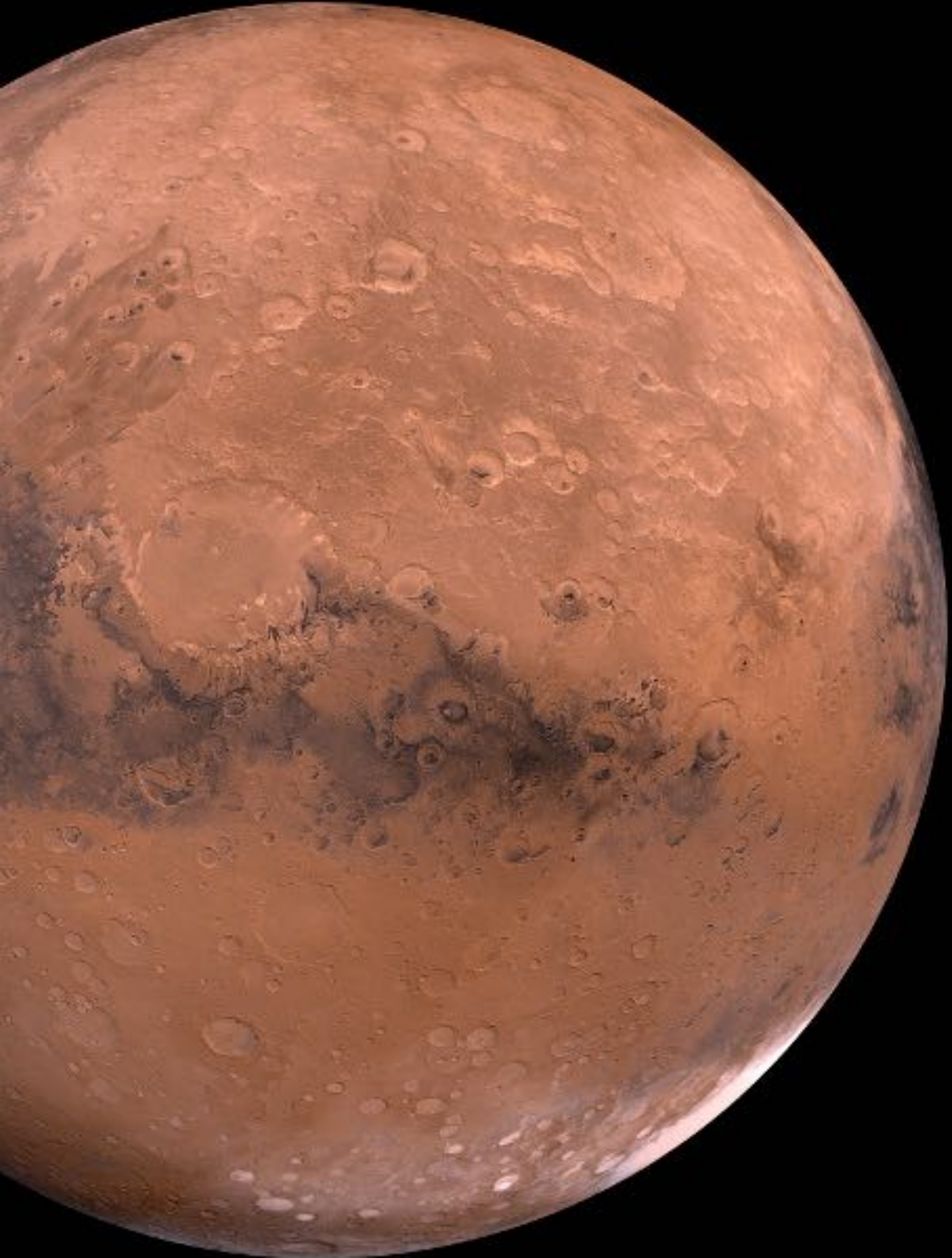
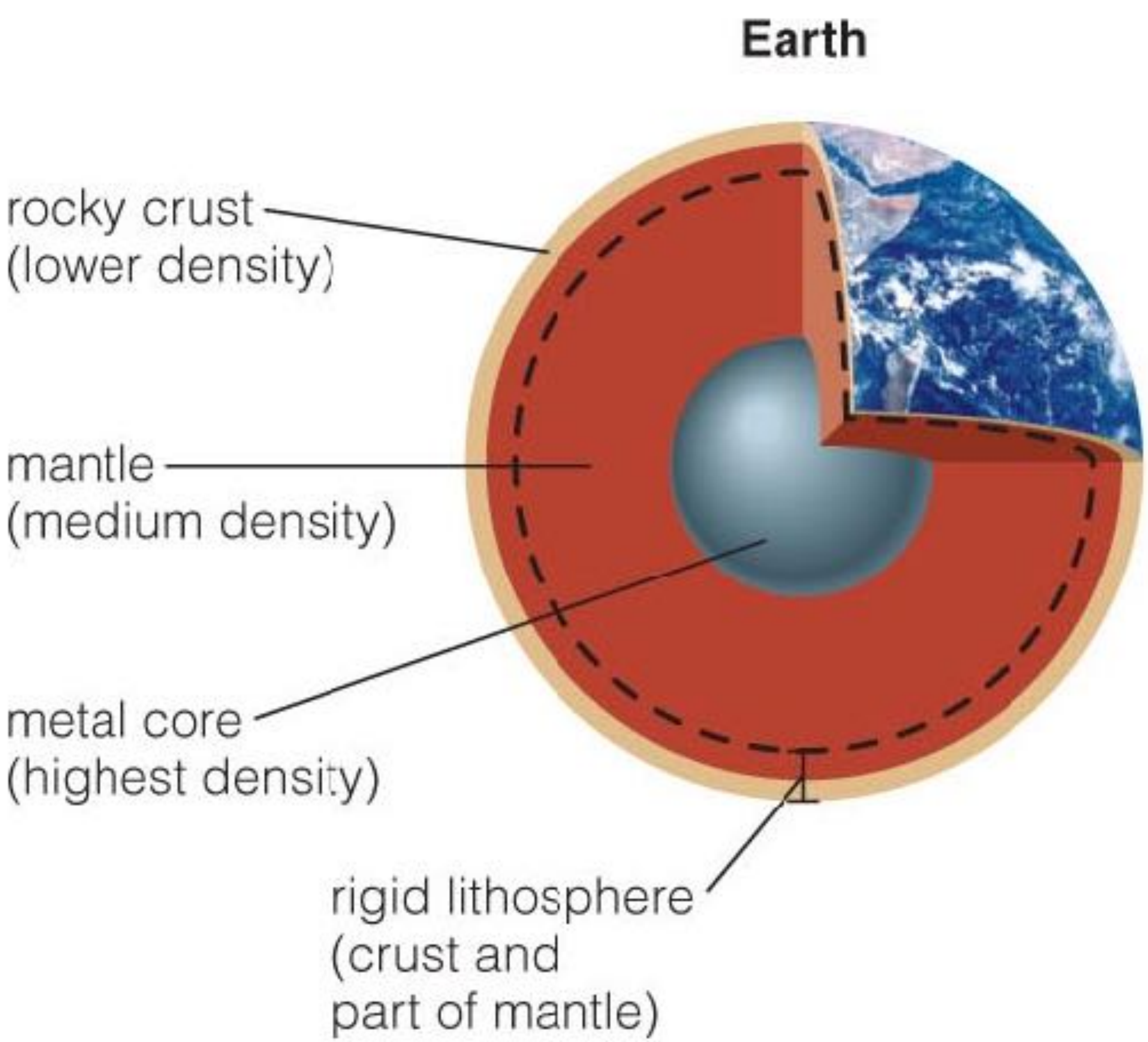


Today

- Terrestrial Planets
  - Geology & surface features

Homework 4 due next time

Earth's Interior

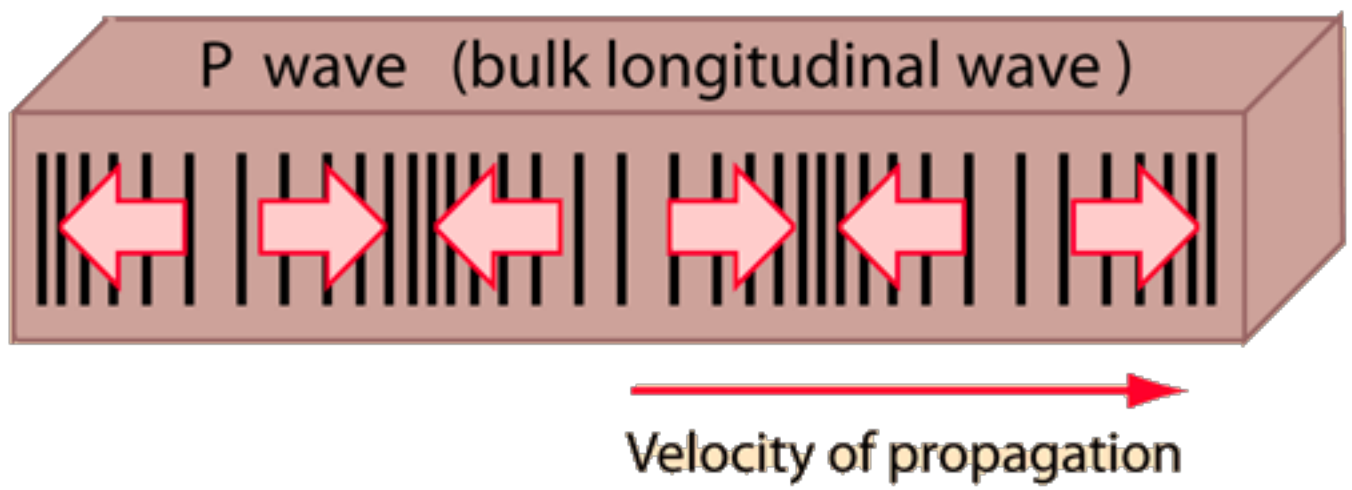


- Core: highest density; nickel and iron
- Mantle: moderate density; silicon, oxygen, etc.
- Crust: lowest density; granite, basalt, etc.

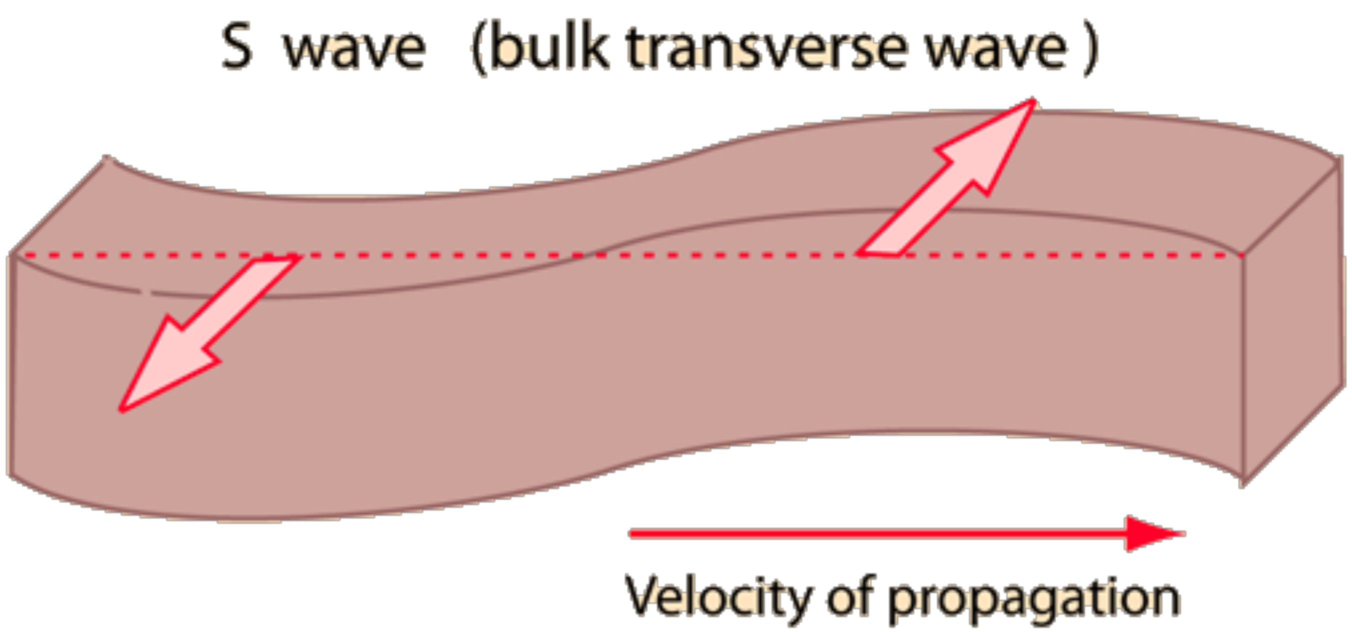
Seismic waves

How do we know what's inside Earth?

The brittle lithosphere is prone to Earthquakes that generate seismic waves.
The propagation of these waves probe the interior through which they travel.



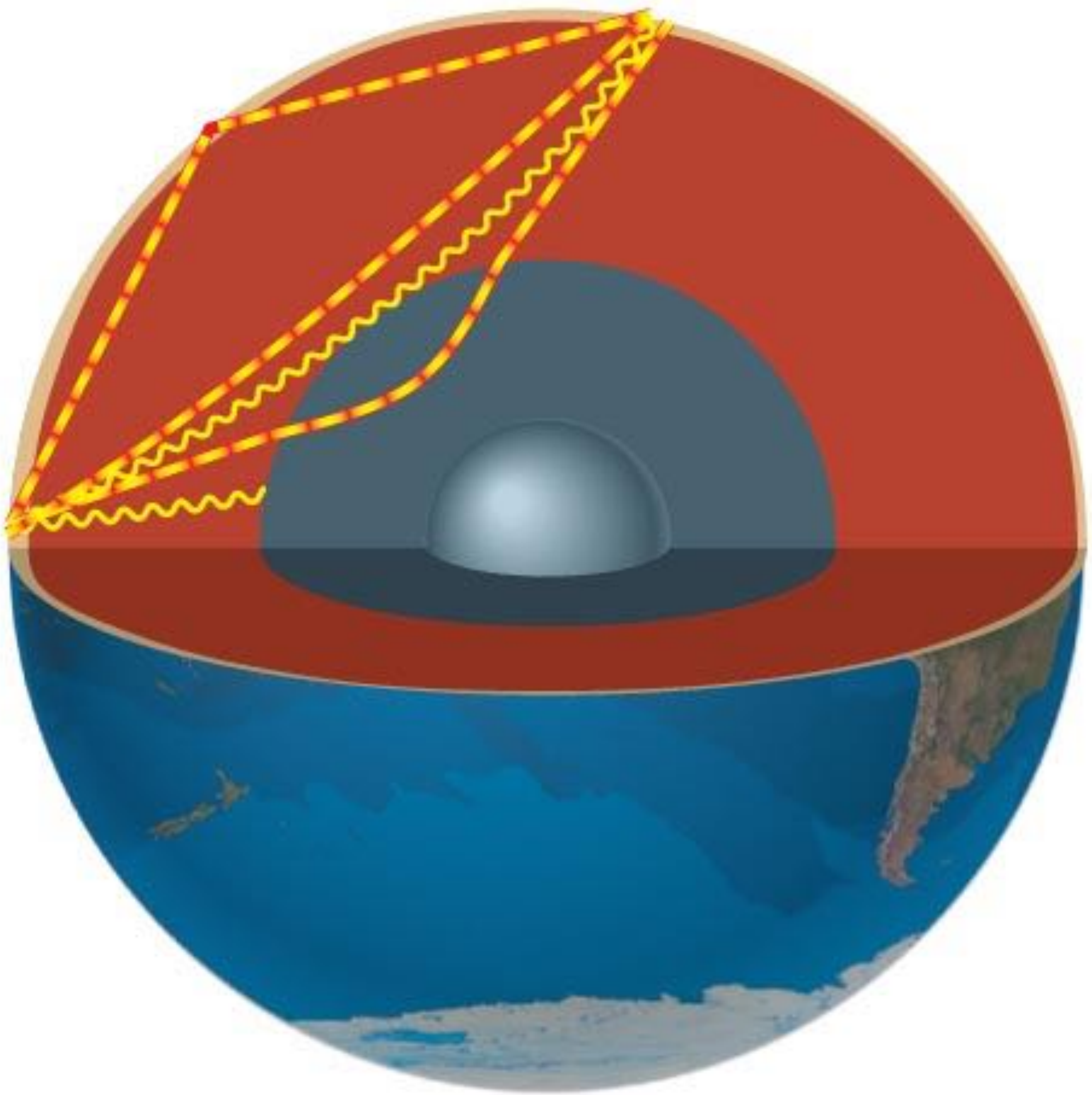
- P waves (primary) compressional.
  - fast propagation
  - traverse all material



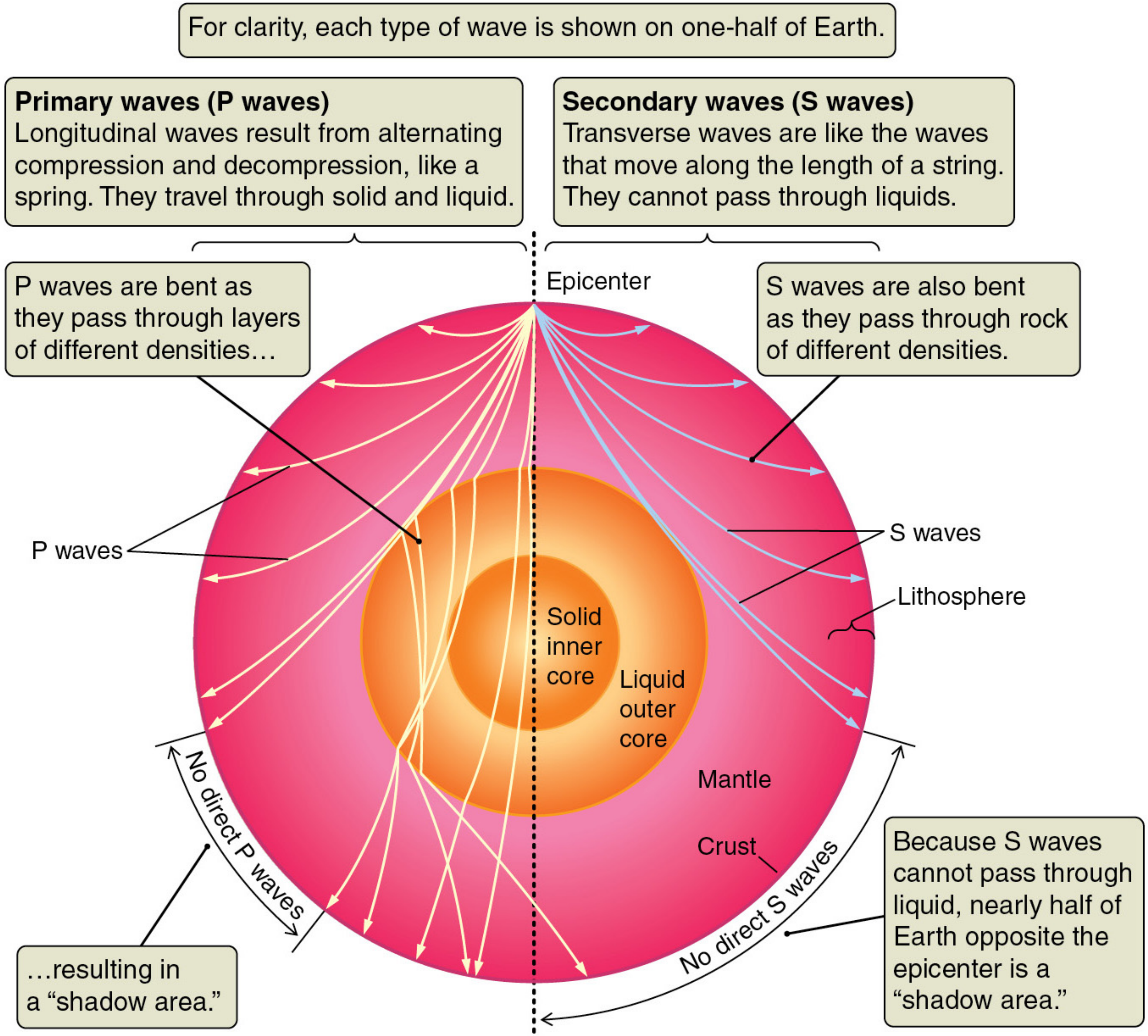
- S waves (secondary) transverse shear.
  - slower propagation
  - do not travel through liquid or gas

Seismic waves

How do we know what's inside Earth?

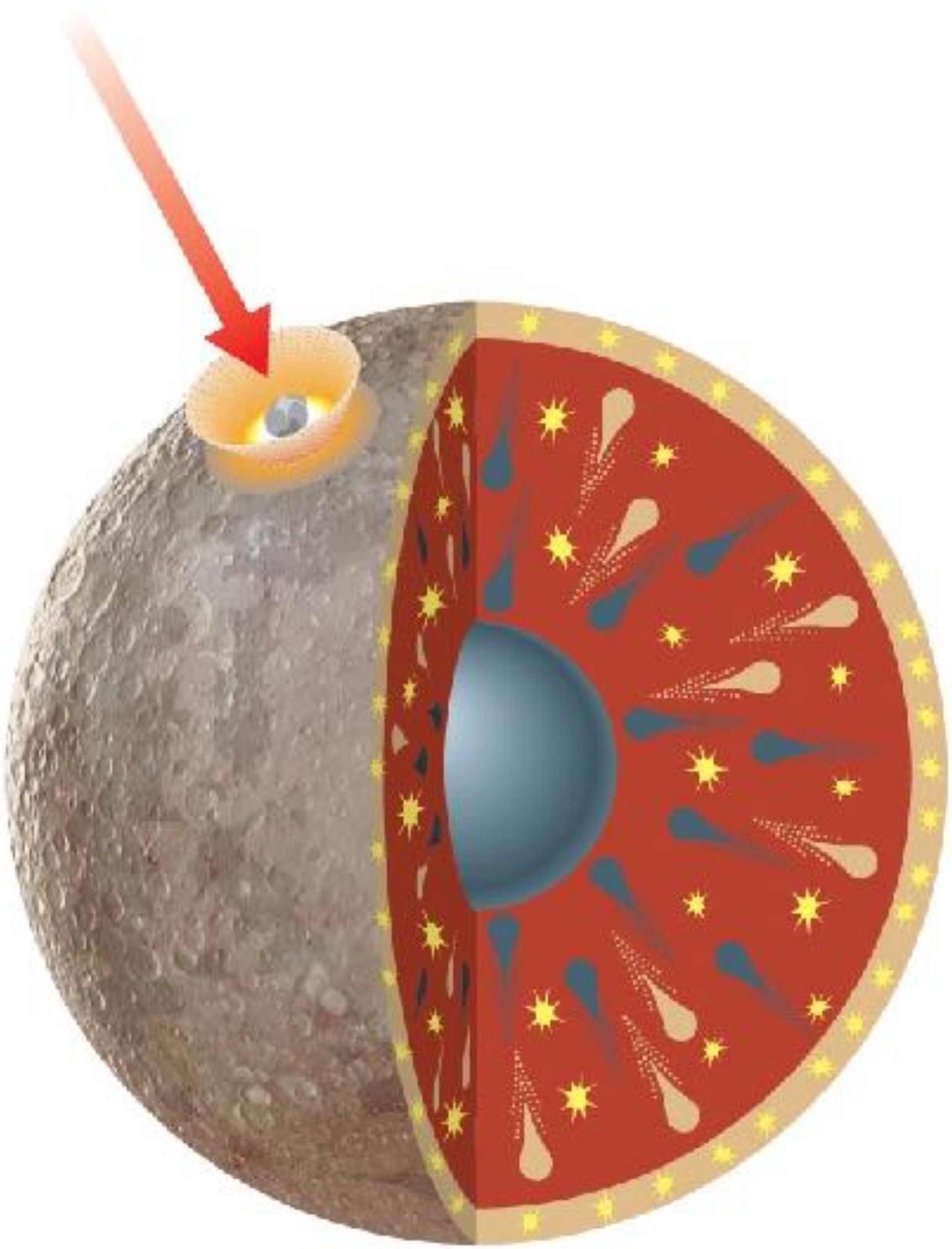


- P waves go through Earth's core, but S waves do not.
- Earth's core has a liquid outer layer that reflects S waves & refracts P waves.



For clarity, each type of wave is shown on one-half of Earth.
Primary waves (P waves)
Longitudinal waves result from alternating compression and decompression, like a spring. They travel through solid and liquid.
Secondary waves (S waves)
Transverse waves are like the waves that move along the length of a string. They cannot pass through liquids.
P waves are bent as they pass through layers of different densities…
Epicenter
S waves are also bent as they pass through rock of different densities.
P waves
S waves
Lithosphere
Solid inner core
Liquid outer core
Mantle
Crust
No direct P waves
No direct S waves
…resulting in a “shadow area.”
Because S waves cannot pass through liquid, nearly half of Earth opposite the epicenter is a “shadow area.”

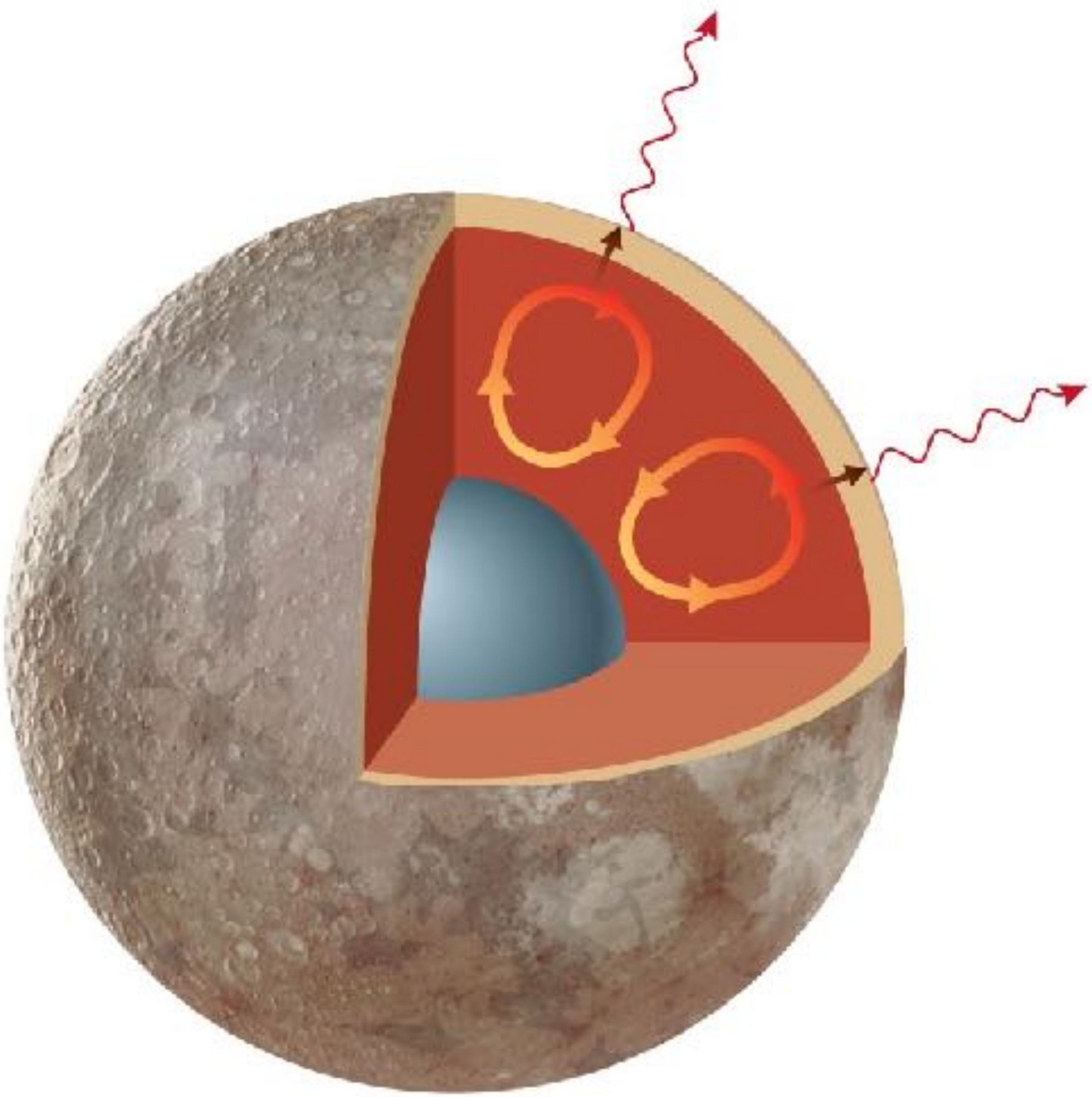
Heating of Planetary Interiors



Heat drives geological activity

- Accretion and differentiation when planets were young
  - Heat of formation
  - Differentiation releases gravitational energy as dense material sinks
- Radioactive decay is most important heat source today.
  - Long lasting energy source from trapped radioactive material

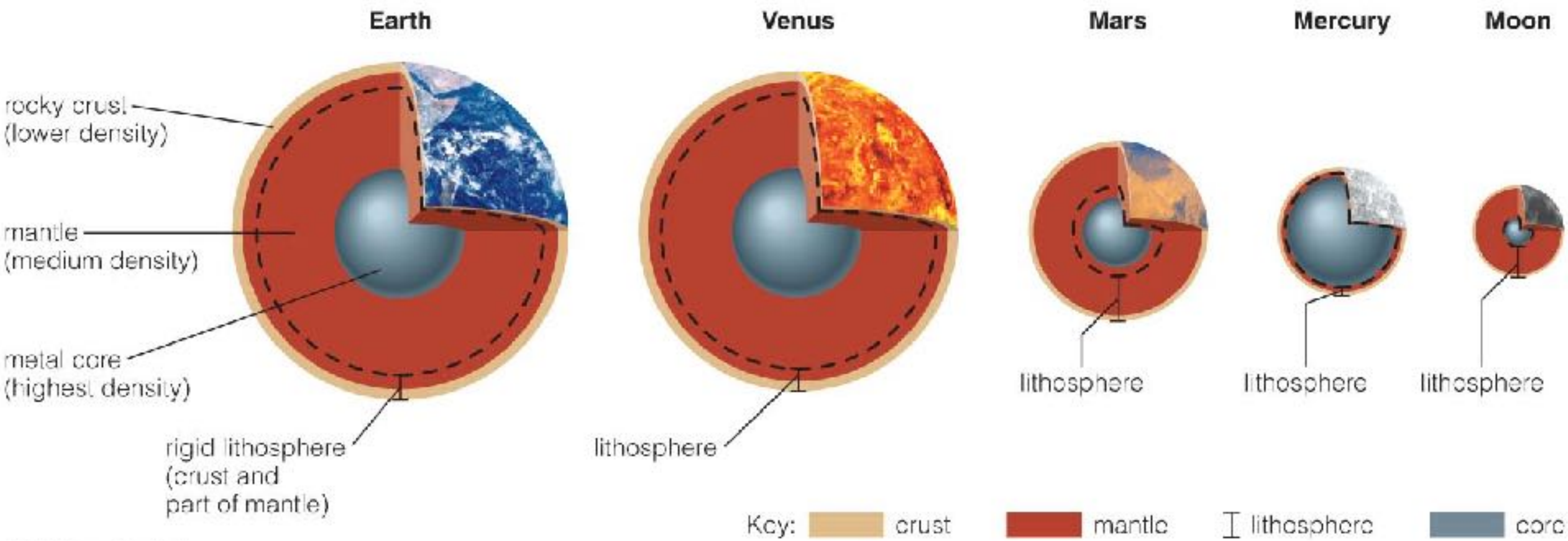
Cooling of Planetary Interiors



Heat drives geological activity

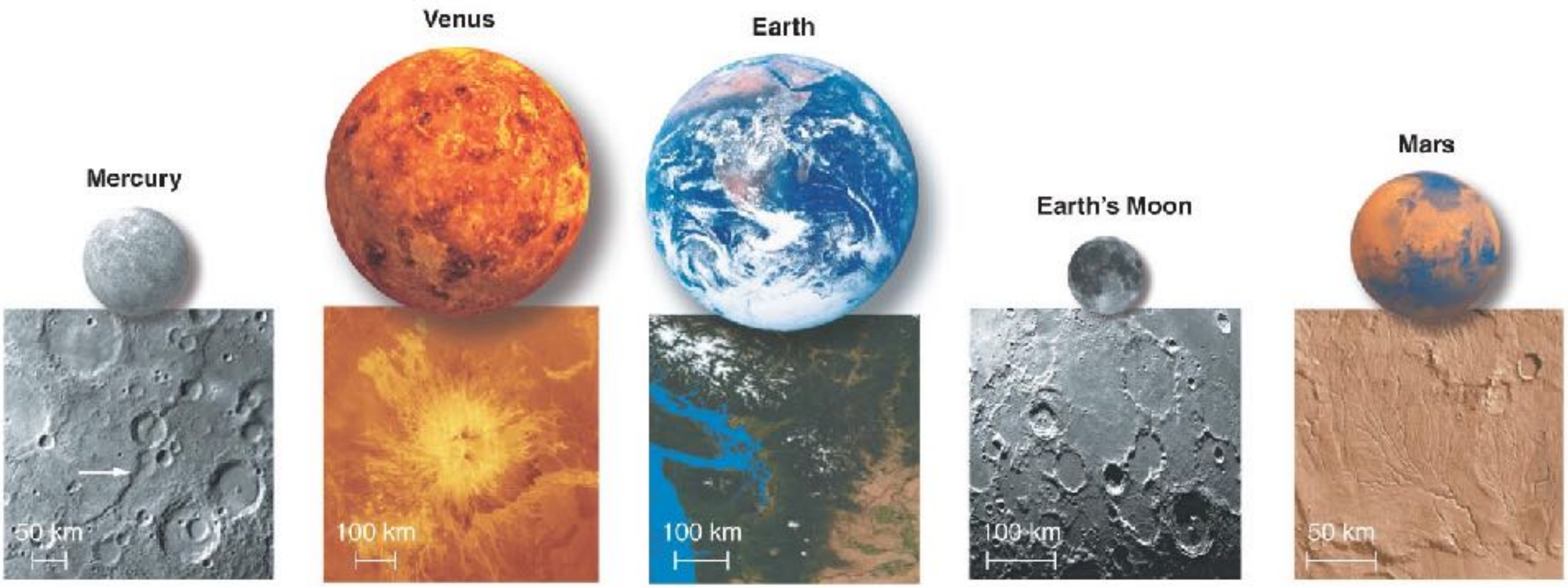
- Convection transports heat as hot material rises and cool material falls.
- Conduction transfers heat from hot material to cool material.
- Radiation sends energy into space.
  - thermal emission

Role of Size



- Smaller worlds cool off faster and harden earlier.
  – cooling time depends on surface area/volume ratio
- The Moon and Mercury are now geologically "dead."

What processes shape planetary surfaces?



Heavily cratered Mercury has long steep cliffs (arrow).

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

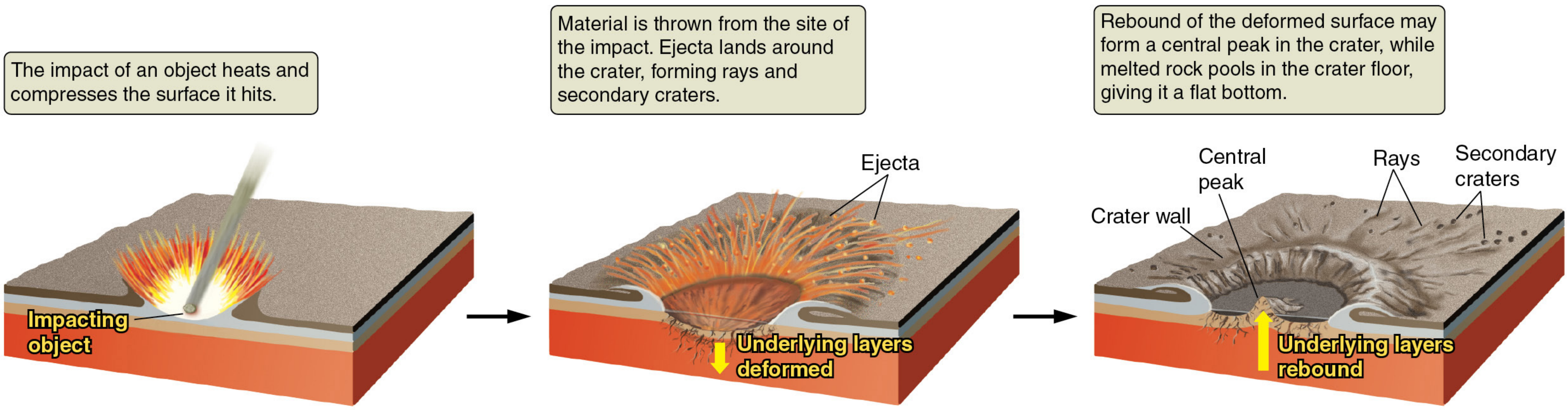
A portion of Earth's surface as it appears without clouds.

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



- Most cratering happened soon after the solar system formed.
  - Late heavy bombardment 3.8 billion years ago
- Heavily cratered surfaces are old.
  - need active geology to erase craters
- Small craters greatly outnumber large ones.
  - small impactors more common than large ones

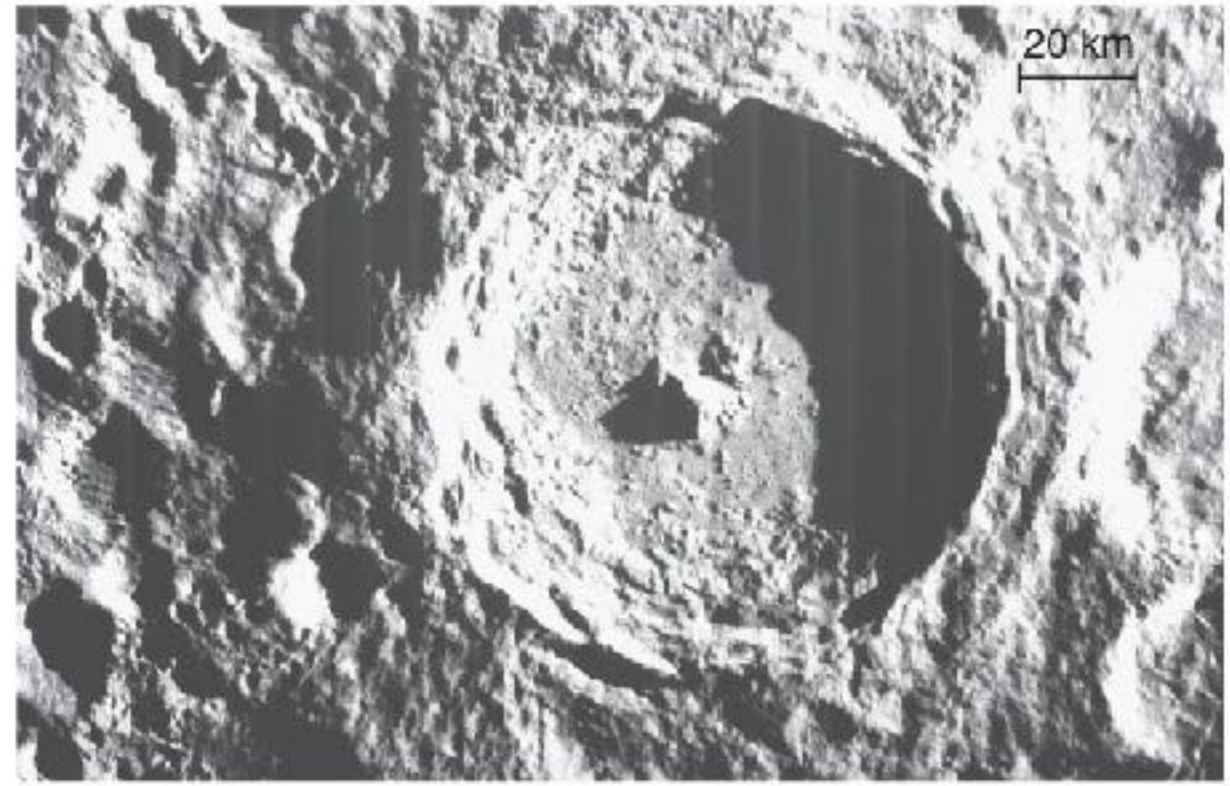
Craters are a sign of an ancient surface, unaltered since the last throes of planet formation

Whatever happened here, I think we missed it

https://getyarn.io/yarn-clip/0ca72a08-174c-4b9e-b3c3-5aa9be93dac2

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.

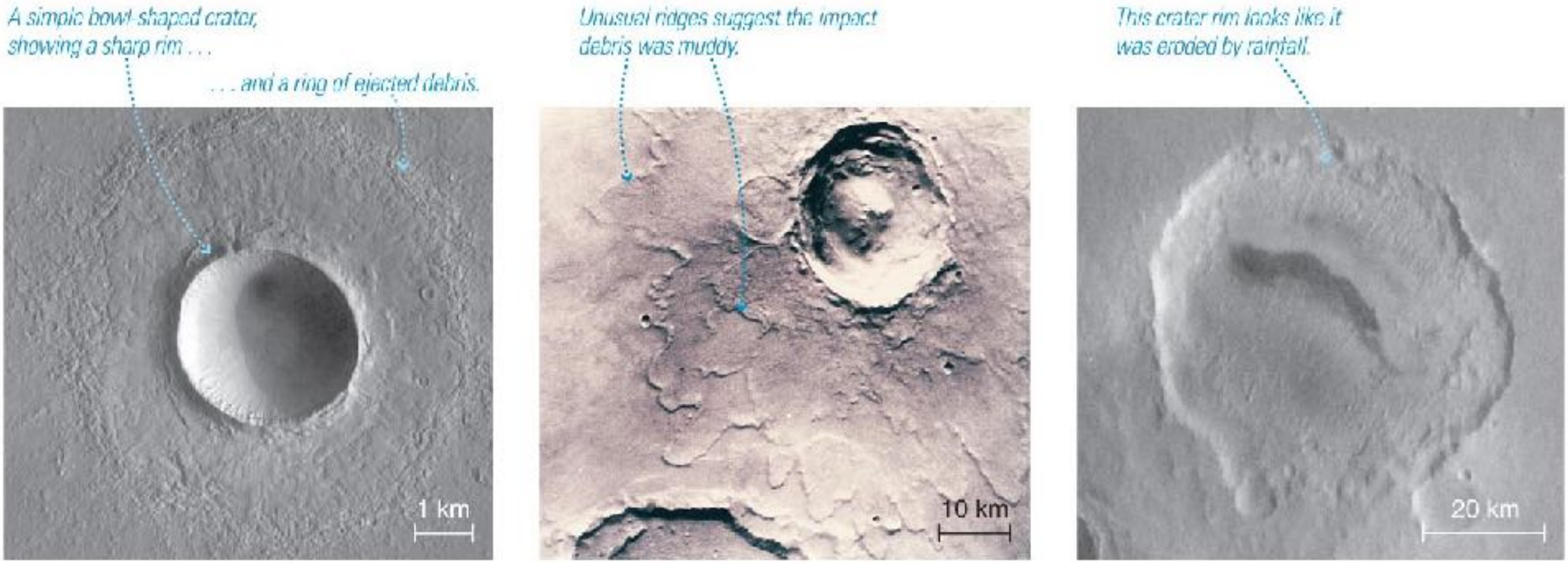


b This photo shows a crater, named Tycho, on the Moon. Note the classic shape and central peak.

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

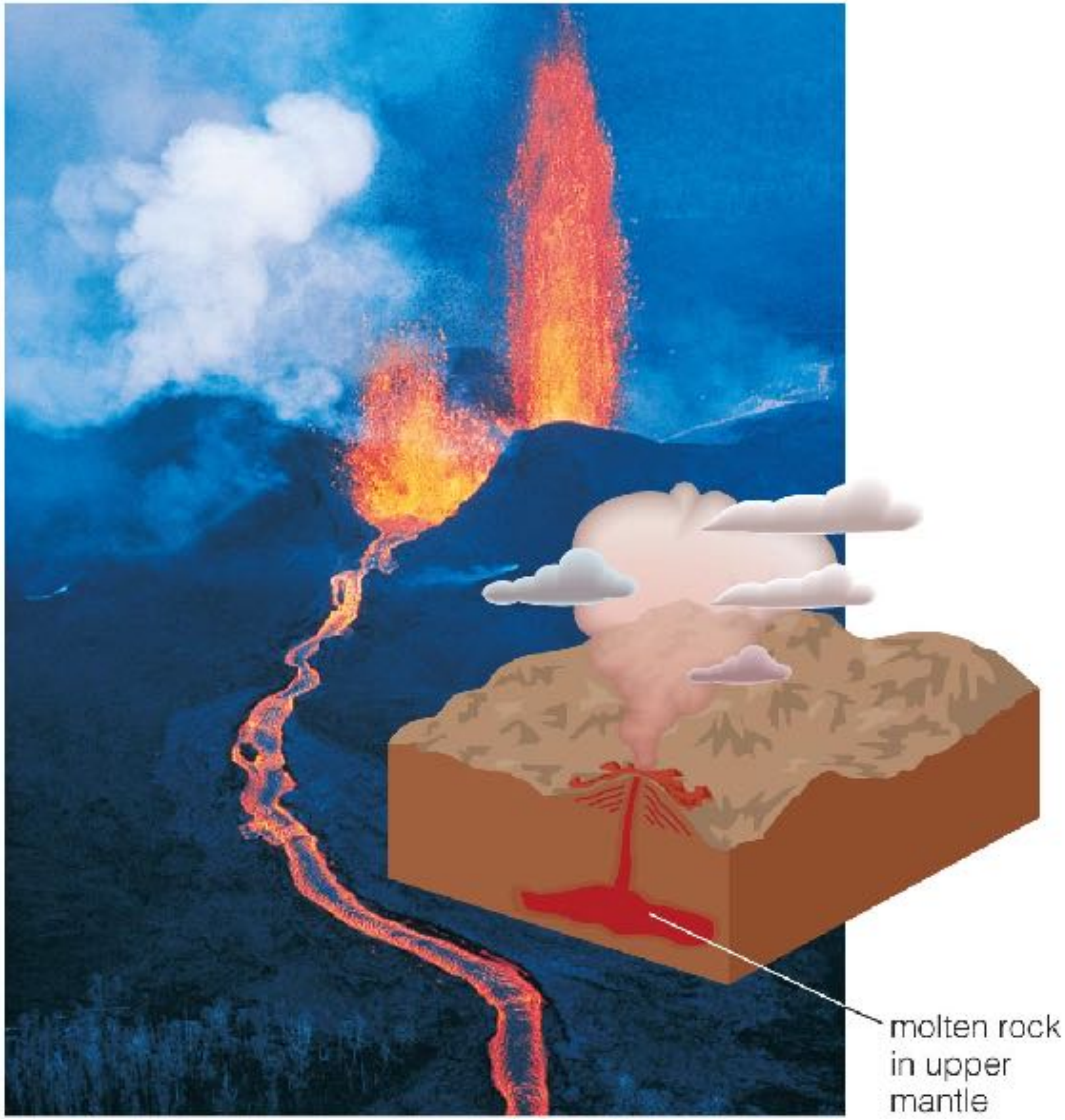
Impact into icy ground

Eroded crater

https://www.youtube.com/watch?v=8xv0ik3ugRg

water droplet video

Volcanism

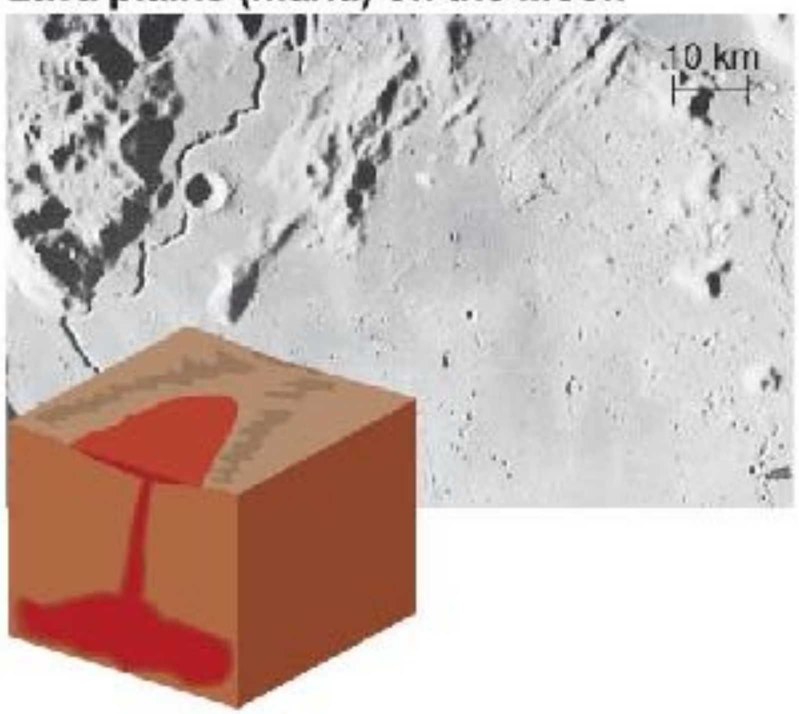


- Volcanism happens when molten rock (magma) finds a path through lithosphere to the surface.
- Molten rock is called lava after it reaches the surface.

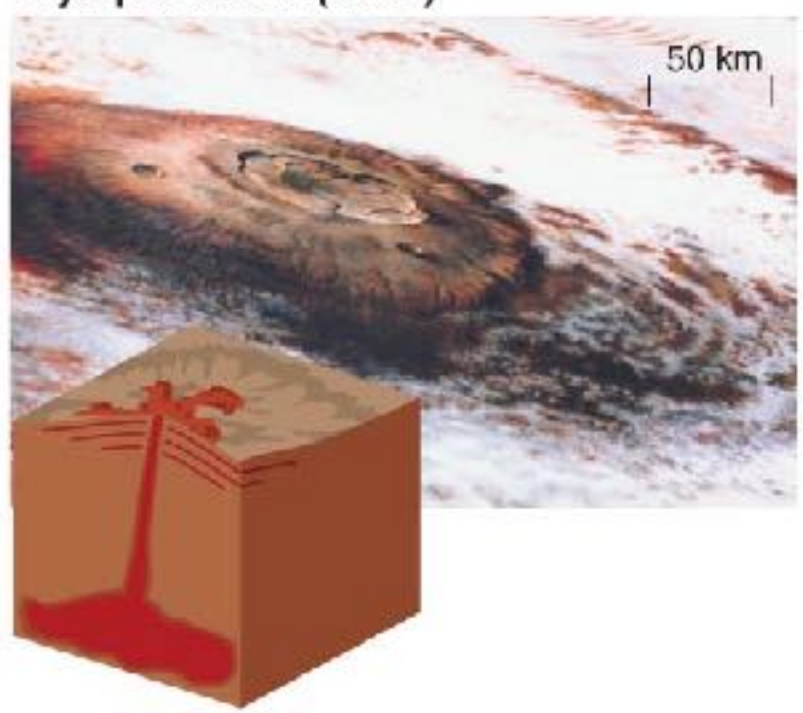
Iceland's Bardarbunga eruption 2014/15

https://www.theguardian.com/world/video/2015/jan/17/icelands-bardarbunga-erupting-five-months-later

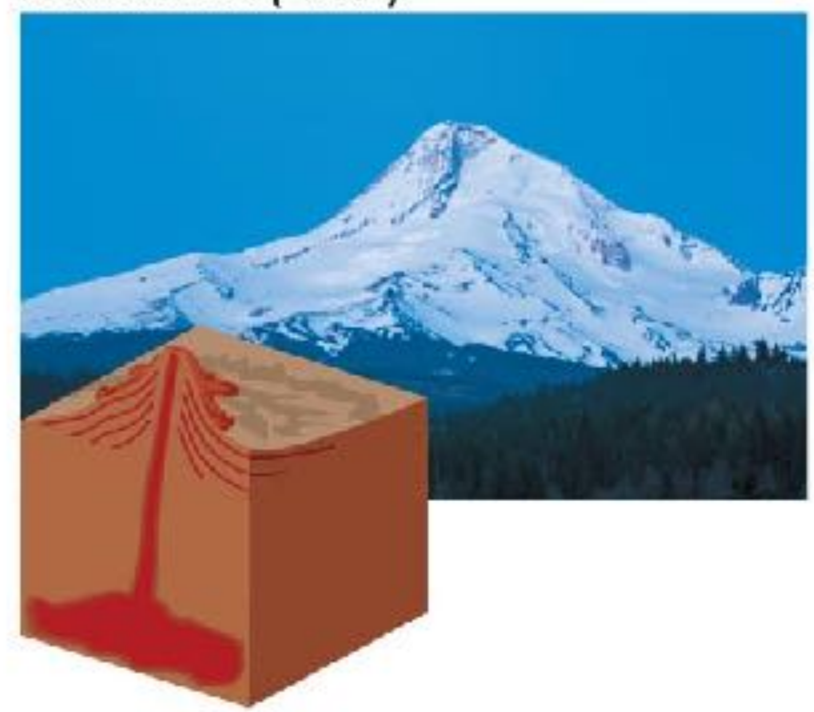
Lava and Volcanoes



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.

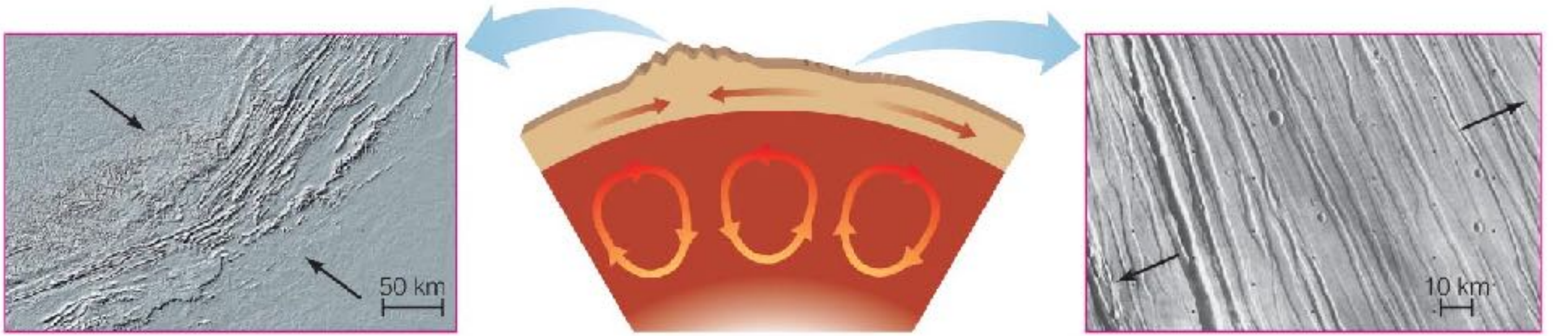
Outgassing

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

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

- Volcanism releases gases from Earth's interior into the atmosphere.
- How planets get an atmosphere in the first place!

Tectonics



Appalachian Mountains in eastern United States

Ceraunius Valleys on Mars

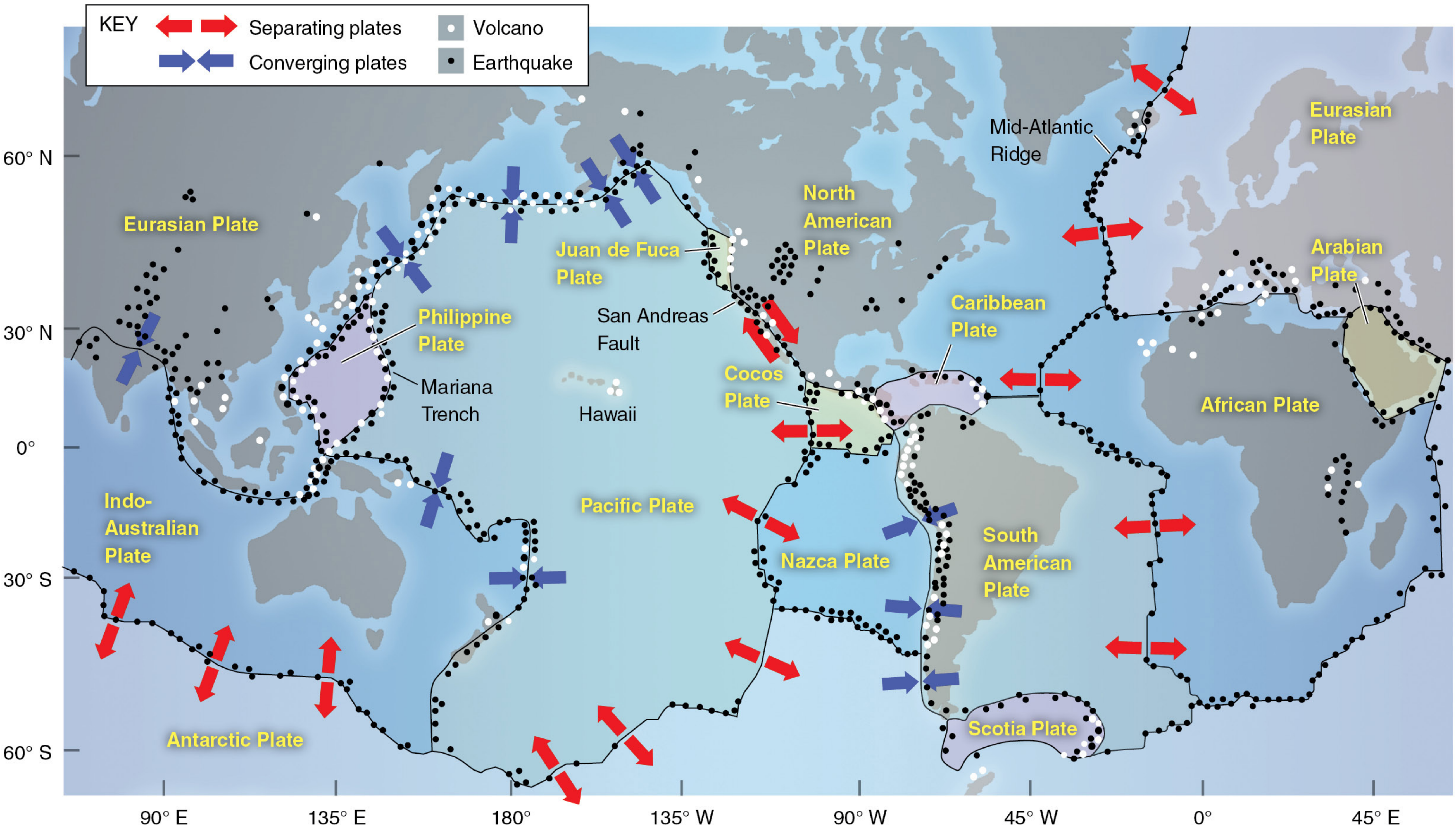
Interactive Figure

- 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.

IF_09_13_MantleConvention.swf

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, rain
  - wind
  - freeze/thaw

Erosion by Water

- The Colorado River continues to carve the Grand Canyon.

Local examples of Erosion

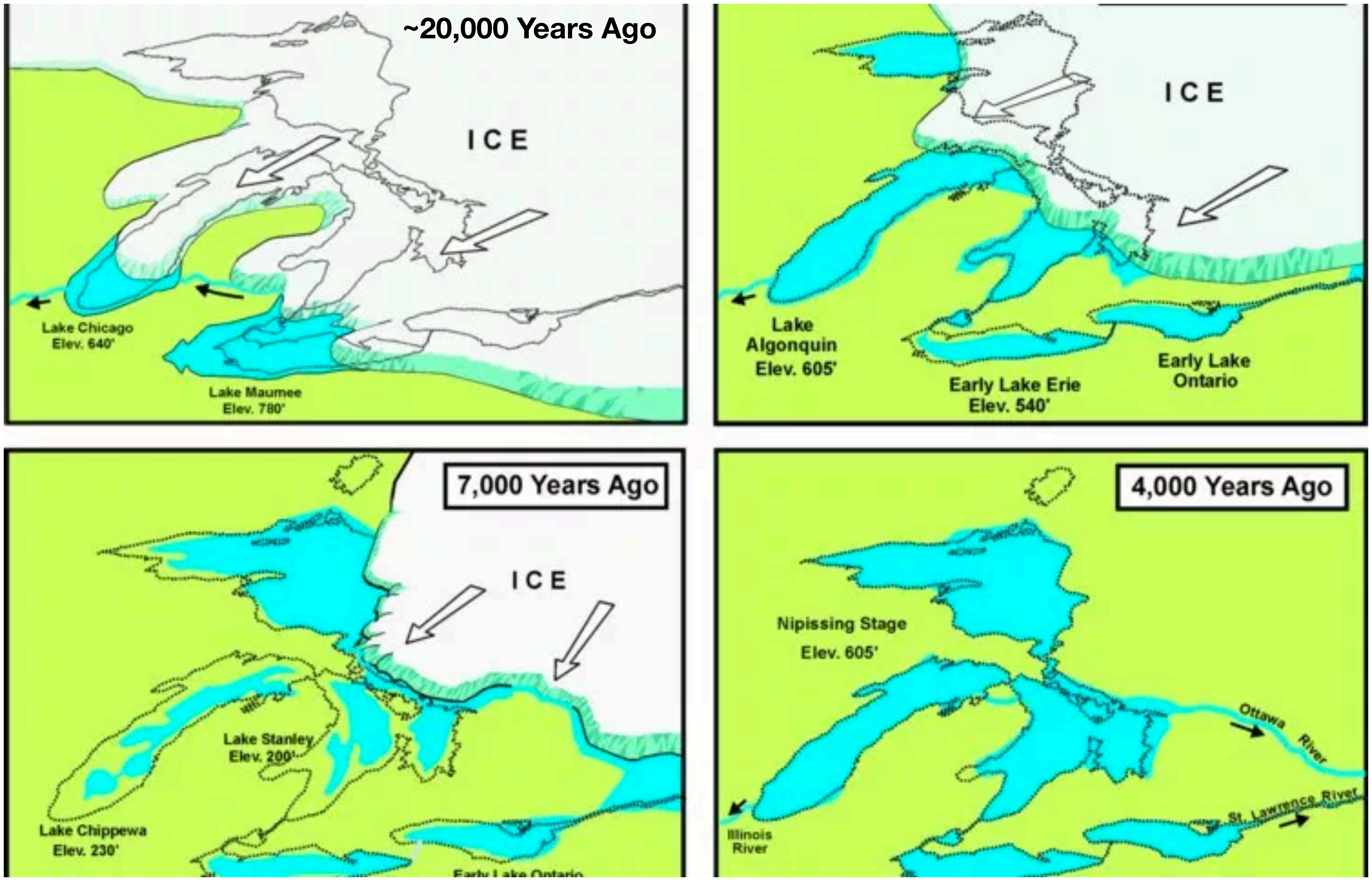
- freeze/thaw

Erosion by Ice

- Glaciers carved the Yosemite Valley.

Erosion by Ice

The Great Lakes were gouged-out by glaciers as they retreated at the end of the last ice age



Open bodies of water only remain fresh if continuously replenished. They become salty if not. This is the difference between lakes and seas.

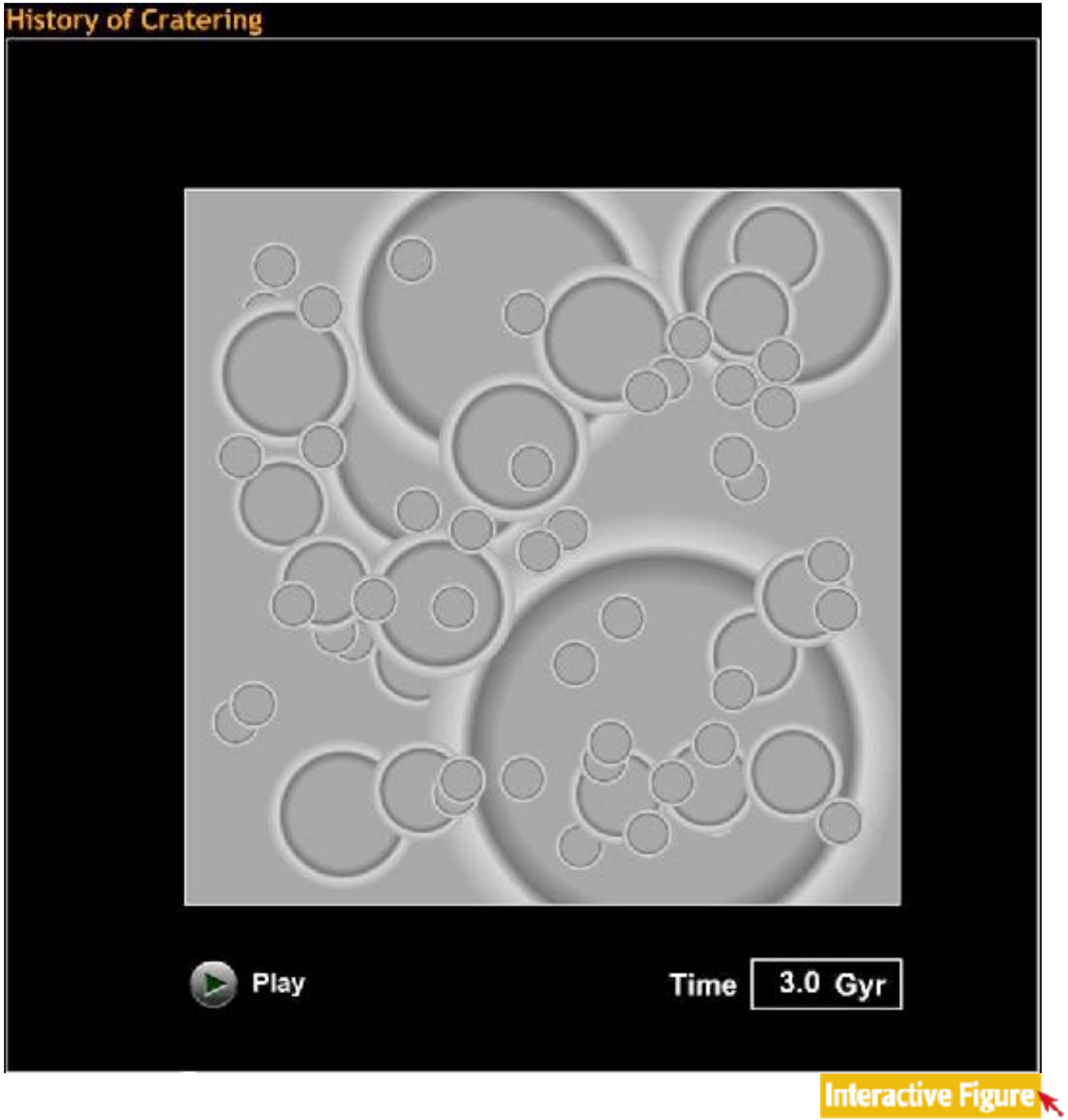
Erosion by Wind

- Wind wears away rock and builds up sand dunes.
- Also active on Mars

Erosional Debris

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

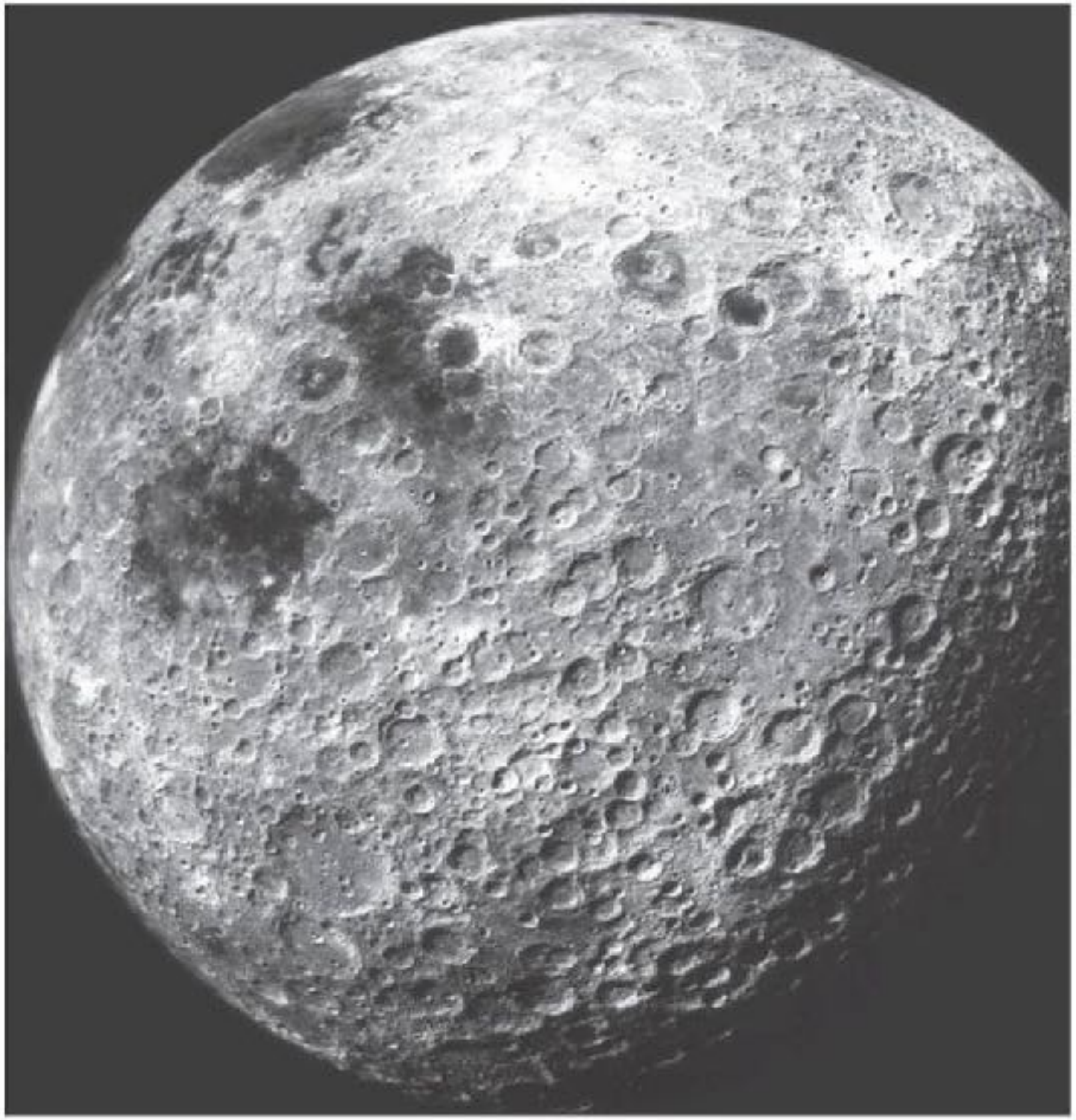
History of Cratering



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

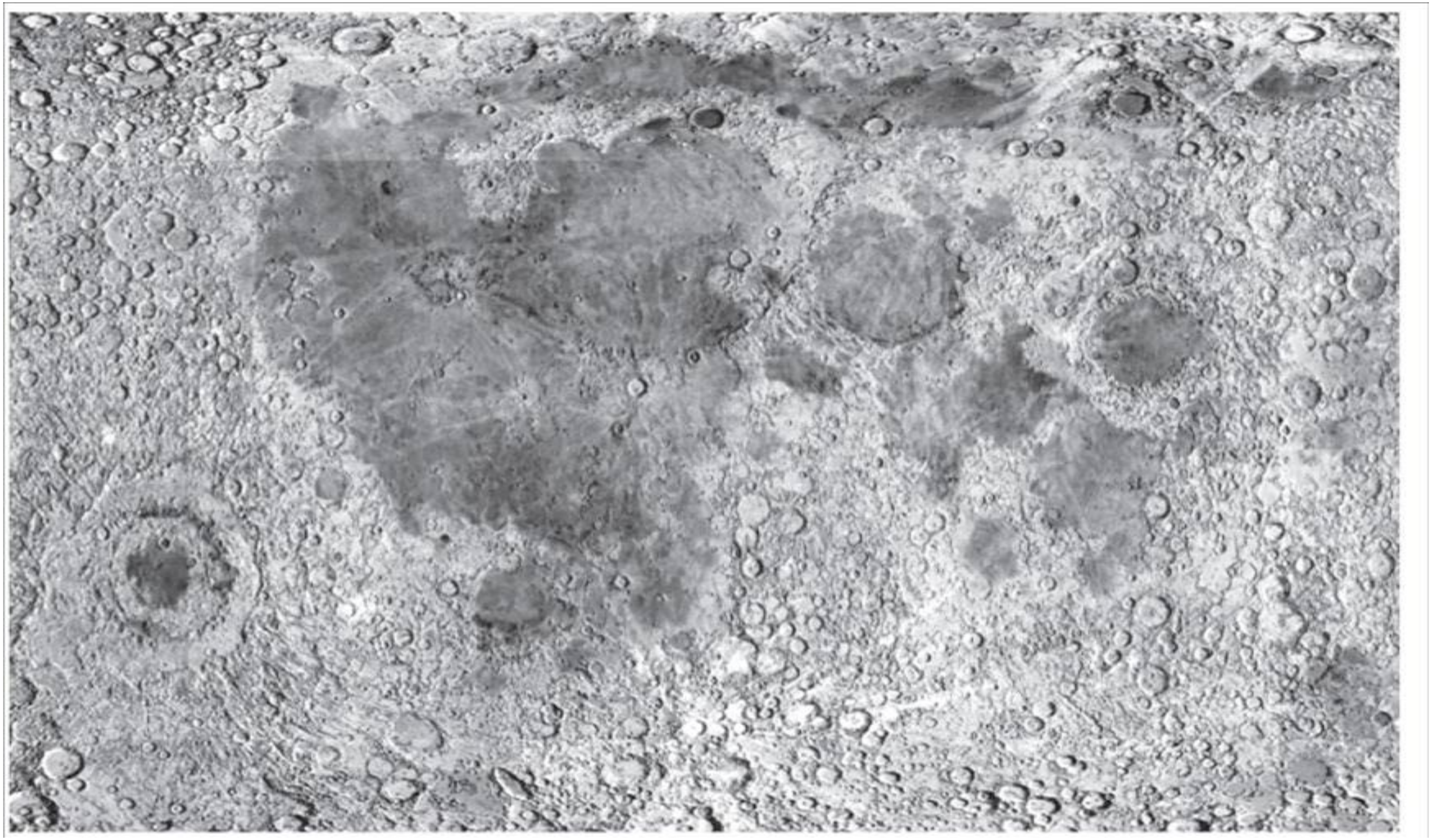
09_HistoryOfCratering.swf

Cratering of Moon

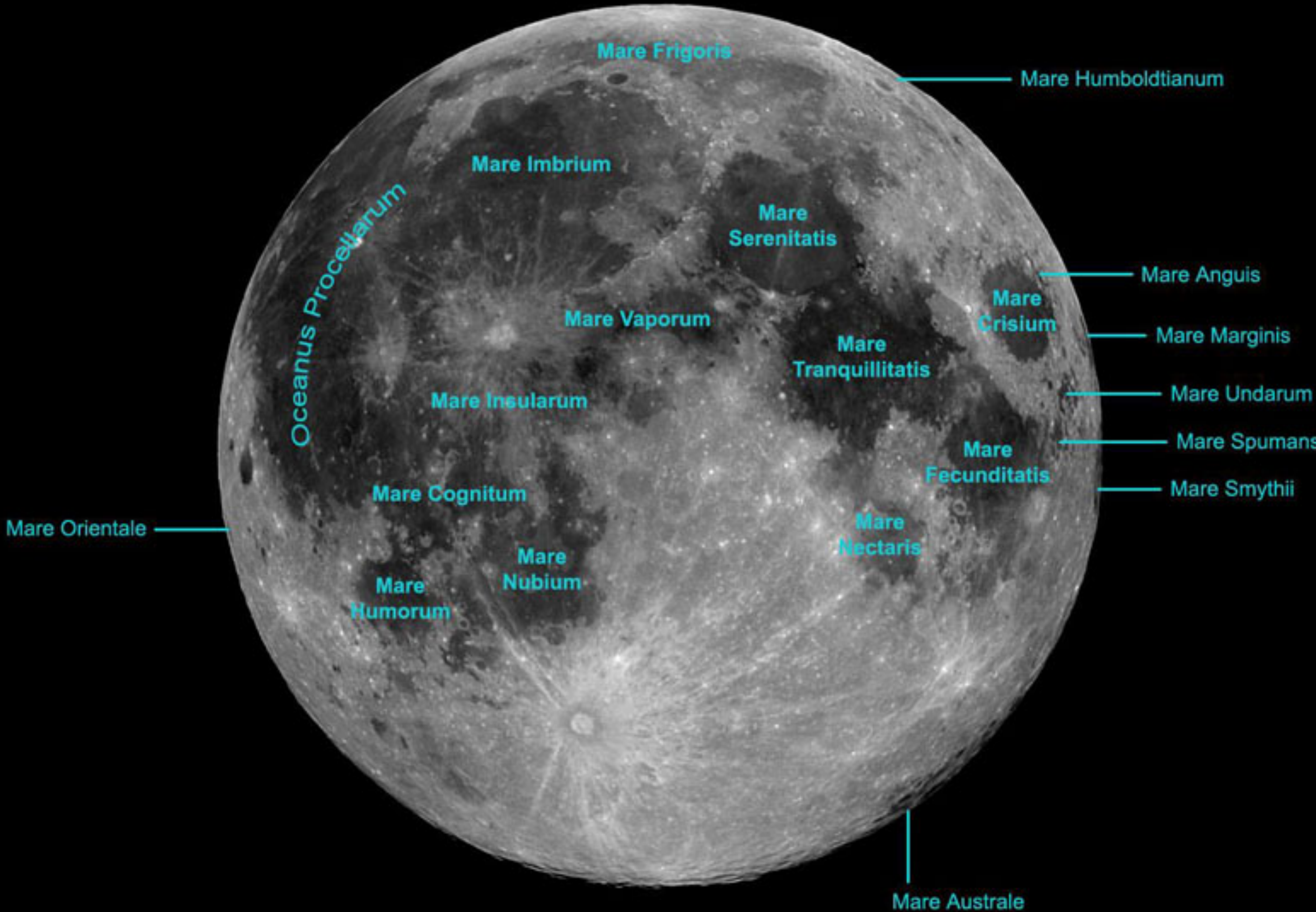


- Some areas of Moon are more heavily cratered than others.
- Younger regions were flooded by lava after most cratering.
  – mare

Cratering of Moon

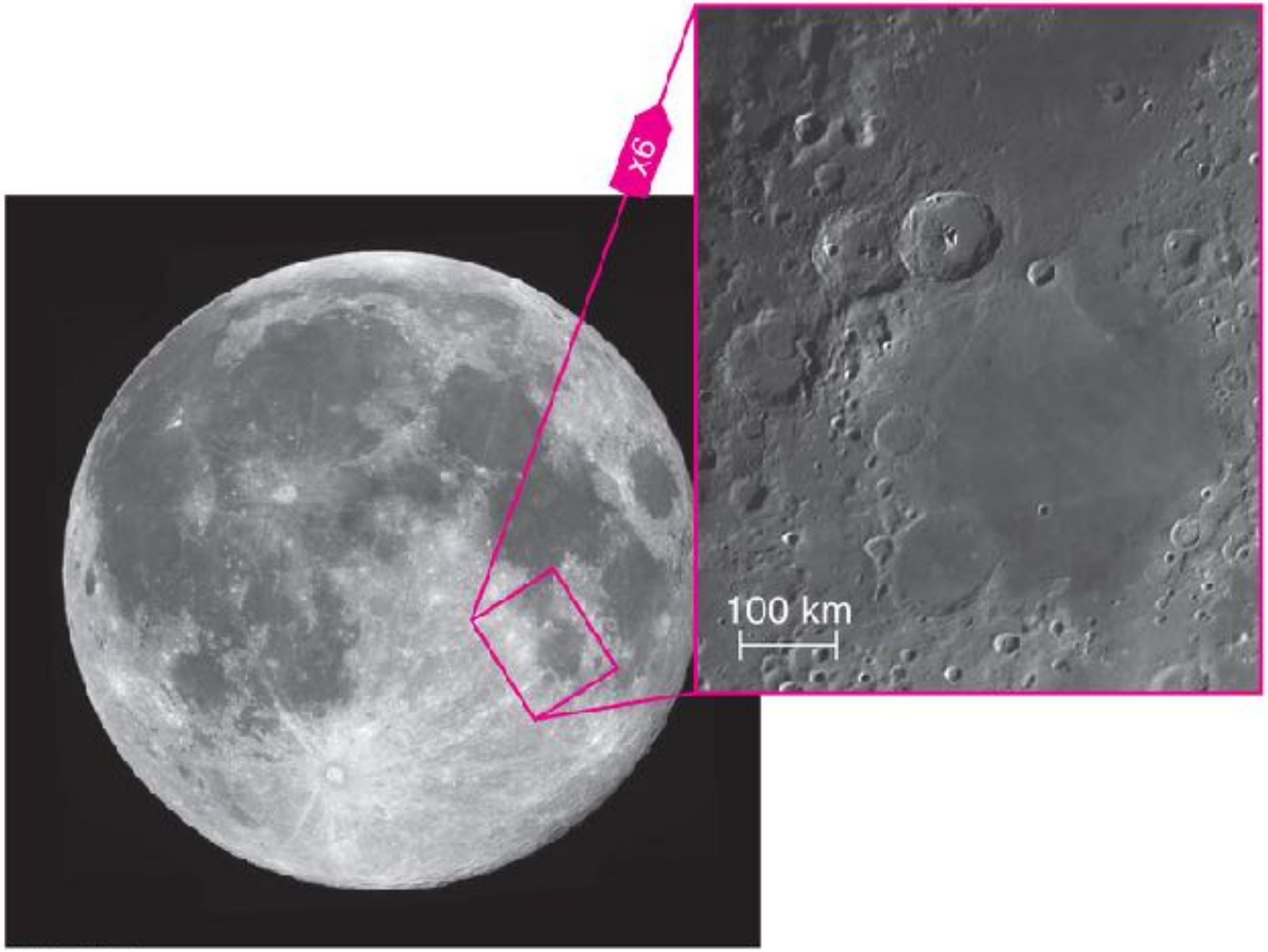


Cratering map of the Moon's entire surface



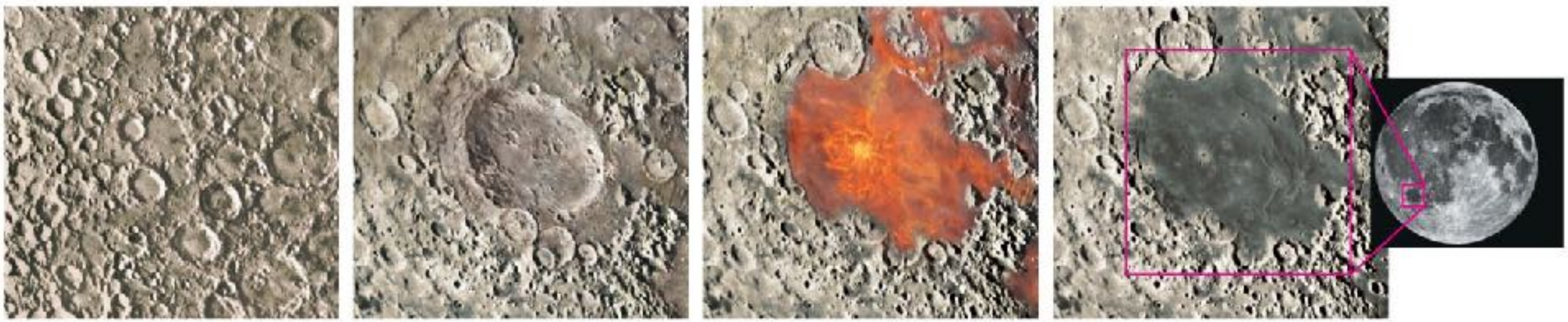
https://www.youtube.com/watch?v=mIRPeYGKfic

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.

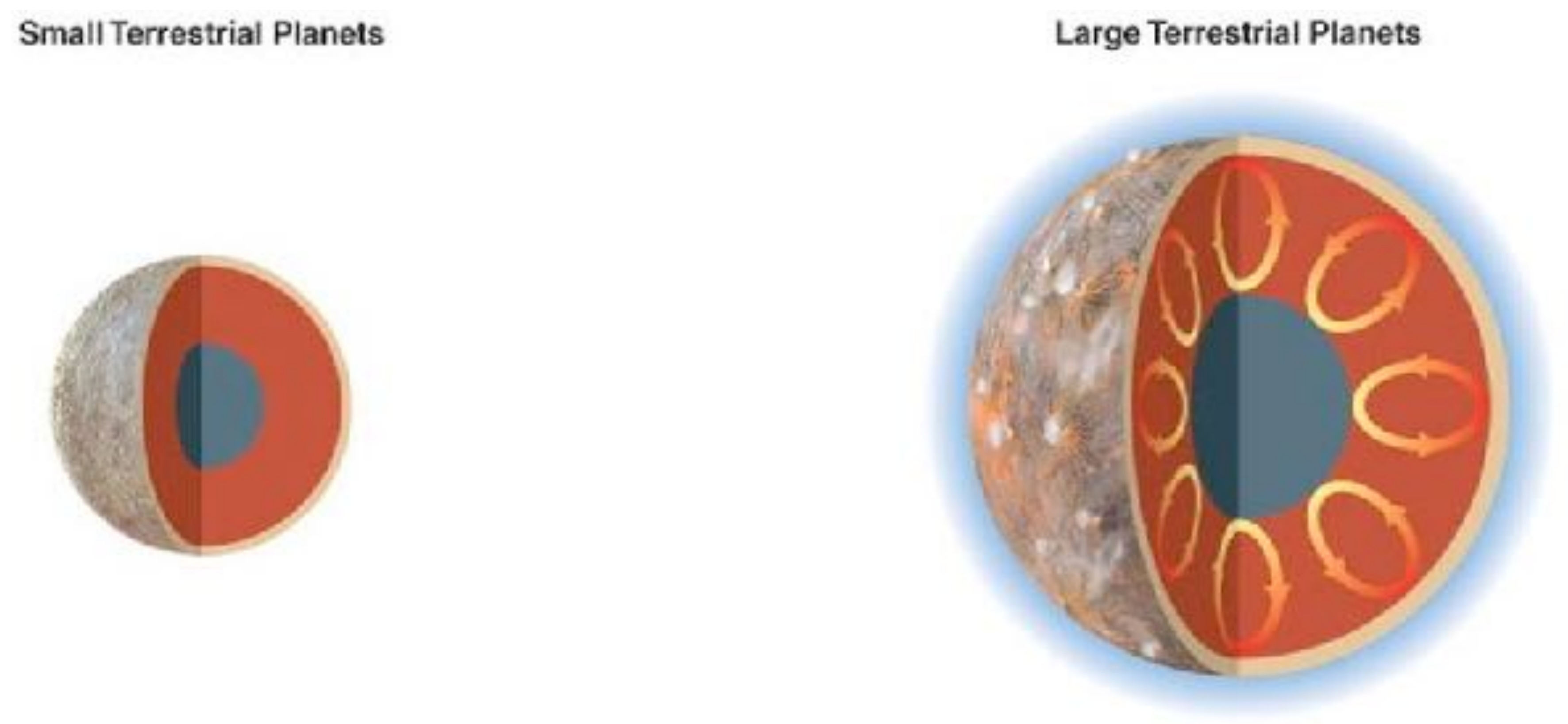
Cooled lava is smoother and darker than surroundings.

Geologically Dead

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

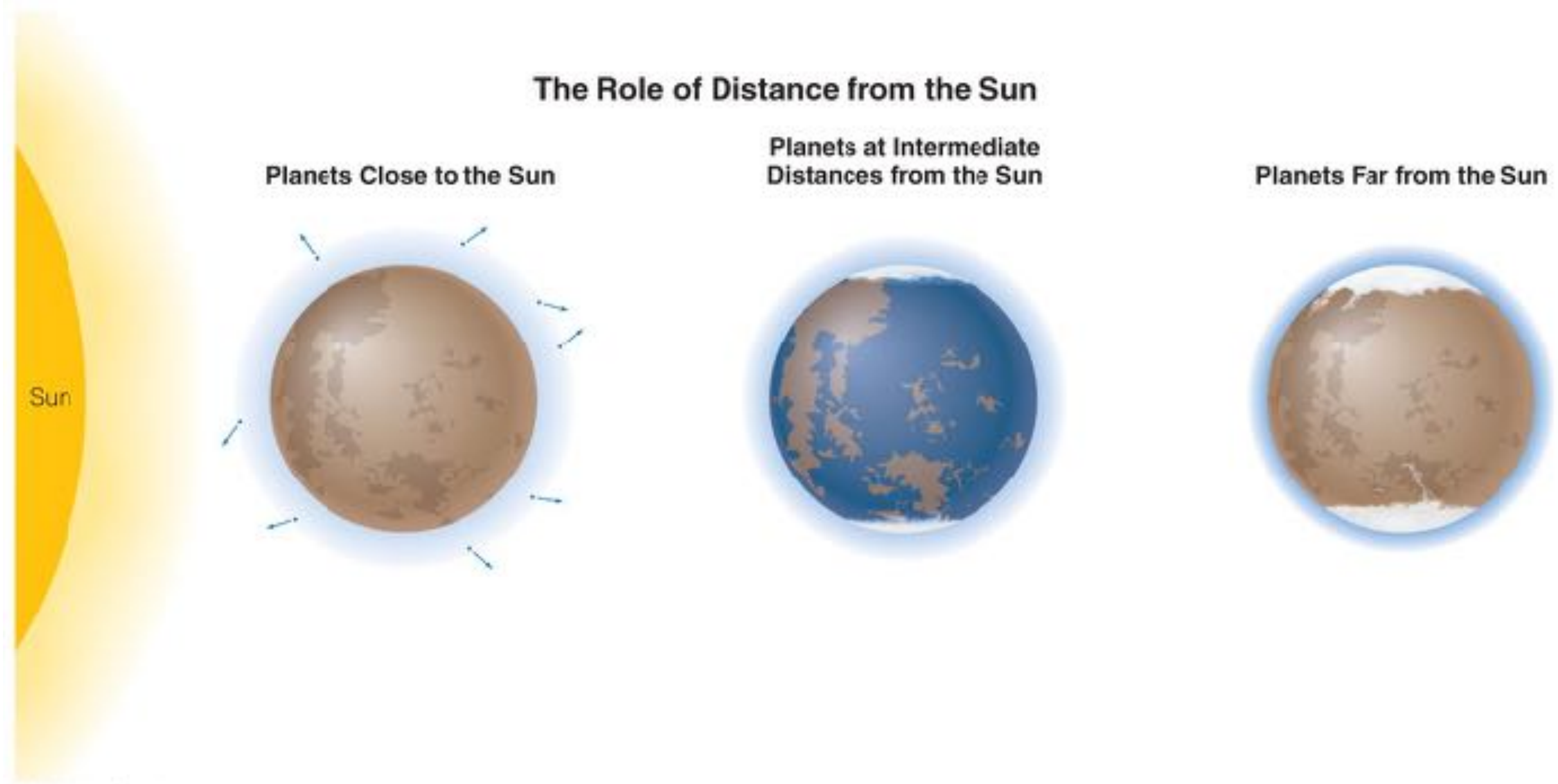
- Cooling process essentially complete
  – no more geology because there isn’t any interior heat to drive it

Role of Planetary Size



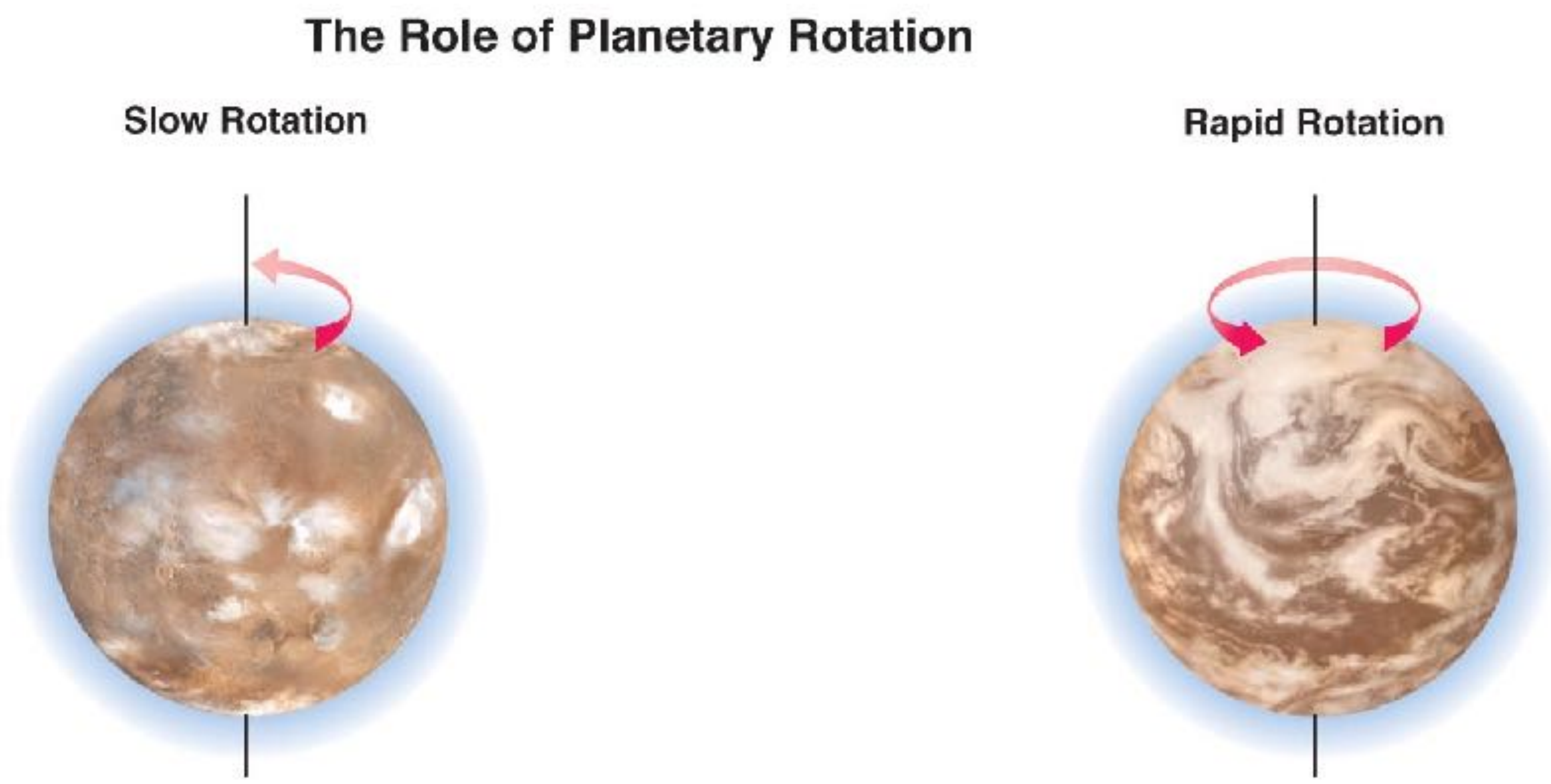
- Smaller worlds cool off faster and harden earlier.
- Larger worlds remain warm inside, promoting volcanism and tectonics.
- Larger worlds also have more erosion because their gravity retains an atmosphere.

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

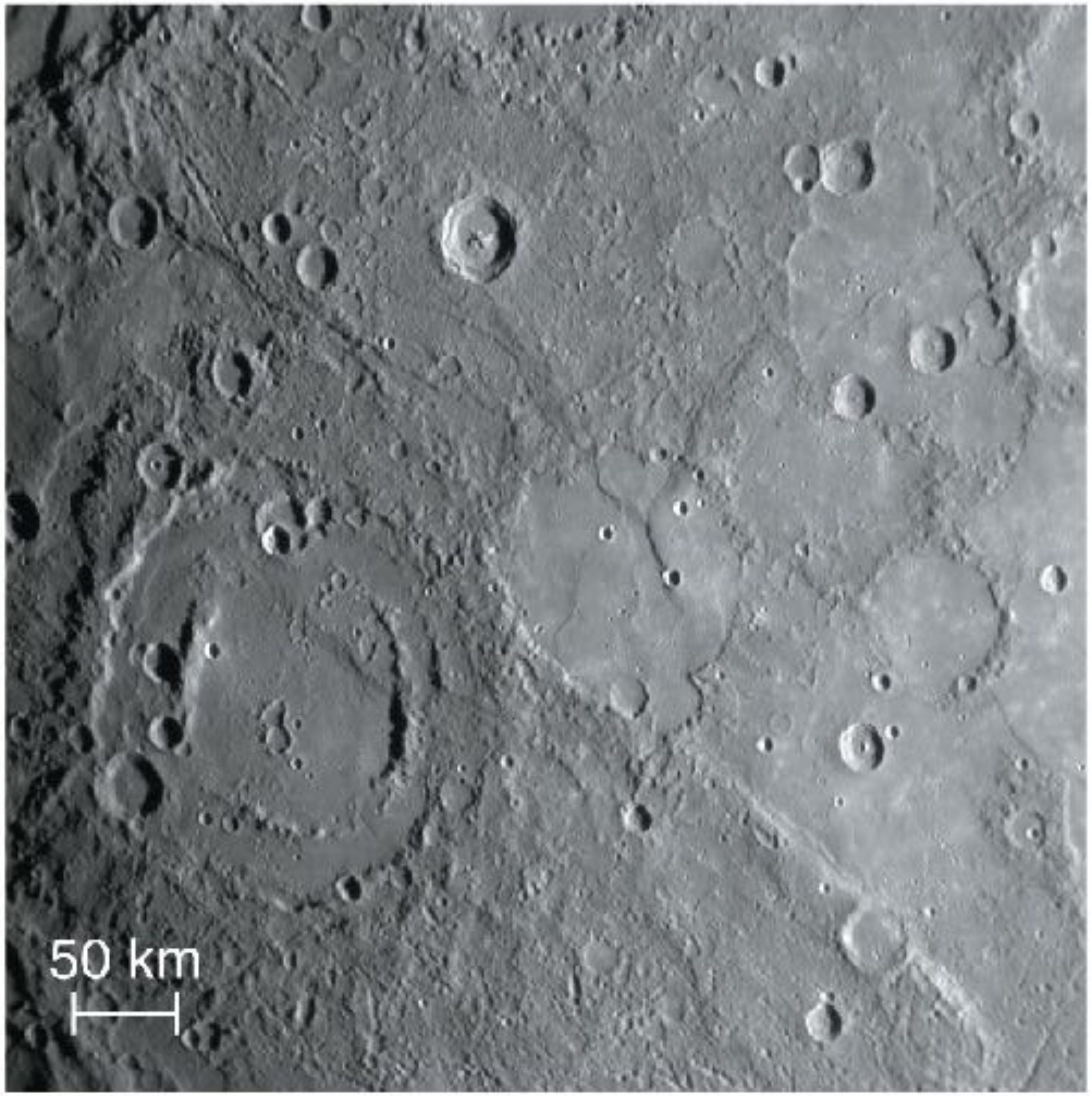


- Planets with slower rotation have less weather, less erosion, and a weak magnetic field.
- Planets with faster rotation have more weather, more erosion, and a stronger magnetic field.

Mercury

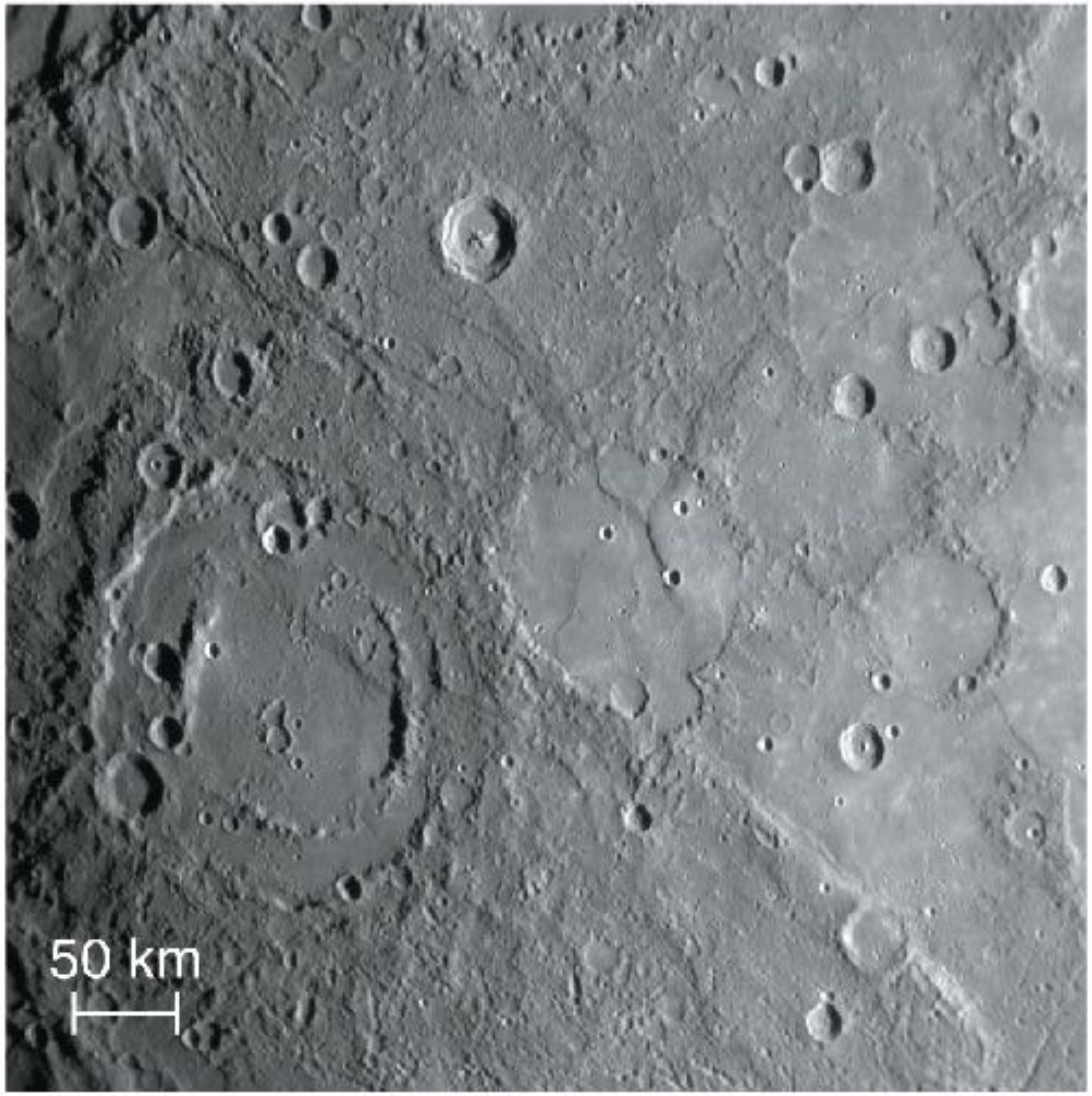
http://www.space.com/19920-mercury-color-video-messenger-spacecraft.html

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



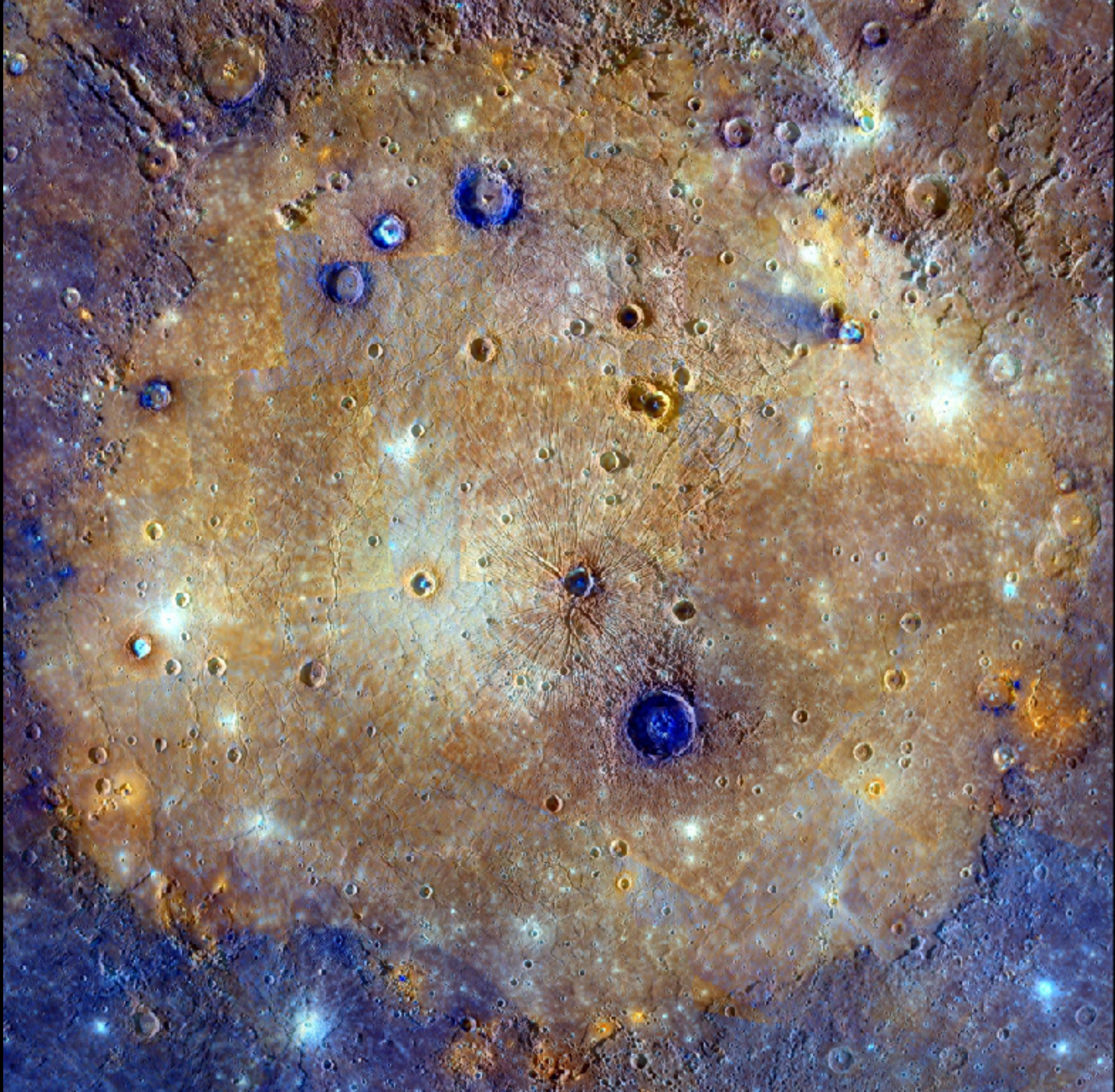
- Mercury has a mixture of heavily cratered and smooth regions like the Moon.
- Smooth regions are likely ancient lava flows.

Caloris basin

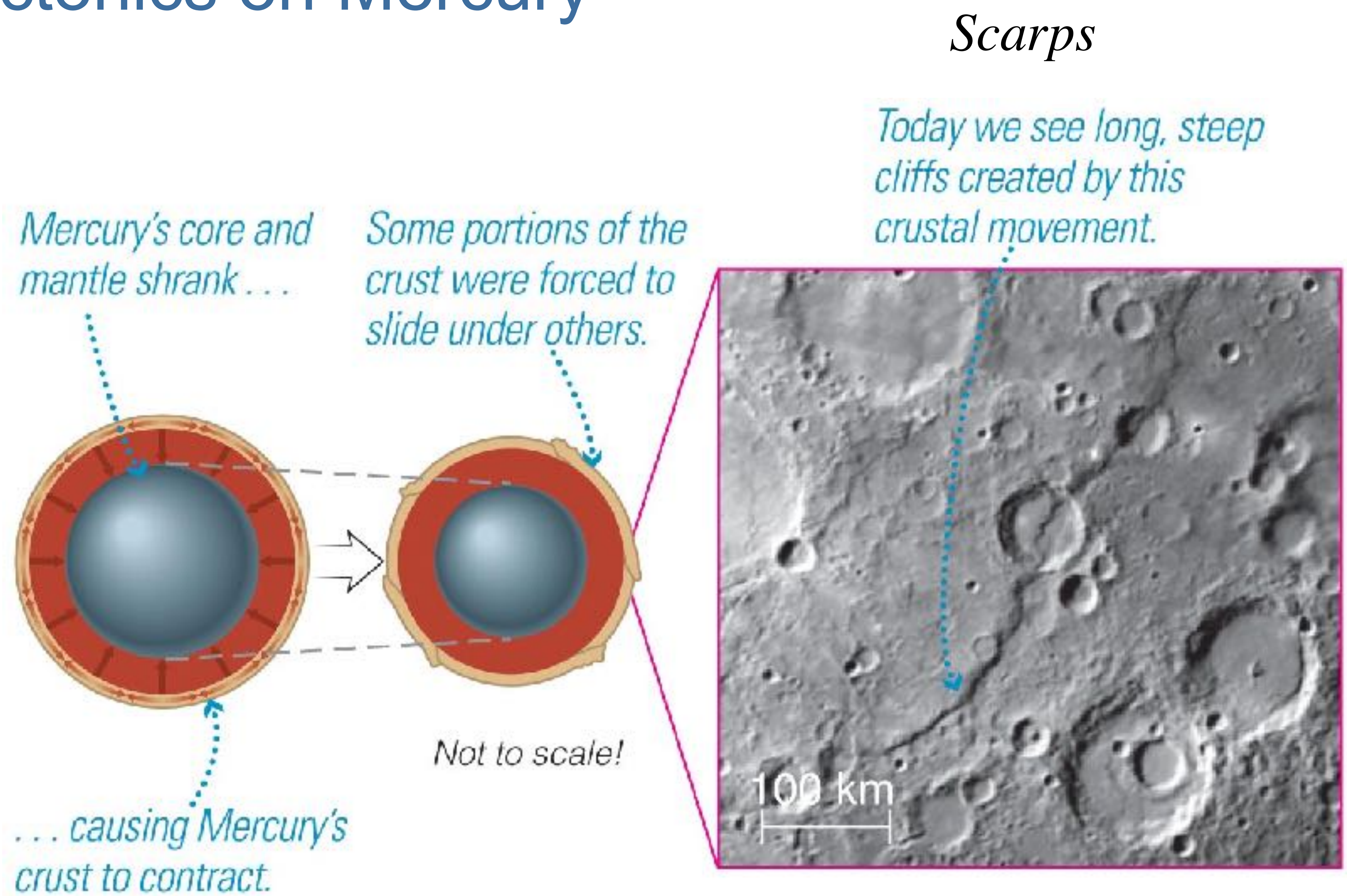
largest crater in Solar system

lava (orange)

older material (blue) sometimes excavated by later impact

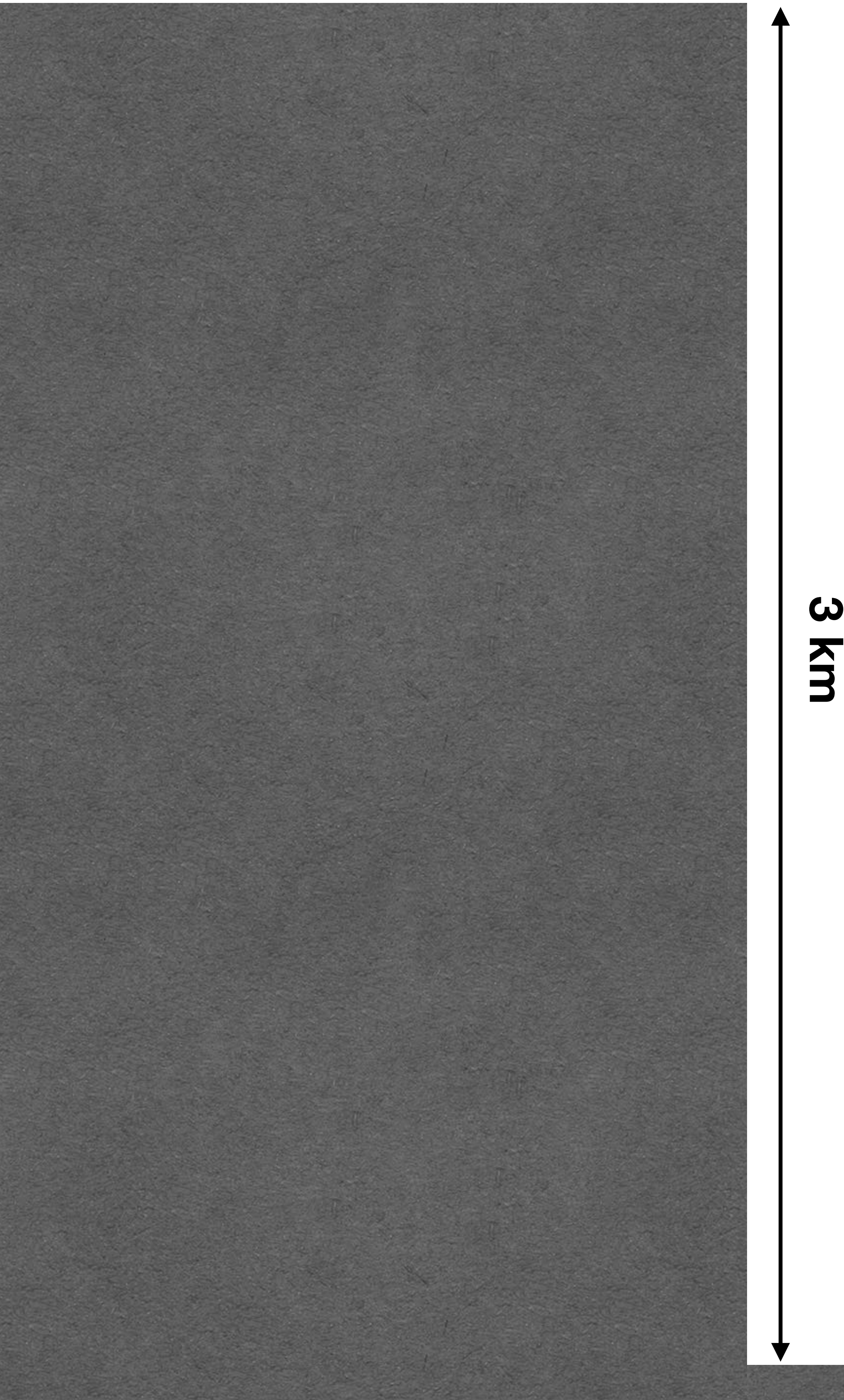


Tectonics on Mercury



- Long cliffs (scarps) created when Mercury shrank (about 10 km in diameter) as it cooled.

Scarp on Mercury, to scale



Surface gravity on Mercury: 3.7 m/s/s

$$d = \frac{1}{2}at^2 \quad \text{so} \quad t = \sqrt{2ad}$$

time to fall off scarp

t = 149 s (about 2 and a half minutes)

velocity on impact

$$v = at = (3.7\ \mathrm{m\,s^{-2}})(149\ \mathrm{s})$$

$$v = 551\ \mathrm{m/s}$$

(1,233 mph)

Tall buildings on Earth