Today

- Terrestrial Planets
  - Earth/moon, Venus, Mars, Mercury

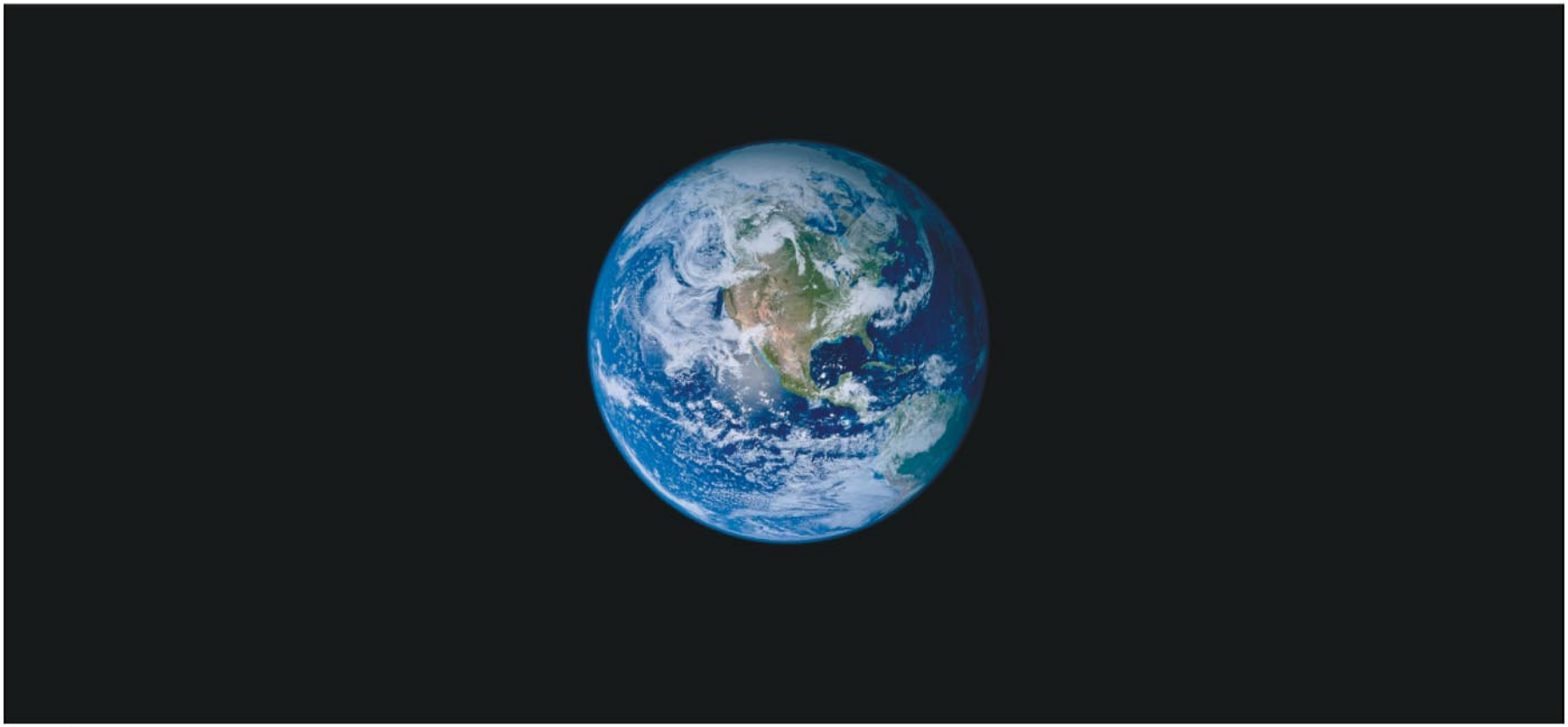
Homework due now

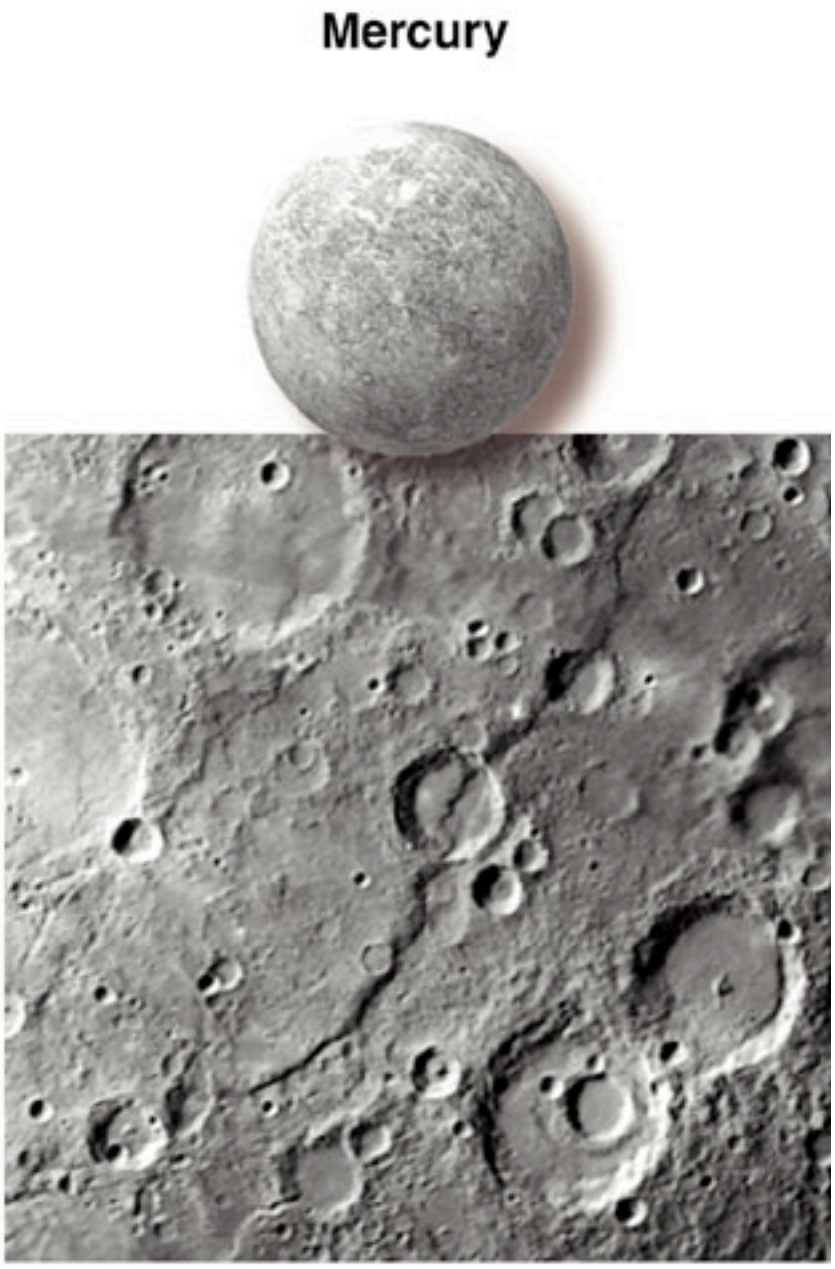
Exam next Thursday

Exam Review Session

- This Monday, 6-8 PM, this room
- Completely driven by your questions! The TAs will not prepare summary slides, but can go to the lecture slides if needed.
- When your questions are done, the review is over
- Don’t ask them what will be on the exam; they don’t know :)

Earth and the Terrestrial Worlds





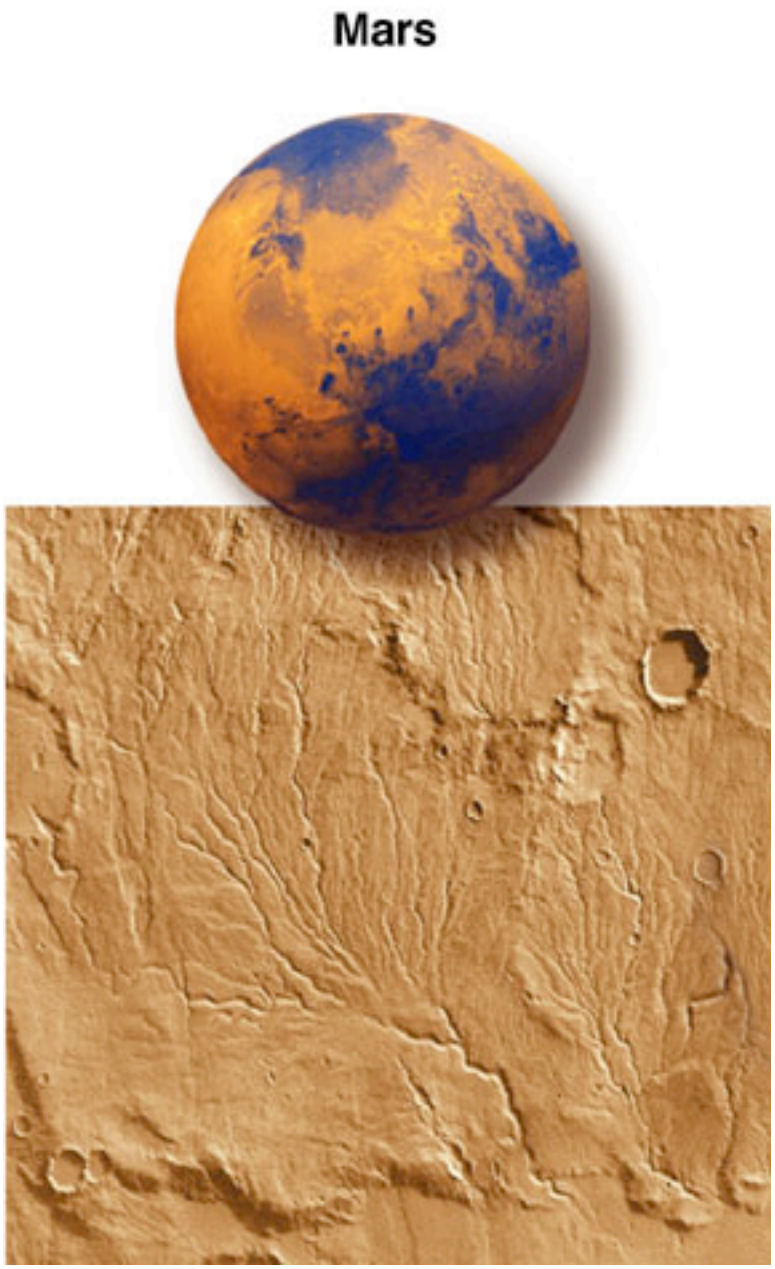
Mercury

craters
smooth plains
cliffs

Venus

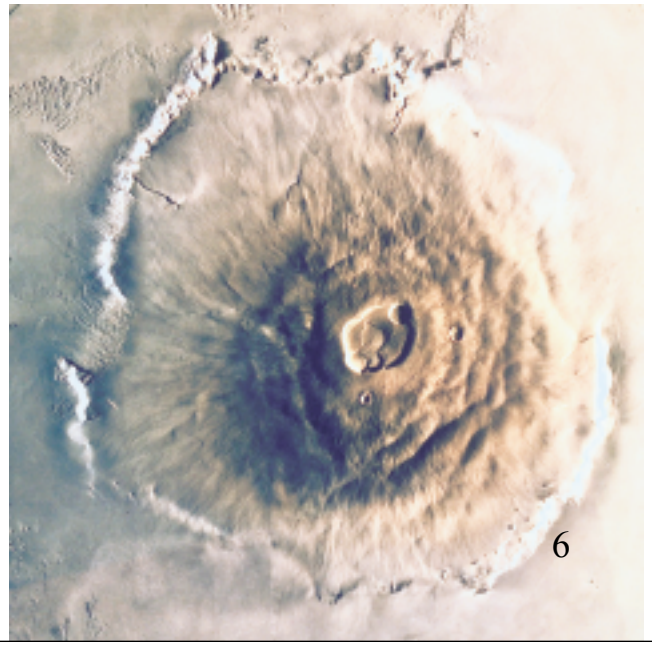
volcanoes
few craters

Radar view of a twin-peaked volcano

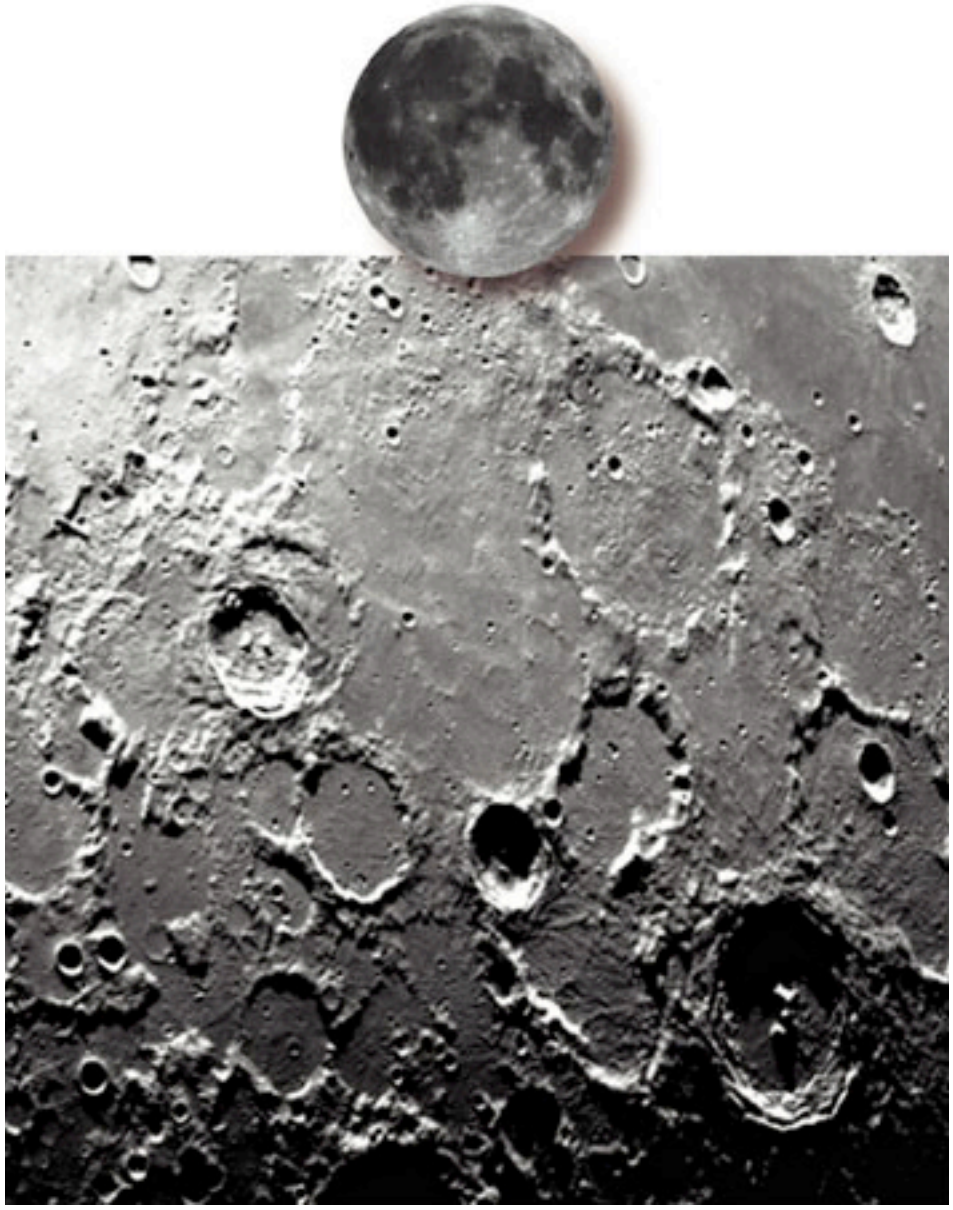


Mars

some craters
volcanoes
riverbeds?



Earth's Moon



Moon

craters
smooth plains

Earth

volcanoes
craters
mountains
riverbeds

Why have the planets turned out so differently, even though they formed at the same time from the same materials?

Terrestrial Planets

The terrestrial planets (including our Moon) have a wide variety of appearances. What is the main cause of their **geological** differences (as opposed to the presence or absence of life)?

A. Distance from the Sun

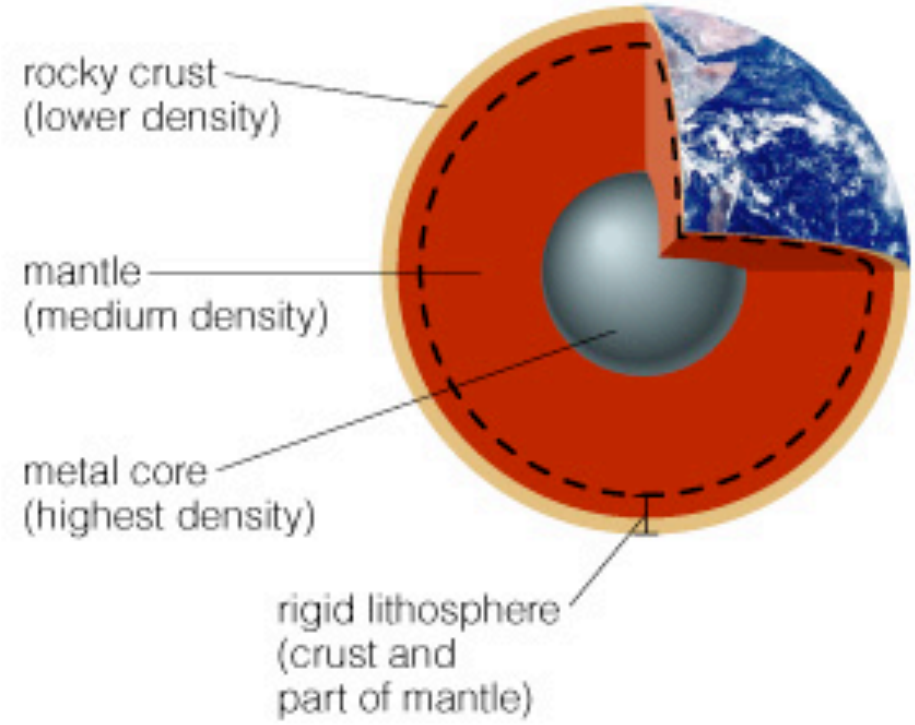
B. Strength of their magnetic field

C. Size/mass of the planets

D. Presence or absence of a large moon

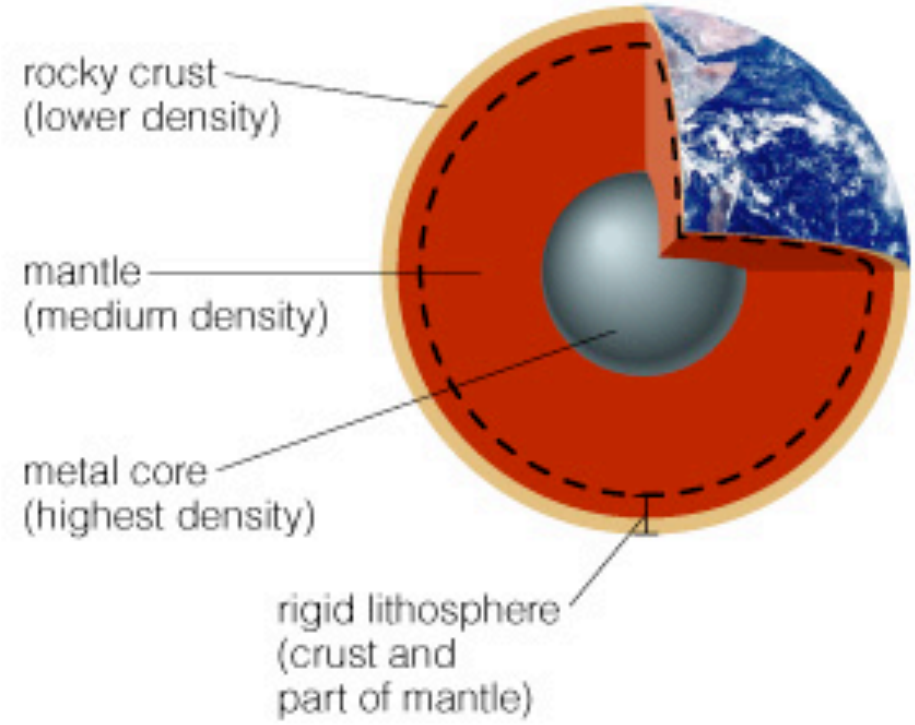
E. I don't know

Earth's Interior



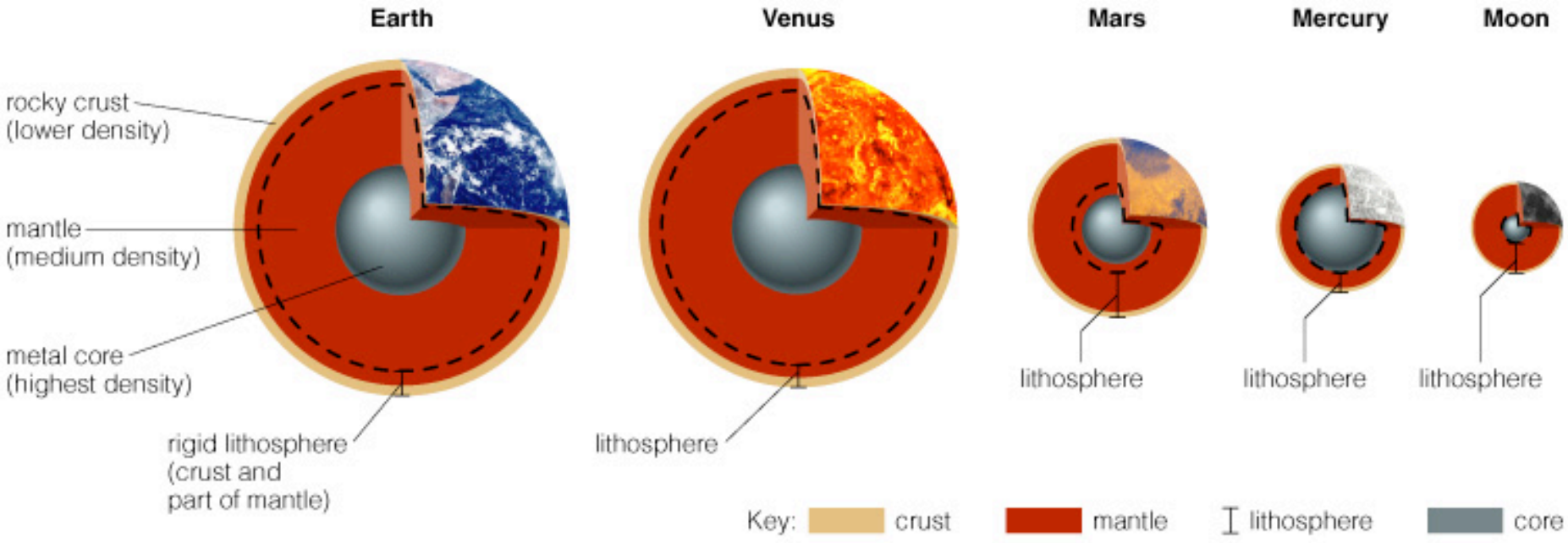
- **Core:** Highest density; nickel and iron
- **Mantle:** Moderate density; silicon, oxygen, etc.
- **Crust:** Lowest density; granite, basalt, etc.

Differentiation



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

Terrestrial Planet Interiors

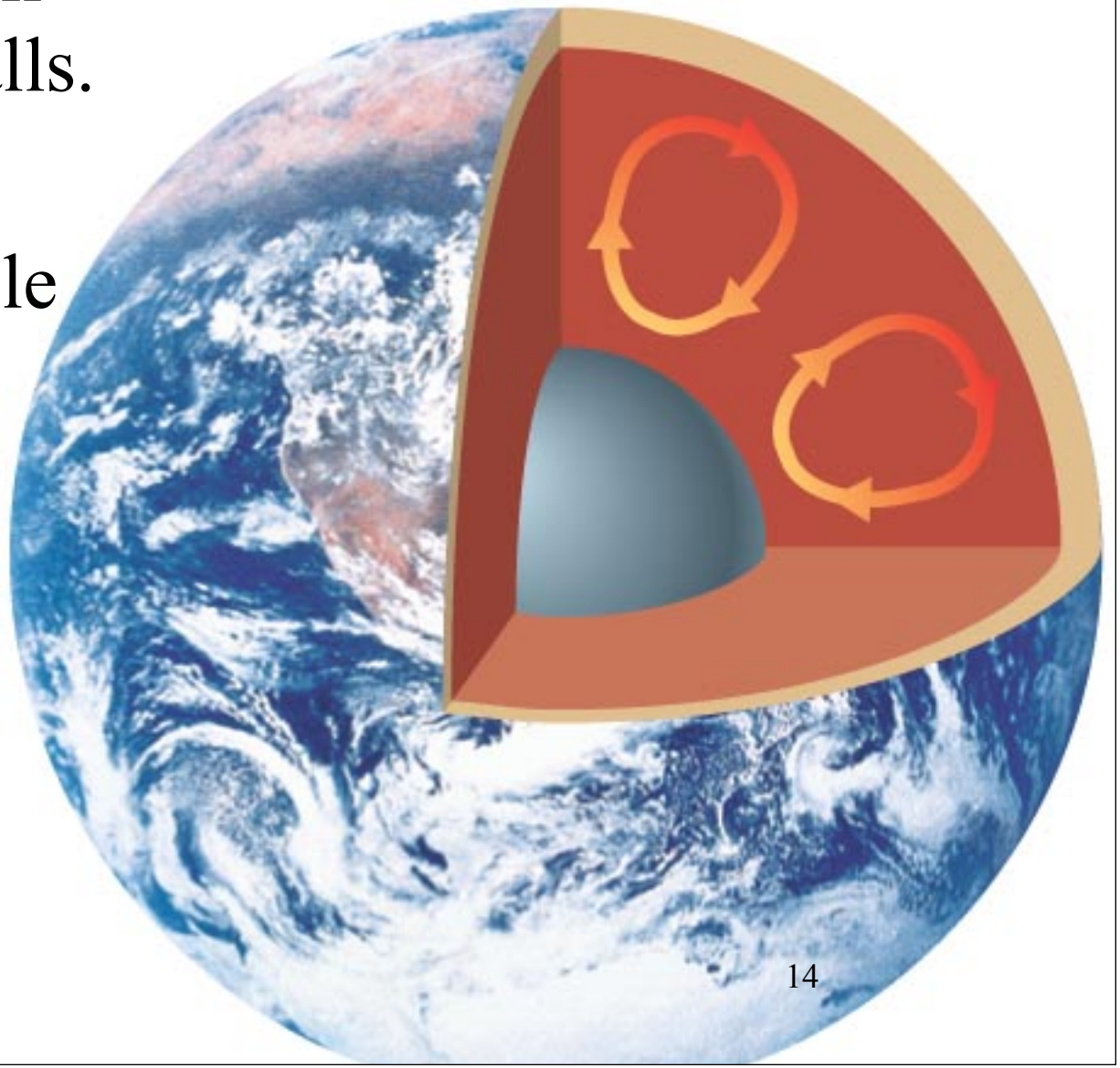


- Applying what we have learned about Earth's interior to other planets tells us what their interiors are probably like.

Heat Drives Geological Activity

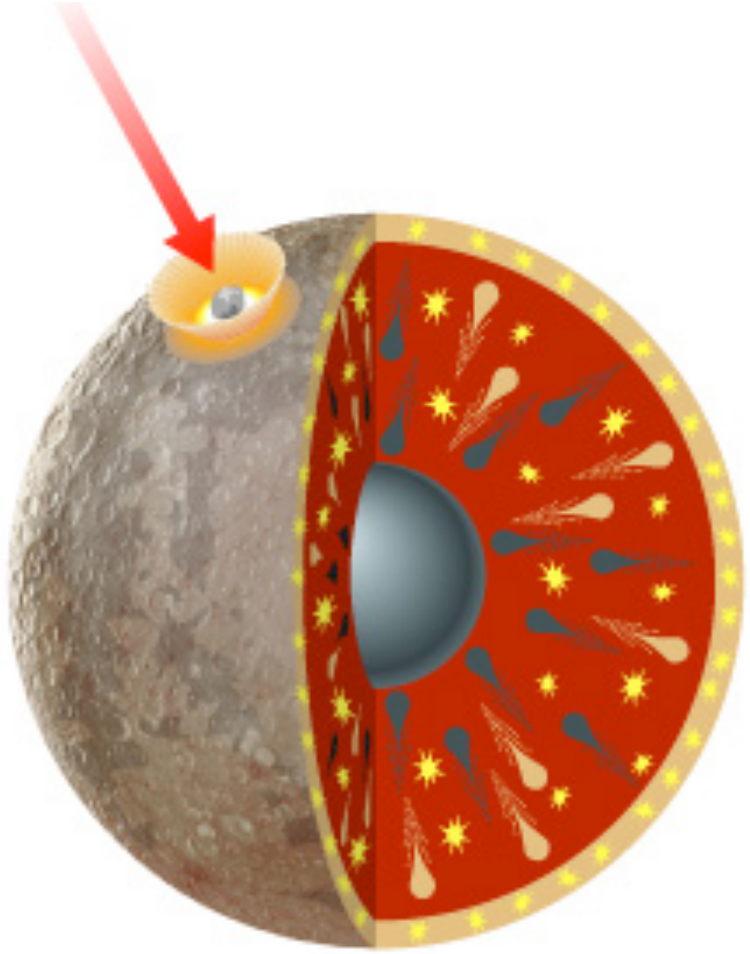
Convection: hot rock rises, cool rock falls.

One convection cycle takes 100 million years on Earth.

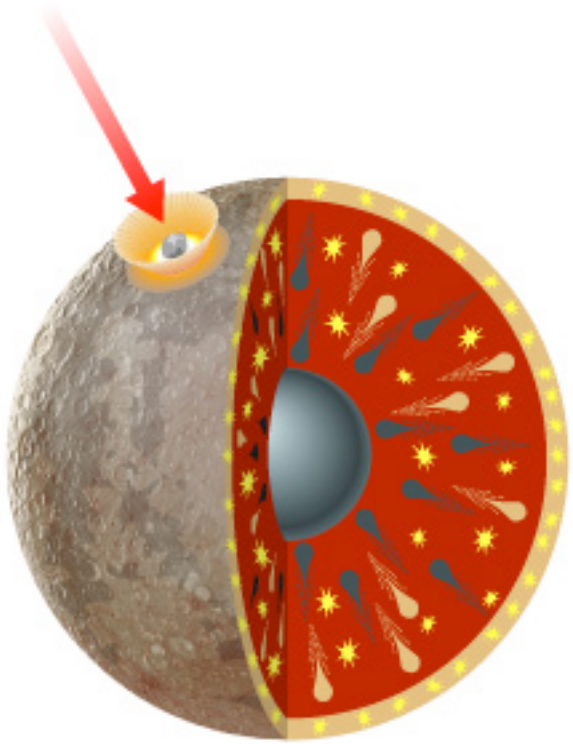


Sources of Internal Heat

1. Gravitational potential energy of accreting planetesimals
2. Differentiation
3. Radioactivity

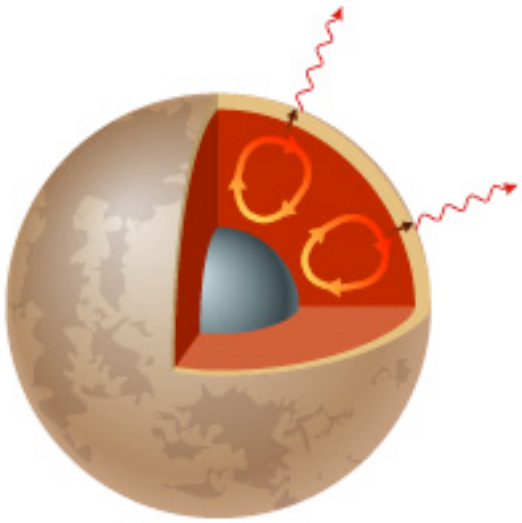


Heating of Interior over Time



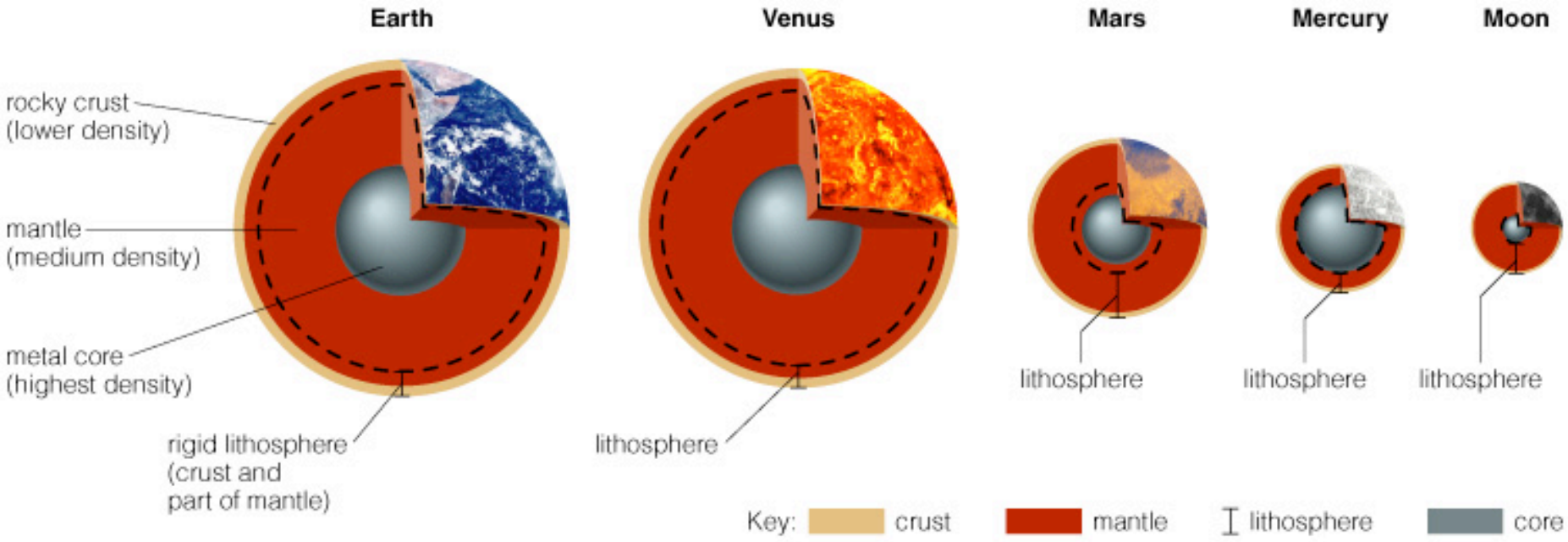
- Accretion and differentiation when planets were young
- Radioactive decay is most important heat source today

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

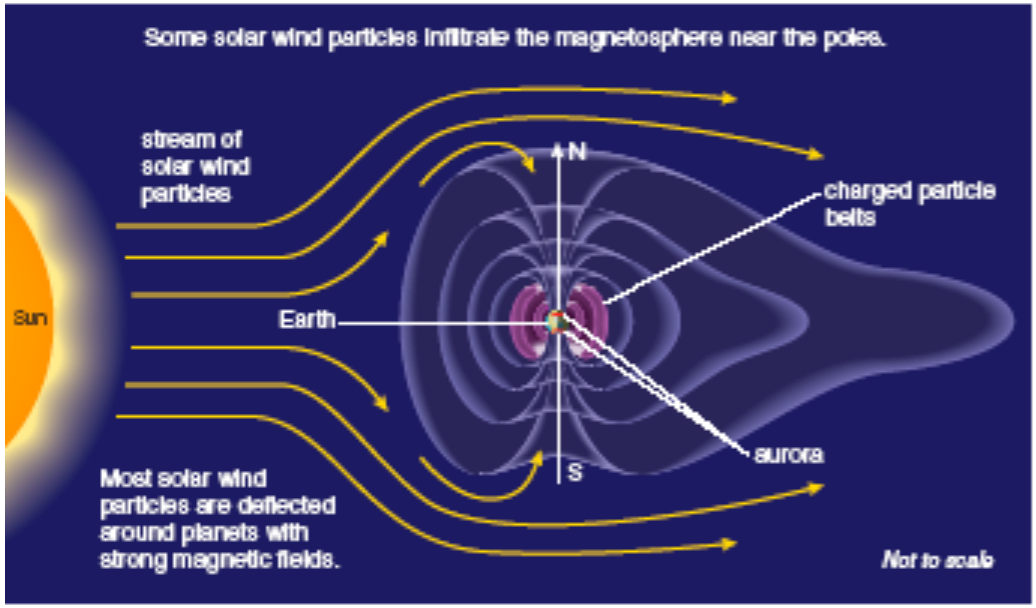


- Smaller worlds cool off faster and harden earlier.
- Moon and Mercury are now geologically "dead."

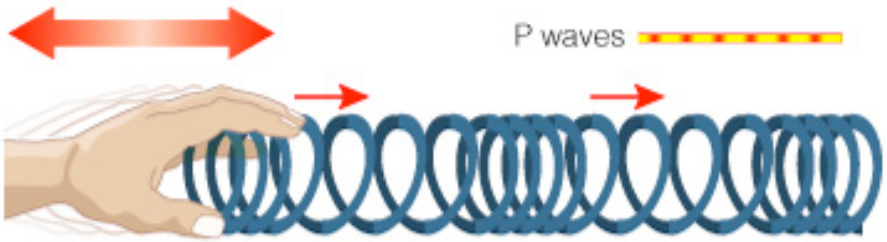
Earth's Magnetosphere

Earth's magnetic fields protects us from charged particles from the Sun.

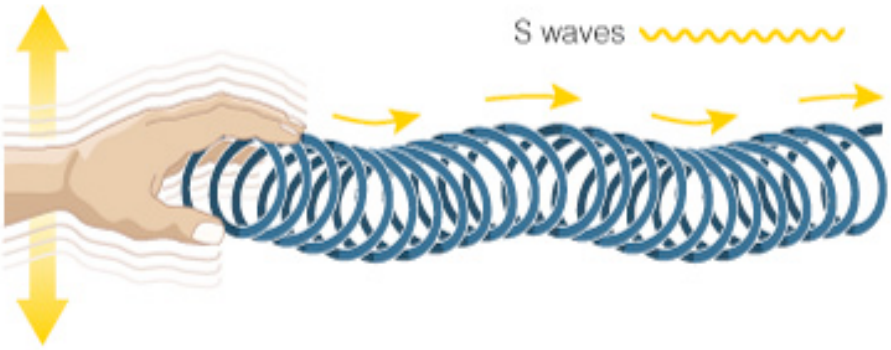
The charged particles can create aurorae ("Northern lights").



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

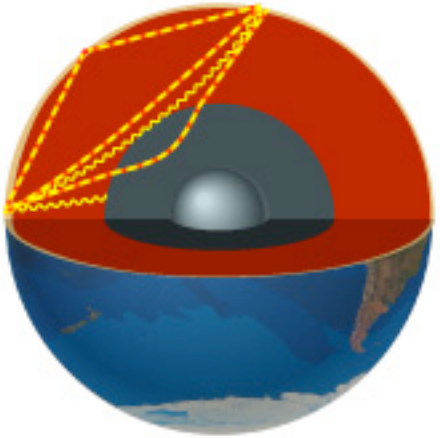


- P waves push matter back and forth.



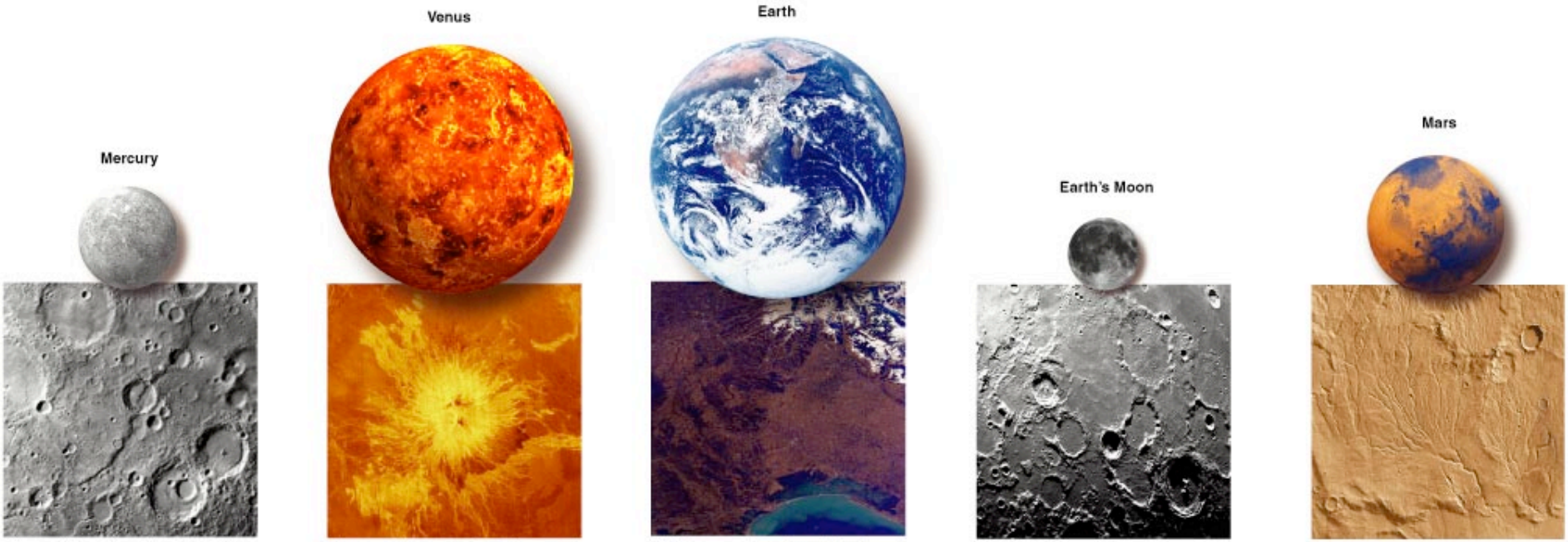
- S waves shake matter side to side.

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.

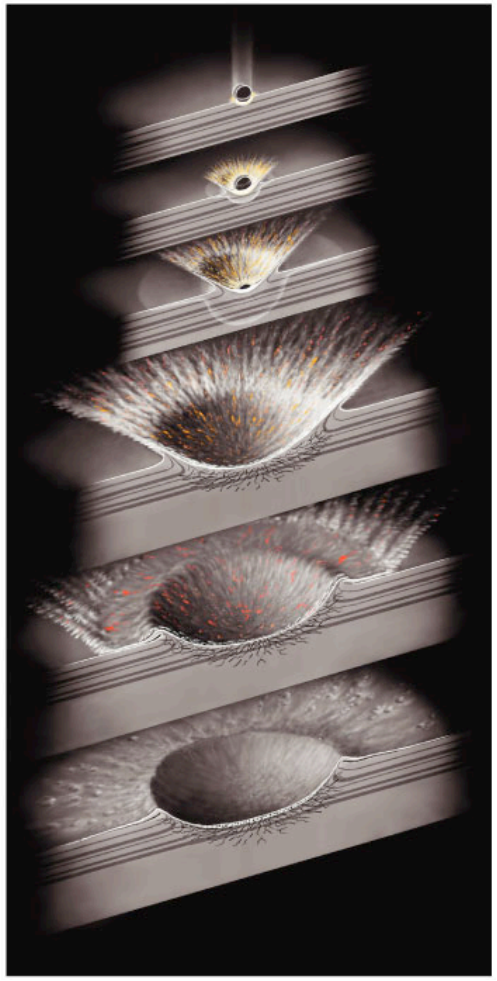
What processes shape a planet's surface?



Geological Processes

- 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

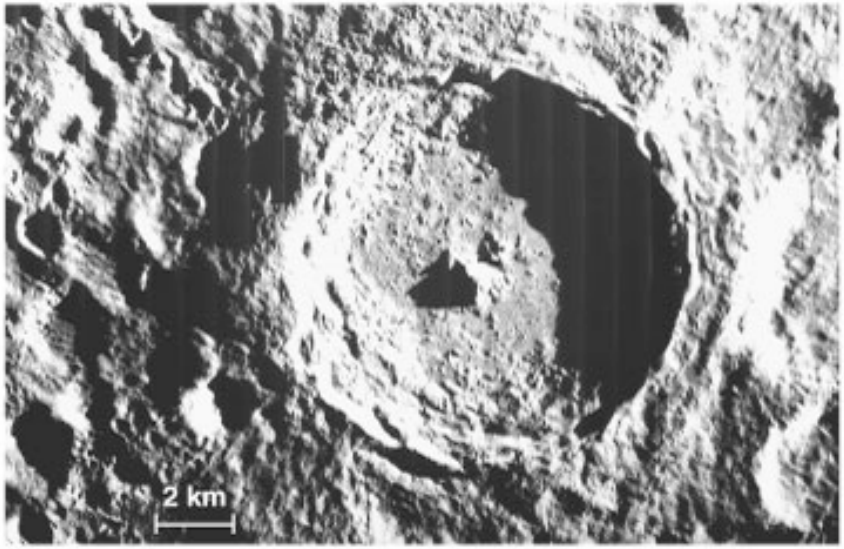
Impact Cratering



- Most cratering happened soon after the solar system formed.
- Craters are about 10 times wider than objects that made them.
- Small craters greatly outnumber large ones.
- A heavily cratered surface is *normal* - a planet needs active geology or erosion to erase craters

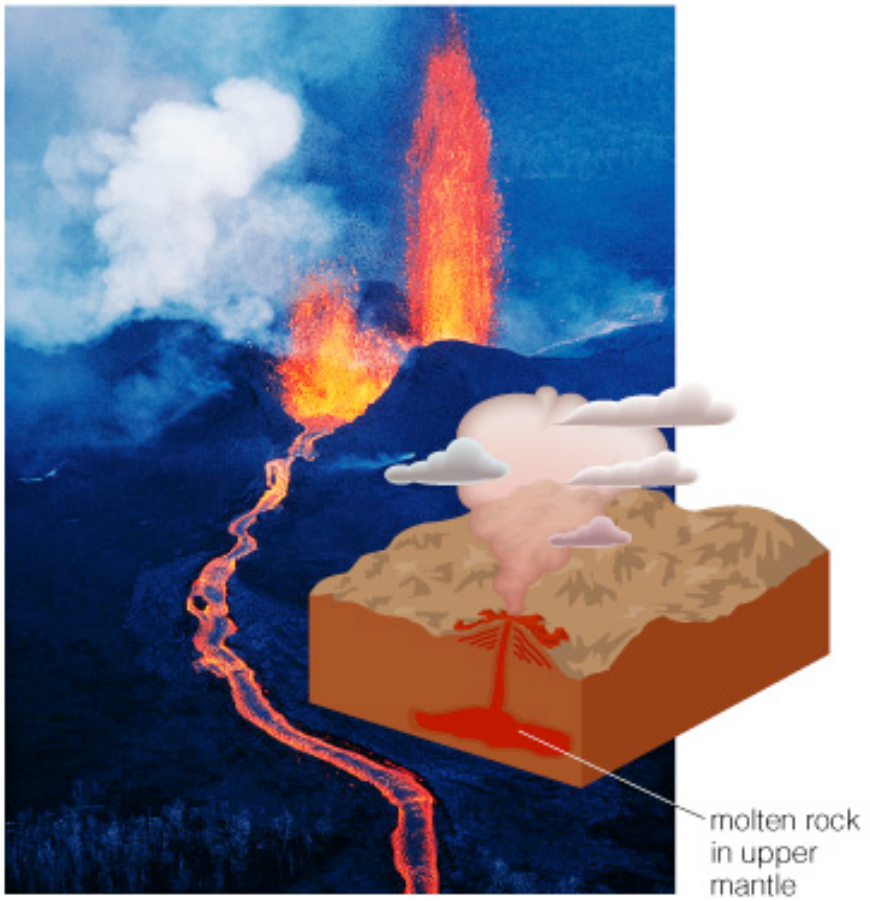
Impact Craters

Meteor Crater (Arizona)



Tycho (Moon)

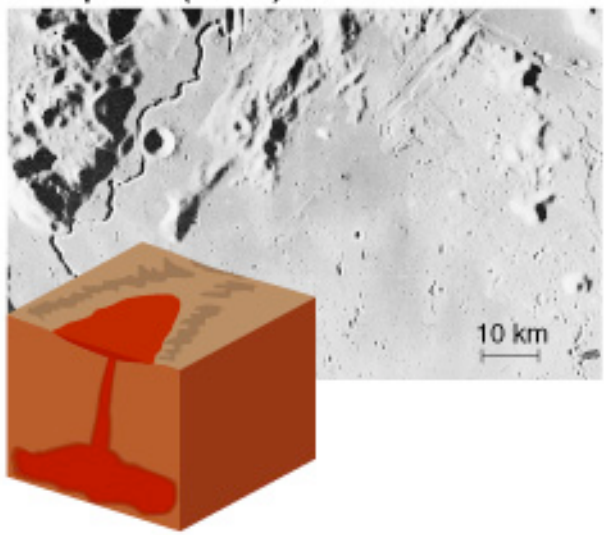
Volcanism



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

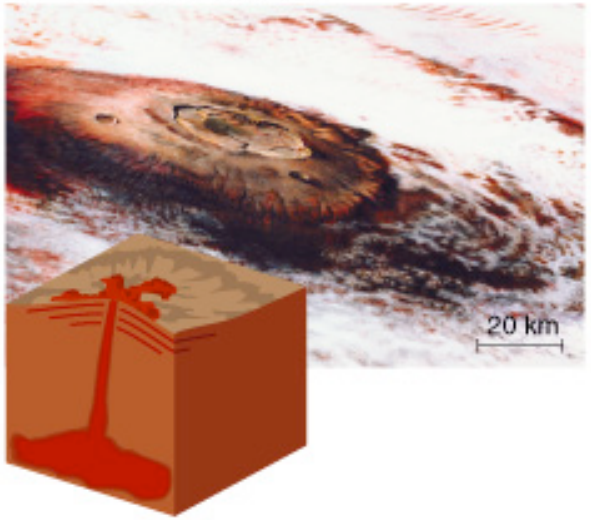
Lava and Volcanoes

Lava plains (maria) on the Moon



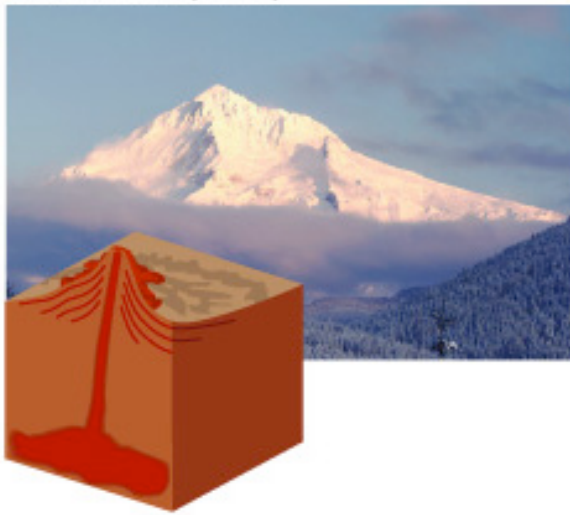
Runny lava makes flat lava plains.

Olympus Mons (Mars)



Slightly thicker lava makes broad *shield volcanoes*.

Mount Hood (Earth)



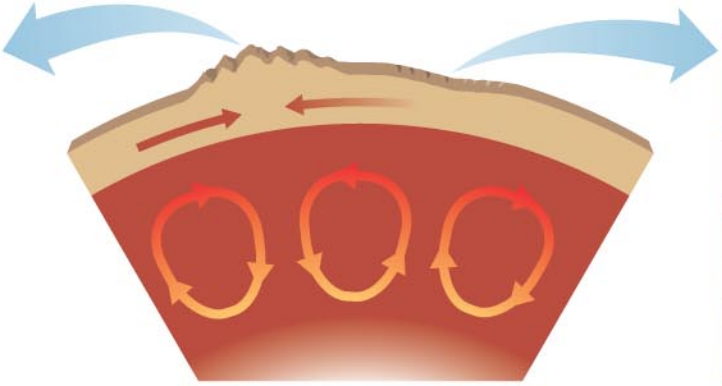
Thickest lava makes steep *stratovolcanoes*.

Outgassing

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

Tectonics

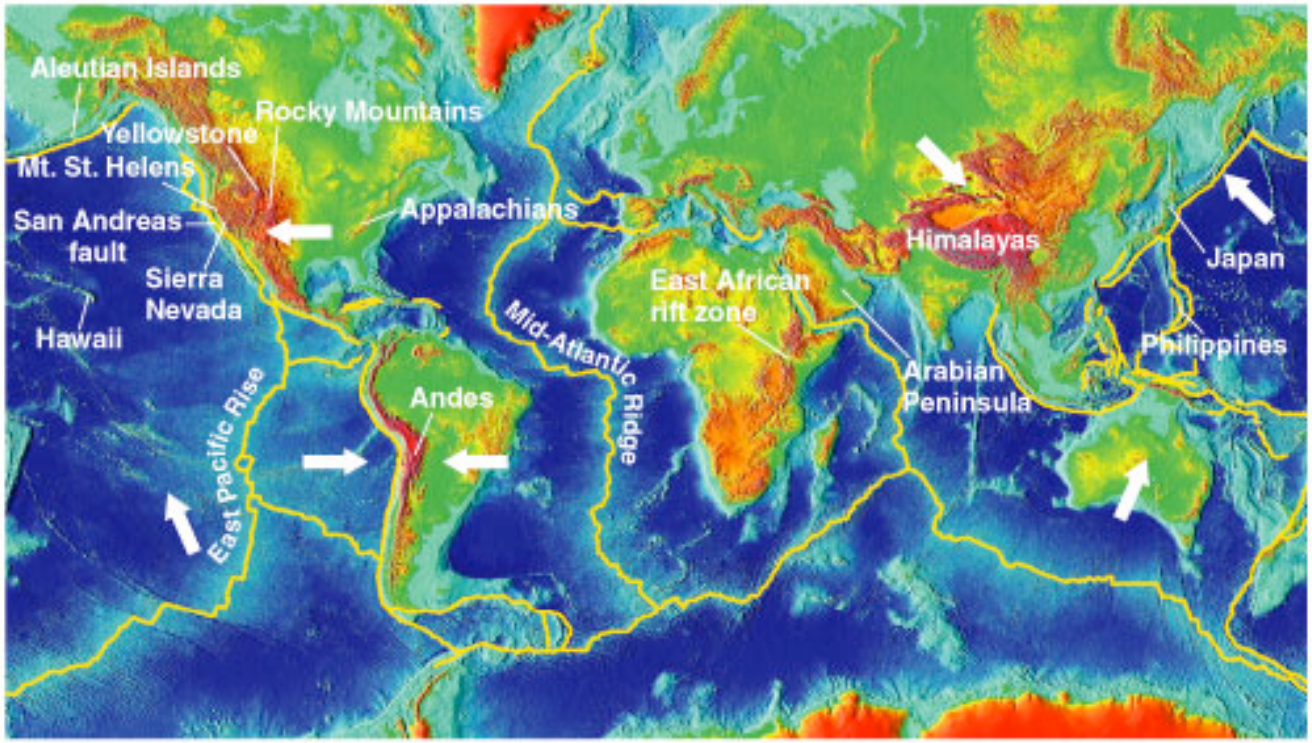
Earth's tallest mountain range, the Himalayas, created as India pushes into the rest of Asia.



The Red Sea, created as the Arabian Peninsula was torn away from Africa.

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

Plate Tectonics

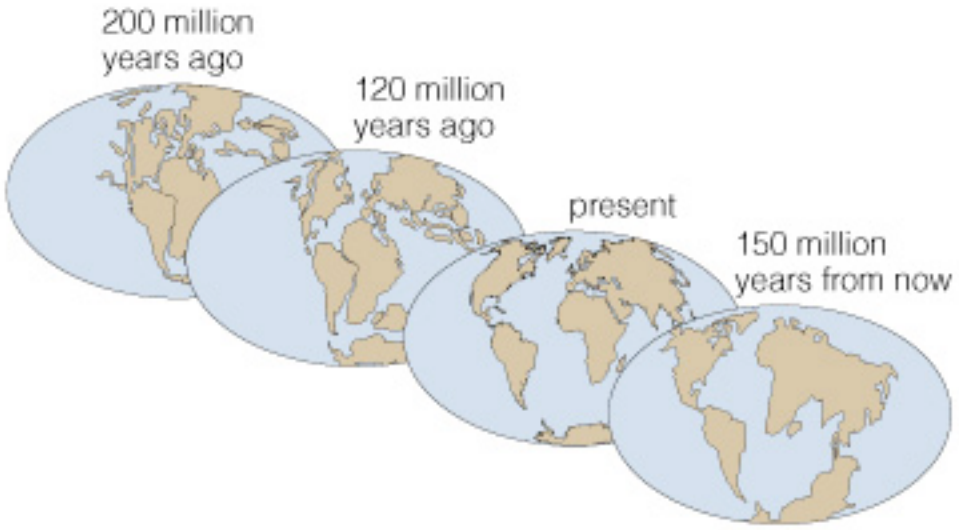


- Motion of continents can be measured with GPS

Continental Motion

- Idea of continental drift was inspired by puzzle-like fit of continents
- Mantle material erupts where seafloor spreads

Plate Motions



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

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 the Grand Canyon.

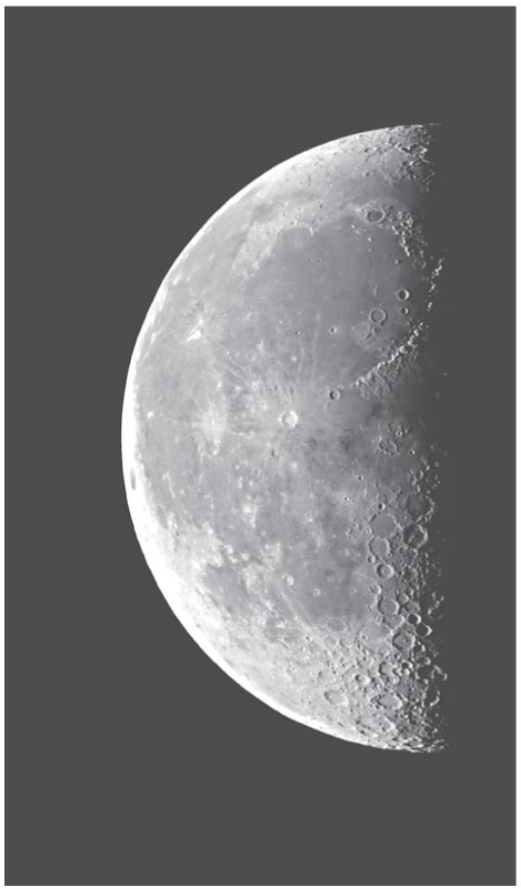
Erosion by Ice

- Glaciers carved the Yosemite Valley.

Erosion by Wind

- Wind wears away rock and builds up sand dunes.

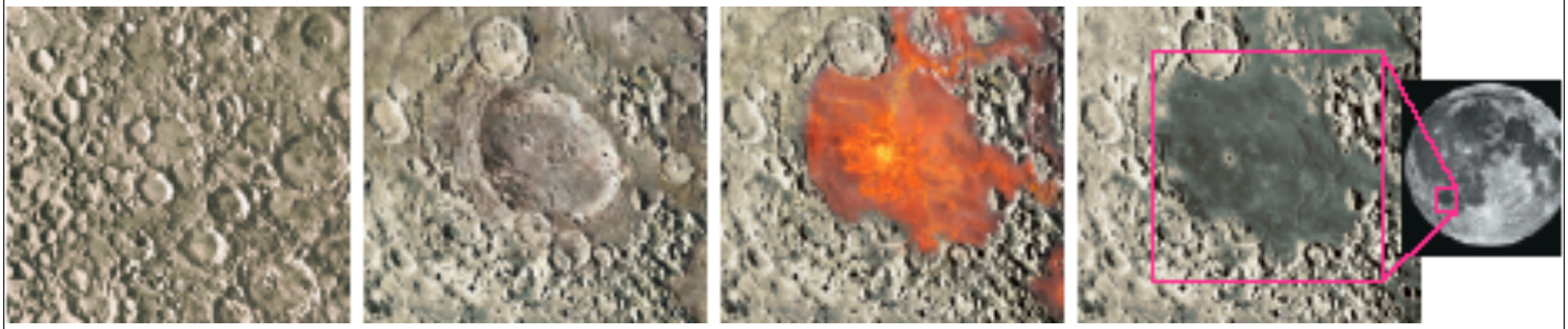
Was there ever geological activity on the Moon or Mercury?



Moon

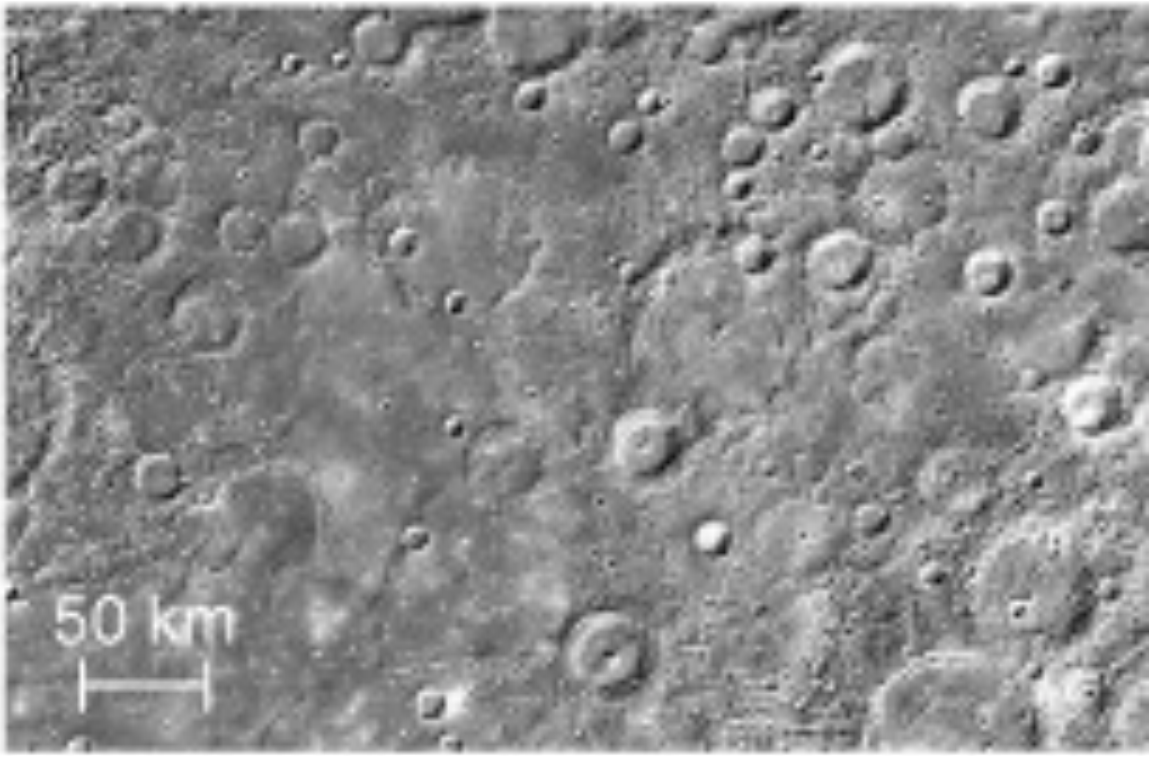
Mercury

Moon



- Some volcanic activity 3 billion years ago must have flooded lunar craters, creating *lunar maria*.
- The Moon is now geologically dead.

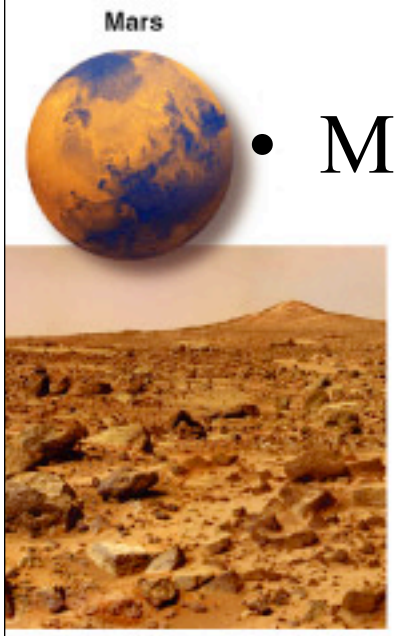
Cratering of Mercury



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

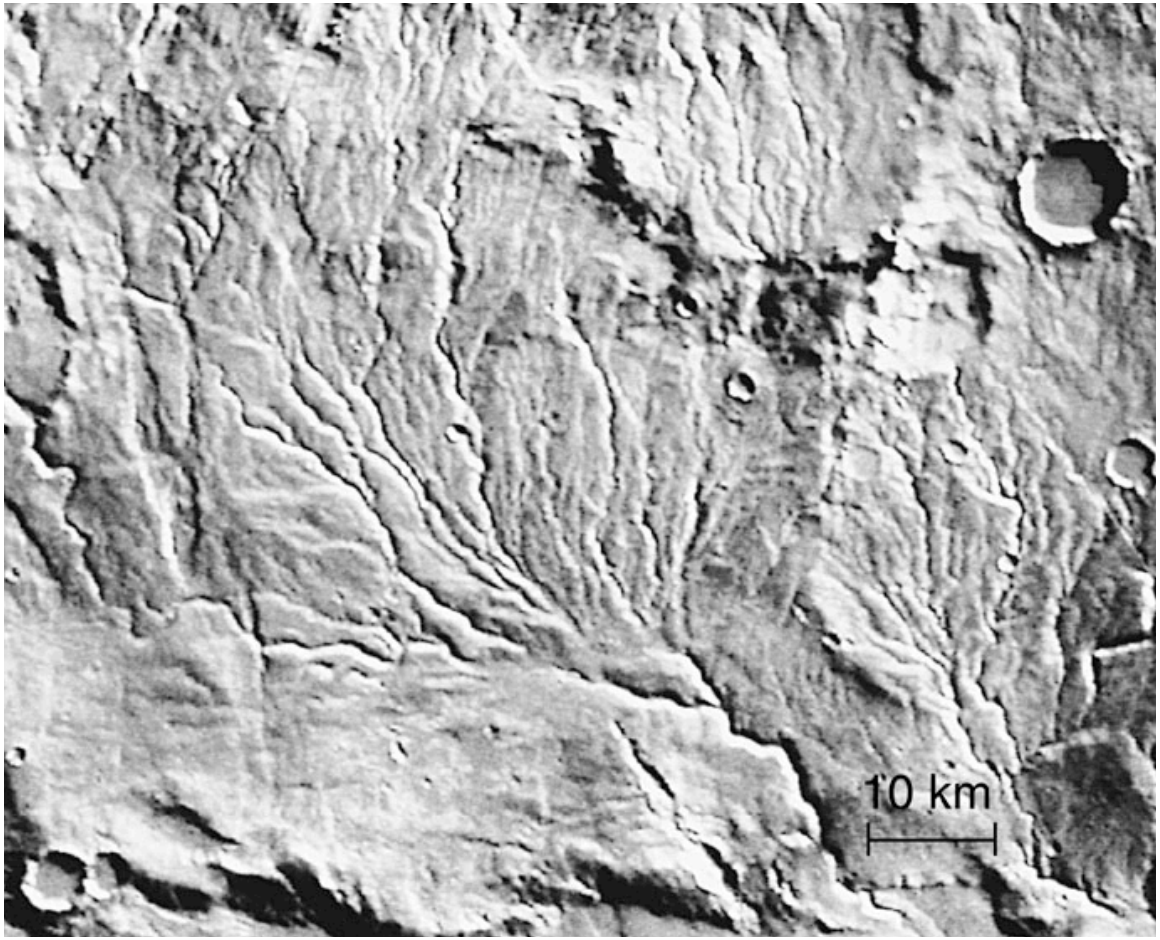
Mars versus Earth

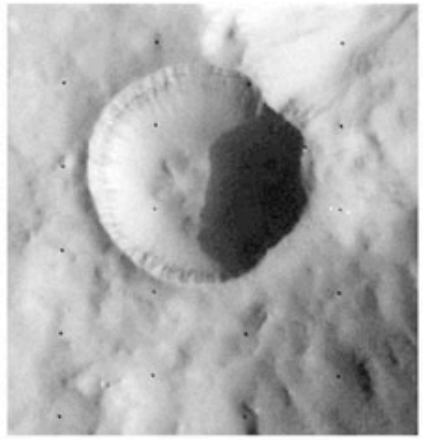
- 50% Earth's radius, 10% Earth's mass
- 1.5 AU from the Sun
- Axis tilt about the same as Earth
- Similar rotation period
- Thin CO_2 atmosphere: little greenhouse

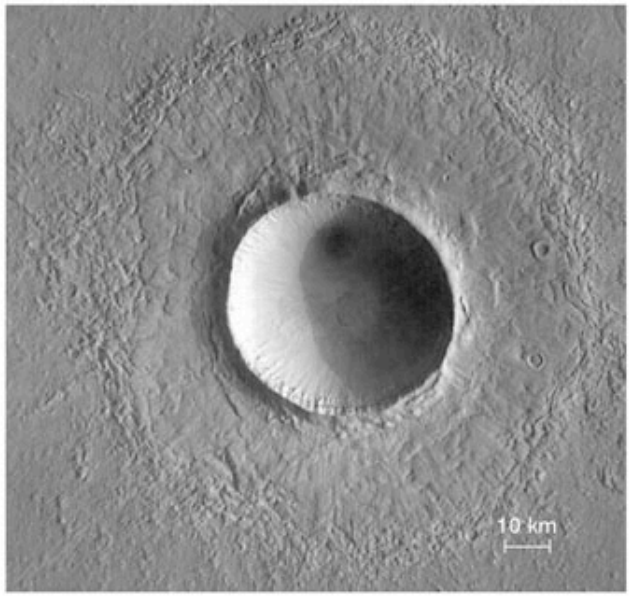


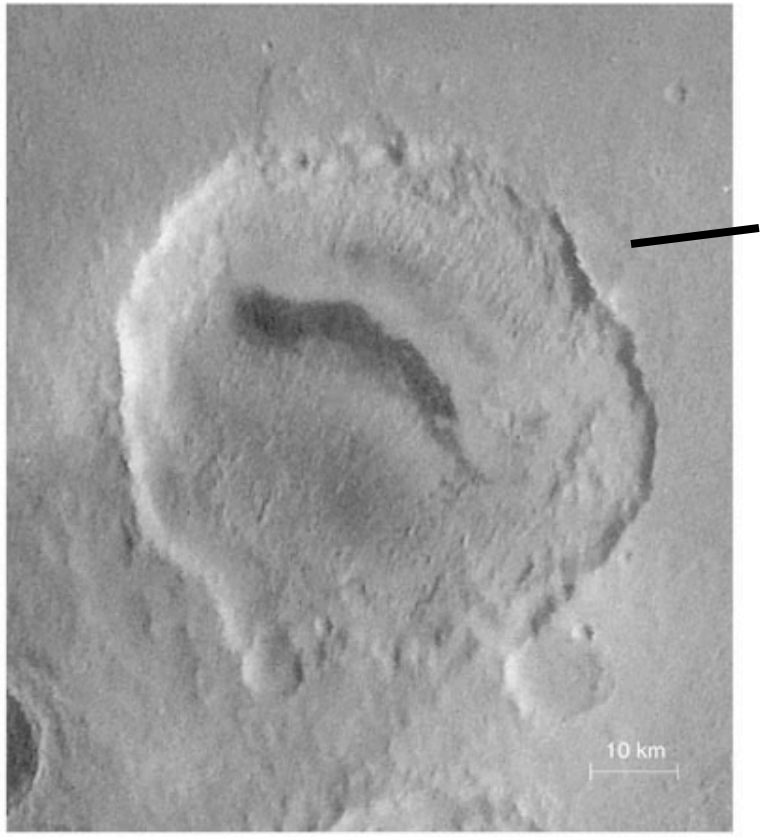
- Main difference: Mars is SMALLER

The surface of Mars appears to have ancient riverbeds.



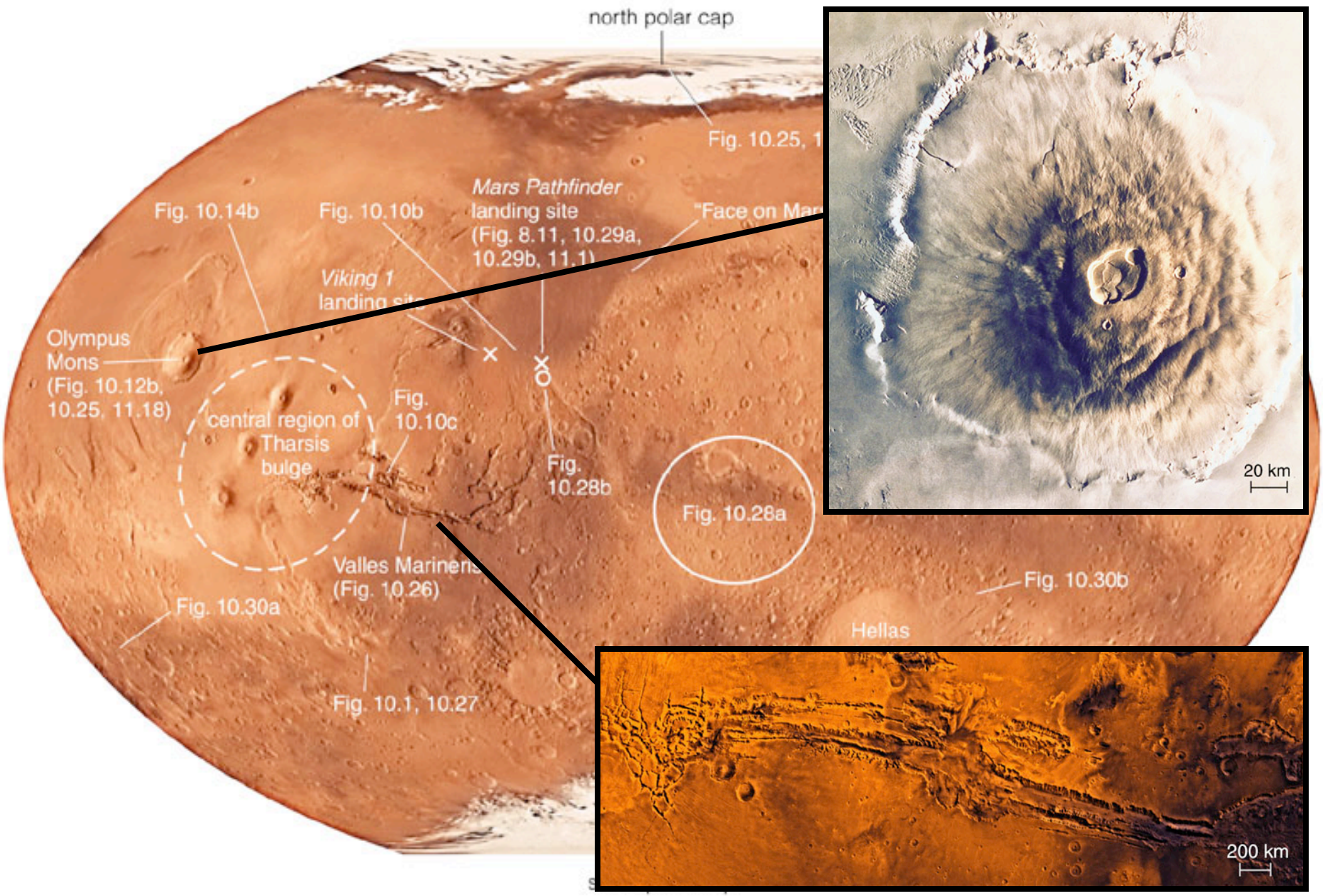




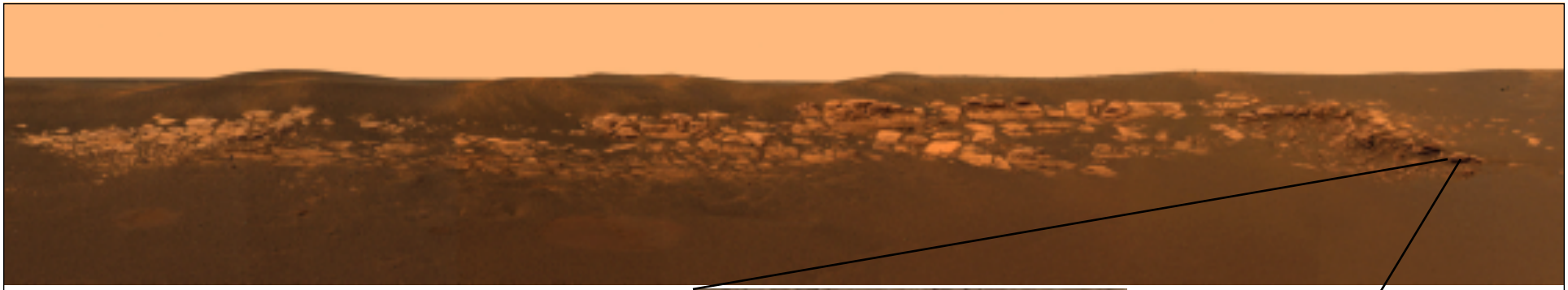


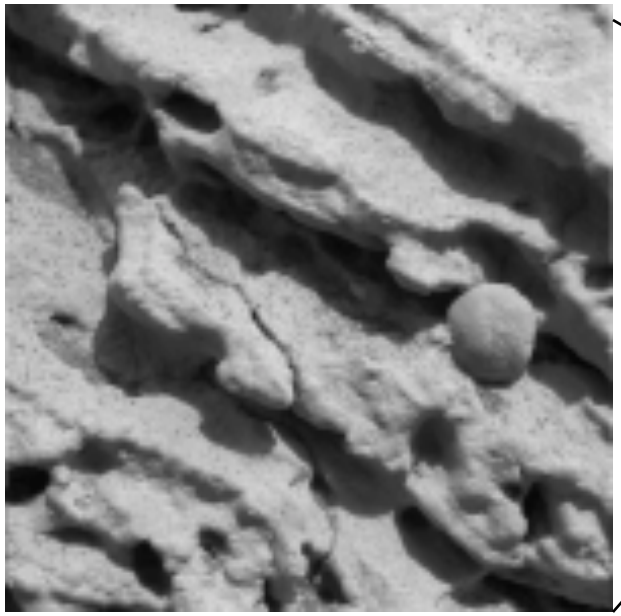
Eroded crater

The condition of craters indicates surface history.



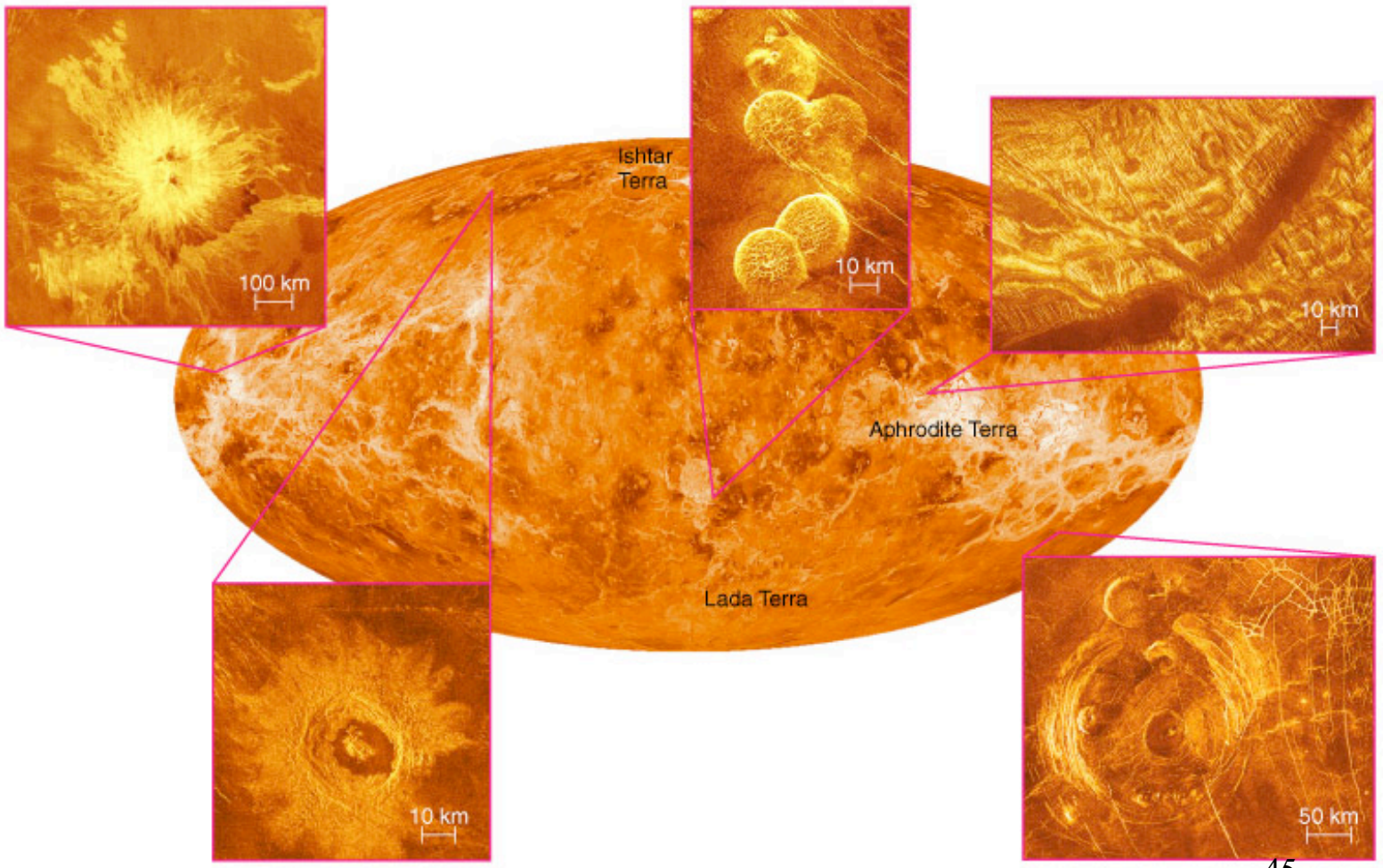
Past tectonic activity…



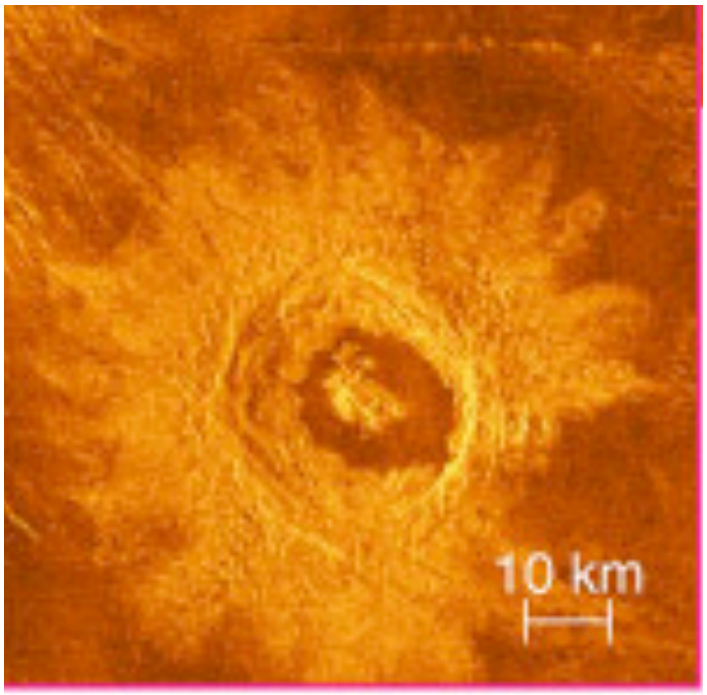


- 2004 *Opportunity* Rover provided strong evidence for abundant liquid water on Mars in the distant past.

Is Venus geologically active?

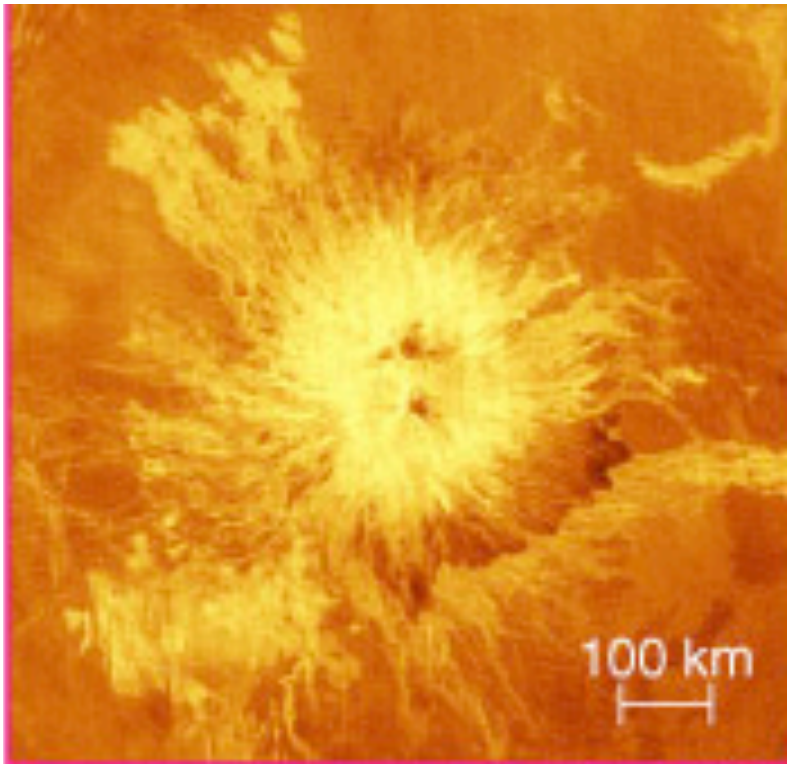


Cratering on Venus



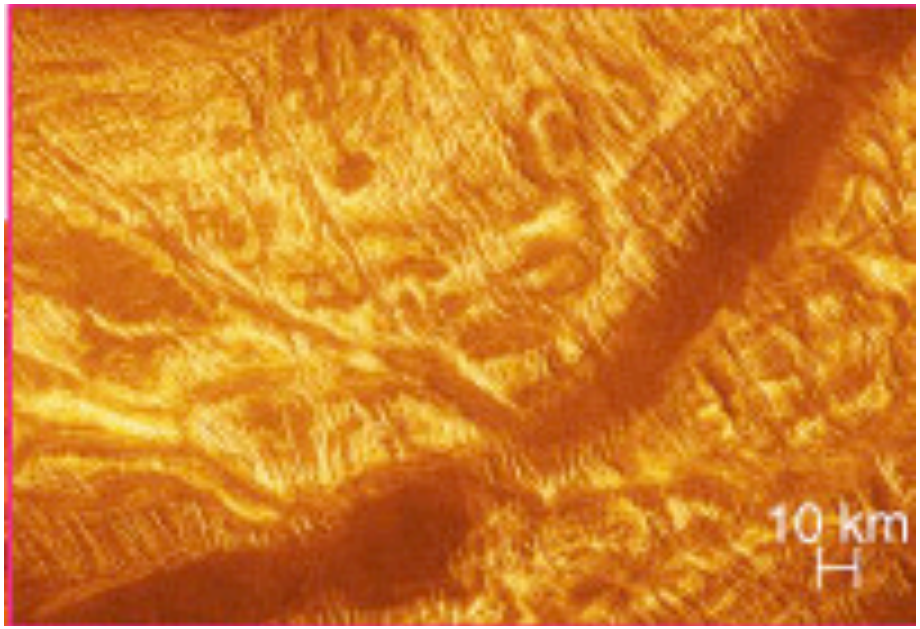
- Impact craters, but fewer than Moon, Mercury, Mars

Volcanoes on Venus



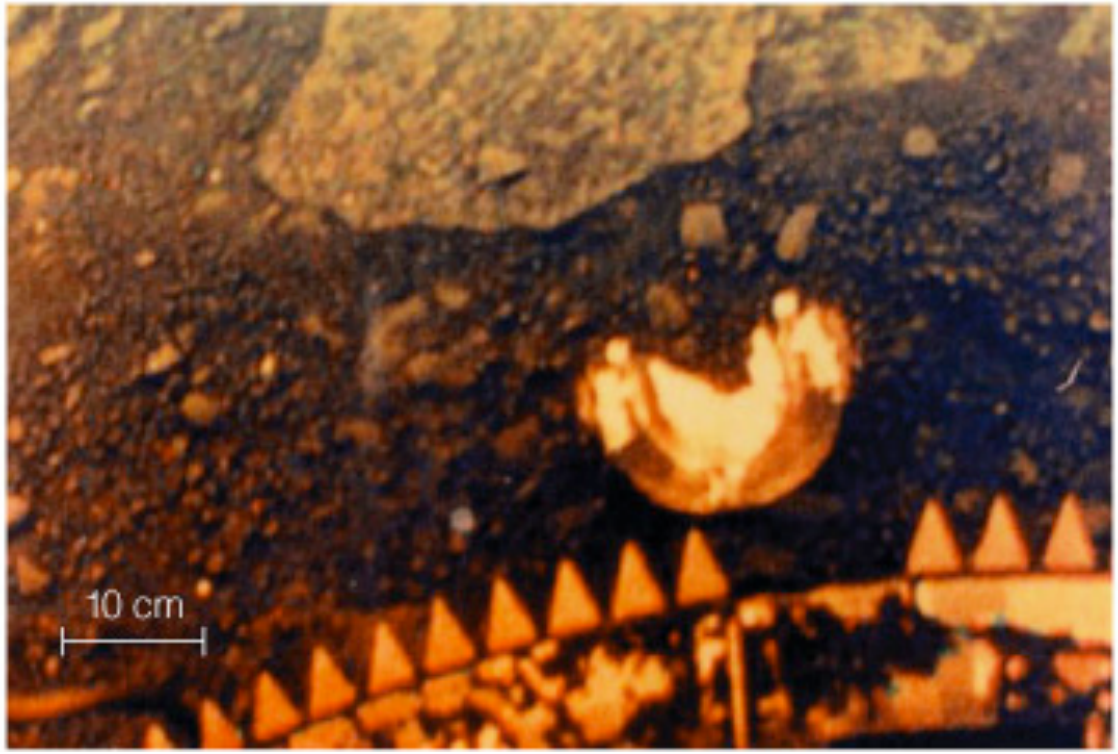
- Many volcanoes, including both shield volcanoes and stratovolcanoes

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 its entire surface seems to have been "repaved" 750 million years ago.

Terrestrial planet surfaces

- Craters are the normal state
  - need geological activity to erase
- e.g.,
  - Volcanism
  - Erosion
  - Plate tectonics