

Earth & Moon

The Earth: basic facts.

- Average distance from Sun = 1 AU
- Perihelion = 0.983 AU
- Aphelion = 1.017 AU – pretty low e
- Orbital period = 1 year (by definition)
- Tilt of axis = 23.5 degrees
- Rotation period = 23 hr, 56 min
- Temperature range 200-350 K
- Average Density = 5500 kg/m³
- Teeming with life

Earth's Interior

- **Crust**

- Density 2.5-3.5 g/cm³
- rock

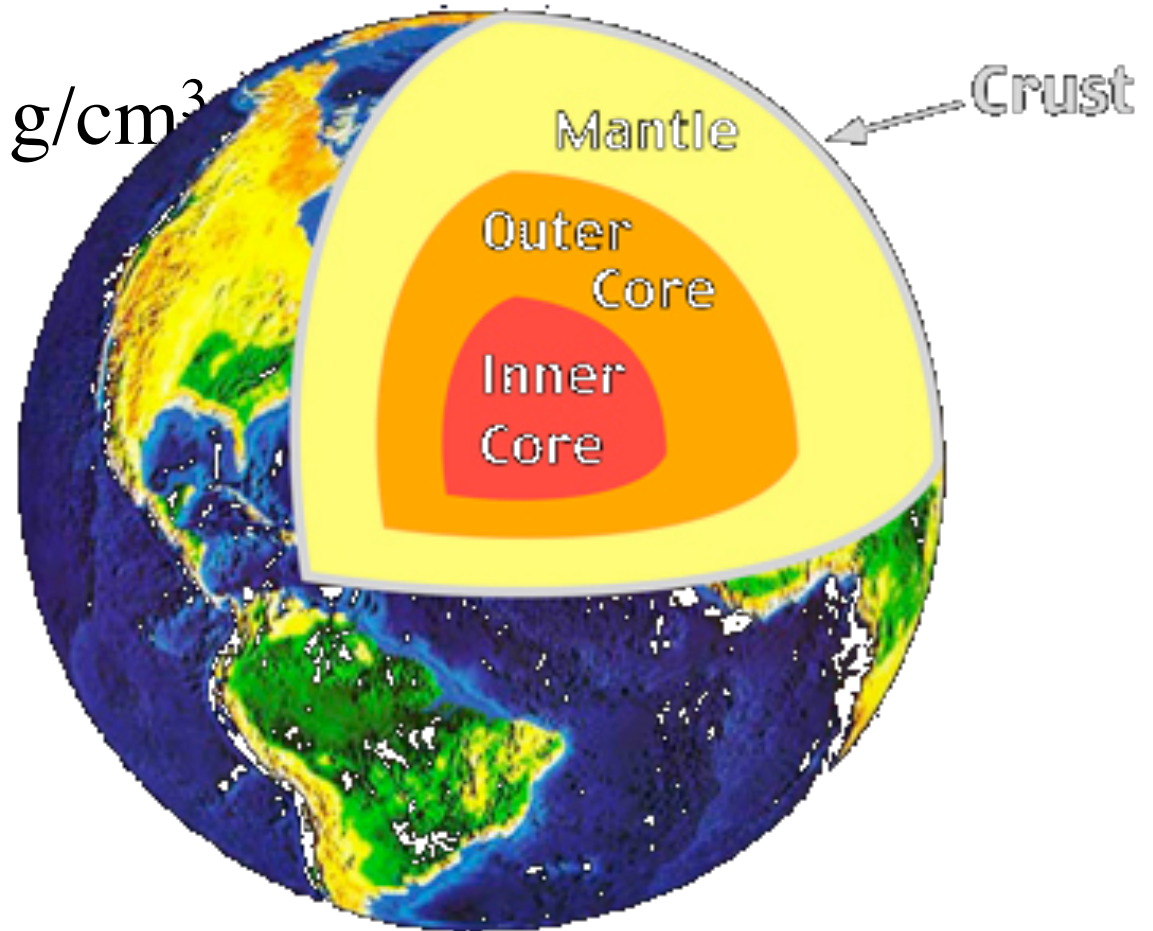
- **Mantle**

- 3.5-4.8 g/cm³
- rock and metal

- **Core**

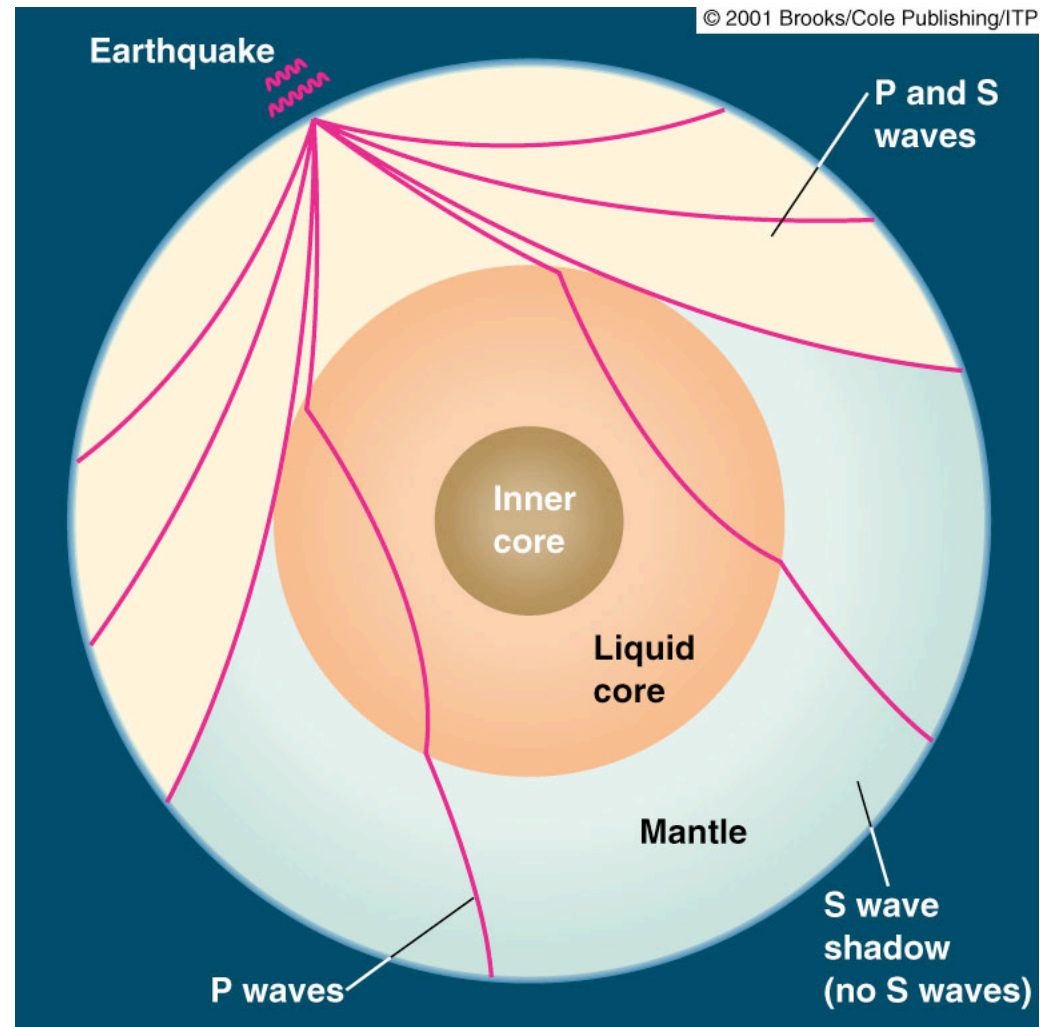
- 14 g/cm³
- metal

Earth's interior is *differentiated* – densest material has sunk to center



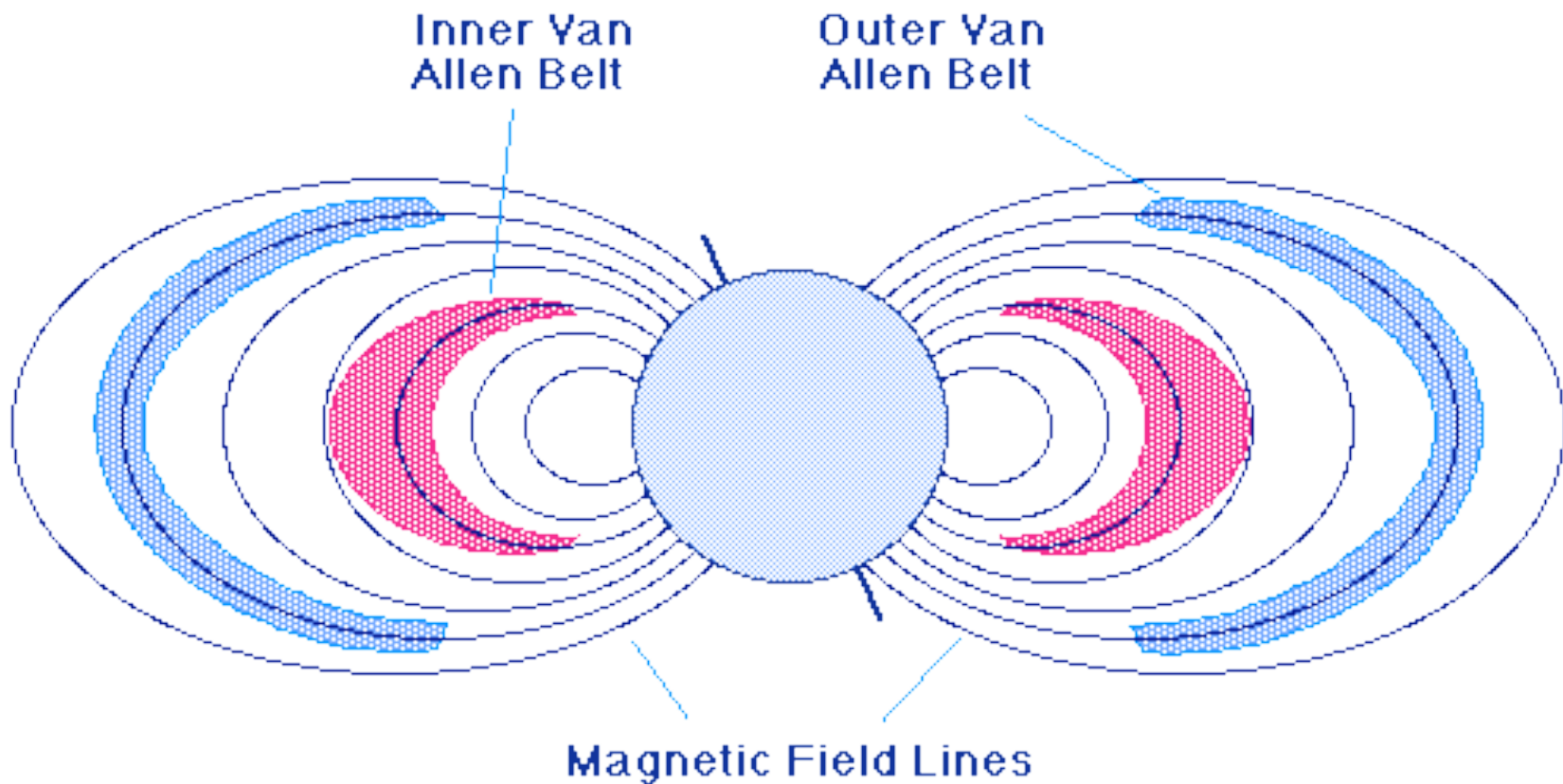
How do we know outer core is liquid?

- S (shear)-type seismic waves can't penetrate liquid



How do we know Earth's core is liquid?

Earth's Magnetic Field can only be generated if there is motion in interior via *dynamo*



Earth's Magnetic Field

- Aurora (Northern Lights)



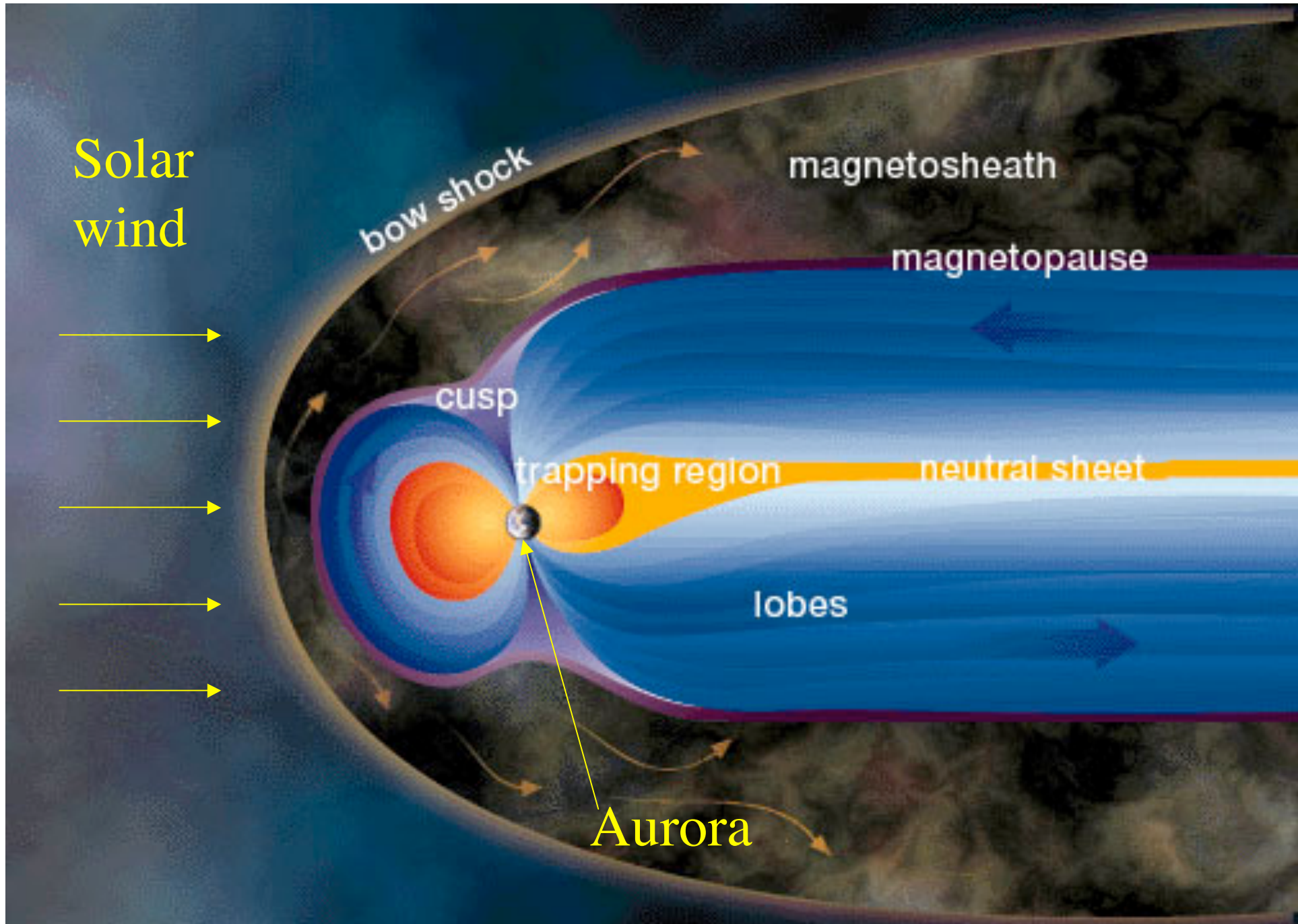
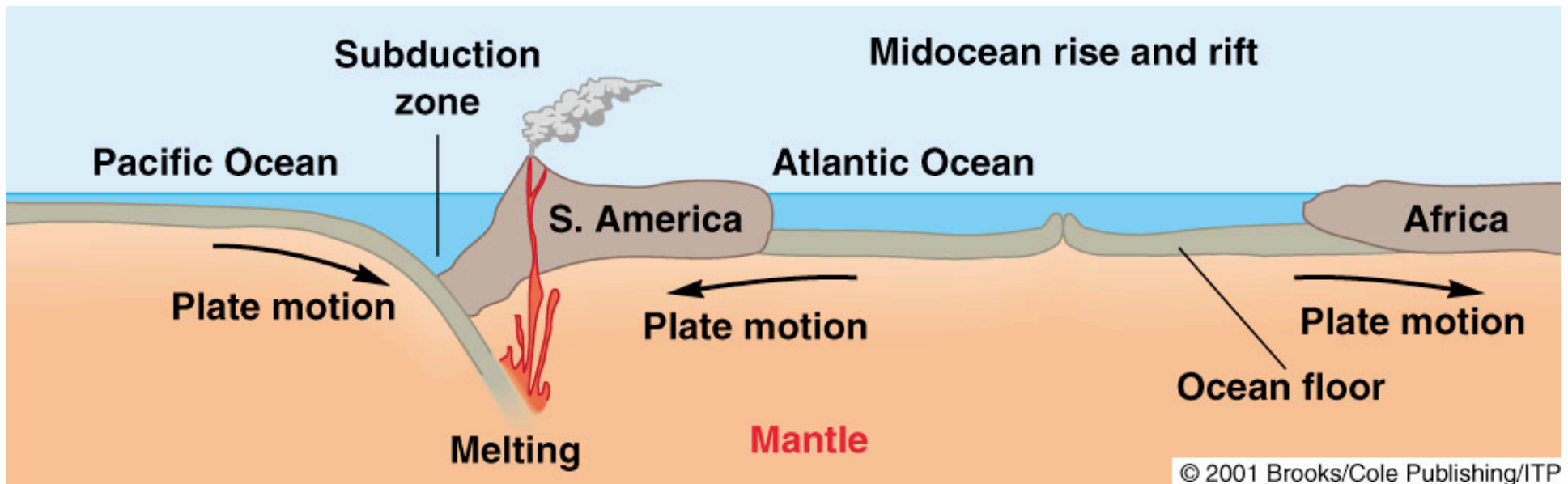


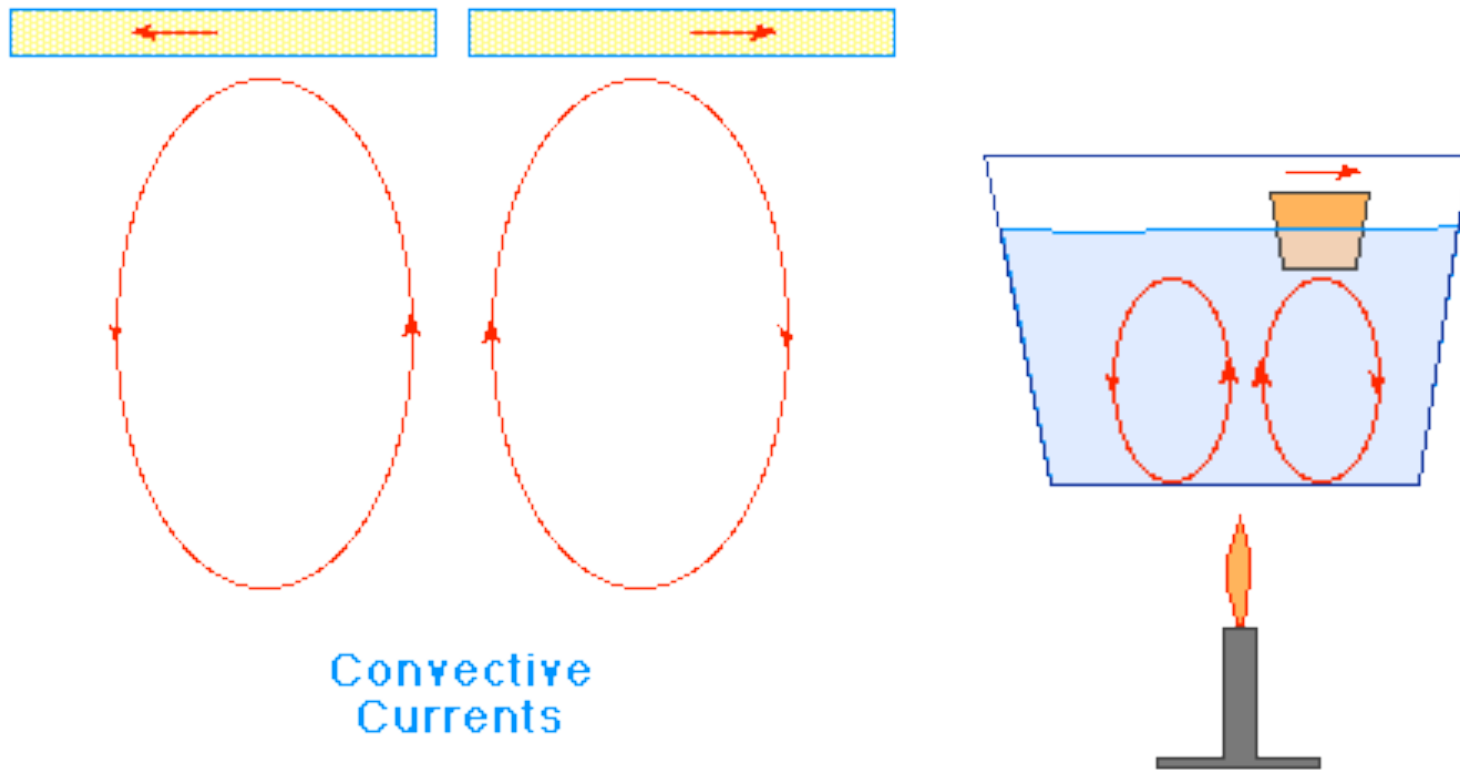
Plate Tectonics shape surface

- Activity of crust as plates collide with each other – produces volcanoes, earthquakes, mountain ranges



Plates driven by convection in mantle

- tectonic activity indicator of liquid interior



Convective
Currents

Radioactive decay, core solidification keeps Earth's core liquid

Earth's Atmosphere

- Primeval atmosphere
 - carbon dioxide (CO_2)
 - nitrogen (N_2)
 - water vapor (H_2O)
 - ammonia (NH_3)
 - methane (CH_4)
- even today, these continue to be vented by volcanoes



Mt St Helens volcano

Earth's Atmosphere evolved

As Earth cooled:

- H₂O rained out, forming oceans
- CO₂ dissolved in oceans, deposited in limestone
- Result: atmosphere mainly composed of N₂
- Later, life (photosynthesis) added oxygen
 - Oxygen is highly reactive
 - without plant life, it would quickly disappear from atmosphere

Lunar topography



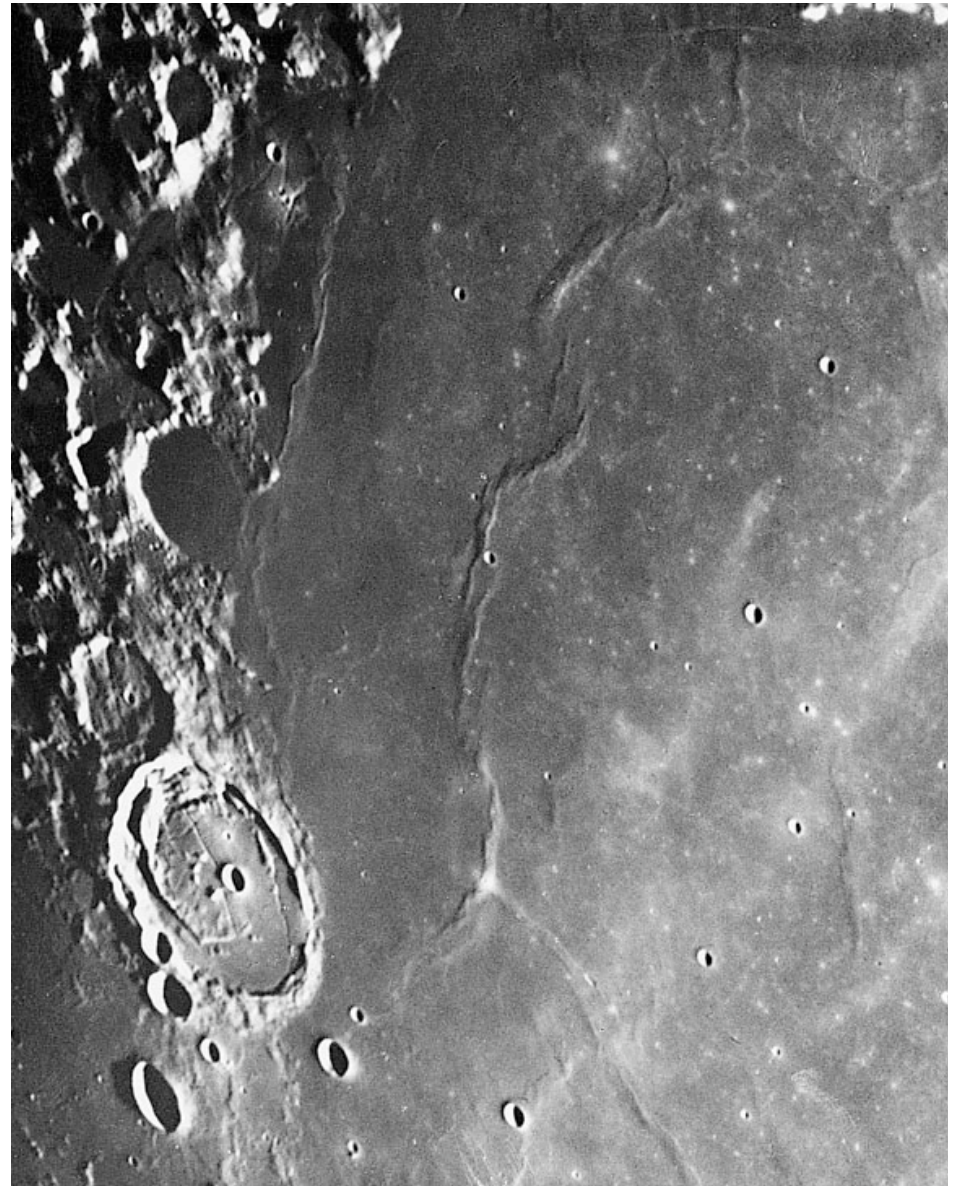
Lunar topography

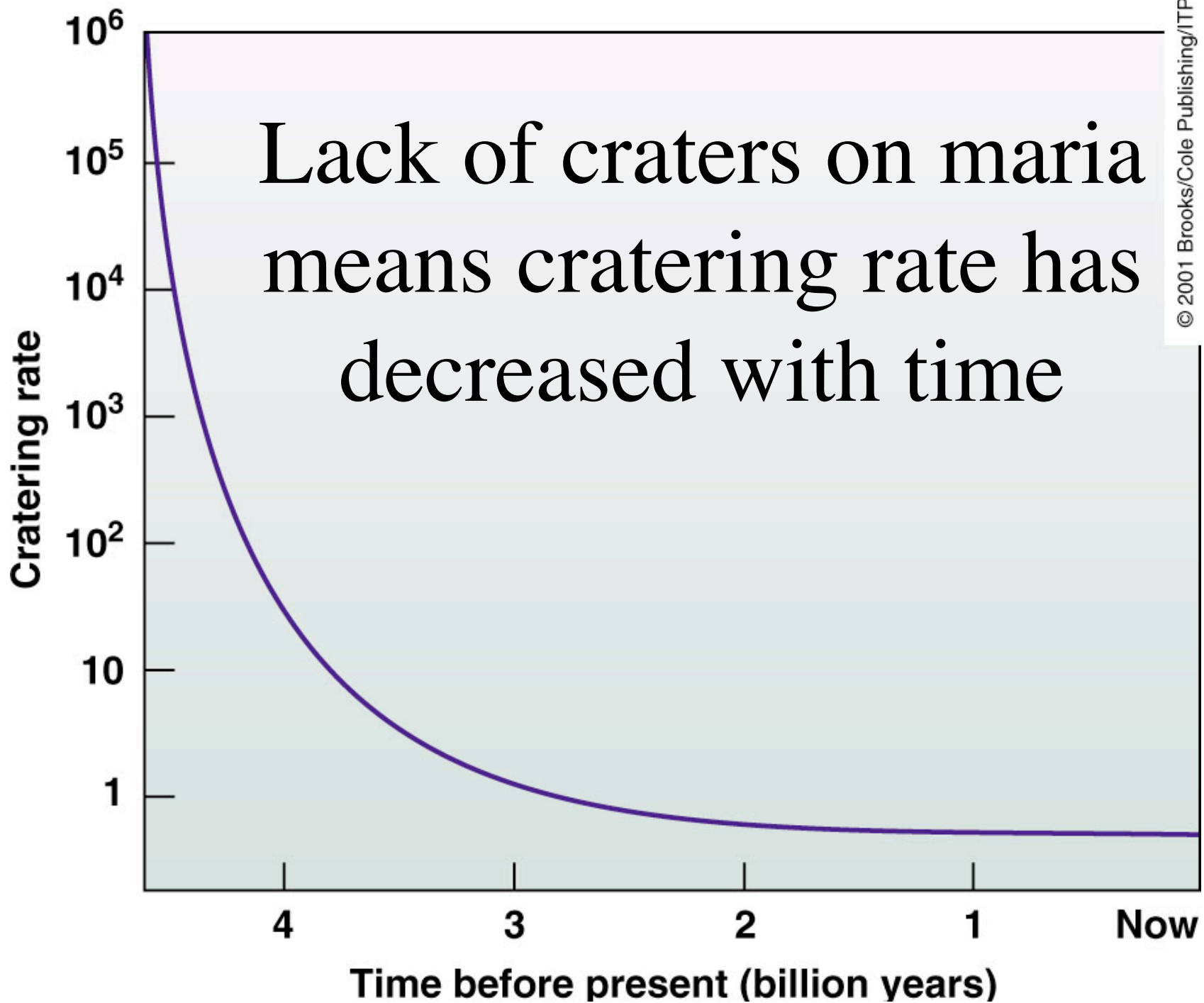
- Maria
 - Lowland plains covering 1/5 of Moon
 - Covered by great lava flows
 - Relatively few craters
- Highlands
 - Light colored
 - Heavily cratered

Highlands

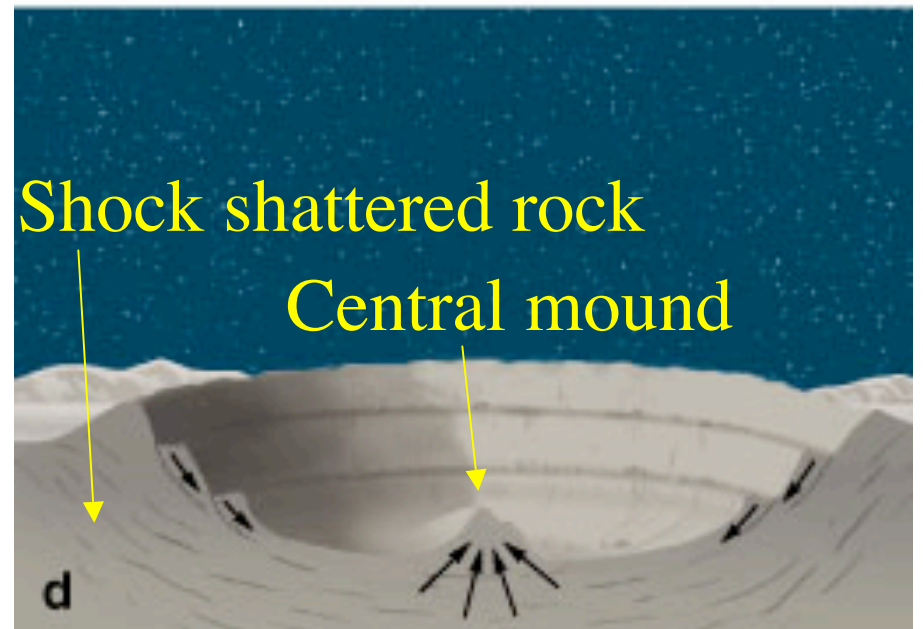
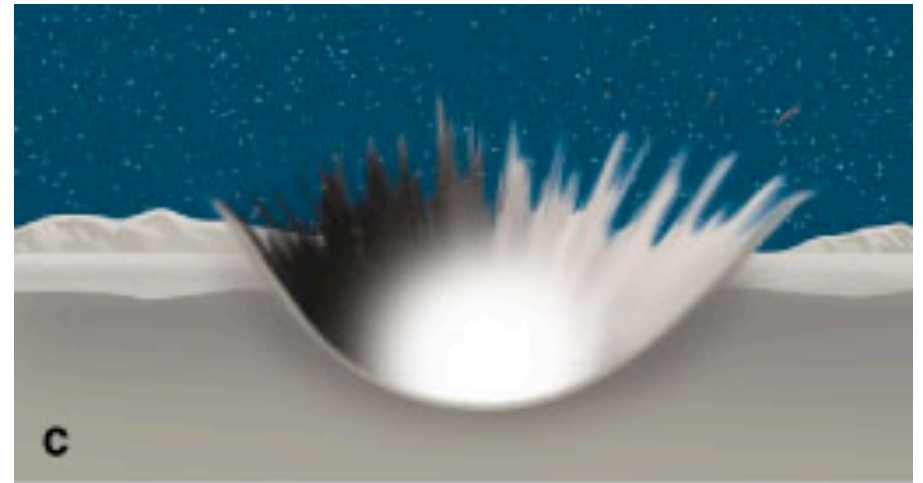
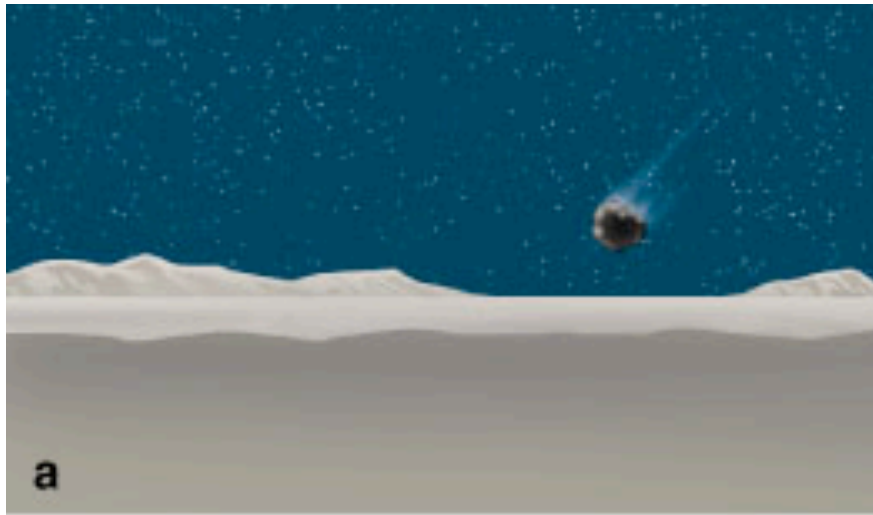


Maria





How to distinguish volcano from impact crater: debris and central mound



Crater Copernicus



Highland rock

- Less dense and lighter-colored than maria rocks
- 4.0 to 4.4 billion years old



Maria rock

- Darker & denser than highland rock
- Typically 3.1 to 3.8 billion years old



Moon is now geologically dead

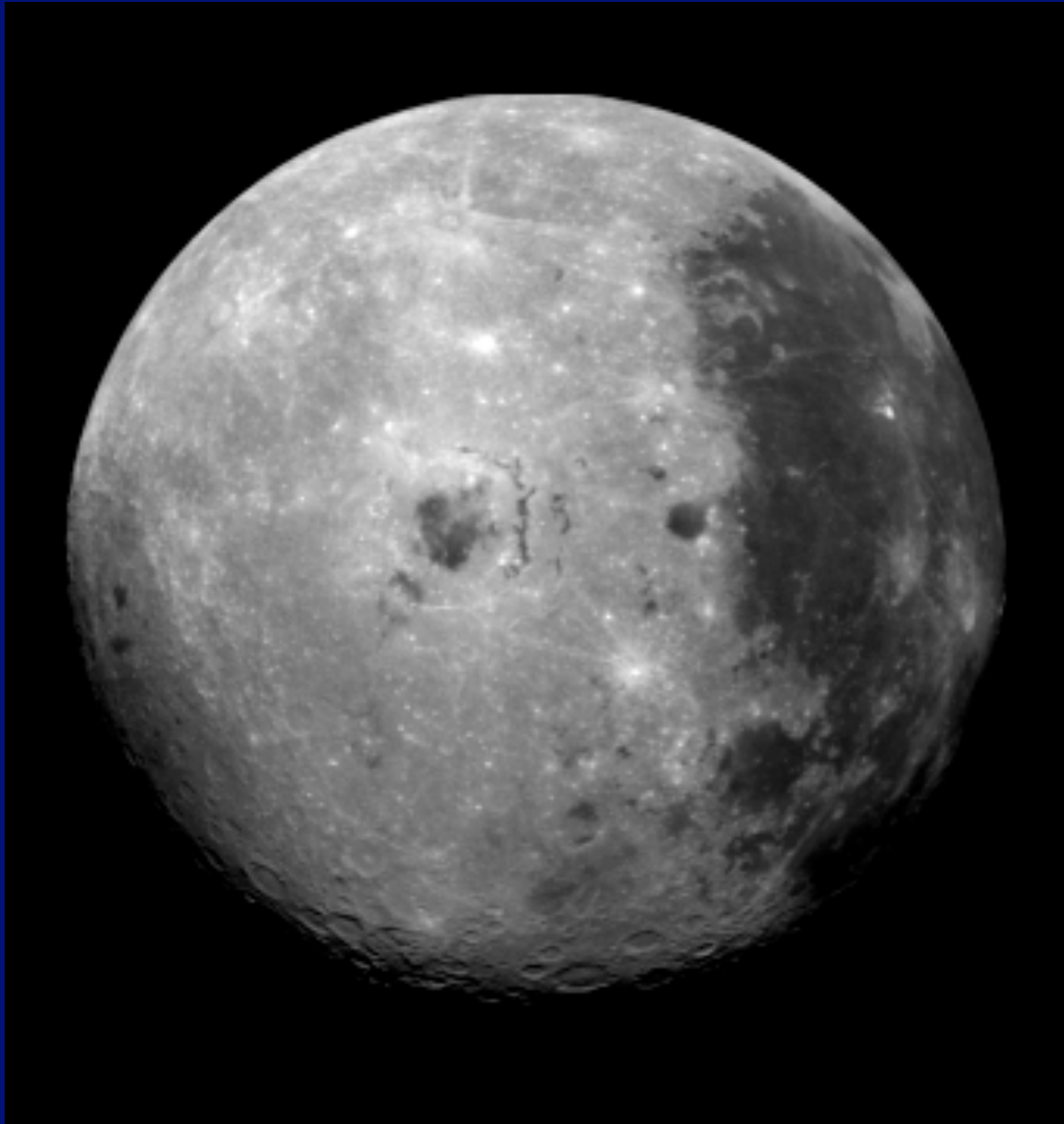
- Volcanoes and tectonic activity **absent**
- Interior is **solid**
 - **No magnetic field - FLASH!:** recent evidence for small field
 - Seismographs show **no liquid interior**
- Heat retention depends on radius (size)
 - Heat energy stored is proportional to volume (R^3)
 - Cooling rate is proportional to surface area (R^2)
 - The larger the object, the larger the volume is relative to the surface area.
- Moon is so small it has **“frozen” solid**

Maria are all on near side of Moon - tidal effect?

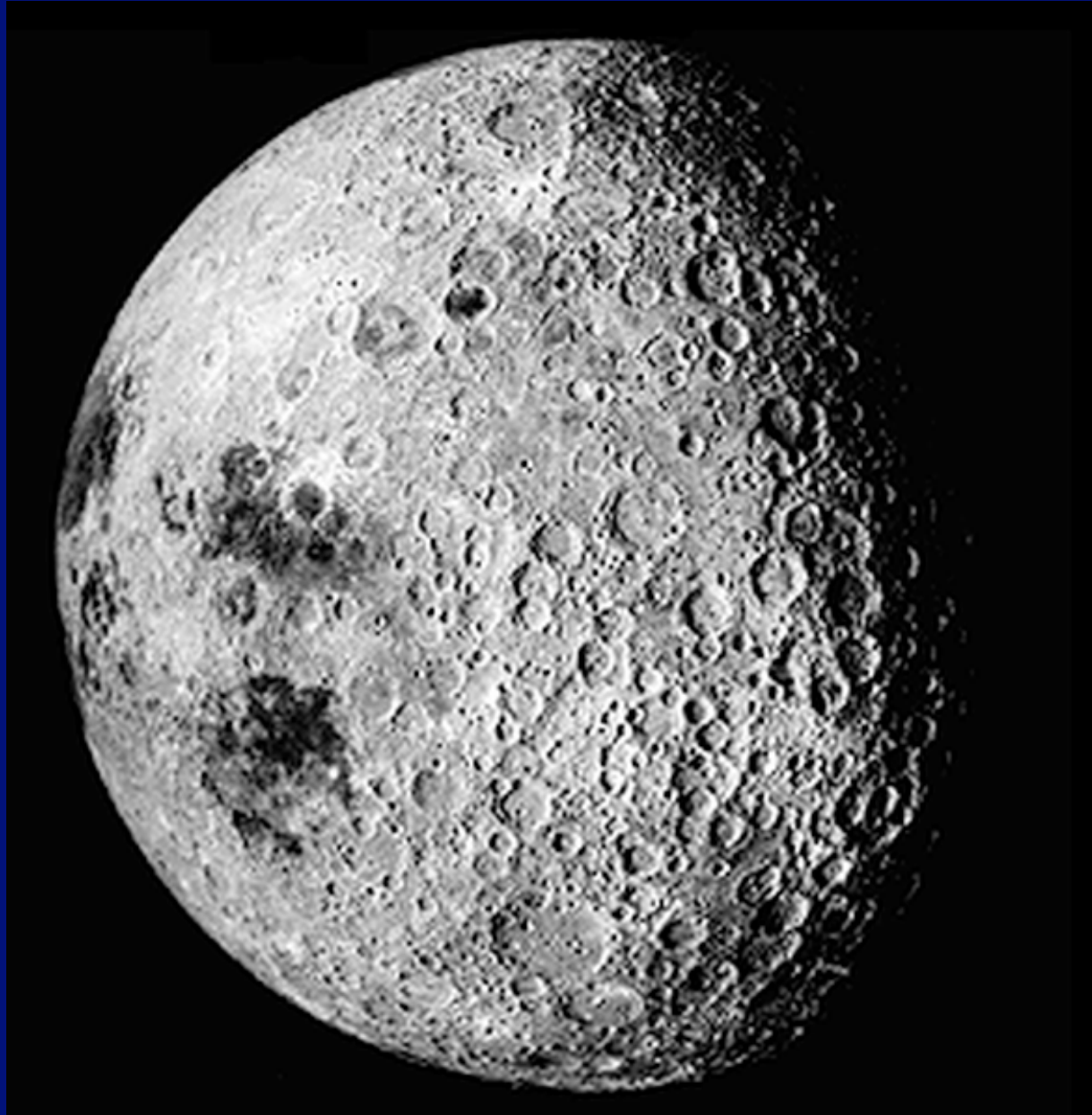


Far Side

Near Side



Far side



Origin of Moon

- Large-Impact hypothesis: Mars-sized body hit proto-Earth, ejecting mantle material which condensed into Moon
- Explains why moon has **so little iron** (only mantle ejected)
- Explains why Moon has **so few volatiles** (they escaped)
- Explains why **isotopic abundances same as Earth**

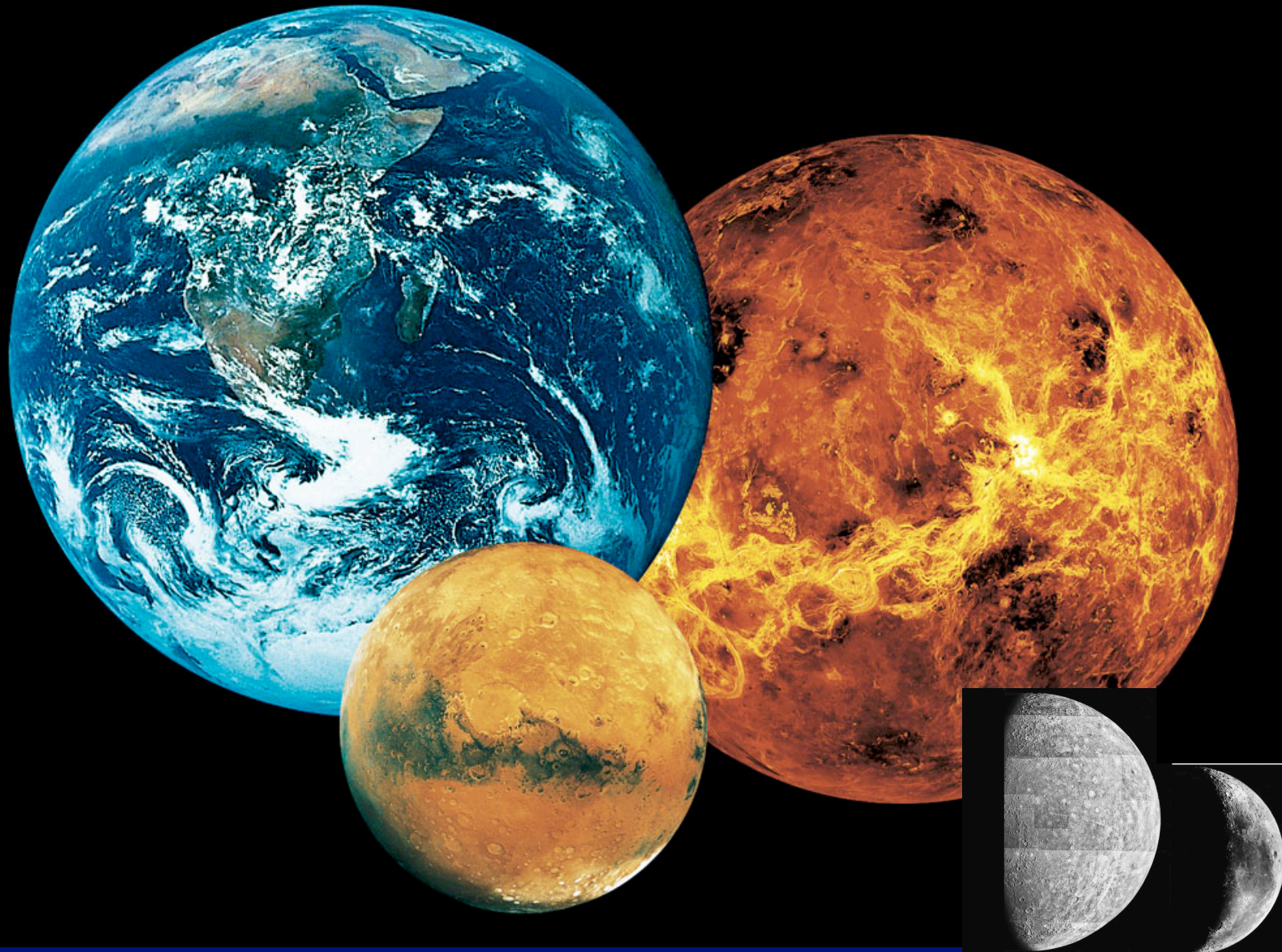


The Other Terrestrials

- Mercury
- Venus
- Mars

Terrestrial planets and moon to

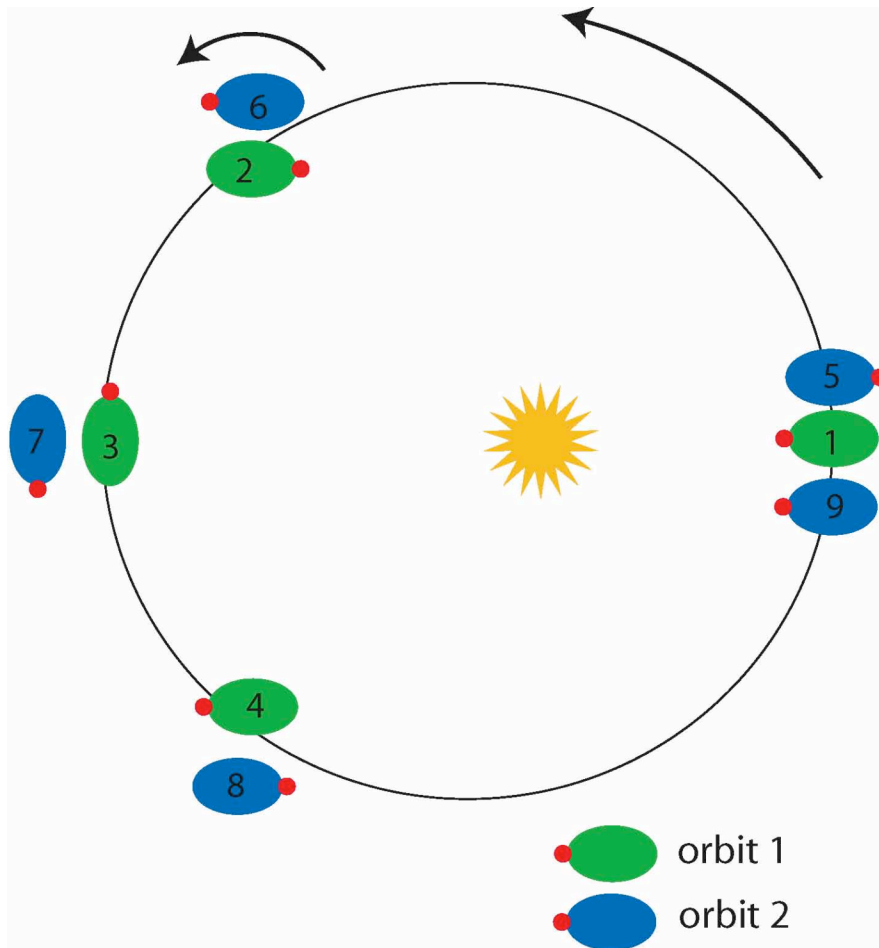
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Mercury: basic facts.

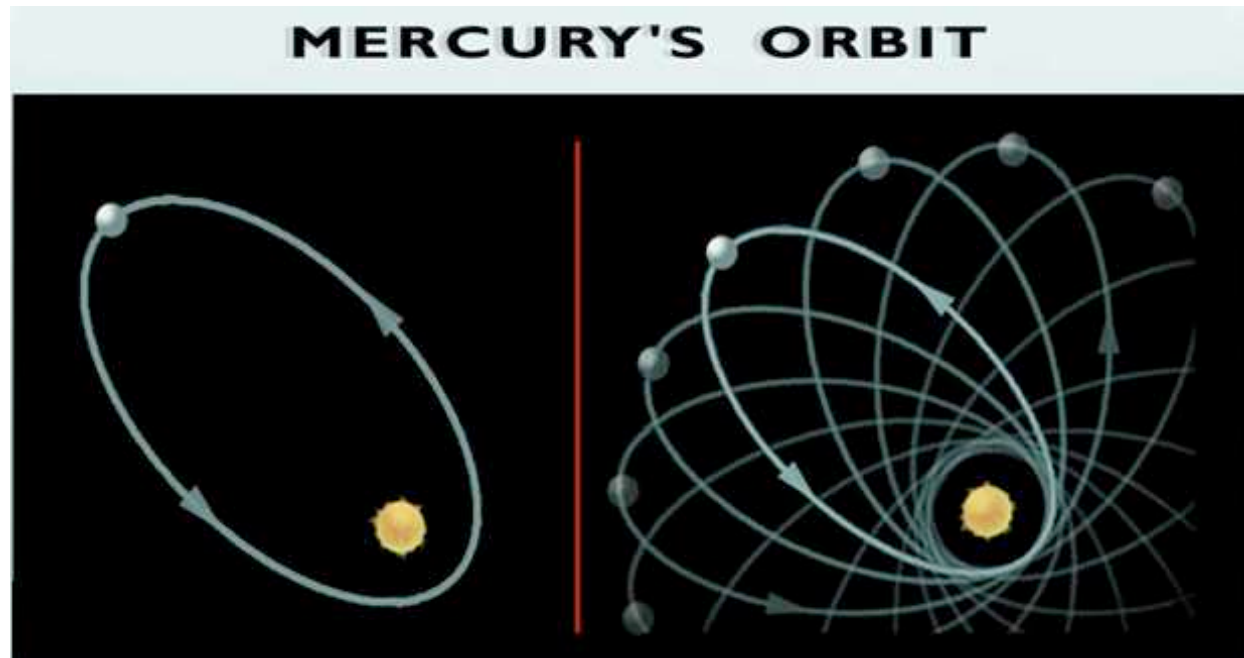
- Average distance from Sun = 0.39 AU
- Perihelion = 0.31 AU
- Aphelion = 0.47 AU ← orbit quite elliptical
- Orbital period = 0.24 years (88 days)
- Tilt of axis = 0 degrees
- Rotation period = 58.6 days
- Temperature range 100-700 K
- Size = 0.4 size of Earth
- Average density 5.4 g/cc

Spin-orbit coupling



- 3 rotations every 2 orbits
- Orbit too elliptical for 1:1 coupling – **not fully synchronized**
- Produced by planetary torques on **tidal bulge**

Precession of perihelion



Precesses 574 arcsecs/century

- 531"/century due to perturbations of other planets
- Remaining 43"/century accounted for by GR

Mercury

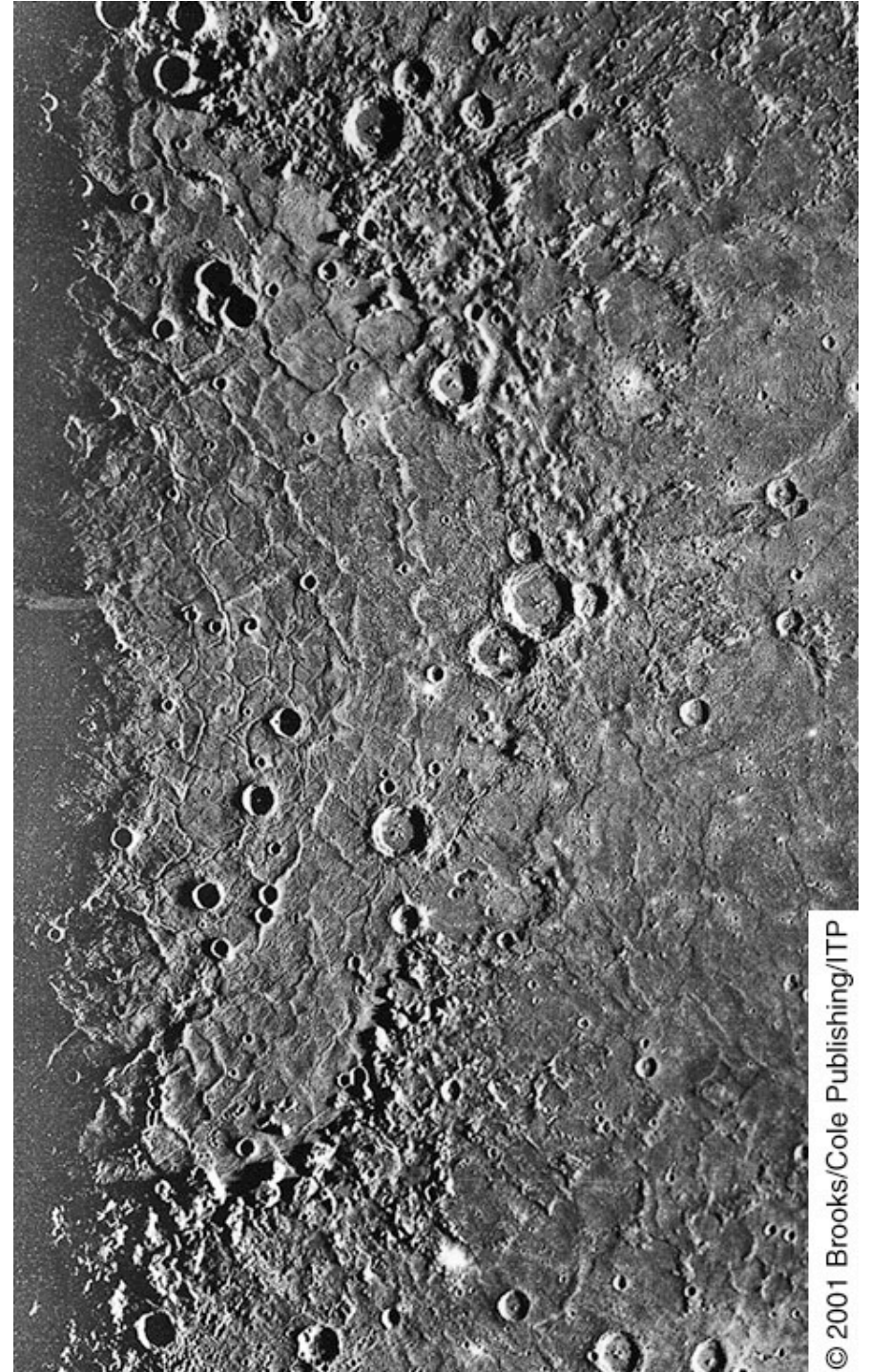
- Similarities to Moon:
 - Heavily cratered highlands
 - No atmosphere
 - Geologically dead (also frozen solid?)
- Differences from Moon:
 - More massive
 - Denser, with large iron core
 - Weak magnetic field

Mercury

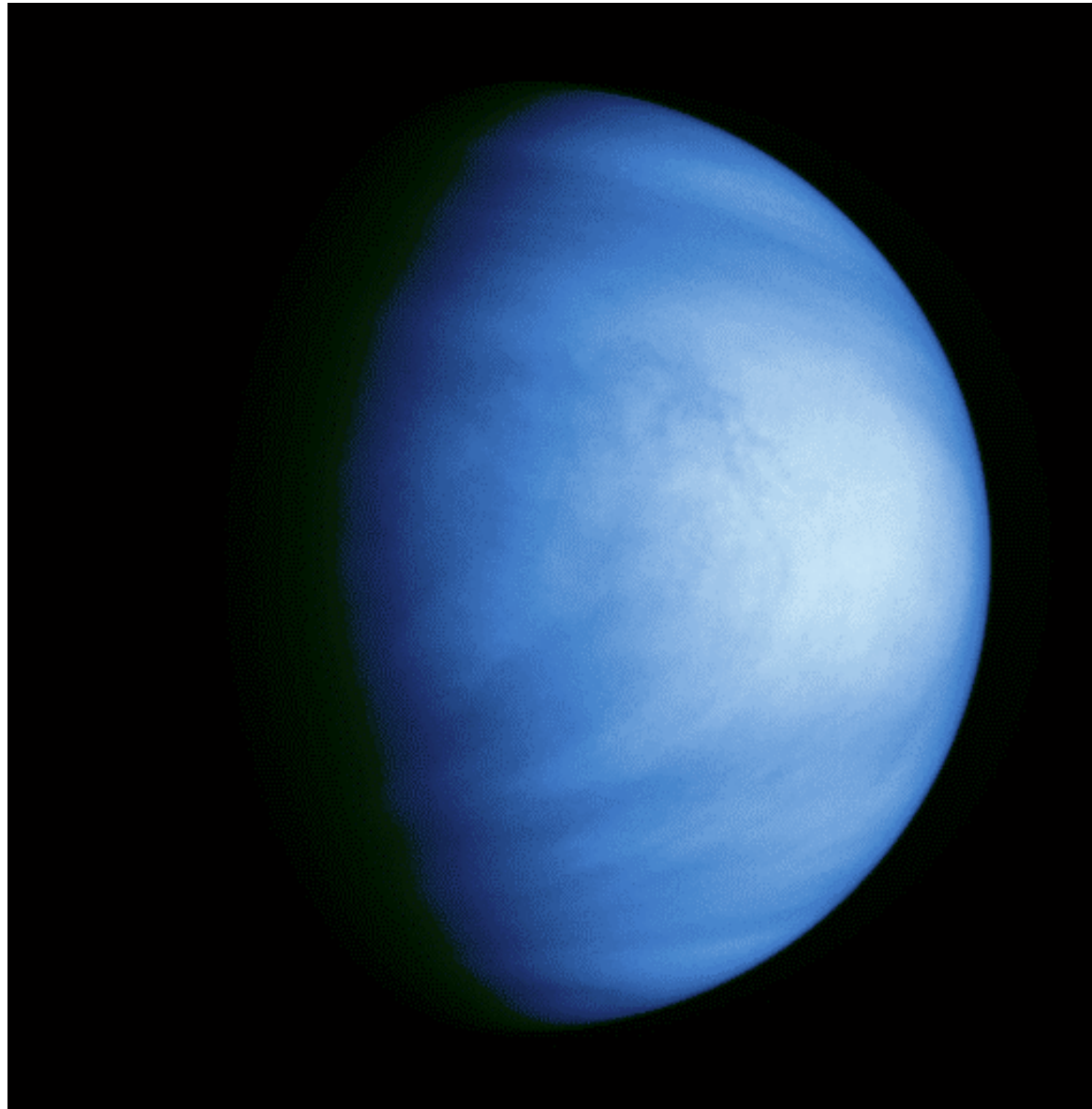
- A planetary atmosphere:
 - Insulates
 - Transfers energy from hot to cold regions (winds)
- Absence of atmosphere, proximity to Sun, & long day/night produce most *extreme* temperature range in solar system:
 - Daytime: 700 K
 - Nighttime: 100 K

Giant Impacts

- Filled with lava, like on Moon, but not dark like lunar maria
- This one is 1300 km across



Venus: view of cloud tops



Venus: basic facts.

- Average distance from Sun = 0.72 AU
- Perihelion = 0.72 AU
- Aphelion = 0.73 AU – low e
- Orbital period = 0.62 years (225 days)
- Tilt of axis = 177 degrees (!)
- Rotation period = 243 days
- Temperature 745 K
- Size = 0.95 size of Earth
- Average density 4.2 g/cc (rocky)

Venus: Radar view of surface



Bright = rough

Dark = smooth

Venera picture of surface



ВЕНЕРА-14 ОБРАБОТКА ИППИ АН СССР И ЦДКС



ВЕНЕРА-14 ОБРАБОТКА ИППИ АН СССР И ЦДКС

Venus

- Sometimes called Earth's twin
 - Similar diameter (95% that of Earth)
 - Similar mass (82% that of Earth)
 - Similar density

Venus

- Some differences from Earth:
 - No moon
 - No magnetic field
 - Due to slow rotation (day=243 earth days)?
 - Rotates backward
 - Due to *large impact*?
 - Completely cloud covered
 - Surface dry (no water)
 - Hot Hot Hot! 745 K (880 F)

Atmosphere of Venus

- Composition
 - 96 % CO₂
 - 3.5% N₂
 - Trace H₂O, sulfuric acid, other compounds
- Pressure
 - 90 times greater than Earth!
- Temperature
 - 745 K at surface

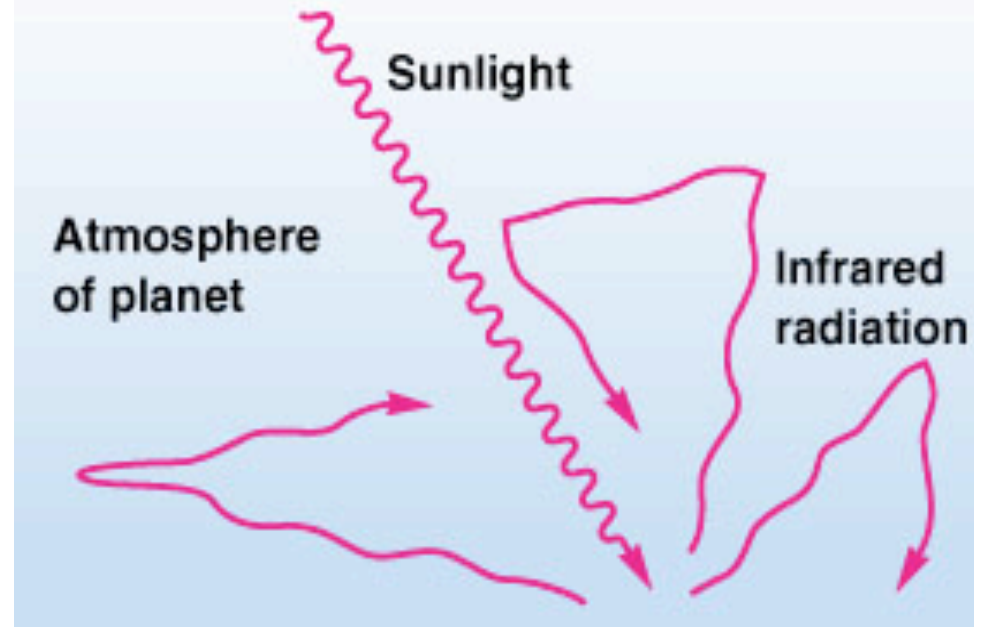
Earth vs. Venus: why so different?

- *Venus*: too hot for water to condense into oceans
 - Water vapor split by solar UV into H and O
 - H lost from atmosphere, water effectively lost forever
 - Without oceans, CO₂ can't be cleansed from air
 - So now, CO₂ produce strong **greenhouse effect**
- *Earth*: further from sun, so somewhat cooler
 - Cool enough so most of water vapor rained into oceans
 - Oceans (and plants) cleanse CO₂ from air, most now trapped in rocks (limestone, CaCO₃)

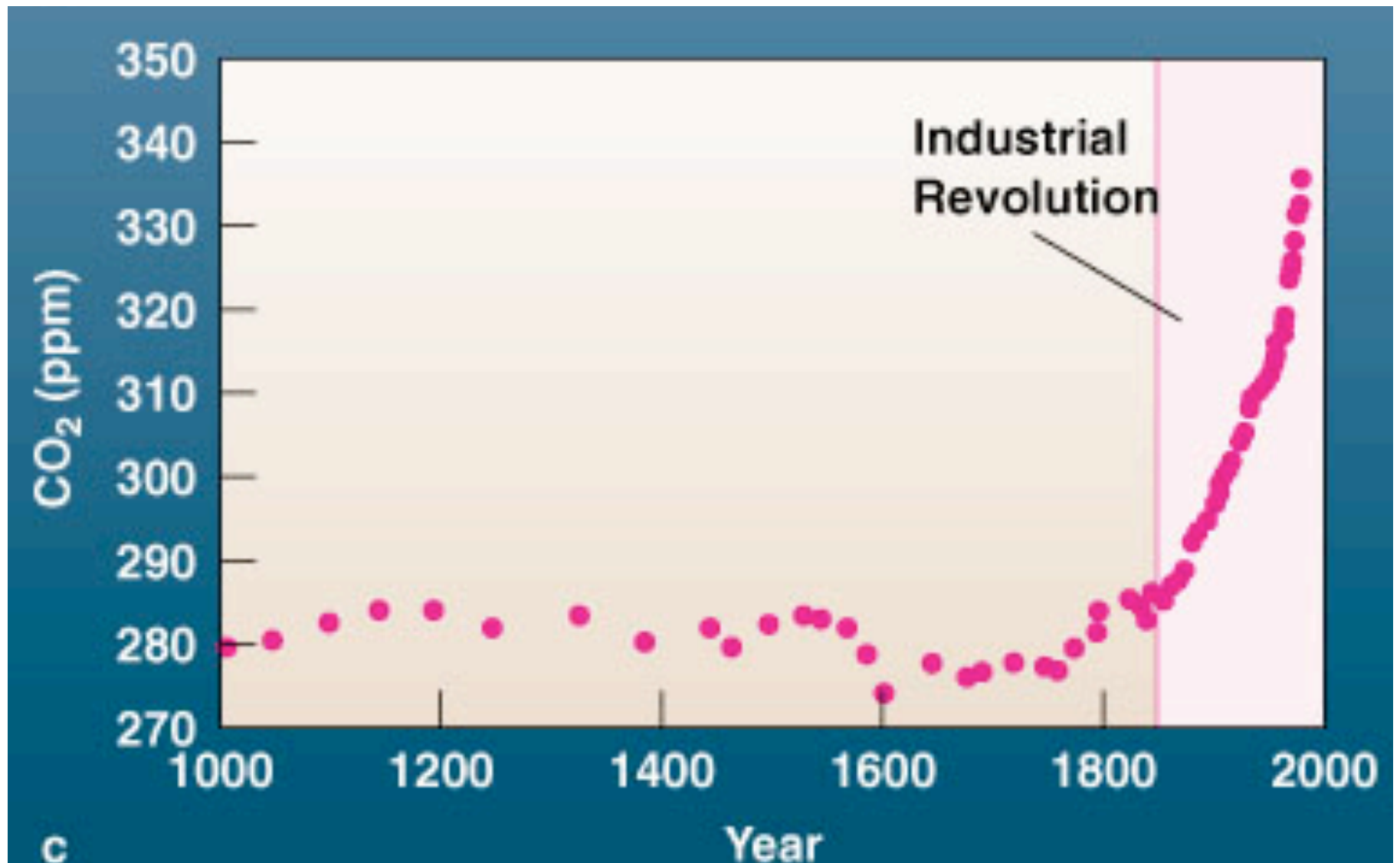
Atmospheric Greenhouse Effect

1. Visible light from sun absorbed by surface
2. Reradiated as infrared radiation
3. Water vapor (H_2O) , carbon dioxide (CO_2) and other greenhouse gases trap infrared

- Without greenhouse, surface of Earth would be *frozen*
- Venus has *huge* greenhouse effect

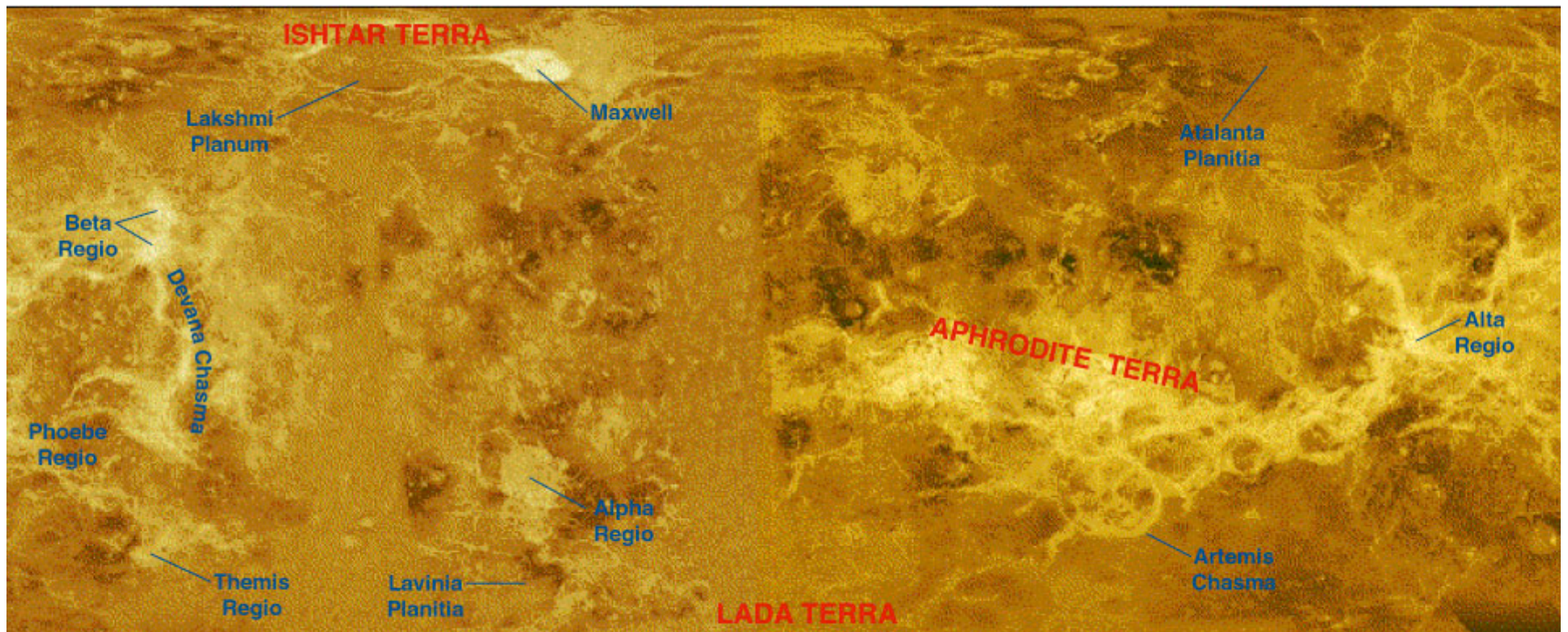


Since industrial revolution,
atmospheric CO₂ has increased



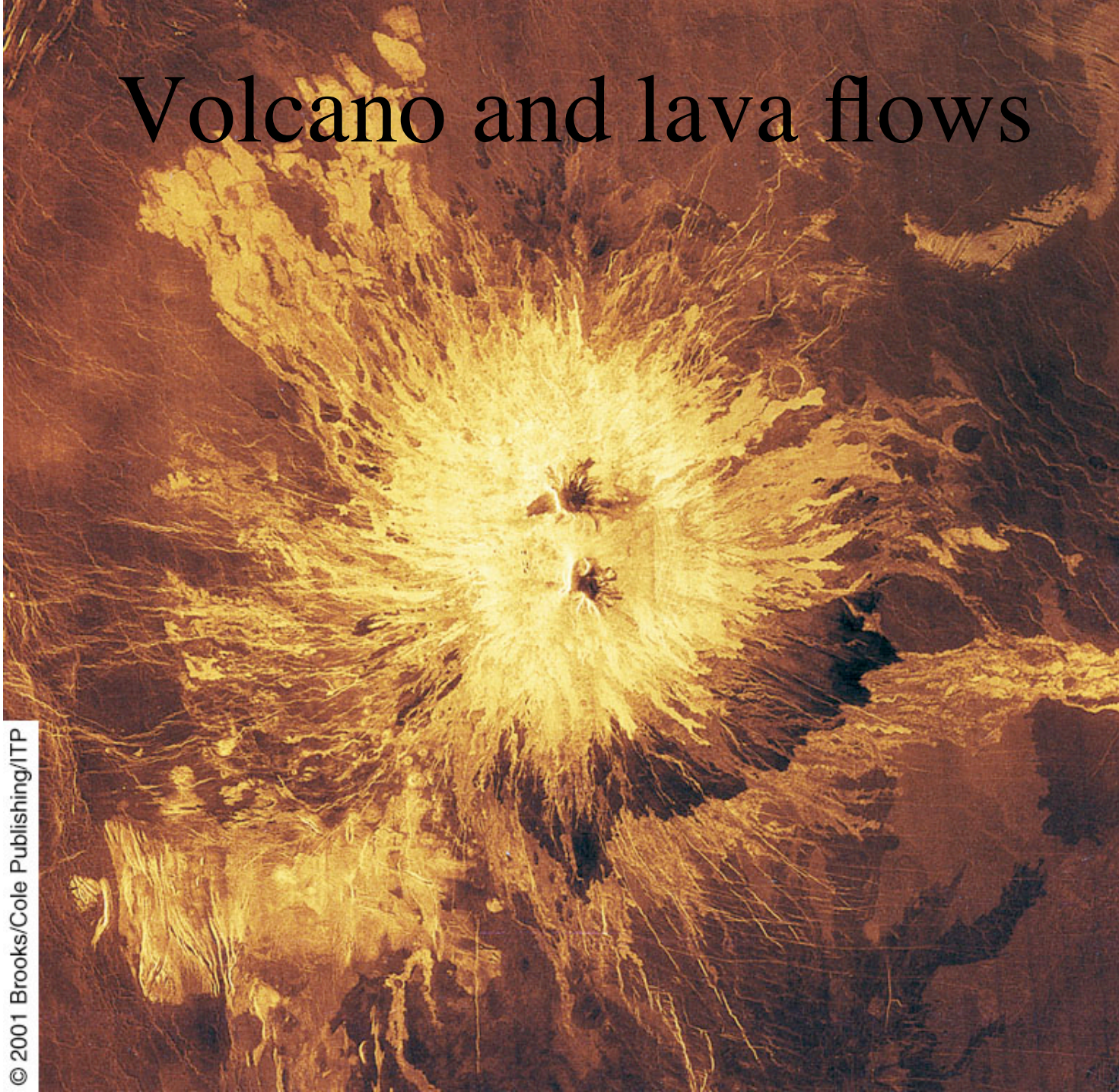
Radar images of Venus surface

- 60% rolling plains 24% highlands
- 16% volcanic peaks

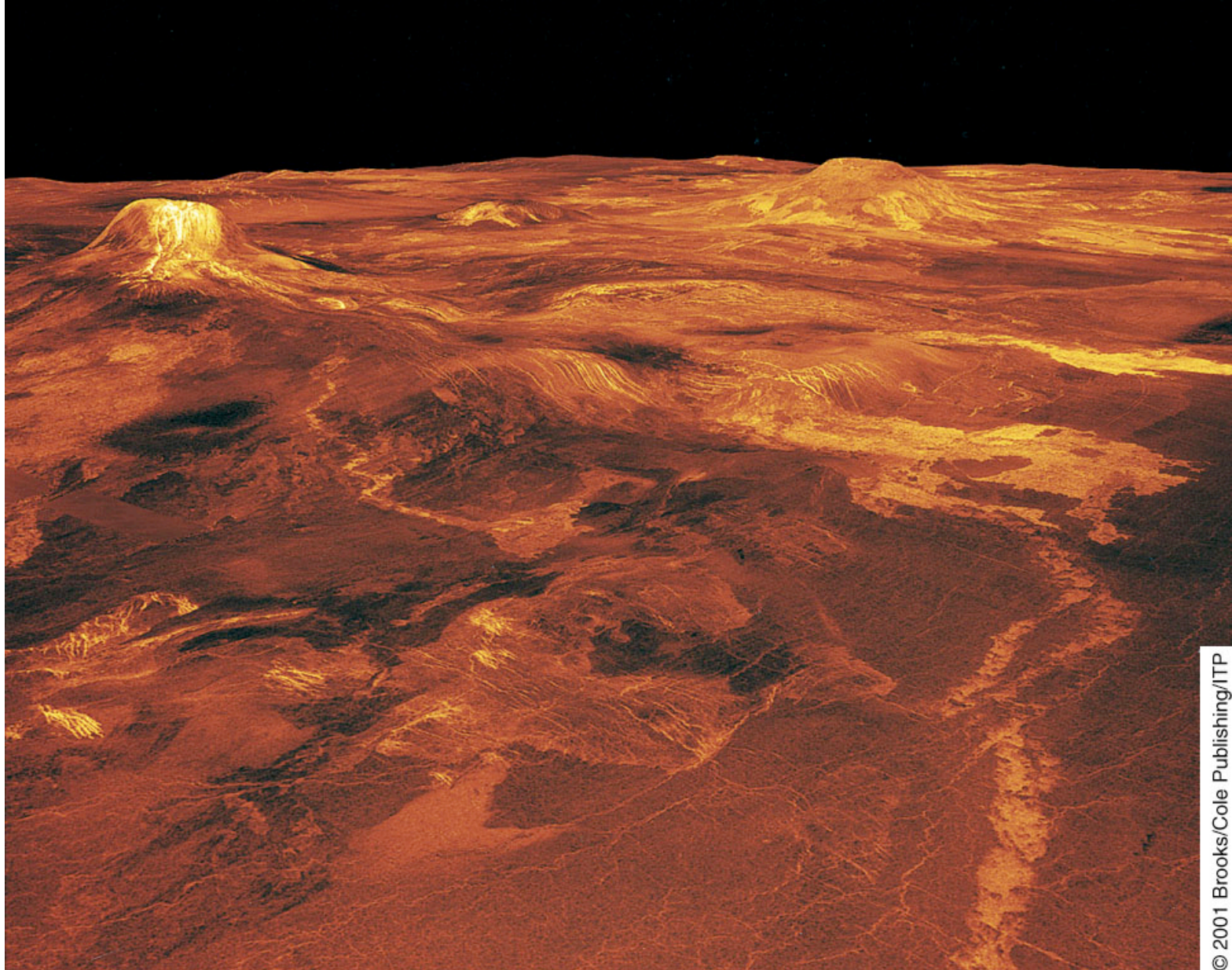


Volcano and lava flows

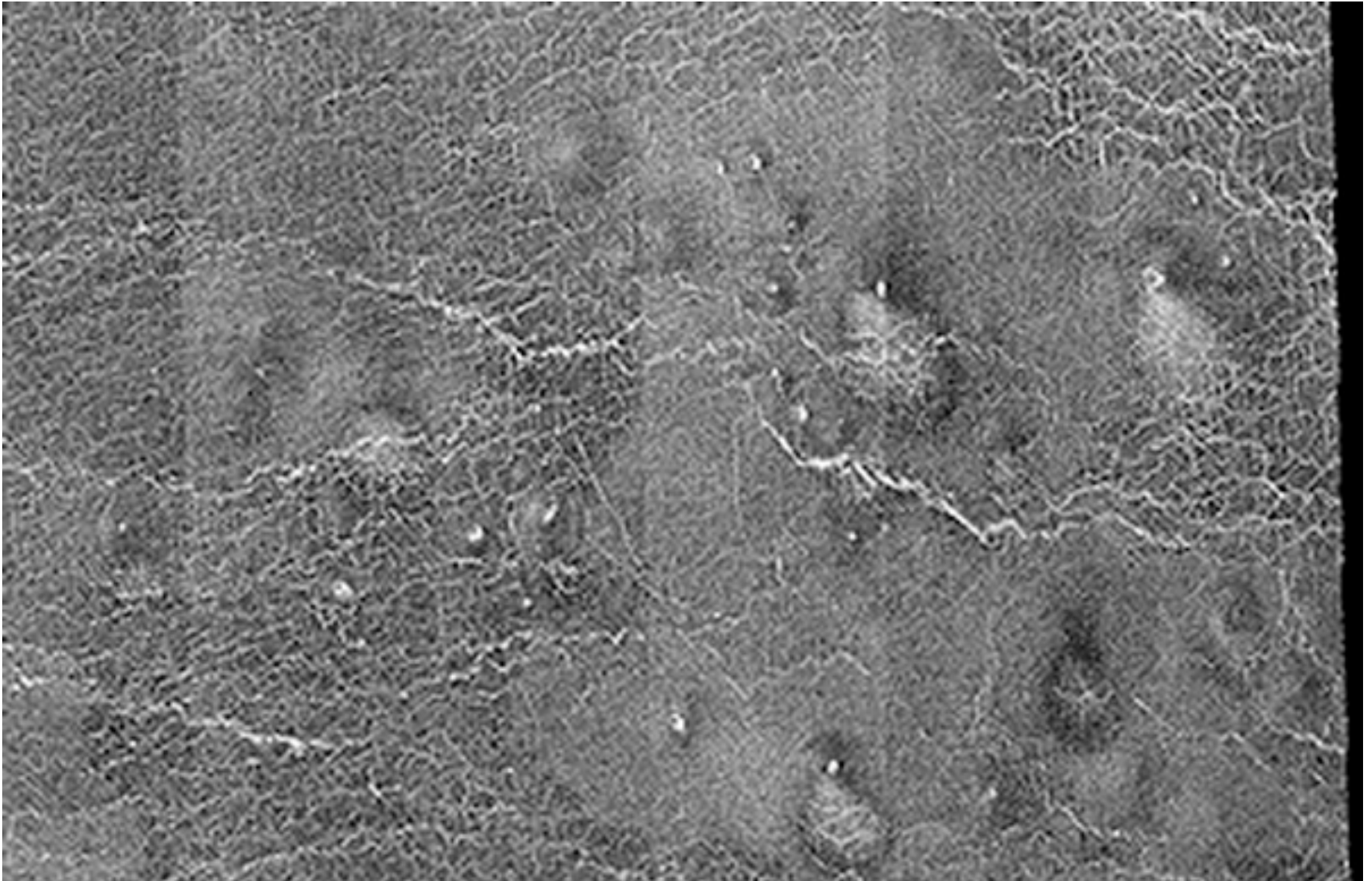
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Volcanoes, lava flows, rift valley



Wind streaks



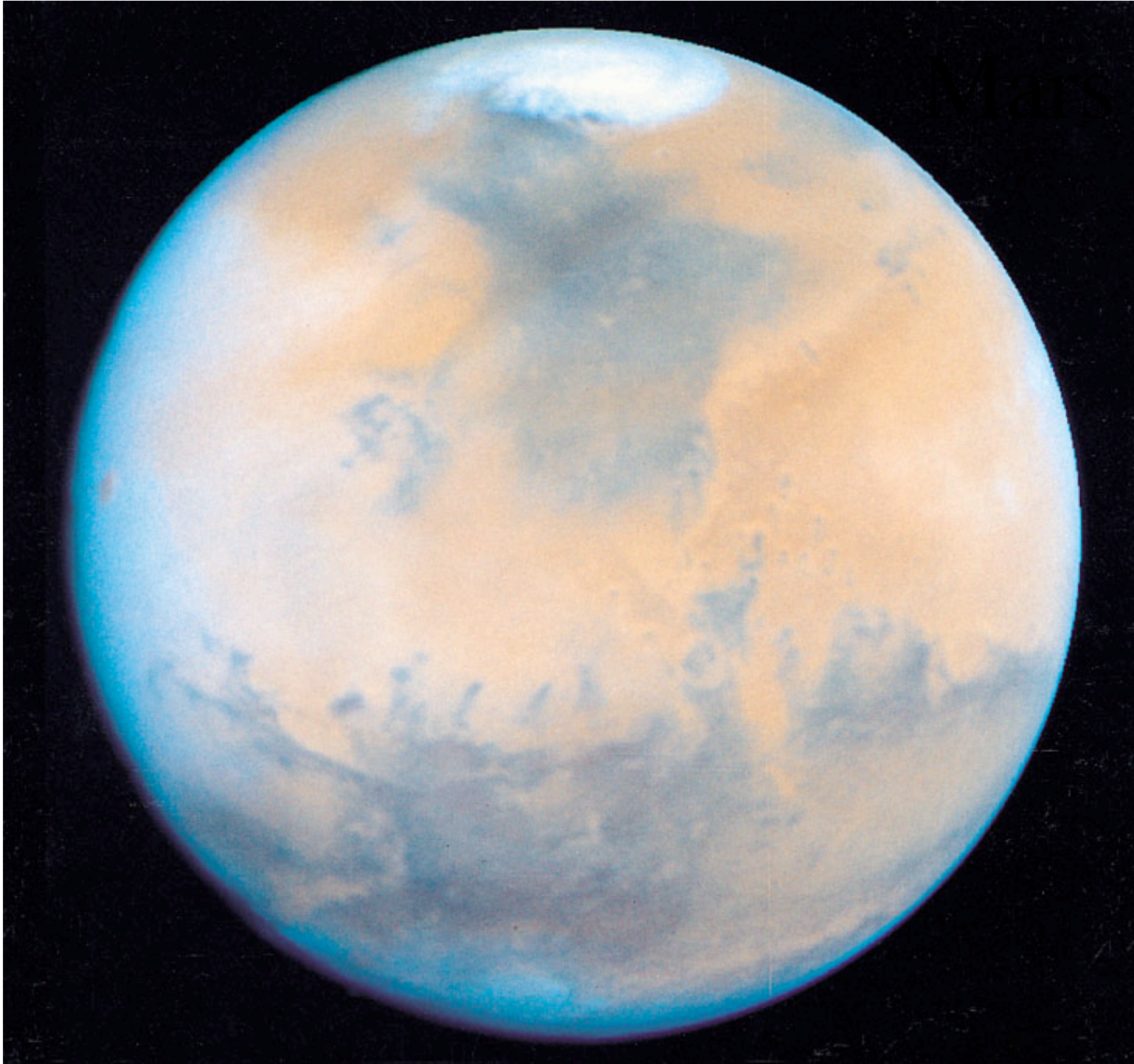
Impact craters

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Reworking the surface

- No water, very little erosion
- Only large impact craters (small meteors do not make it through thick atmosphere)
- Extensive lava flows, but...
- No obvious plate tectonics
- Impact crater density suggest surface < 800my old

It has been suggested that variations in chemical abundances in atmosphere imply active volcanoes, but this is **controversial**



MARS

Mars: basic facts.

- Average distance from Sun = 1.52 AU
- Perihelion = 1.38 AU
- Aphelion = 1.66 AU ← orbit very elliptical,
- Orbital period = 1.88 years $(R_p/R_a)^2=0.69$
- Tilt of axis = 25 degrees
- Rotation period = 24 hrs, 37 min
- Temperature range 150-300 K (-220-68 F)
- Size = 0.5 size of Earth
- Average density 3.3 g/cc (light rocks)

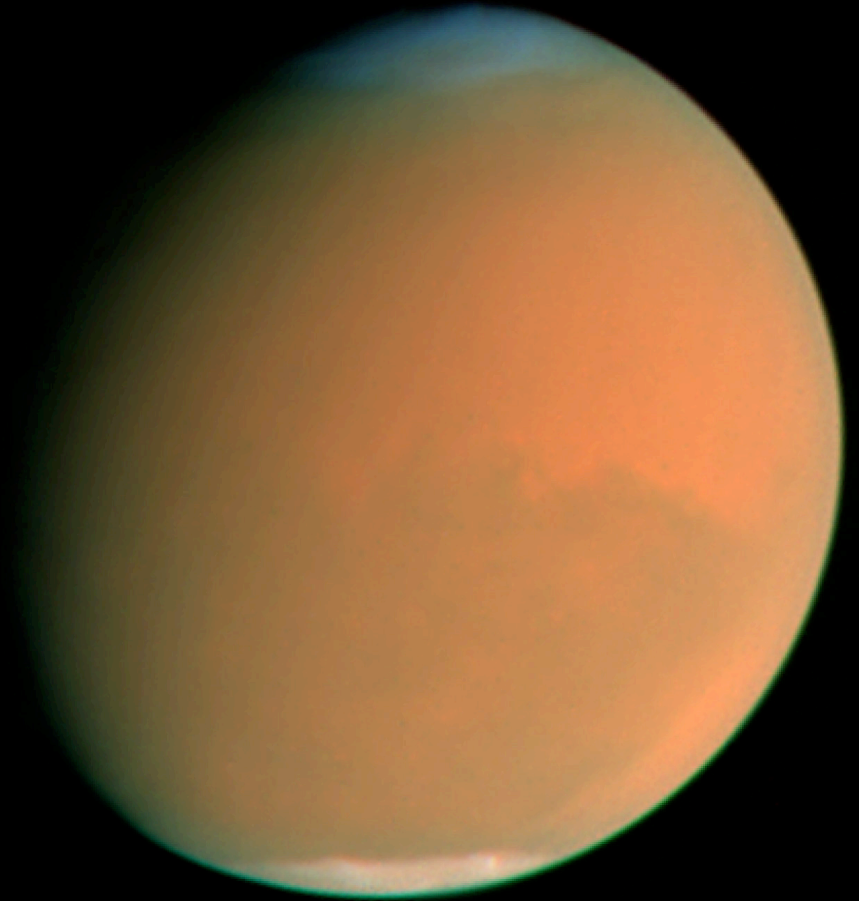
Mars' climate

- Similarities to Earth
 - Length of day about the same
 - Axis tipped 25 degrees to ecliptic – seasons!
- Differences compared to Earth
 - Orbit highly elliptical, so total solar radiation changes significantly over Martian year
 - Drives stronger seasonal variations, global dust storms

Great storm of 2001



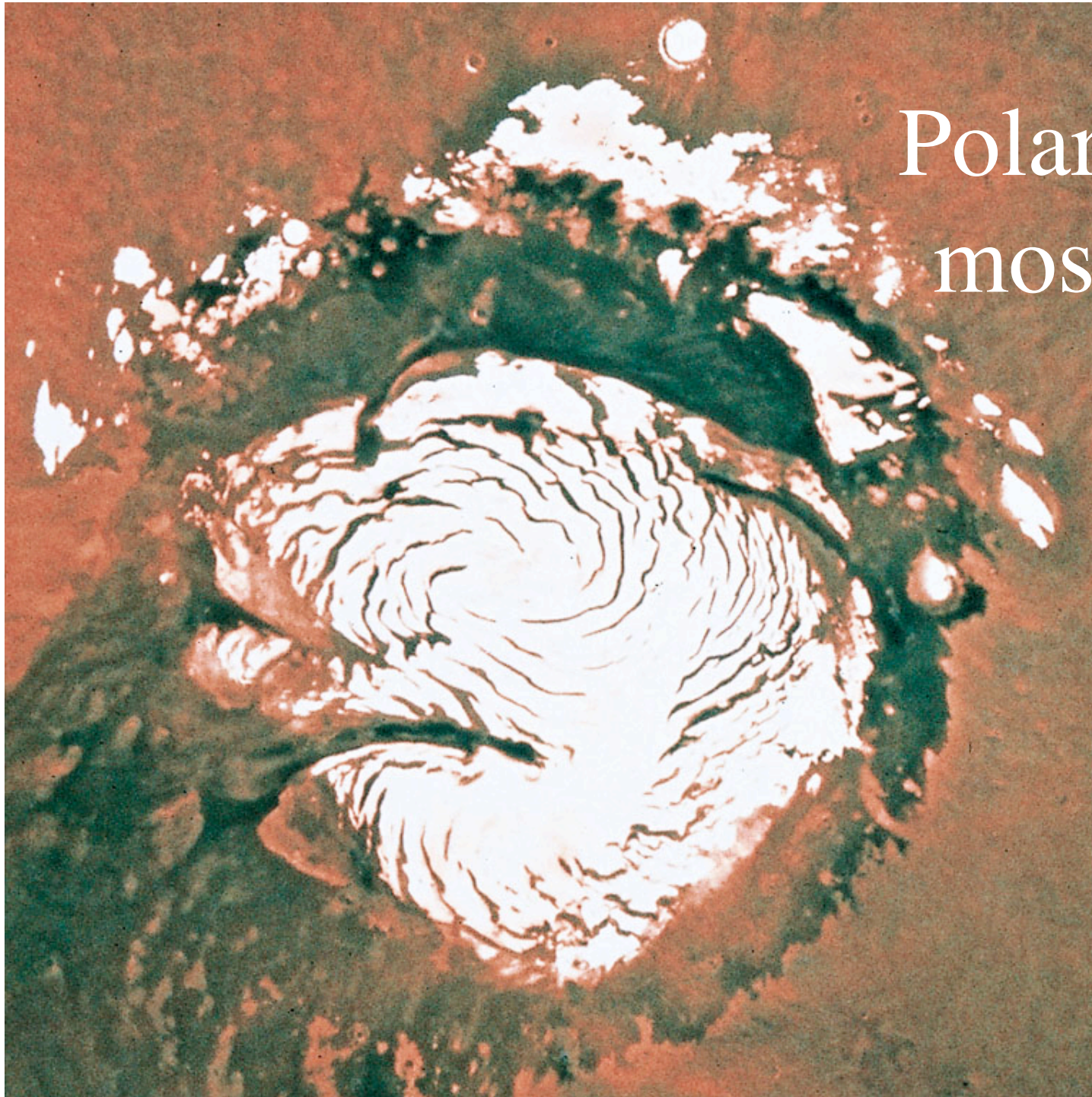
June 26, 2001



September 4, 2001

Atmosphere

- Most oxygen is in the soil (iron oxides, which give Mars its distinctive reddish color)
- 95% CO₂ (like Venus)
- But atmospheric density is
 - nearly 100 times less than Earth's
 - nearly 10,000 times less than Venus'
- Little greenhouse effect, too cold for liquid water



Polar ice cap,
mostly CO₂

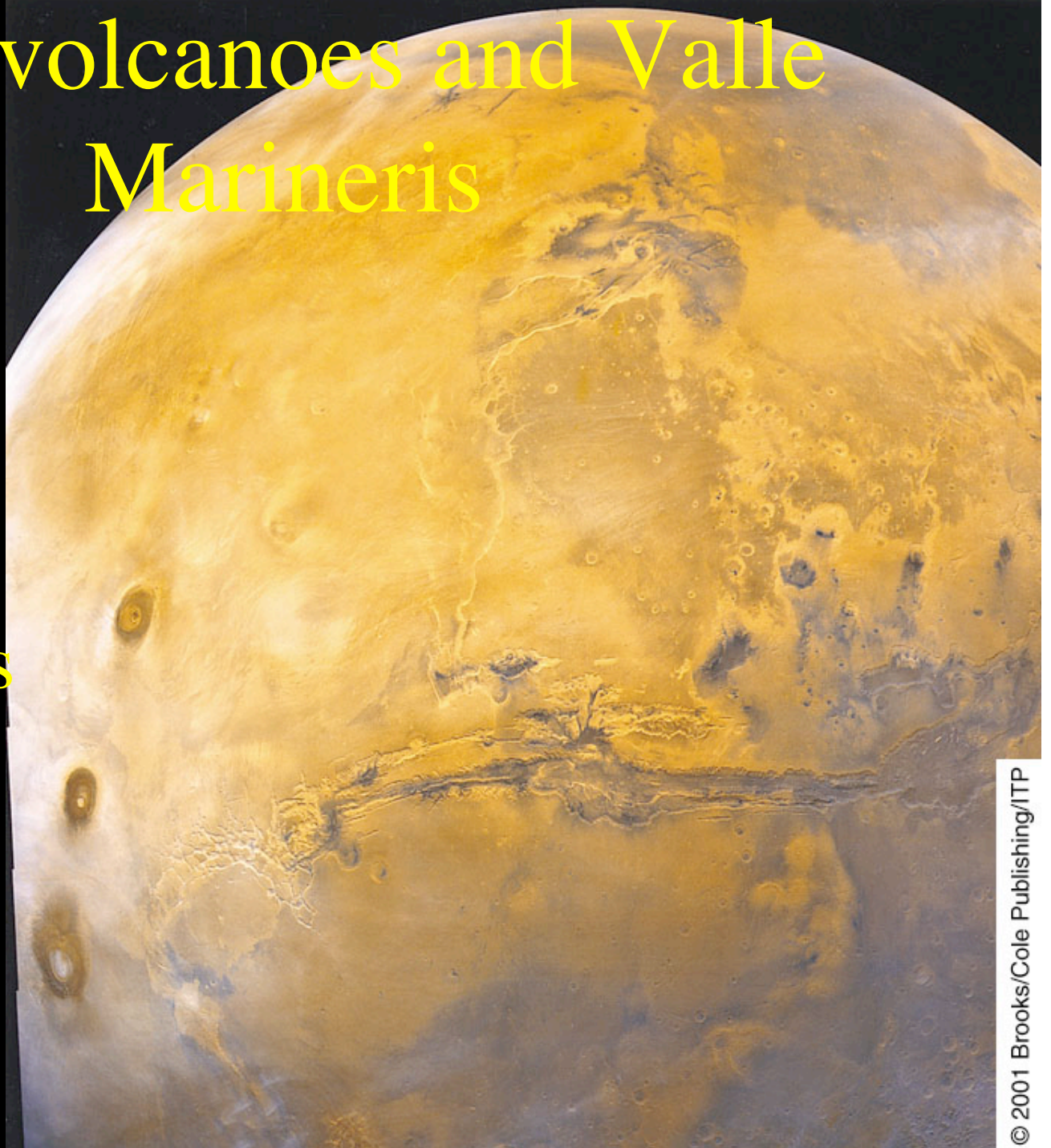
Impact craters

- Mostly found in southern half of planet
- Southern surface is over 3 billion years old

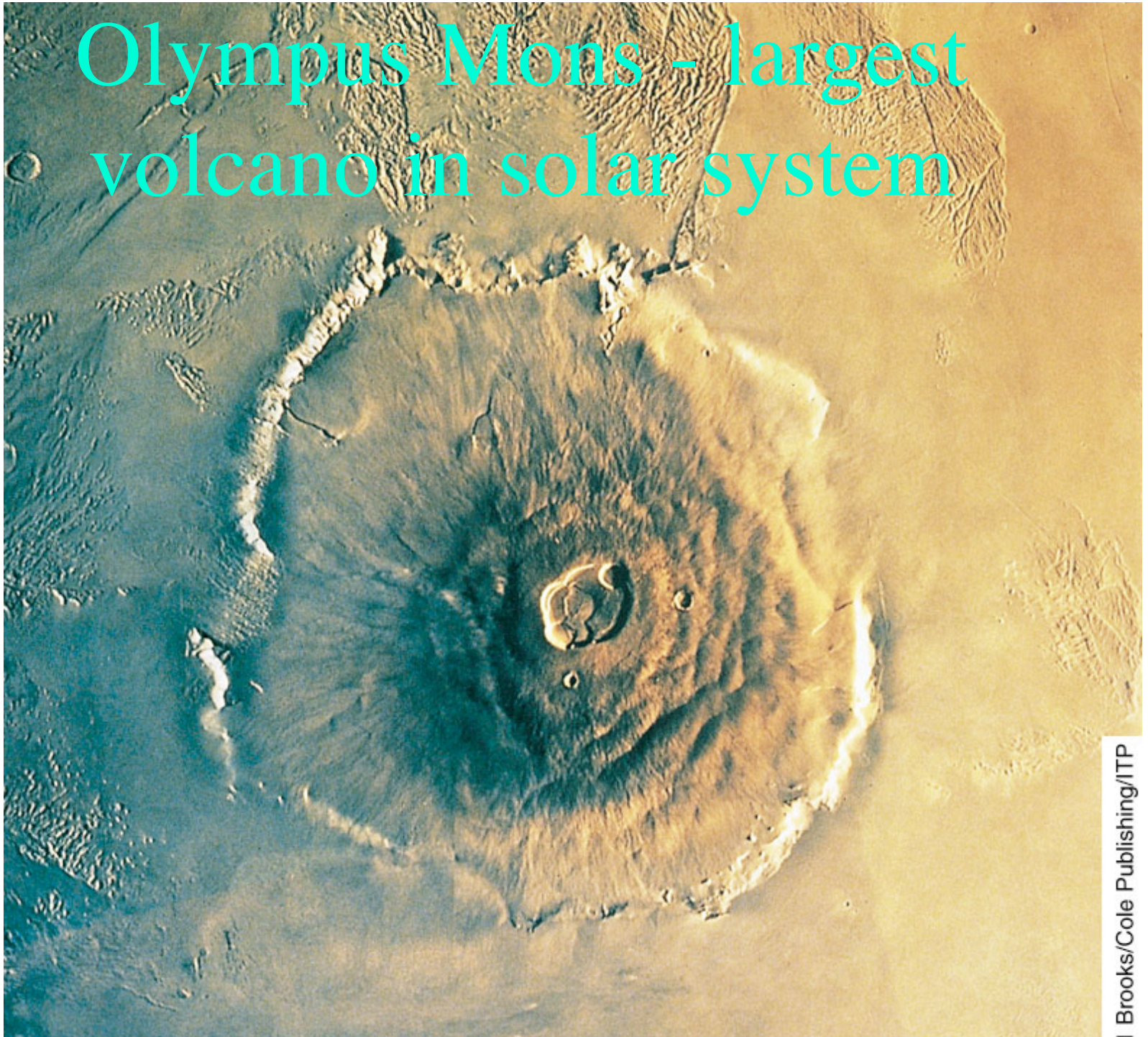


Giant volcanoes and Valle Marineris

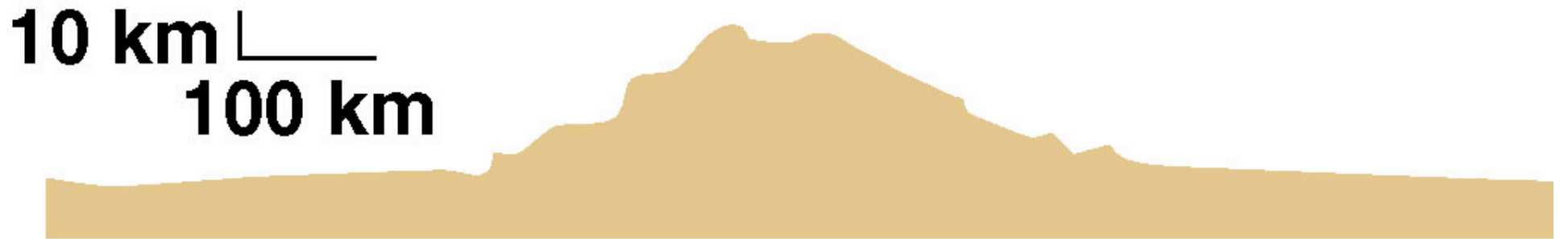
- Volcanism resurfaced northern part as recently as 1 billion years ago



Olympus Mons - largest volcano in solar system



Comparison of biggest mountains



Olympus Mons

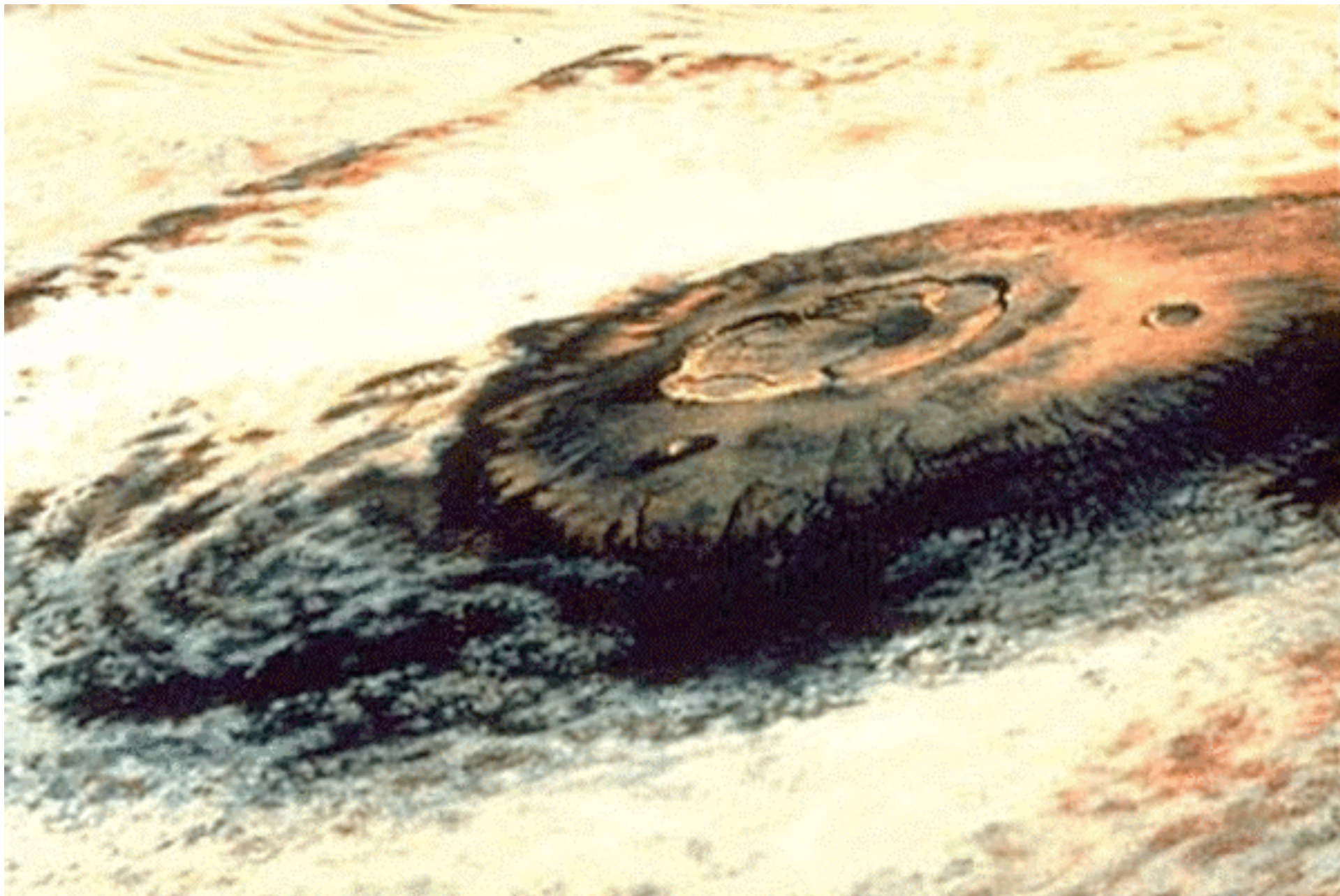
Sea level



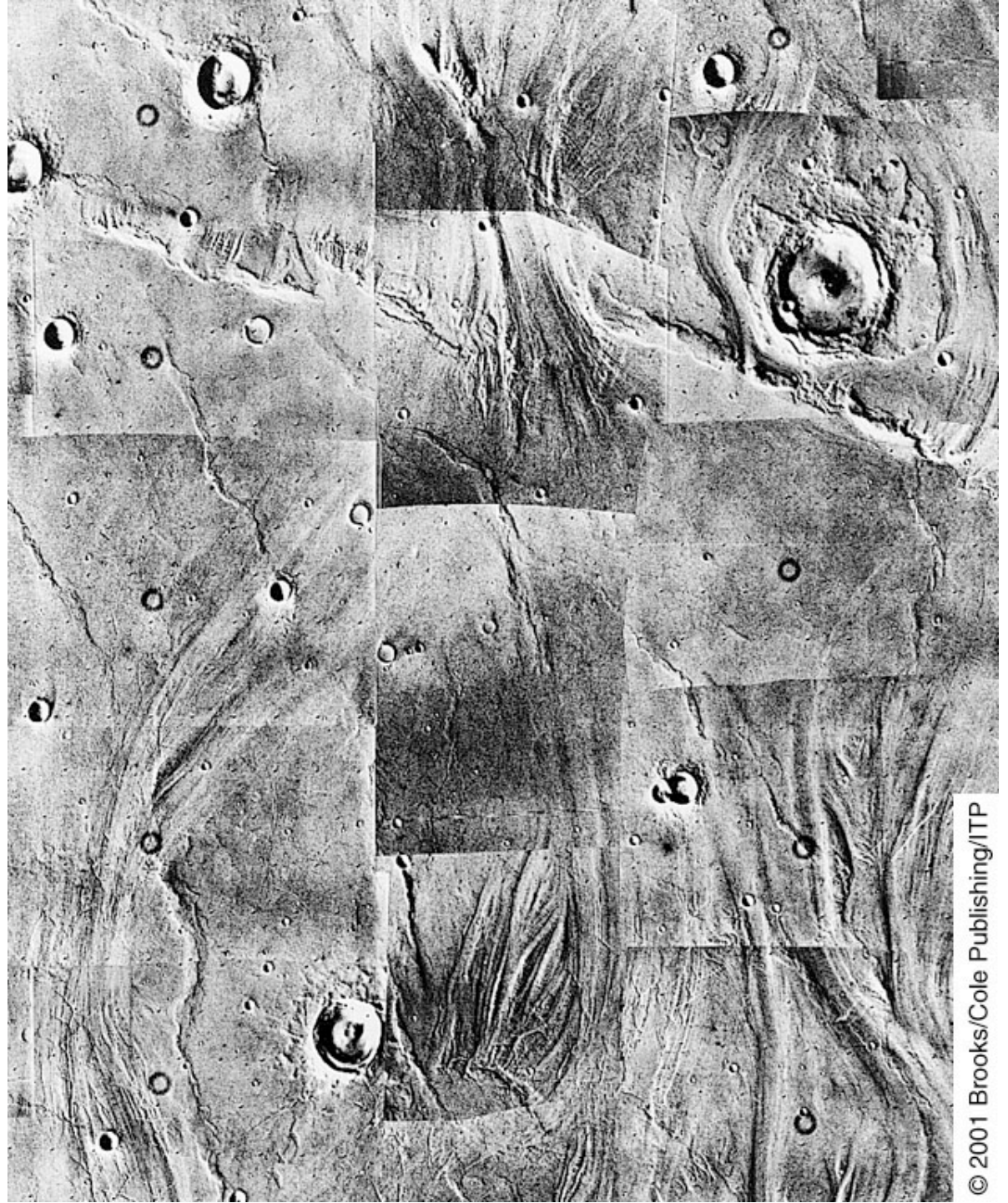
Mauna Loa

Weaker gravity allows bigger mountains

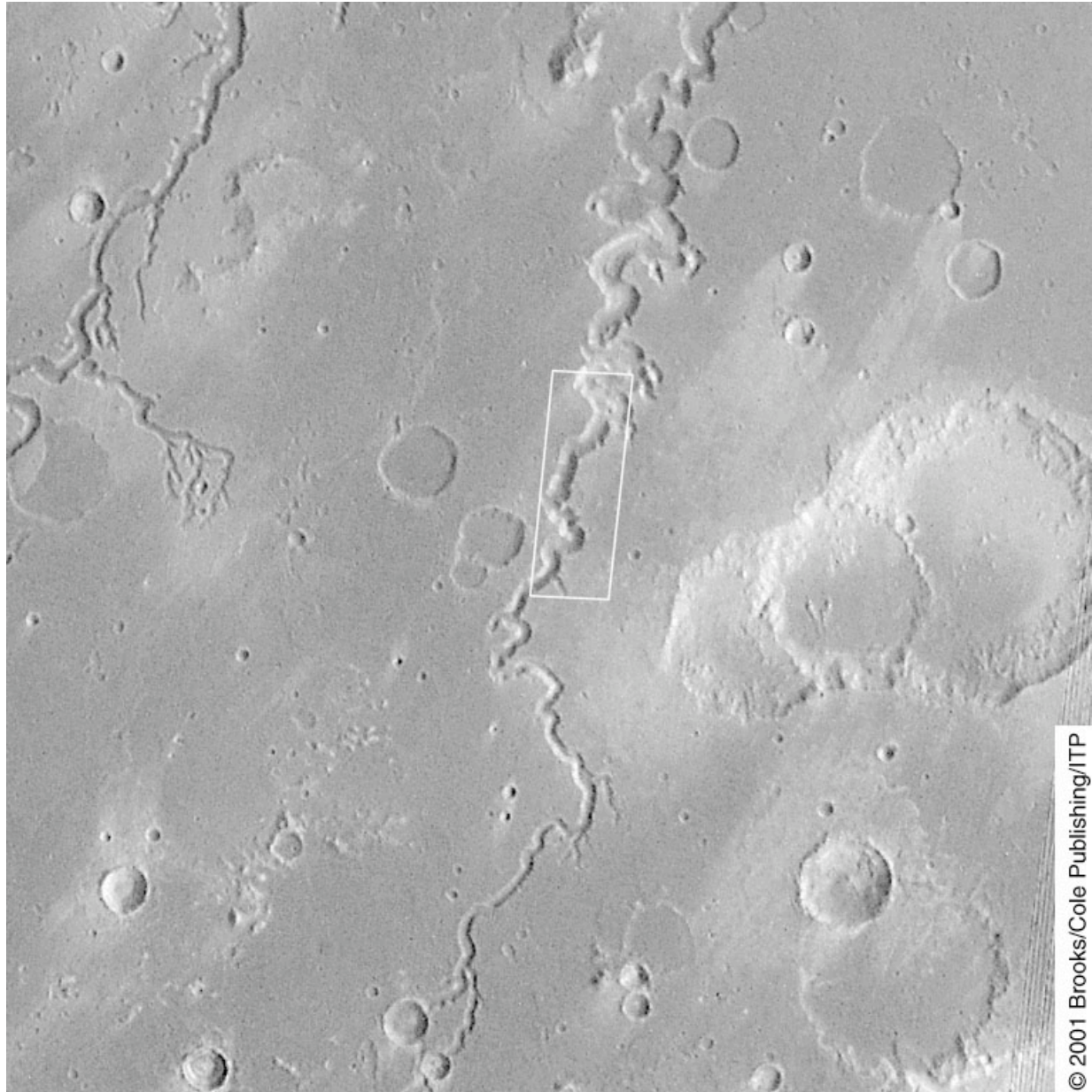
Olympus Mons



Great Floods



Steady ancient streams





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Science results from rovers

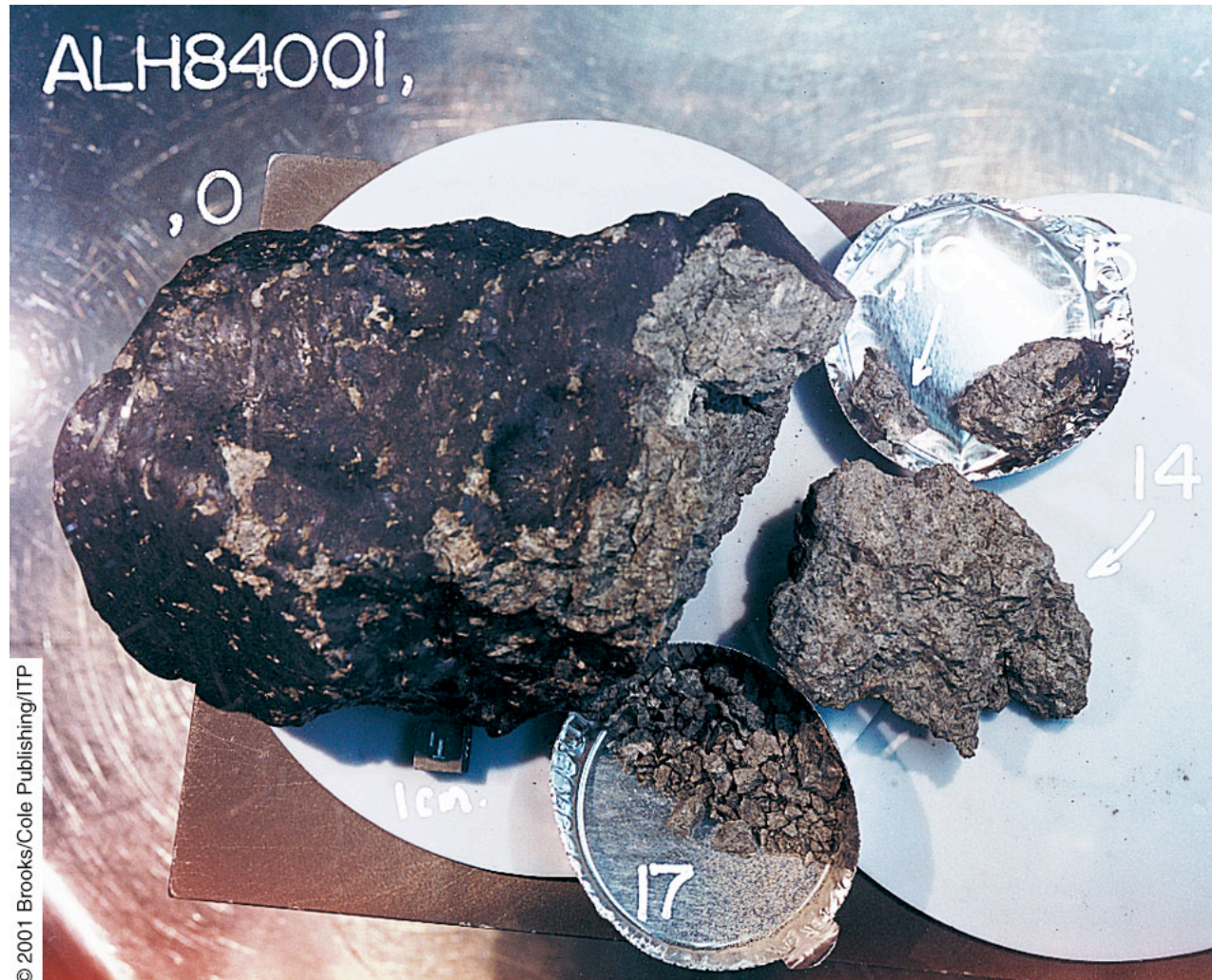
No doubt that liquid water once existed on Mars

Chemical evidence it was very acidic

Liquid water may have existed beneath ice layer

- Was Mars a good place for life in the past?

Antartica meteorite from Mars



Microscopic mineral formation in rock looks like bacteria.

Phobos & Deimos, captured asteroids?

