valles Marineris thought to originate from tectonics

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

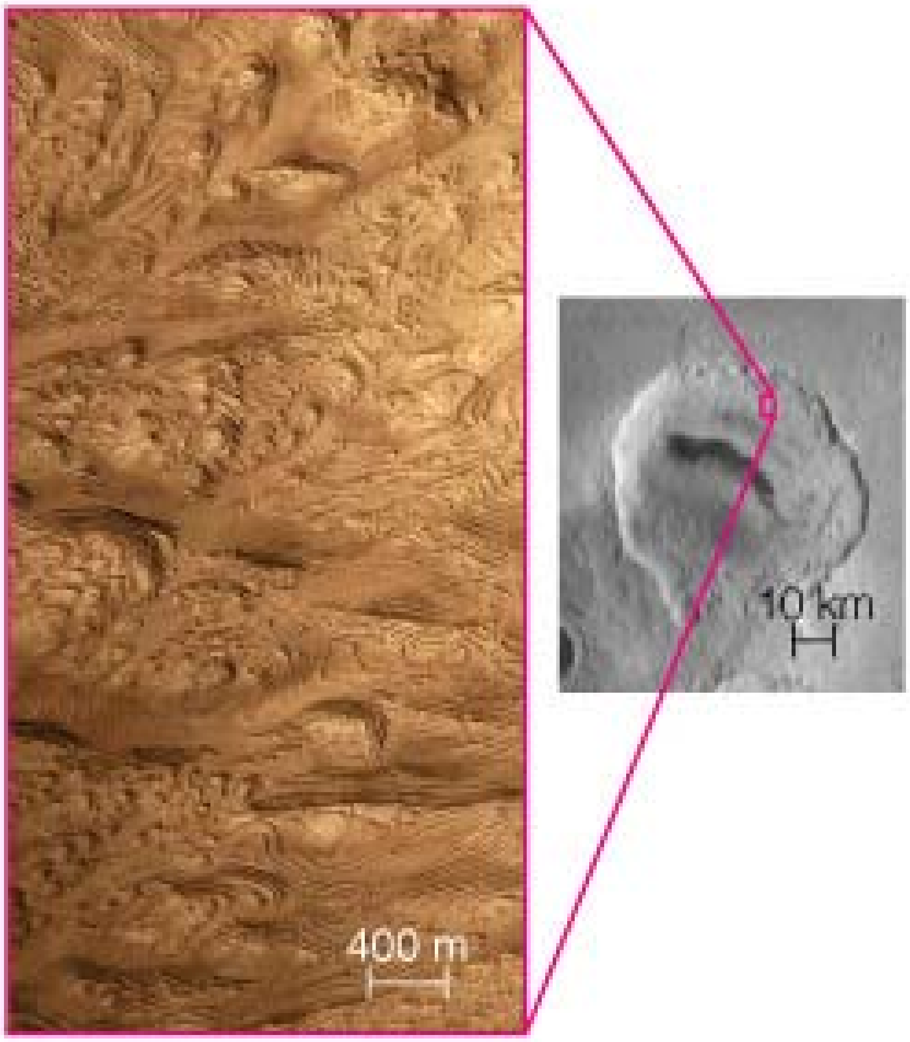


Dry Riverbeds?



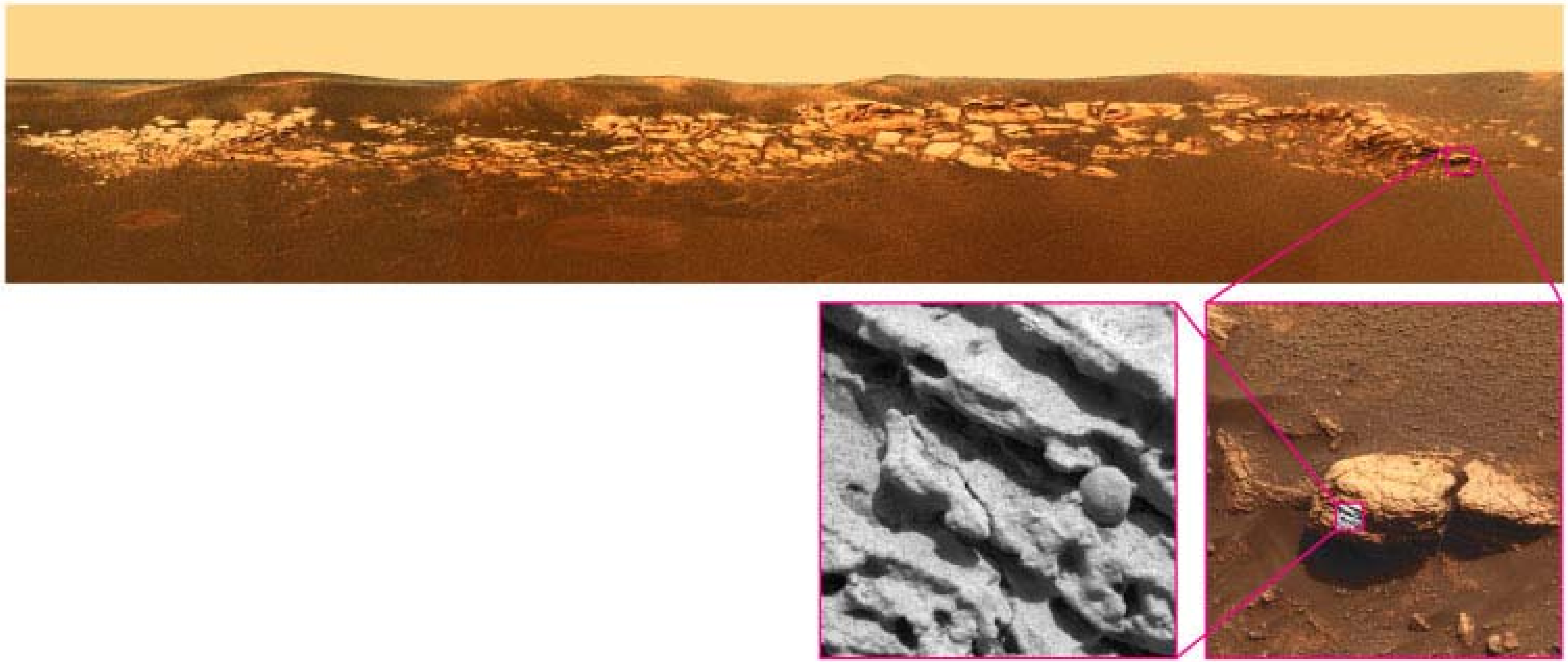
- Close-up photos of Mars show what appear to be dried-up riverbeds

Erosion of Craters



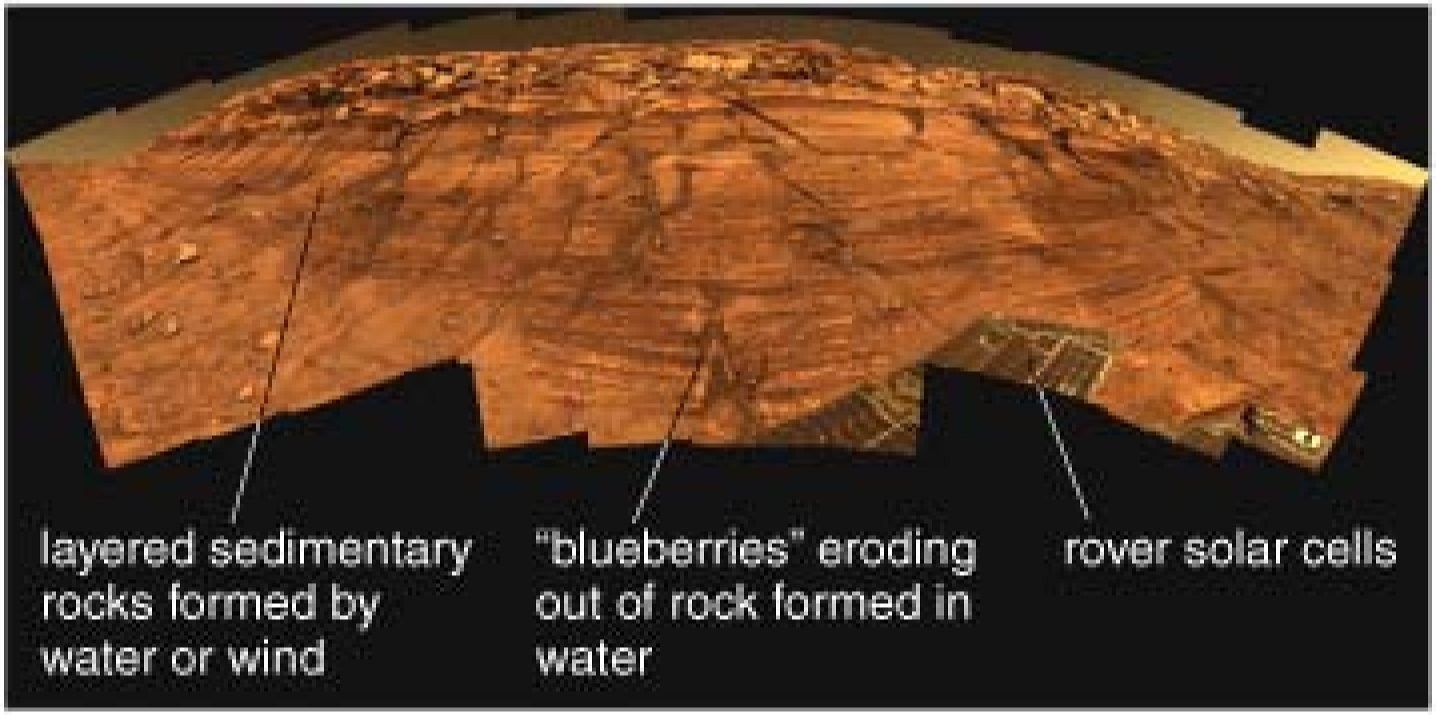
- Details of some craters suggest they were once filled with water

Martian Rocks



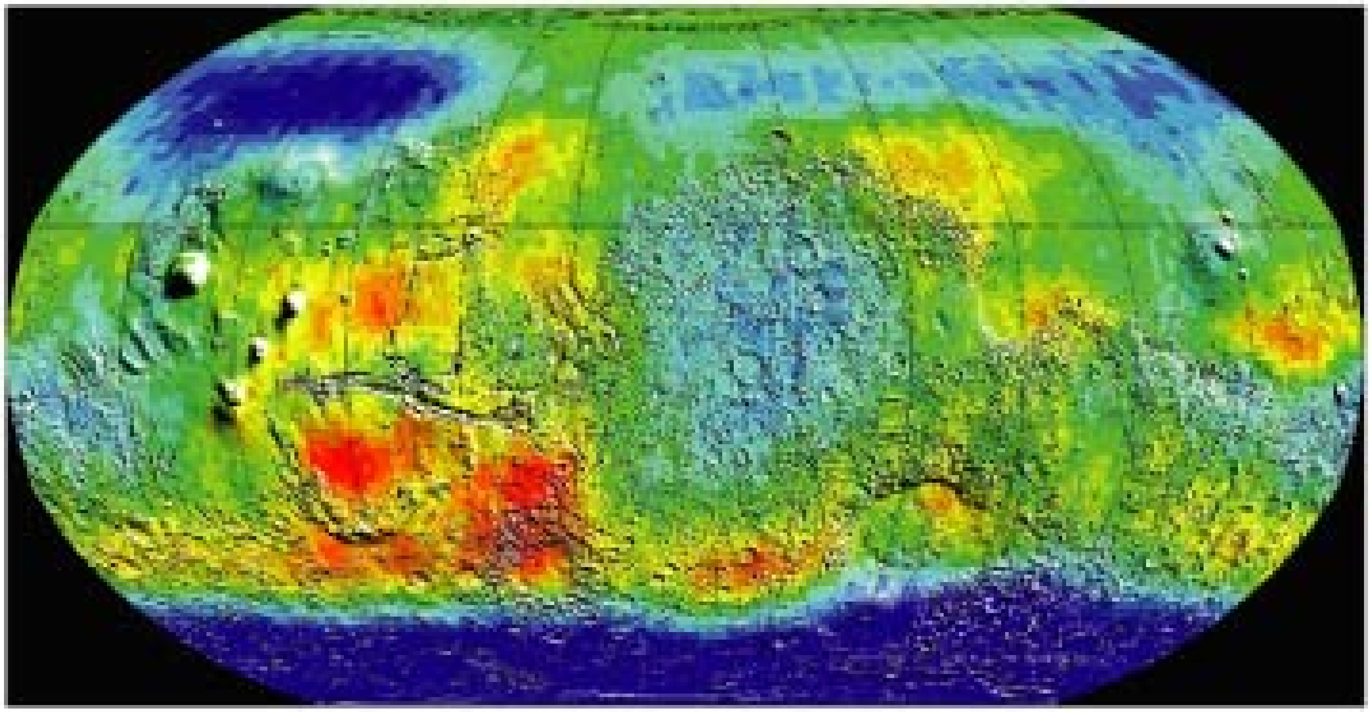
- Mars rovers have found rocks that appear to have formed in water

Martian Rocks



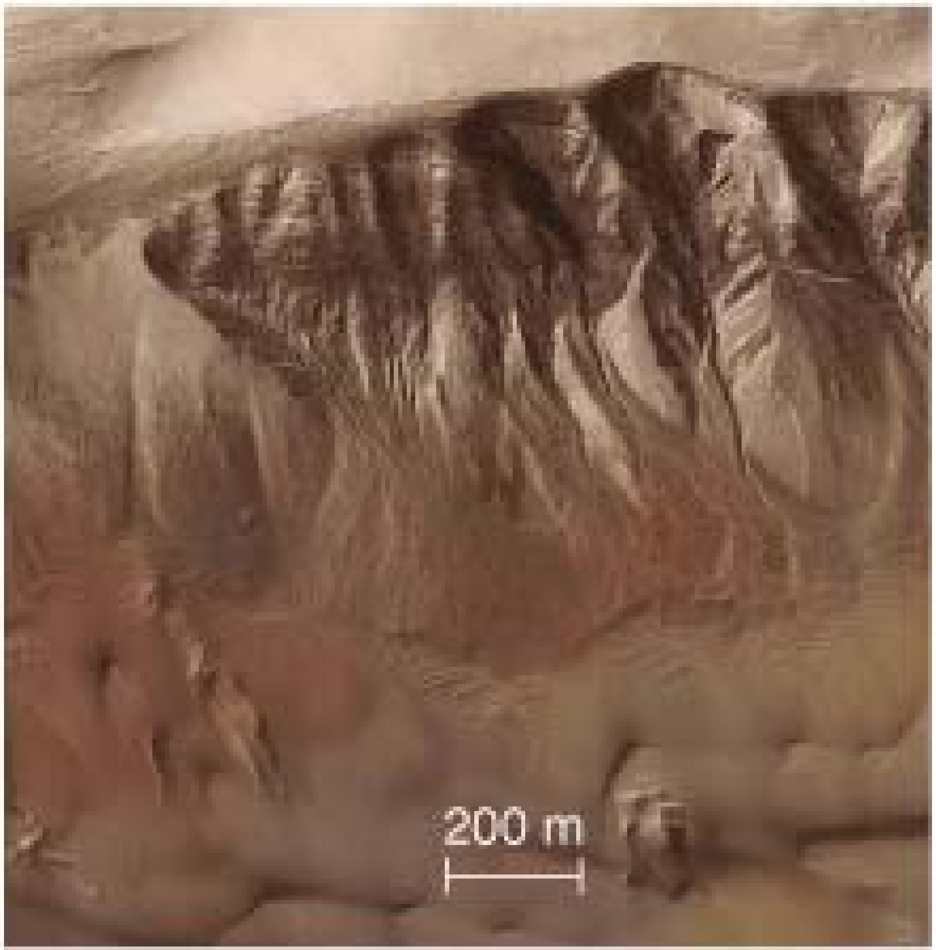
- Exploration of impact craters has revealed that Mars' deeper layers were affected by water

Hydrogen Content



- Map of hydrogen content (blue) shows that low-lying areas contain more water ice

Crater Walls



- Gullies on crater walls suggest occasional liquid water flows have happened less than a million years ago

What have we learned?

- How did Martians invade popular culture?
  - Surface features of Mars in early telescopic photos were misinterpreted as "canals"
- What are the major geological features of Mars?
  - Differences in cratering across surface
  - Giant shield volcanoes
  - Evidence of tectonic activity

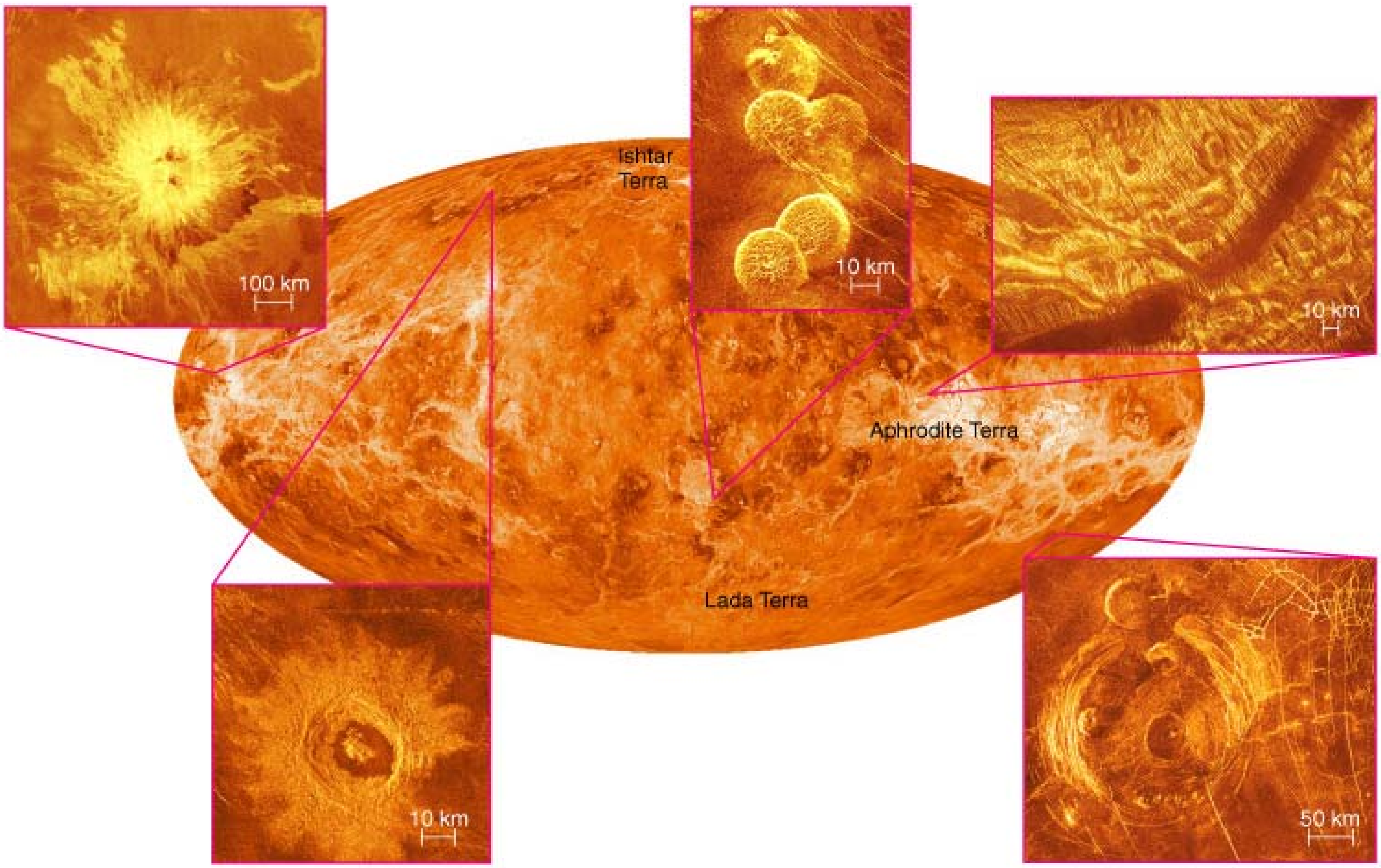
What have we learned?

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

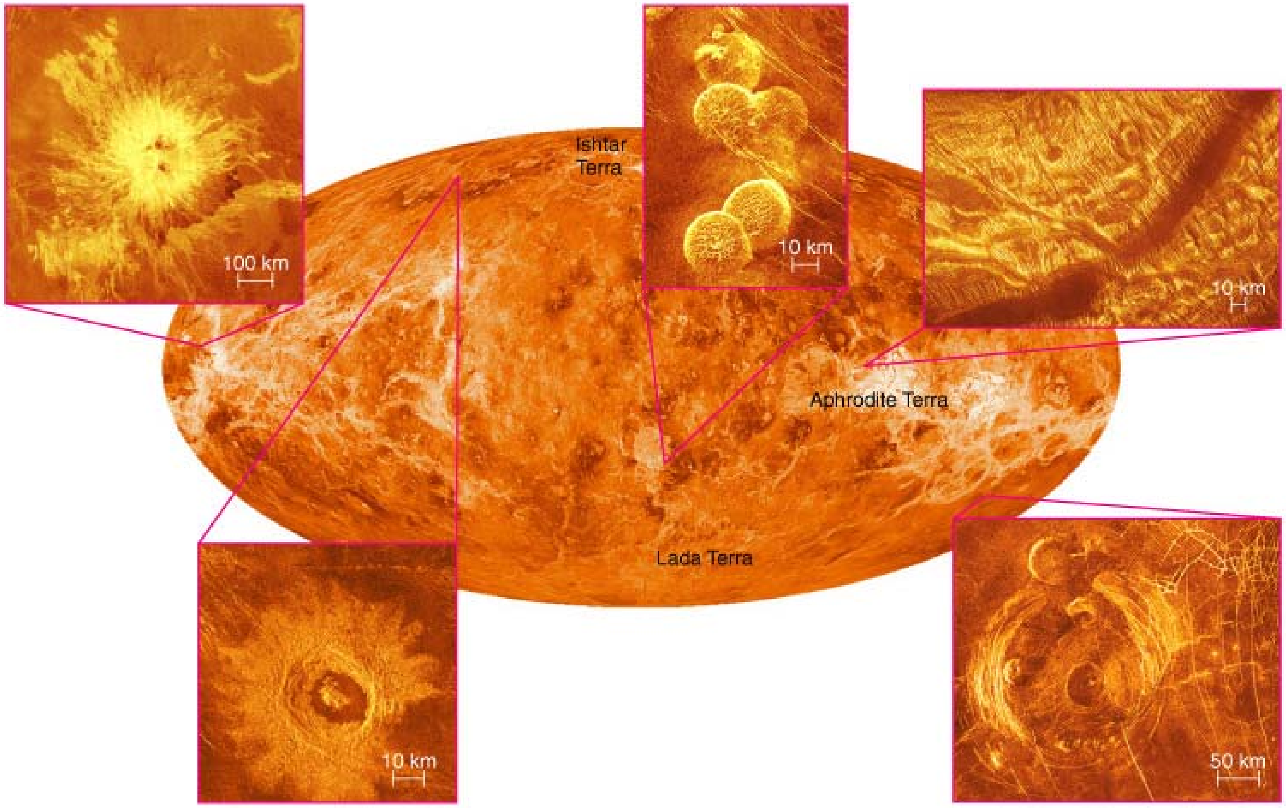
9.5 Geology of Venus

- Our goals for learning
- What are the major geological features of Venus?
- Does Venus have plate tectonics?

What are the major geological features of Venus?

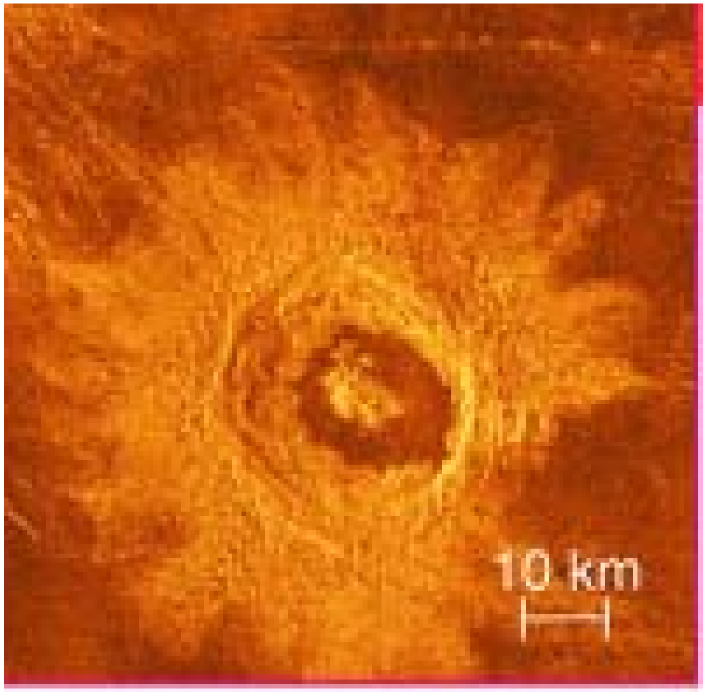


Radar Mapping



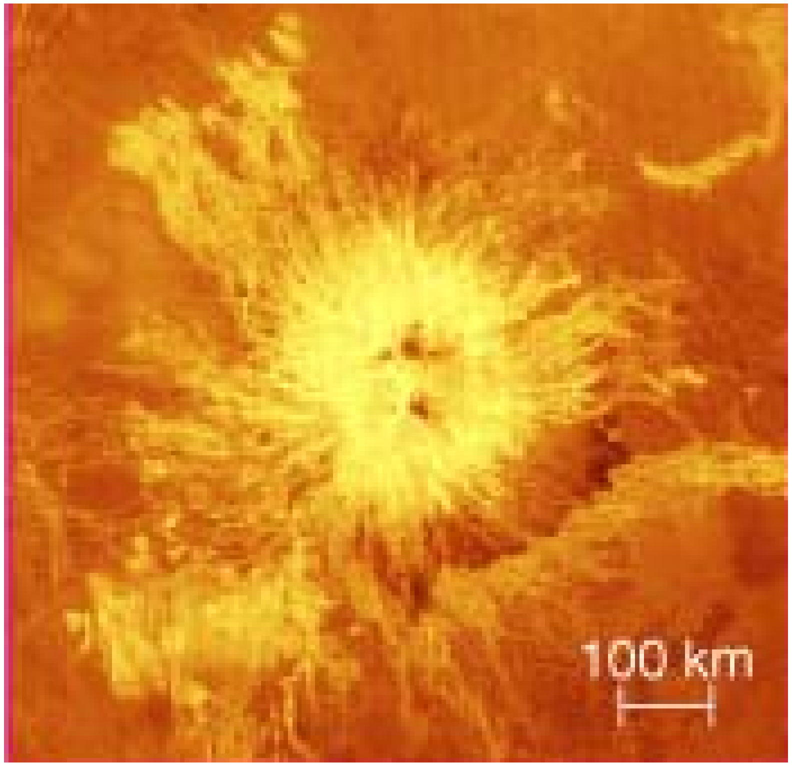
- Thick atmosphere forces us to explore Venus' surface through radar mapping

Cratering on Venus



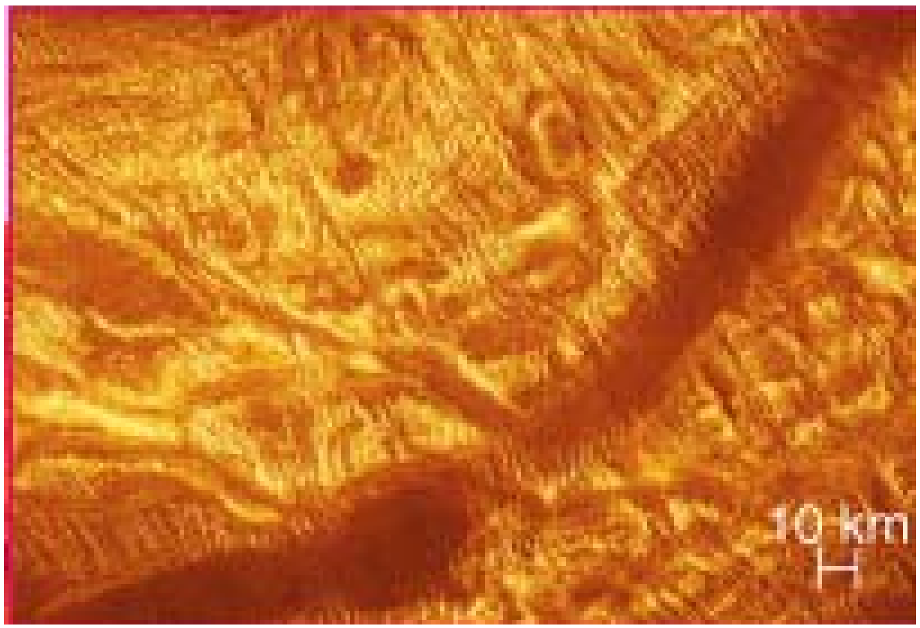
- Impact craters, but fewer than Moon, Mercury, Mars

Volcanoes on Venus



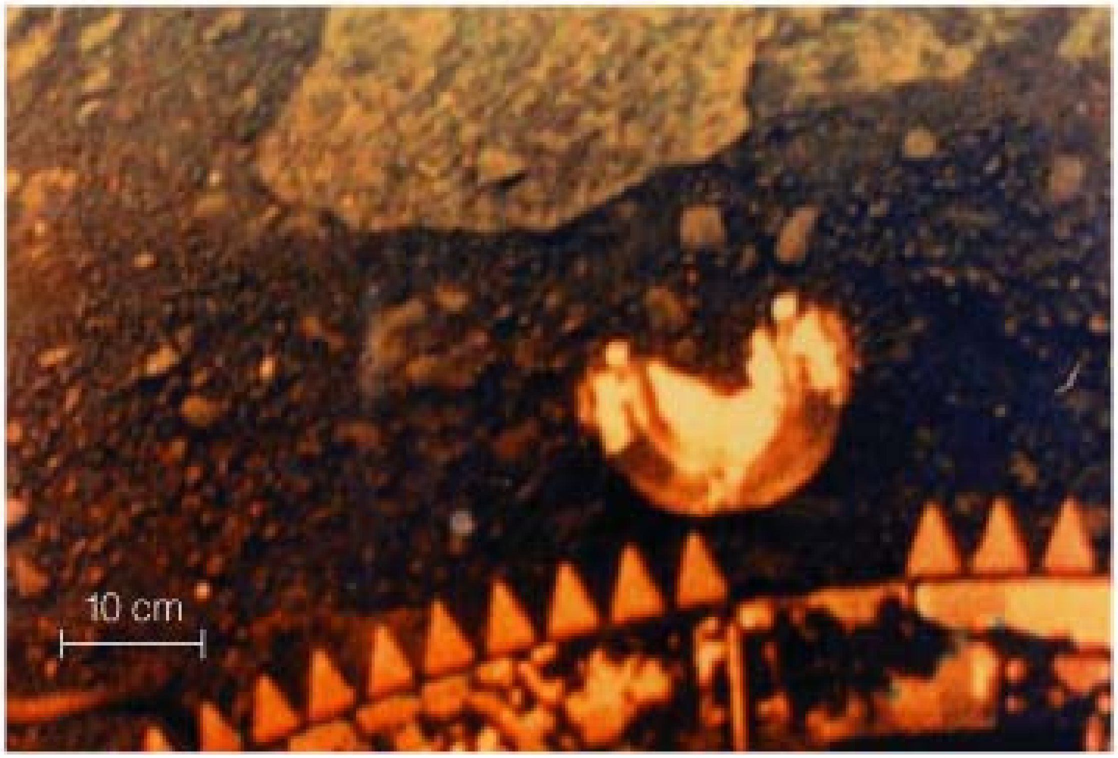
- Many volcanoes, including both shield volcanoes and stratovolcanoes

Tectonics on Venus



- Fractured and contorted surface indicates tectonic stresses

Erosion on Venus



- Photos of rocks taken by lander show little erosion

Does Venus have plate tectonics?

- Most of Earth’s major geological features can be attributed to plate tectonics, which gradually remakes Earth’s surface
- Venus does not appear to have plate tectonics, but entire surface seems to have been “repaved” 750 million years ago

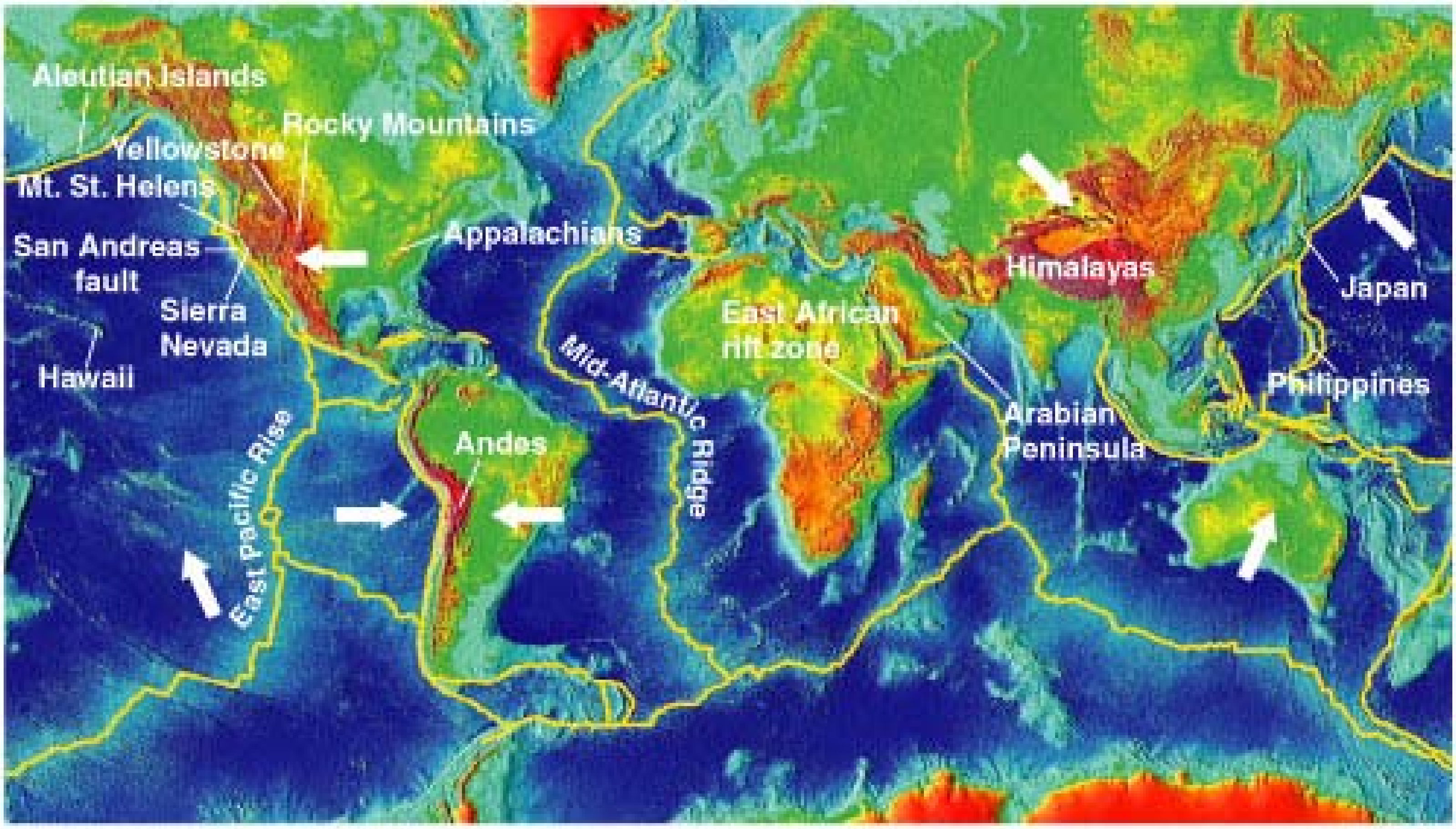
What have we learned?

- Our goals for learning
- What are the major geological features of 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

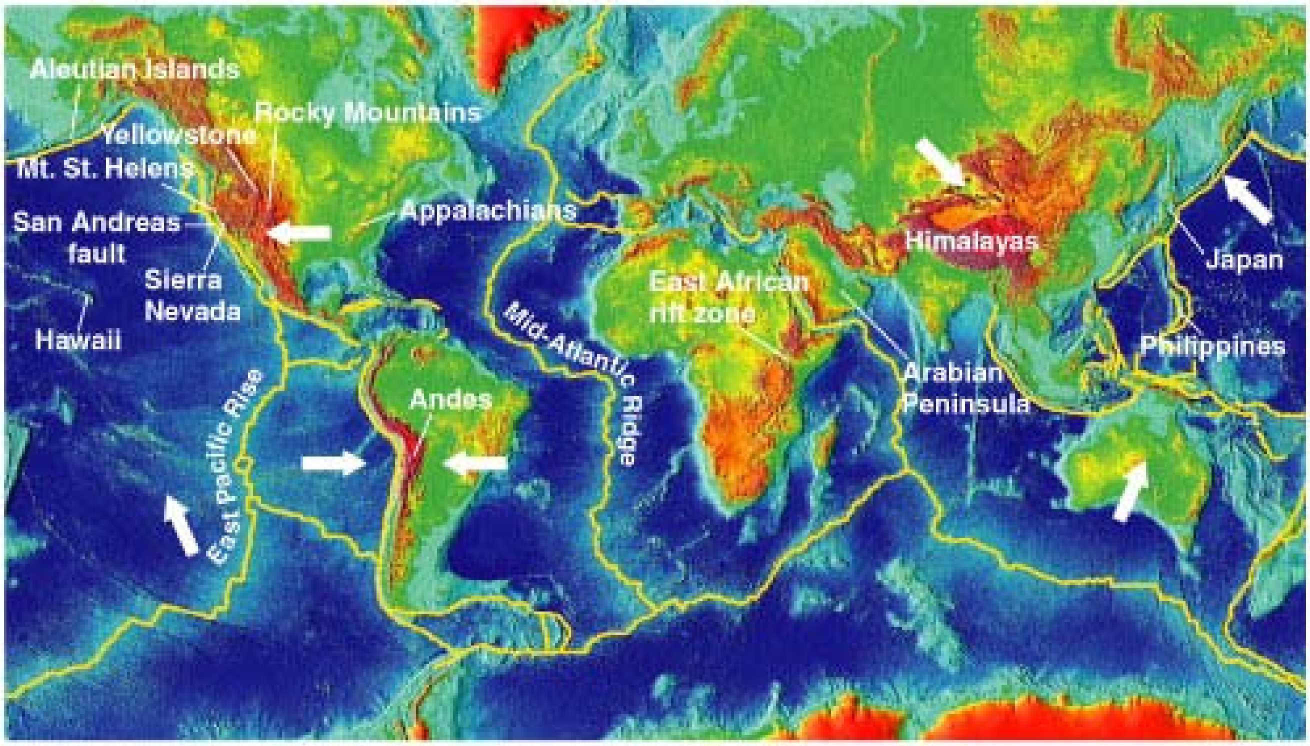
9.6 The Unique Geology of Earth

- Our goals for learning
- How do we know Earth's surface is in motion?
- How is Earth's surface shaped by plate tectonics?
- Was Earth's geology destined from birth?

How do we know Earth's surface is in motion?



Continental Motion



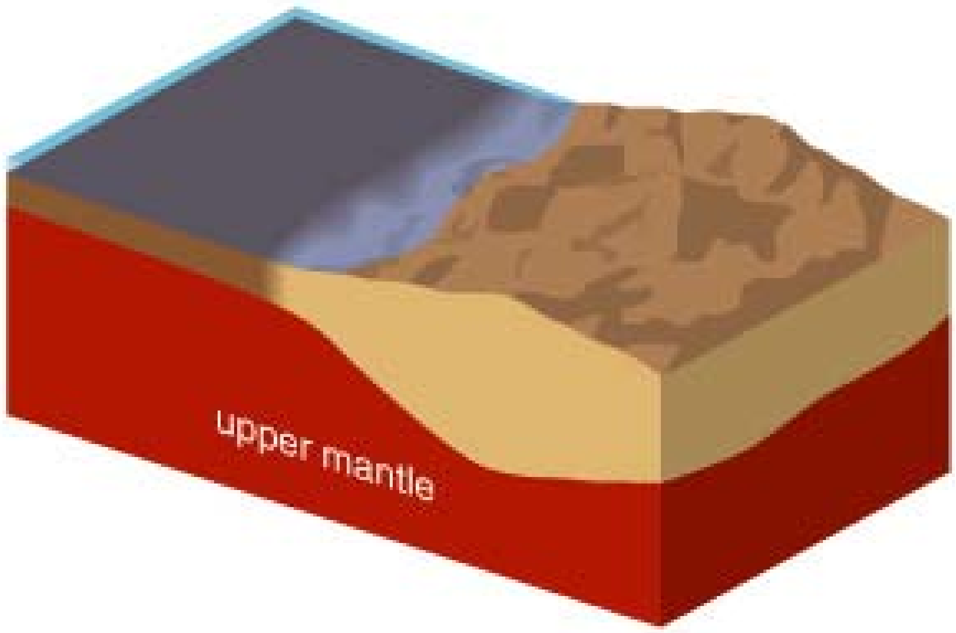
- Motion of continents can be measured with GPS

Continental Motion

- Idea of continental drift was inspired by puzzle-like fit of continents

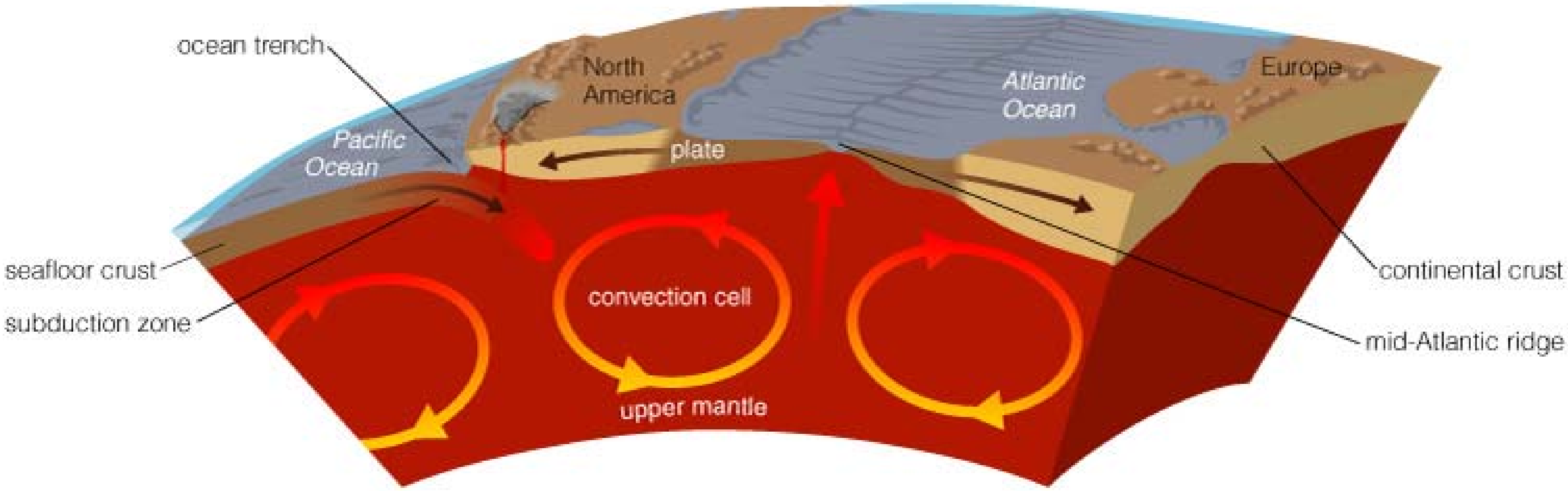
- Mantle material erupts where seafloor spreads

Seafloor Crust

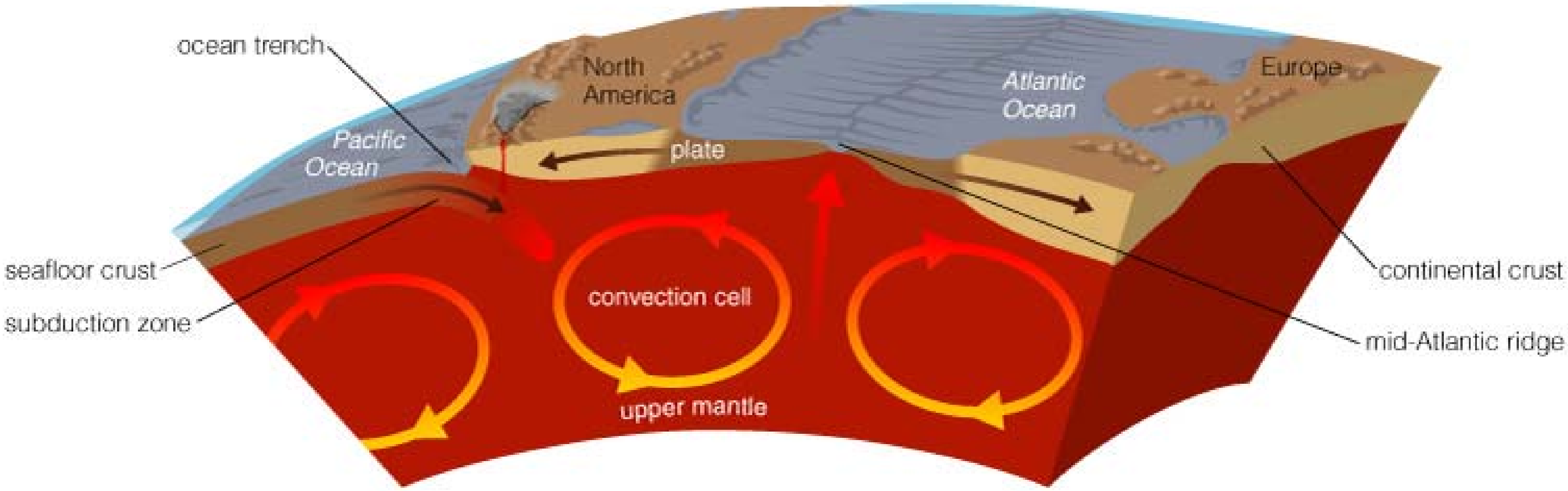


- Thin seafloor crust differs from thick continental crust
- Dating of seafloor shows it is usually quite young

How is Earth's surface shaped by plate tectonics?

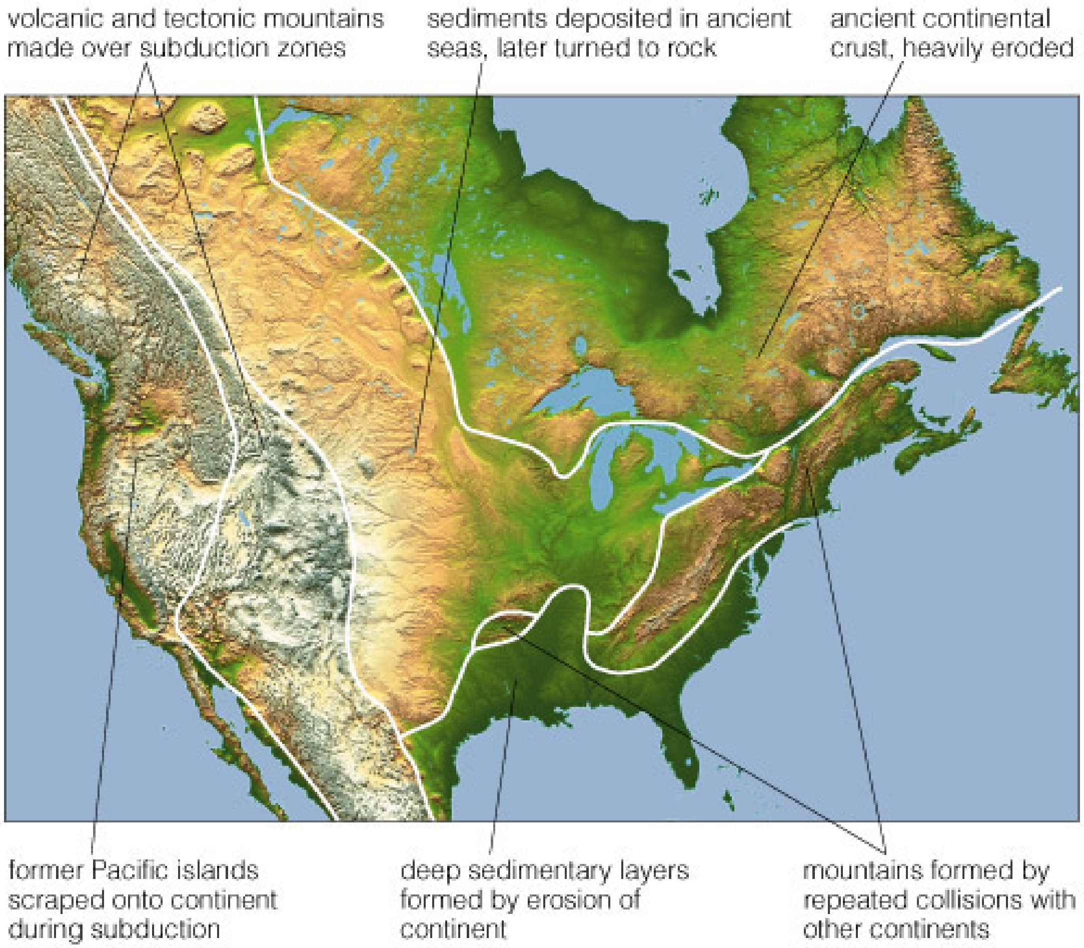


Seafloor Recycling



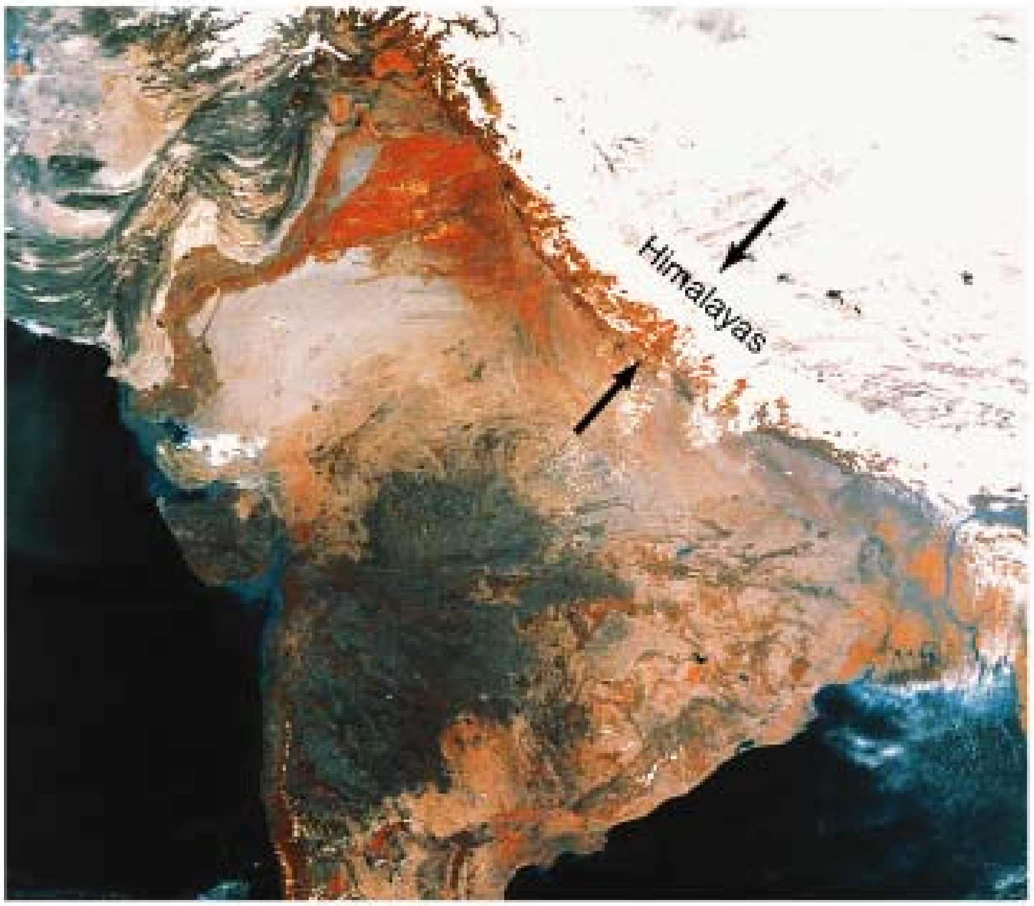
- Seafloor is recycled through a process known as subduction

Surface Features



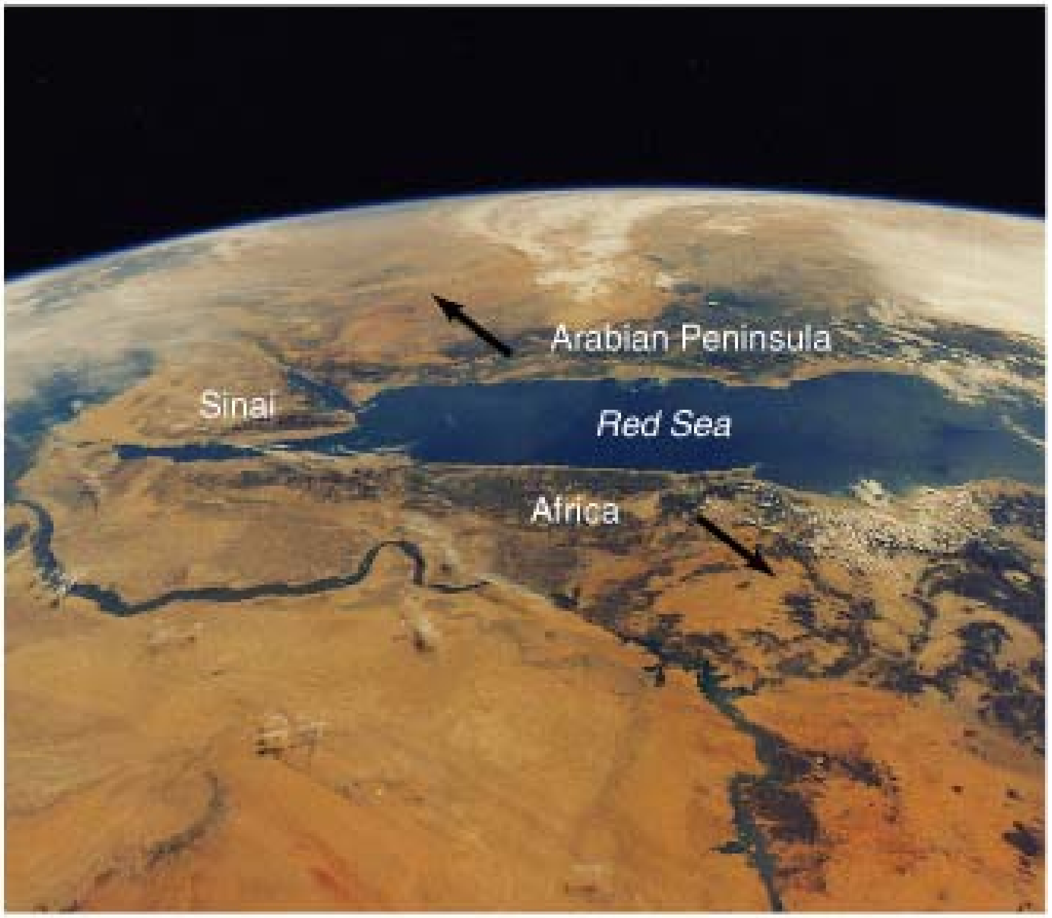
- Major geological features of North America record history of plate tectonics

Surface Features



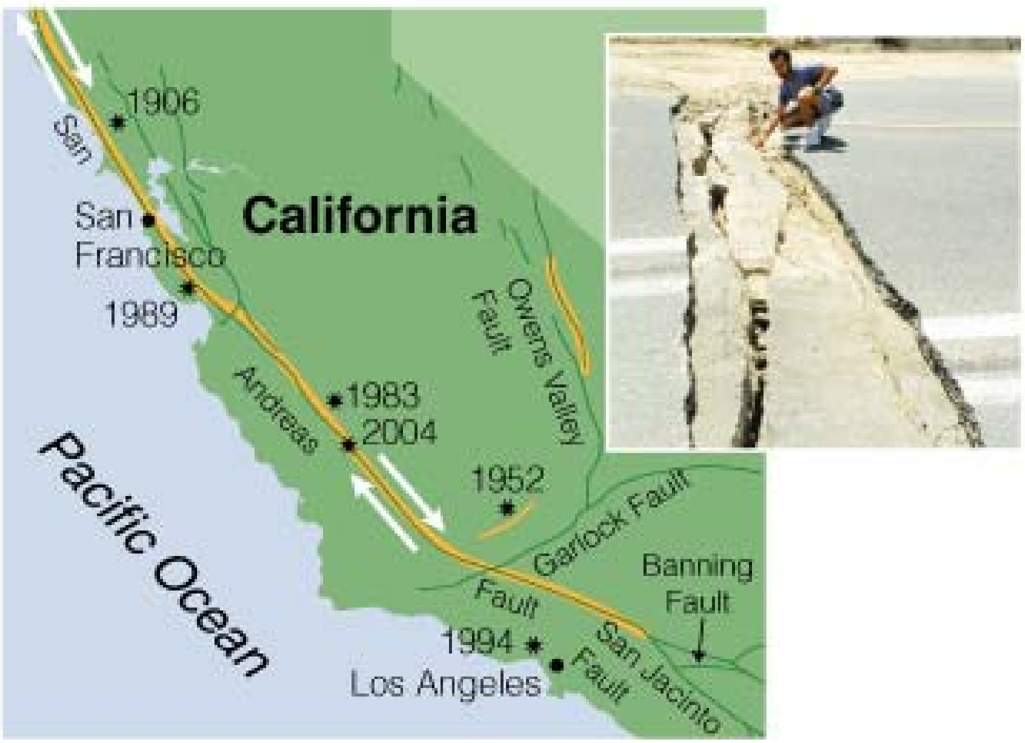
- Himalayas are forming from a collision between plates

Surface Features



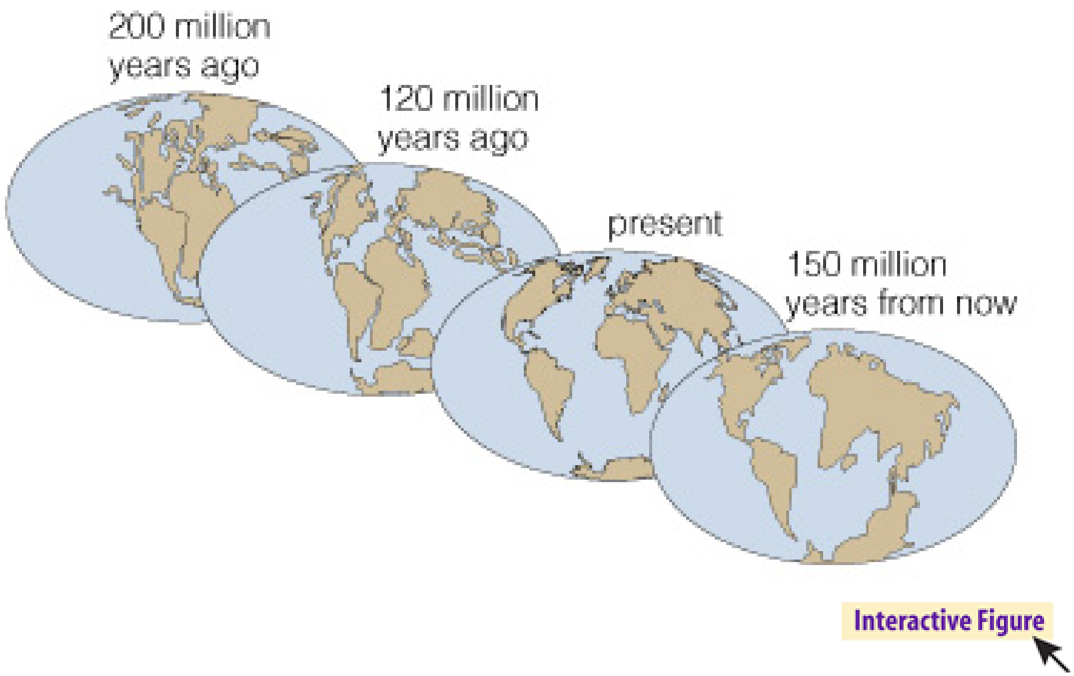
- Red Sea is forming where plates are pulling apart

Rifts, Faults, Earthquakes



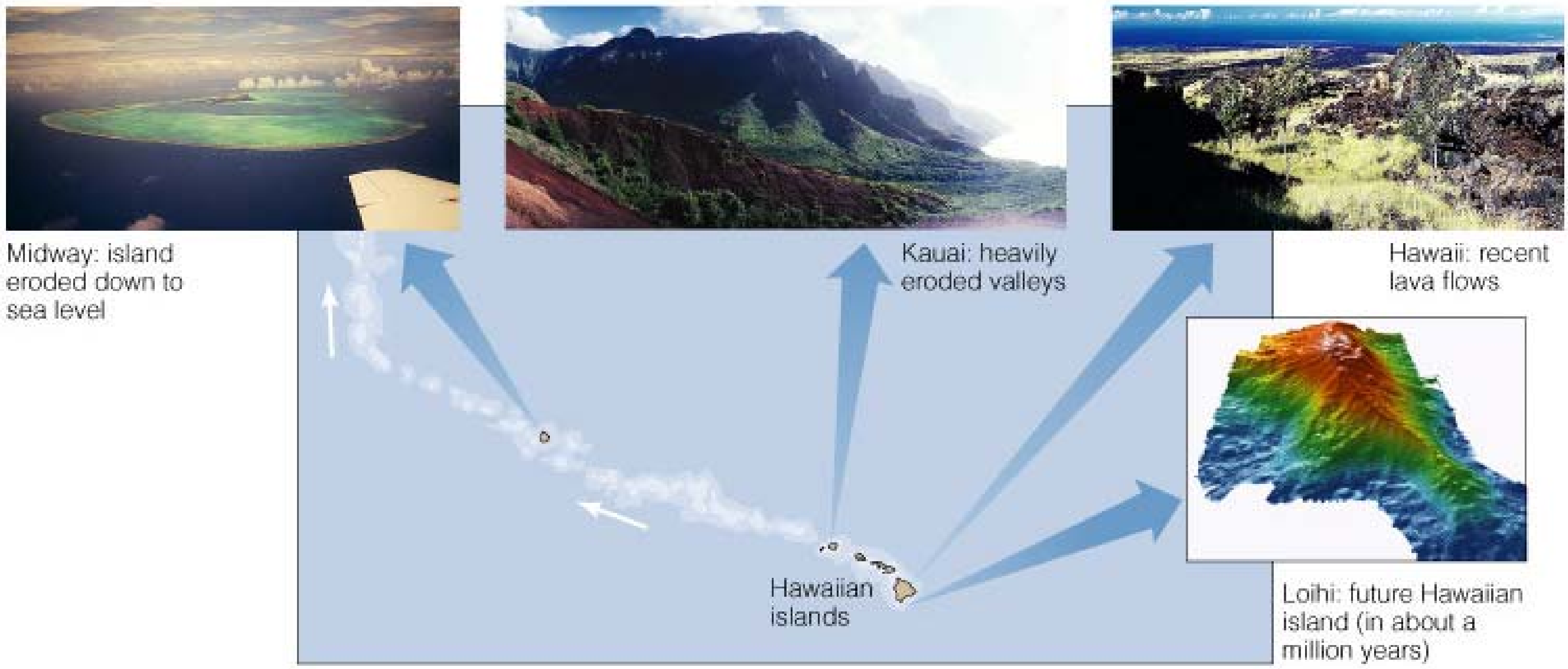
- San Andreas fault in California is a plate boundary
- Motion of plates causes earthquakes

Plate Motions



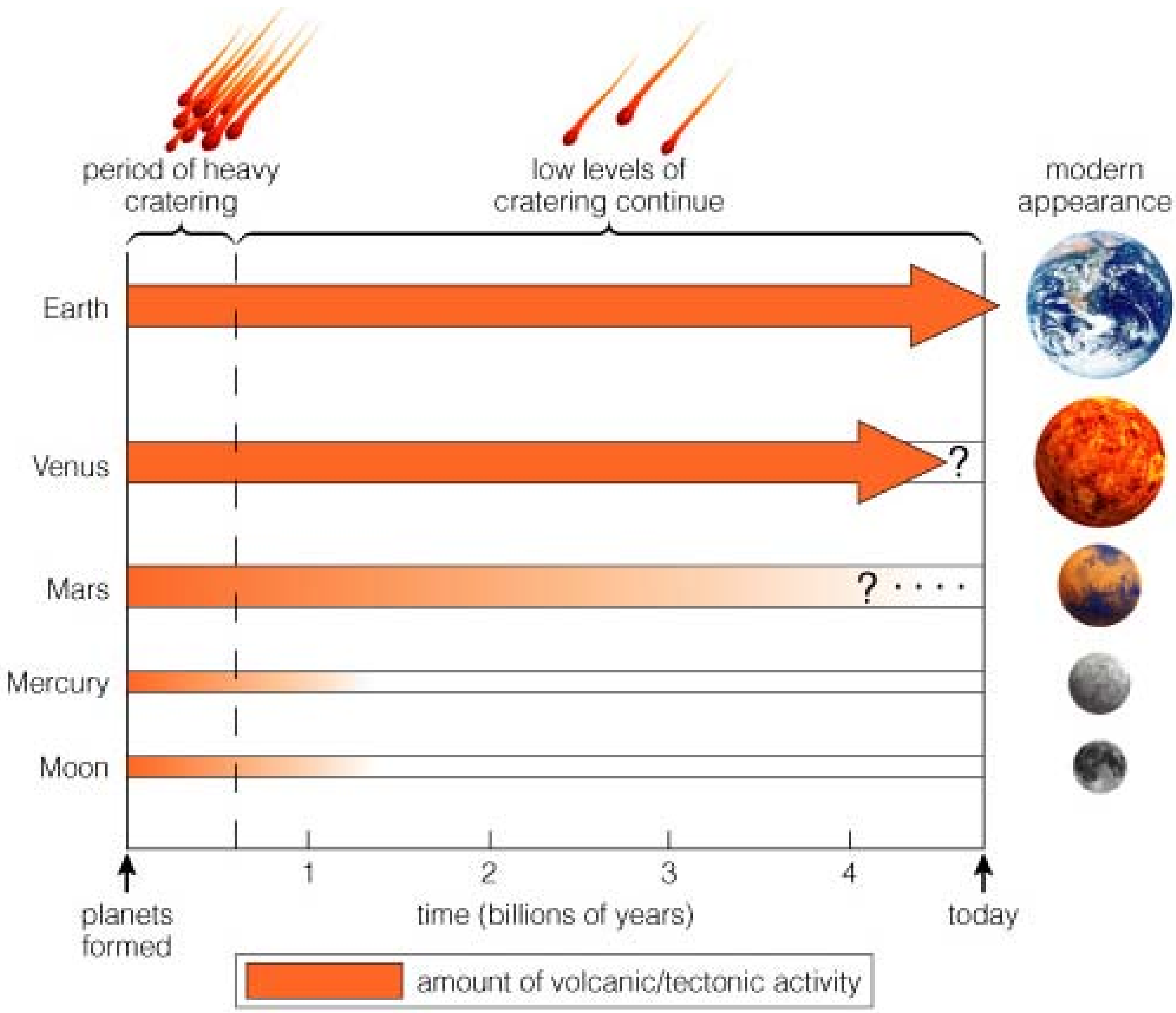
- Measurements of plate motions tell us past and future layout of continents

Hot Spots

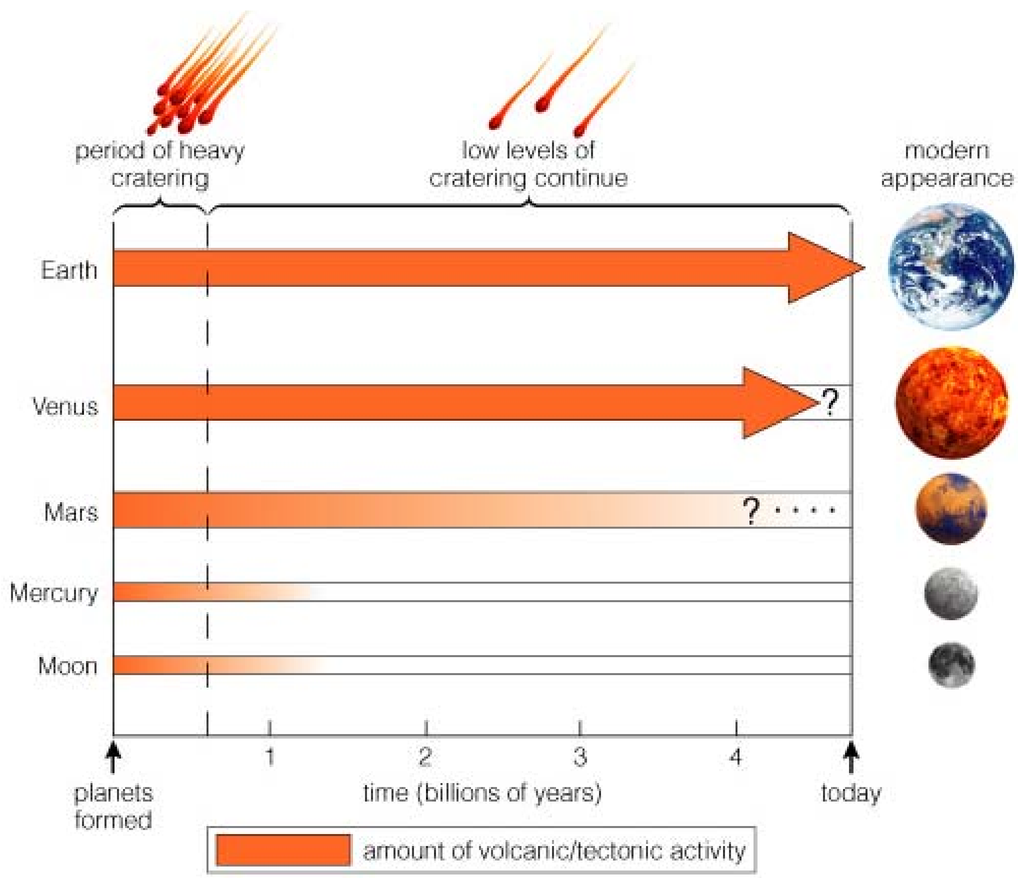


- Hawaiian islands have formed where plate is moving over volcanic hot spot

Was Earth's geology destined from birth?



Earth’s Destiny



- Many of Earth’s features determined by size, rotation, and distance from Sun
- Reason for plate tectonics not yet clear

What have we learned?

- How do we know that Earth's surface is in motion?
  - Measurements of plate motion confirm idea of continental drift
- How is Earth's surface shaped by plate tectonics?
  - Plate tectonics 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 determined by size, distance from Sun, and rotation rate
  - Reason for plate tectonics still a mystery