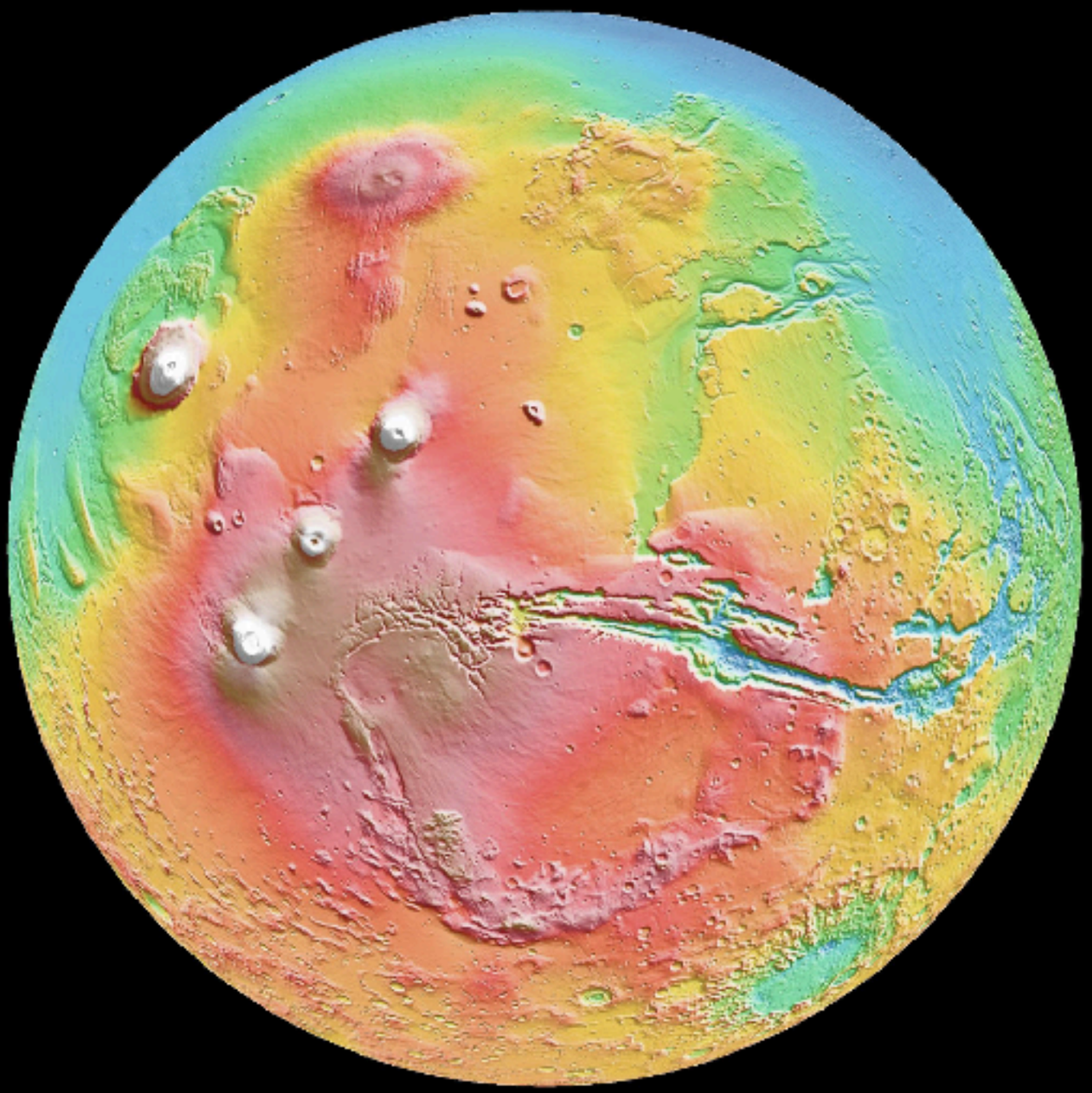
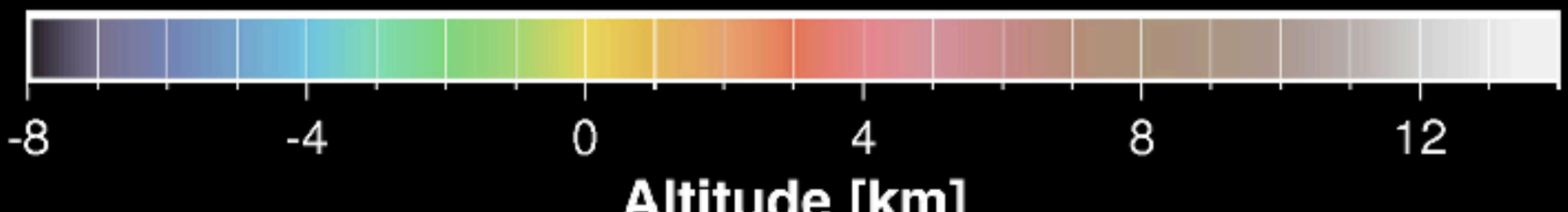


Mars elevation map



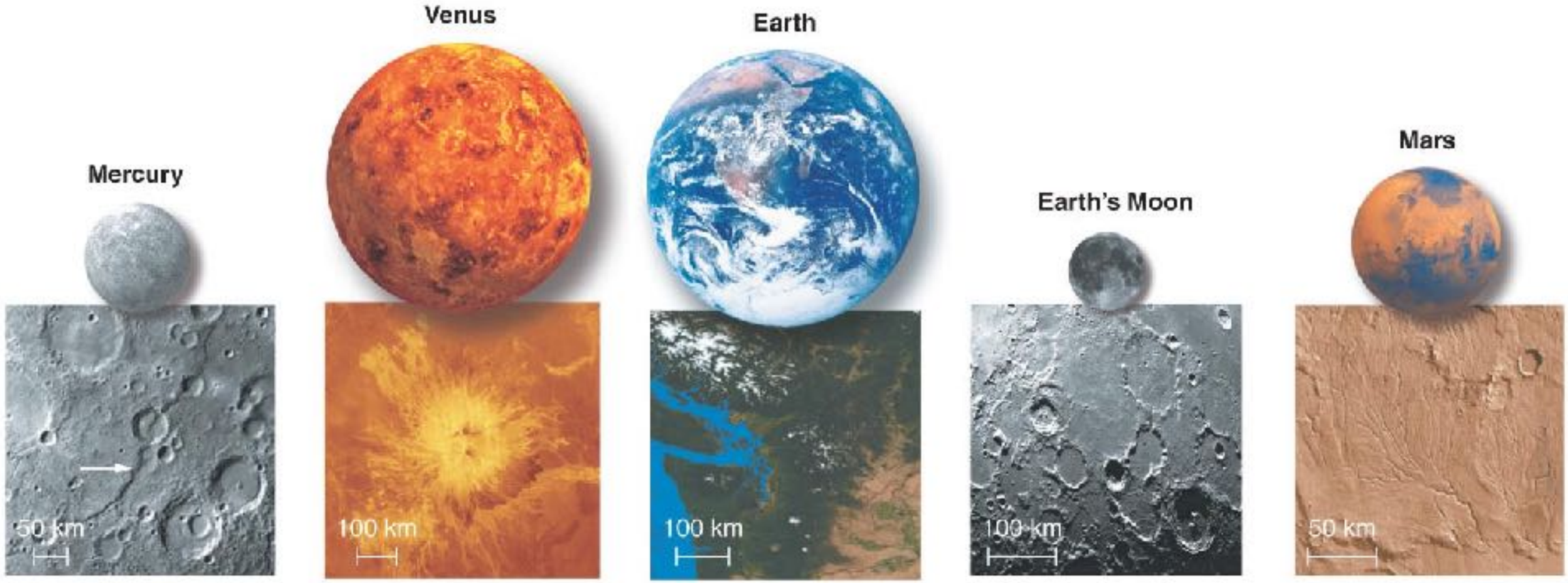
Today

- Terrestrial Planet Geology
  - individual cases

Events

- Spring break next week

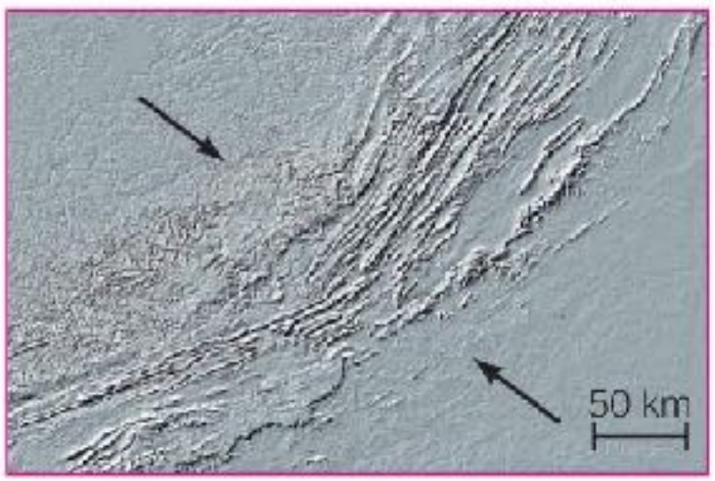
Why do the terrestrial planets have different geological histories?



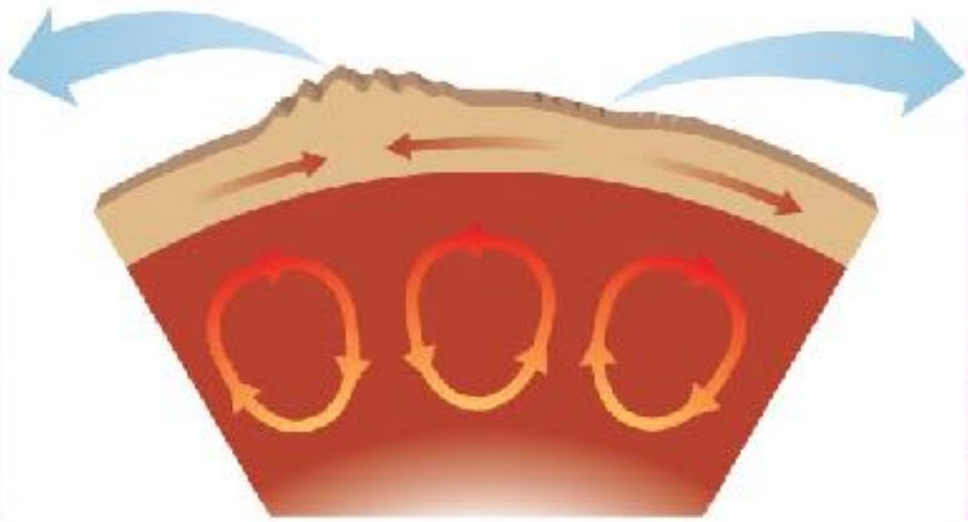
Processes That Shape Surfaces

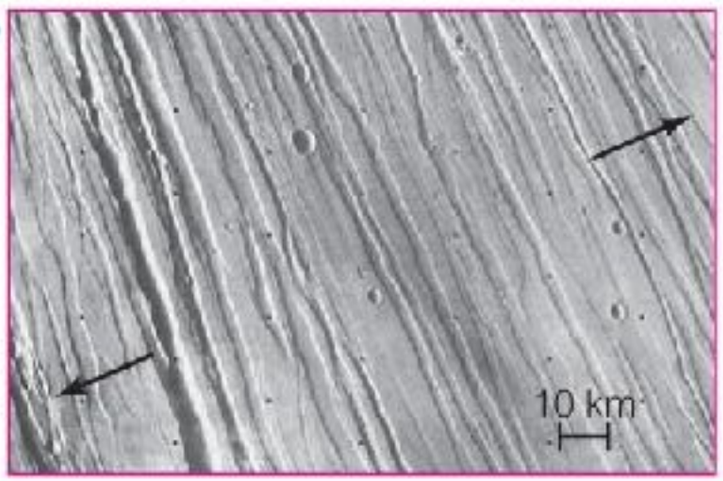
- Impact cratering
  - Impacts by asteroids or comets
- Volcanism
  - Eruption of molten rock onto surface
- Tectonics
  - Disruption of a planet's surface by internal stresses
- Erosion
  - Surface changes made by wind, water, or ice

Tectonics



Appalachian Mountains in eastern United States





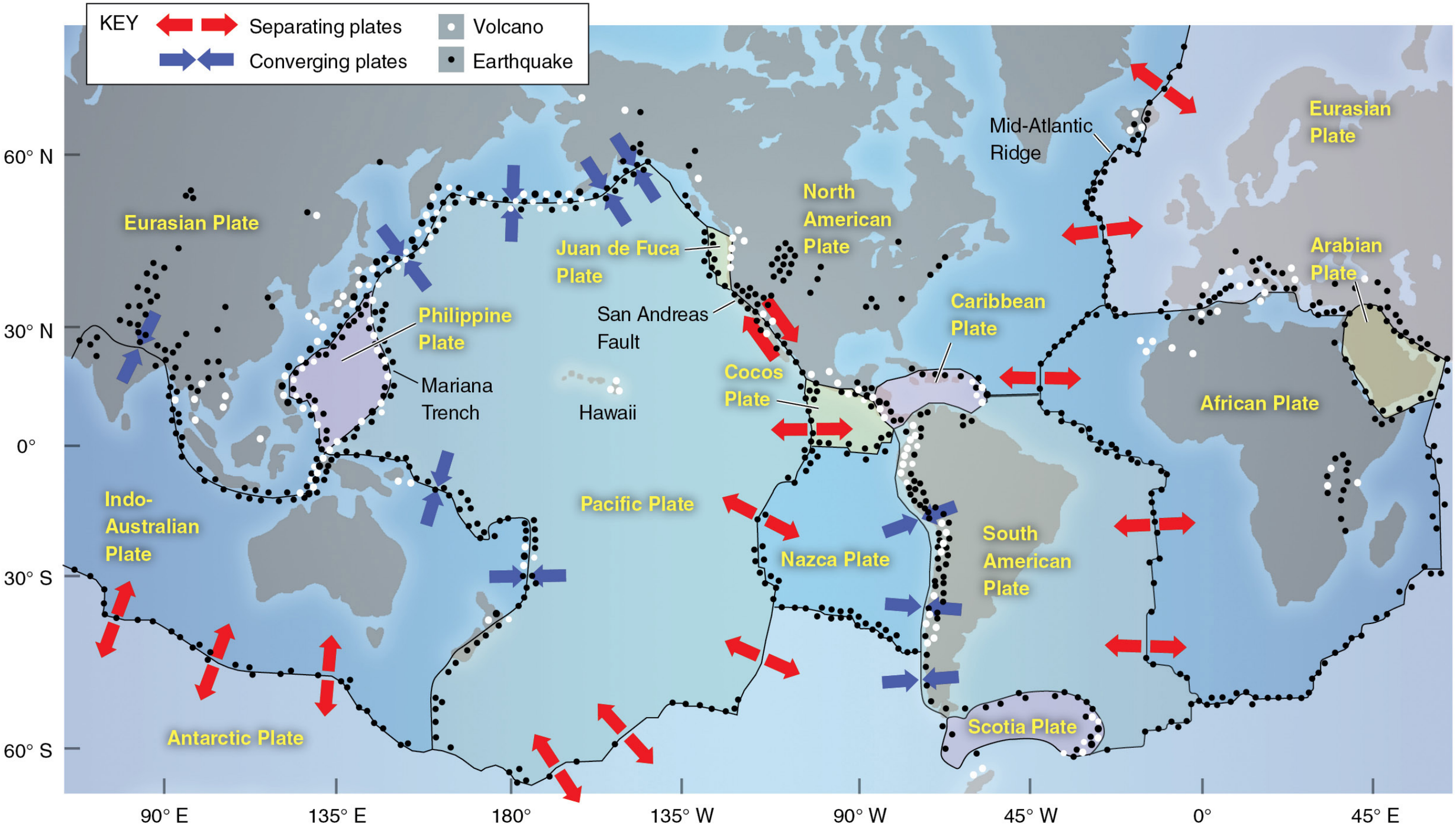
Ceraunius Valleys on Mars

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.

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
    - flowing ice grinds and transports rock
  - rivers, rain
    - flowing liquid water dissolves and transports rock
  - wind
    - blowing air, often transporting dust like a sandblaster
  - freeze/thaw
    - ice pressure weakens rock, then liquid water drains away

Erosion by Water

- The Colorado River carved the Grand Canyon like a knife in slow motion, and continues to do so.
- The current water course is about 6 million years old; the cut through the canyon exposes progressively older geological layers (200 - 2,000 Myr old)

Local examples of Erosion

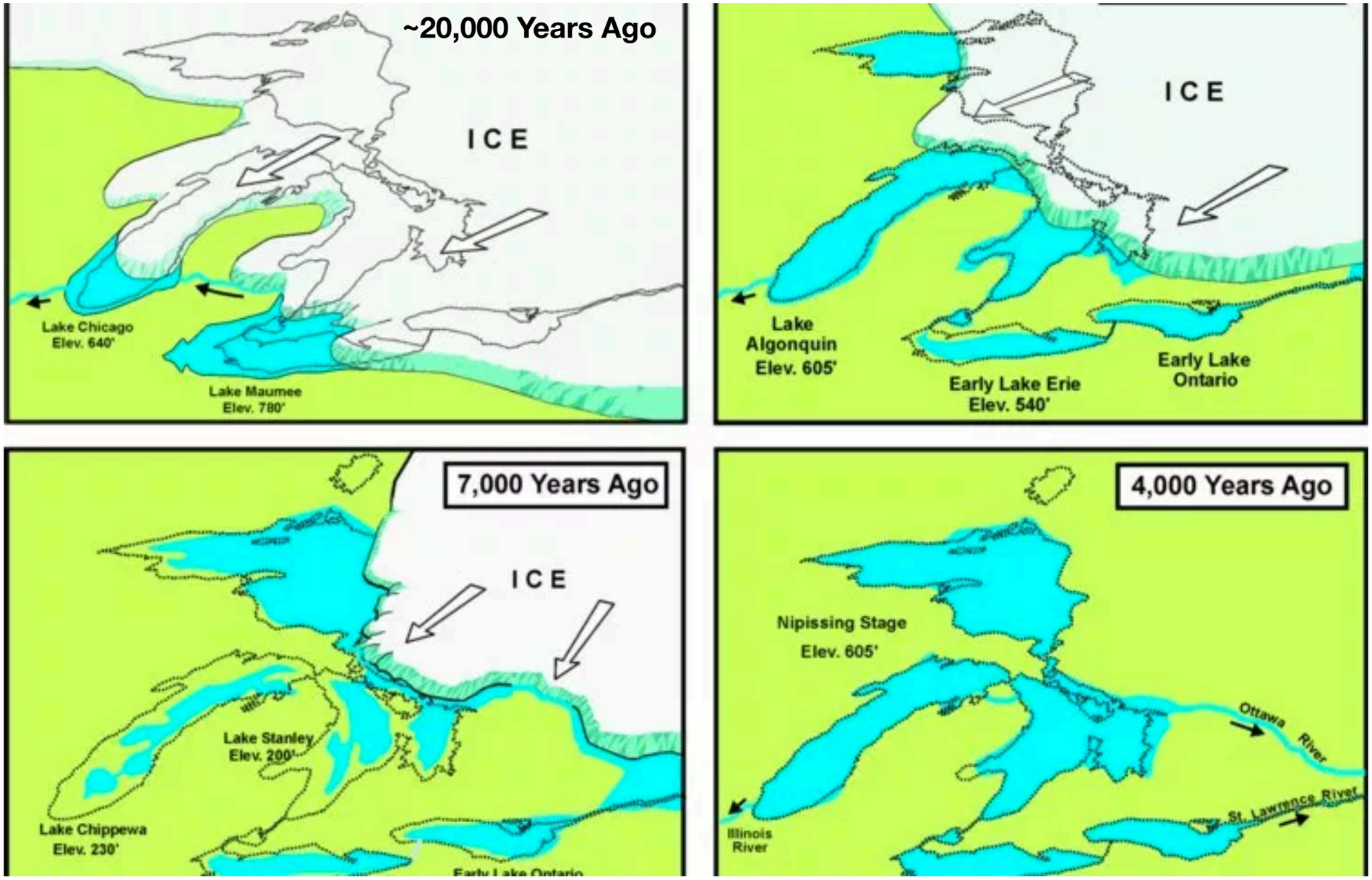
- freeze/thaw

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

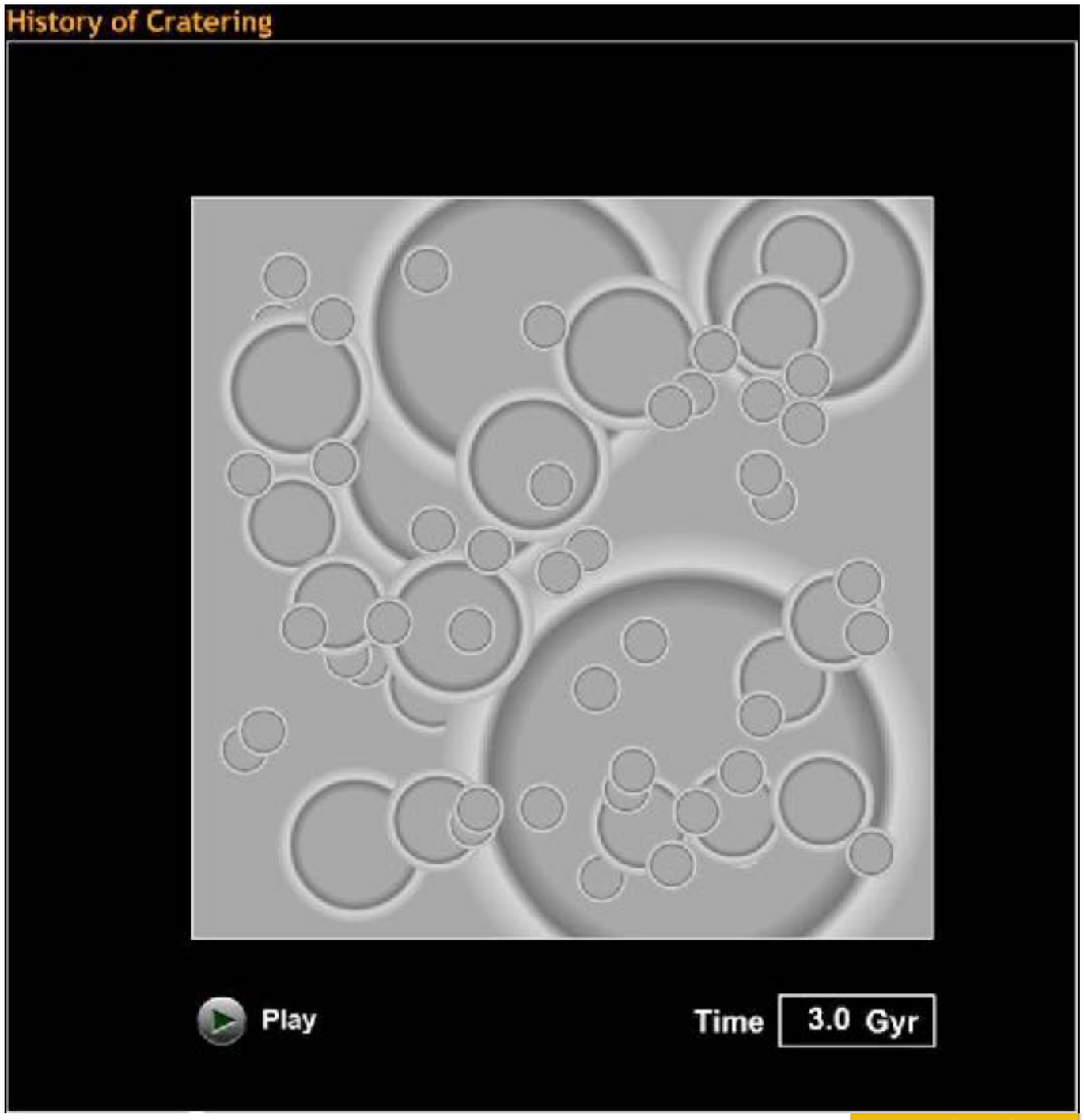
- Wind wears away rock and builds up sand dunes.
- Also active on Mars

Erosional Debris

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

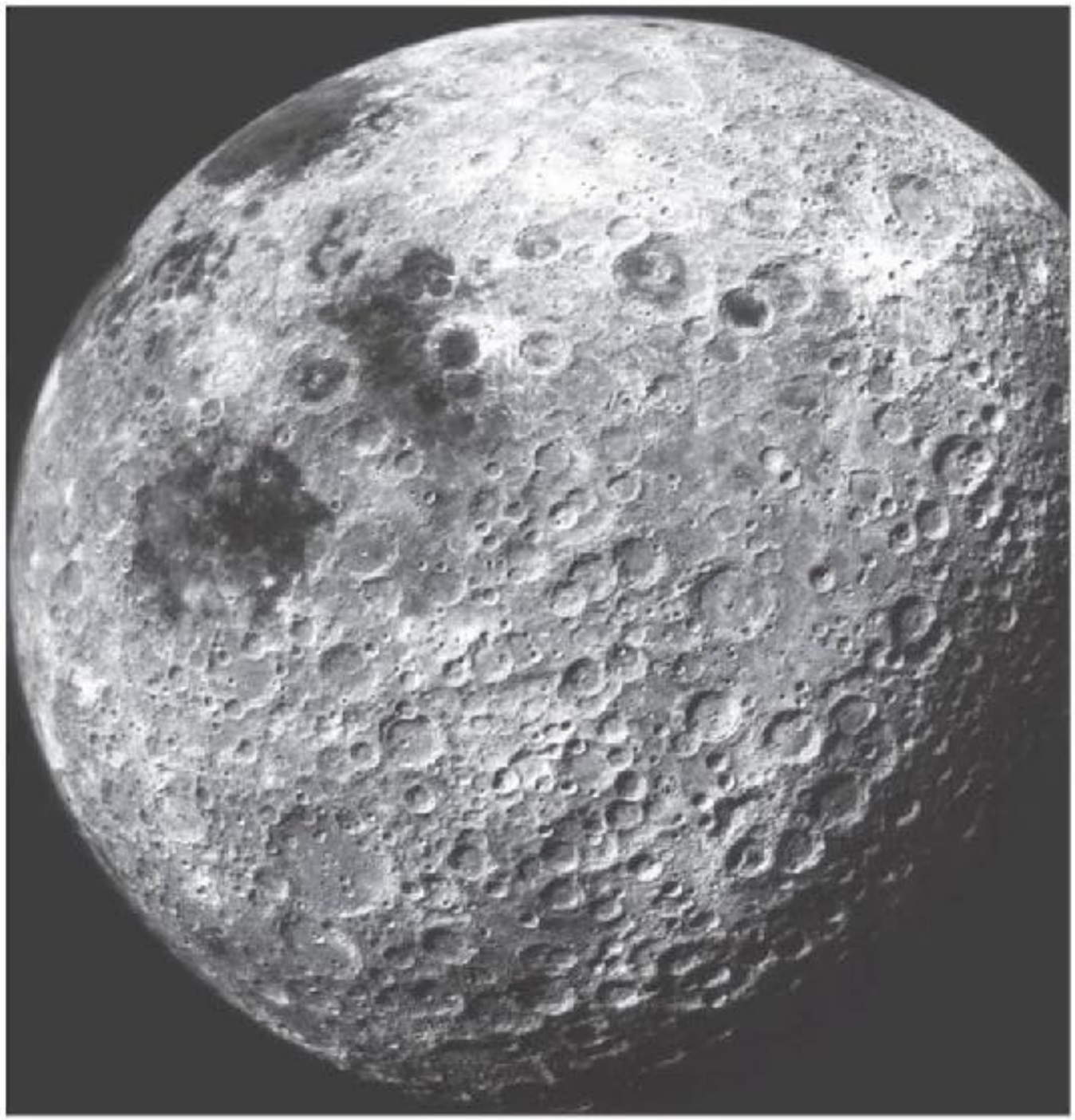
History of Cratering

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



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

Cratering of Moon

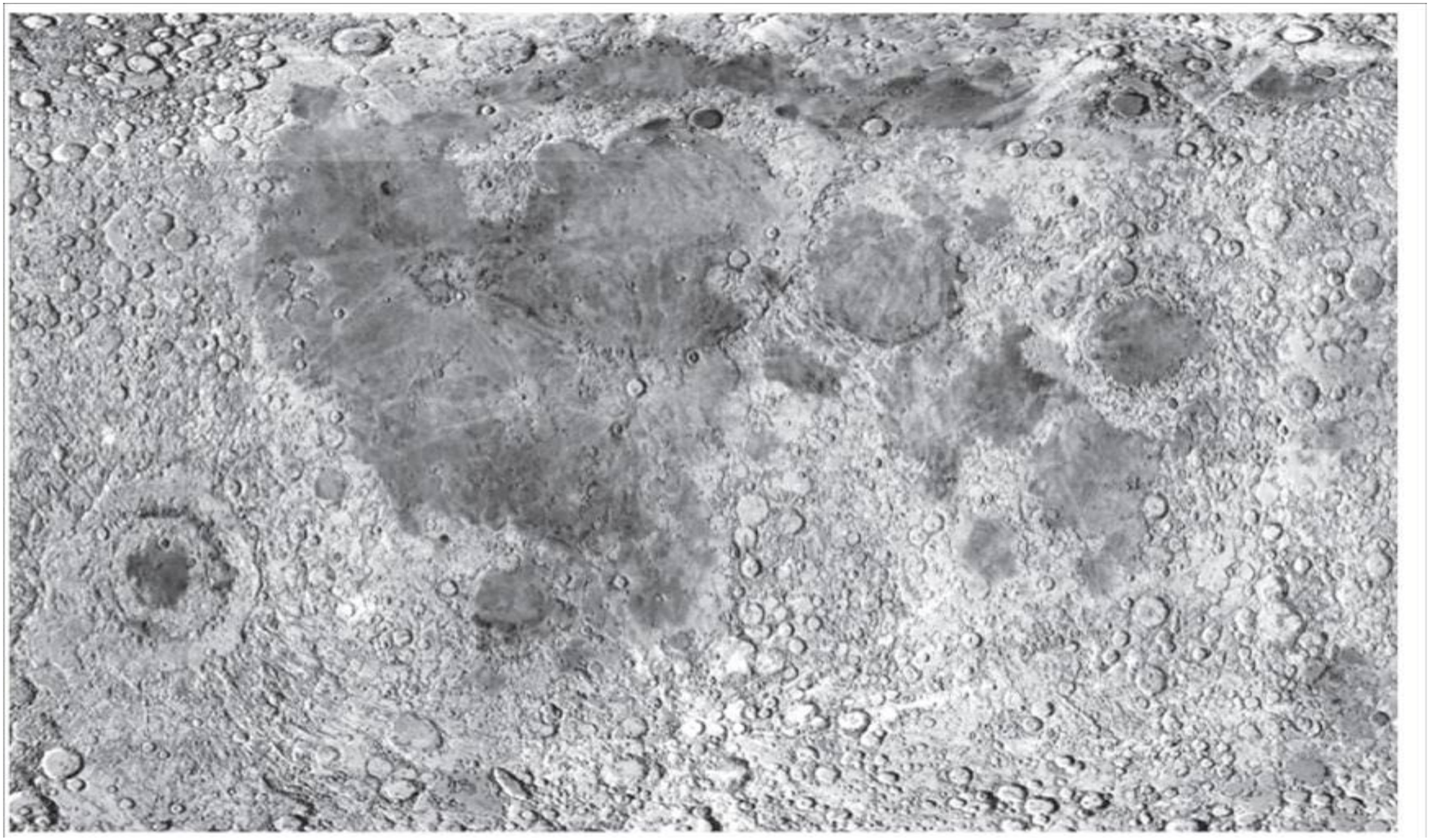


- Some areas of Moon are more heavily cratered than others.

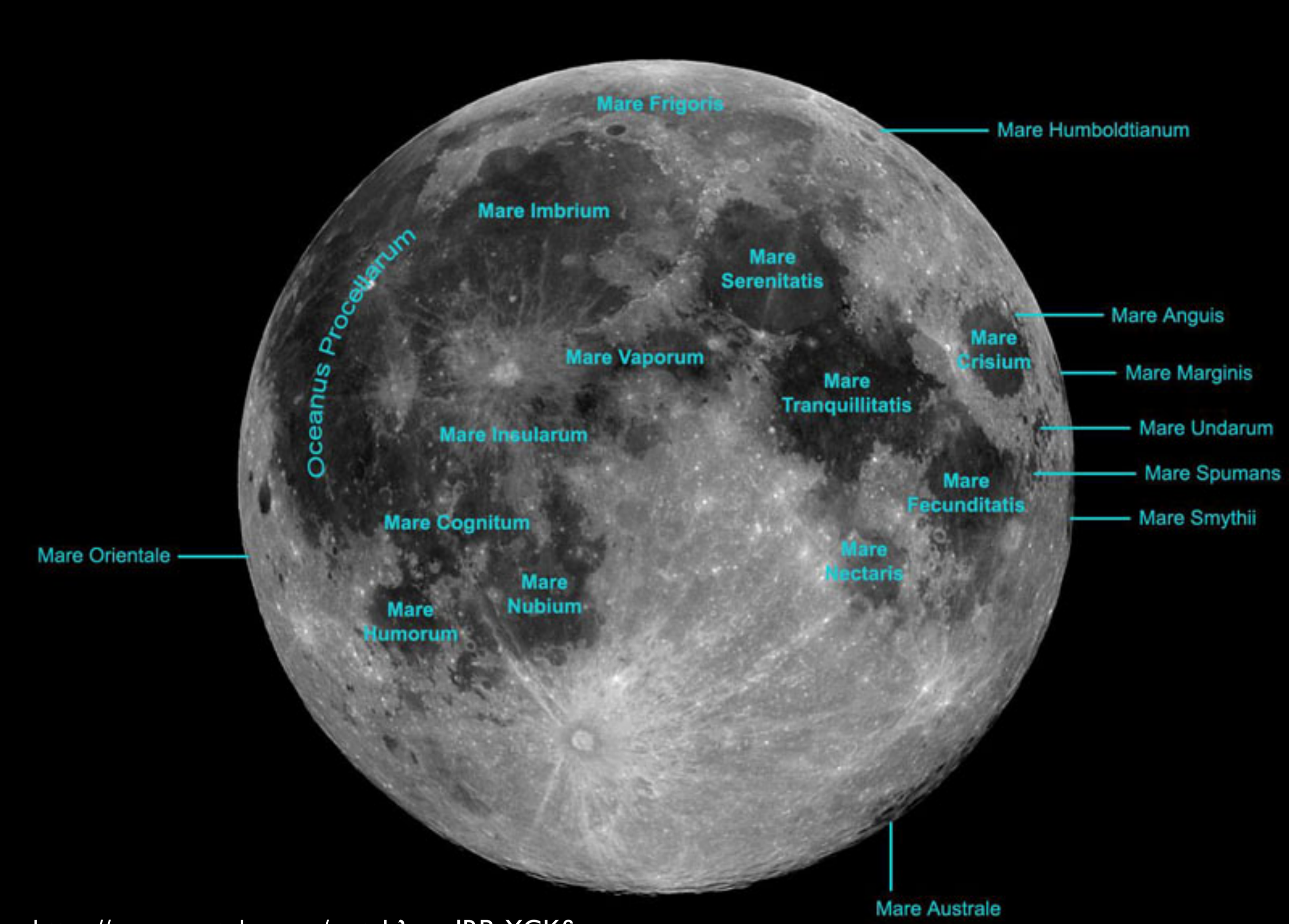
- Younger regions were flooded by lava after most cratering.

  – mare

Cratering of Moon

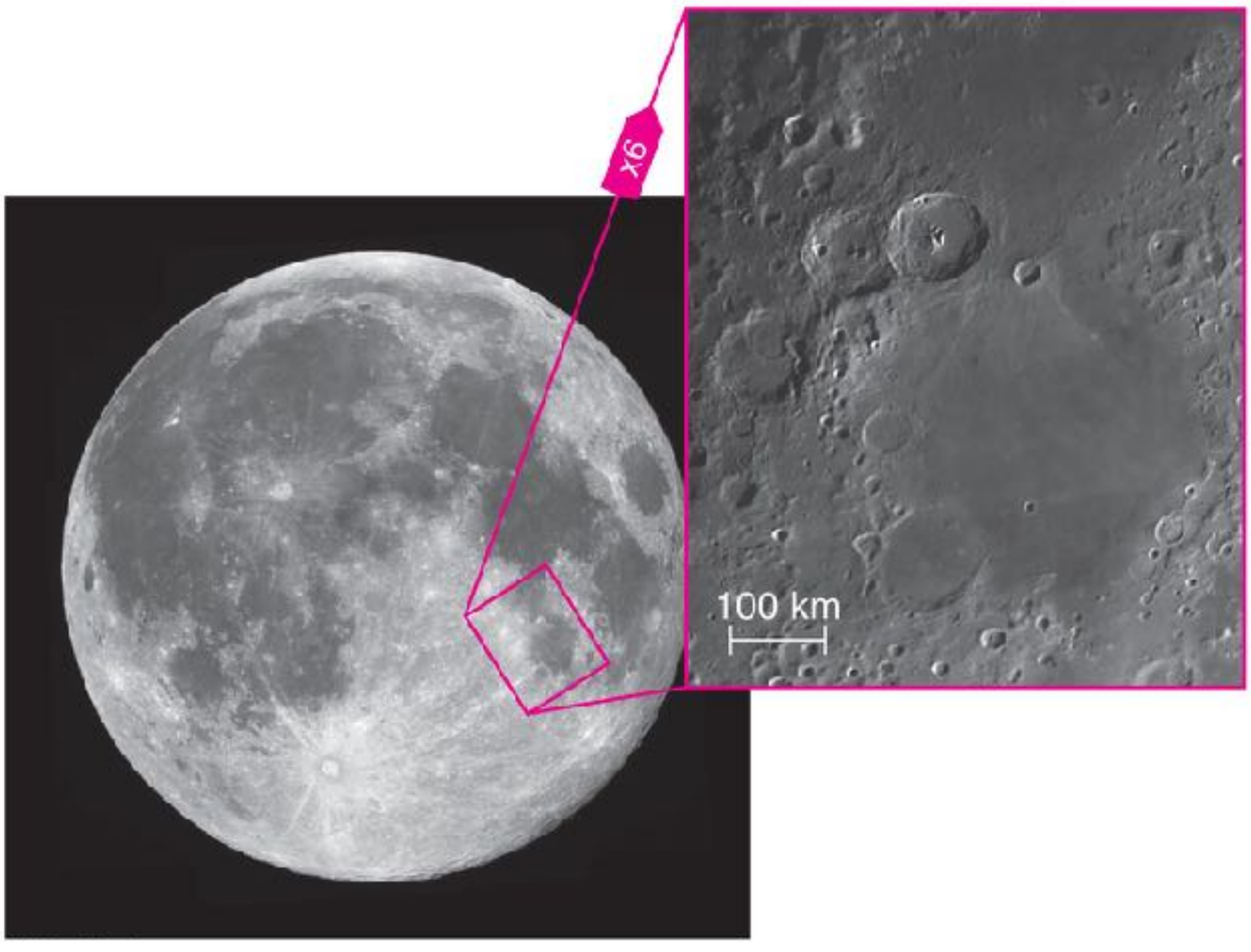


Cratering map of the Moon's entire surface



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

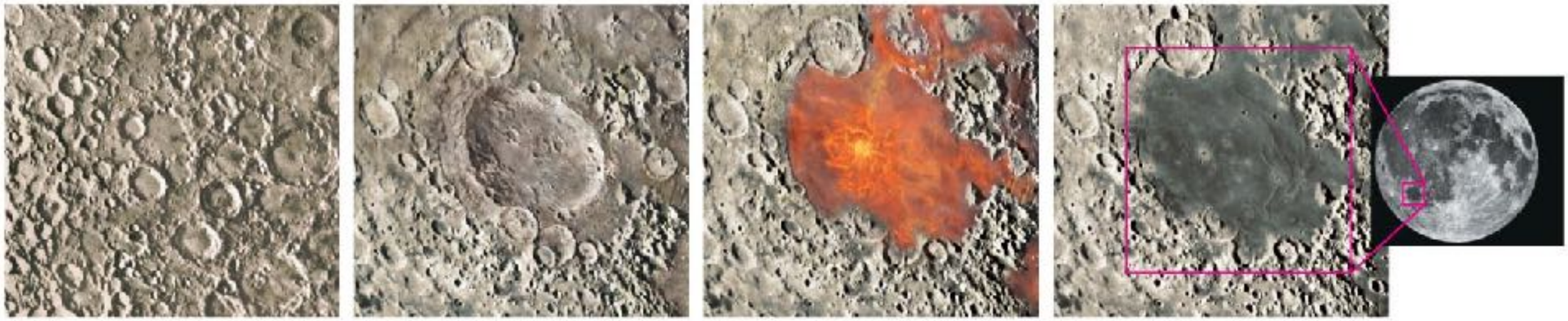
Lunar Maria



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

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

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.

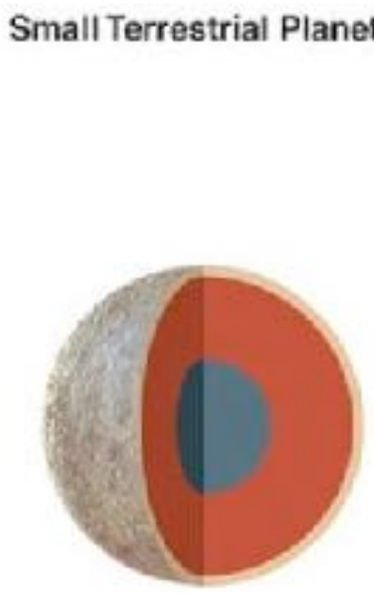
Cooled lava is smoother and darker than surroundings.

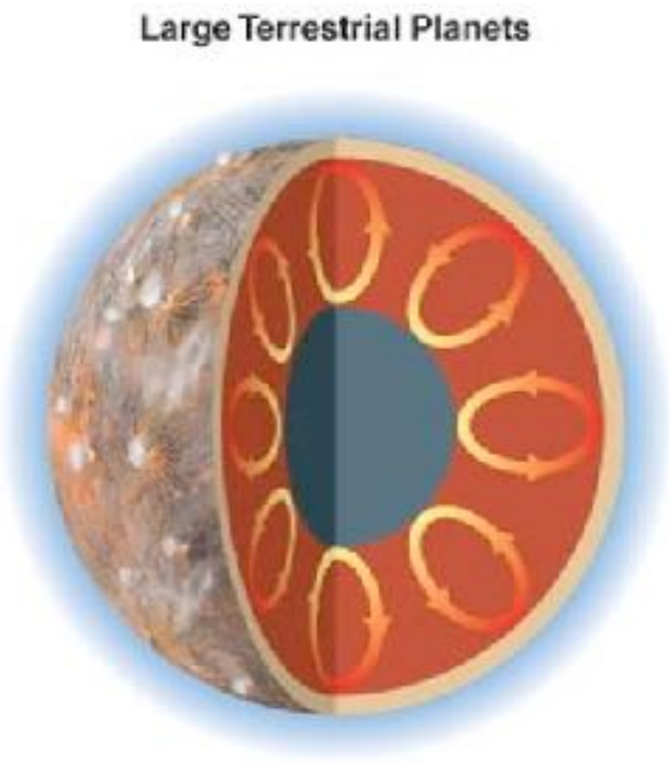
Geologically Dead

- 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

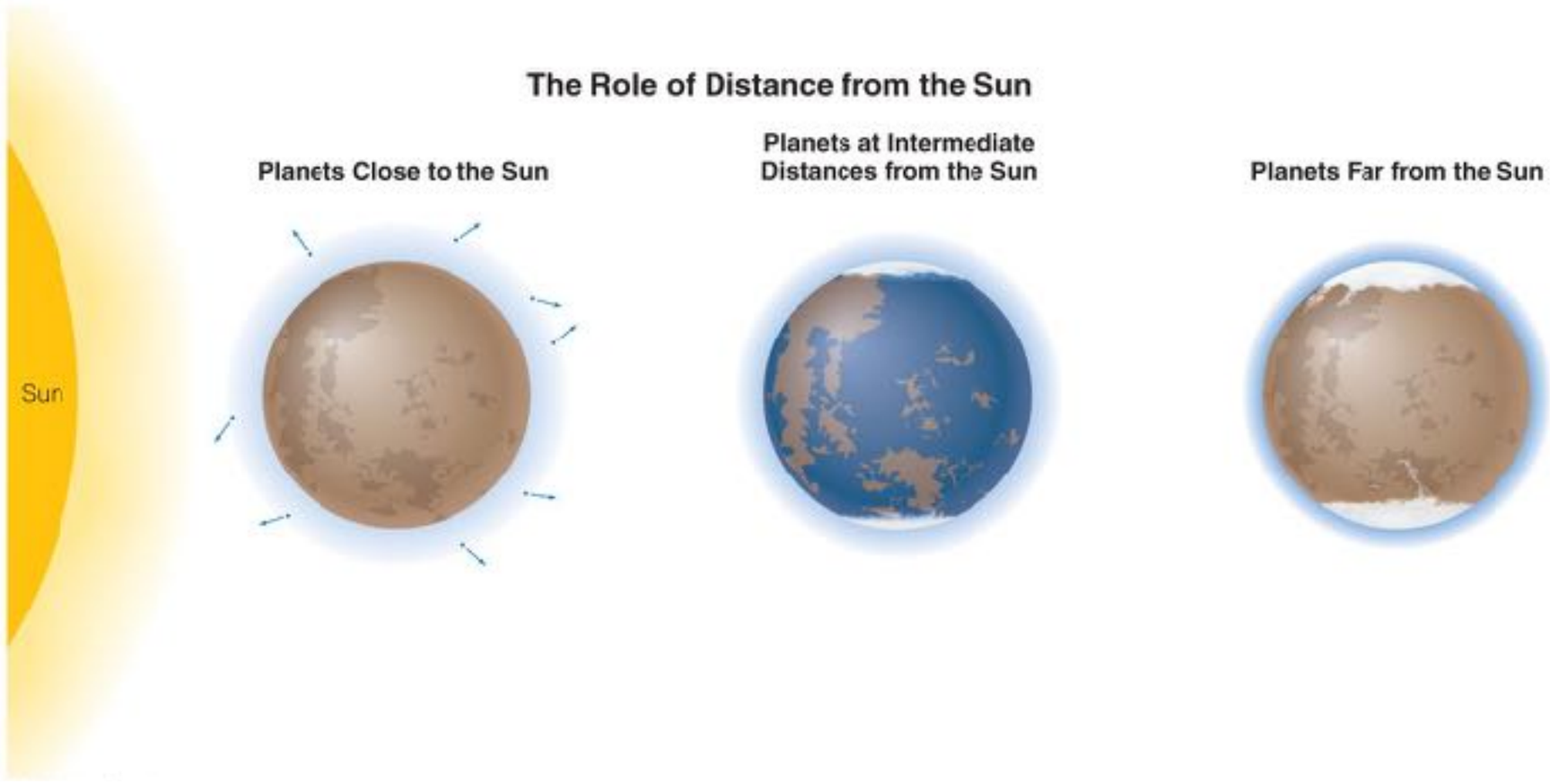
Role of Planetary Size





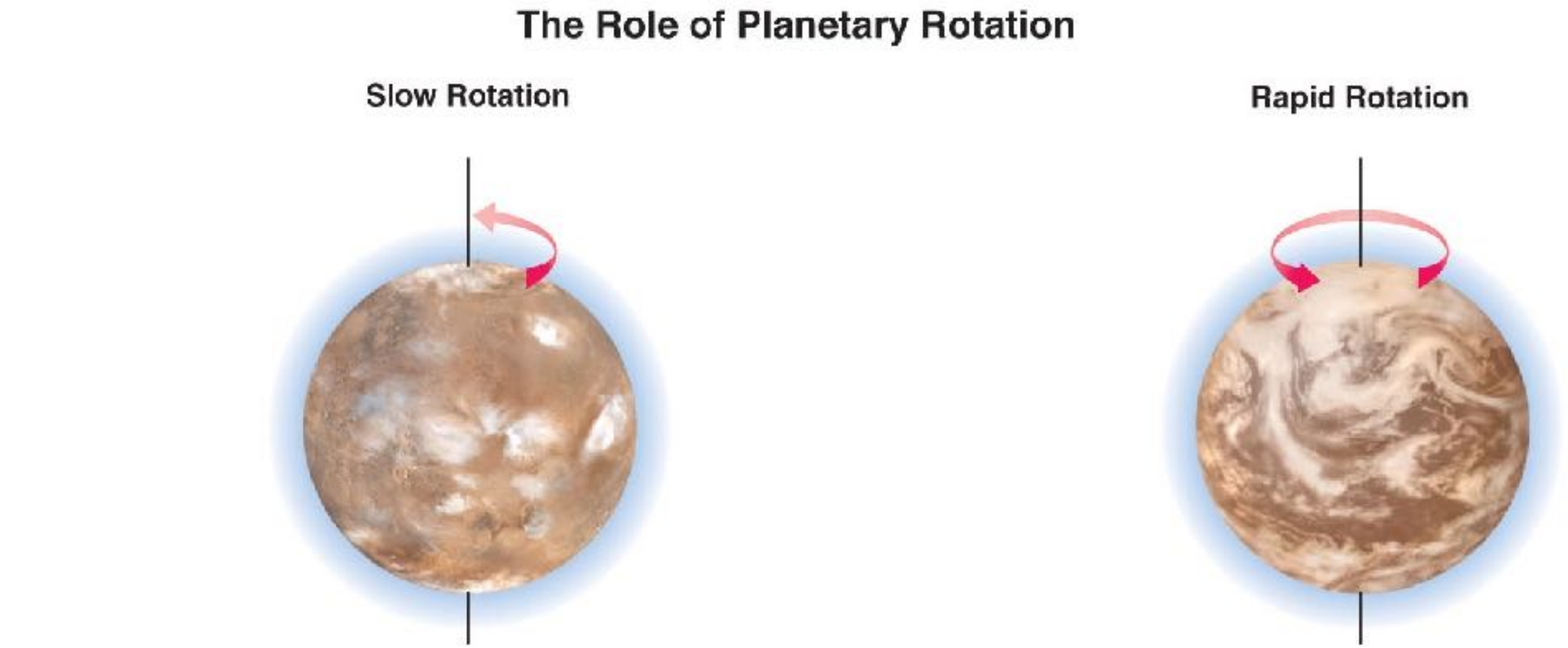
- Smaller worlds cool off faster and harden earlier.
- Larger worlds remain warm inside, promoting volcanism and tectonics.
- Larger worlds also have more erosion because their gravity retains an atmosphere.

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

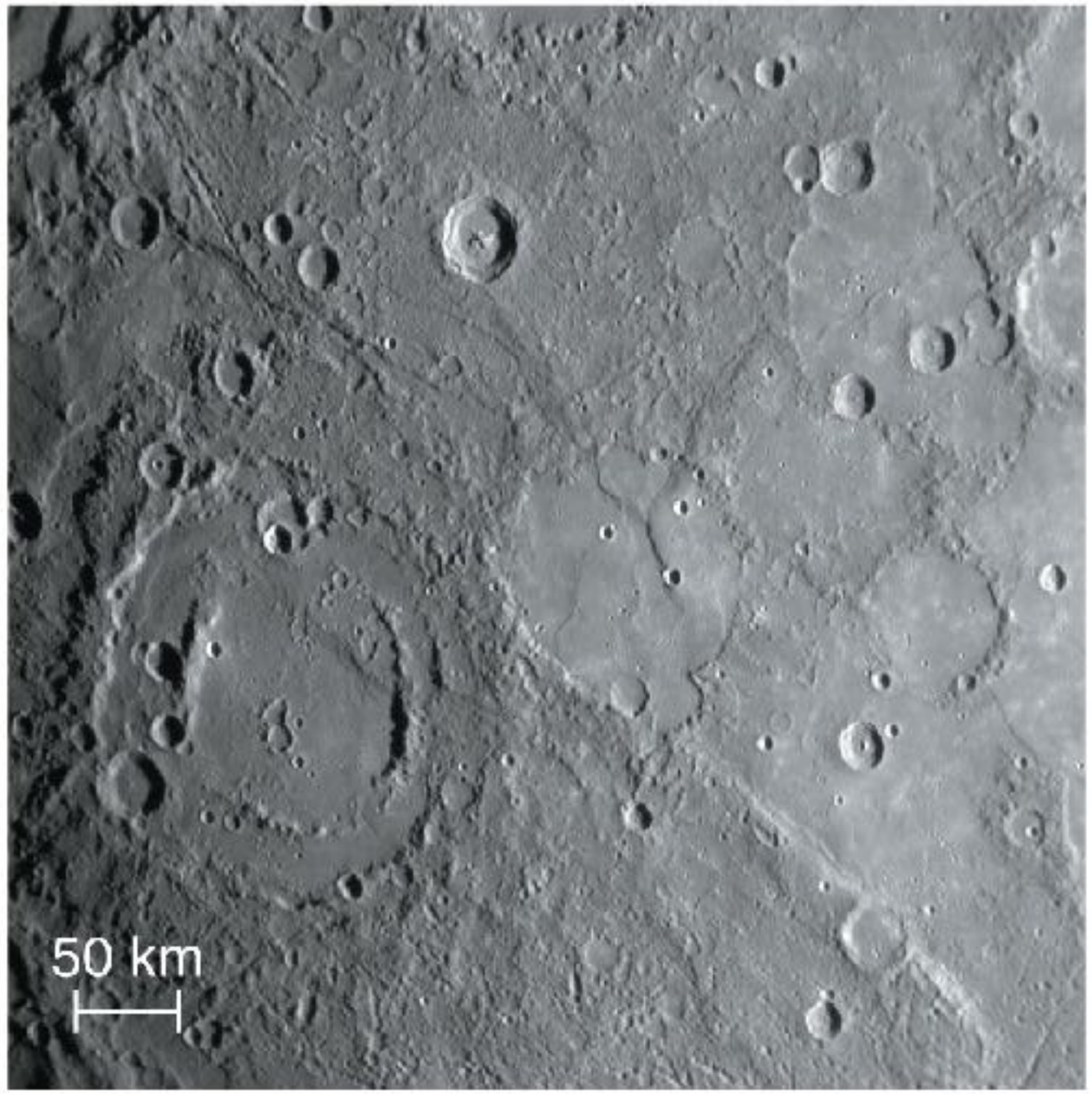


- Planets with slower rotation have less weather, less erosion, and a weak magnetic field.
- Planets with faster rotation have more weather, more erosion, and a stronger magnetic field.

Mercury

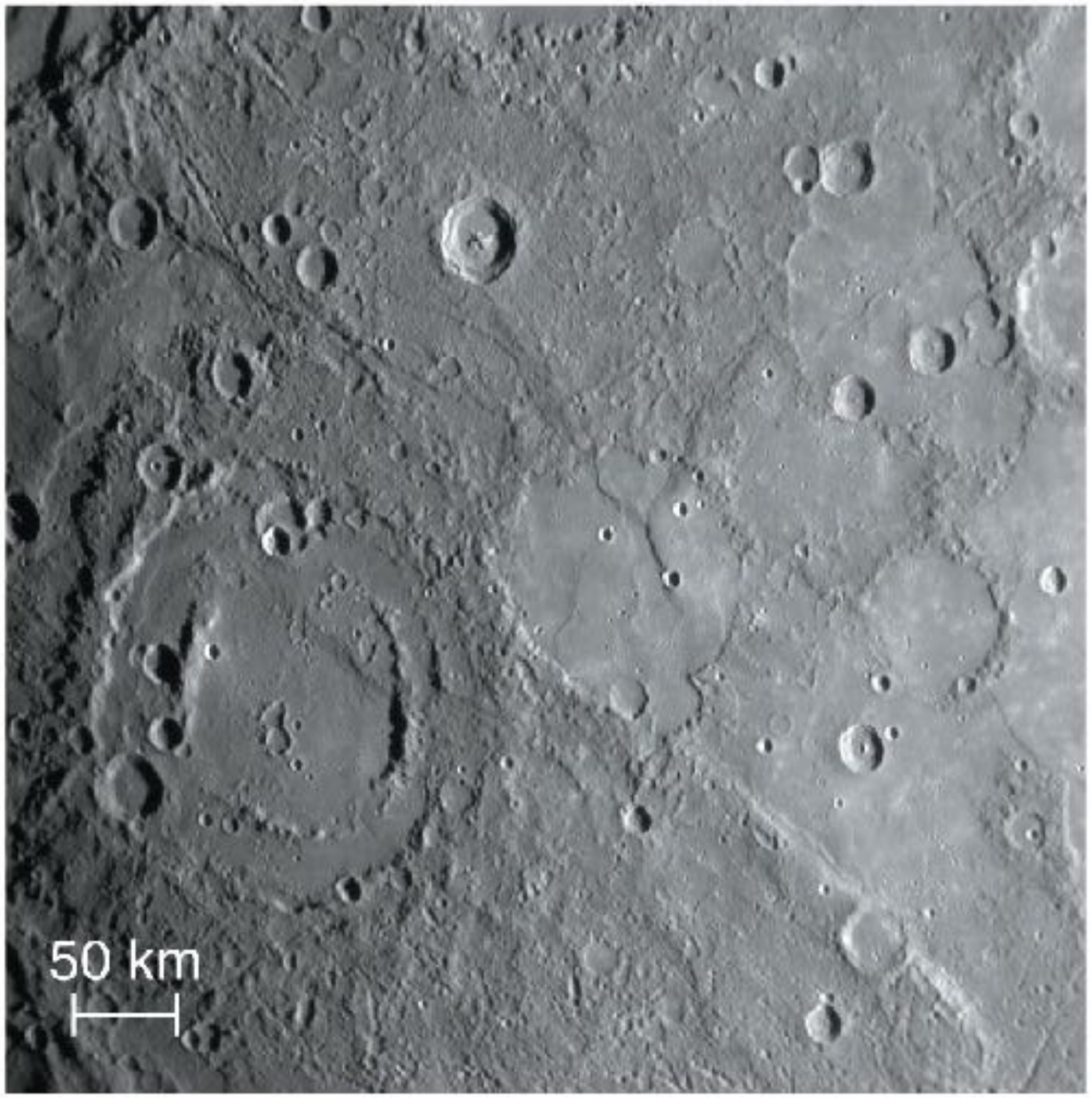
http://www.space.com/19920-mercury-color-video-messenger-spacecraft.html

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

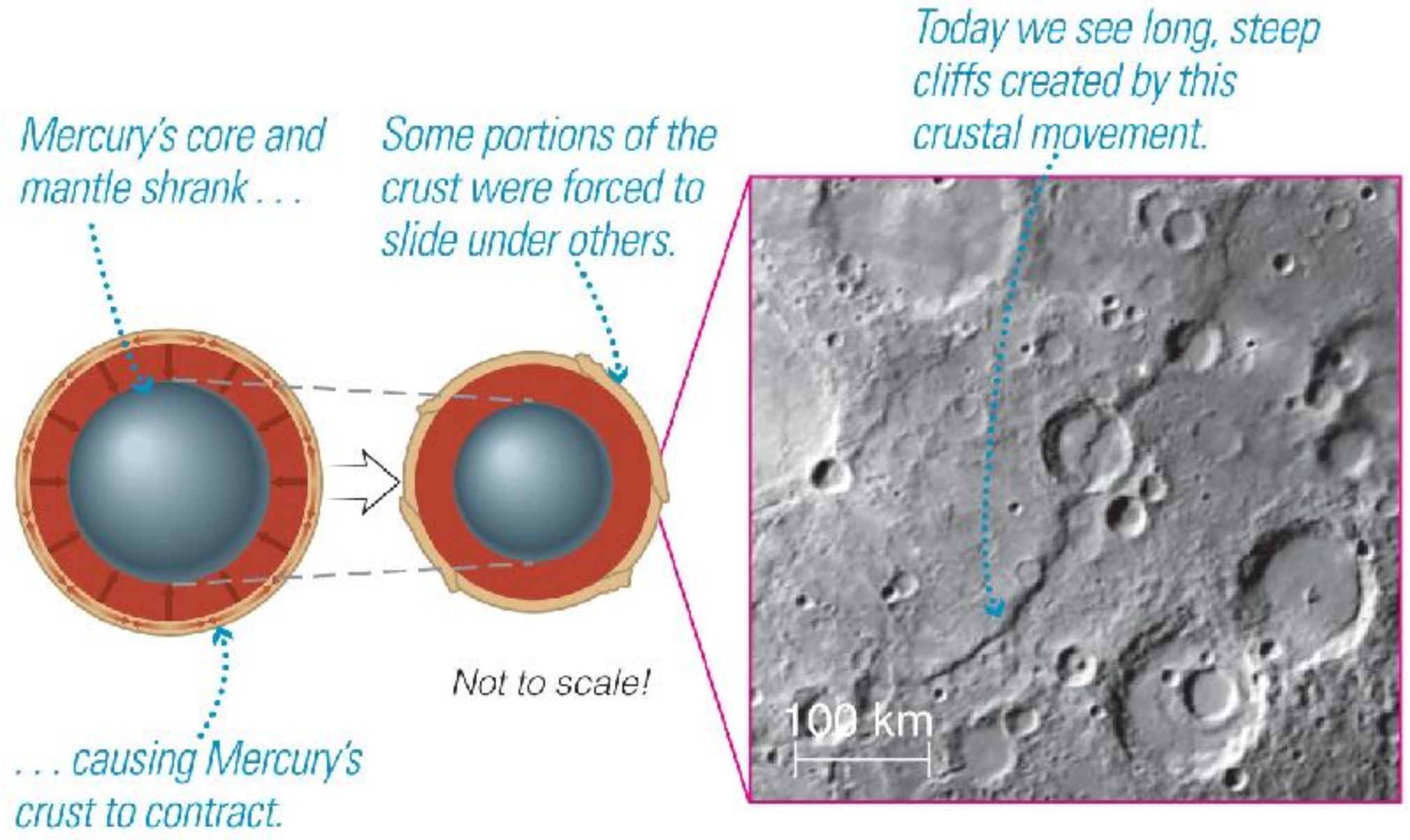
largest crater in Solar system

lava (orange)

older material (blue) sometimes excavated by later impact

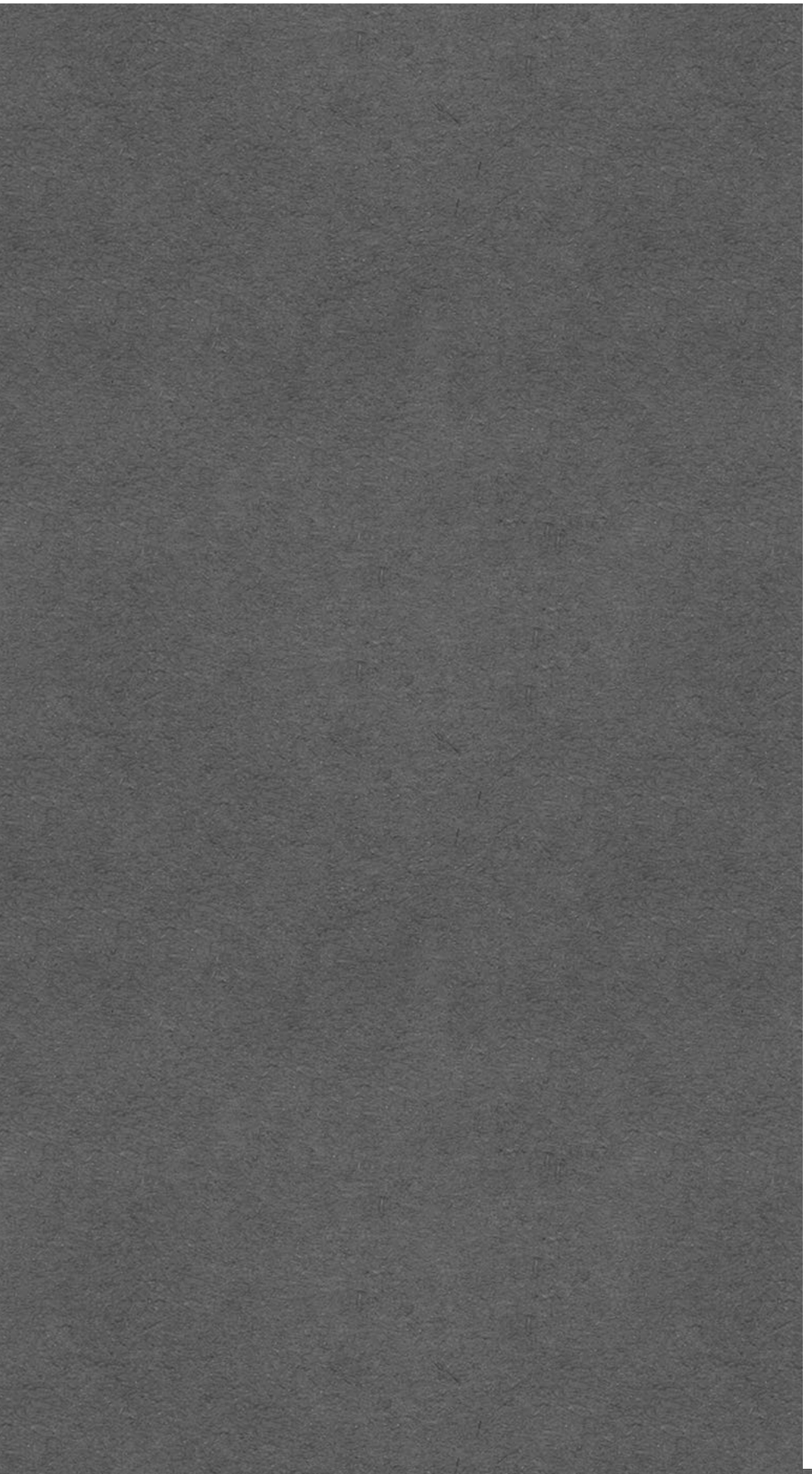
Tectonics on Mercury

Scarps



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

Scarp on Mercury, to scale



3 km

Surface gravity on Mercury: 3.7 m/s/s

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

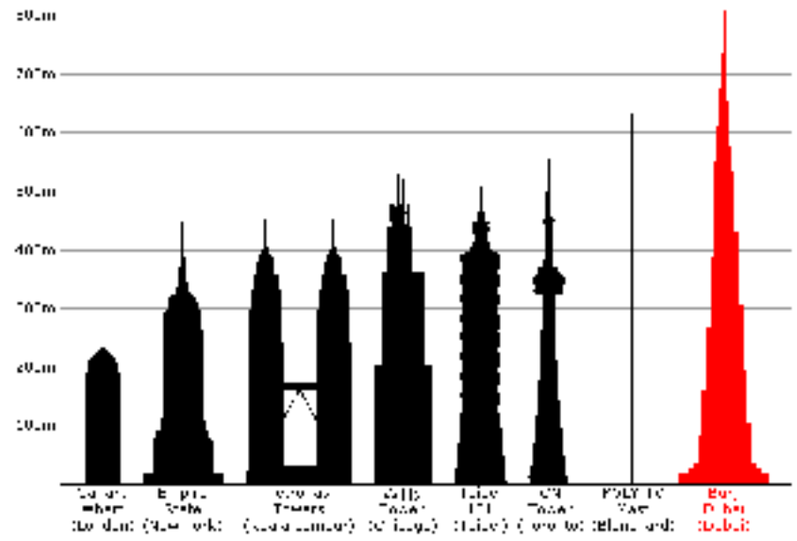
time to fall off scarp
t = 149 s (about 2 and a half minutes)

velocity on impact

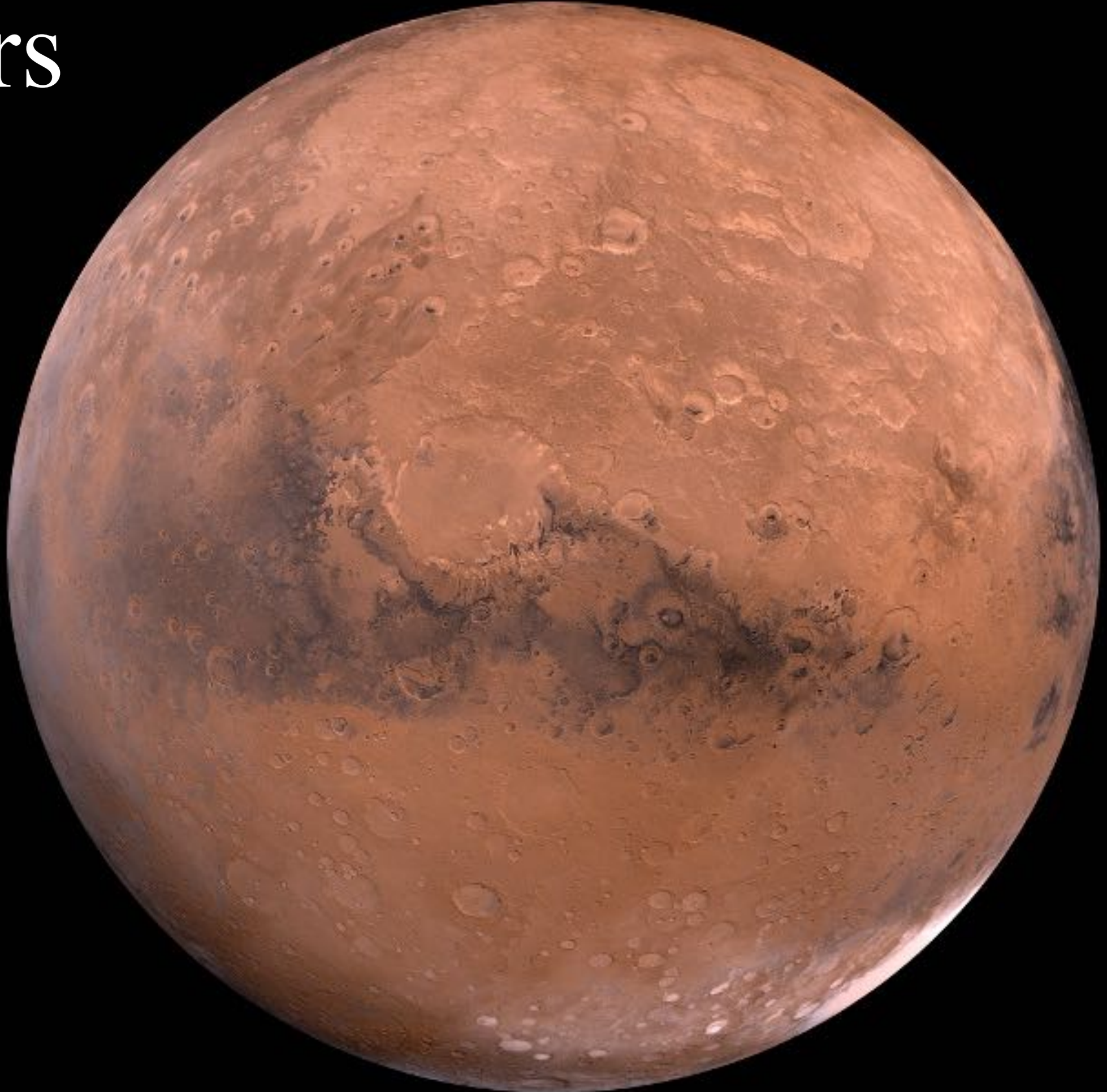
$$v = at = (3.7\ \mathrm{m\,s^{-2}})(149\ \mathrm{s})$$

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

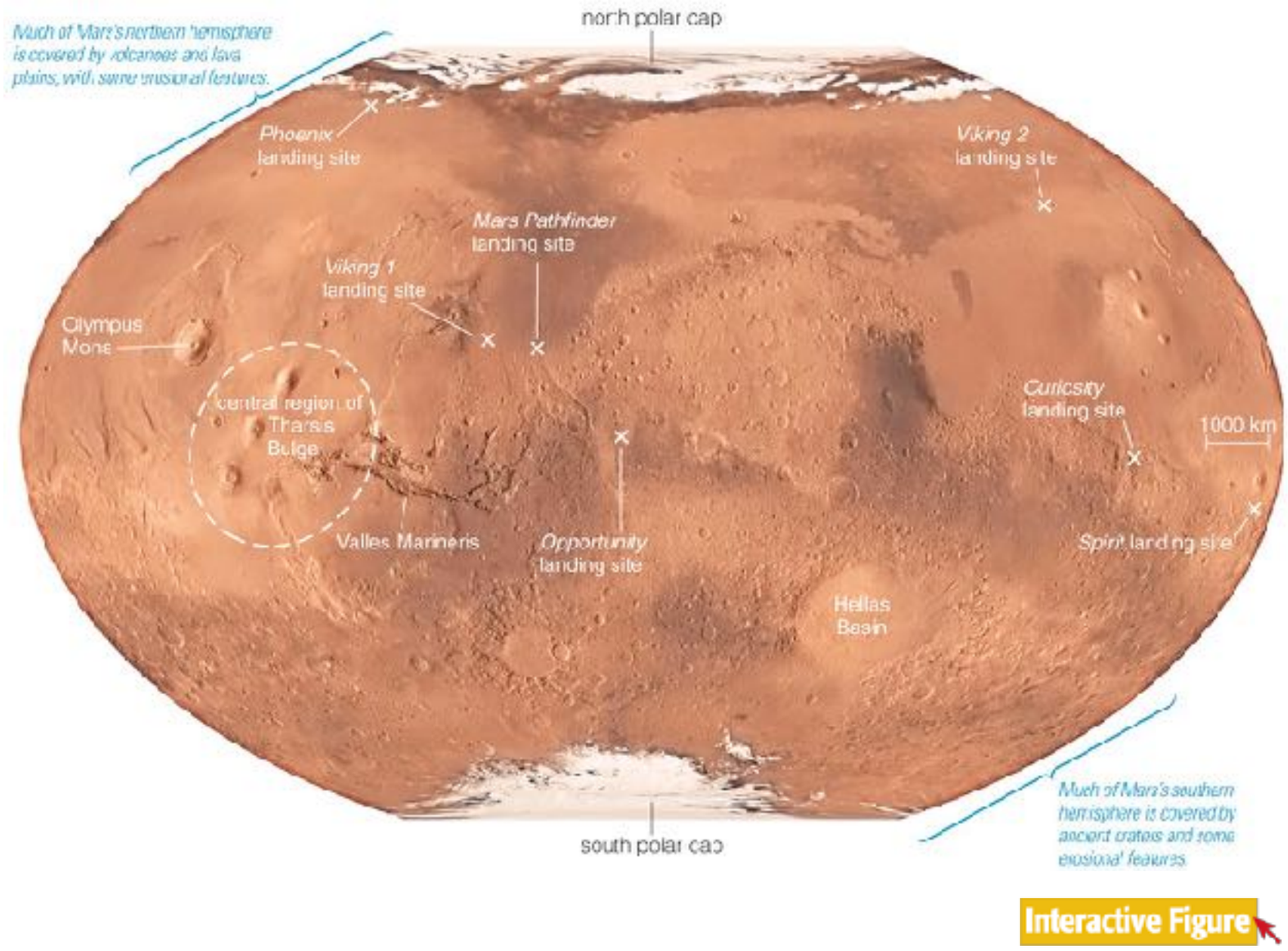
(1,233 mph)



Mars



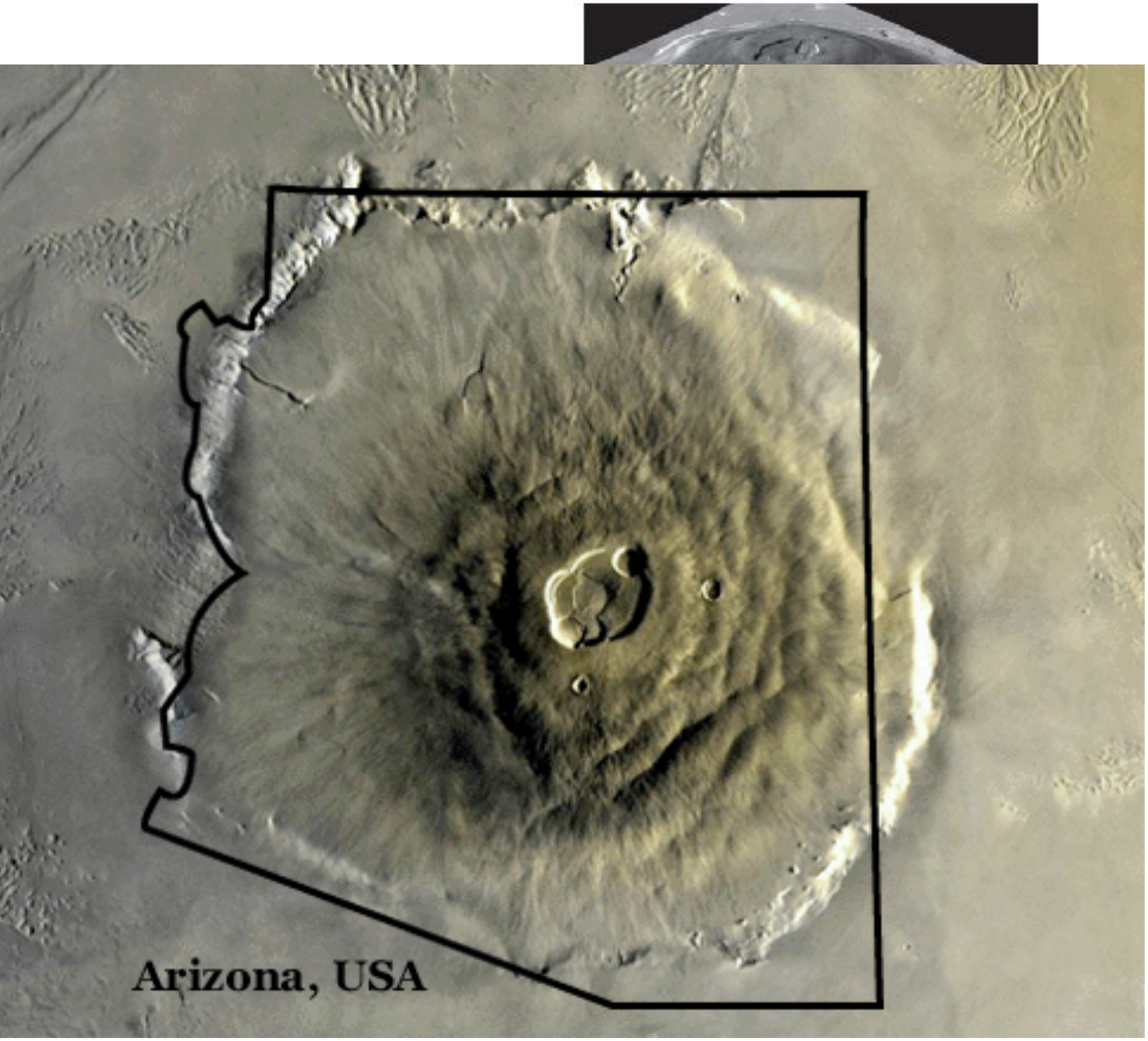
Cratering on Mars



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

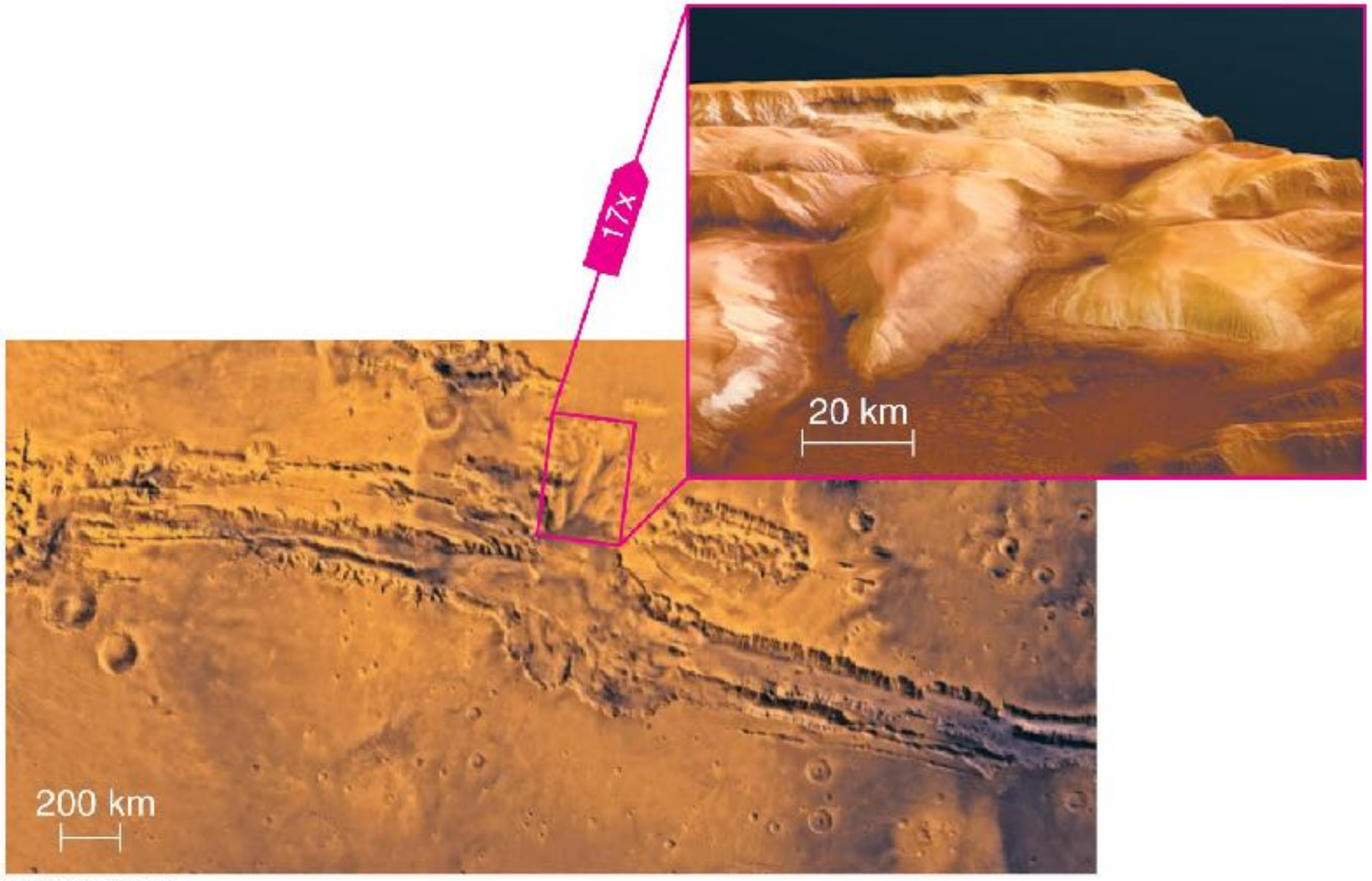
IF_09_25_MarsFeatures

Volcanism on Mars



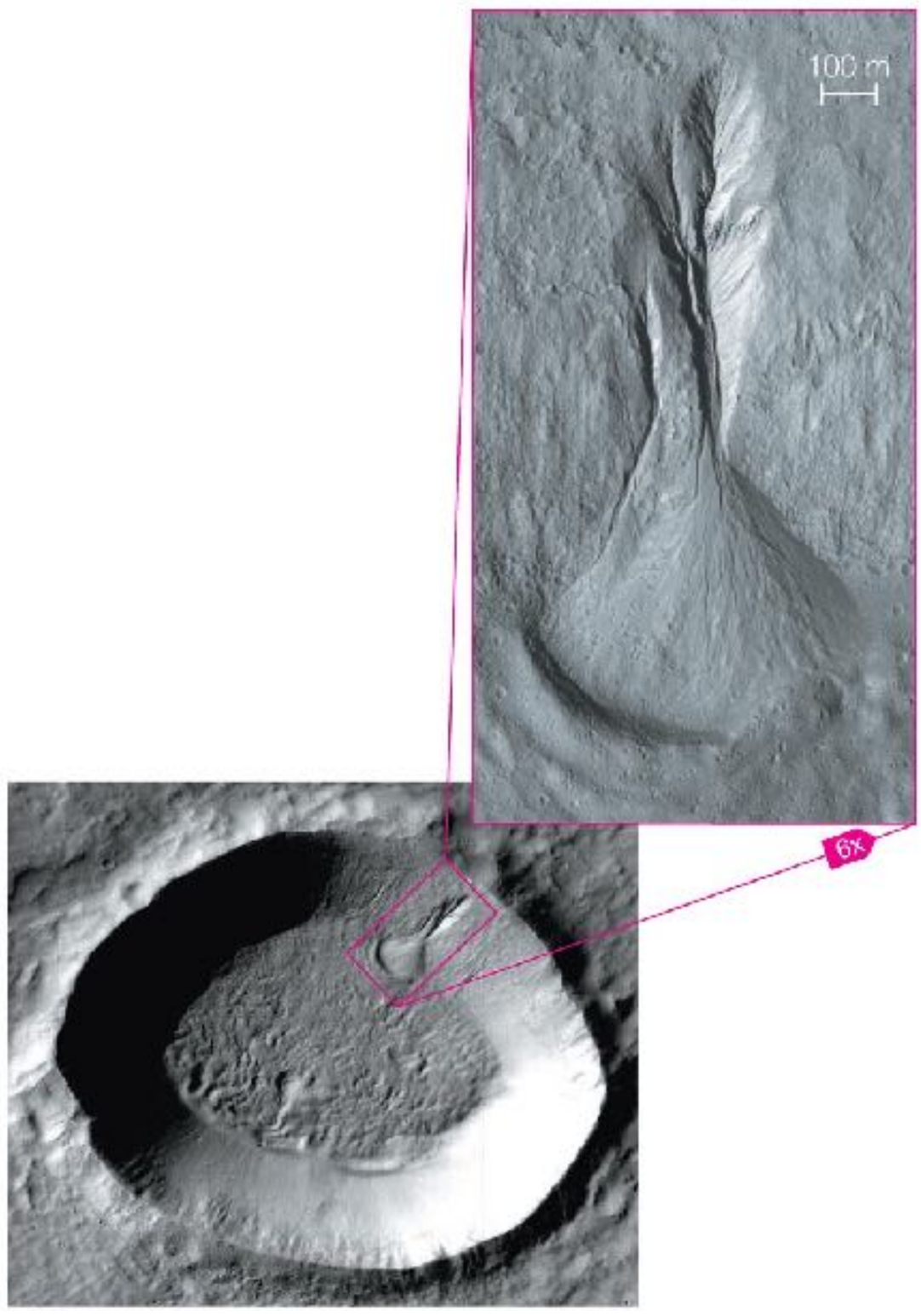
- Mars has many large shield volcanoes.
- Olympus Mons is largest volcano in solar system.

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?

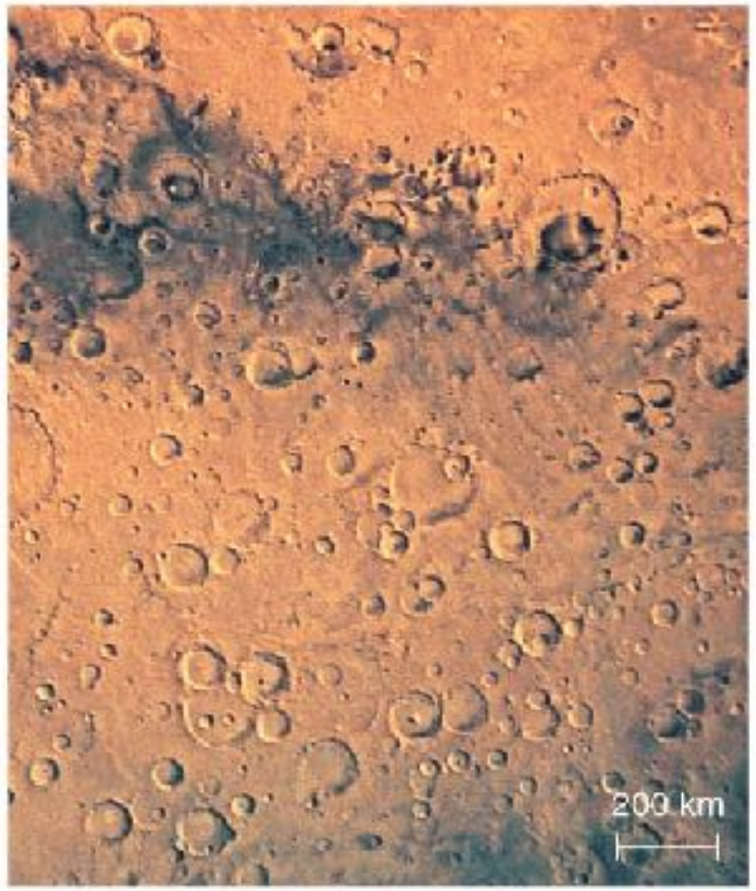


Dry Riverbeds?

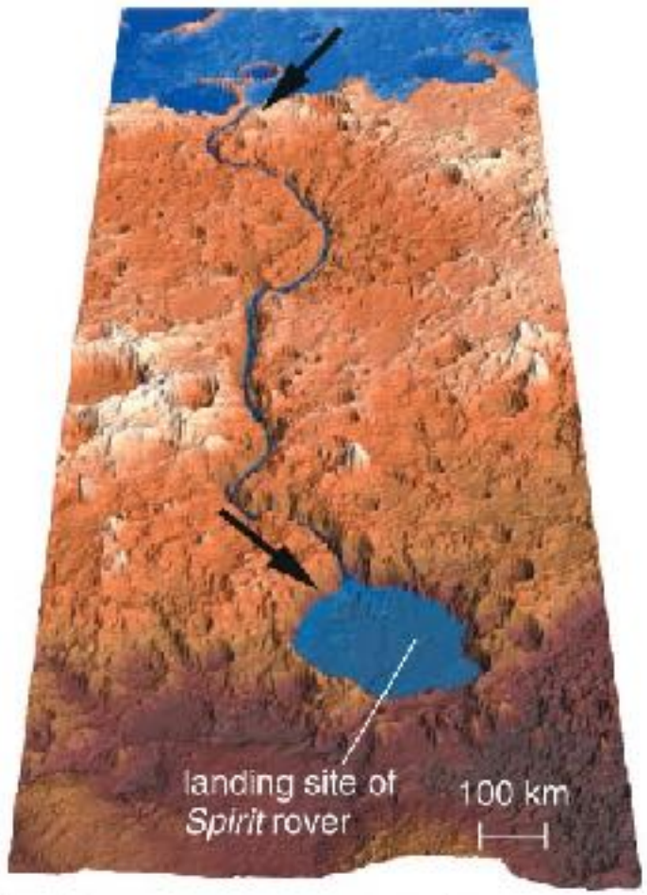
- Close-up photos of Mars show what appear to be dried-up riverbeds.

Erosion of Craters

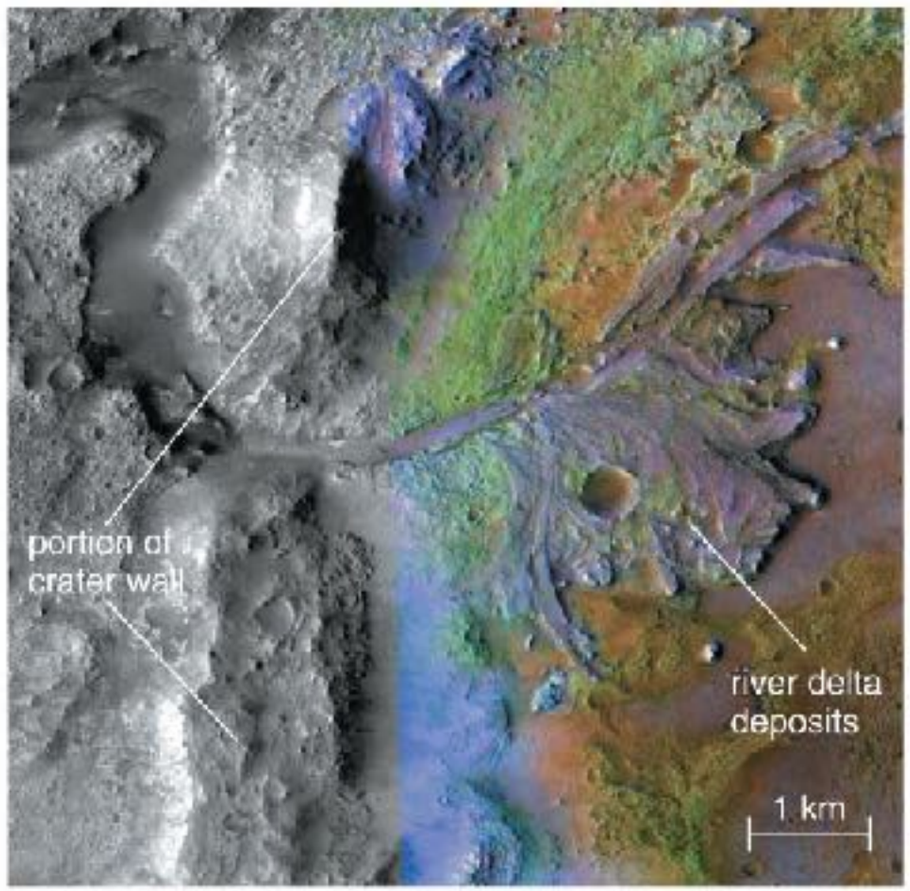
- Details of some craters suggest they were once filled with water.



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.

Rovers photoshopped together for scale

Spirit & Opportunity (2004)

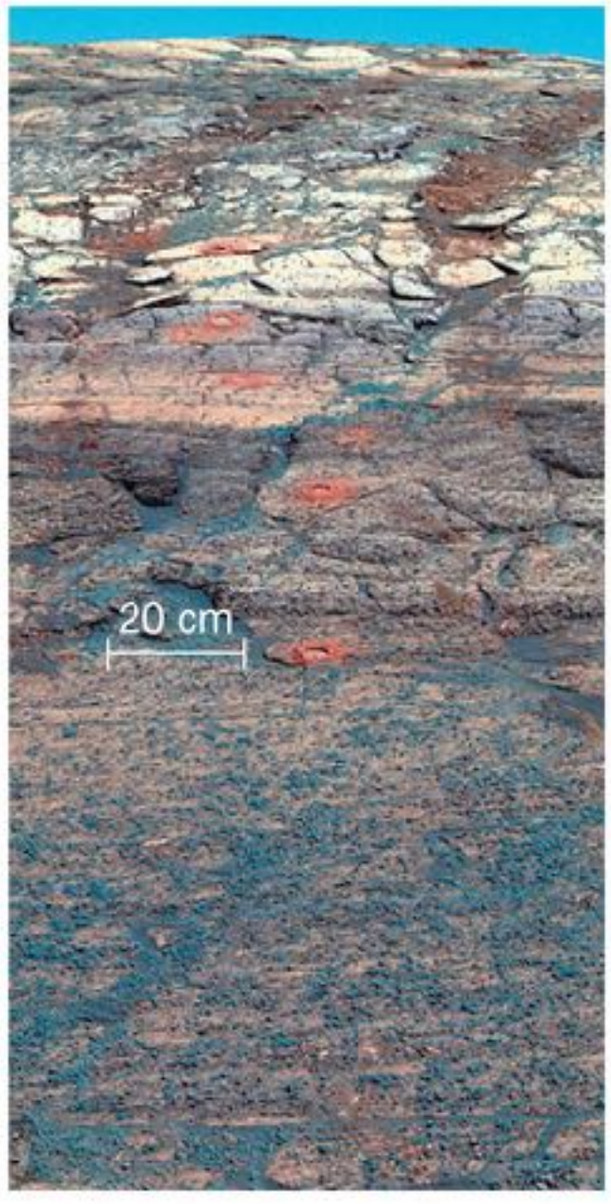
Curiosity (2012)

Pathfinder (1997)

https://www.youtube.com/watch?v=5-cBjl2zgB0

Pathfinder landing video

Martian Rocks



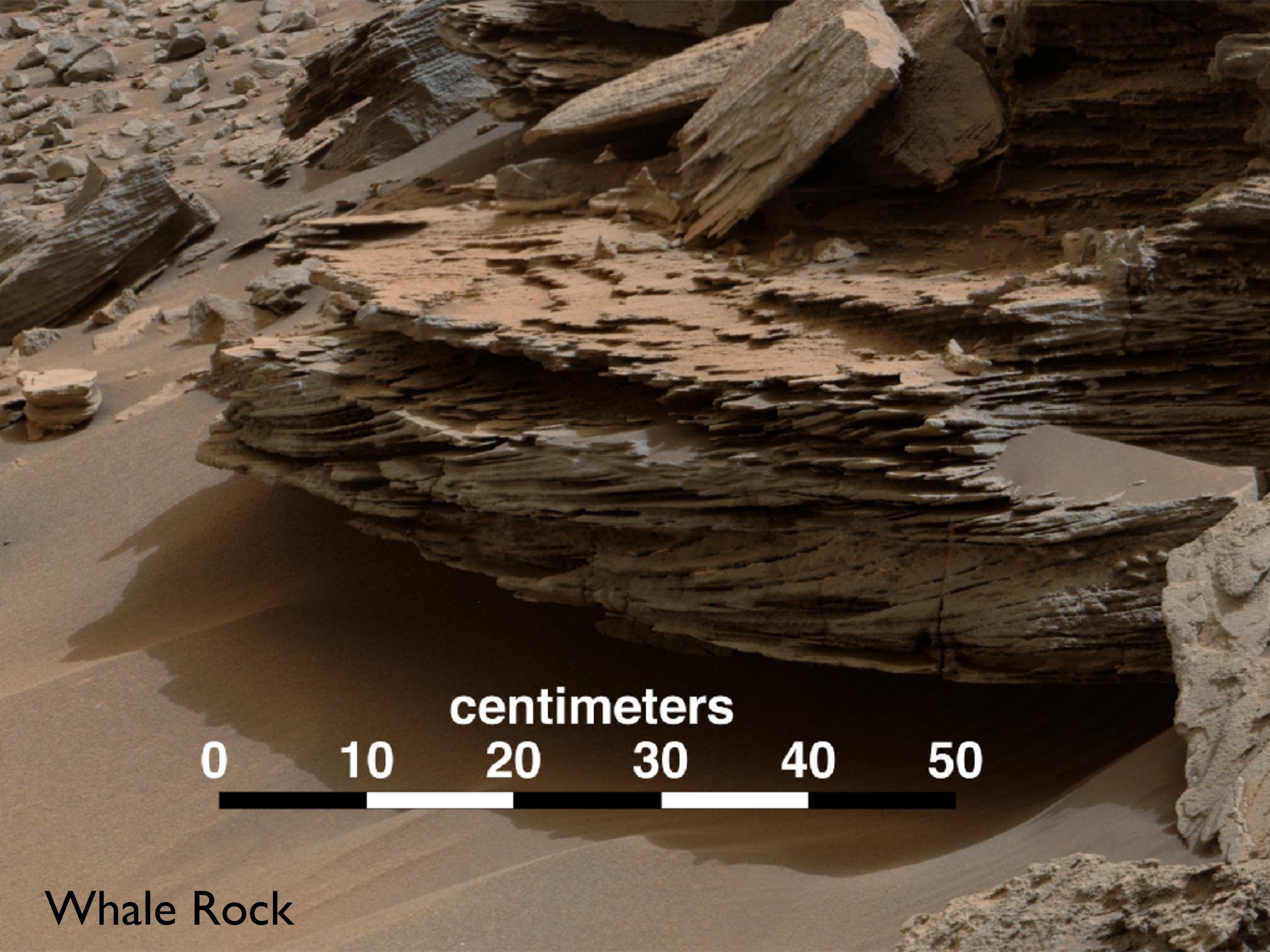
Mars (Endurance Crater)

Earth (Utah)

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

Martian Rocks

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



Whale Rock

Hydrogen Content

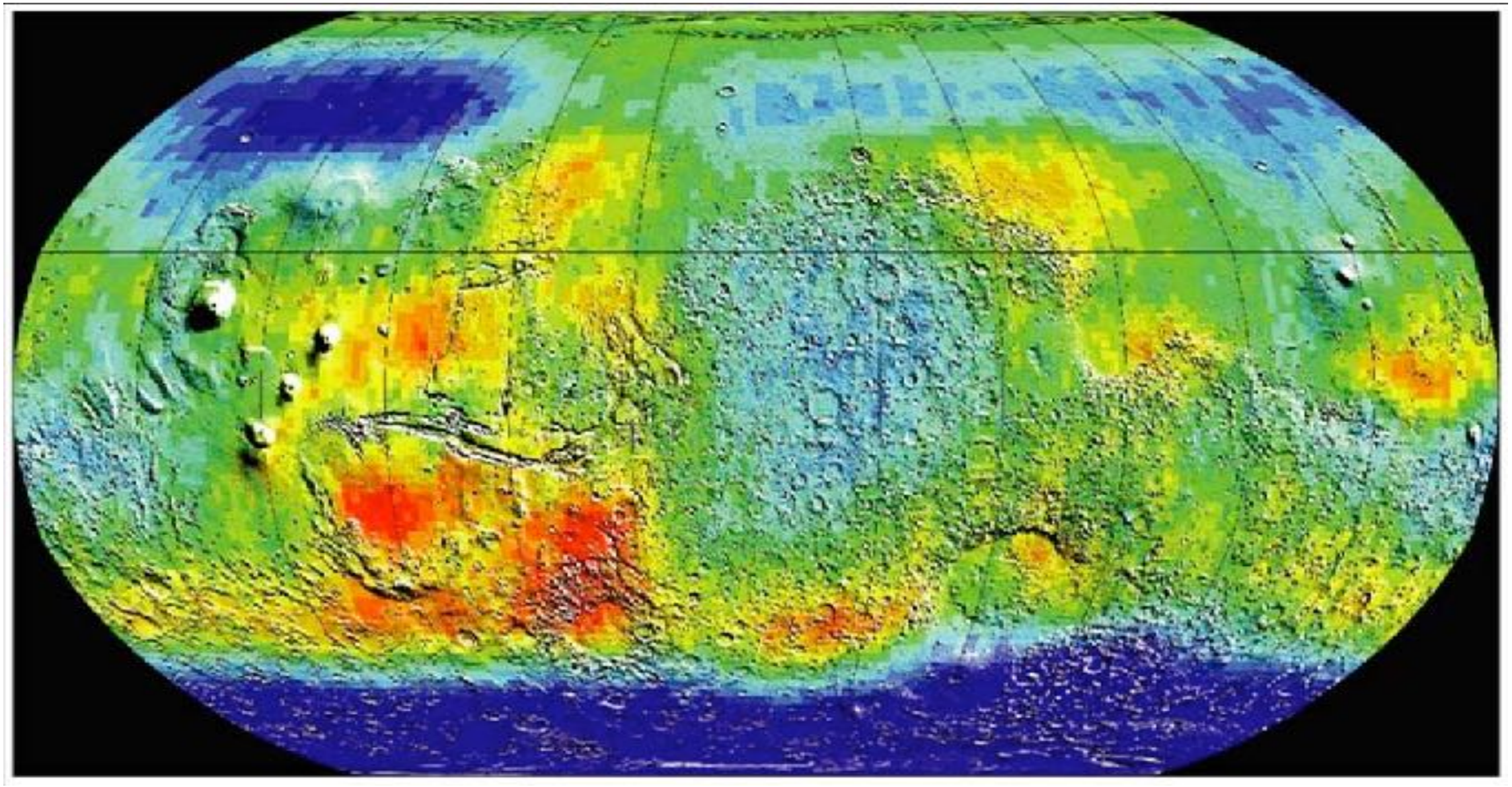


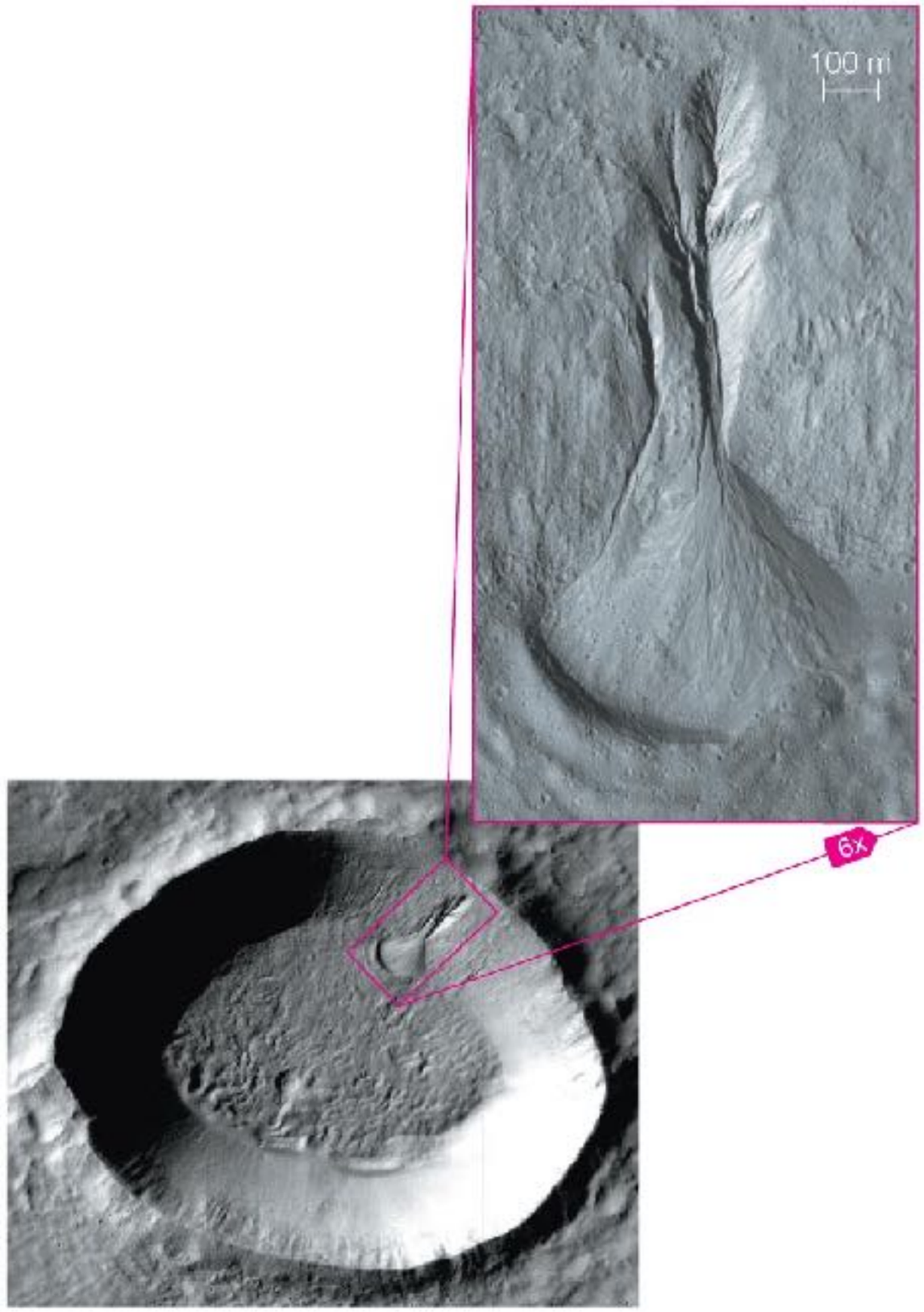
Image Credit: NASA/JPL

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

Crater Walls

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

- or, like, now

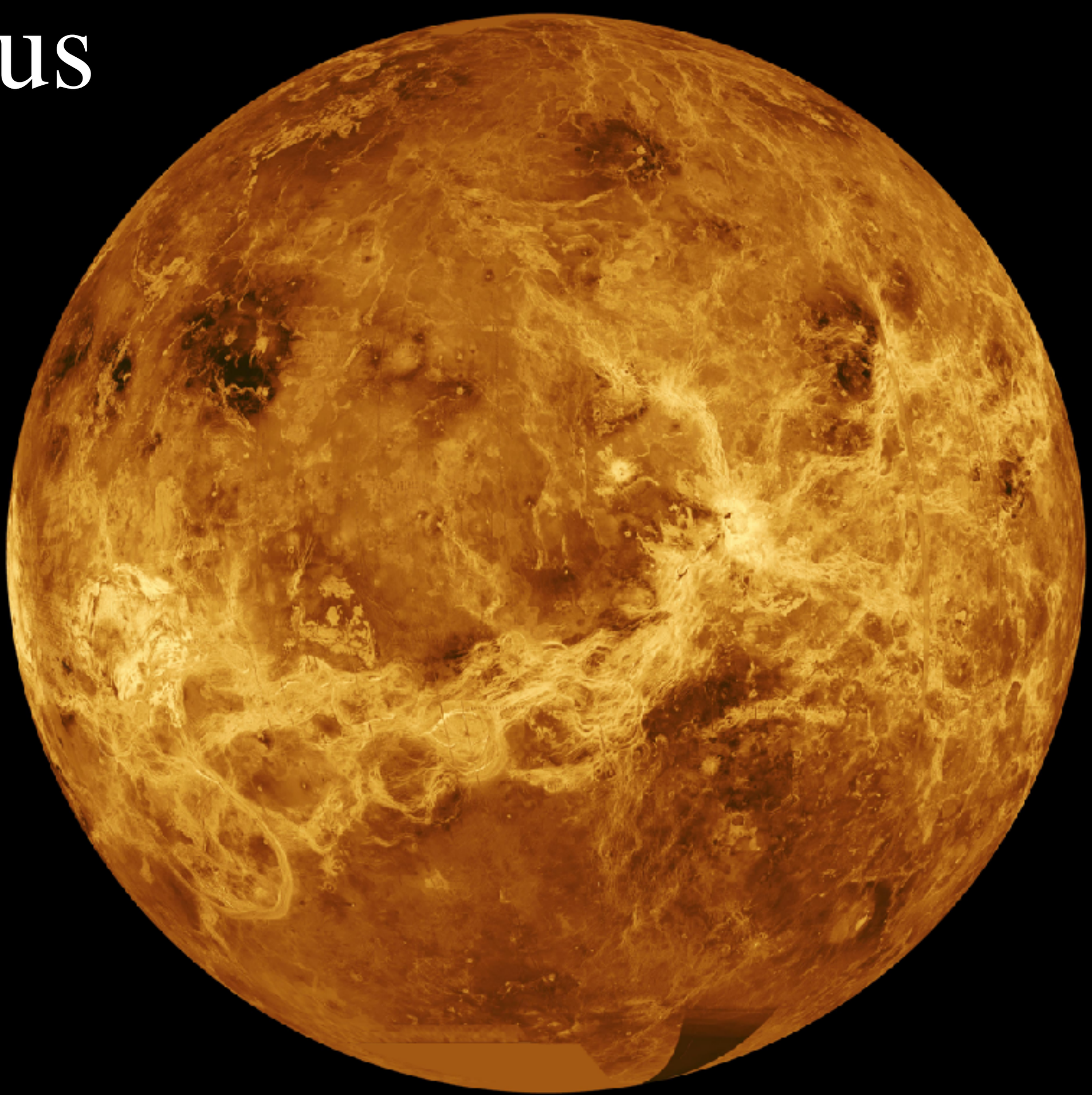


https://static01.nyt.com/newsgraphics/2015/09/28/mars-water/d910b431eb0ab62d9a5542dd1c10f5373df35383/images/flows.gif

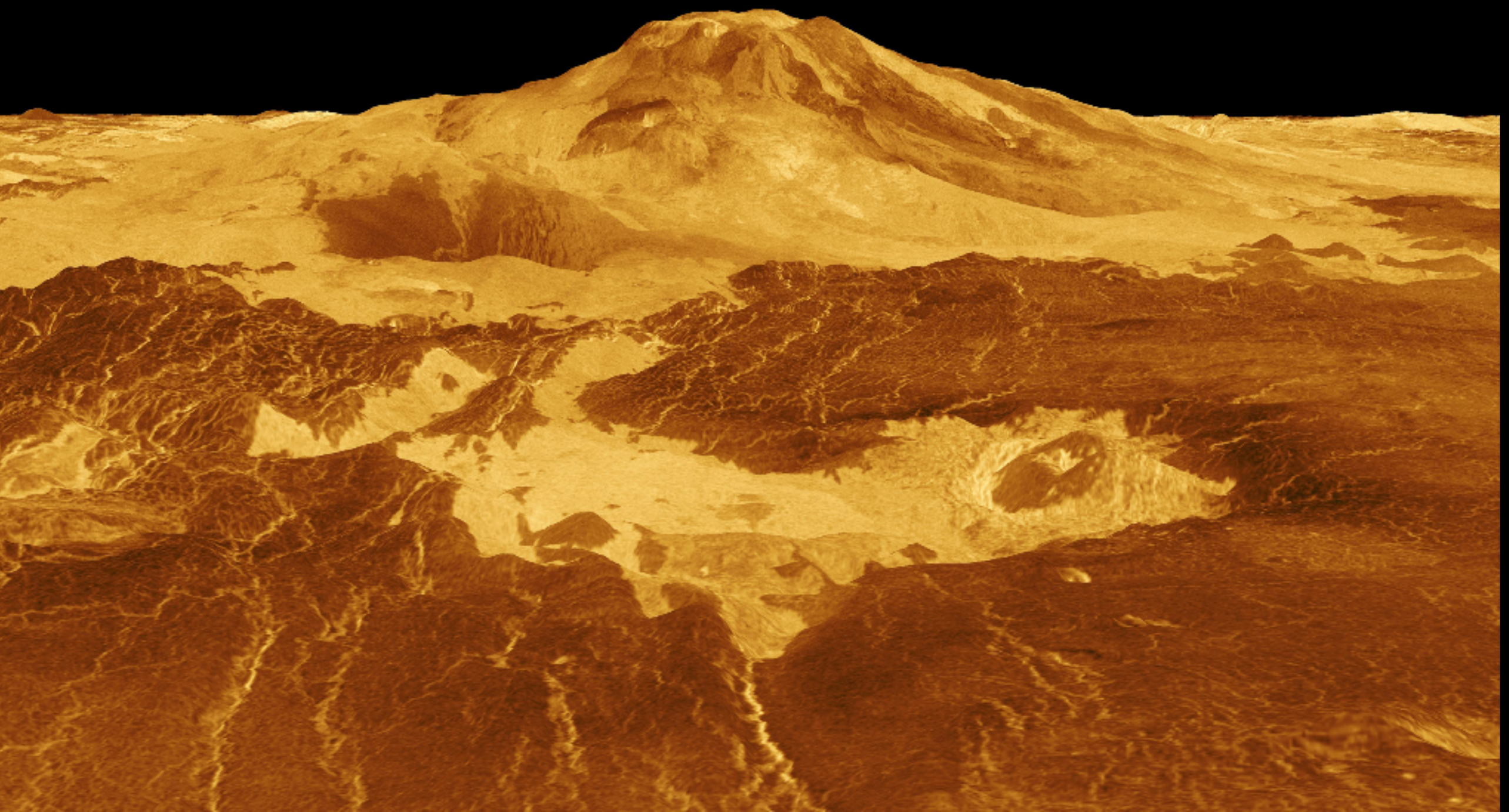
- Major geological features of Mars
  - Differences in cratering across surface
  - Giant shield volcanoes
  - Evidence of tectonic activity
- Evidence that water once flowed on Mars
  - Some surface features look like dry riverbeds.
  - Some craters appear to be eroded.
  - Rovers have found rocks composed of minerals that form in water.
  - Gullies in crater walls may indicate recent water flows.

https://www.nasa.gov/mission_pages/msl/images/index.html

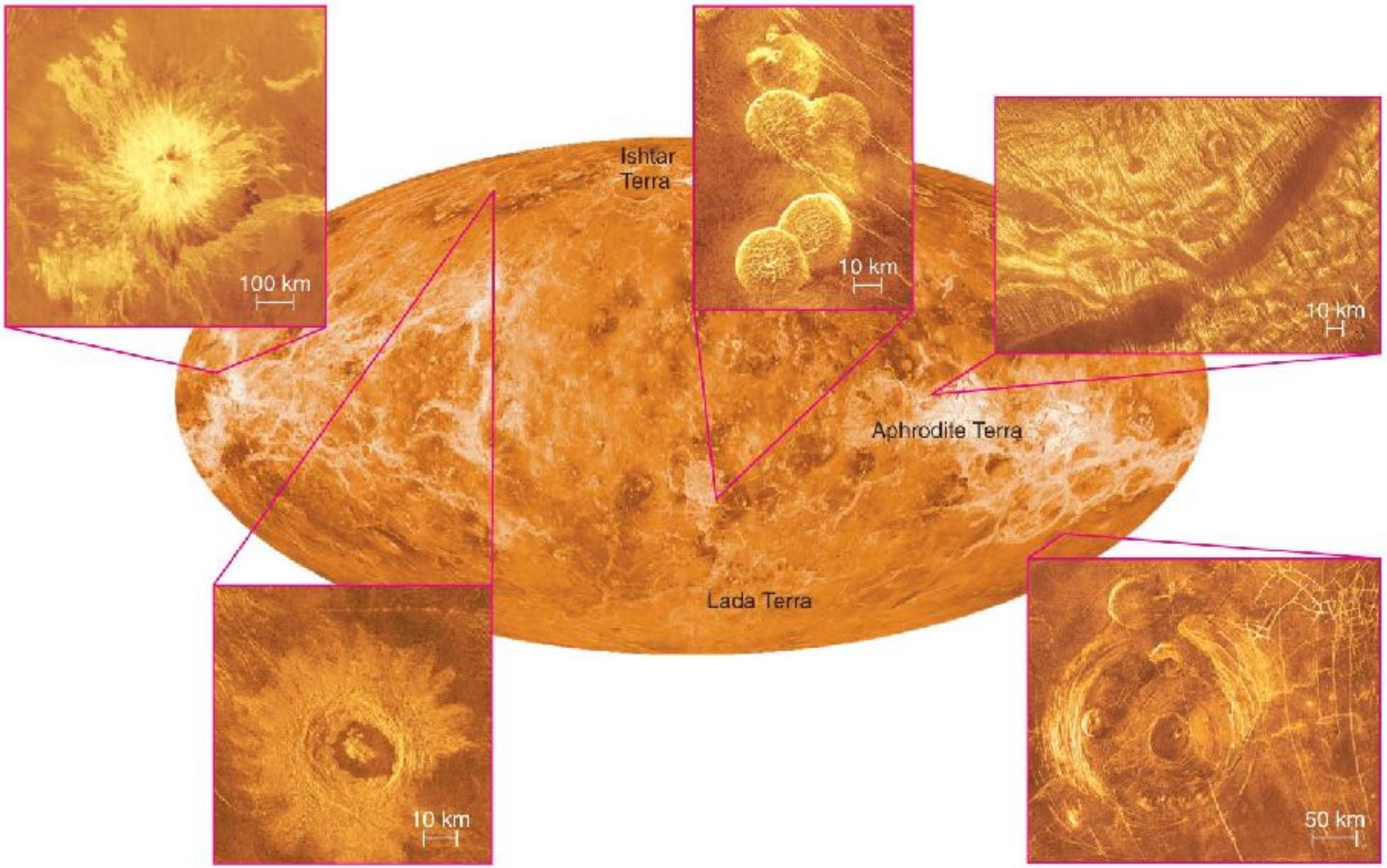
Venus



- Surface mapped by radar to penetrate thick clouds
- Magellan orbiter (1990 - 1994)
  - burned up in atmosphere

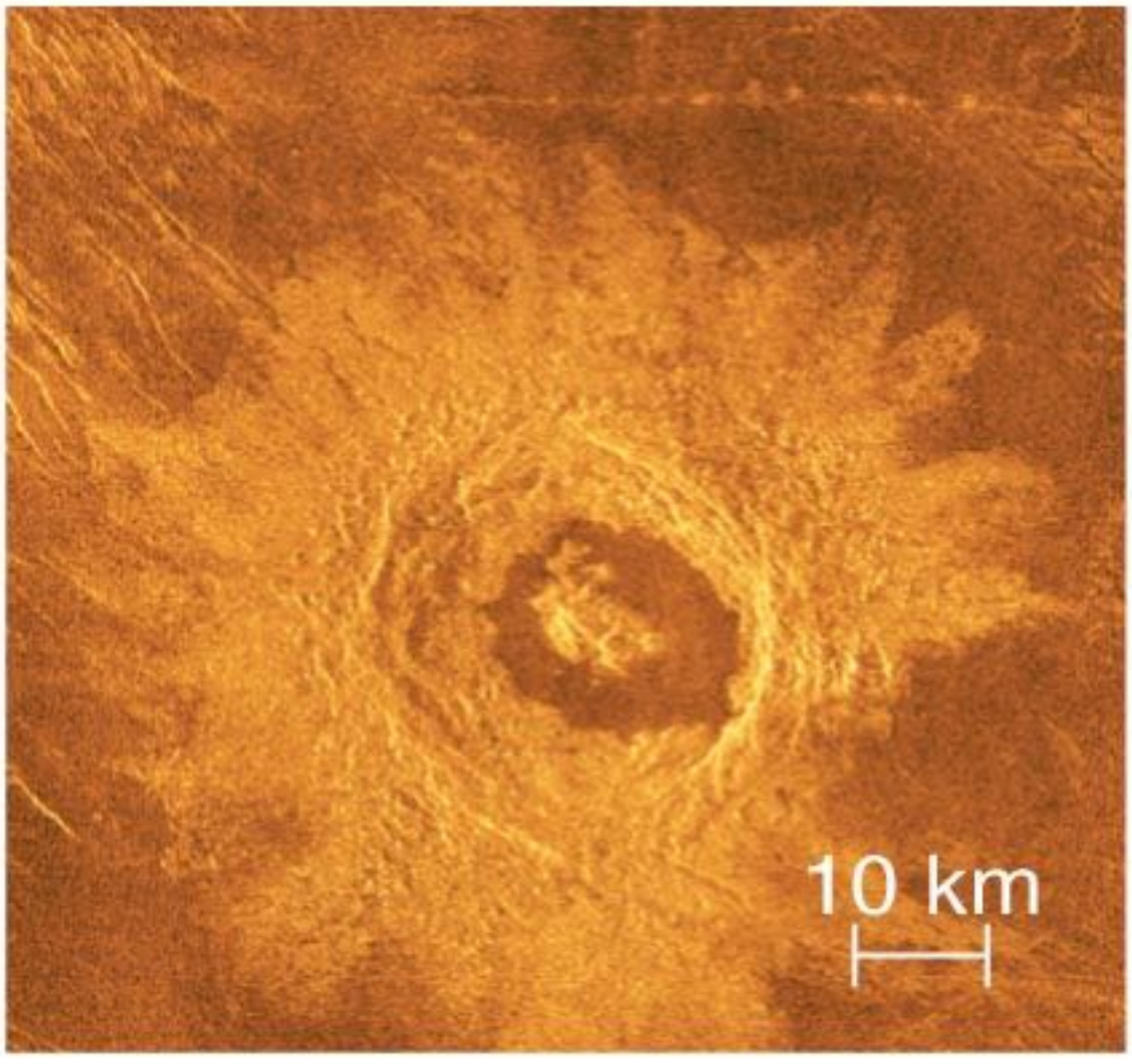


What geological processes have shaped Venus?



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

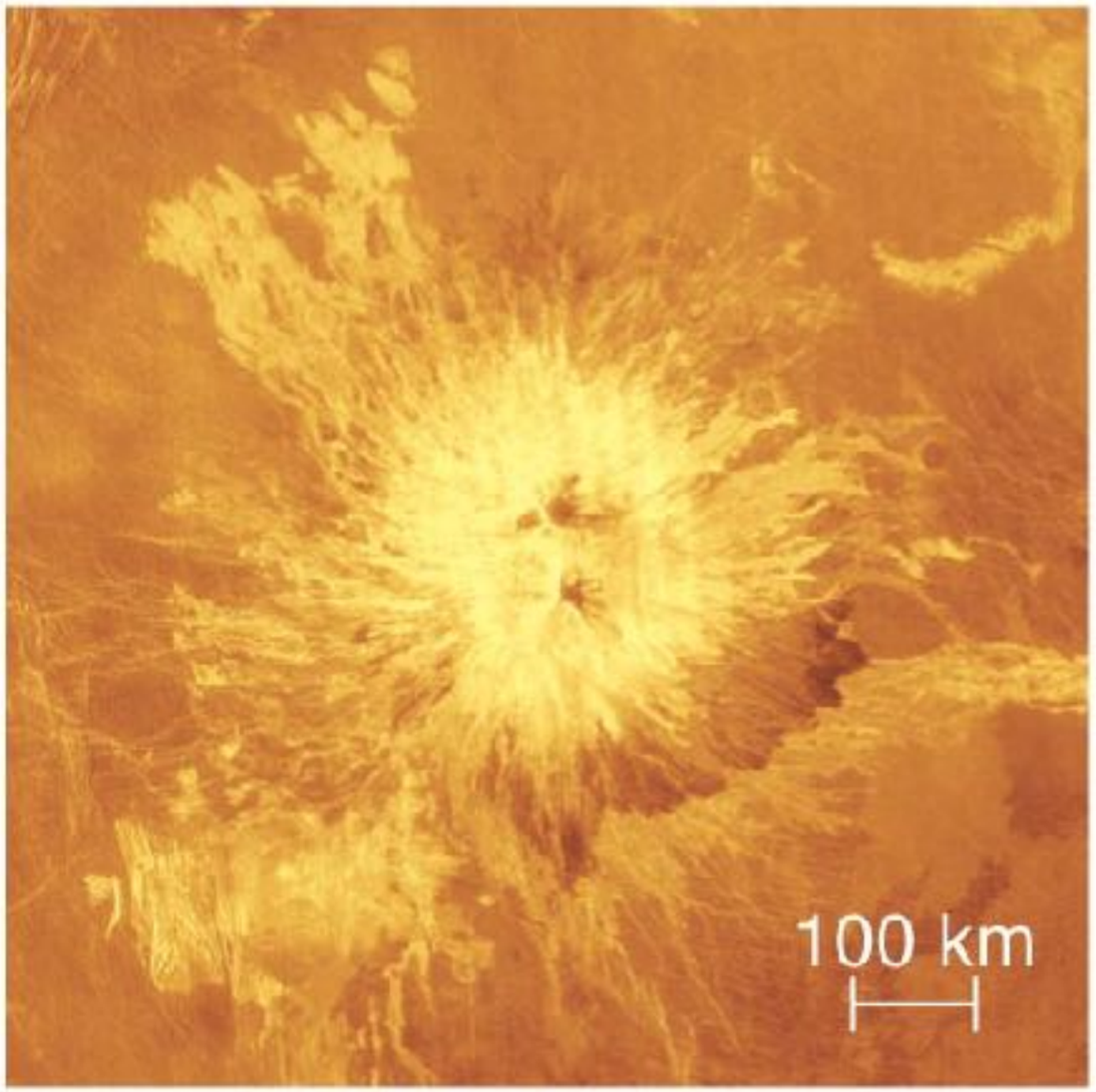
Cratering on Venus



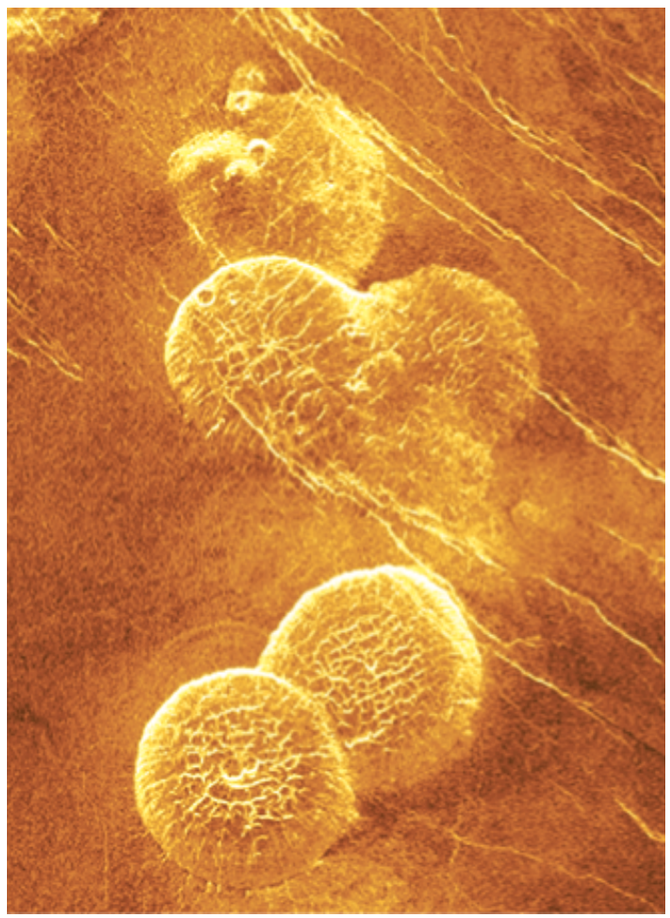
- Venus has impact craters, but fewer than the Moon, Mercury, or Mars.

- Mostly large craters
  - shielded from small impactors by thick atmosphere

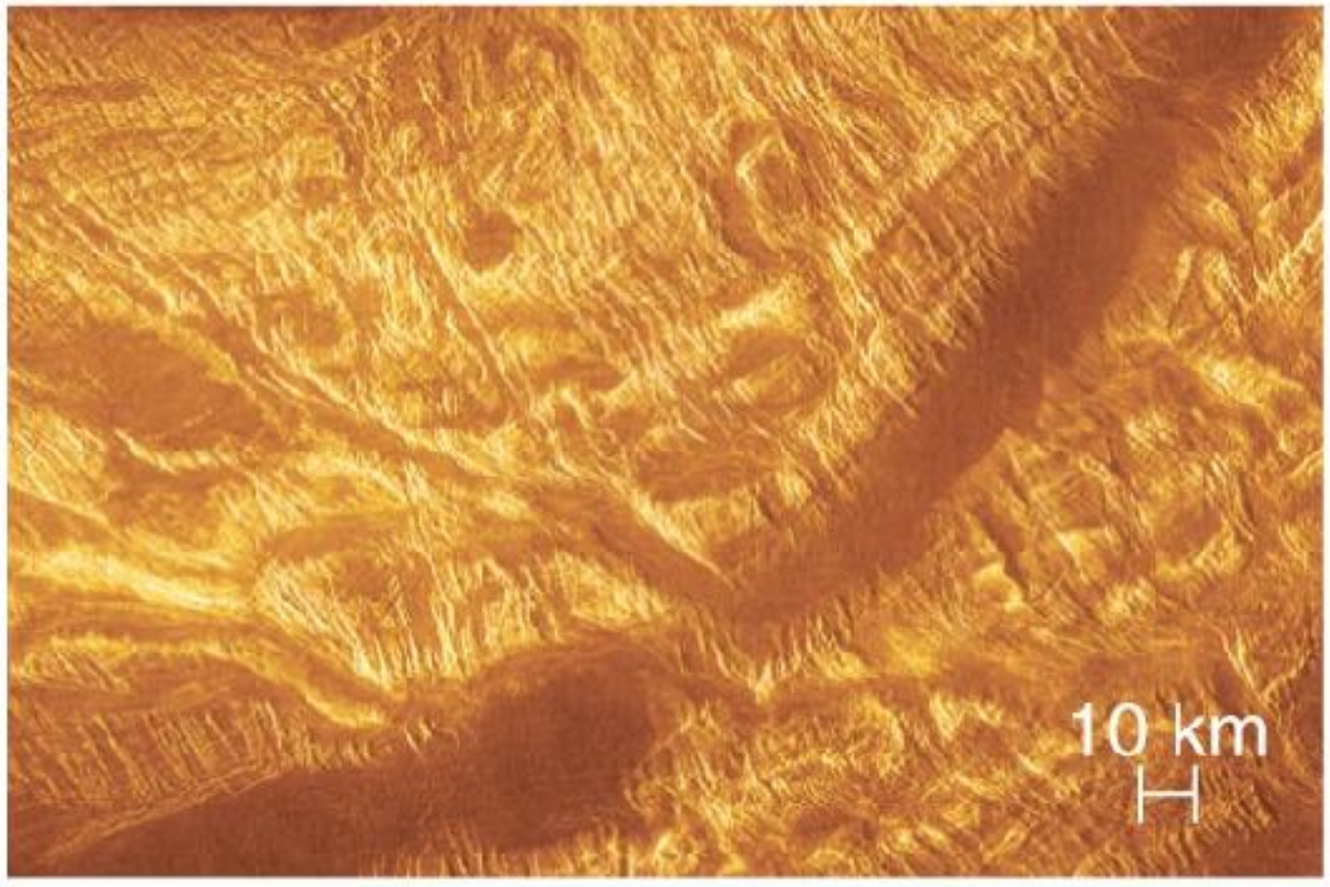
Volcanoes on Venus



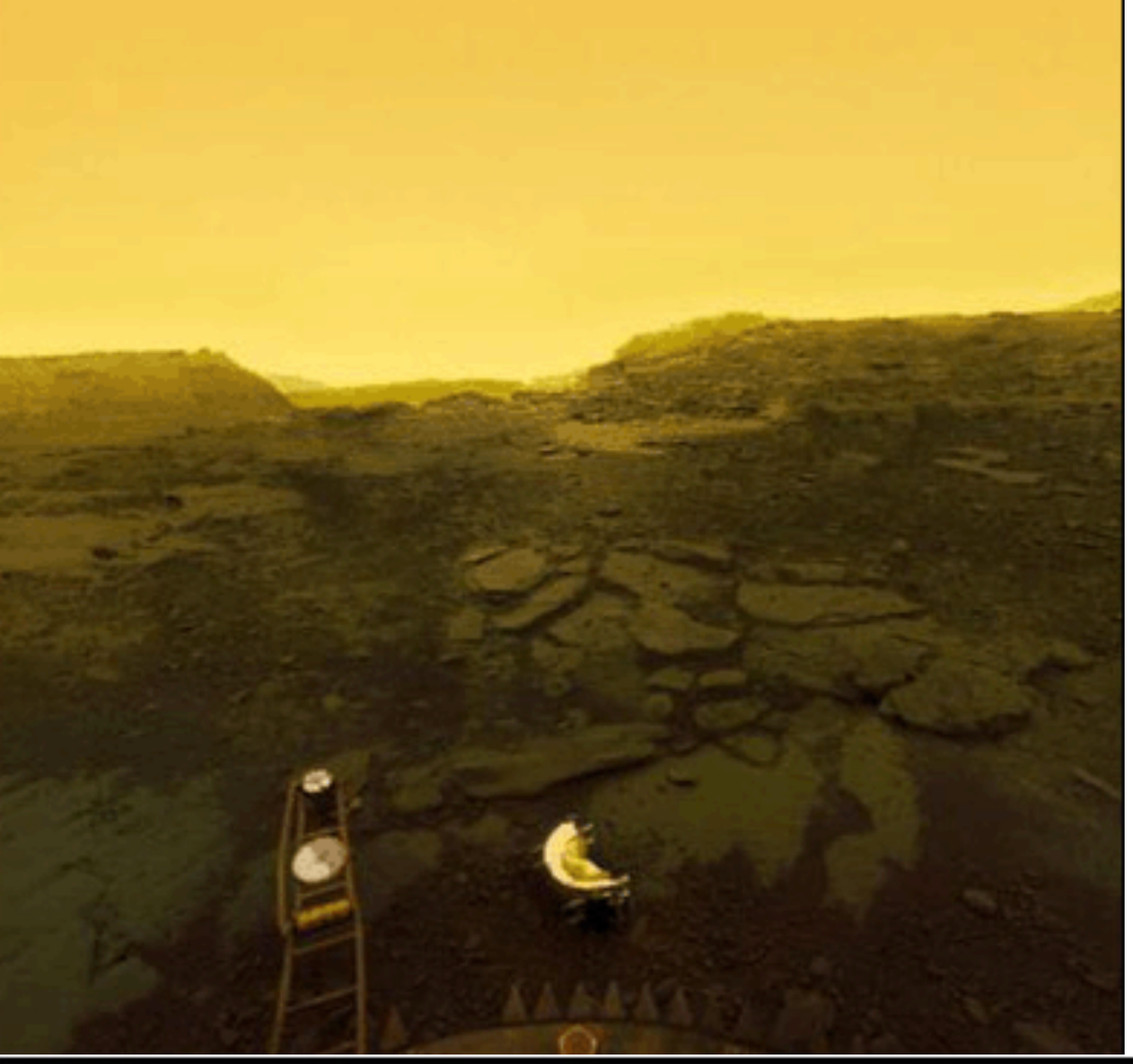
- It has many volcanoes, including both shield volcanoes and stratovolcanoes.

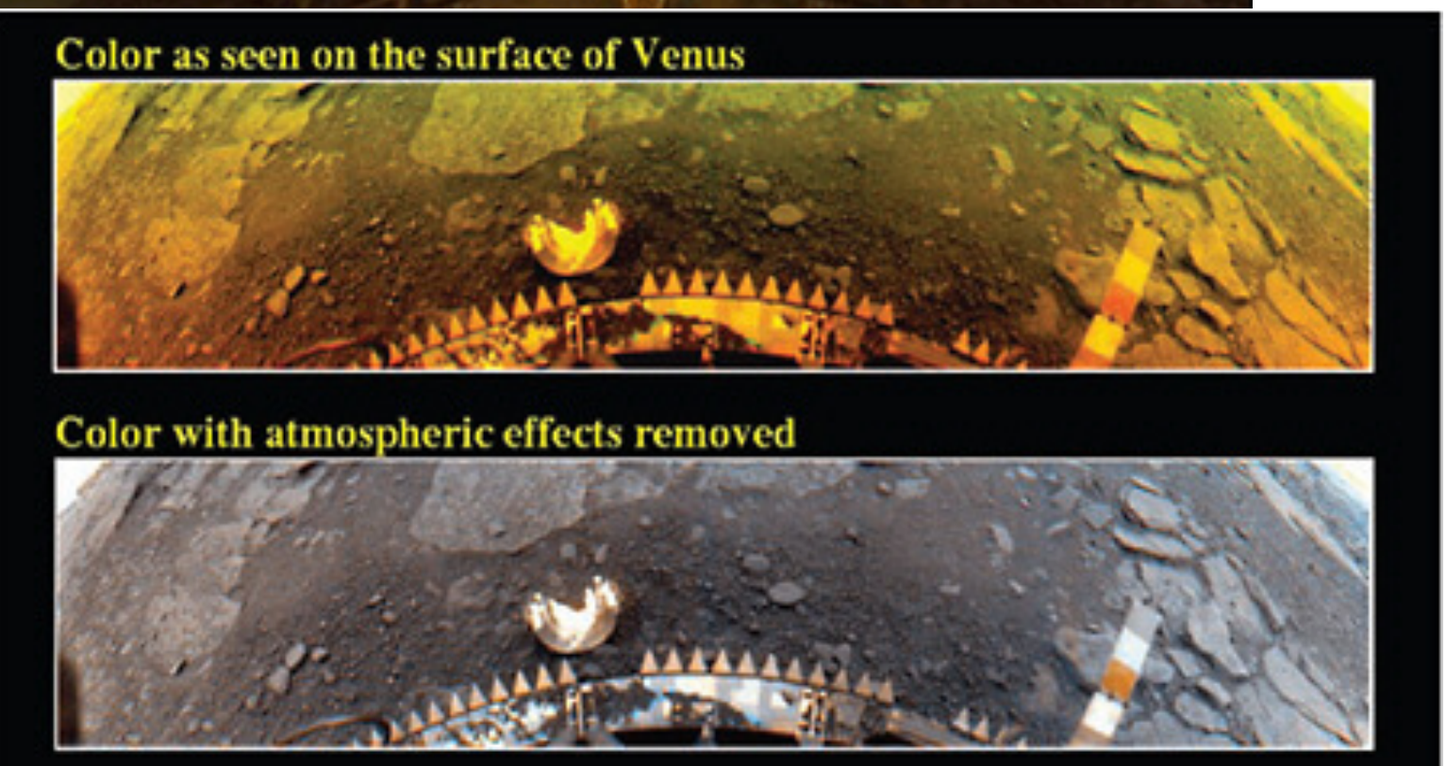


Tectonics on Venus



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





- Photos of rocks taken by landers show little erosion.

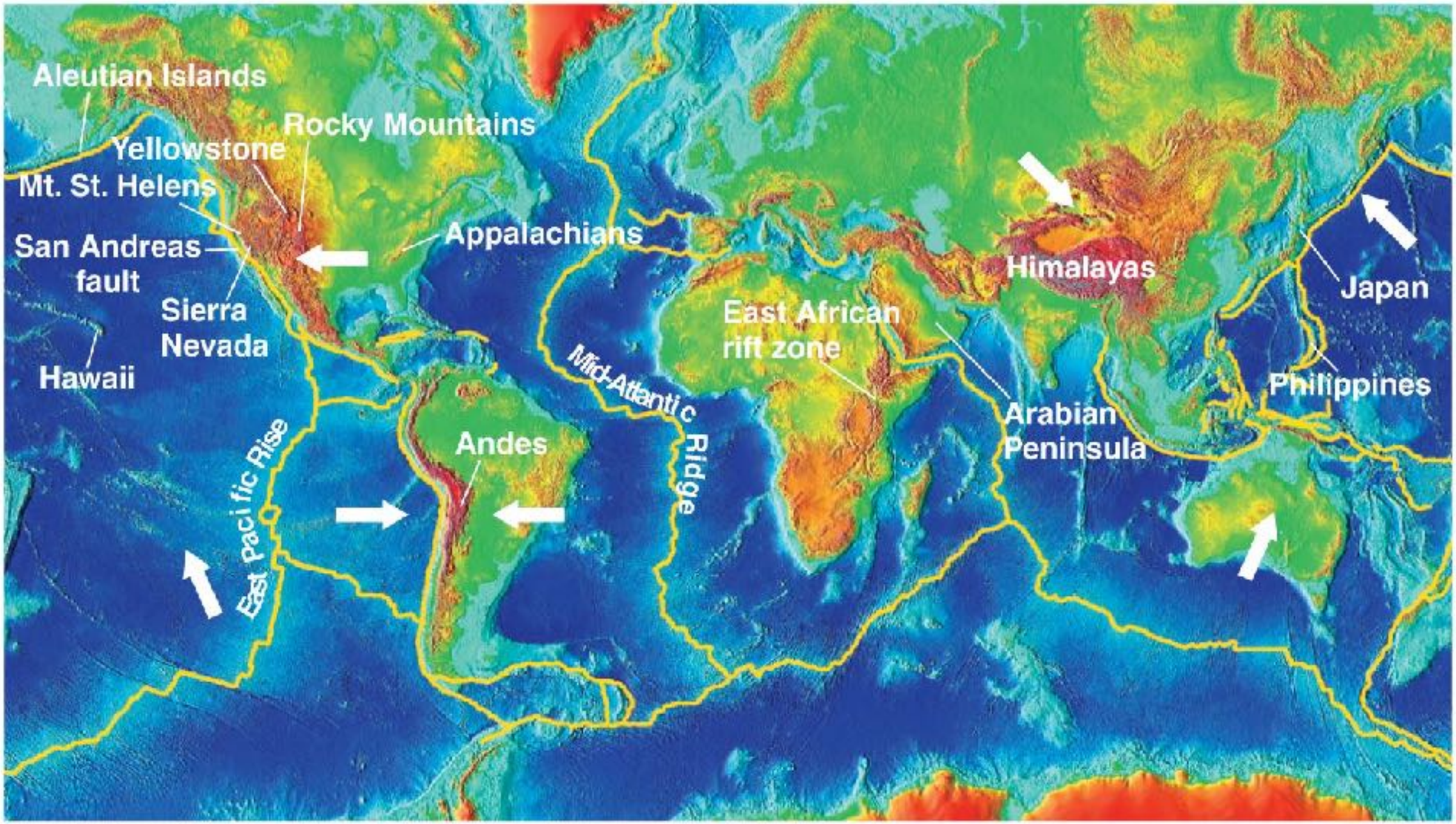
- No flowing water

- Series of Russian landers; lasted from 23 minutes to a couple of hours

Does Venus have plate tectonics?

- Venus does not appear to have plate tectonics currently, but entire surface seems to have been "repaved" 750 million years ago.
  - Weaker convection?
  - Thicker or more rigid lithosphere?
    - Some role for water in greasing plate tectonics on Earth?

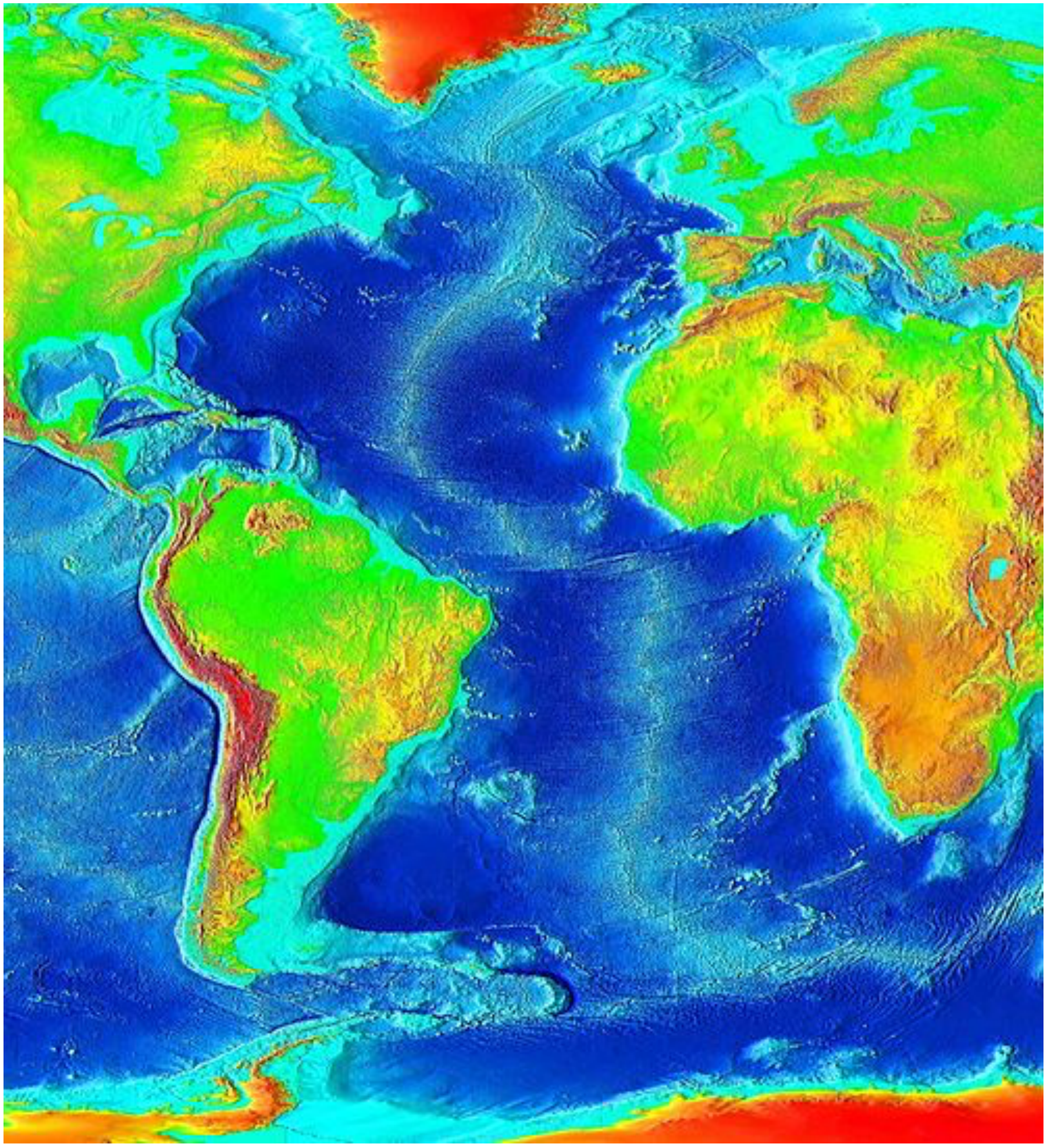
How is Earth's surface shaped by plate tectonics?



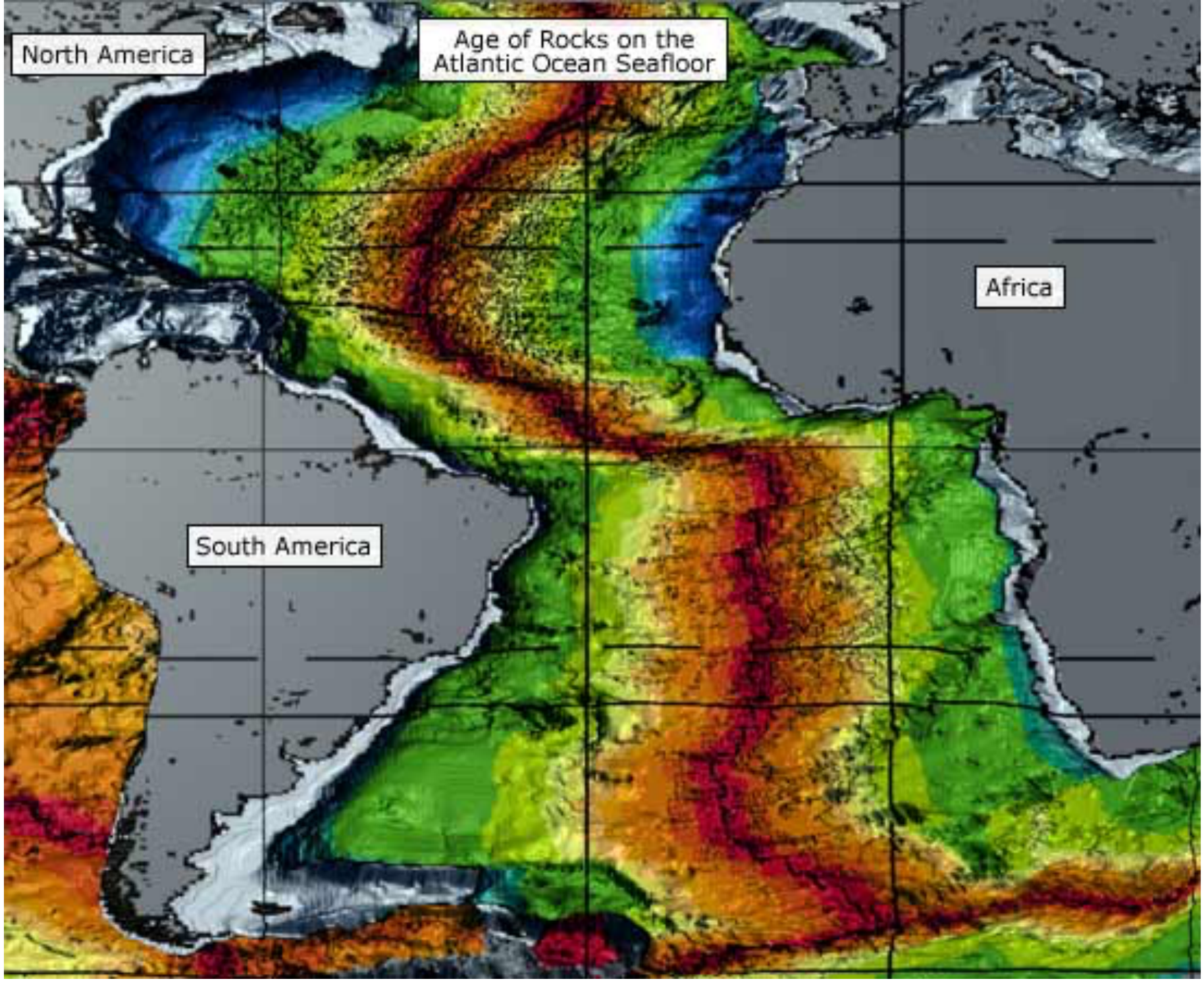
Continental Motion

- The idea of continental drift was inspired by the puzzle-like fit of the continents.

- Mantle material erupts where the seafloor spreads.

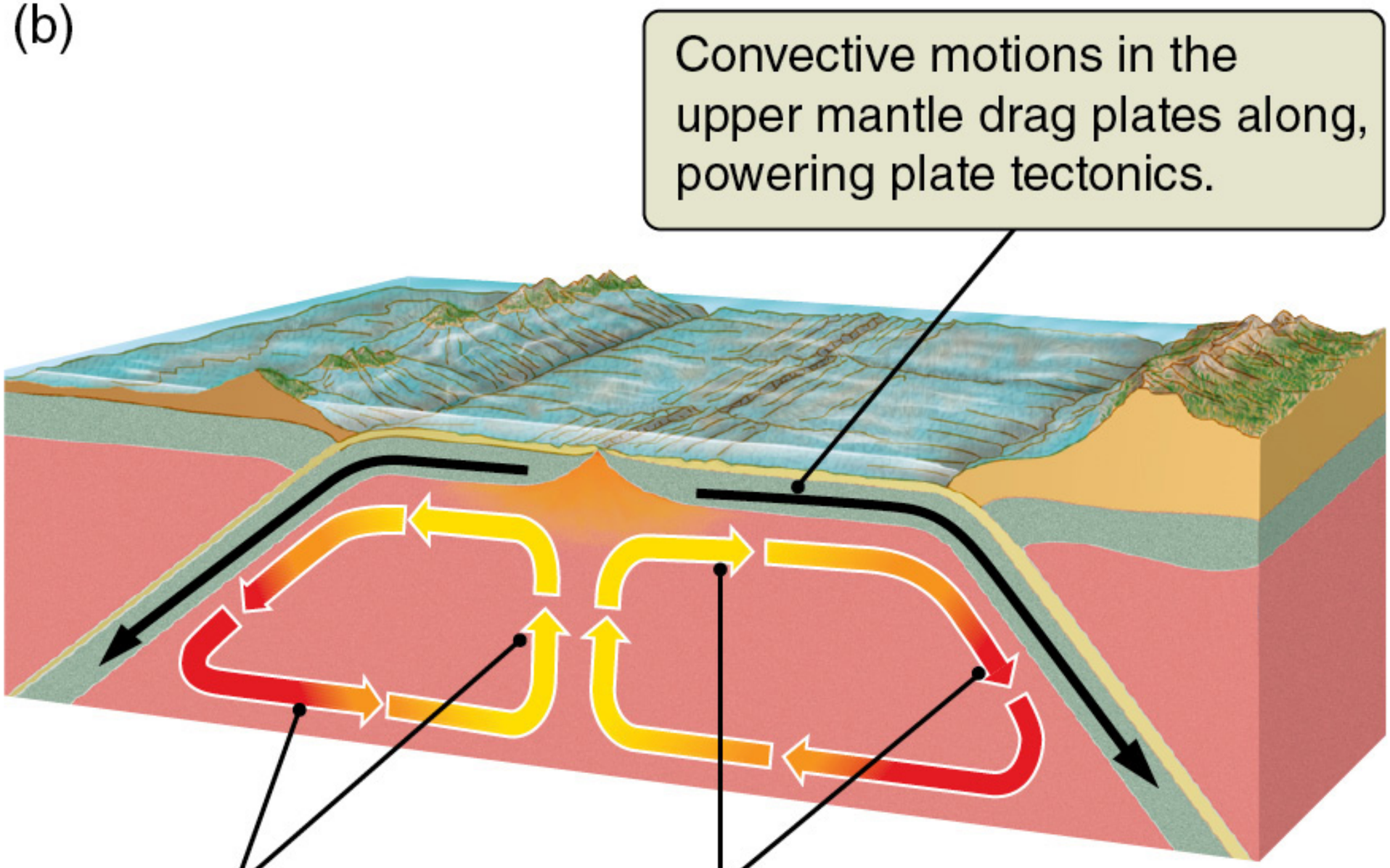


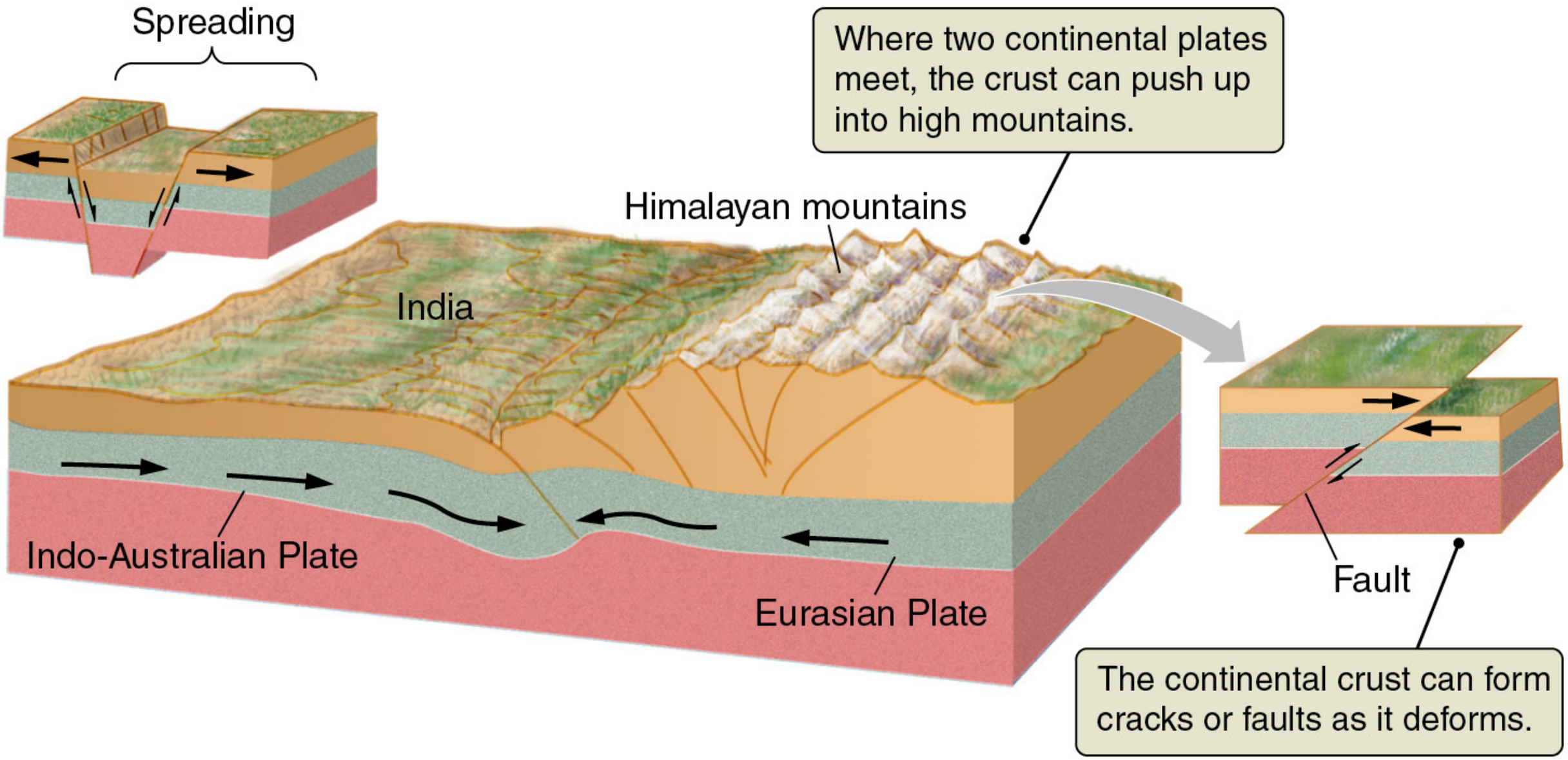
- Mid-Atlantic ridge
- Chain of mountains from whence seafloor spreads
- Age gradient in rocks with youngest at the center of spreading



Younger rocks colored red

(b)

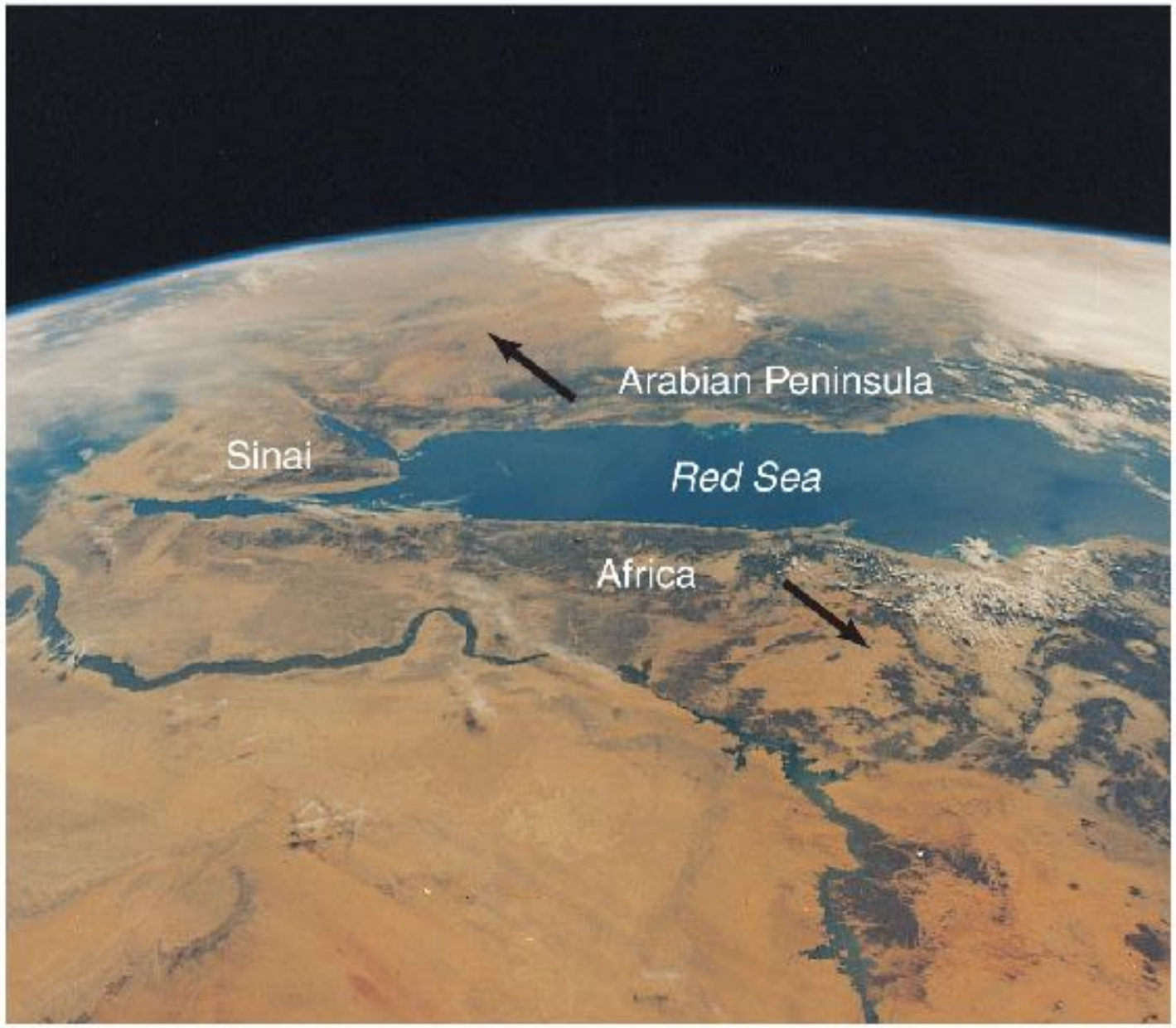

Convective motions in the upper mantle drag plates along, powering plate tectonics.
Mantle is heated from below, becomes buoyant, and rises.
Mantle cools near surface and sinks, displacing hot mantle and pushing it upward.


Spreading
Where two continental plates meet, the crust can push up into high mountains.
Himalayan mountains
India
Indo-Australian Plate
Eurasian Plate
Fault
The continental crust can form cracks or faults as it deforms.

Surface Features

- The Himalayas formed from a collision between plates.

Surface Features



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