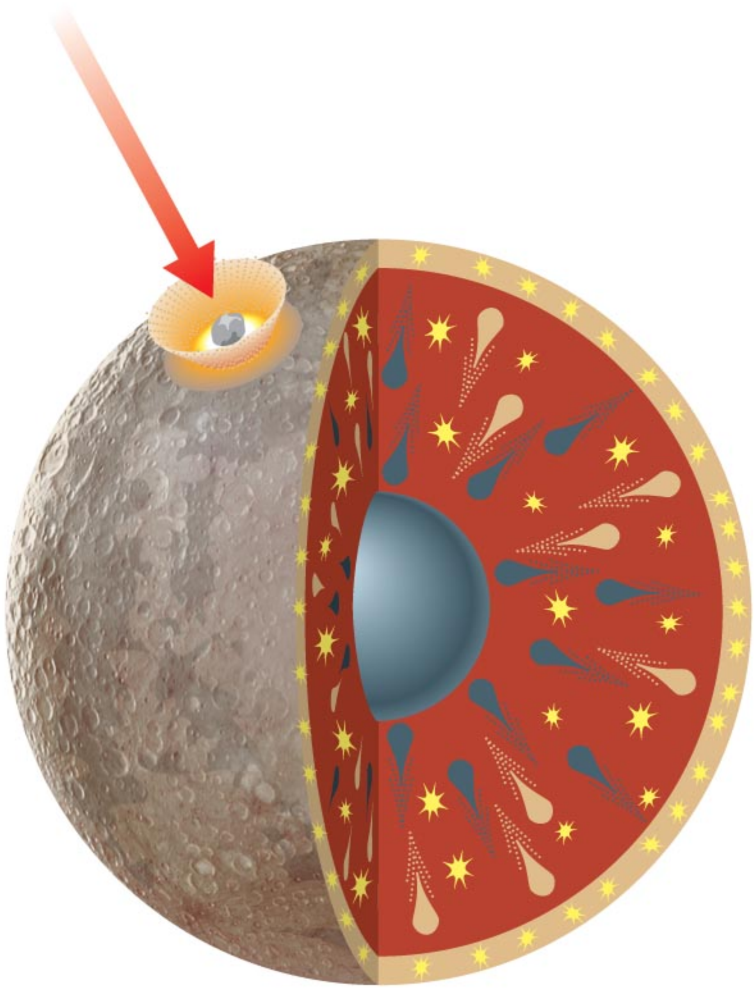
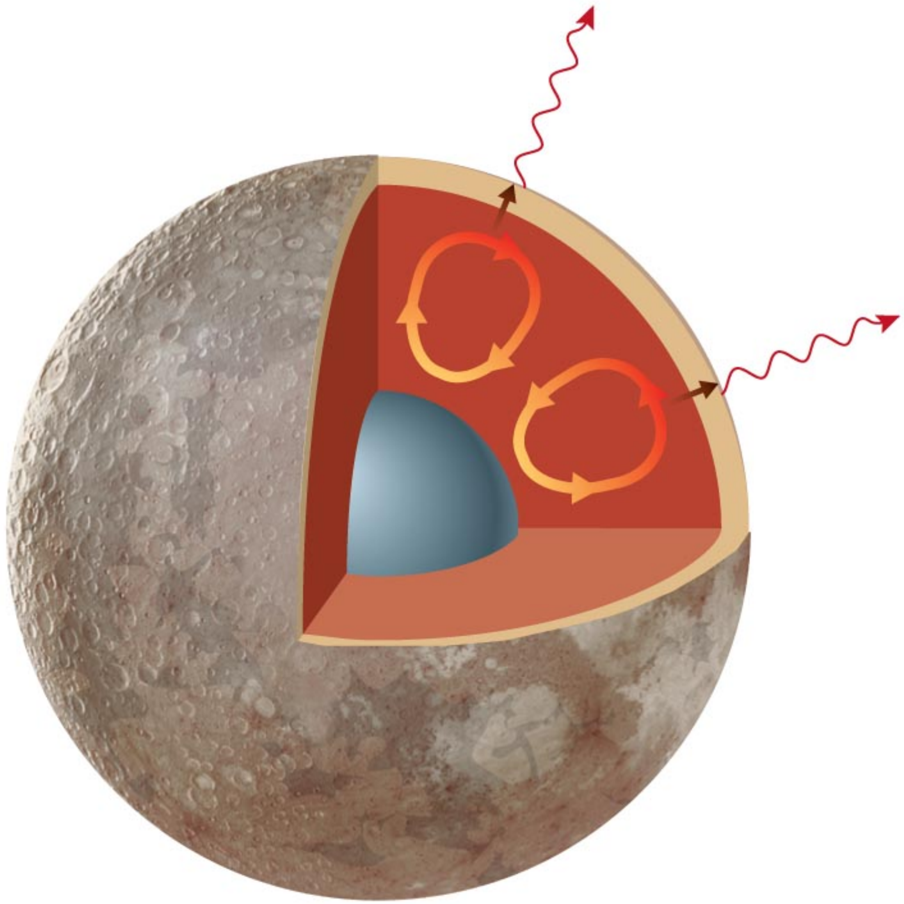
Heating of Planetary Interiors



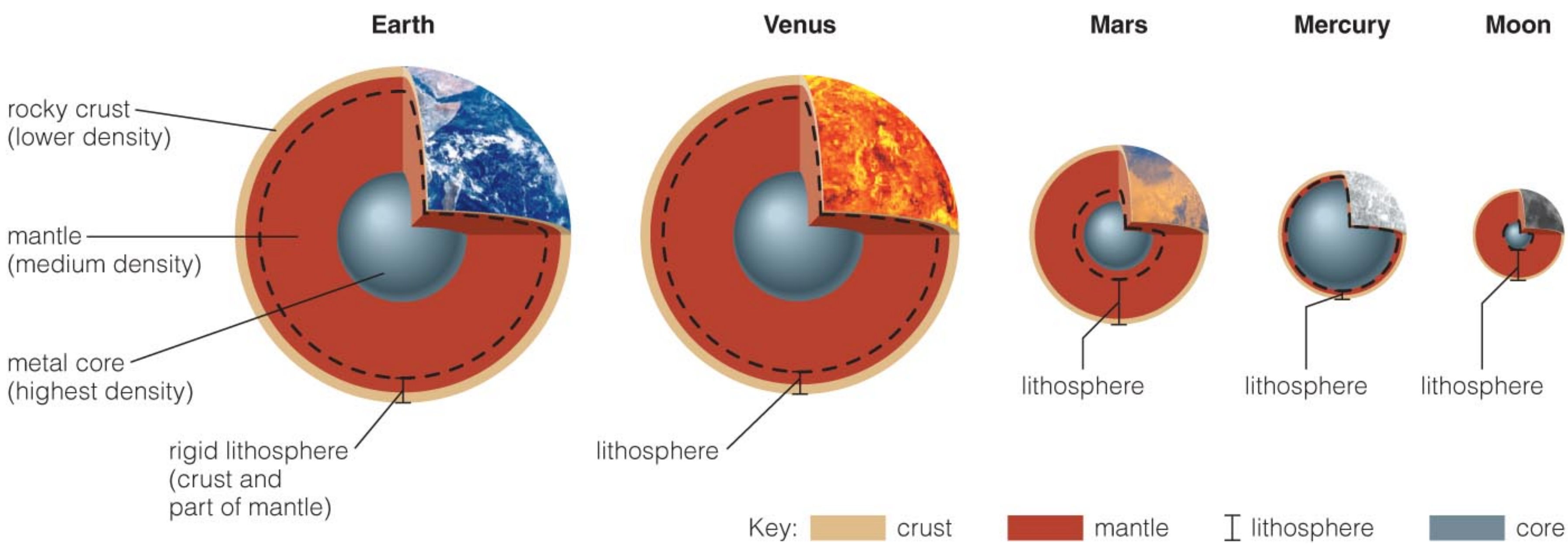
- **Accretion** and **differentiation** when planets were young
- **Radioactive decay** is most important heat source today.

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."

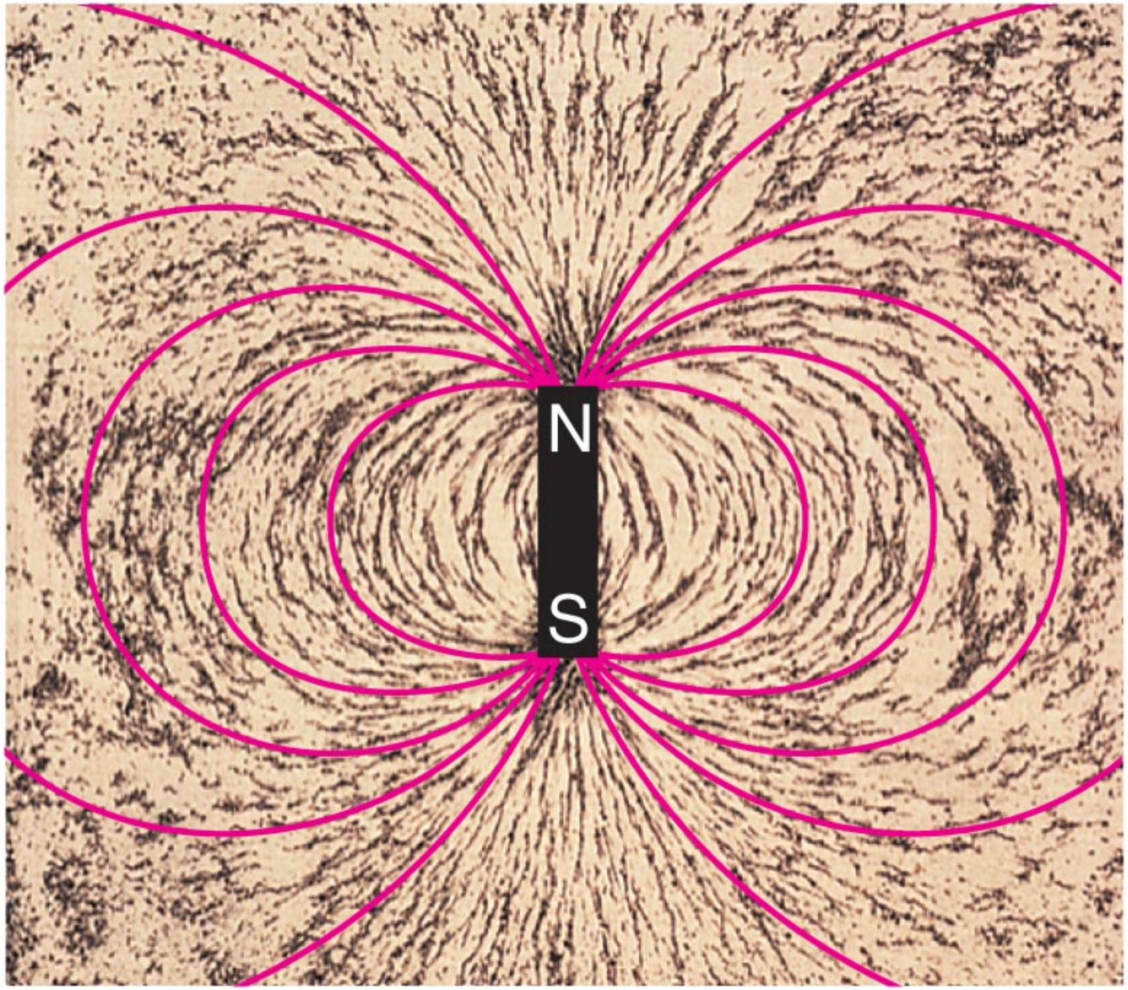
Surface Area–to–Volume Ratio

- Heat content depends on volume.
- Loss of heat through radiation depends on surface area.
- Time to cool depends on volume (amount of heat) divided by the surface area (how fast you get rid of heat):

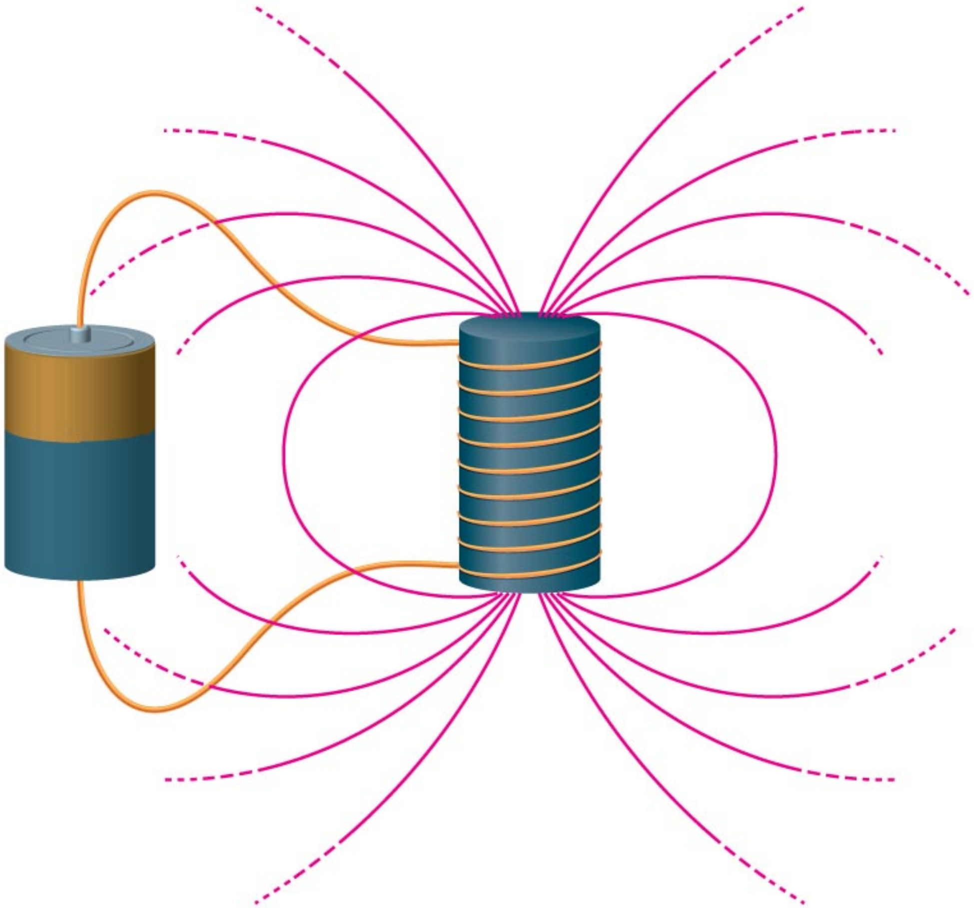
$$cooling\ time \sim \frac{\frac{4}{3}\pi R^3}{4\pi R^2} = \frac{R}{3}$$

- Larger planets (bigger radius R) take longer to cool.

Why do some planetary interiors create magnetic fields?

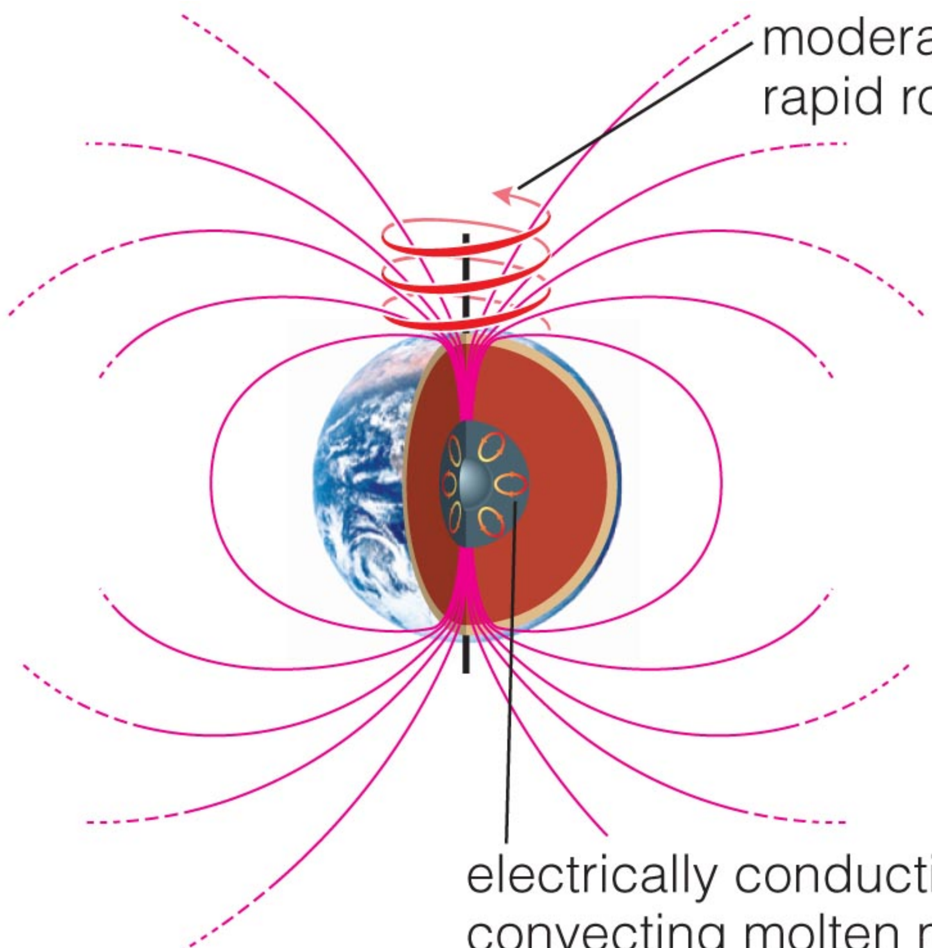


Sources of Magnetic Fields



- 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

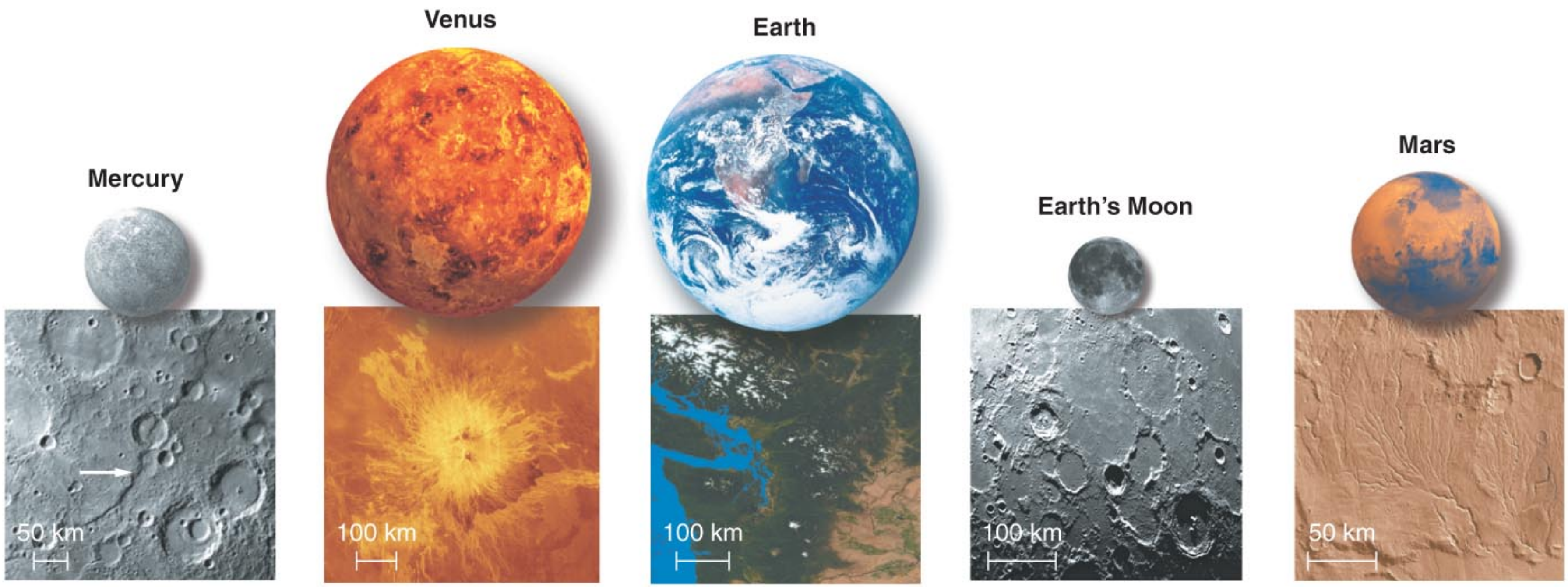
What have we learned?

- **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?



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.

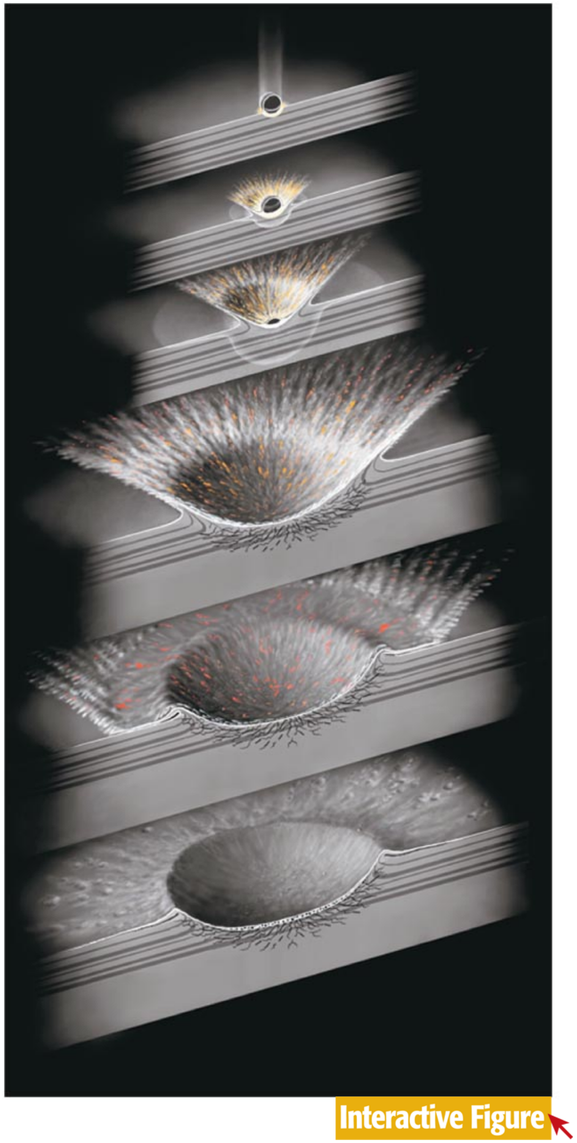
The Moon's surface is heavily cratered in most places.

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

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 object that made them.
- Small craters greatly outnumber large ones.

Impact Craters

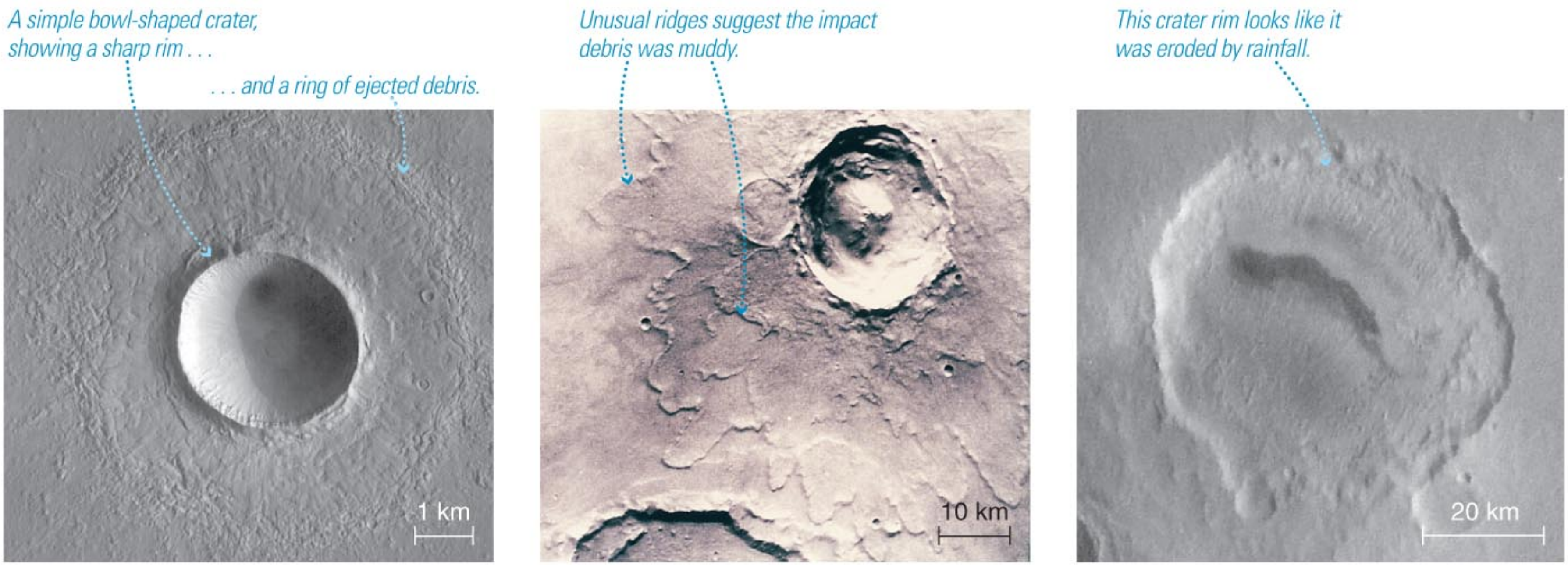
a Meteor Crater in Arizona is more than a kilometer across and almost 200 meters deep. It was created around 50,000 years ago by the impact of a metallic asteroid about 50 meters across.

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



a A crater with a typical bowl shape.

b This crater was probably made by an impact into icy ground.

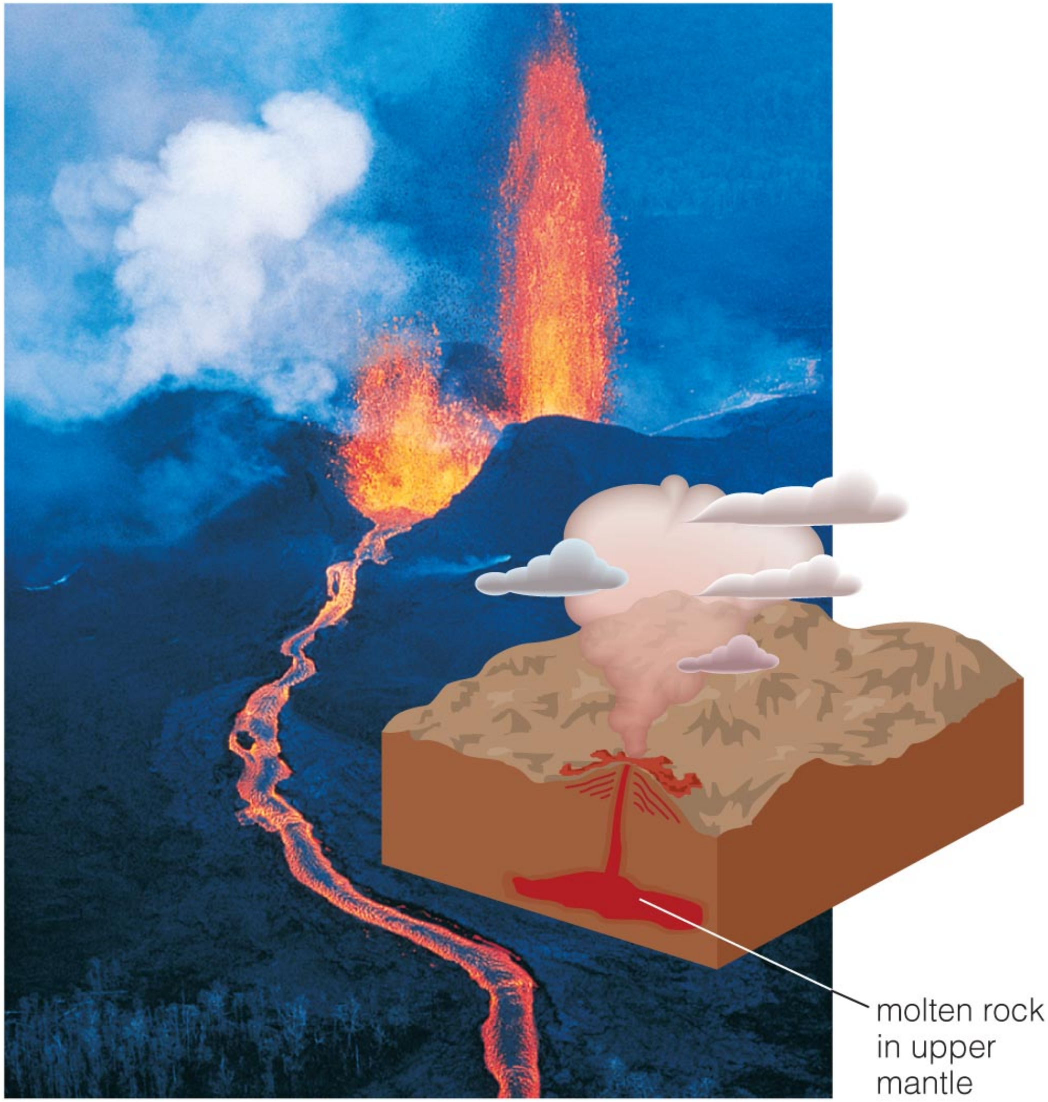
c This crater shows evidence of erosion.

"Standard" crater

Impact into icy ground

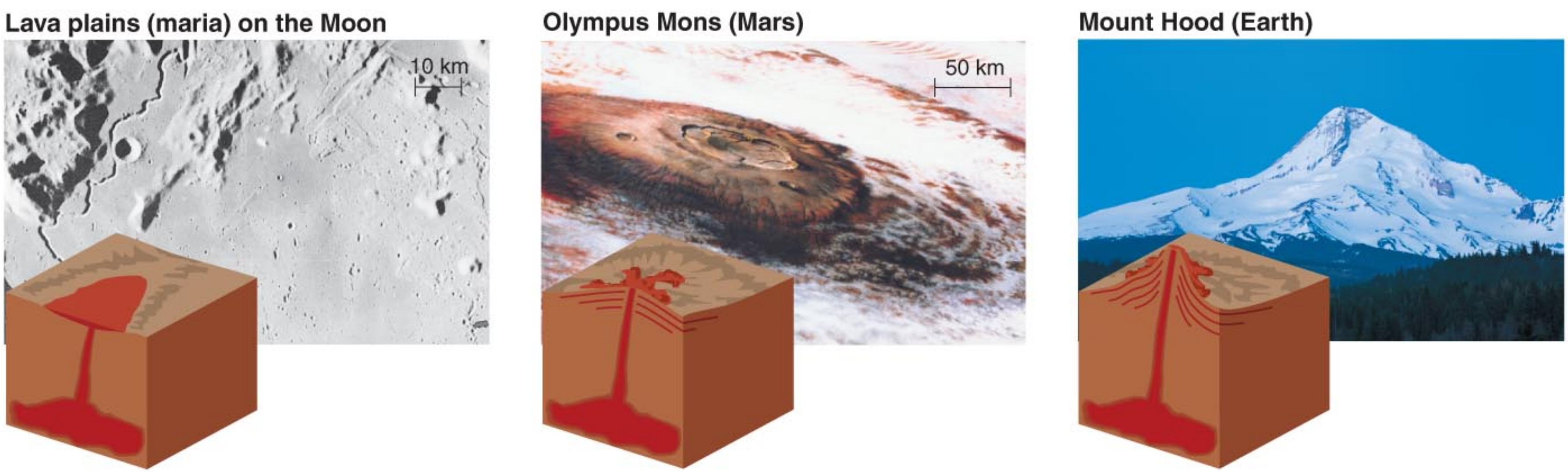
Eroded crater

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



a Very runny lava makes flat lava plains like these on the Moon. The long, winding channel near the upper left was made by a river of molten lava.

b Slightly thicker lava makes shallow-sloped shield volcanoes, such as Olympus Mons on Mars.

c The thickest lavas make steep-sloped stratovolcanoes like Oregon's Mount Hood.

Runny lava makes flat lava plains.

Slightly thicker lava makes broad *shield volcanoes*.

Thickest lava makes steep *stratovolcanoes*.

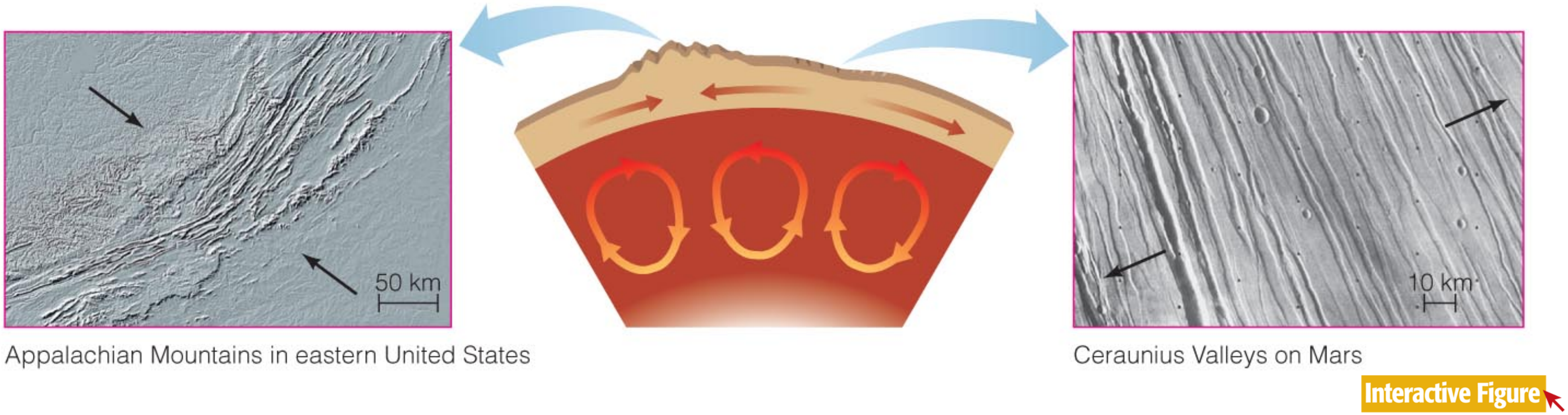
Outgassing

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



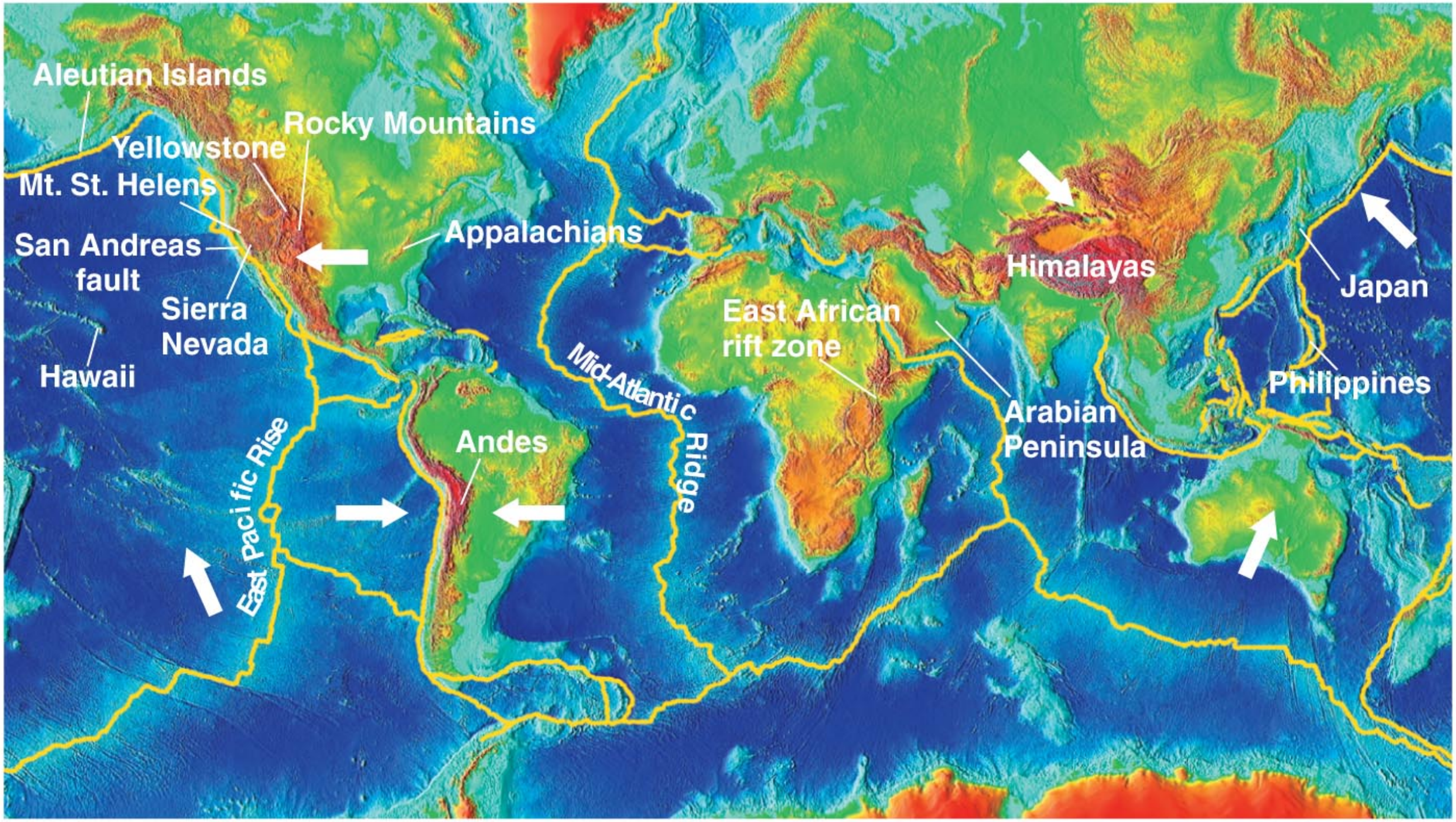
Appalachian Mountains in eastern United States

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.

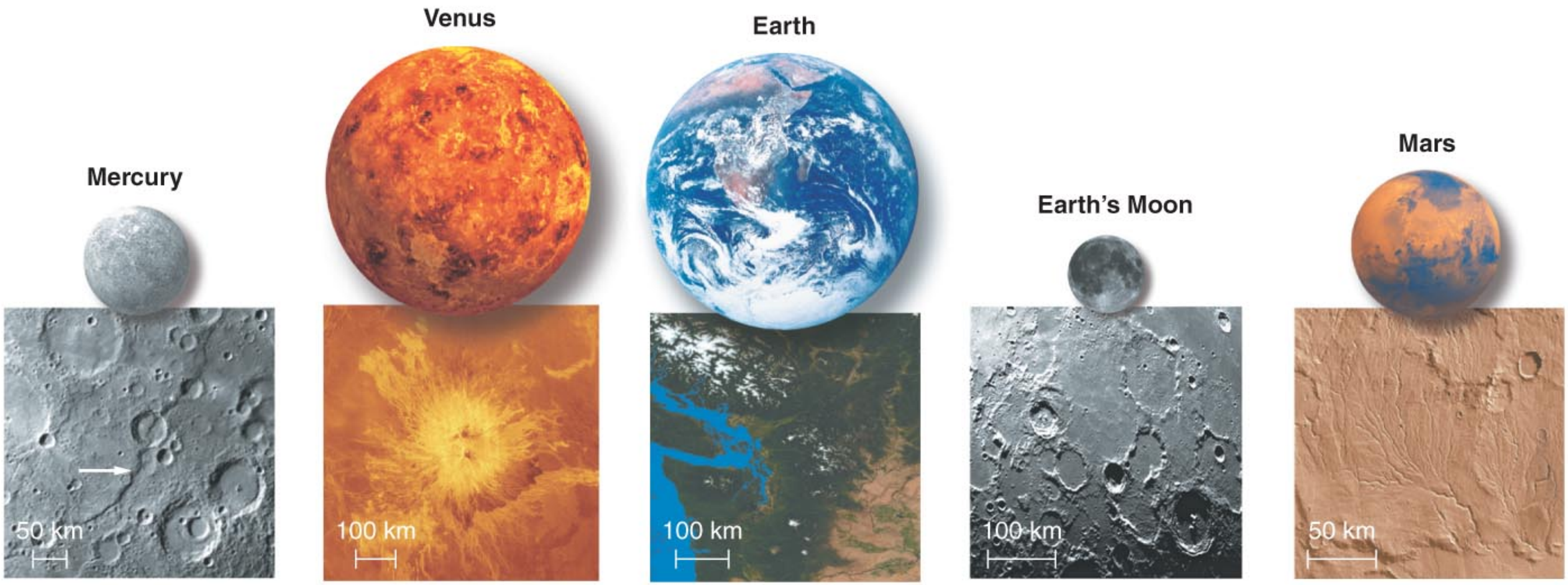
Erosion by Wind

- Wind wears away rock and builds up sand dunes.

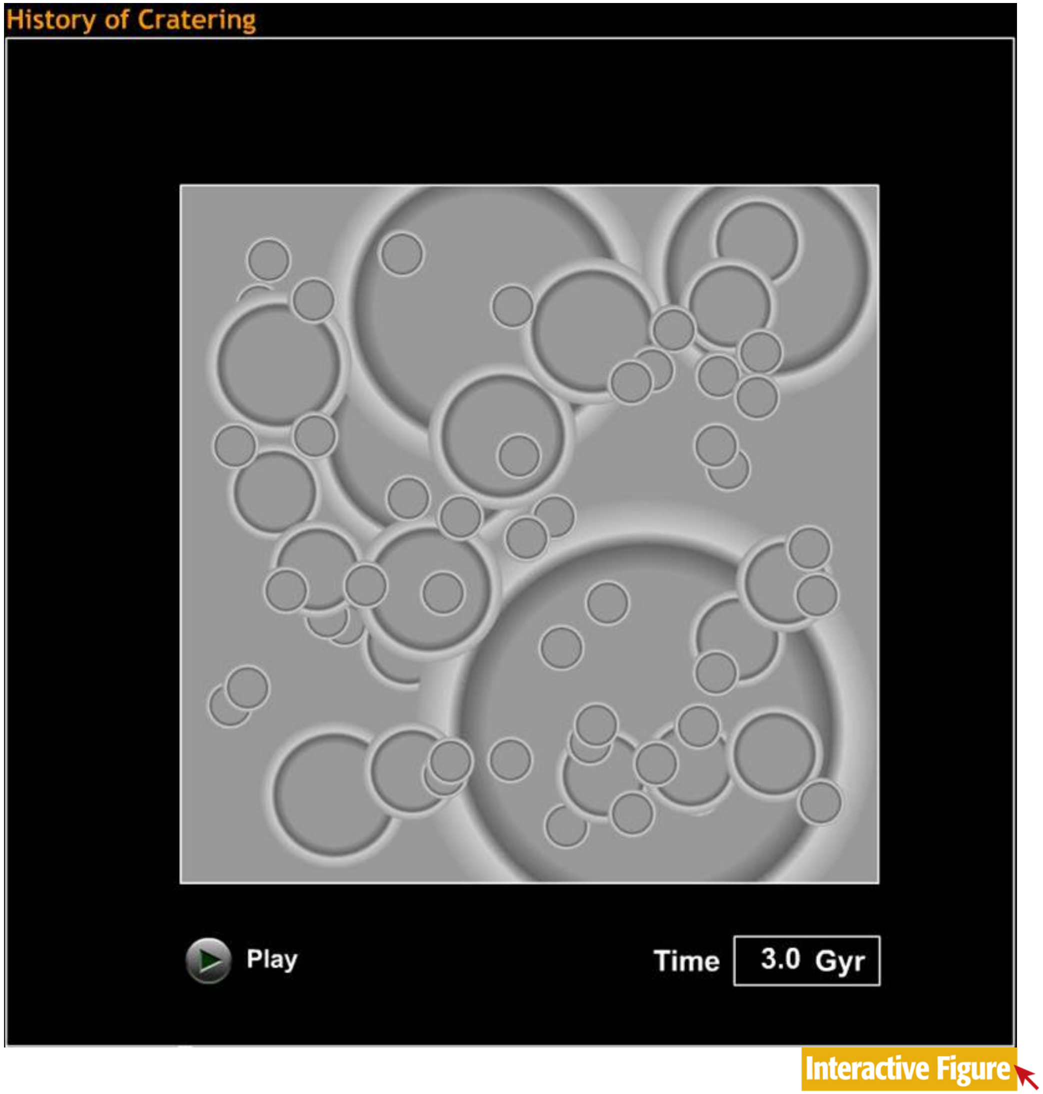
Erosional Debris

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

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

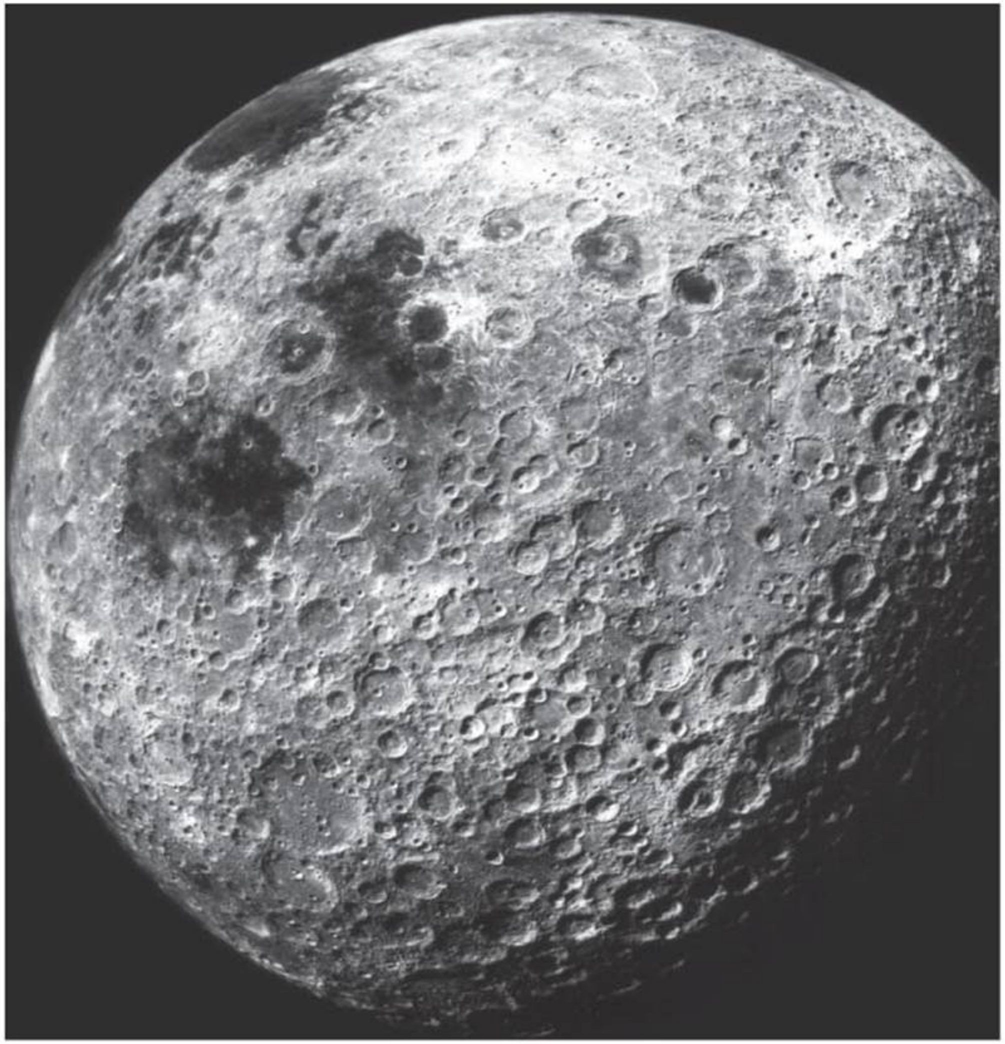


History of Cratering



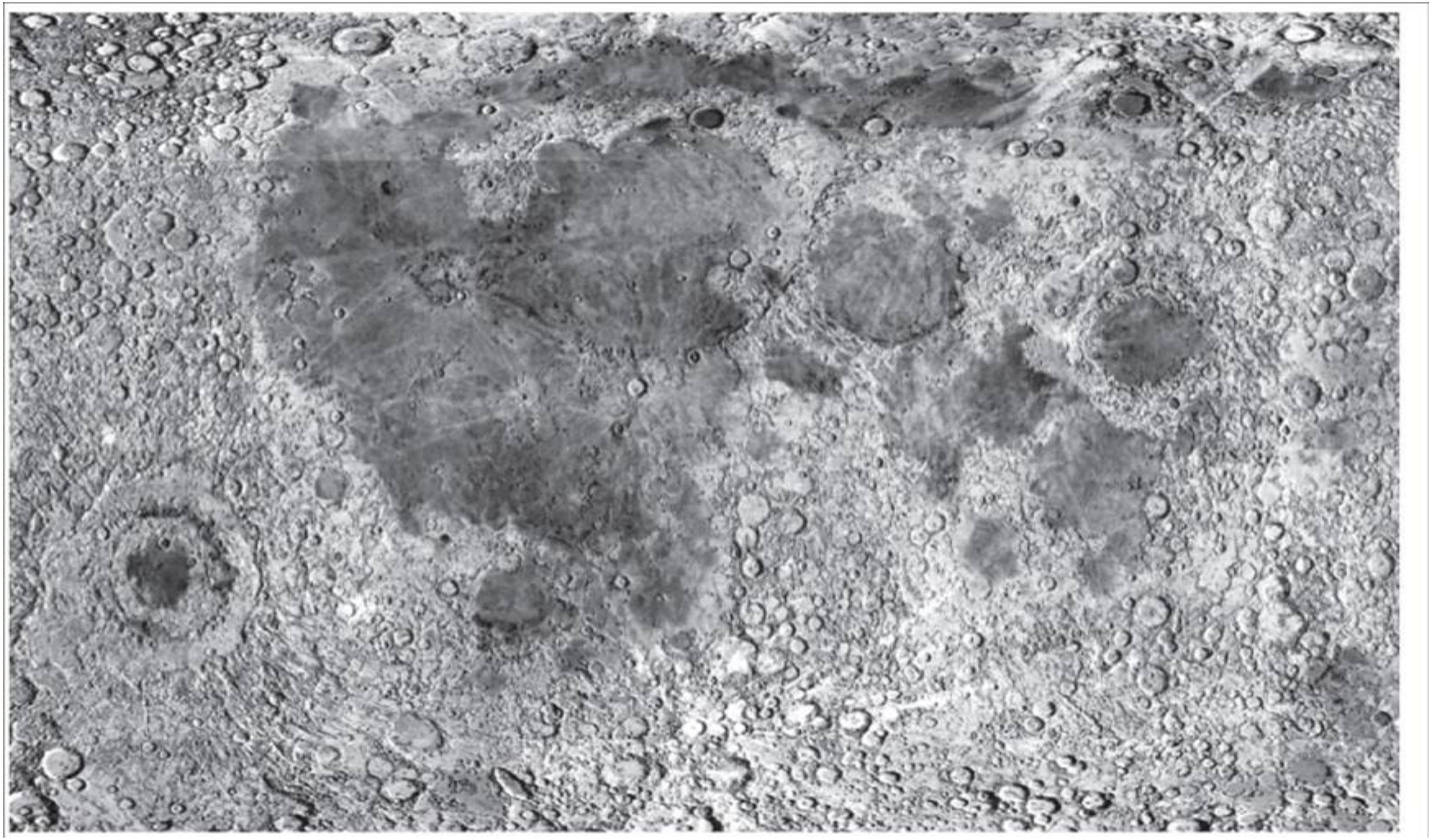
- Most cratering happened in the first billion years.
- A surface with many craters has not changed much in 3 billion years.

Cratering of Moon



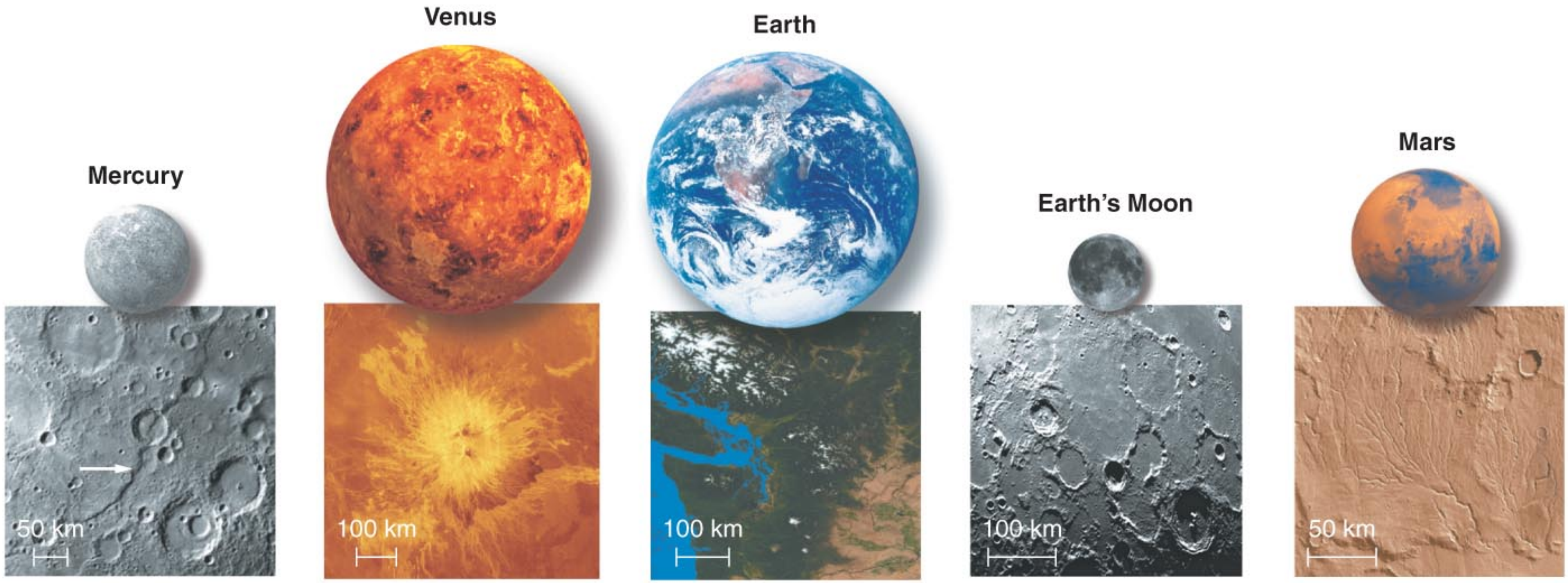
- Some areas of Moon are more heavily cratered than others.
- Younger regions were flooded by lava after most cratering.

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).

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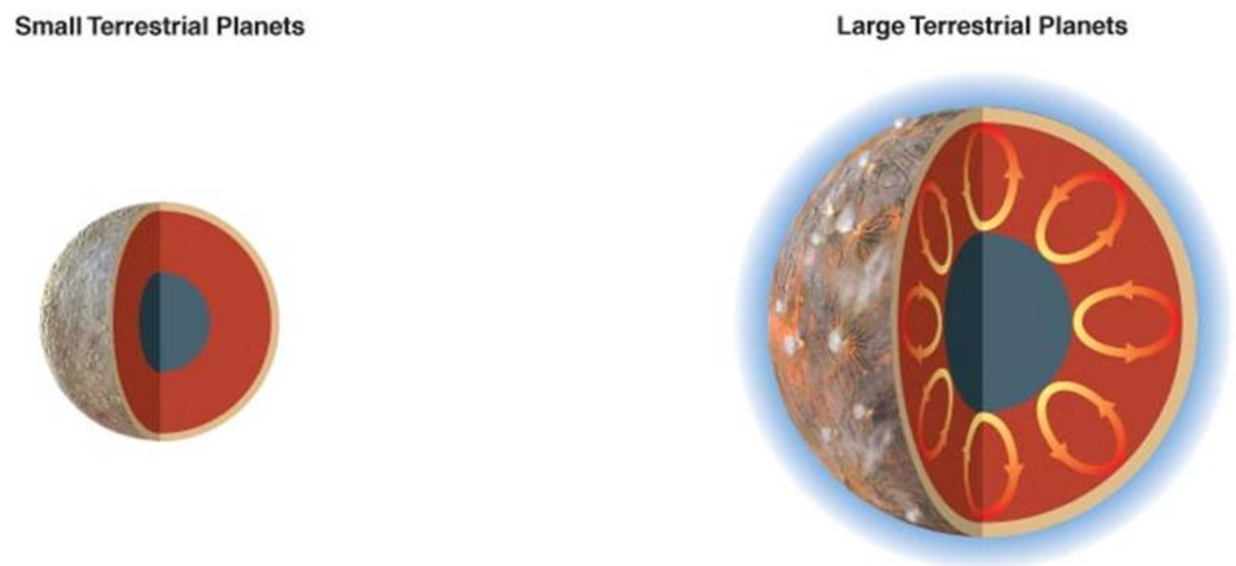
A portion of Earth's surface as it appears without clouds.

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

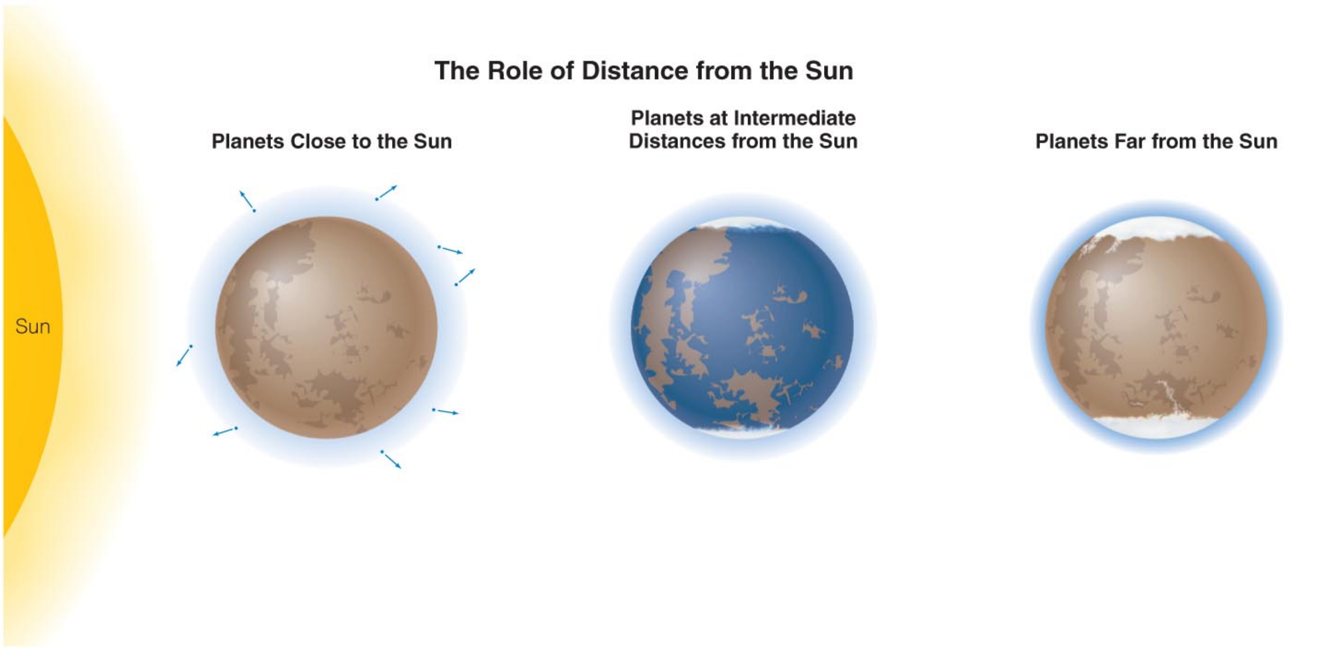
Mars has features that look like dry riverbeds; note the impact craters.

Role of Planetary Size



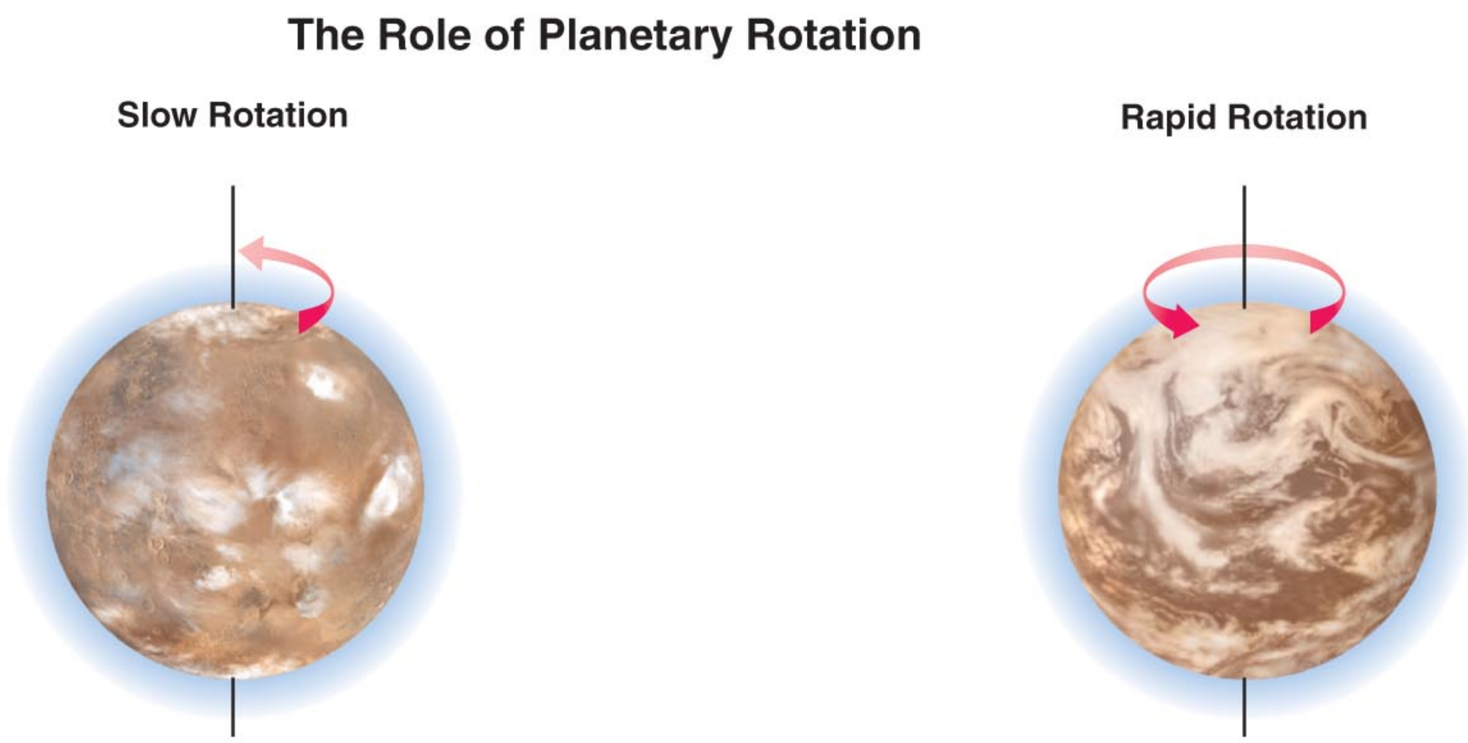
- Smaller worlds cool off faster and harden earlier.
- Larger worlds remain warm inside, promoting volcanism and tectonics.
- Larger worlds also have more erosion because their gravity retains an atmosphere.

Role of Distance from Sun



- Planets close to the Sun are too hot for rain, snow, ice and so have less erosion.
- Hot planets have more difficulty retaining an atmosphere.
- 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.

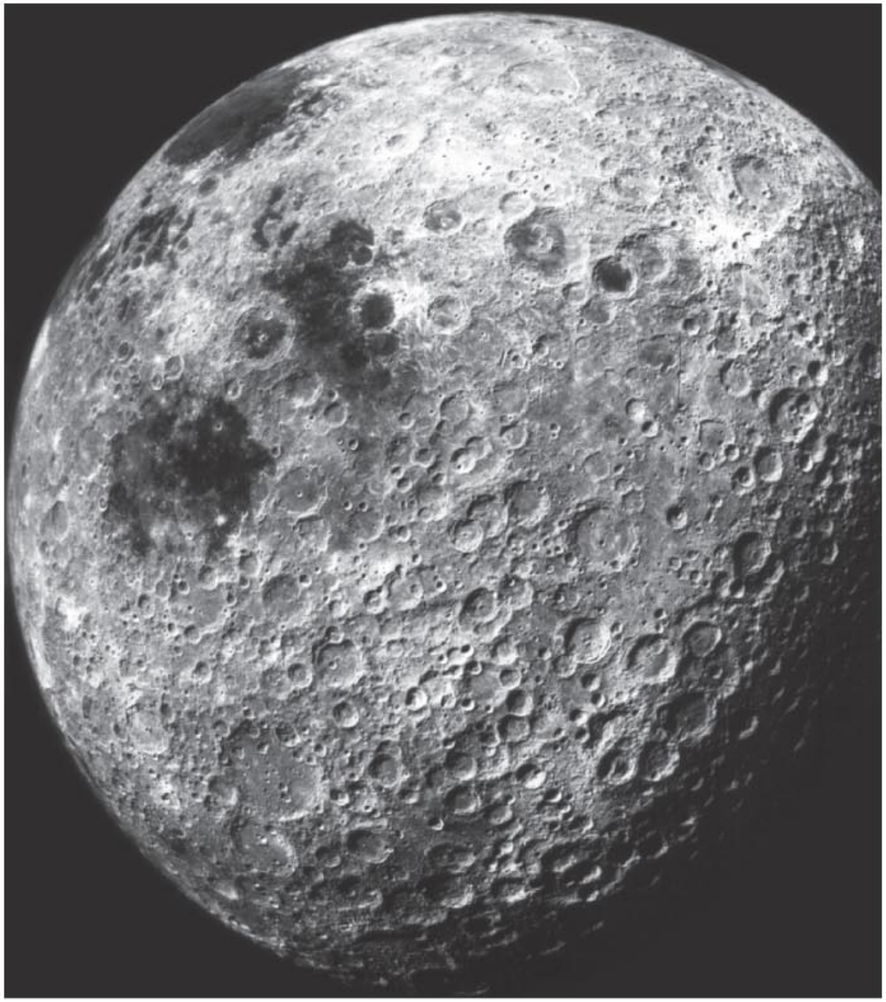
What have we learned?

- **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.

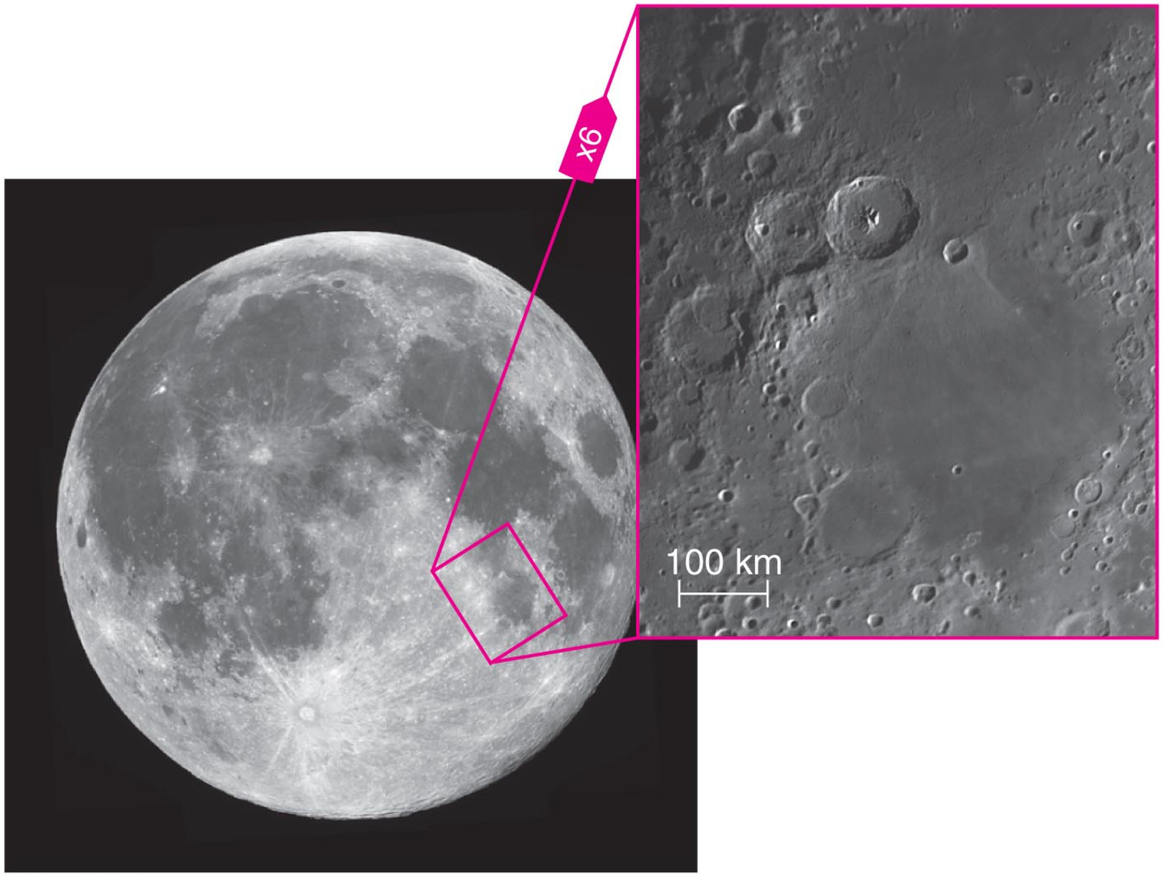
9.3 Geology of the Moon and Mercury

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

What geological processes shaped our Moon?



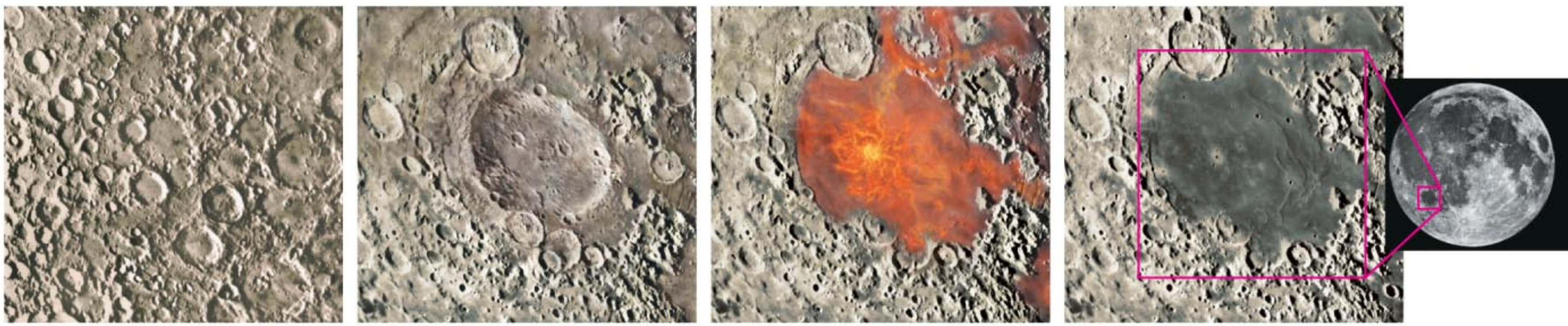
Lunar Maria



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

Formation of Lunar Maria

NASA animation of lunar impacts



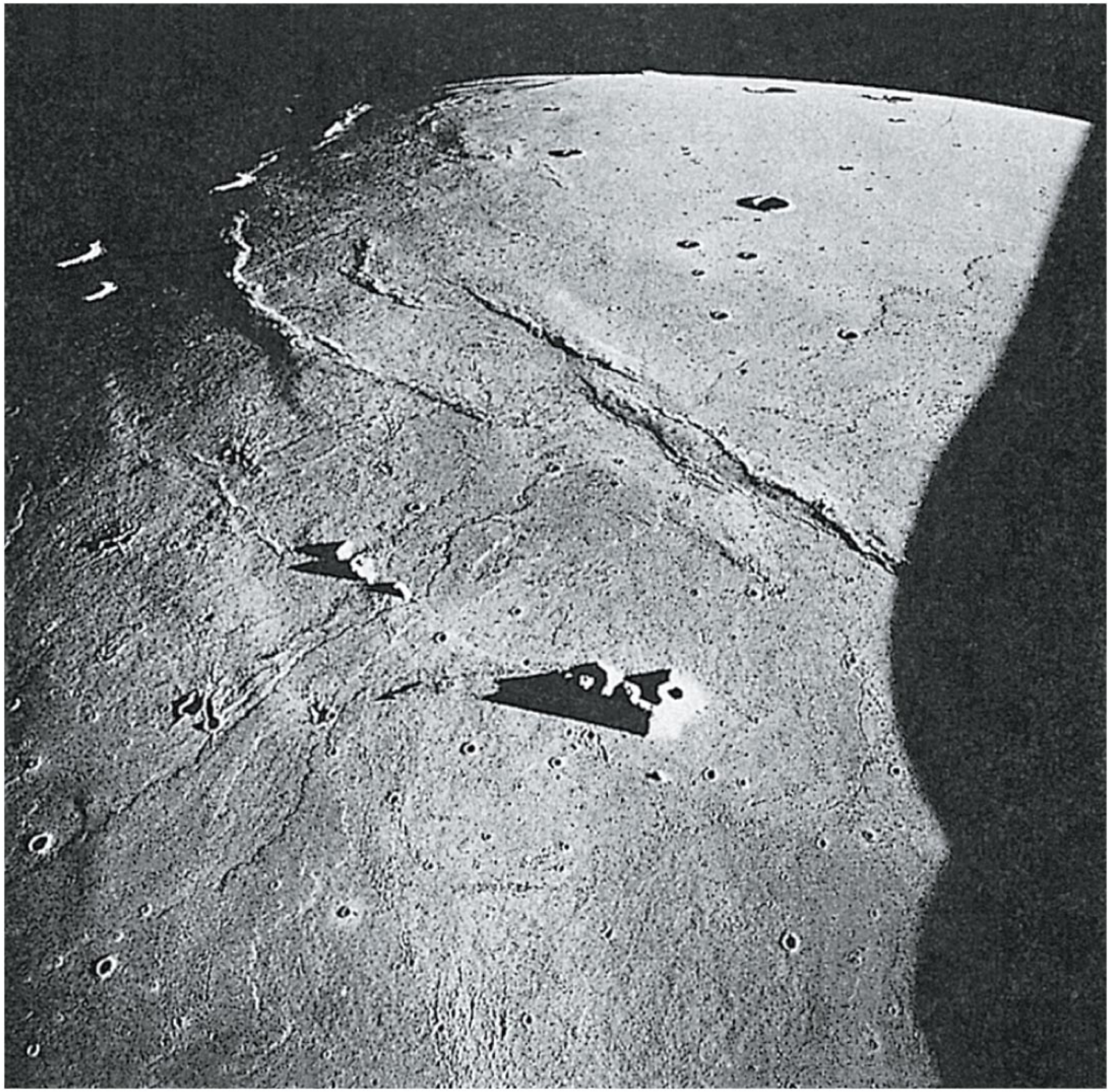
Early surface is covered with craters.

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

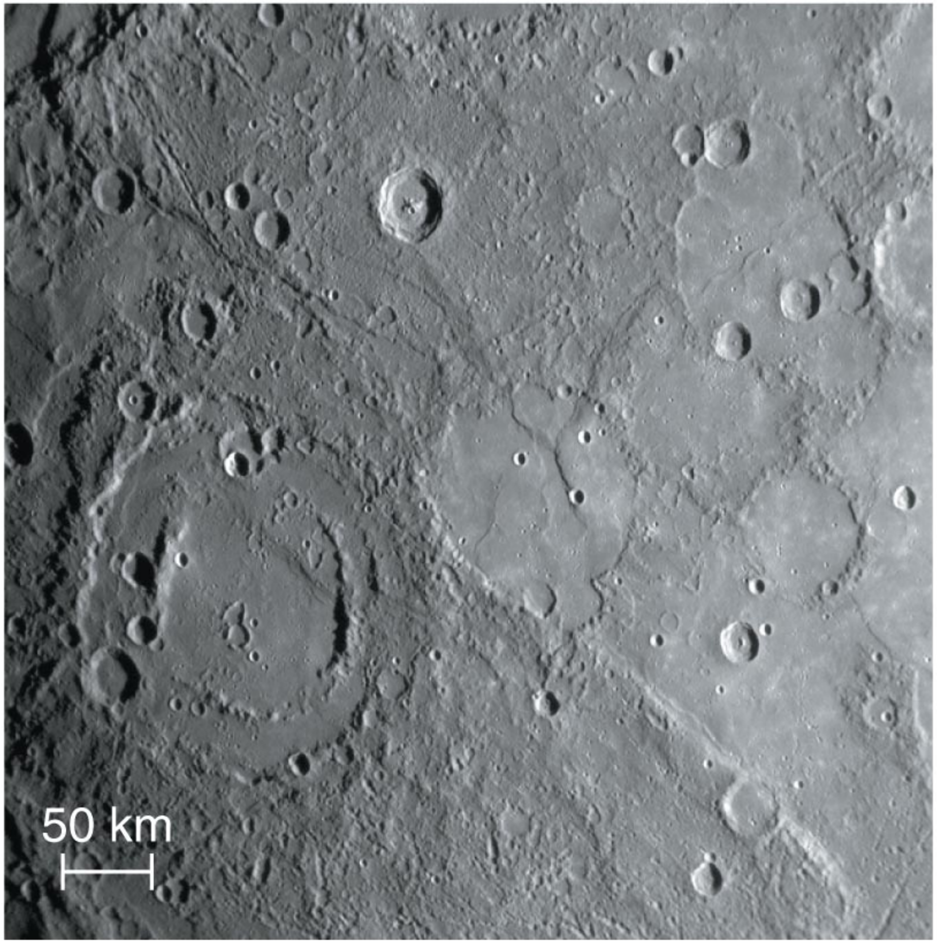


- Wrinkles arise from cooling and the contraction of a lava flood.

Geologically Dead

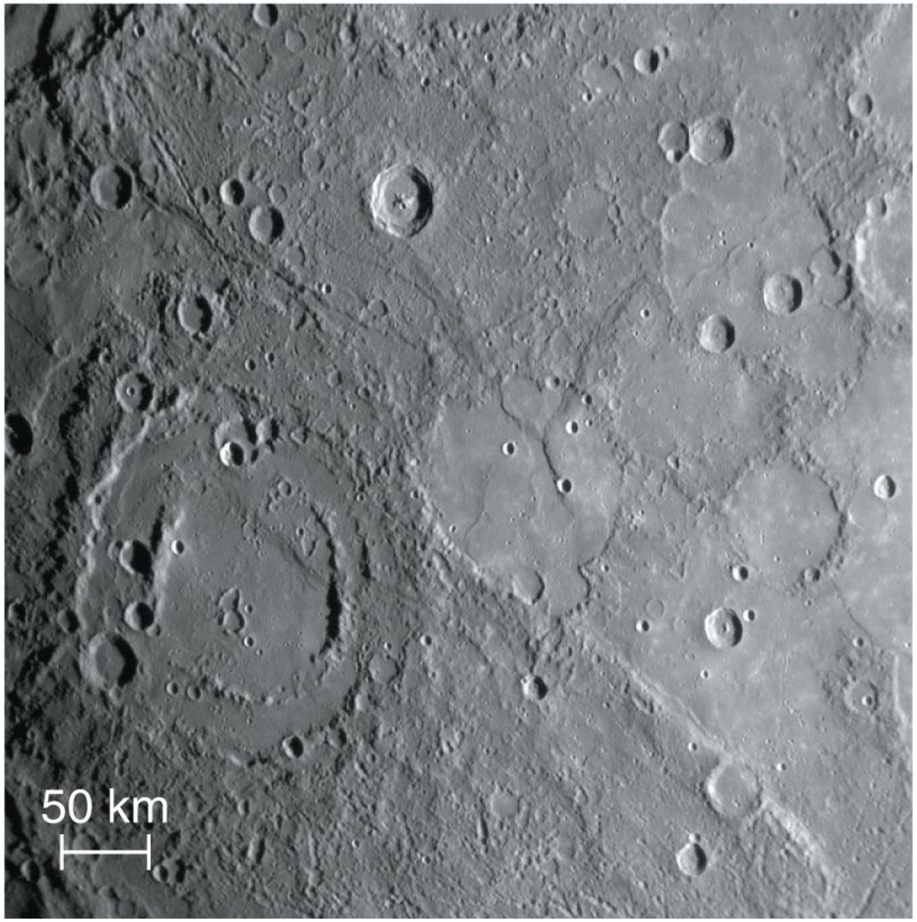
- Moon is considered geologically "dead" because geological processes have virtually stopped.

What geological processes shaped Mercury?



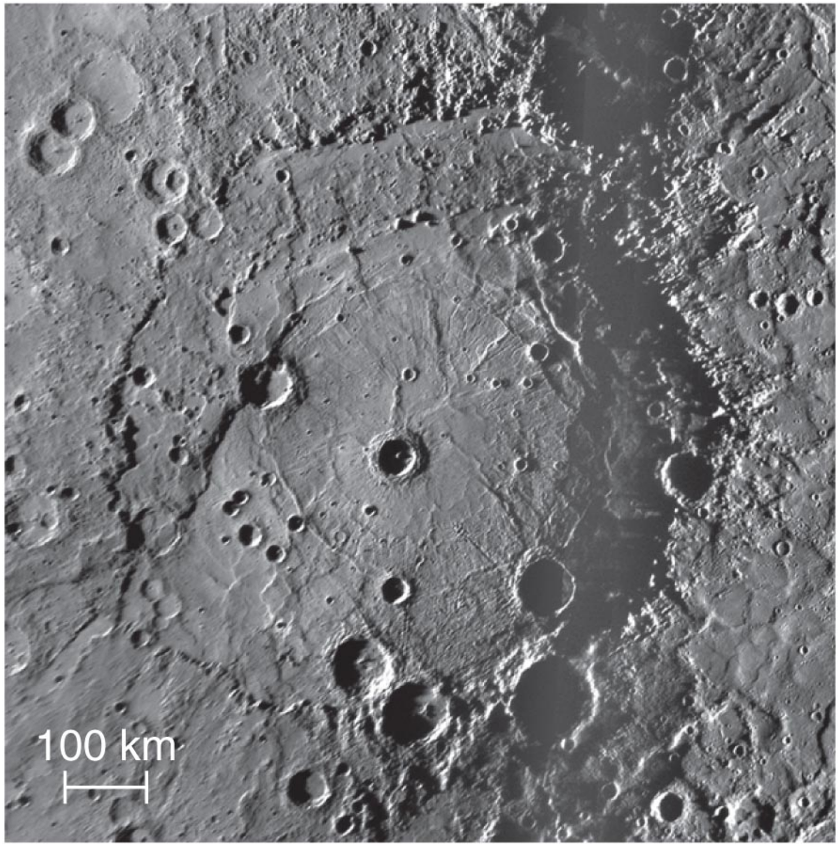
a A close-up view of Mercury's surface, showing impact craters and smooth regions where lava apparently covered up craters.

Cratering of Mercury

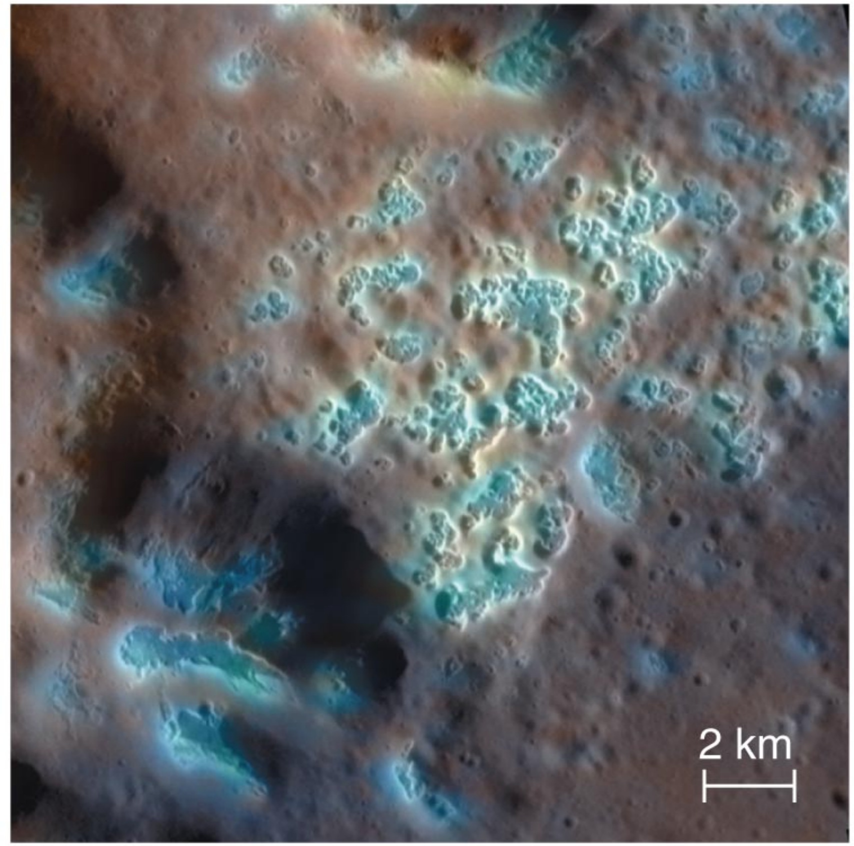


- Mercury has a mixture of heavily cratered and smooth regions like the Moon.
- Smooth regions are likely ancient lava flows.

Cratering of Mercury

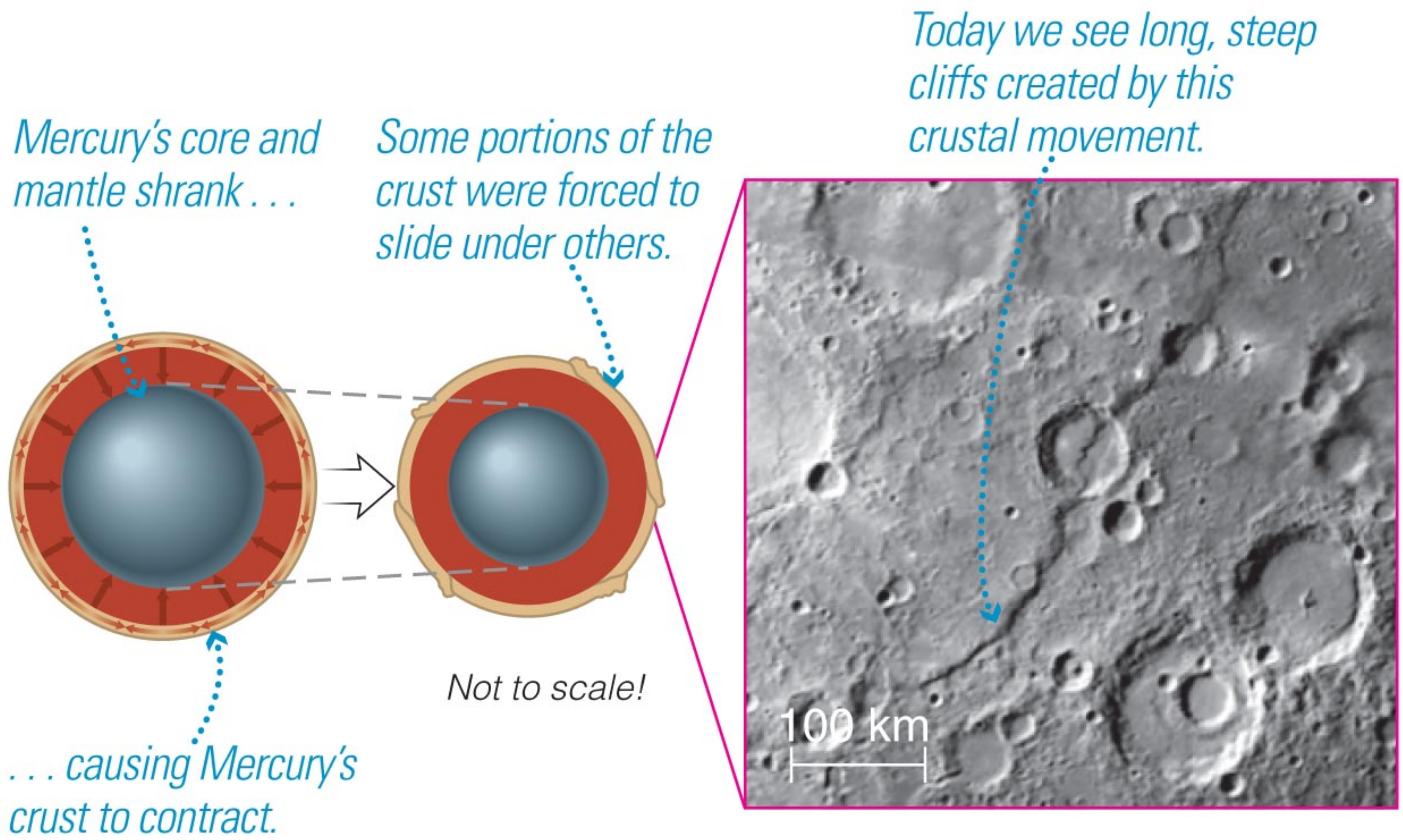


The Rembrandt Basin is a large impact crater on Mercury.



Hollows in a crater floor created by escaping gases.

Tectonics on Mercury



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

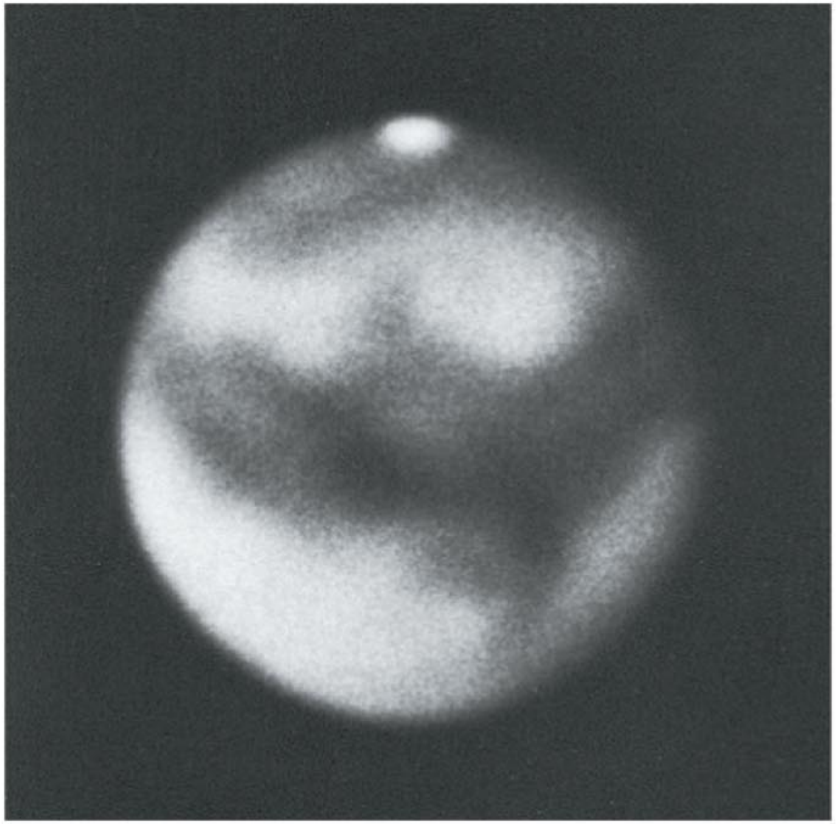
What have we learned?

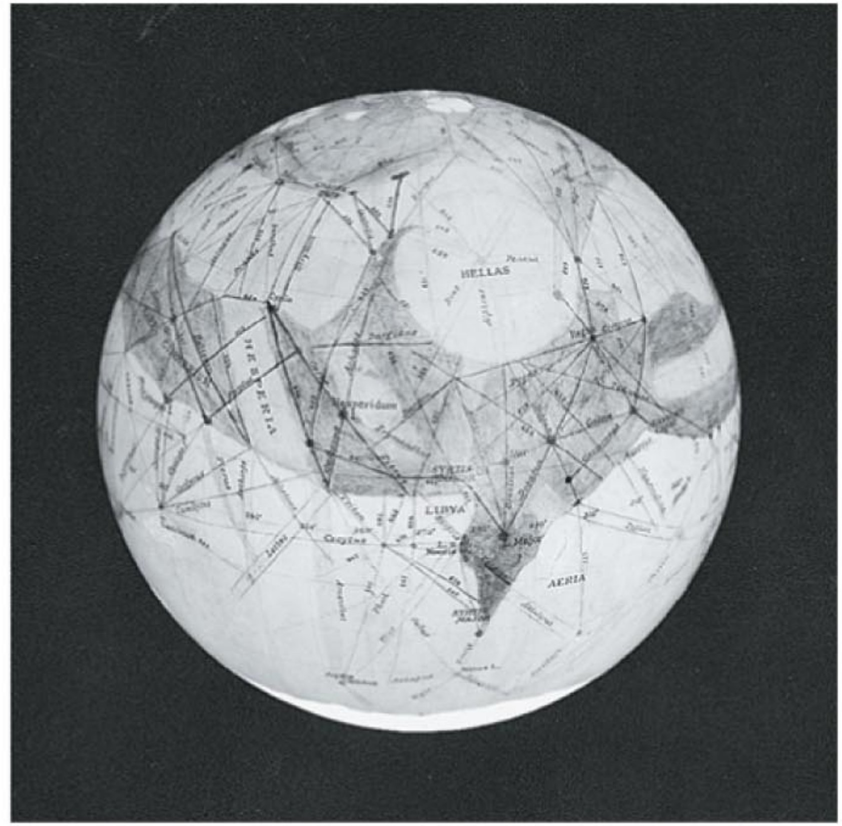
- **What geological processes shaped our Moon?**
  – Early cratering is still present.
  – Maria resulted from volcanism.
- **What geological processes shaped Mercury?**
  – Had cratering and volcanism similar to Moon
  – Tectonic features indicate early shrinkage.

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?**

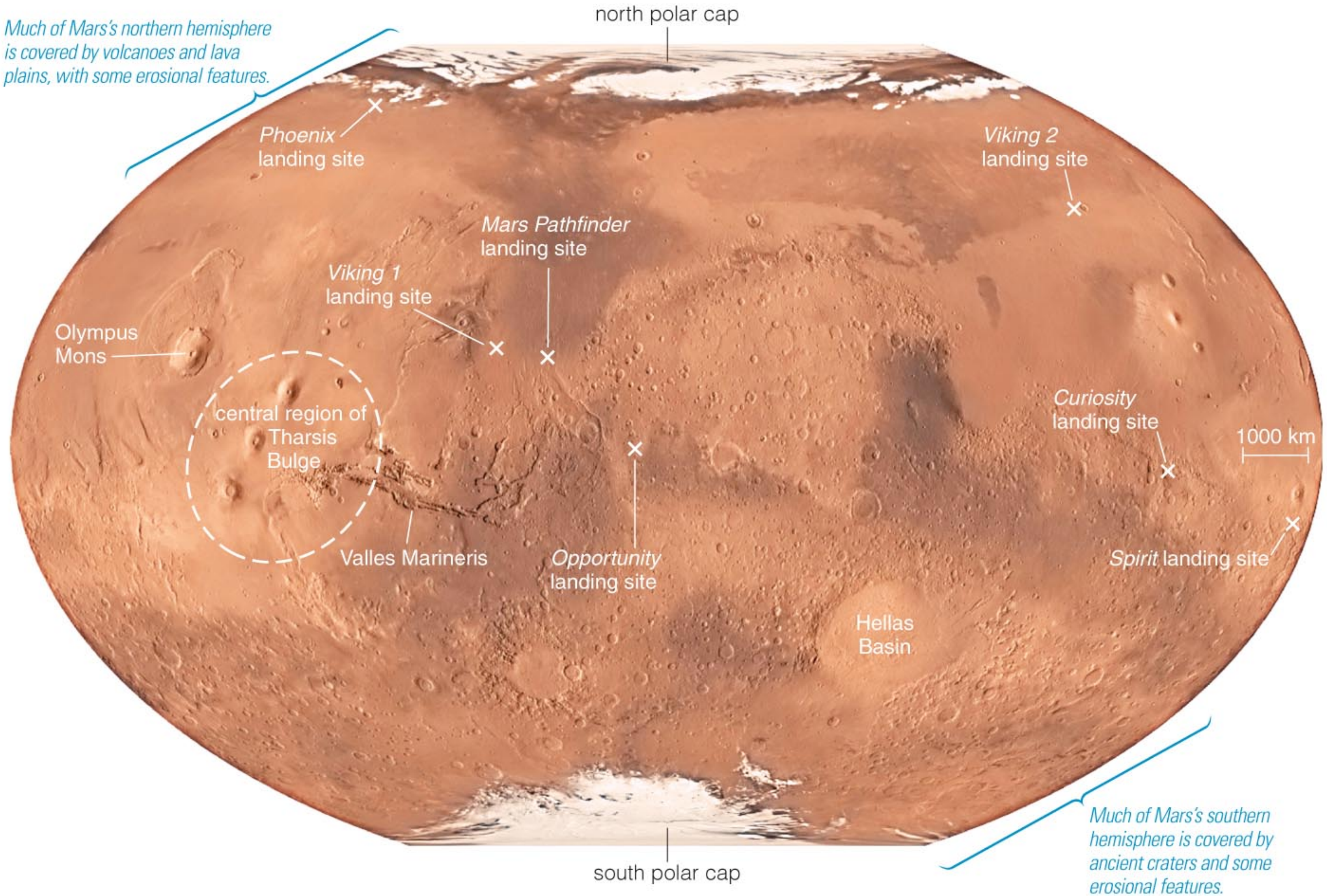
"Canals" on Mars



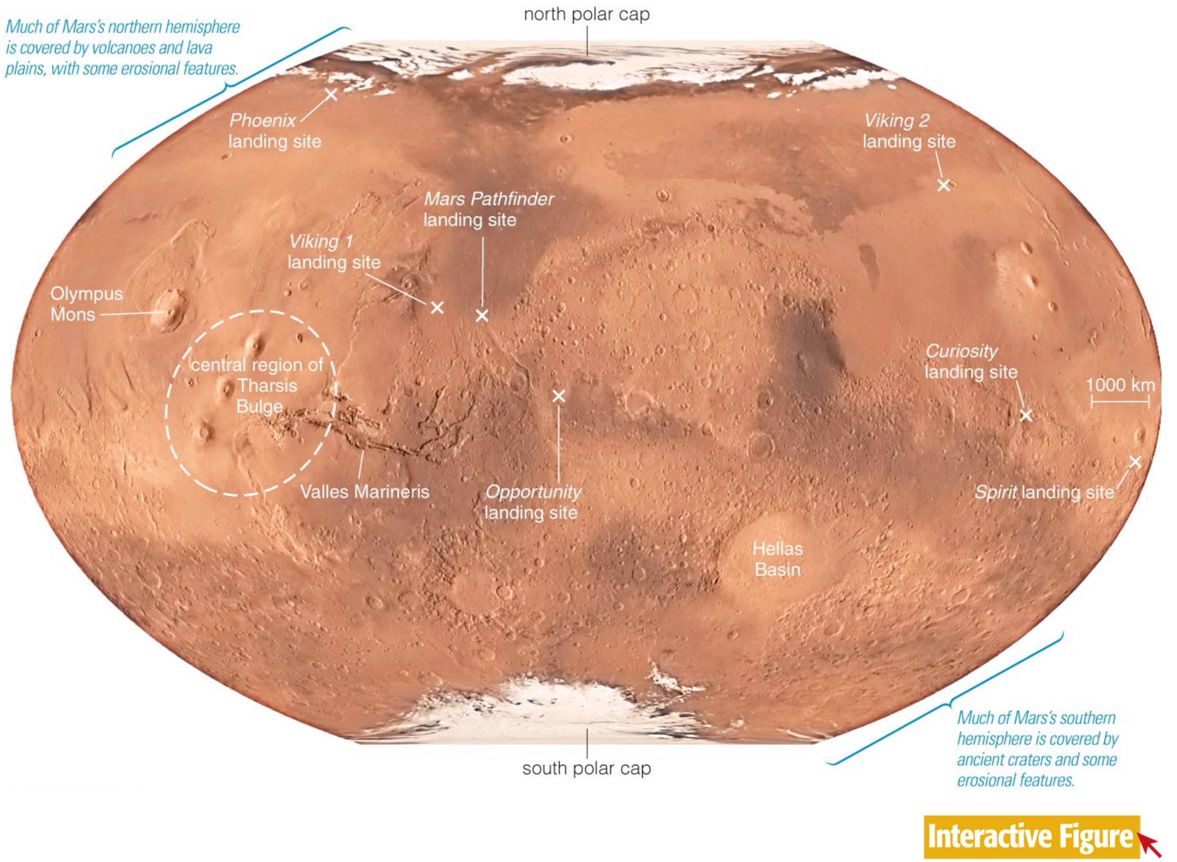


- Percival Lowell misinterpreted surface features seen in telescopic images of Mars.

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.