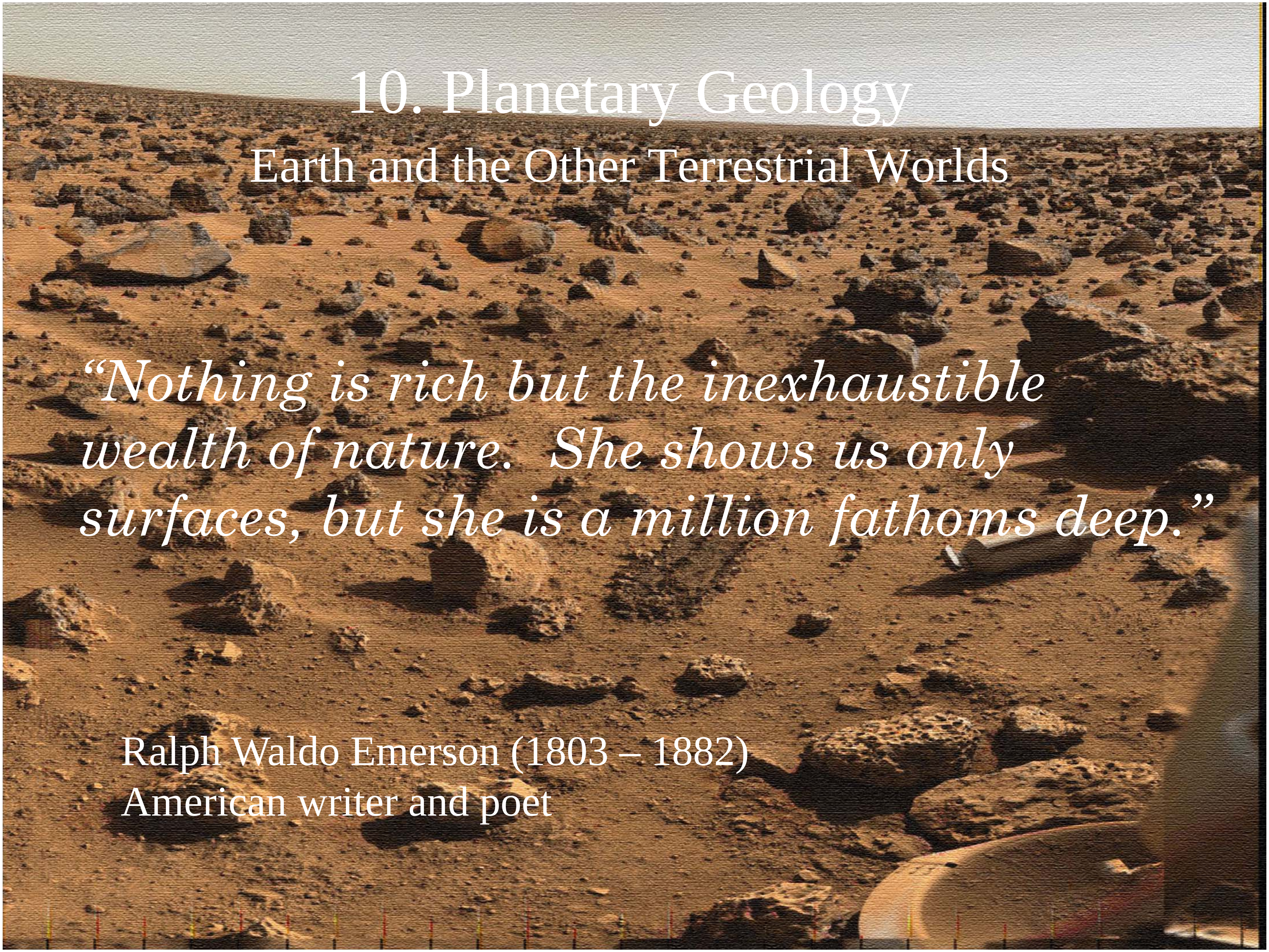
ASTR 1030
November 8, 2010

Exams graded yet. Av=75 StDev=13

Observatory opportunity Tuesday 9th

Guest Lecture – Prof Burns
Wednesday, November 10
at Planetarium



10. Planetary Geology

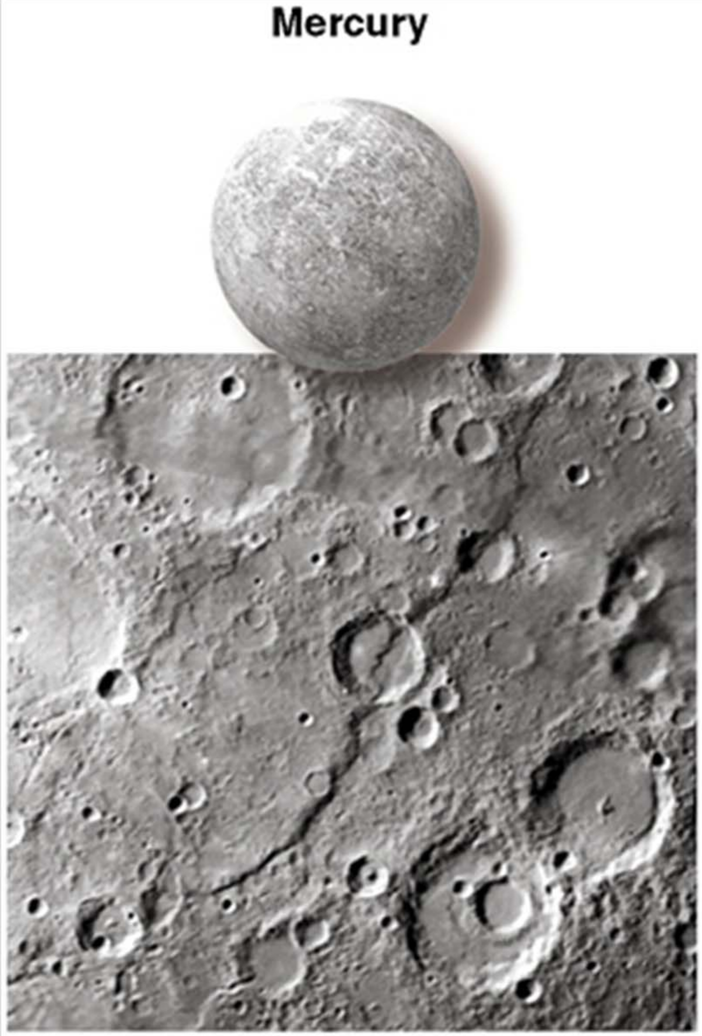
Earth and the Other Terrestrial Worlds

“Nothing is rich but the inexhaustible wealth of nature. She shows us only surfaces, but she is a million fathoms deep.”

Ralph Waldo Emerson (1803 – 1882)
American writer and poet

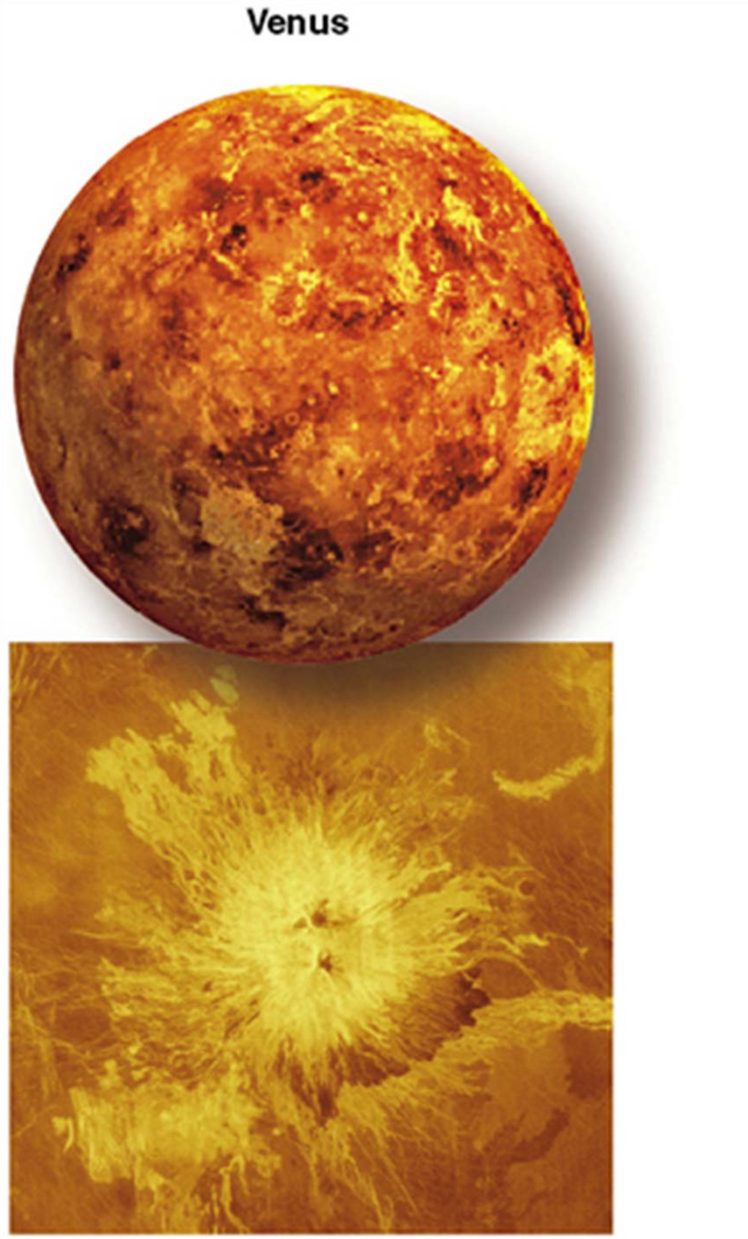
Mercury

- Small, dense
- Heavily cratered
- Some steep cliffs



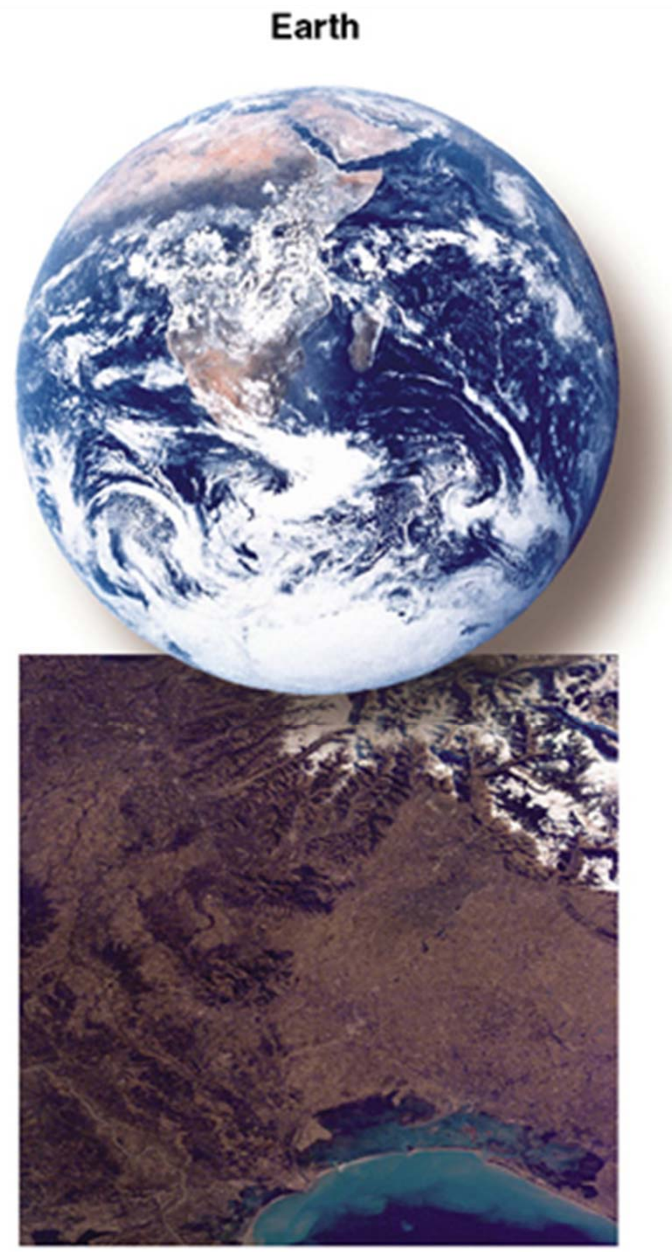
Venus

- Surface blocked by clouds
- Radar data used to map surface
- Not heavily cratered
- Volcanic activity
- Strange formations



Earth

- Very few craters
- Large variety of geologic features
  - Mountains
  - Volcanoes
  - Water
    - Canyons
    - valleys



Moon

- Heavily cratered like Mercury
- Evidence for volcanic activity

Mars

- Visible cratering
- Large volcanoes and huge canyons
- Signs of water

Comparison of Planetary Surfaces

- Mercury & the Moon
  - heavily cratered {scars from the heavy bombardment}
  - some volcanic plains
- Venus
  - volcanoes and bizarre bulges
- Mars
  - volcanoes and canyons
  - apparently dry riverbeds {evidence for running water?}
- Earth
  - all of the above plus liquid water and life

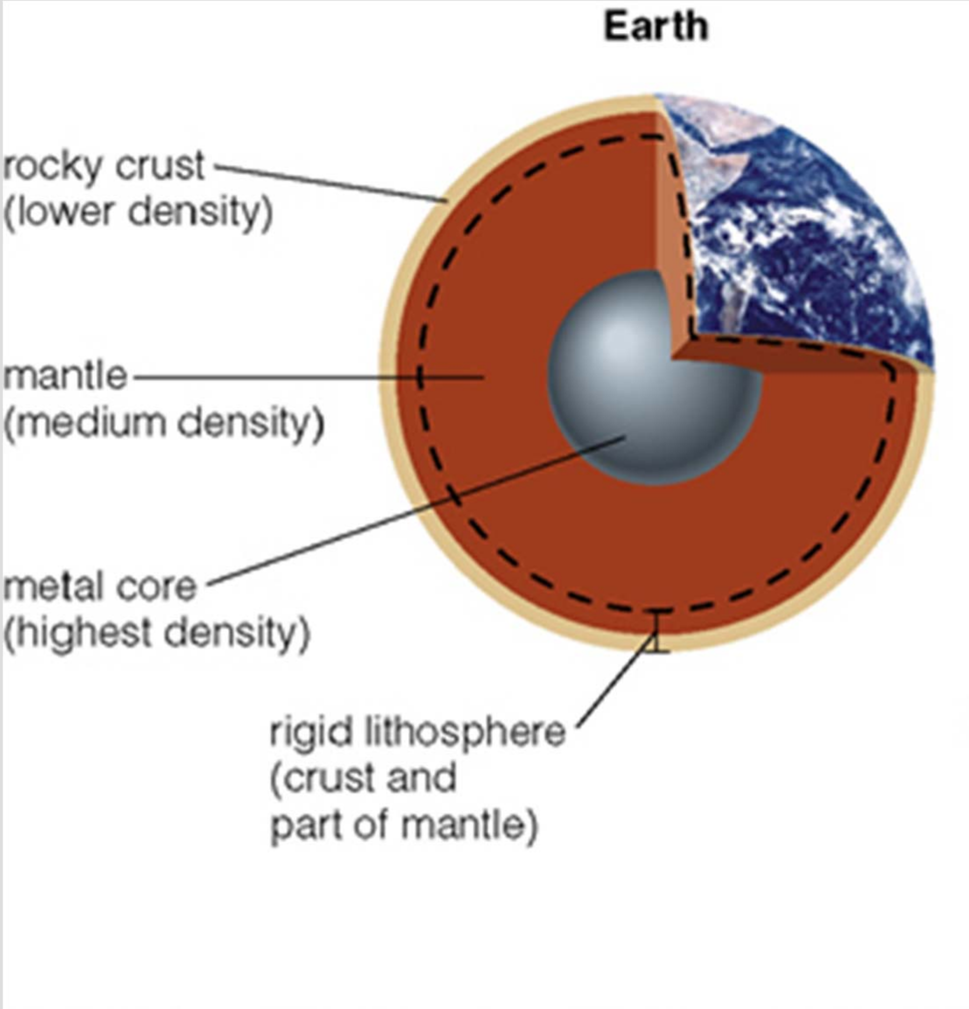
Planetary interiors

- Seismic waves can tell composition vs. depth
- Overall density versus surface density
- Magnetic field
- Analysis of lava

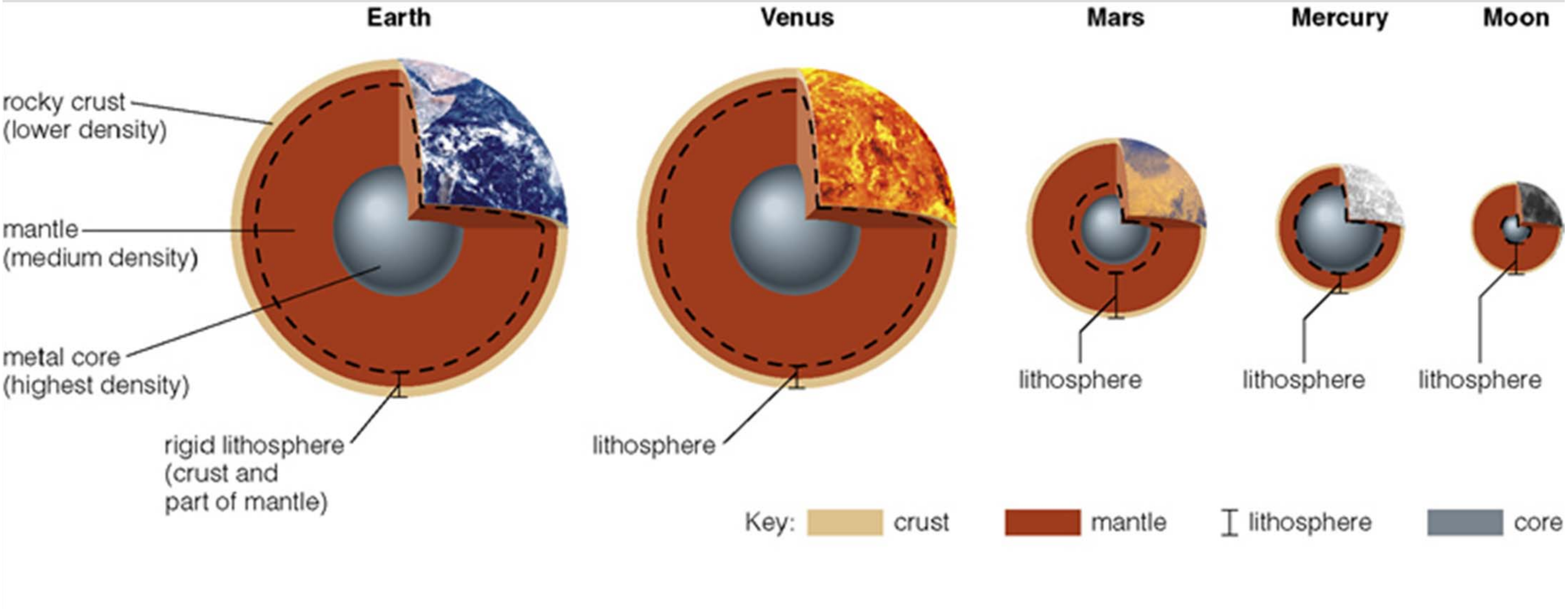
Inside the Terrestrial Worlds

- After they have formed, the molten planets differentiate into three zones:
  - core - made of metals
  - mantle - made of dense rock
  - crust - made of less dense rock, thin
- Lithosphere - the rigid, outer layer of crust & part of the mantle which does not deform easily

Inside the Terrestrial Worlds



Inside the Terrestrial Worlds



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Thin lithosphere = active geology (warm interior)
Thick lithosphere = inactive geology (cool interior)

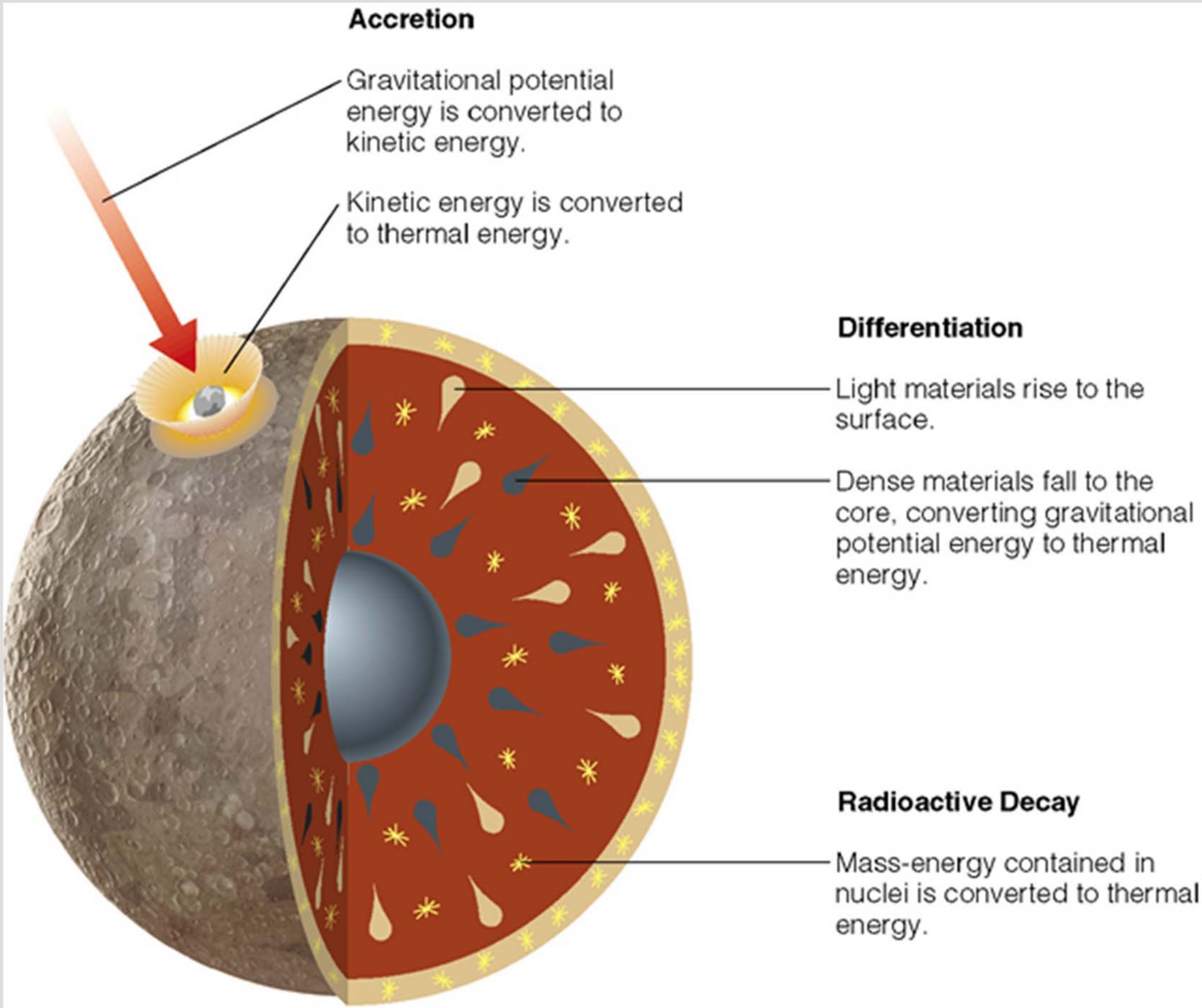
Crust and lithosphere thickness on Earth and Venus exaggerated to make them visible.

Heating the Terrestrial Worlds

- Planetary interiors heat up through:
  - accretion
  - differentiation
  - radioactivity

Supplies all the heat at the beginning (accretion, differentiation)

Supplies heat throughout the planet's life (radioactivity)



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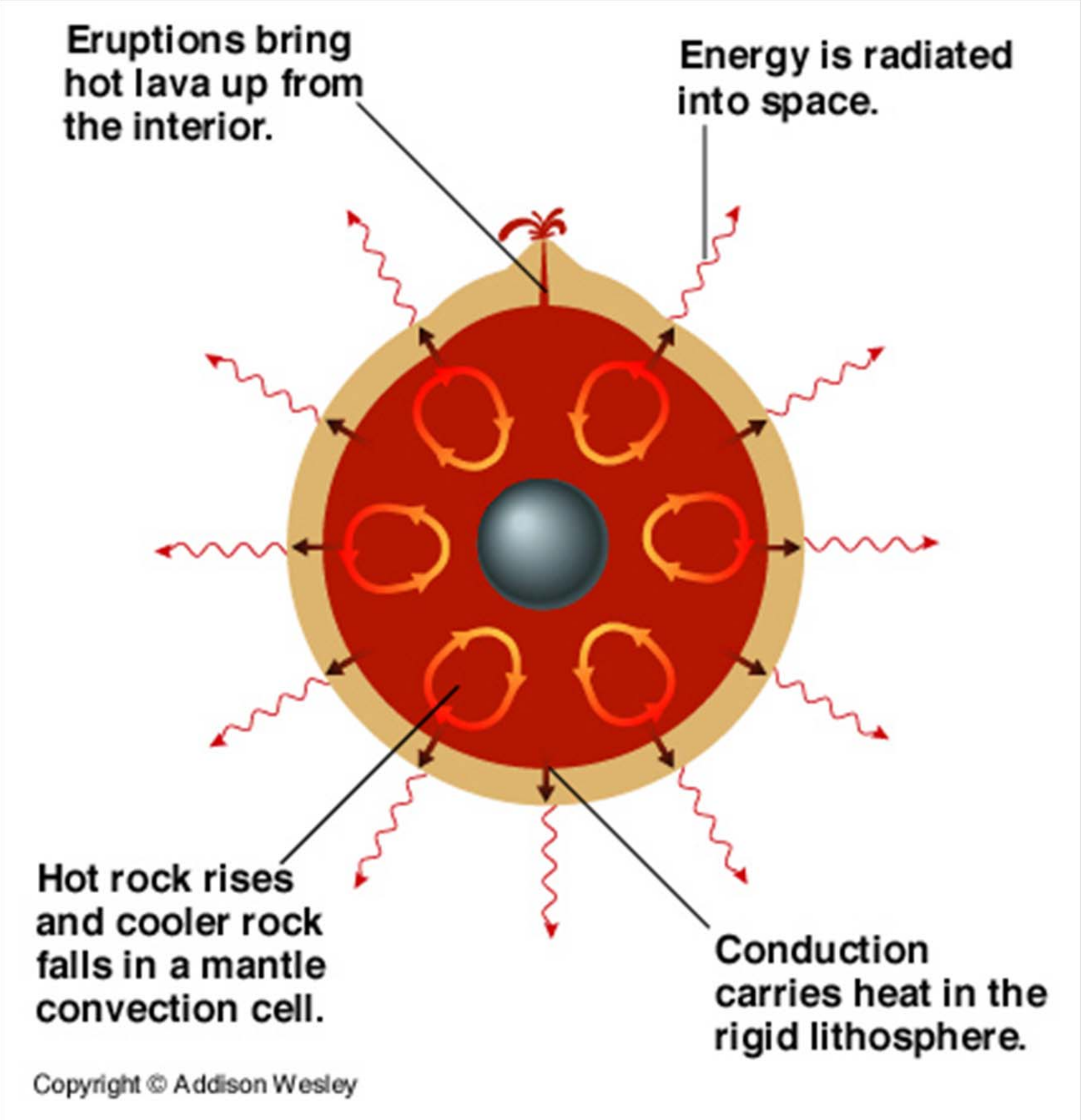
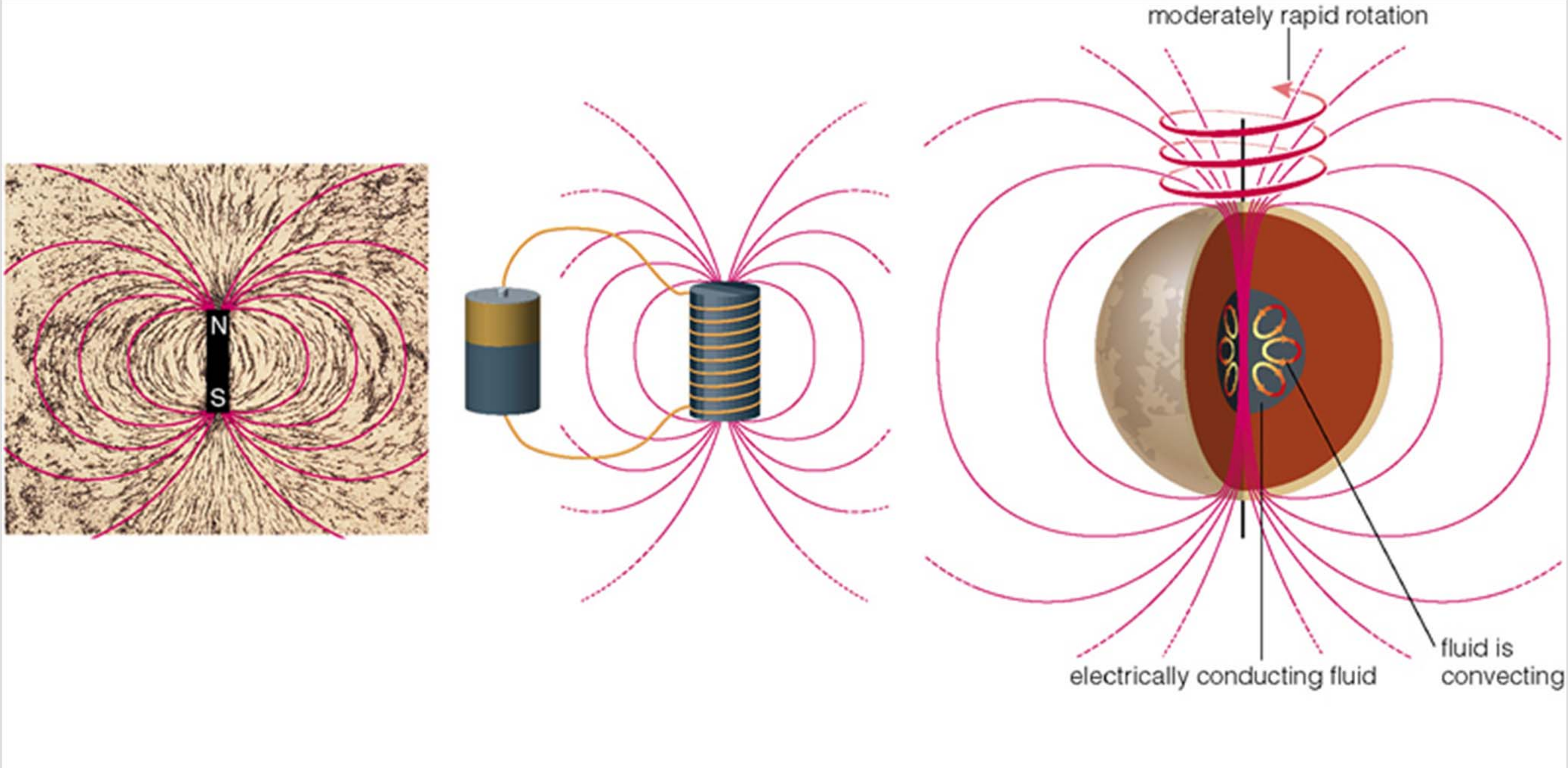
Cooling the Terrestrial Worlds

- Planets cool off through:
  - conduction - heat flowing on the microscopic level
  - convection - heat flowing on the macroscopic level (bulk motions)
  - eruptions - hot lava bursts through crust
- the *larger* the planet, the *longer* it takes to cool off!

Cooling the Terrestrial Worlds



Magnetic fields in planets



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Magnetic Fields

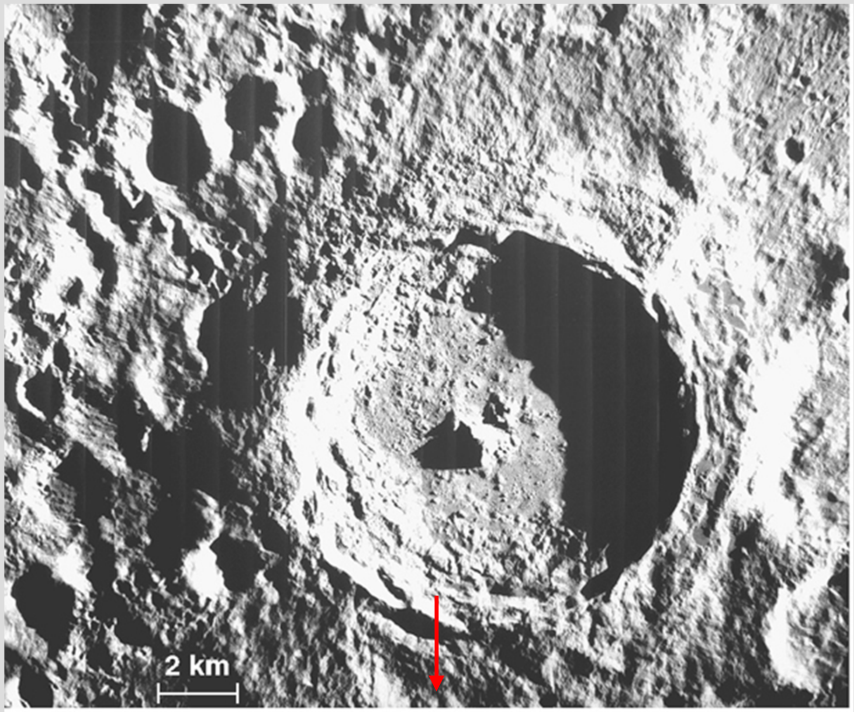
- Electric charges moving via convection in a molten iron core combined with moderately rapid rotation acts like an electromagnet $\Rightarrow$ magnetic field
  - Earth has a magnetic field
  - Venus, Mars, & the Moon do not
  - Mercury surprisingly has a weak magnetic field
- Also good for shielding life

Shaping Planetary Surfaces

- Major geological processes that shape planetary surfaces:
  - impact cratering: excavation of surface by asteroids or comets striking the planet
  - volcanism: eruption of lava from interior onto surface
  - tectonics: disruption of lithosphere by internal stresses
  - erosion: wearing down by wind, water, ice

Impact Cratering

- objects hit planet at 10 – 70 km/s
  - solid rock is vaporized
  - a **crater** is excavated
- matter is ejected in all directions
  - craters are circular
  – large craters have a central peak



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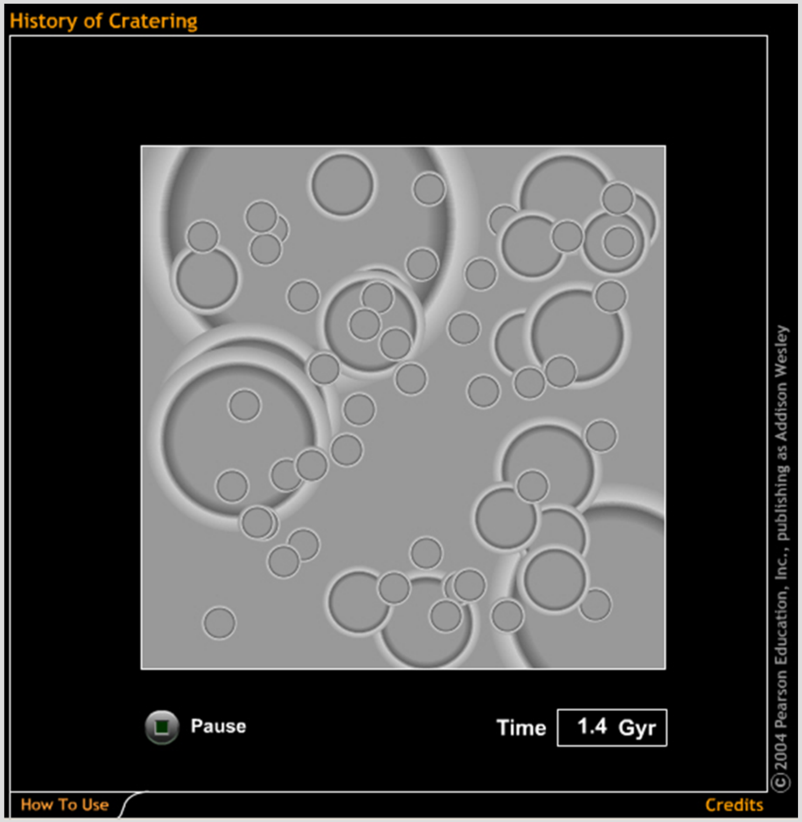
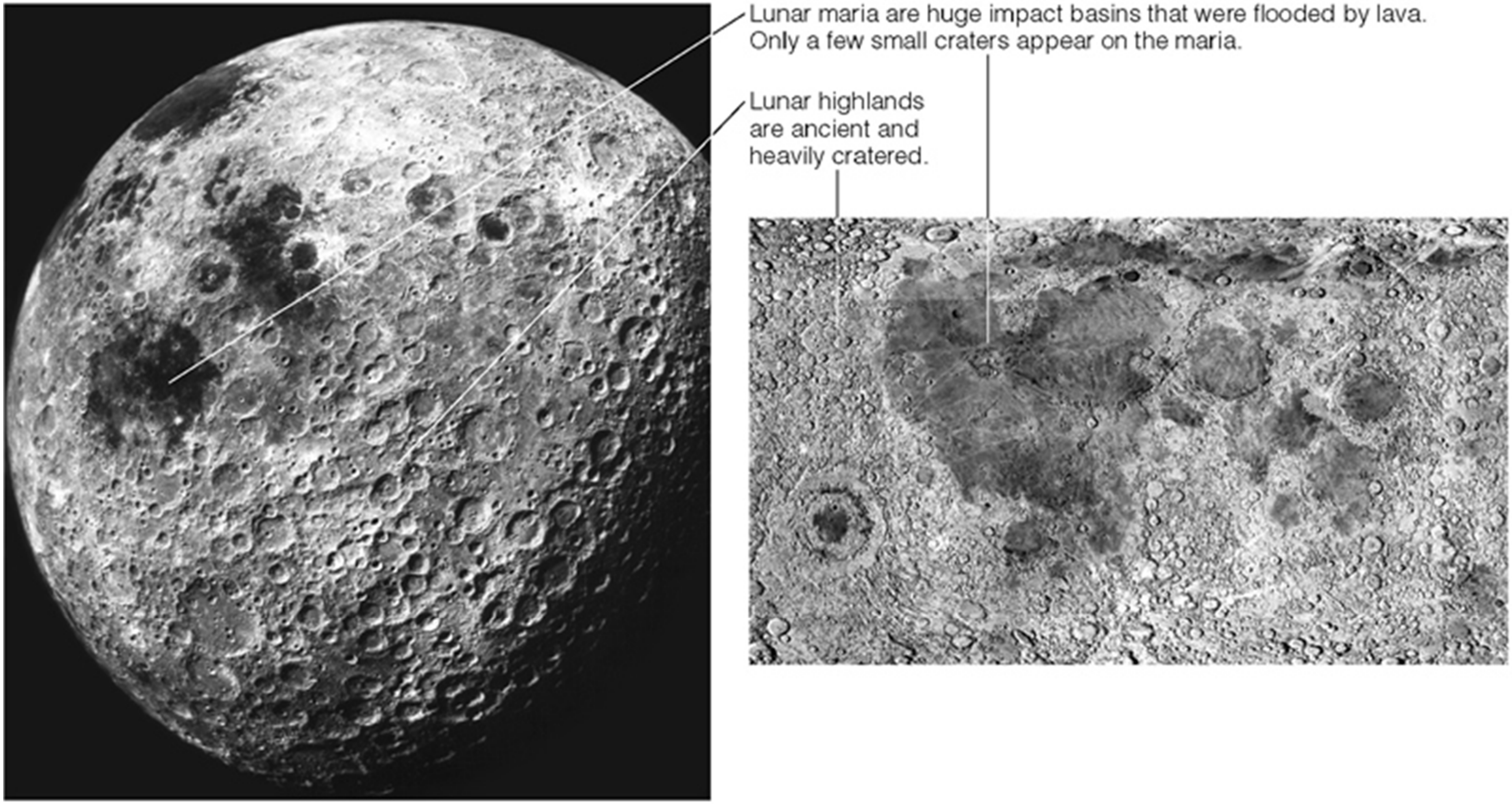
Counting Craters to find Surface Age

- Cratering rate decreased as Solar Systems aged.
- The older the surface, the more craters are present and larger ones as well.



Moon cratering as an example of age



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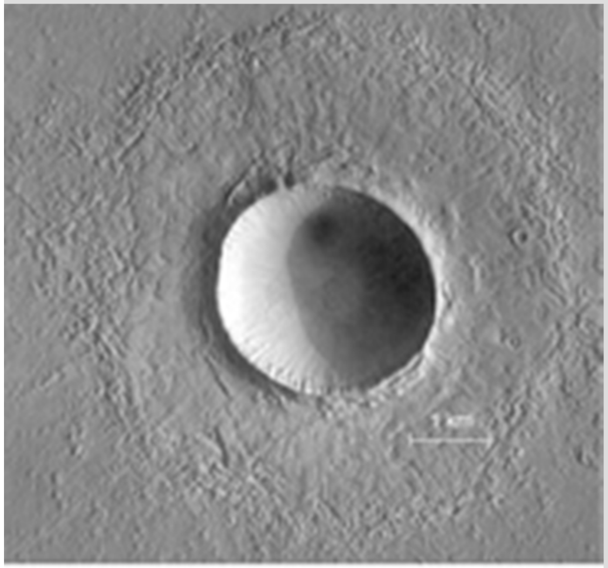
Cratering and surface conditions



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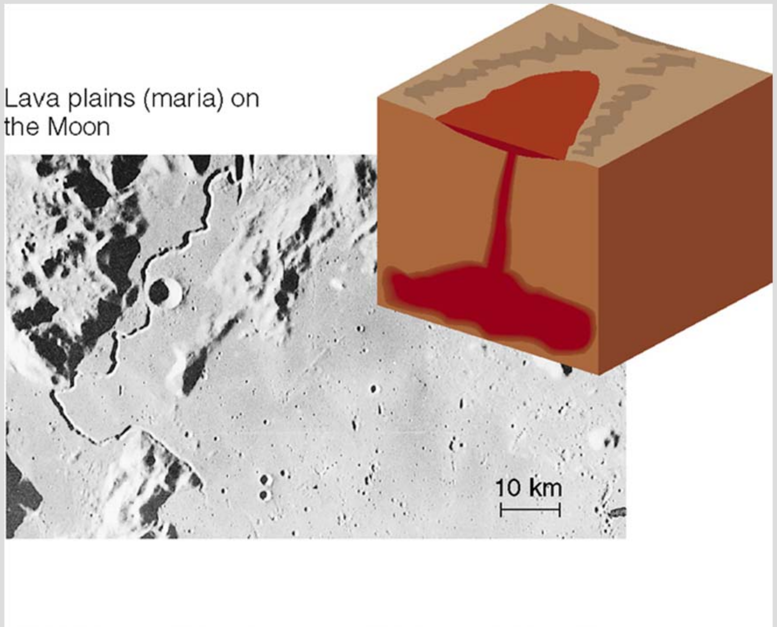
Volcanism

- Underground, molten rock, called **magma**, breaks through cracks in the lithosphere.
- Terrestrial planets need to be large to have volcanism
- Trapped gases are released:
  - H_2O, CO_2, N_2
  - Creates atmospheres
- Viscosity of **lava** (typically basalt) determines type of volcano



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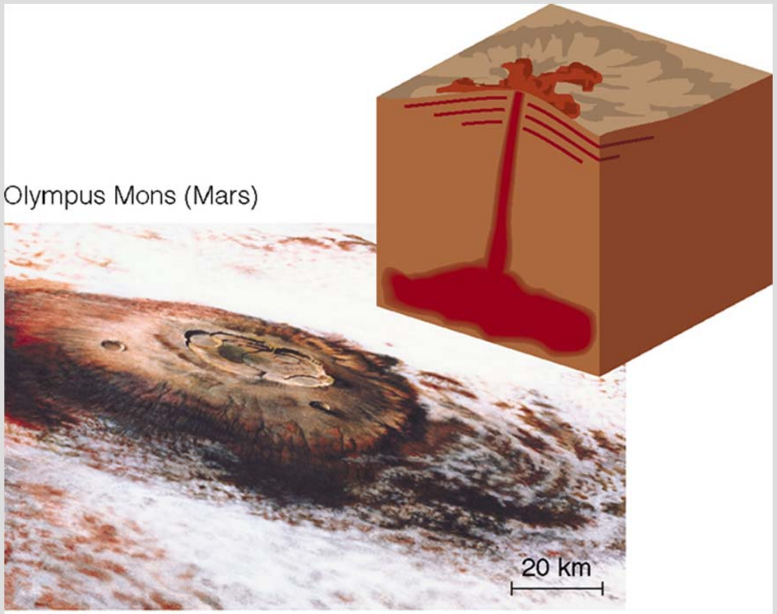
Low viscosity = volcanic plains

Medium viscosity = shield volcano

High viscosity = stratovolcanoes



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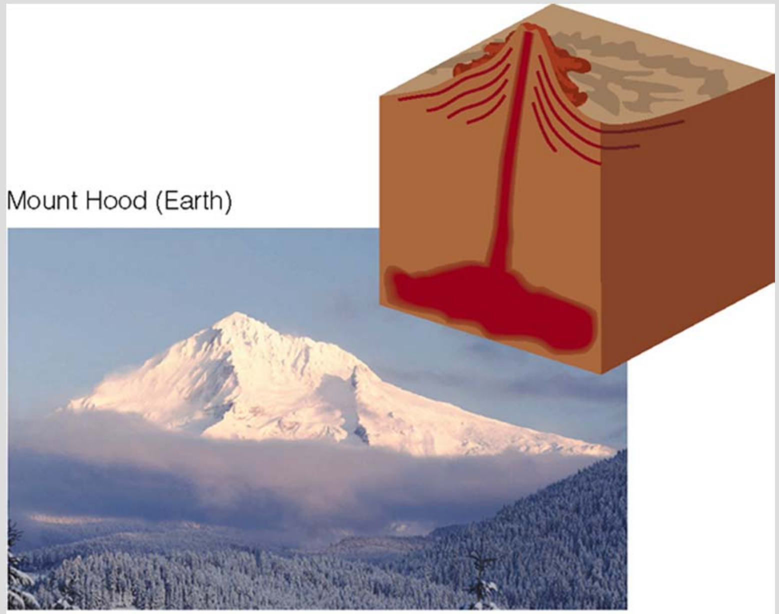

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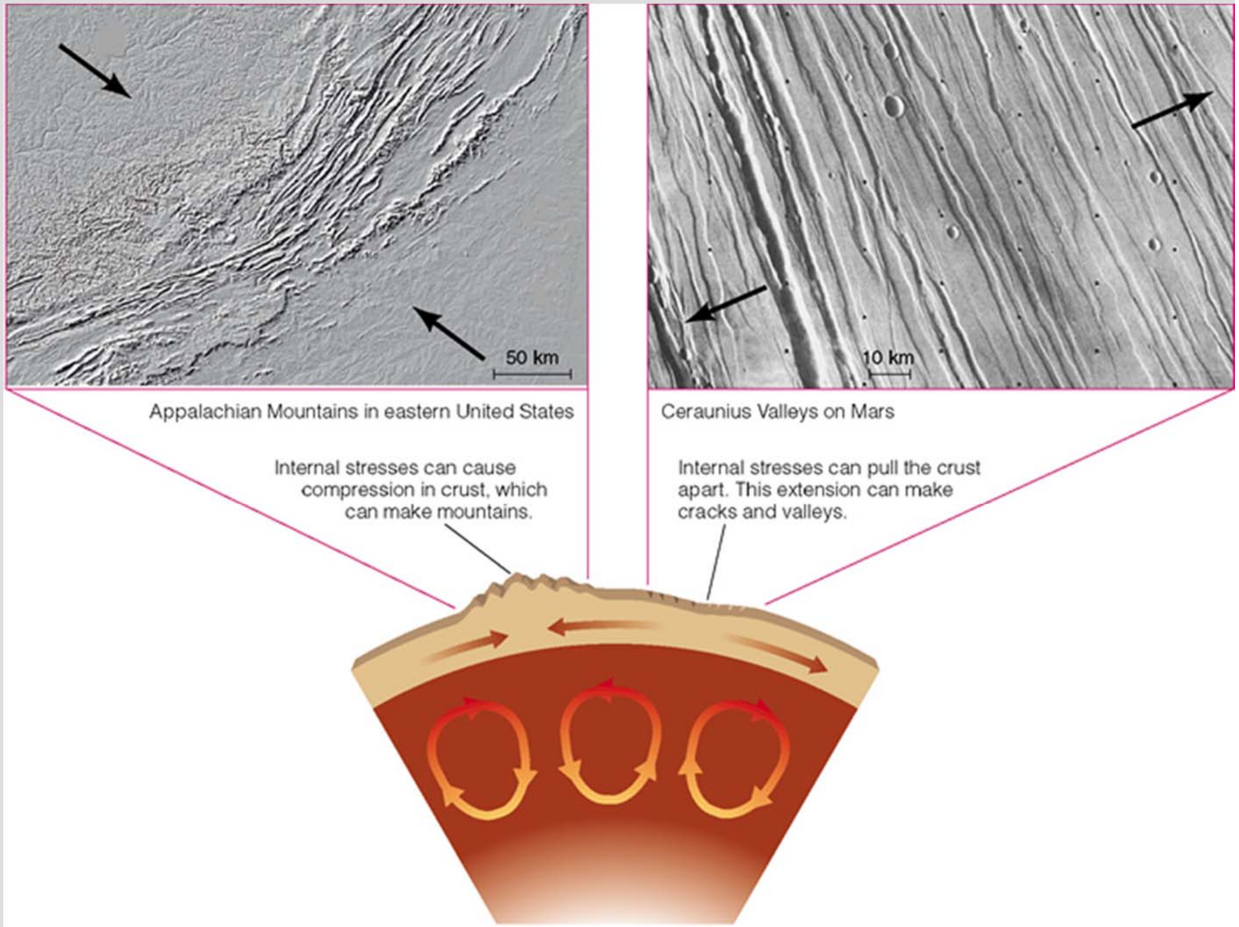
Tectonics

- convection cells in the mantle causes both:
  - compression in lithosphere
    - mountains are produced
  - extension in lithosphere
    - valleys are produced
- mountains & valleys appear on the surface
- Need mantle convection and a thin lithosphere



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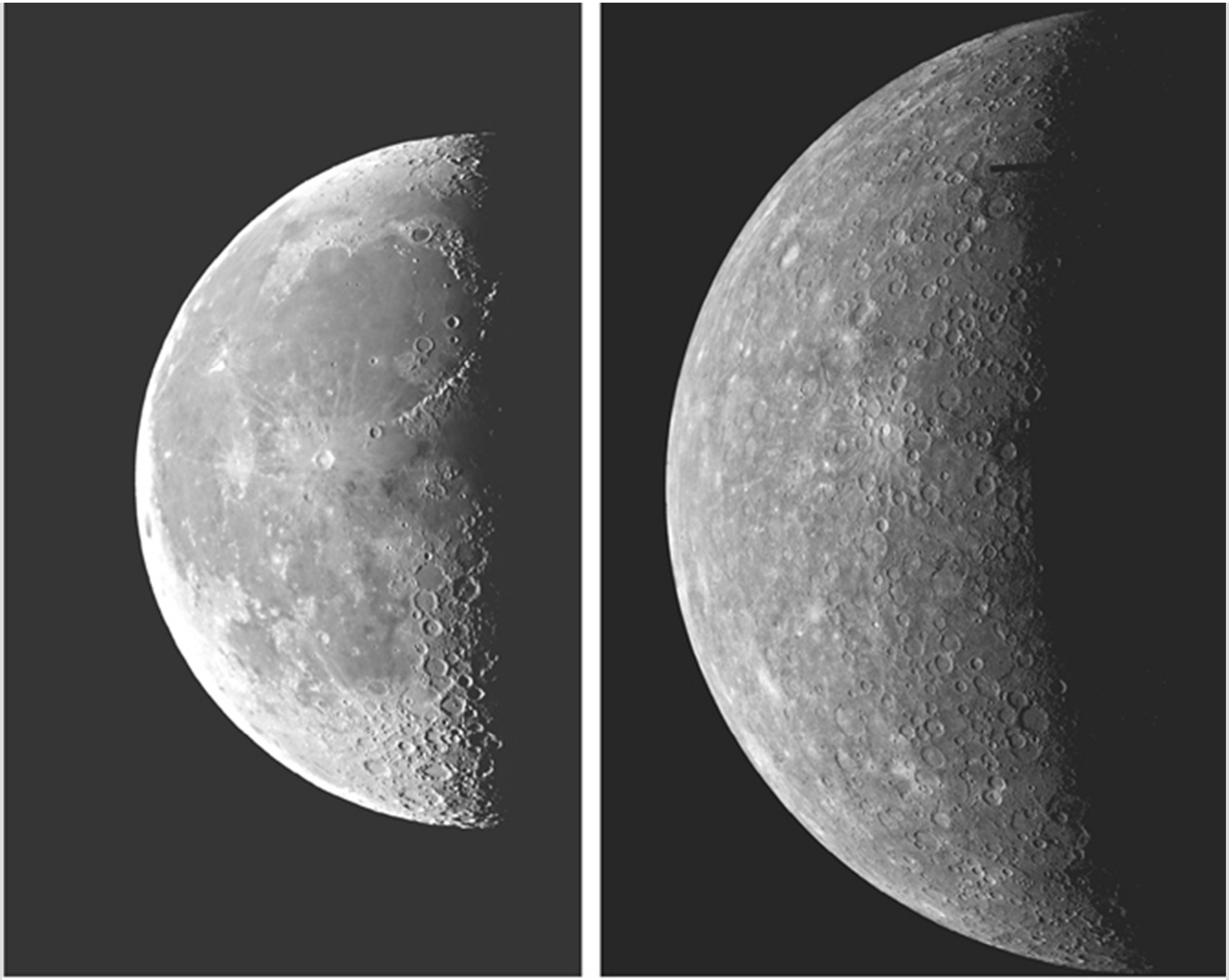
Erosion

- movement of rock by ice, liquid, or gas
  - valleys shaped by glaciers
  - canyons carved by rivers
  - sand blown by wind
- erosion not only wears down features, it also builds them:
  - sand dunes
  - river deltas
  - sedimentary rock

How Planetary Properties affect each Process

- impact cratering
  - # of impacts same for all planets
  - larger planets erase more craters
- volcanism & tectonics
  - requires interior heat
  - retained longer by large planets
- erosion
  - requires an atmosphere
  - large size for volcanic outgassing
  - moderate distance from Sun
  - fast rotation needed for wind



Moon Mercury

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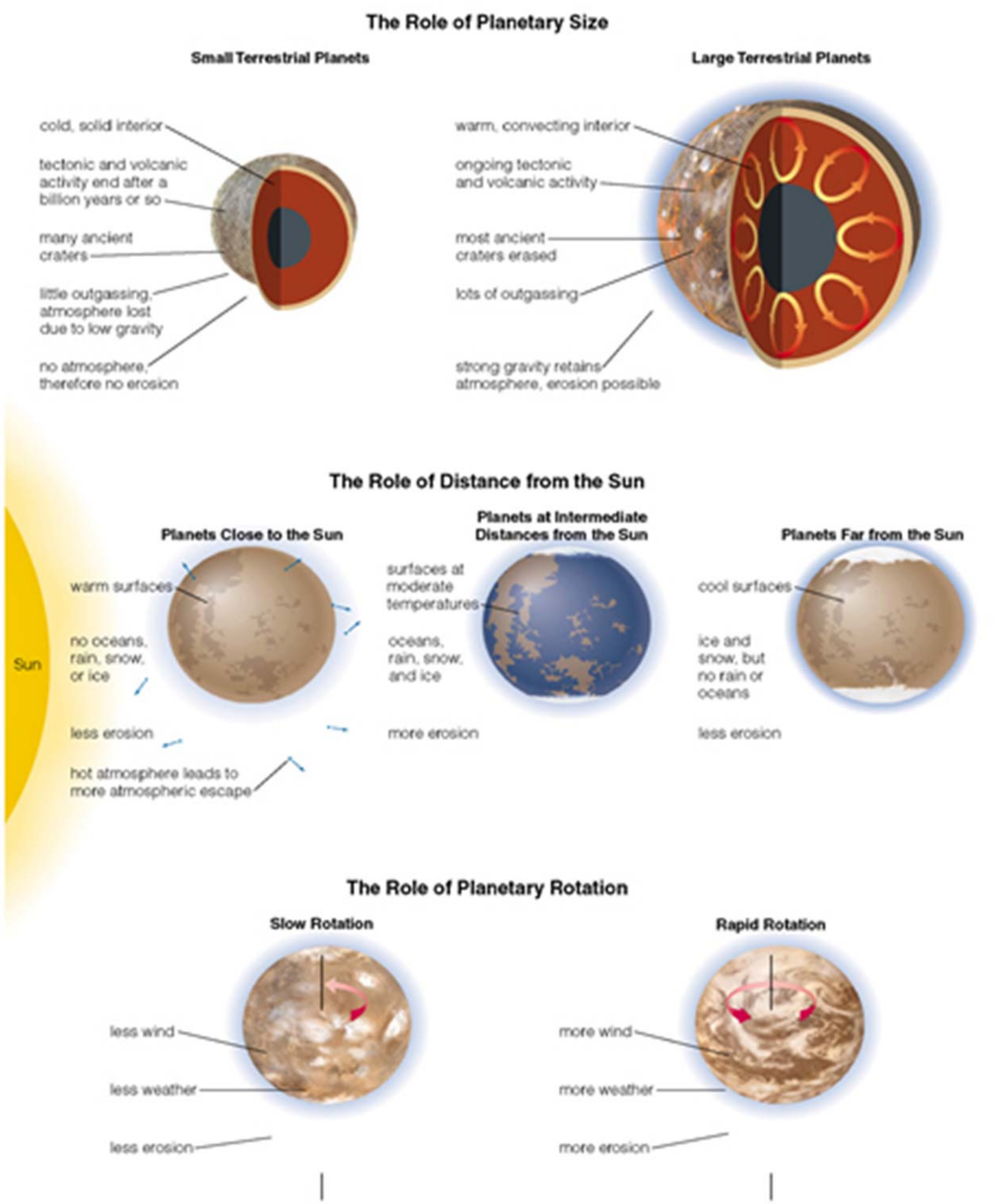

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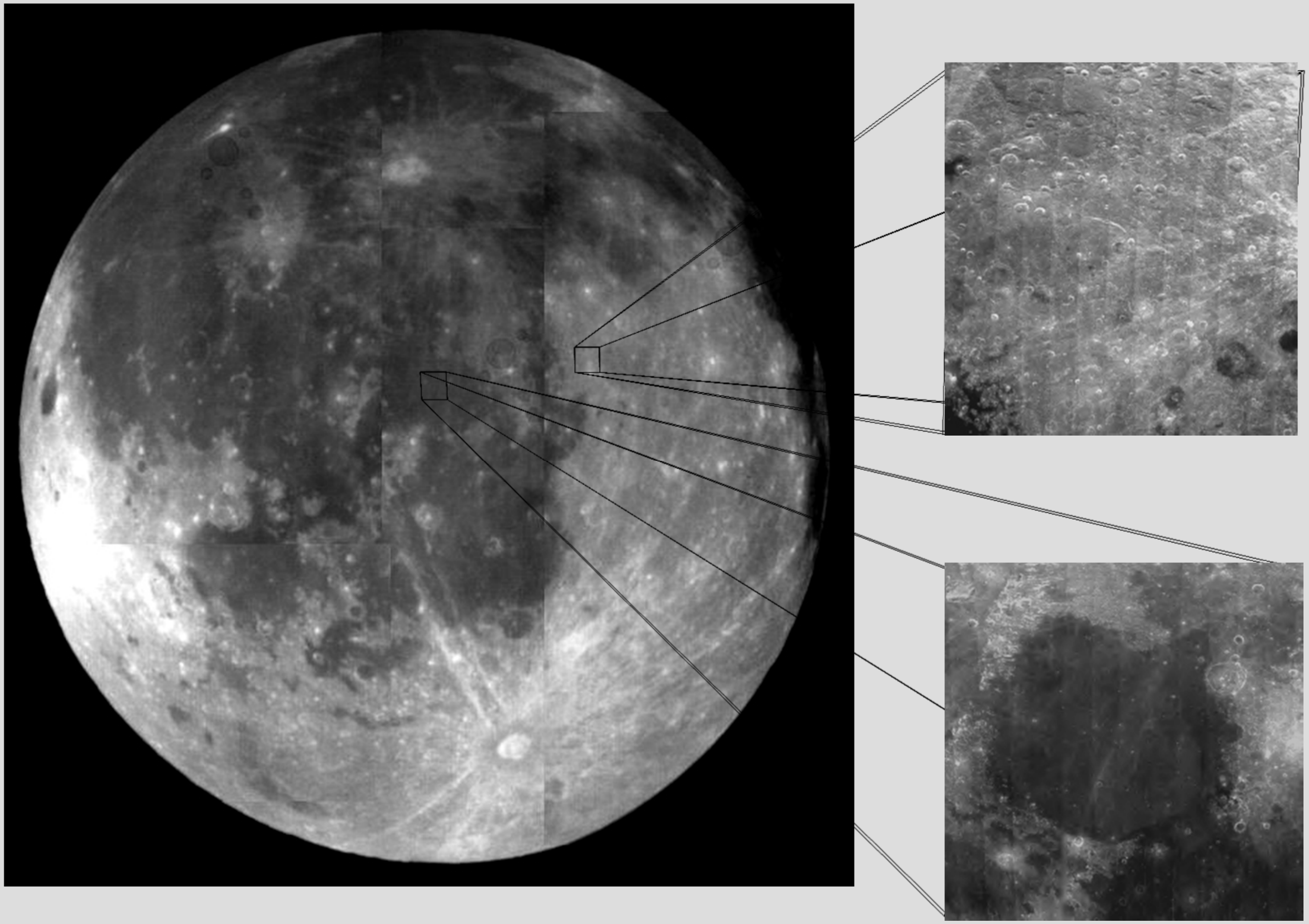
The Moon (☽)



highlands
older surface
more craters

maria
younger surface
3 – 4 billion yrs
fewer craters
dark iron-rich rock

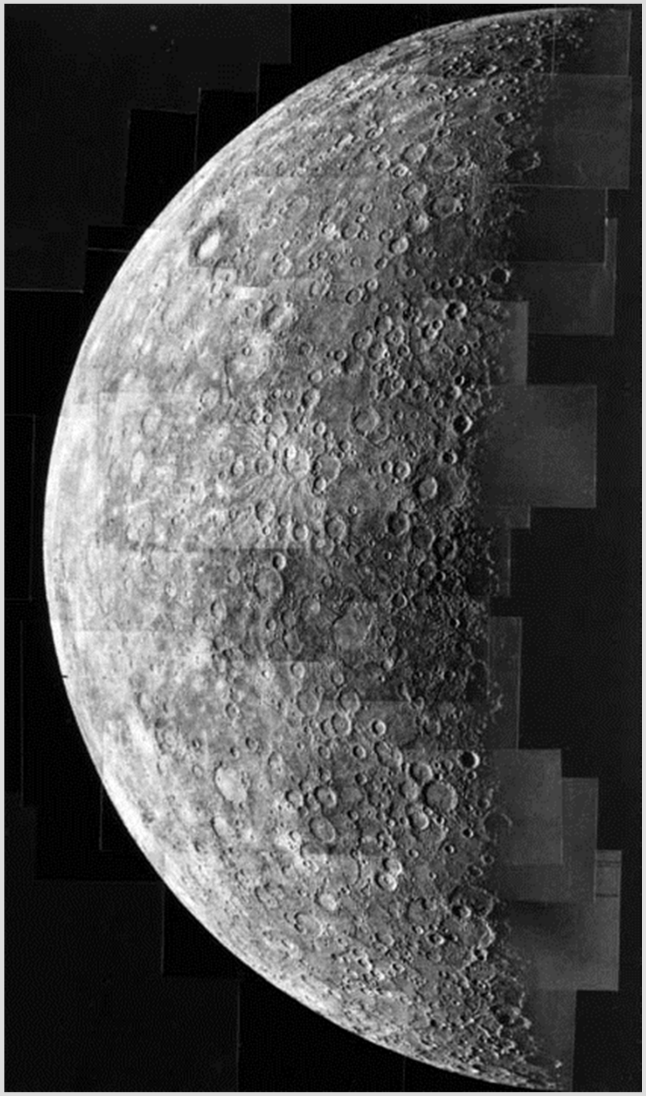
heavily cratered, no atmosphere, geologically inactive

Formation of the *Maria*

- The Moon once had a molten interior that later hardened.
- Several large impacts made huge crater basins.
  - left cracks in lithosphere below
  - at a later time, molten basalt (probably heated by radioactive decay) leaked through the cracks
- This “runny” lava filled in the basins.

Mercury

- dead planet with no atmosphere
- has no *maria*, but small lava plains
- has fewer craters than the Moon
- craters are shallower than Moon
  - due to higher gravity on Mercury
- evidence for tectonic processes
- evidence for ice at the N pole

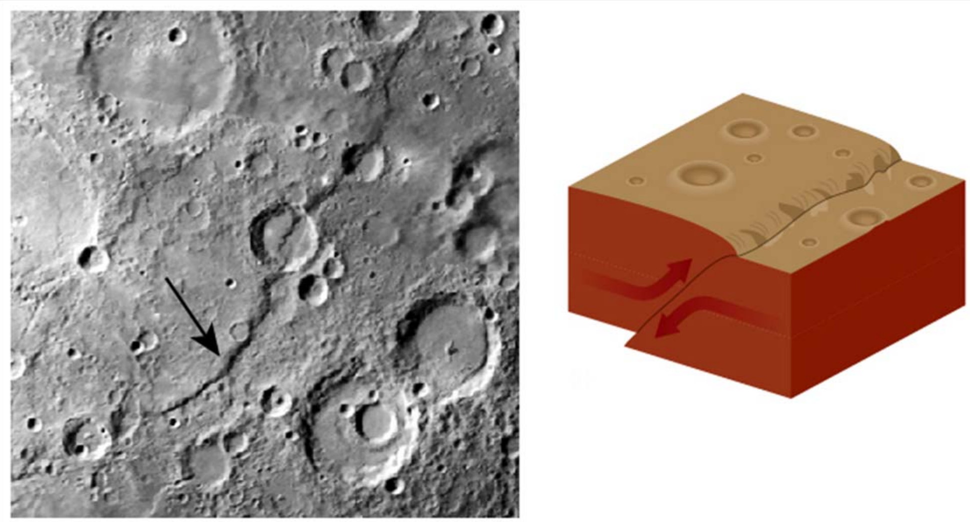


Volcanism & Tectonics in Mercury's Past

Closeup view shows small lava plains that have covered up craters

- tectonic stresses
  - 3 km-high cliffs, 100s km long
  - formed when crust contracted
  - no evidence for expansion features
  - implies the entire planet shrunk!

- volcanism
  - lava plains are small
  - but they are found all over the planet



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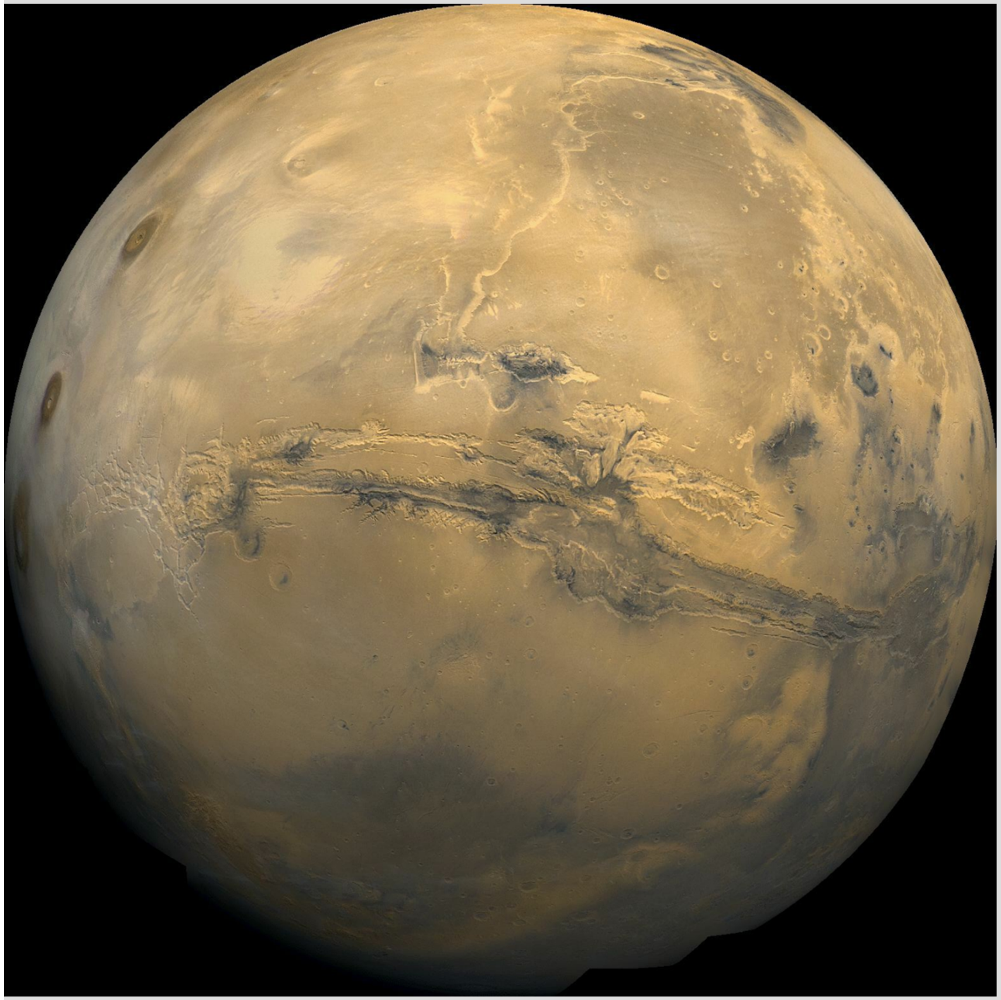
Mars

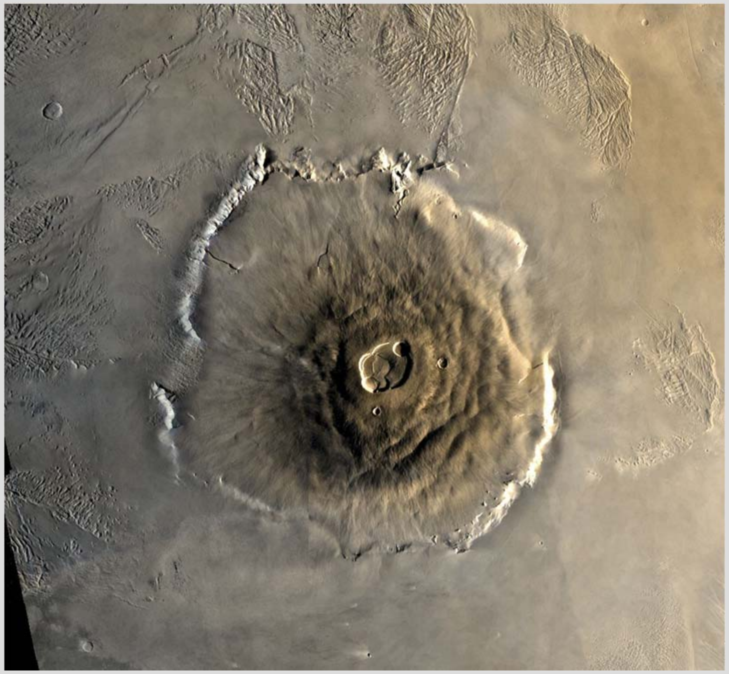
- Larger than Moon and Mercury but only half of the Earth’s radius and only 10% of it’s mass.
- Orbits 50% farther
- Size and distance from sun have dictated Mars’ geological history.

Mars



- mountains & canyons
  - *Valles Marineris*
- volcanoes
- thin atmosphere (CO_2)
- no plate tectonics
- evidence for water erosion
- Southern hemisphere higher elevation and more craters

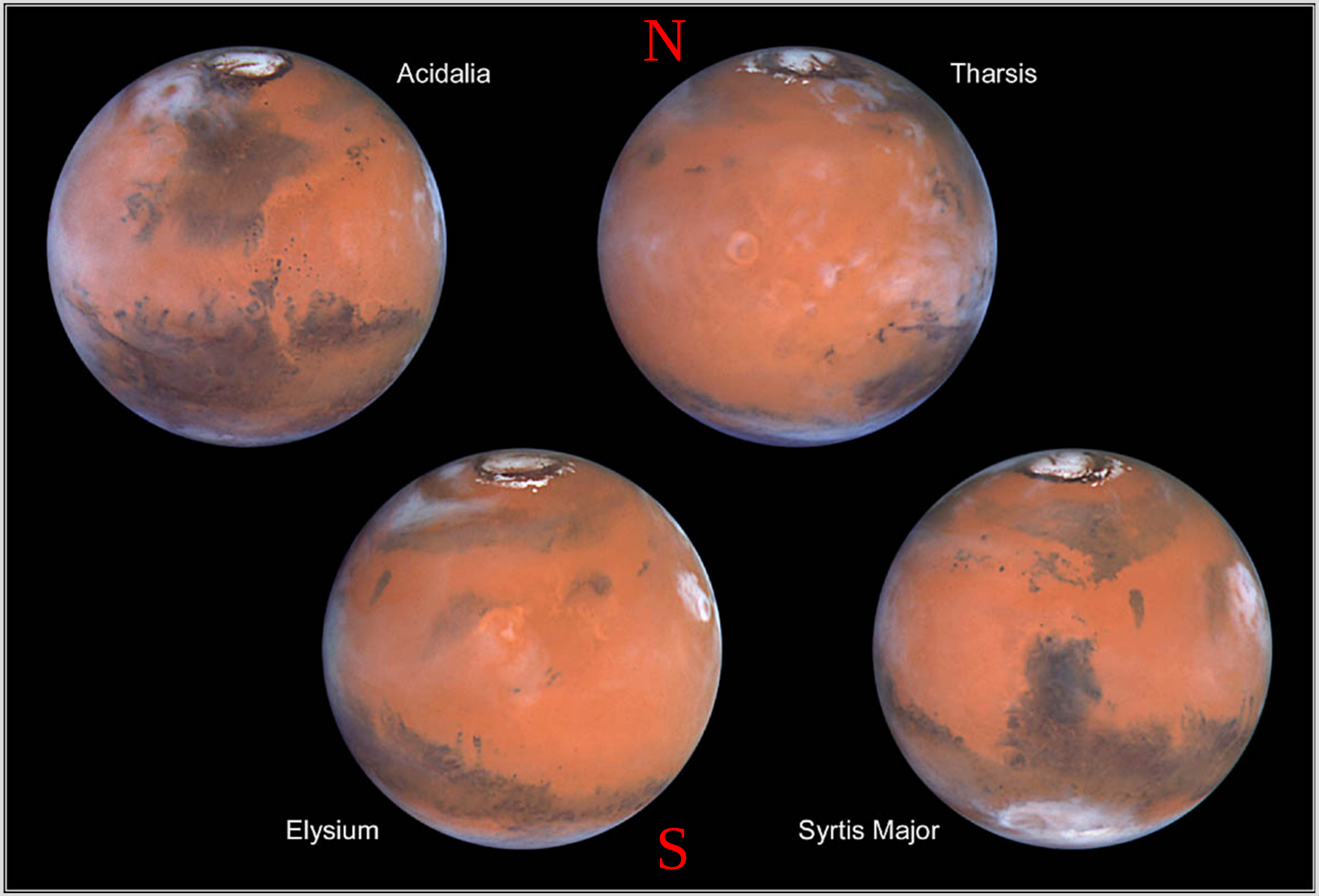
Mars



- *Olympus Mons*
  - the largest volcano in our Solar System, size of Arizona and 3x taller than Everest
  - it is located atop the *Tharsis Bulge* along with several other volcanoes

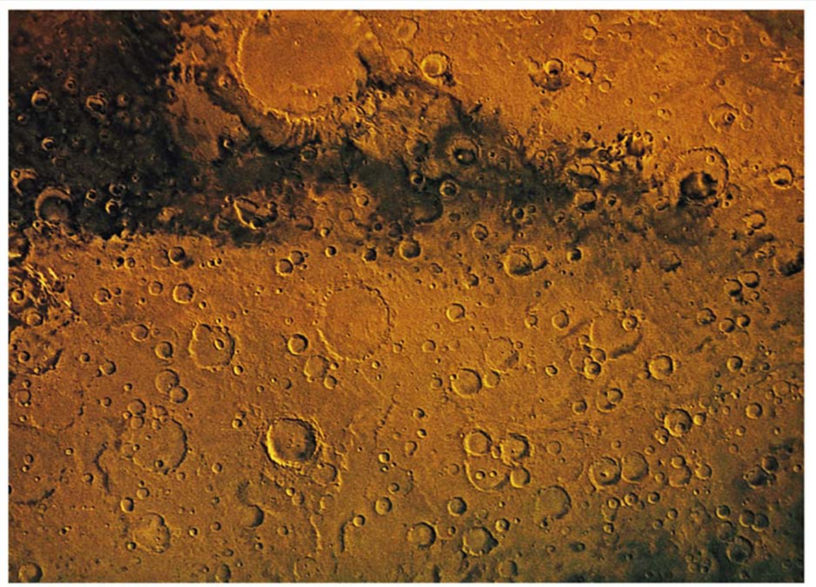
- Mars has a rotation period & axis tilt almost identical to Earth’s
  - this implies that Mars has seasons
  - ice cap and dust variations

Four images of Mars in one Martian Day
Summer in North, Winter in South



Ancient Water on Mars

- Liquid water can not exist on Mars today.
  - temperatures below freezing
  - air pressure too low
- Dry river channels in southern highlands
  - heavily cratered terrain (> 3 billion years old)



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- Some craters are eroded.
  - implies rainfall
  - crater lakes
- Mars was warm & wet over 3 billion years ago.

Recent Water on Mars?

- Liquid water could exist temporarily with today's temperatures and air pressures…in a <u>flash flood</u>
- Underground water seeps out to form erosion gullies
  - these gullies were observed on a crater wall
  - at their size, sandstorms would cover them in few million yrs
  - such floods have occurred within the last few million years


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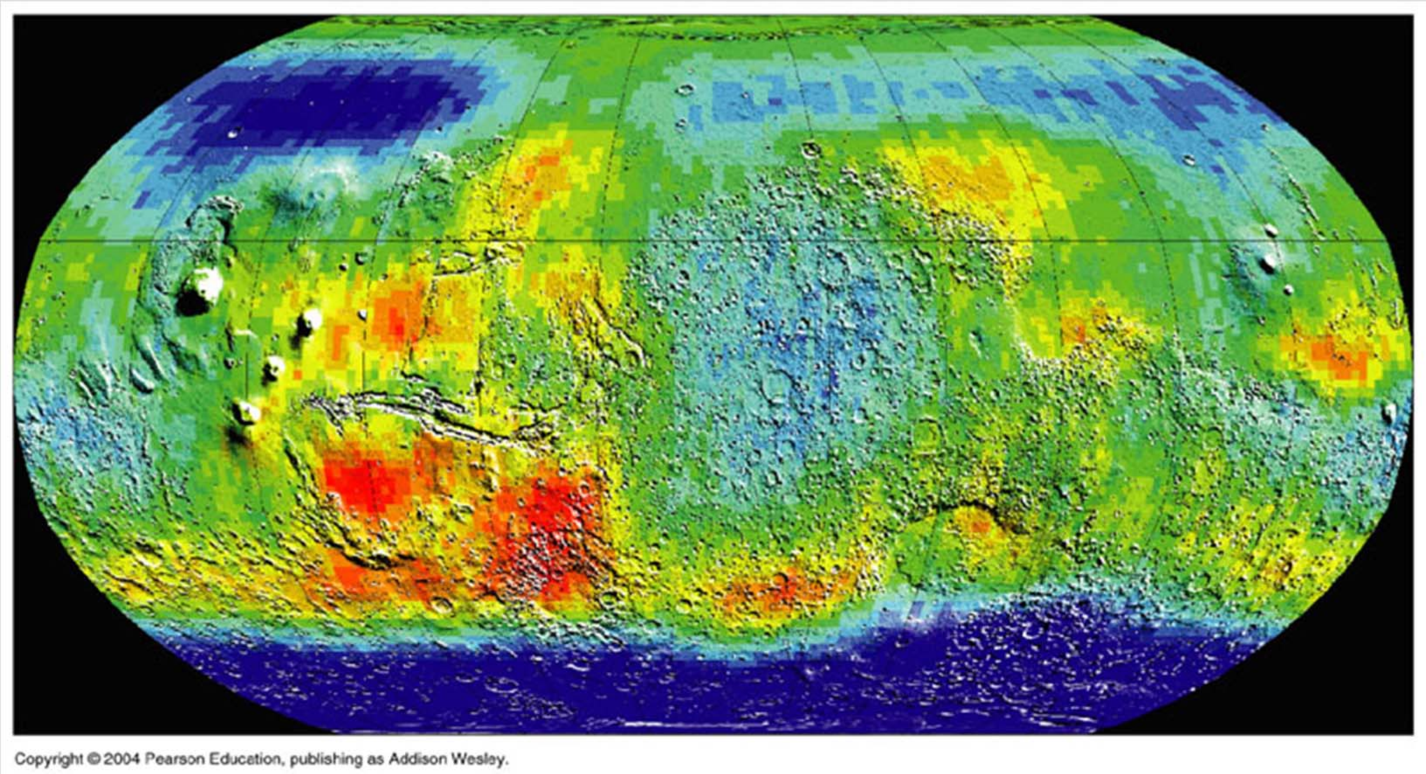
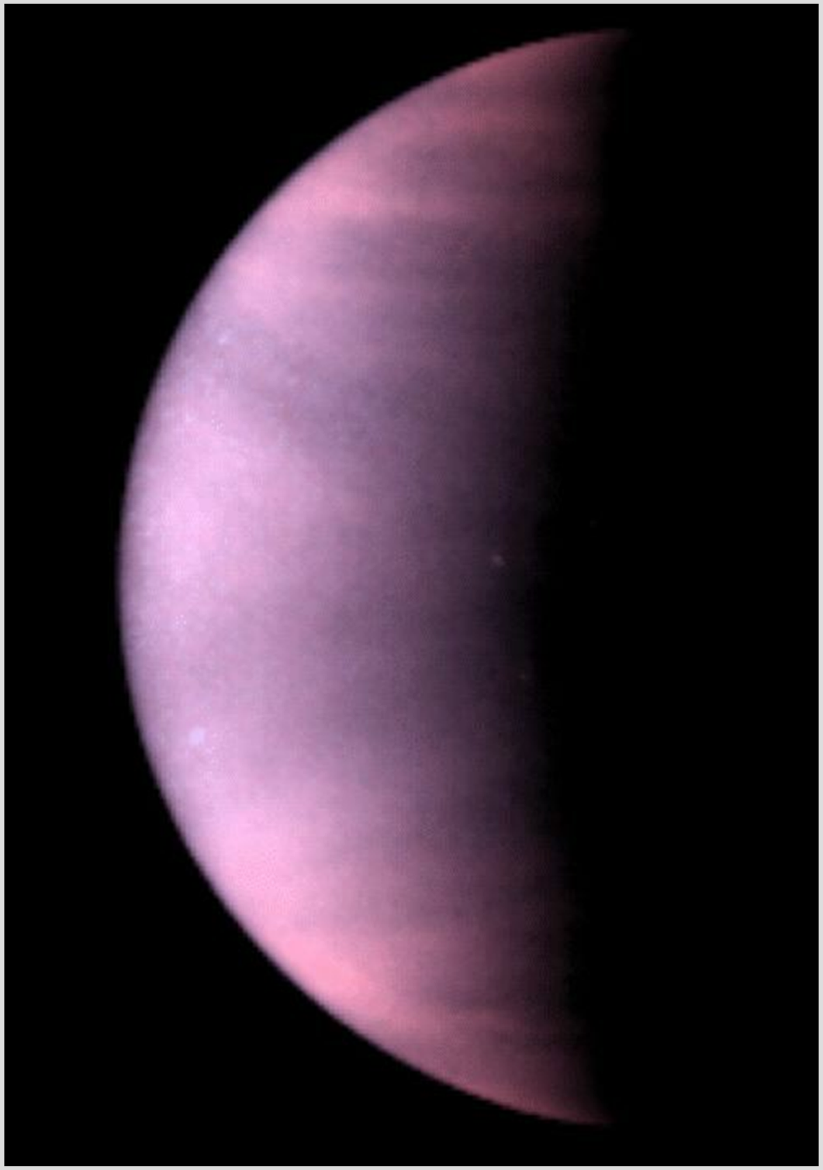
Water on Mars?

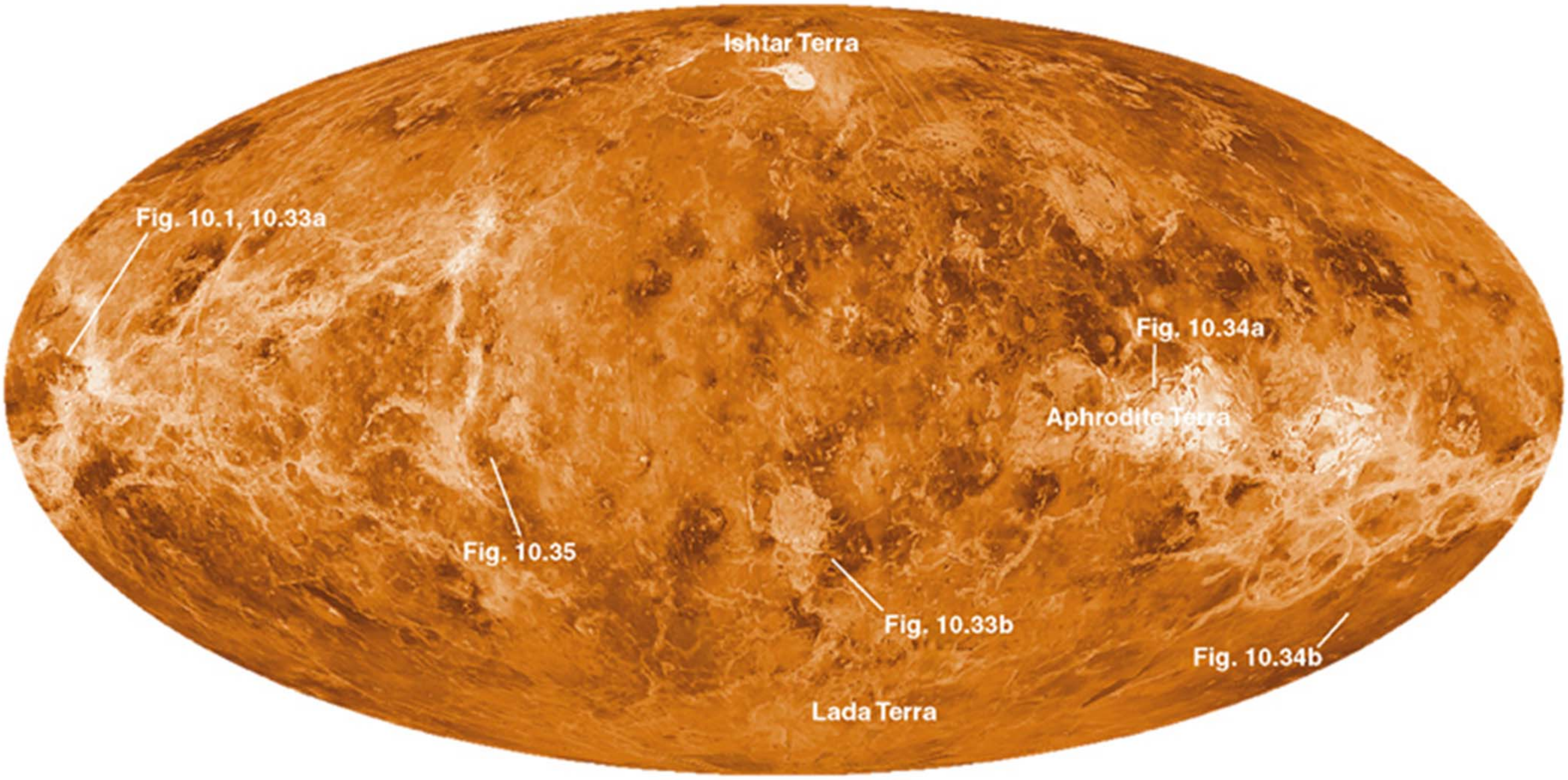


- Recent results from the *Mars Odyssey* mission
  - evidence for (frozen) water within 1 meter under the surface
  - this underground water is found all over the planet

Venus



- Has a thick, cloudy atmosphere -- you can not visually see the surface
- we must image the surface using radar
- smooth plains with few mountain ranges
- few craters
- many volcanoes and domes of lava (*corona*)
- Venus is very active with tectonics & volcanism



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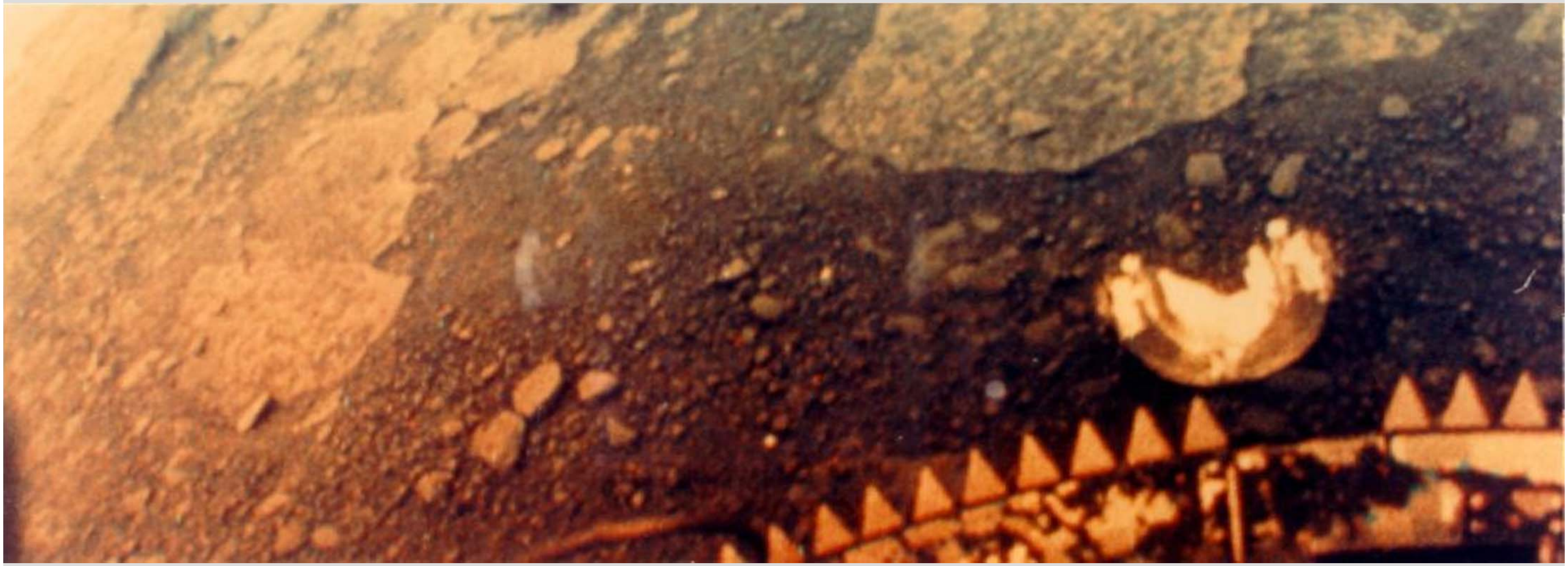
Elevated areas called “terra”

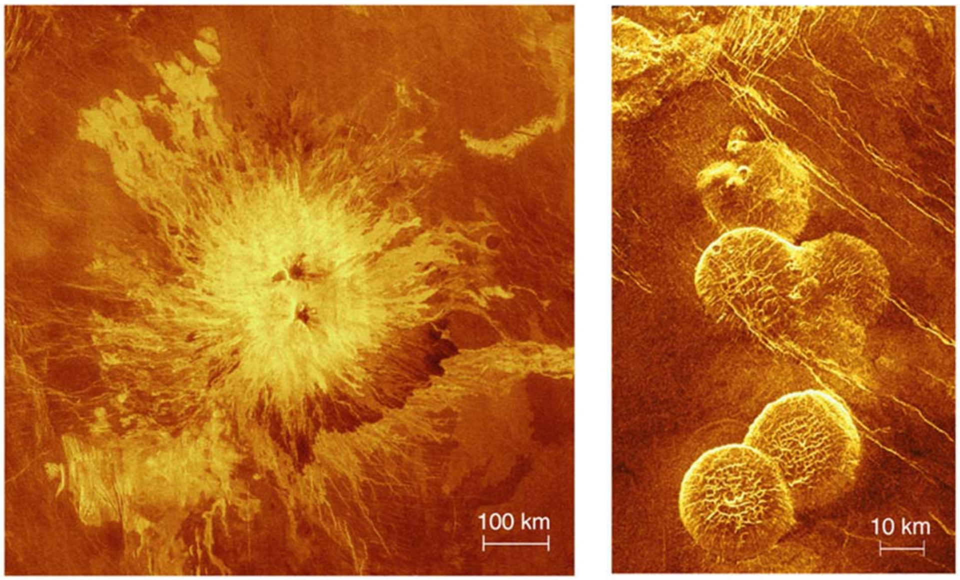
Venus

Searing heat, heavy pressure, clouds of sulfuric acid, frequent volcanic eruptions



Volcanism & Tectonics on Venus

- Impact craters are evenly spread over Venusian surface.
  - implies that the planet's entire surface is the same age
  - crater counting suggests an age of 1 billion years old
- Volcanism "paved over" the surface 1 billion years ago.



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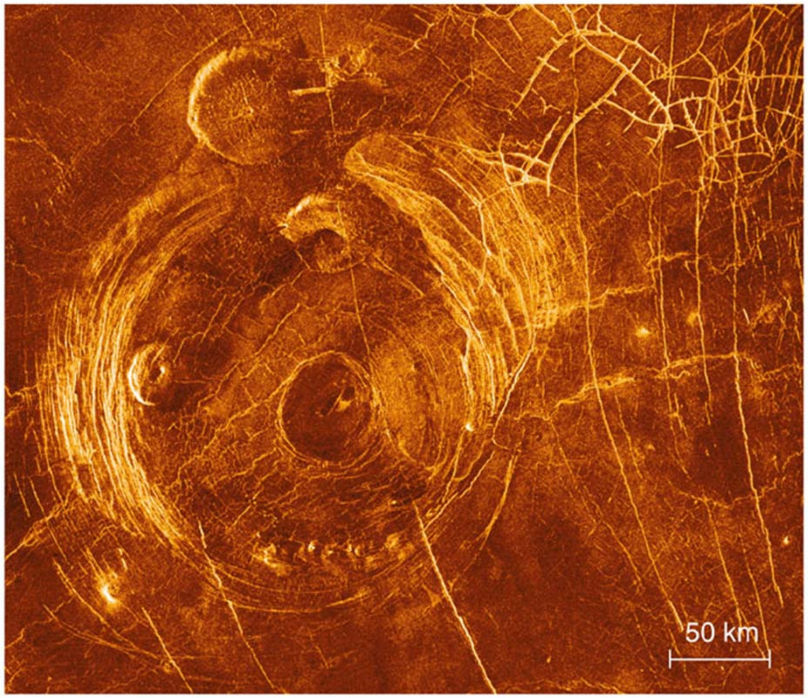
- Two types of volcanism are observed
  - shield volcanoes
  - stratovolcanoes

Volcanism & Tectonics on Venus

- The *corona* is a tectonic feature.
  - rising plume in mantle pushes crust up
  - cause circular stretch marks
- Plume forces magma to the surface.
  - volcanoes are found nearby



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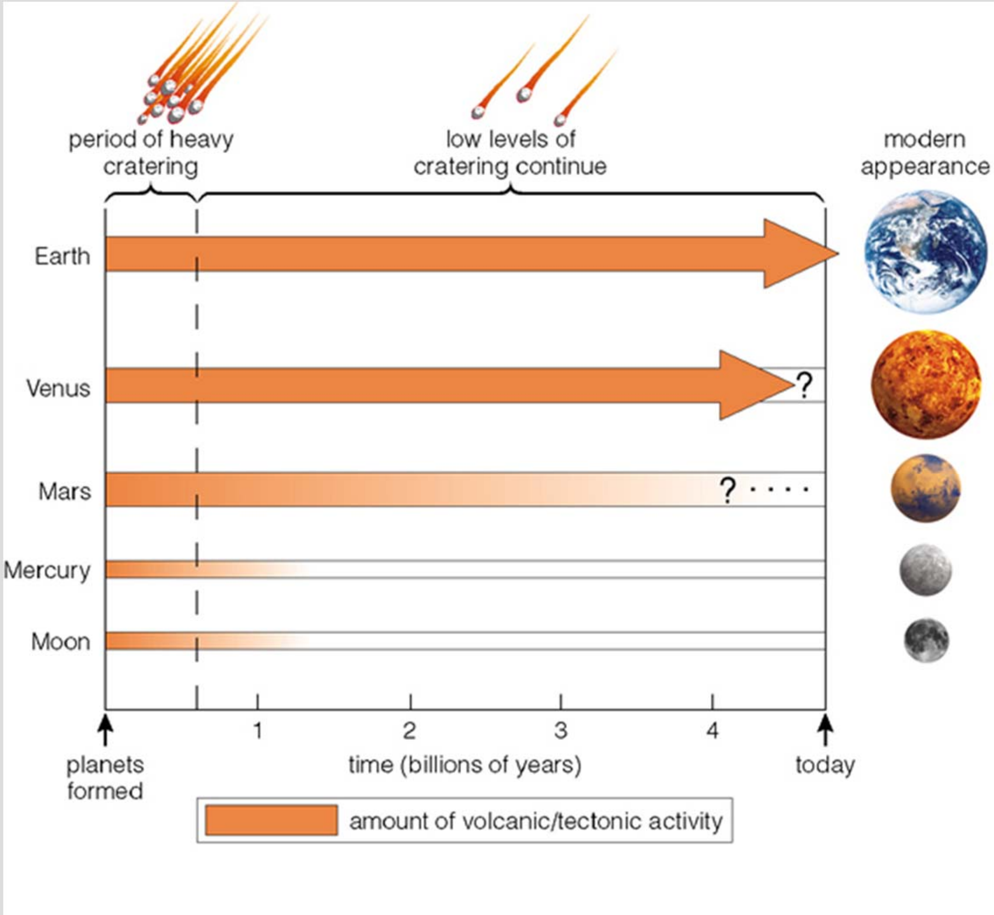
Lack of Erosion on Venus

- No erosion features are seen on Venus. (so far)
- This means no wind, rain, or ice on the surface.
- Such a lack of weather can be explained:
  - the surface of Venus is very hot (430 C)… too hot for liquid or ice to exist
  - Venus rotates very slowly (P = 243 days), so no wind is generated

Geological Destiny

A planet's fundamental properties determine its geological fate.



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planet <u>size</u> determines fate

- Impact cratering
  - important early on
  - affects all planets equally
- Volcanism & Tectonics
  - become dominant later on
  - require internal heat
  - **size** determines how long a planet remains hot
- Erosion
  - ultimately dominant
  - requires volcanism for outgassing of atmosphere

Earth

- most active geology
- volcanoes & tectonics
  - ongoing plate tectonics
- moderate atmosphere
  - N_2 O_2 H_2O
- H_2O exists in **liquid** state
  - rampant erosion
  - few craters
- life