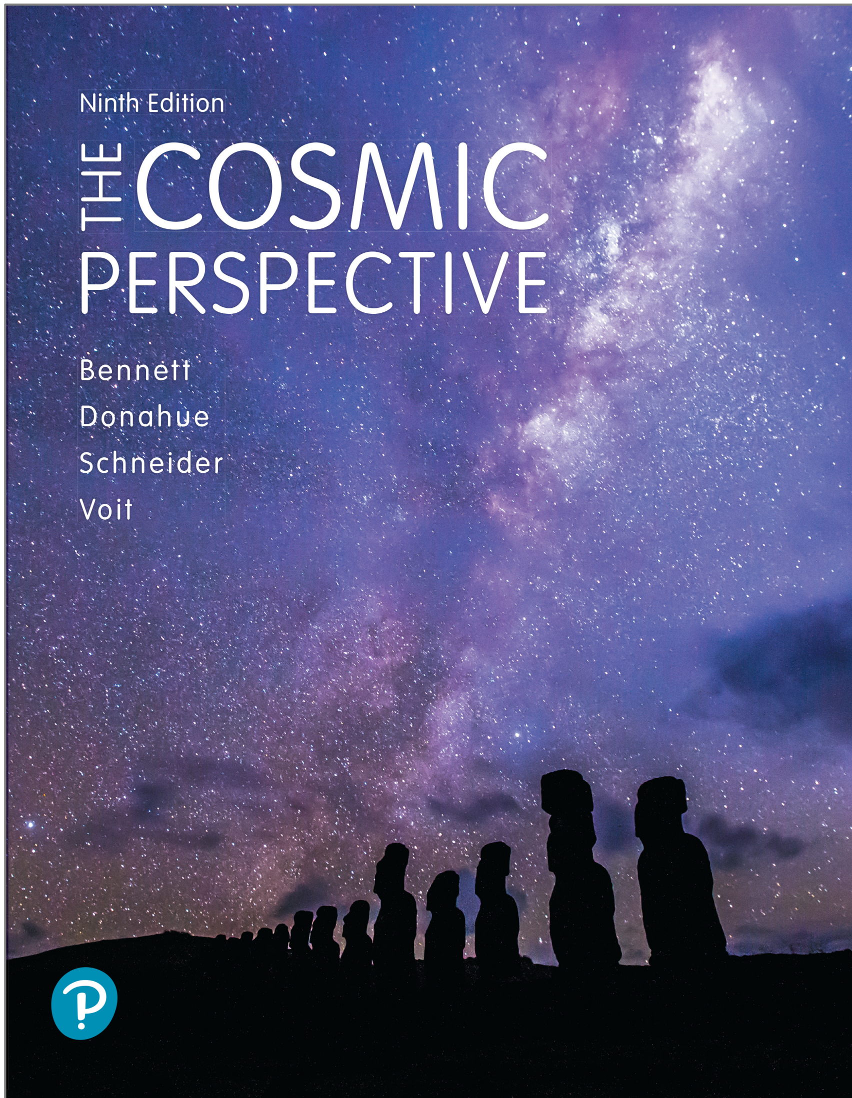
The Cosmic Perspective

Ninth Edition



Planetary Geology

A rock is analyzed and found to contain argon-40, a noble gas. What are possible sources?

1. Argon was trapped inside the rock when the solar nebula was formed
2. The rock's surface was exposed to high levels of argon atoms that gradually drifted into the interior
3. The rock contained radioactive potassium-40 that decayed into argon-40
4. a & b
5. b & c
6. c & a
7. Any of the above are possible

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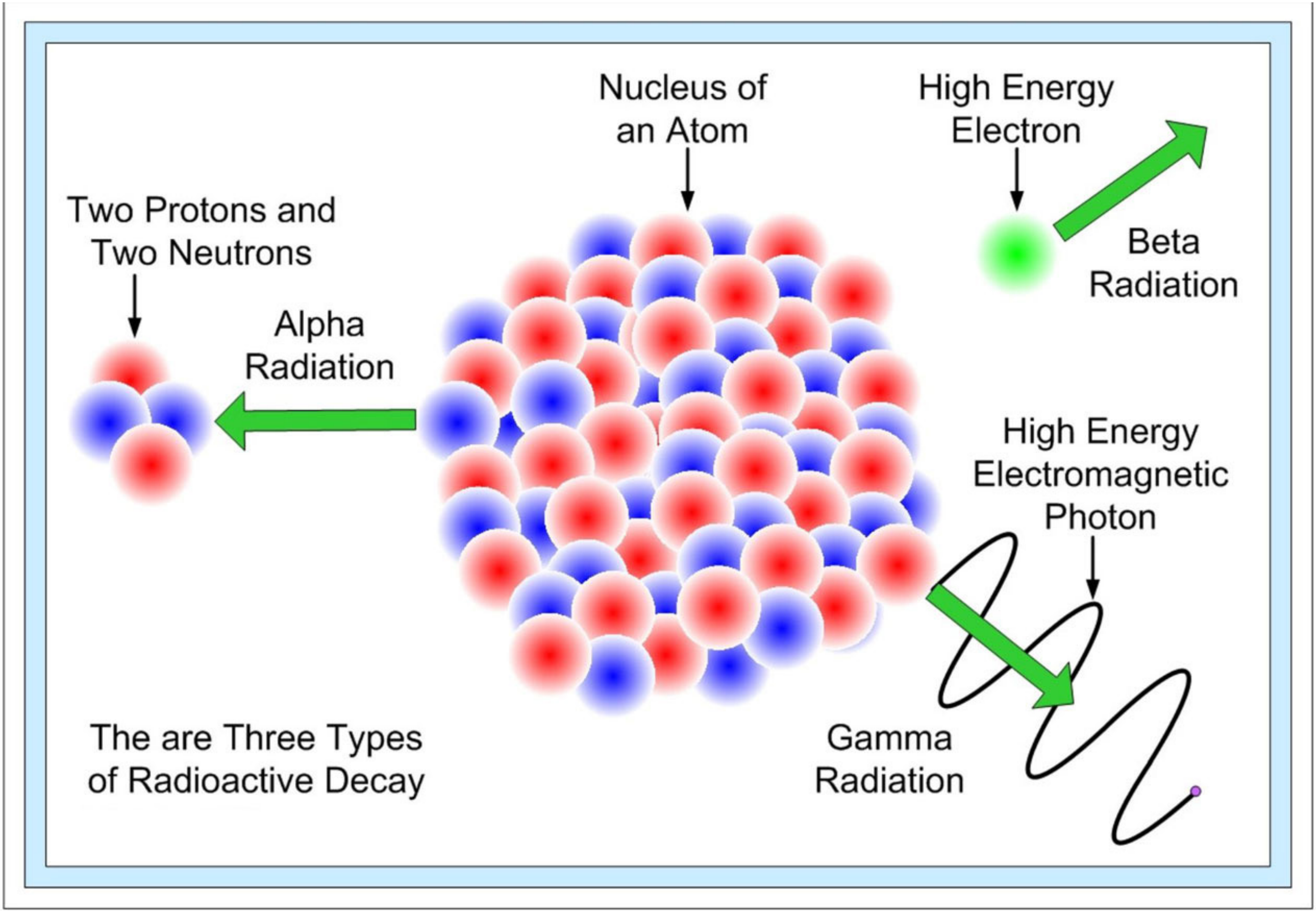
Radioactive elements can change identity!

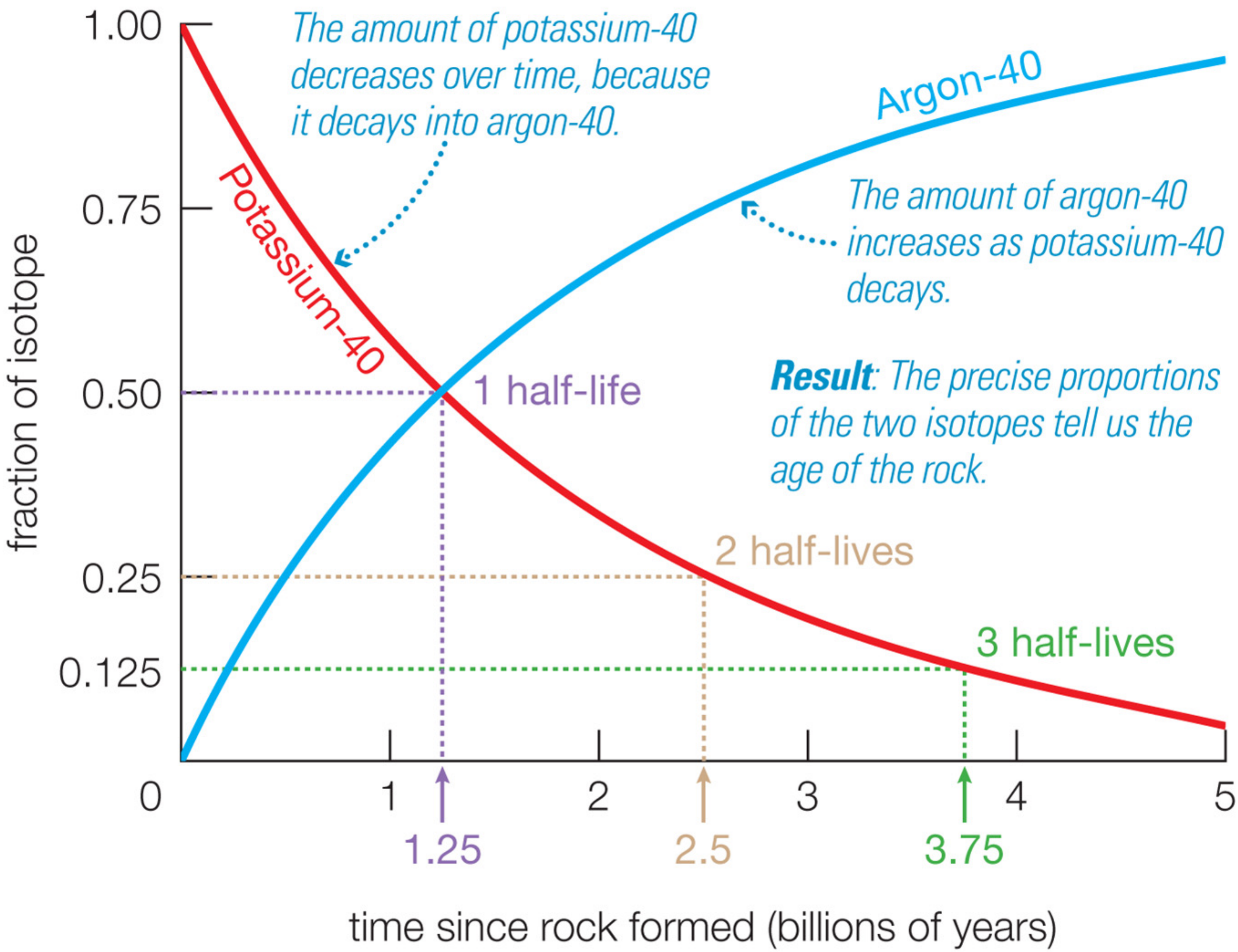
- Unstable radioactive isotopes spontaneously decay
- Typically, a small part of the nucleus is ejected, which can carry away both energy and electrical charge
- If a net amount of charge leaves, that alters the electrical charge of the remaining nucleus


Nucleus of
an Atom
High Energy
Electron
Beta
Radiation
Two Protons and
Two Neutrons
Alpha
Radiation
High Energy
Electromagnetic
Photon
Gamma
Radiation
The are Three Types
of Radioactive Decay

Radioactive elements can change identity!

- Unstable radioactive isotopes spontaneously decay
- Typically, a small part of the nucleus is ejected, which can carry away both energy and electrical charge
- If a net amount of charge leaves, that alters the electrical charge of the remaining nucleus
- Because chemical interactions among elements all depend on the charge of the nucleus (characterized by its “atomic number”), this changes what kind of element it is
- How long a given nucleus will survive is unpredictable, but in a population of identical nuclei, statistically 50% will have decayed in a specific duration of time characteristic of that isotope, the “half-life”

Potassium-40 decays radioactively with a half-life of 1.25 billion years!



A certain rock contains equal parts of argon-40 and potassium-40. How old is it?

1. zero years
2. 1.25 billion years
3. 2.50 billion years
4. 3.75 billion years
5. 5.00 billion years
6. 7.00 billion years

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A certain rock contains 7 atoms of argon-40 for every 1 atom of potassium-40. How old is it?

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Radioactive decay with half-life 703.8 million years

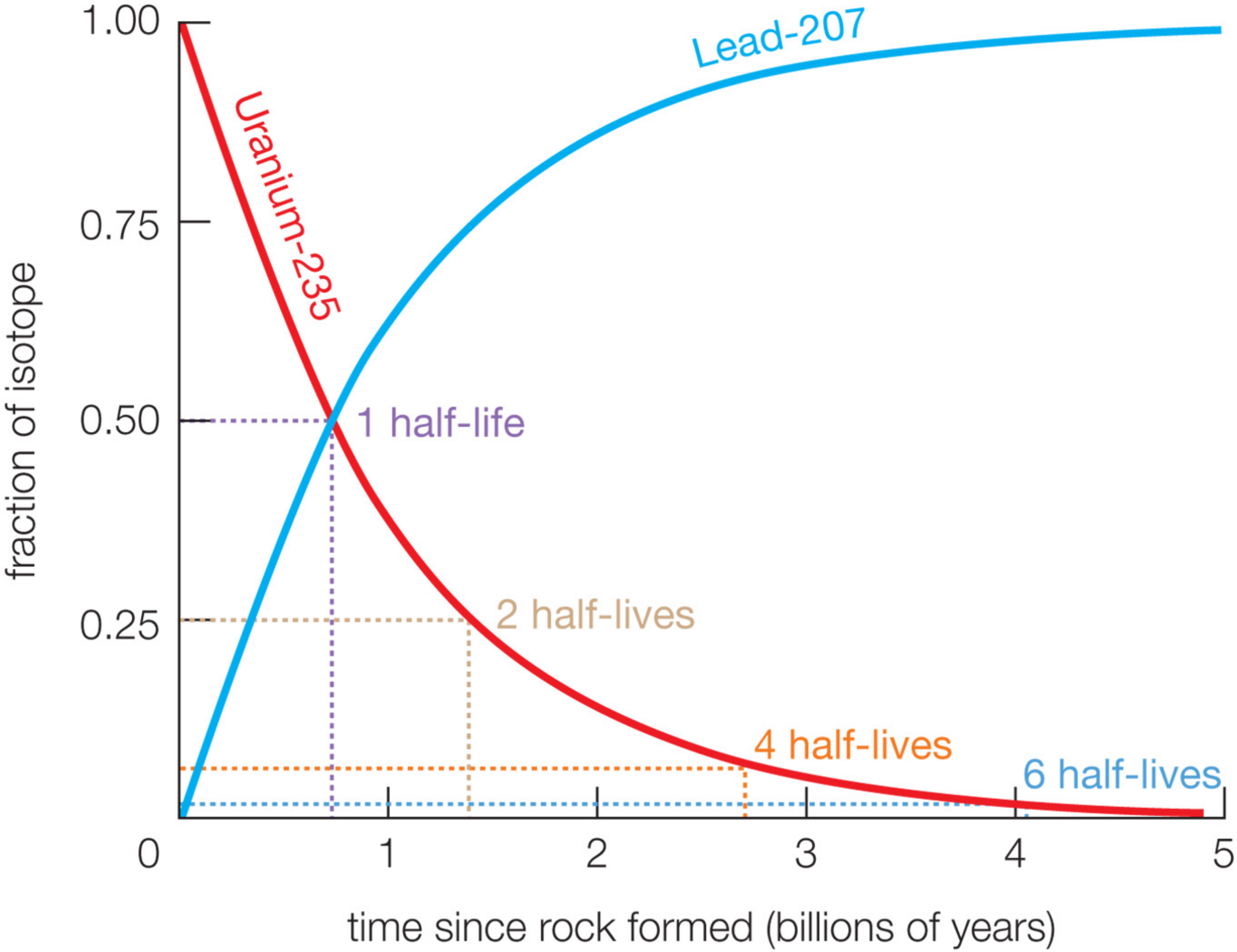
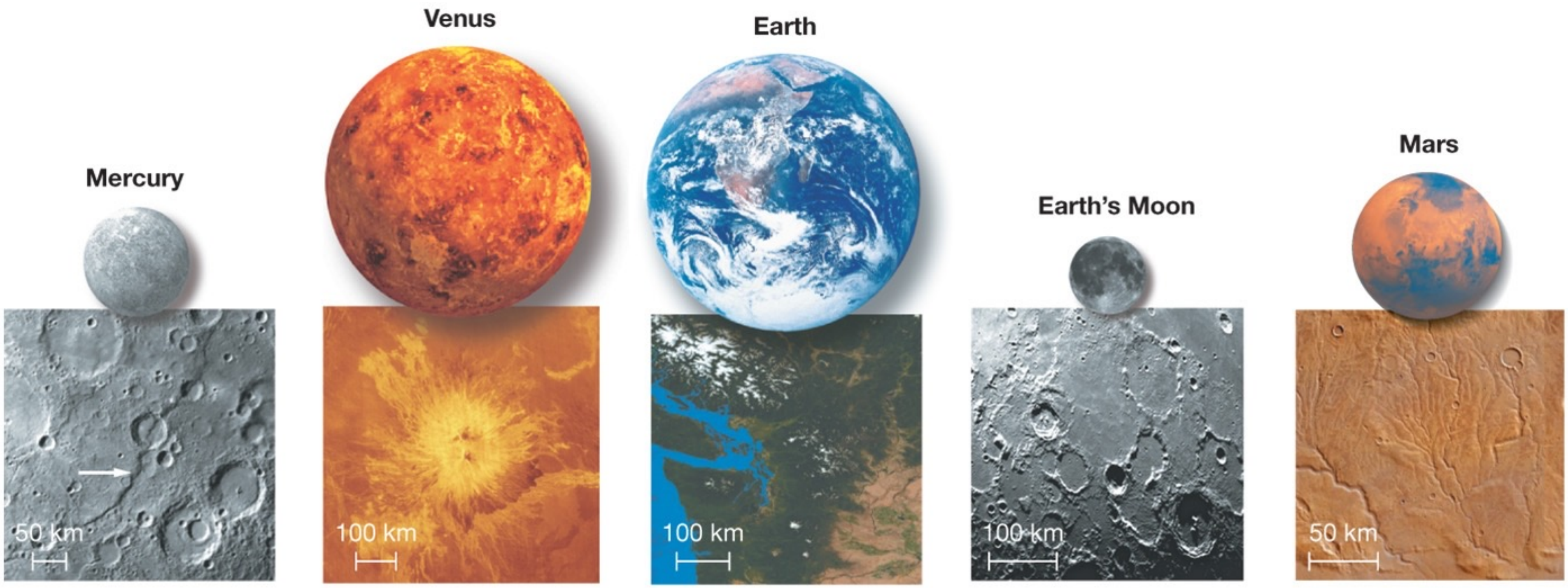


Figure 9.1



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.

Figure 8.6

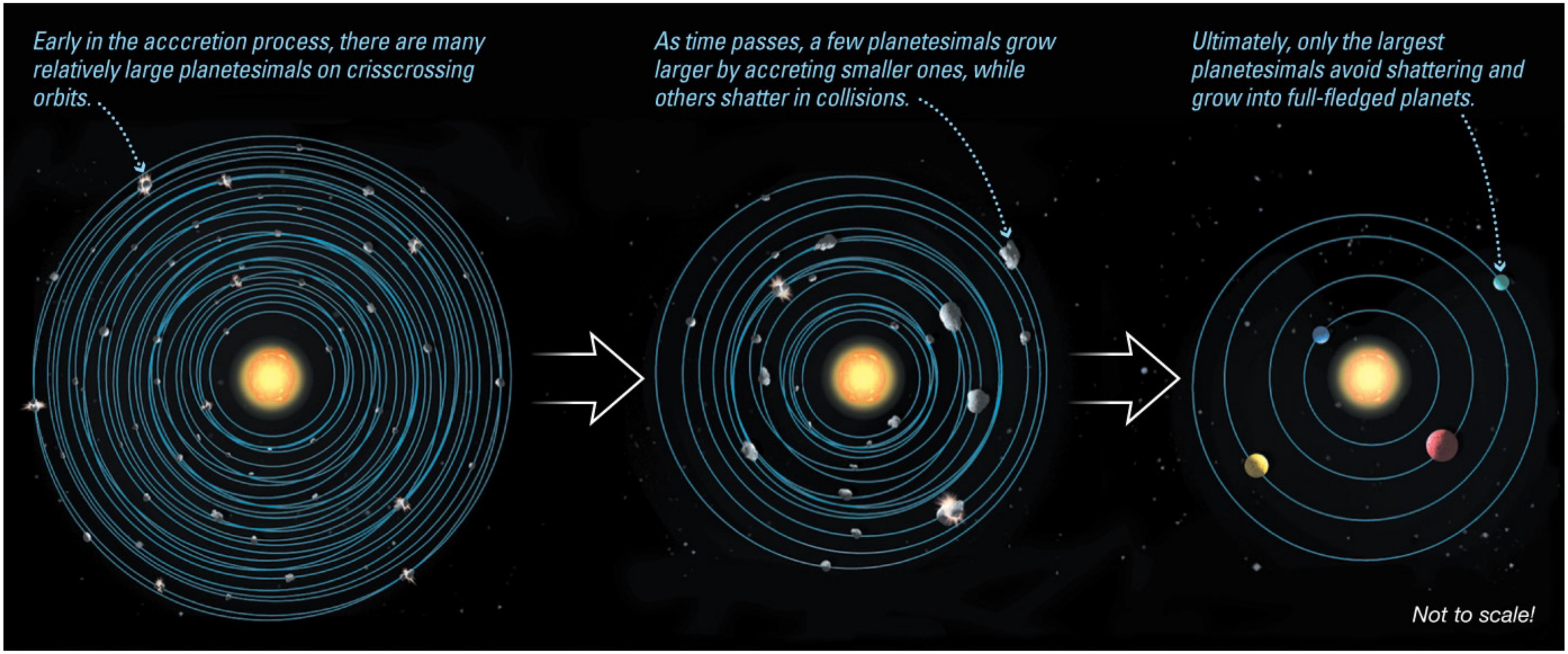

Early in the acccretion process, there are many relatively large planetesimals on crisscrossing orbits.
As time passes, a few planetesimals grow larger by accreting smaller ones, while others shatter in collisions.
Ultimately, only the largest planetesimals avoid shattering and grow into full-fledged planets.
Not to scale!

Figure 9.2

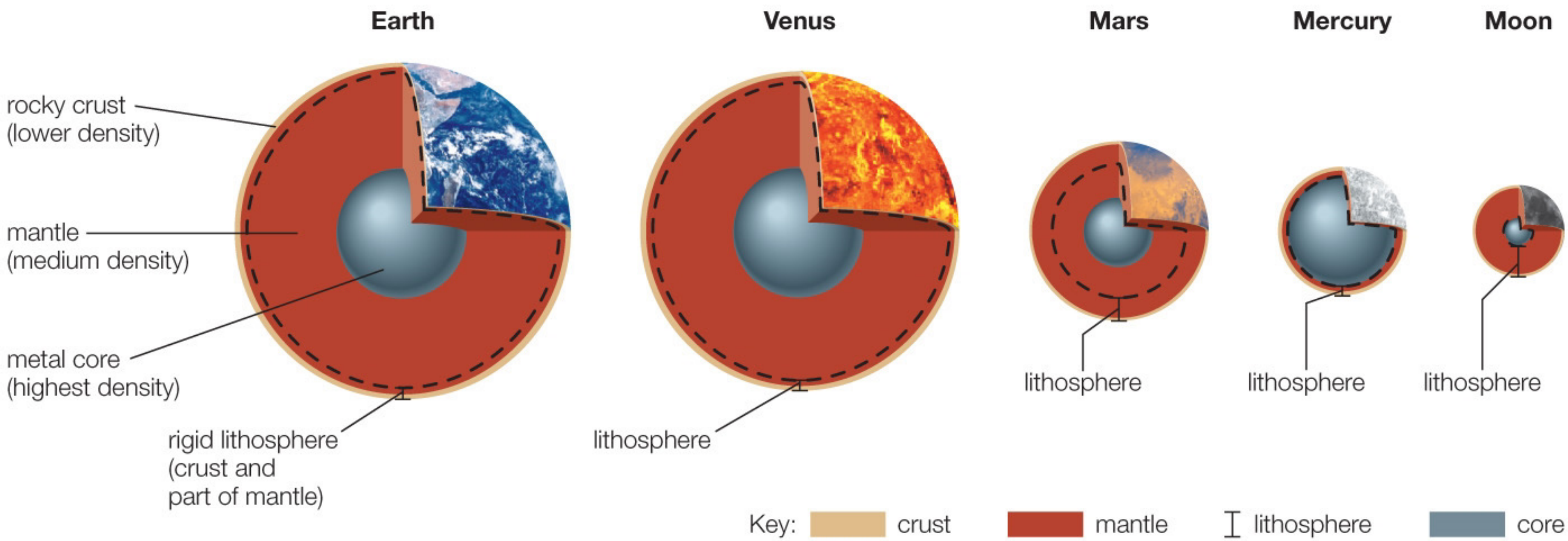
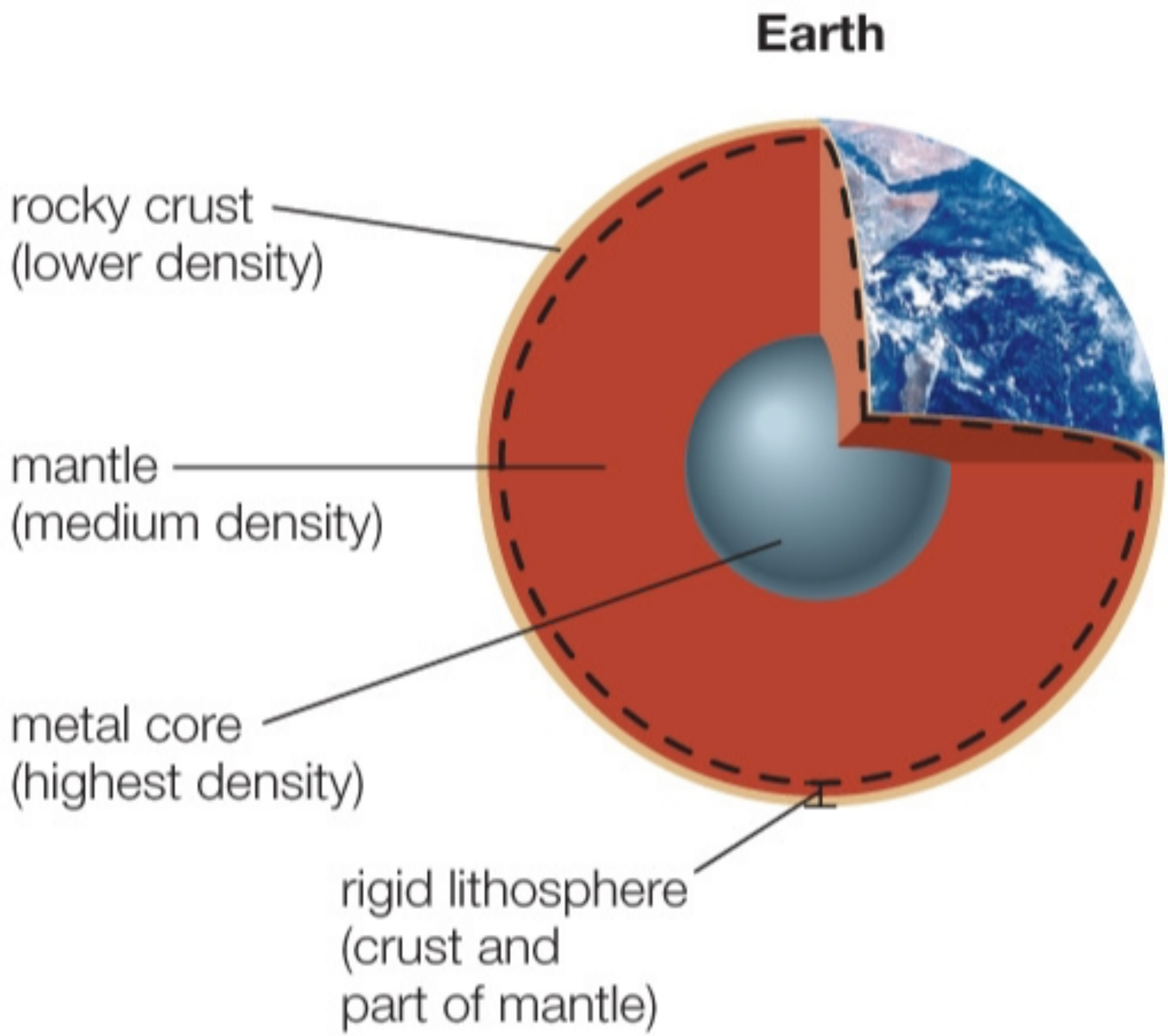

Earth
Venus
Mars
Mercury
Moon
rocky crust
(lower density)
mantle
(medium density)
metal core
(highest density)
rigid lithosphere
(crust and
part of mantle)
lithosphere
lithosphere
lithosphere
lithosphere
Key:
crust
mantle
lithosphere
core

Figure 9.2


Earth
rocky crust
(lower density)
mantle
(medium density)
metal core
(highest density)
rigid lithosphere
(crust and
part of mantle)

Over the last 10 to 200 million years, the most important large-scale changes on the surface of the Earth were caused by

1. erosion by glaciers
2. erosion by wind and water
3. man-made pollutants
4. continental drift/plate tectonics
5. comet and asteroid impacts

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2. erosion by wind and water
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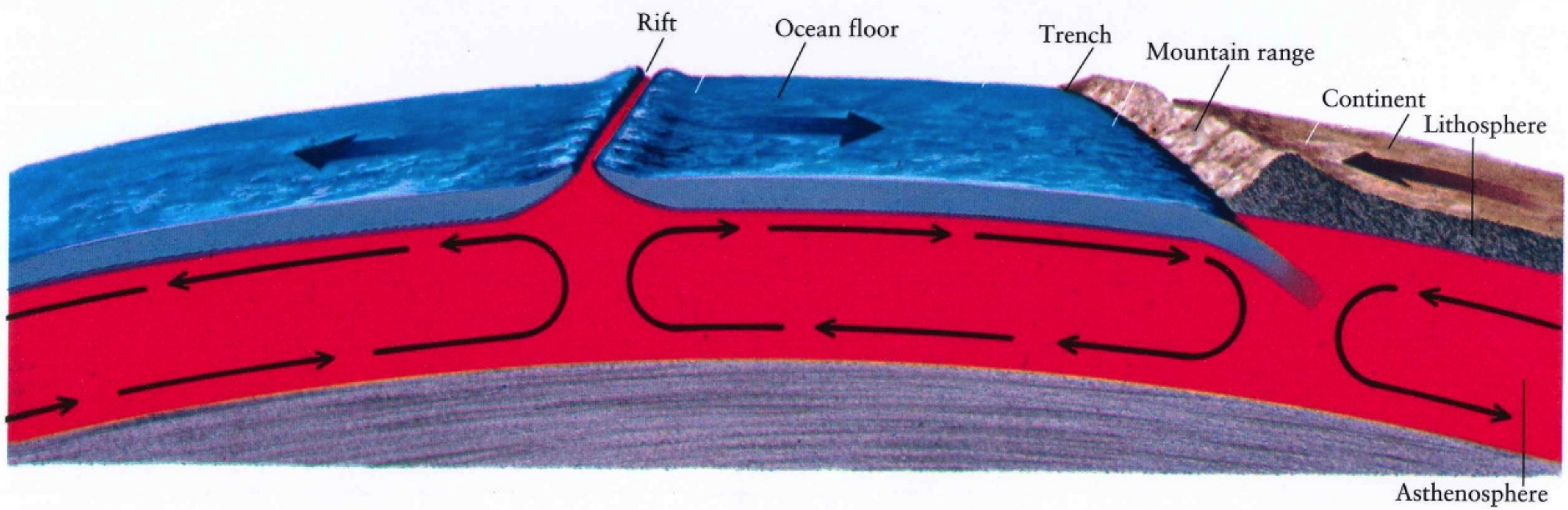
Plate tectonics



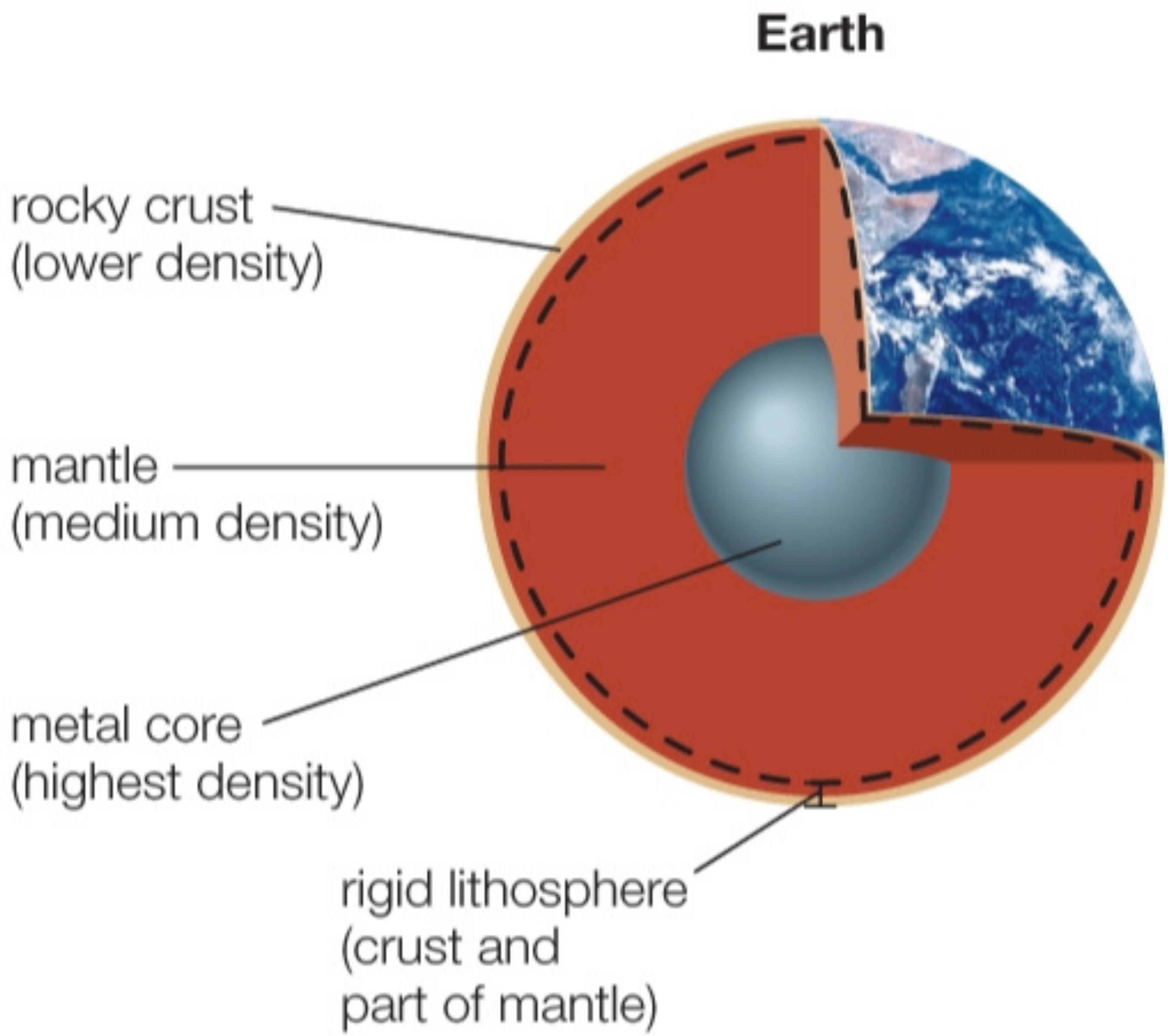
Chapter 9 Opener

Gondwanaland: 200 Ma

What provides the best evidence that the Earth has a liquid core?

1. Volcanoes
2. Earthquakes
3. Hurricanes
4. The Northern Lights
5. Deep holes bored by scientists

Figure 9.2


Earth
rocky crust
(lower density)
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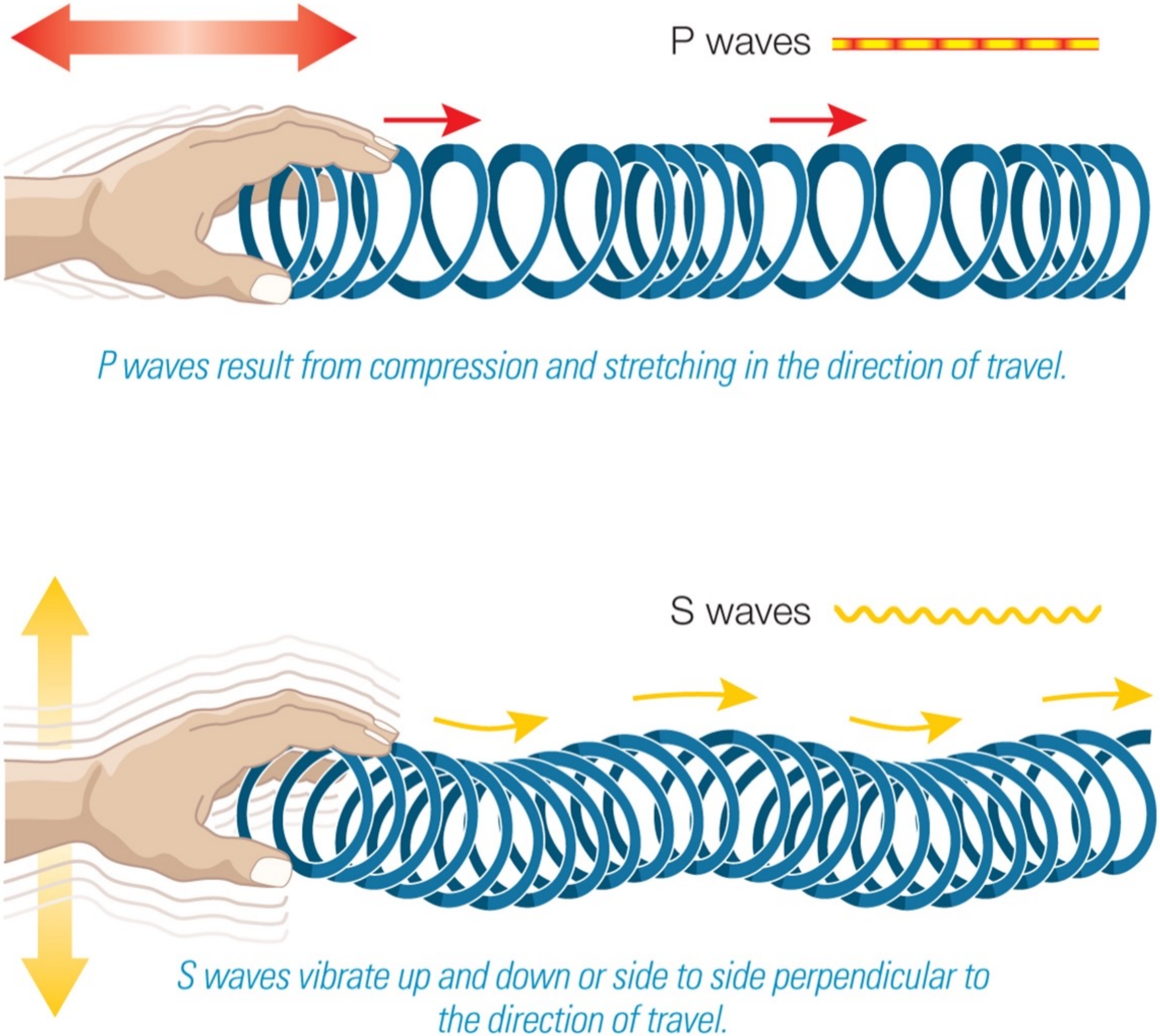
What provides the best evidence that the Earth has a liquid core?

1. Volcanoes
2. **Earthquakes – like an ultrasound for the Earth!**
3. Hurricanes
4. The Northern Lights
5. Deep holes bored by scientists

Unnumbered Figure 1 Page 237



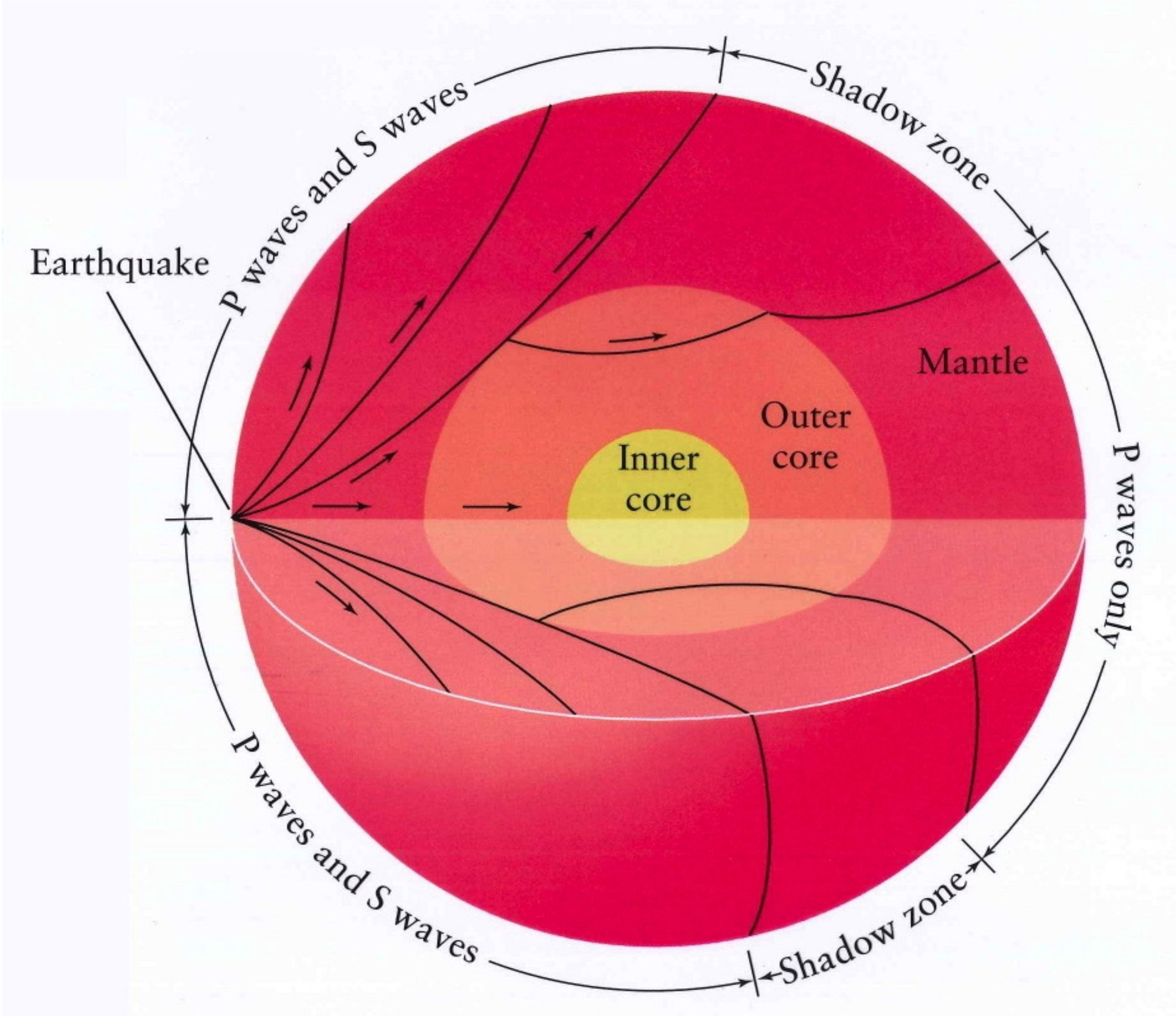
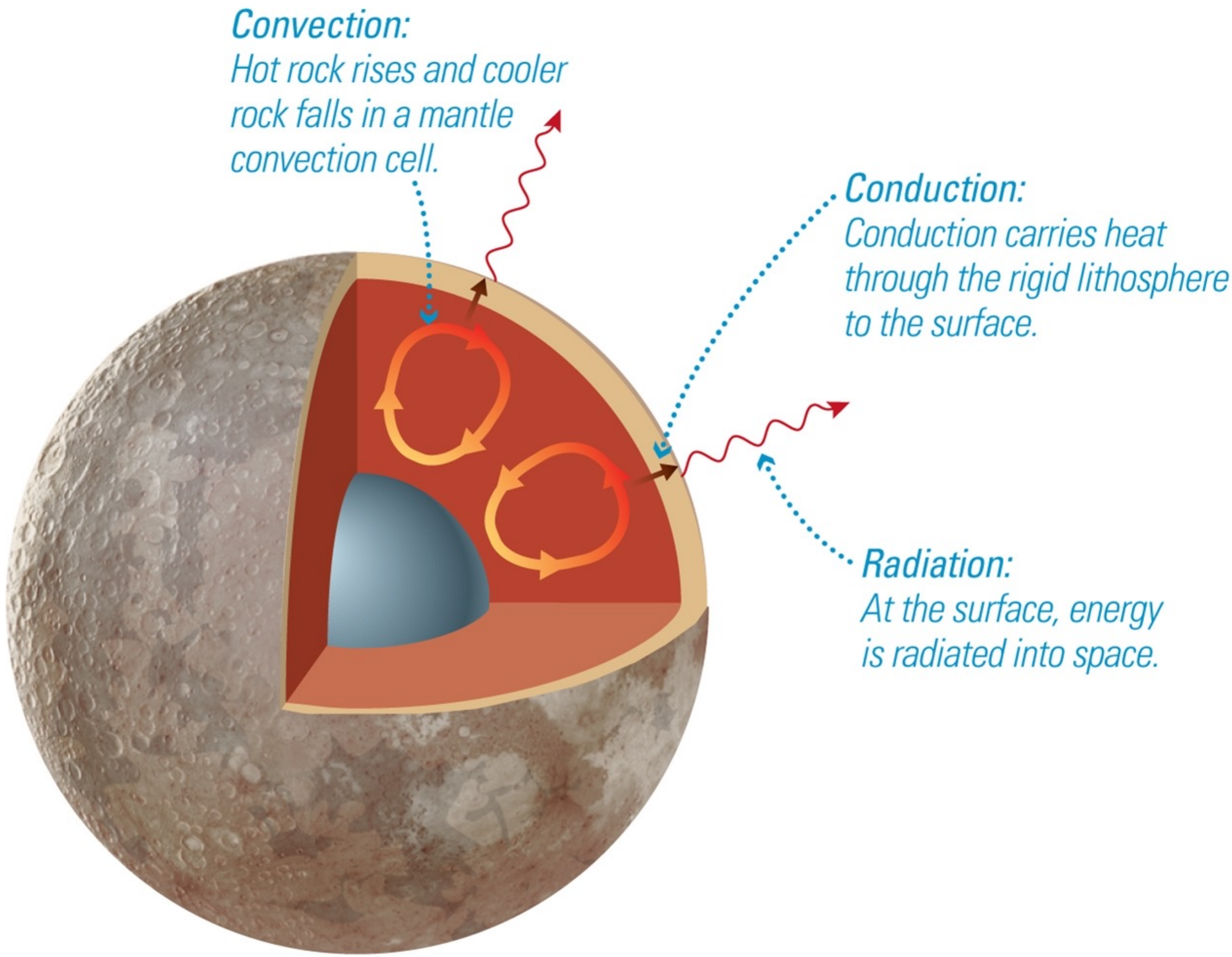
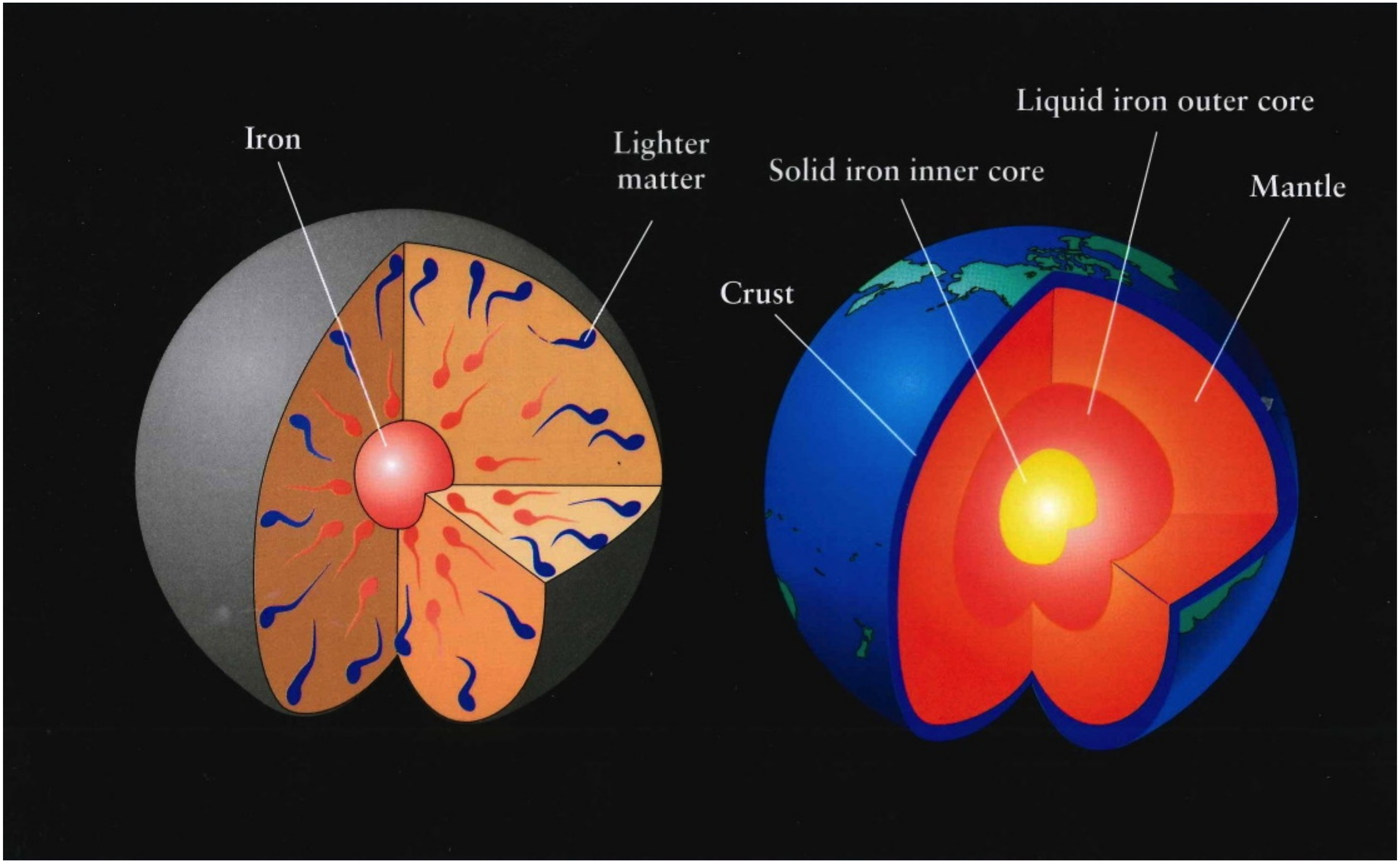

P waves and S waves
Shadow zone
Earthquake
Mantle
Outer core
Inner core
P waves only
P waves and S waves
Shadow zone
Shadow zone

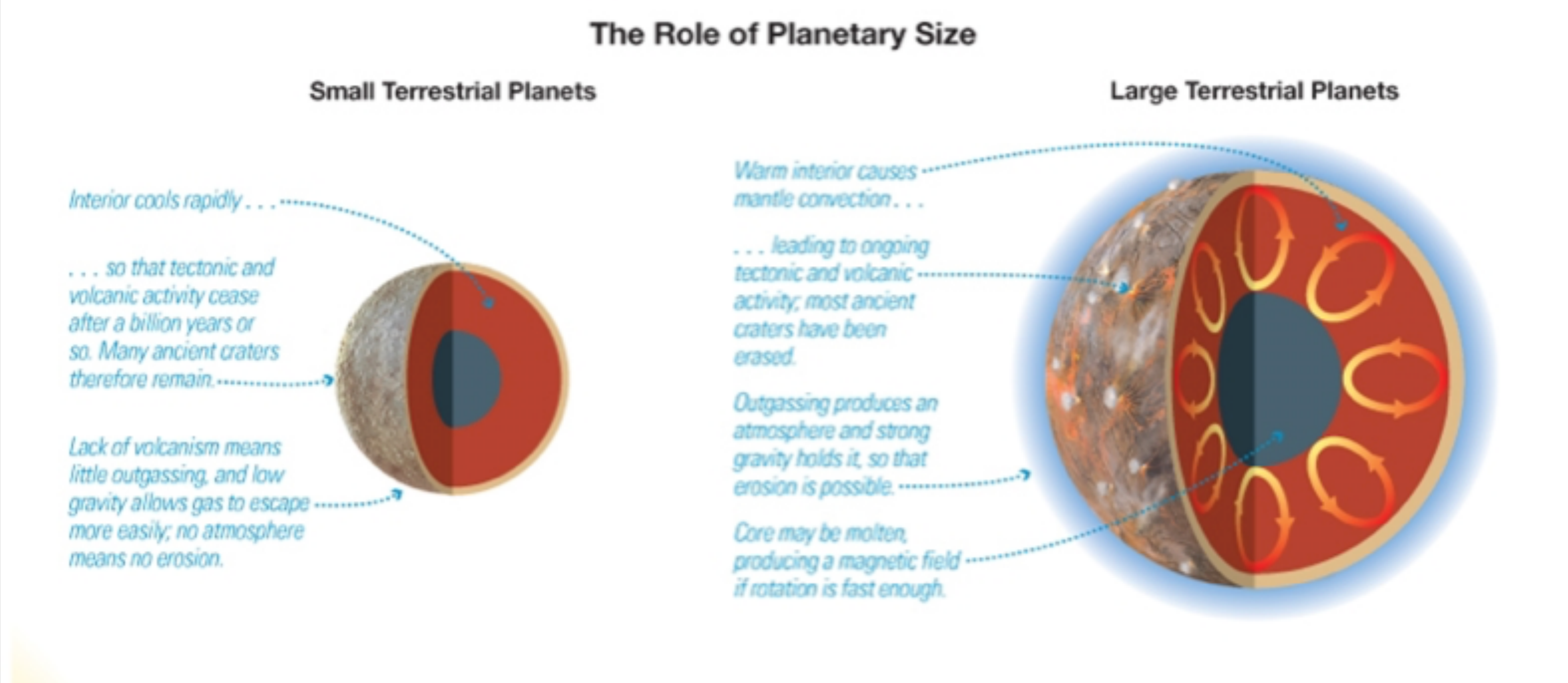
Figure 9.5

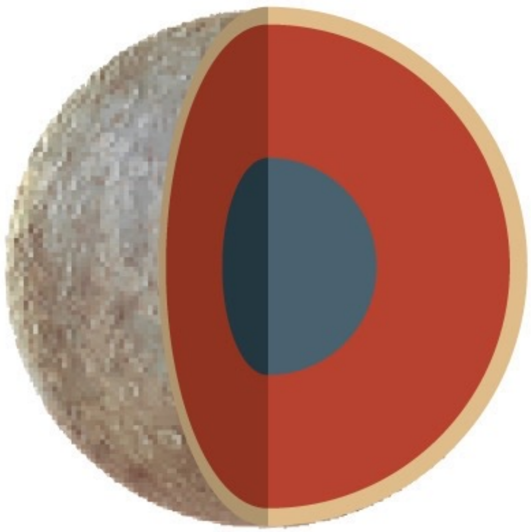
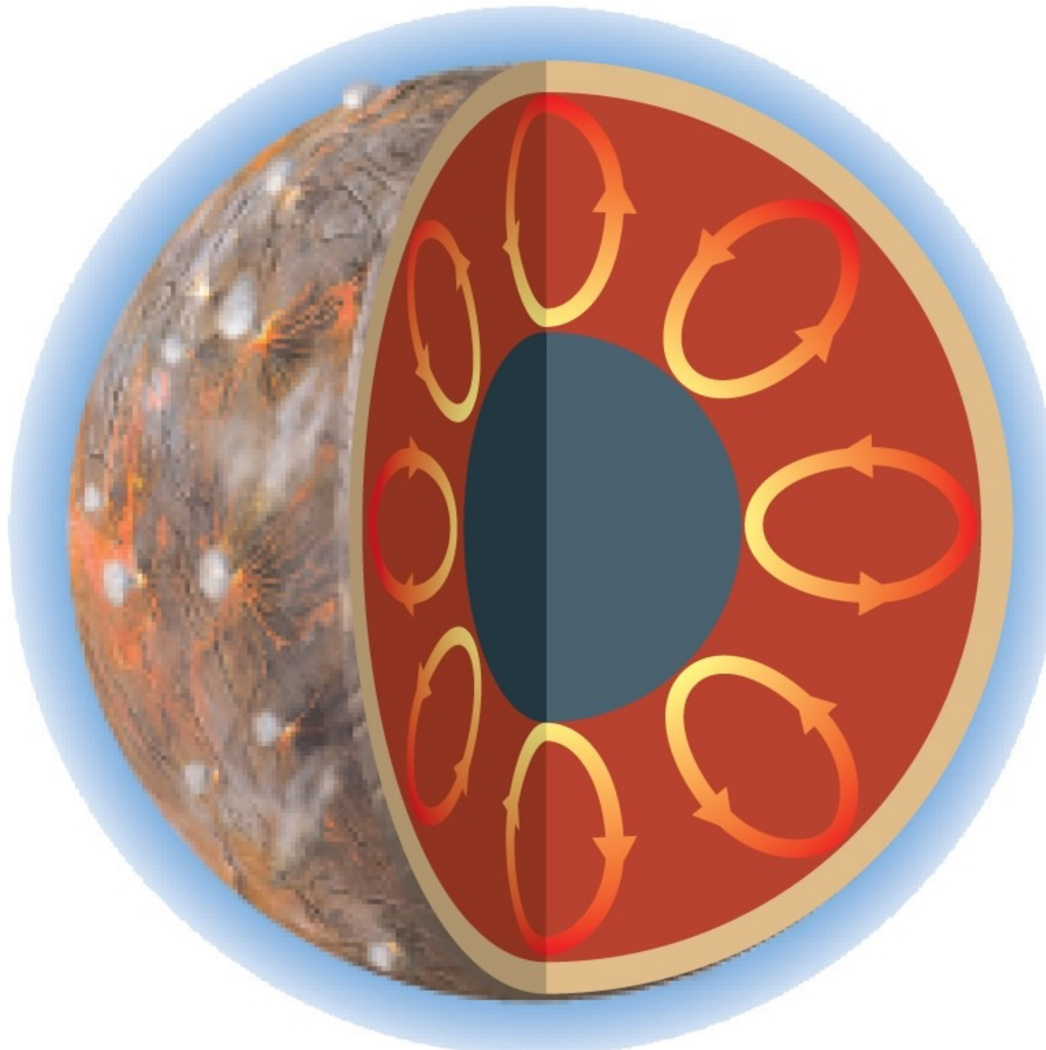


Convection:
Hot rock rises and cooler rock falls in a mantle convection cell.
Conduction:
Conduction carries heat through the rigid lithosphere to the surface.
Radiation:
At the surface, energy is radiated into space.

Differentiation



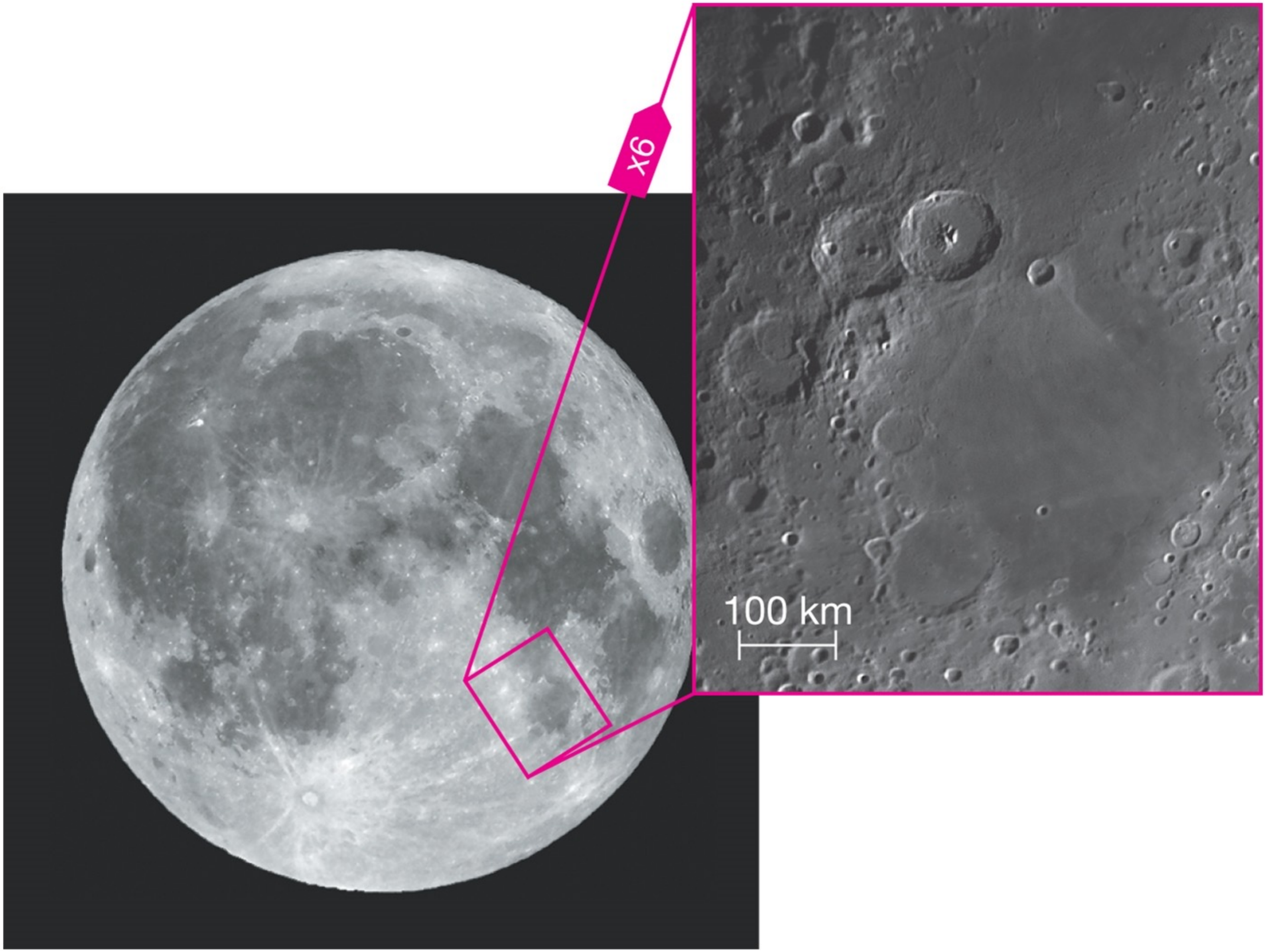

The Role of Planetary Size
Small Terrestrial Planets
Large Terrestrial Planets
Interior cools rapidly . . .
. . . so that tectonic and volcanic activity cease after a billion years or so. Many ancient craters therefore remain.
Lack of volcanism means little outgassing, and low gravity allows gas to escape more easily; no atmosphere means no erosion.
Warm interior causes mantle convection . . .
. . . leading to ongoing tectonic and volcanic activity; most ancient craters have been erased.
Outgassing produces an atmosphere and strong gravity holds it, so that erosion is possible.
Core may be molten, producing a magnetic field if rotation is fast enough.

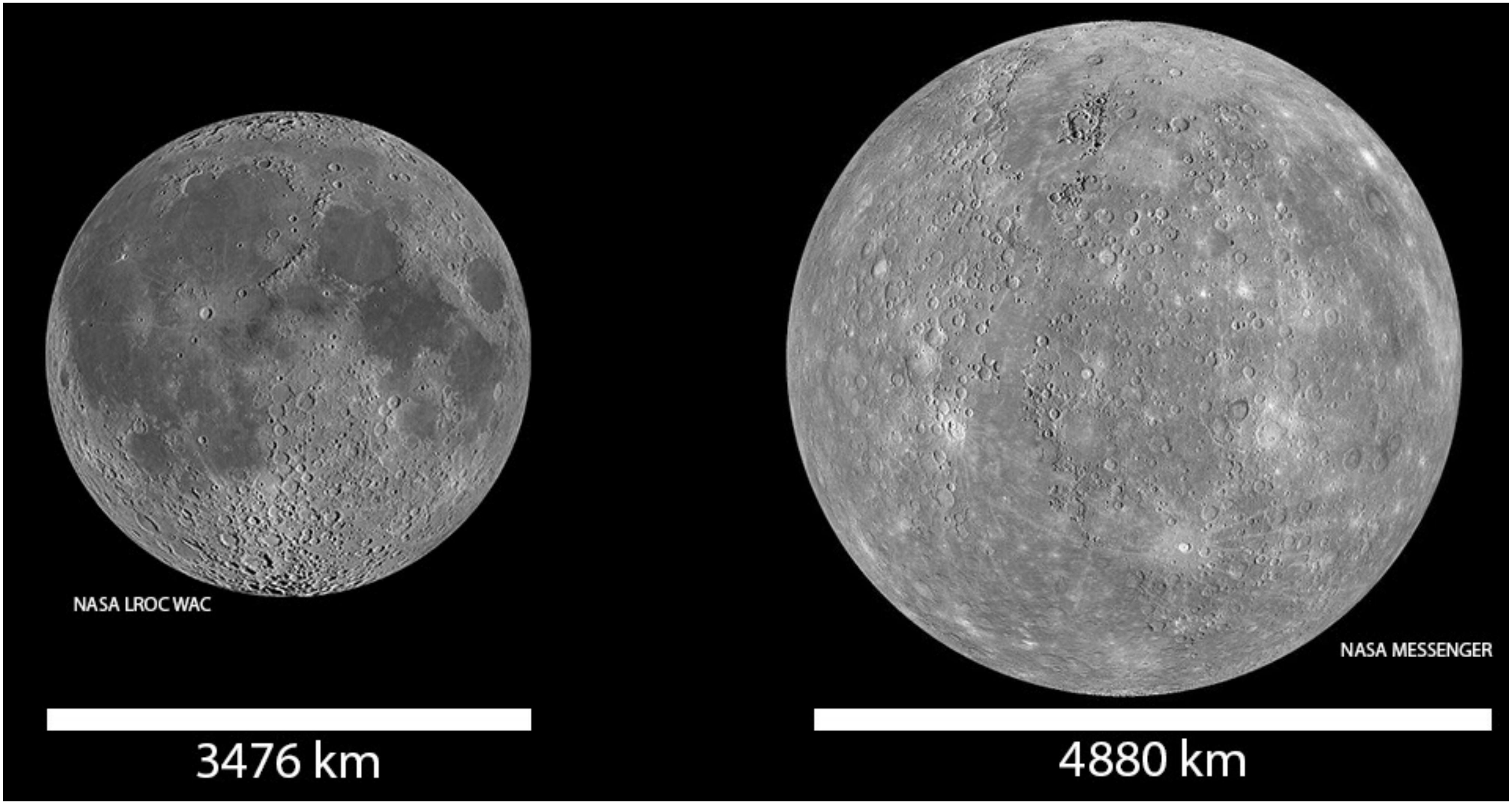
Debate about the age of the earth

- Kelvin (1862) assuming Earth started as molten rock. From measured temperature increase with depth, Earth's cooling rate implies an age of 20-400 million years. Later refined to 100 million, then 20 million.
- Helmholtz (1856) calculated Sun's age as 18-22 million years if energy supply is gravitational contraction only.
- However, most geologists and evolutionary biologists required much longer times for their theories to work
- Both Kelvin and Helmholtz assumed cooling occurred without an additional of energy source. Circa 1895 radioactivity was discovered, which adds additional heat to the Earth. Age now agreed to be about 4.5 billion years
- Nuclear fusion was later shown to power the Sun.

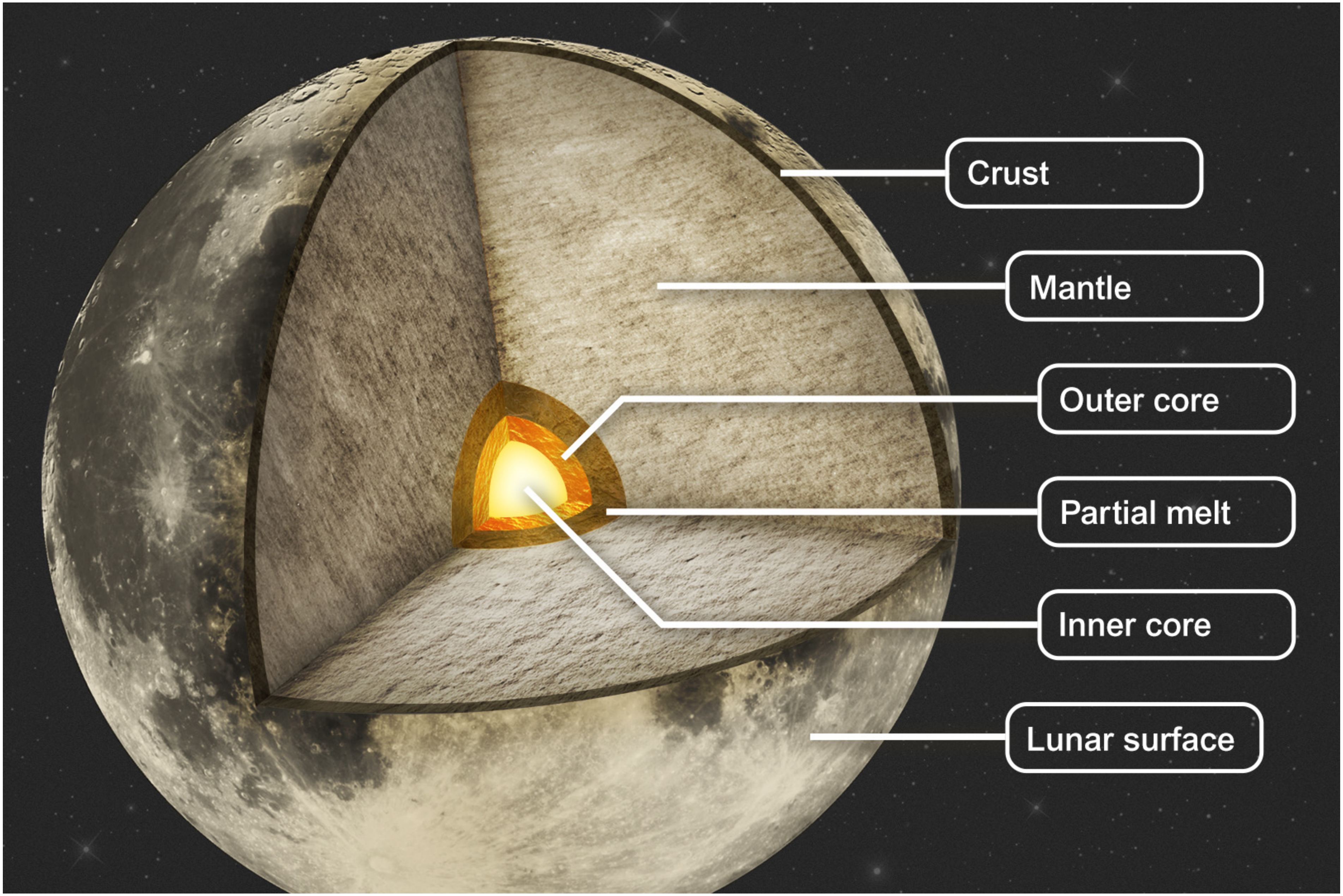
The Moon

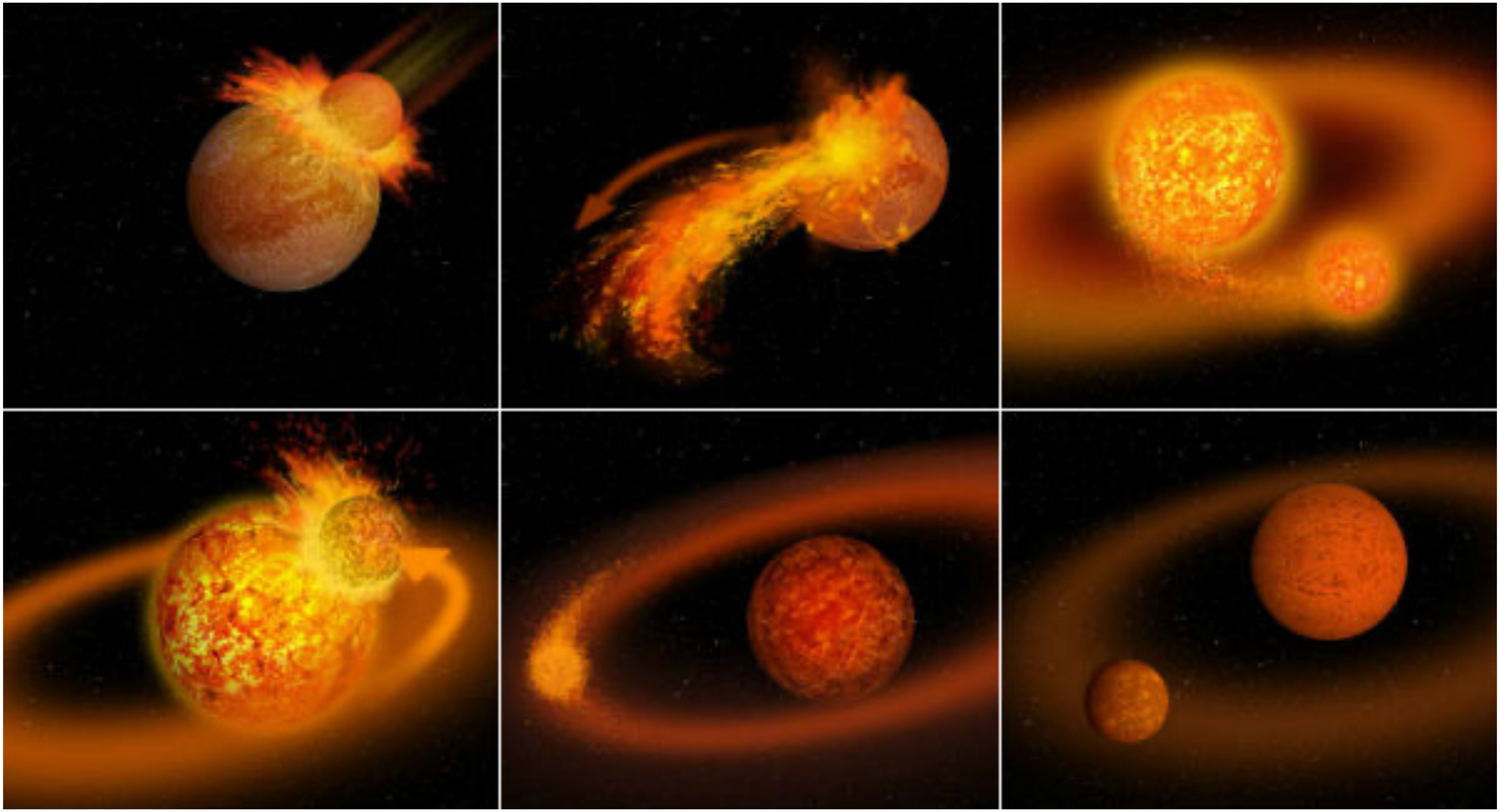


The Moon compared to Mercury

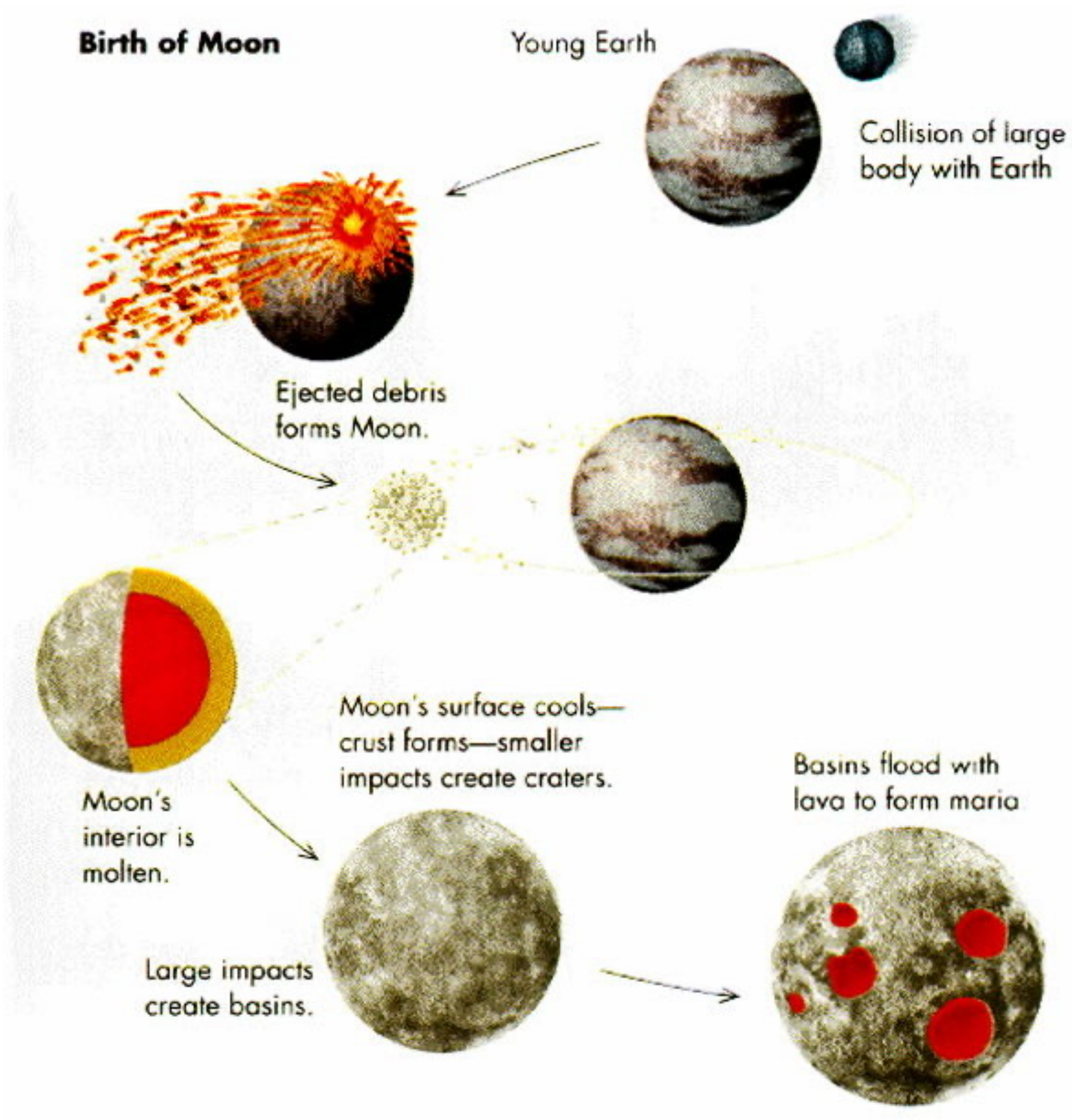


The Moon – Interior Structure





The Moon – originated in massive collision



The Moon

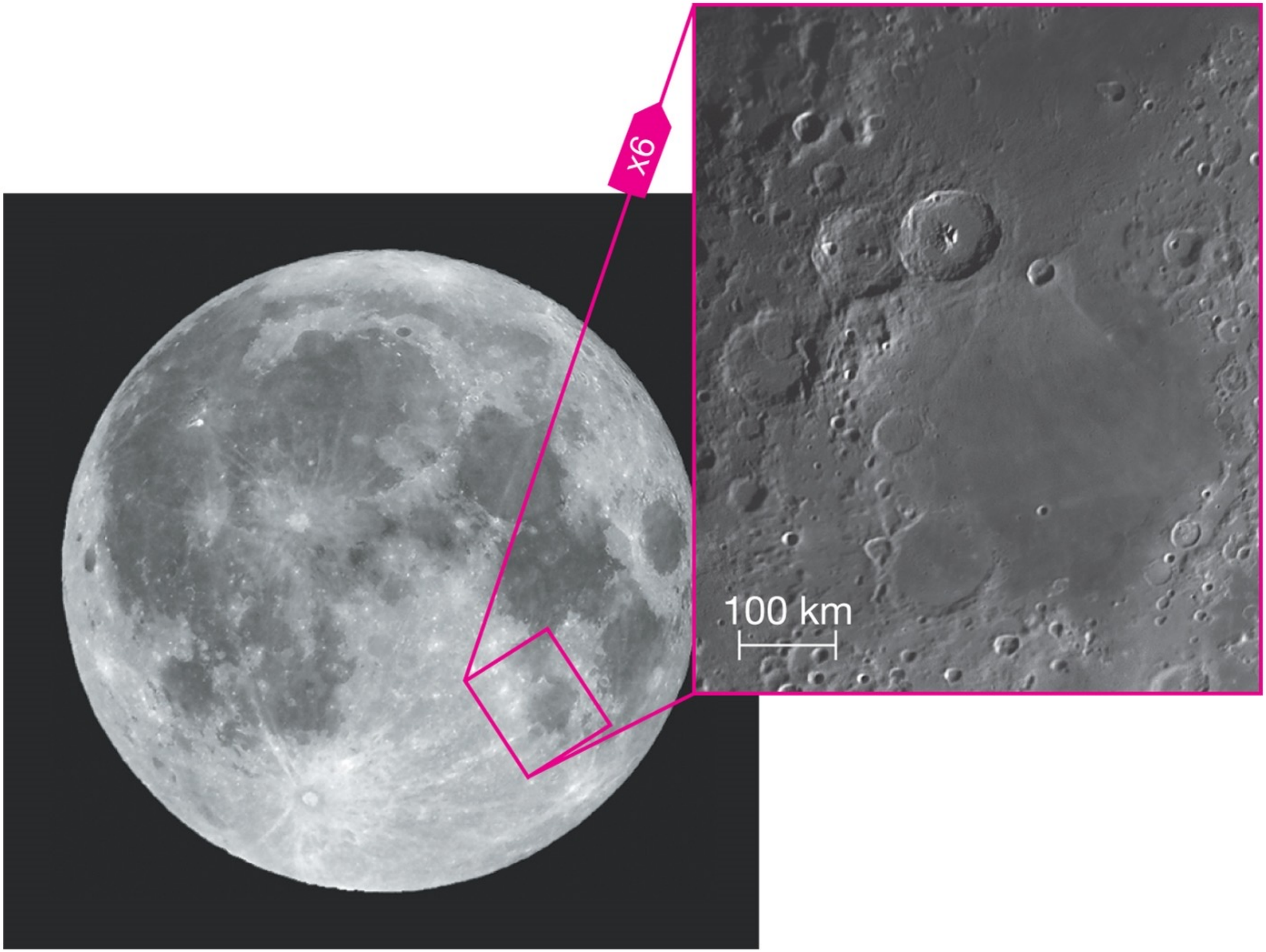
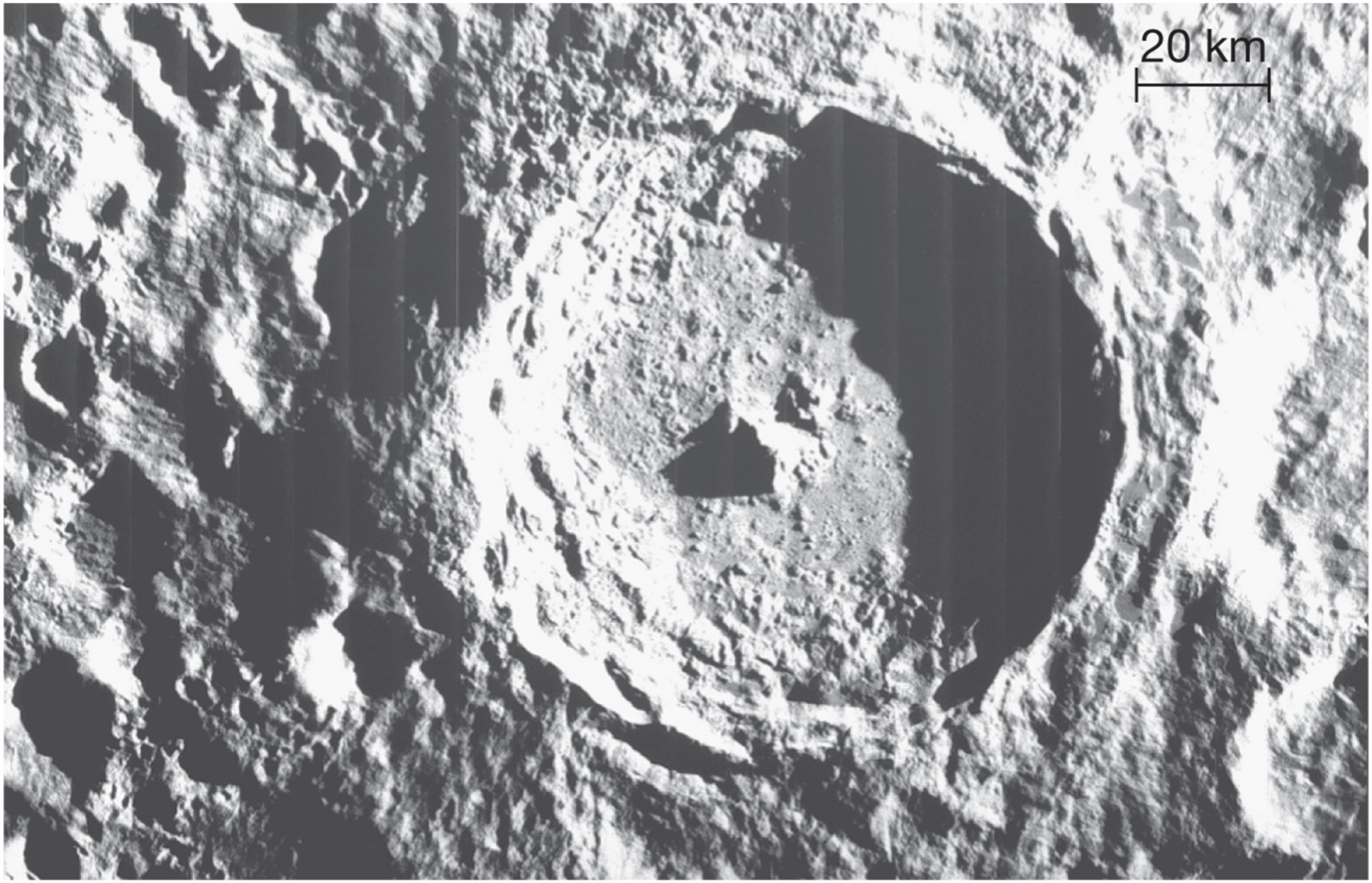


Figure 9.8a

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.

Figure 9.8b



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

Why do the *lunar highlands* have many more craters than the *lunar maria*?

1. They are on the side of the Moon away from Earth, which was hit by more impacts.
2. Lava flooded the maria, hiding many craters.
3. The less cratered surfaces are younger than those with more craters.
4. a and b.
5. b and c.
6. c and a.
7. All of the above.

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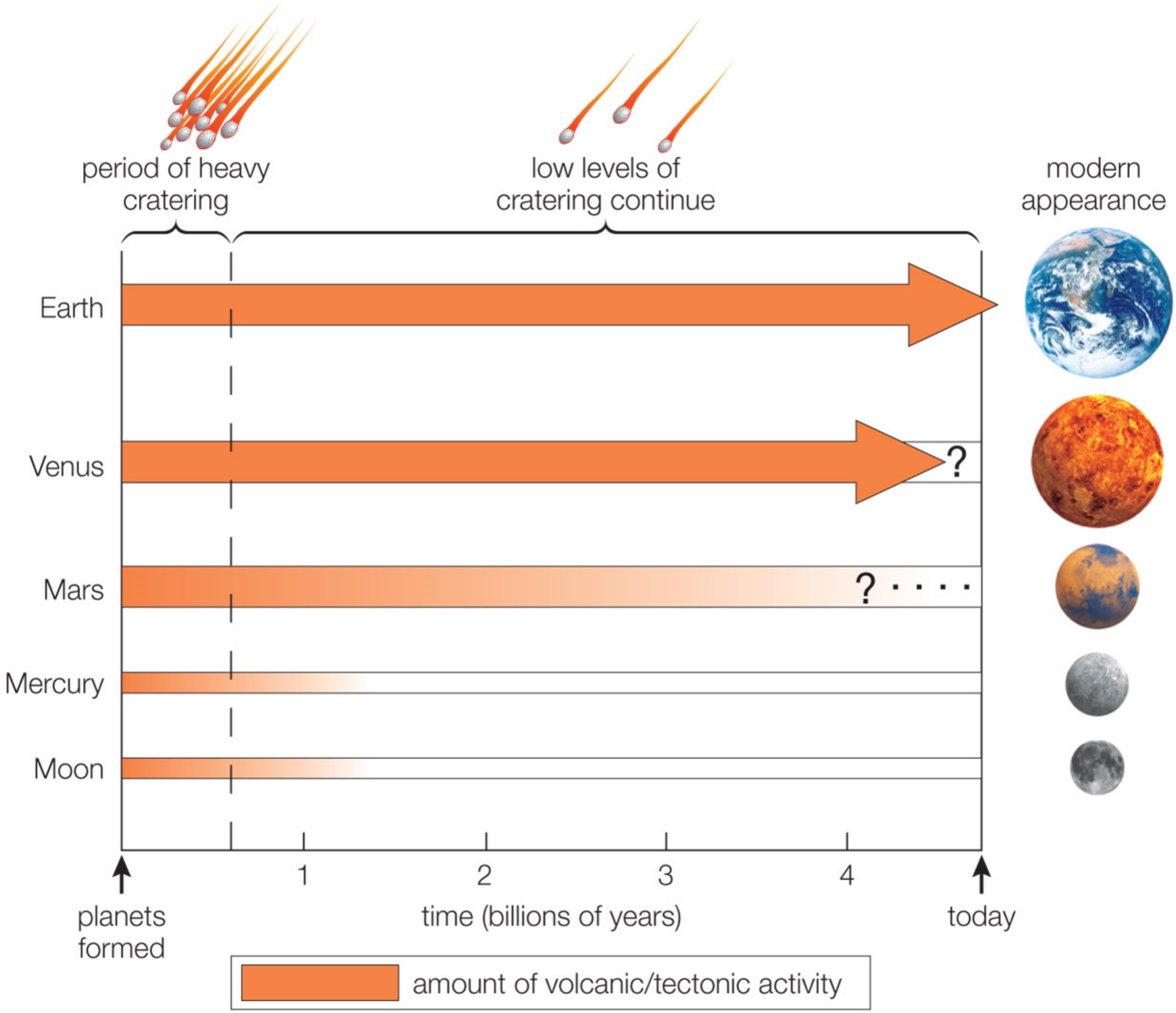
4. a and b.
5. **b and c**.
6. c and a.
7. All of the above.

Figure 9.48



period of heavy cratering
low levels of cratering continue
modern appearance
Earth
Venus
?
Mars
?
Mercury
Moon
1
2
3
4
planets formed
time (billions of years)
today
amount of volcanic/tectonic activity

Craters atop of craters

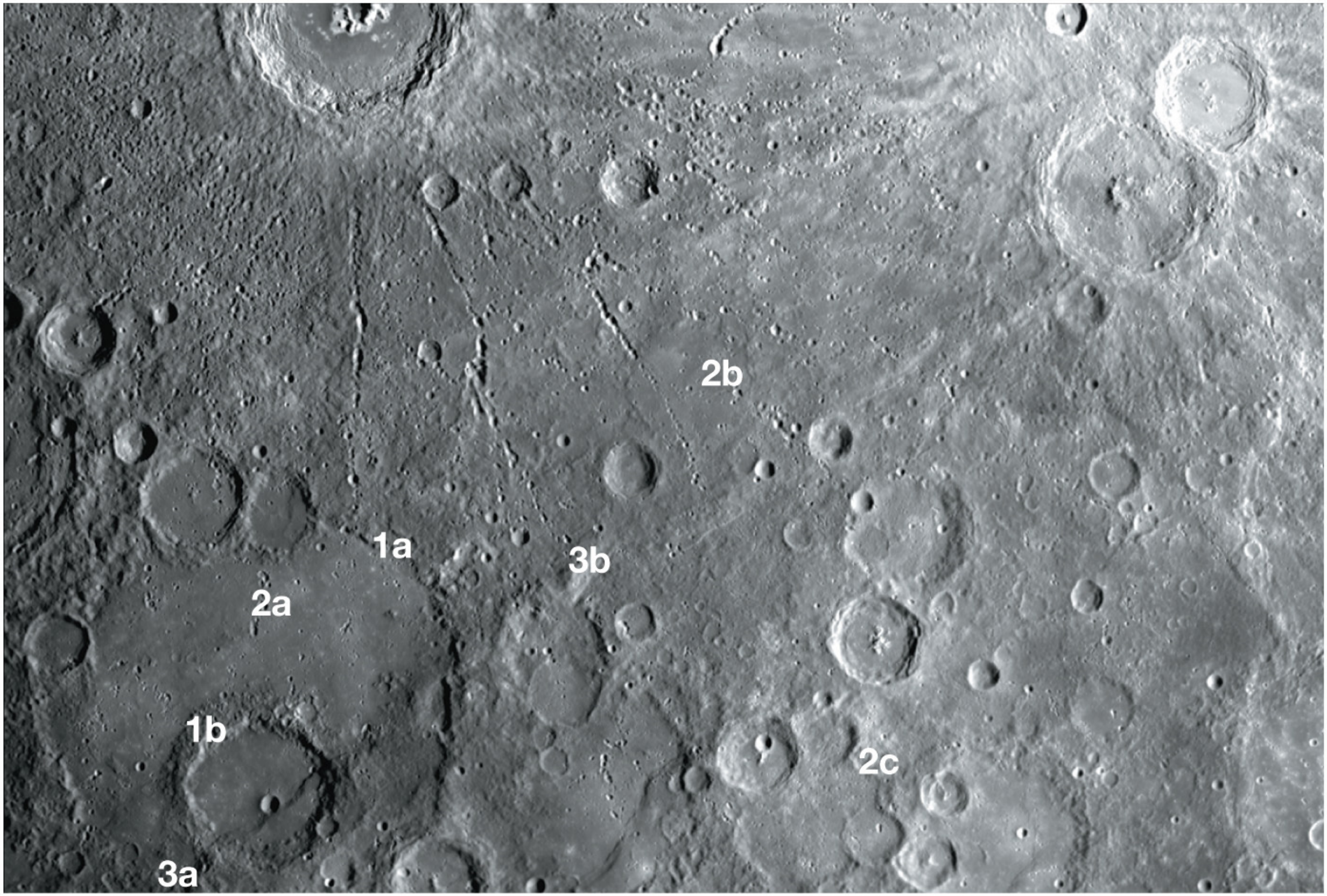
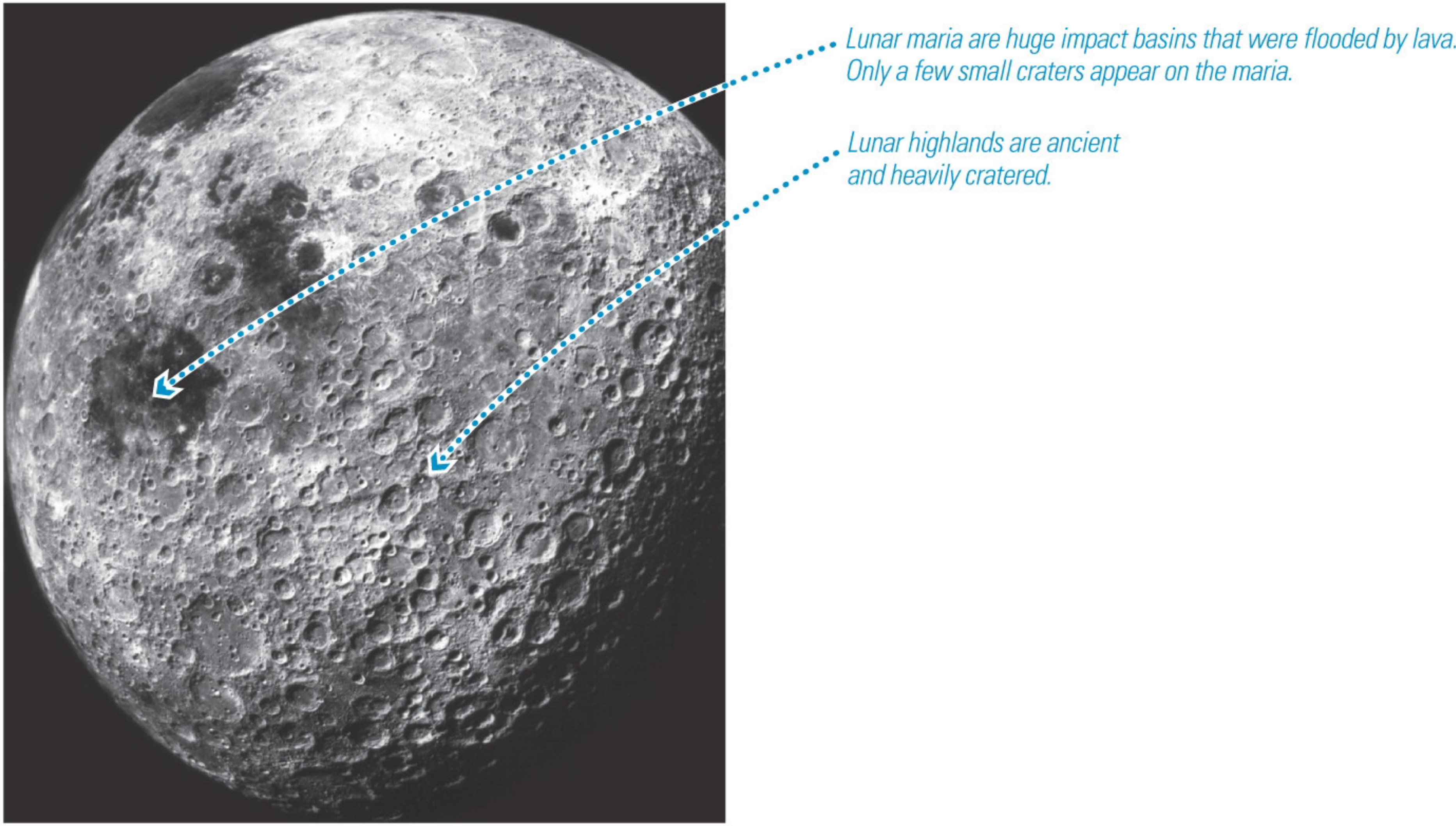
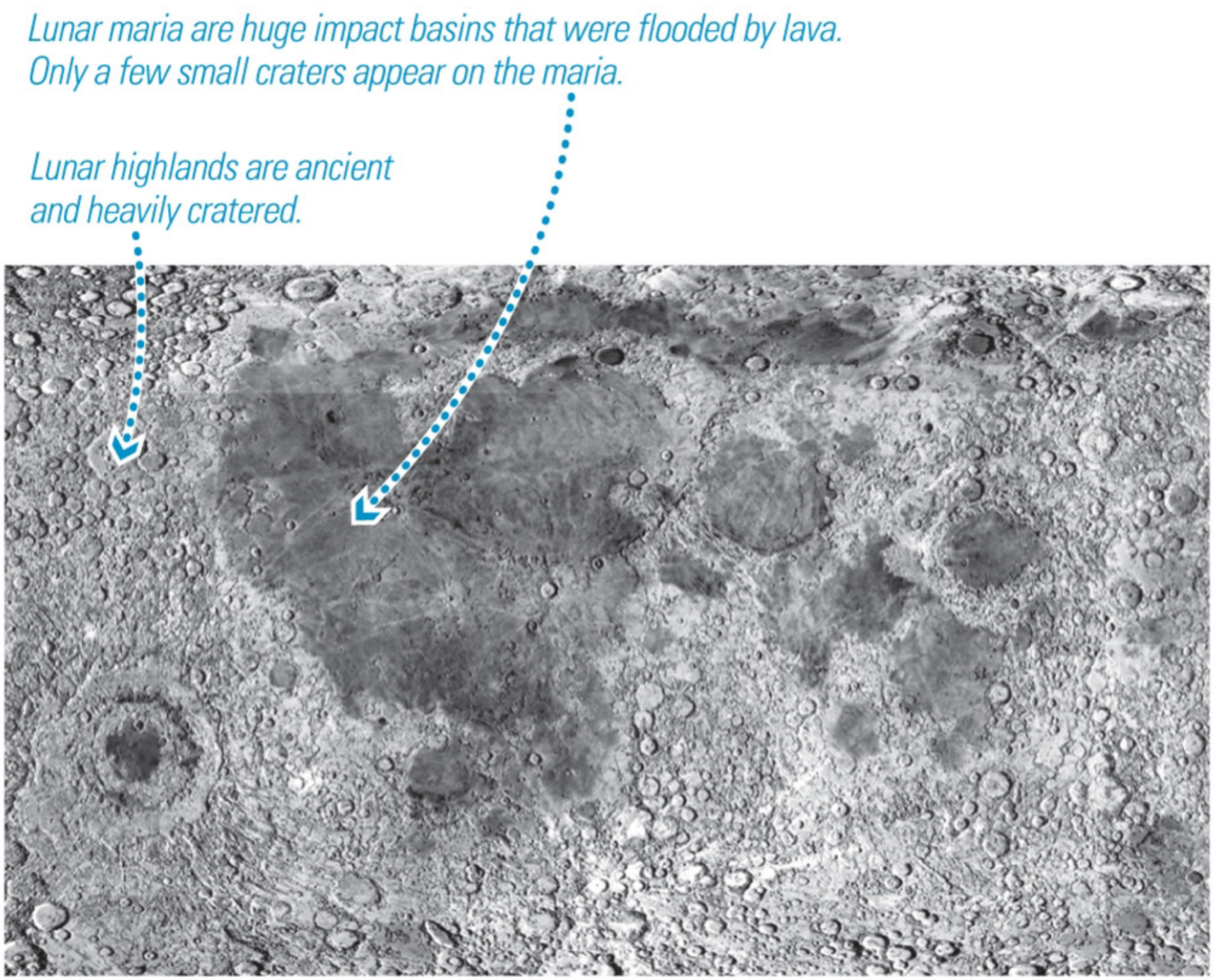


Figure 9.15a



a This *Apollo* photograph of the Moon shows that some areas are much more heavily cratered than others. (This view of the Moon is *not* the one we see from Earth.)

Figure 9.15b



b This map shows the entire surface of the Moon in the same way a flat map of Earth represents the entire globe. Radiometric dating shows the heavily cratered lunar highlands to be a half-billion or more years older than the darkly colored lunar maria, telling us that the impact rate dropped dramatically after the end of the heavy bombardment.

The reason that the Earth's surface has so few meteor craters compared to other nearby bodies in the solar system is that

1. the Moon blocked almost all of the meteors that otherwise would have hit the Earth.
2. the atmosphere causes almost all objects entering from space to burn up before they hit the ground.
3. the Earth's surface has been modified by various forces which cover or remove traces of the craters.
4. meteorite impacts break the crust and release lava from the mantle to fill in the hole.

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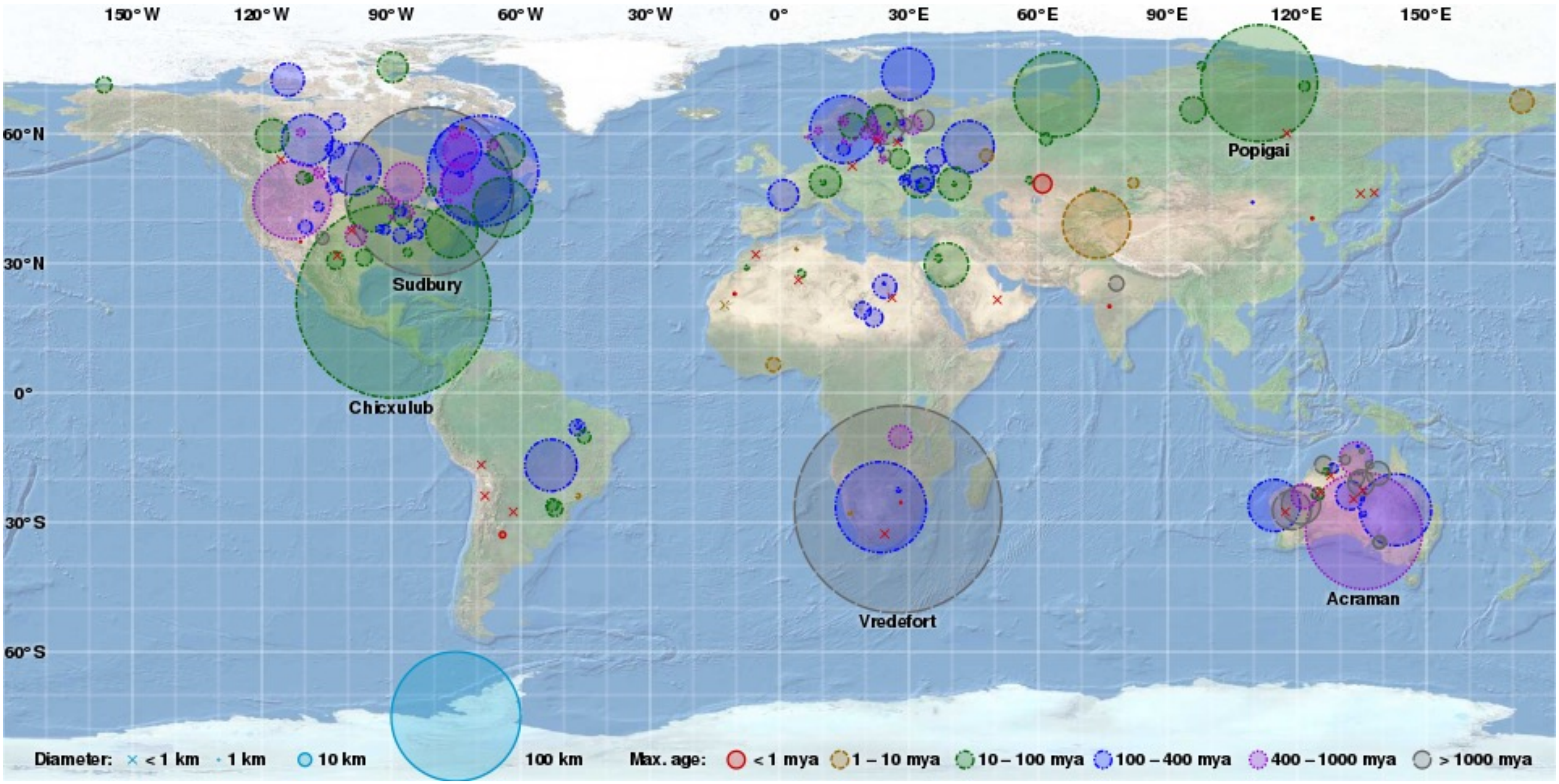
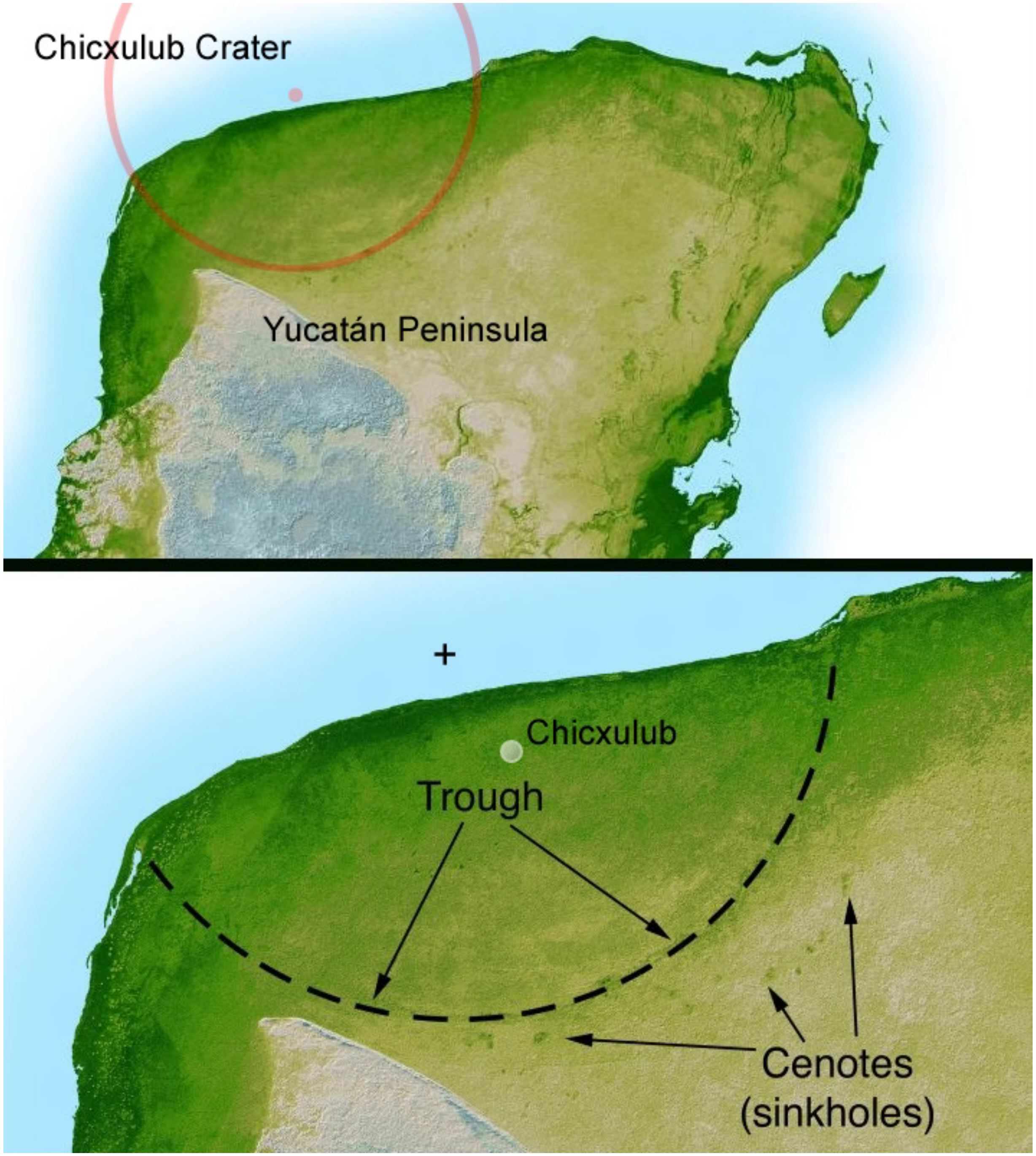
Craters identified on the Earth

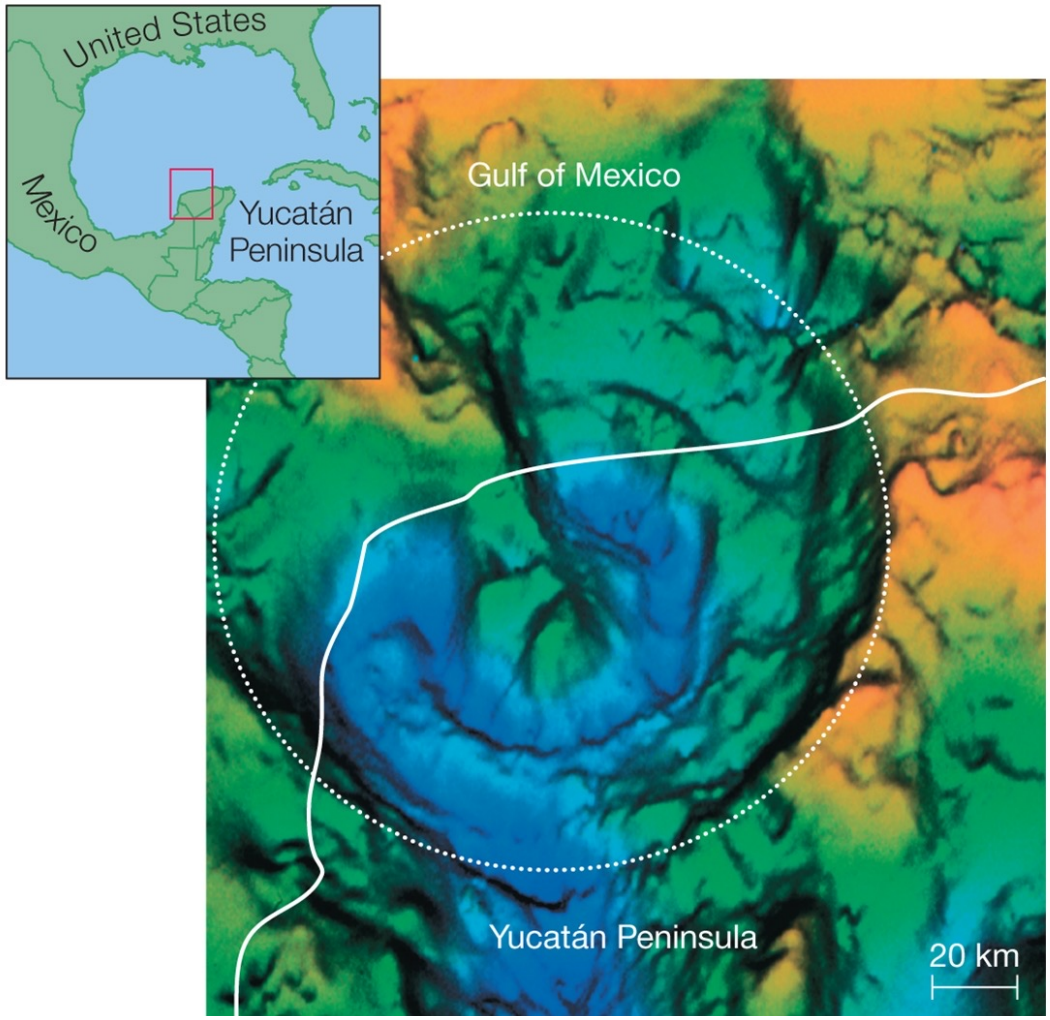


Chicxulub



Chicxulub Crater
Yucatán Peninsula
+
Chicxulub
Trough
Cenotes
(sinkholes)

Figure 12.29


United States
Mexico
Yucatán
Peninsula
Gulf of Mexico
Yucatán Peninsula
20 km

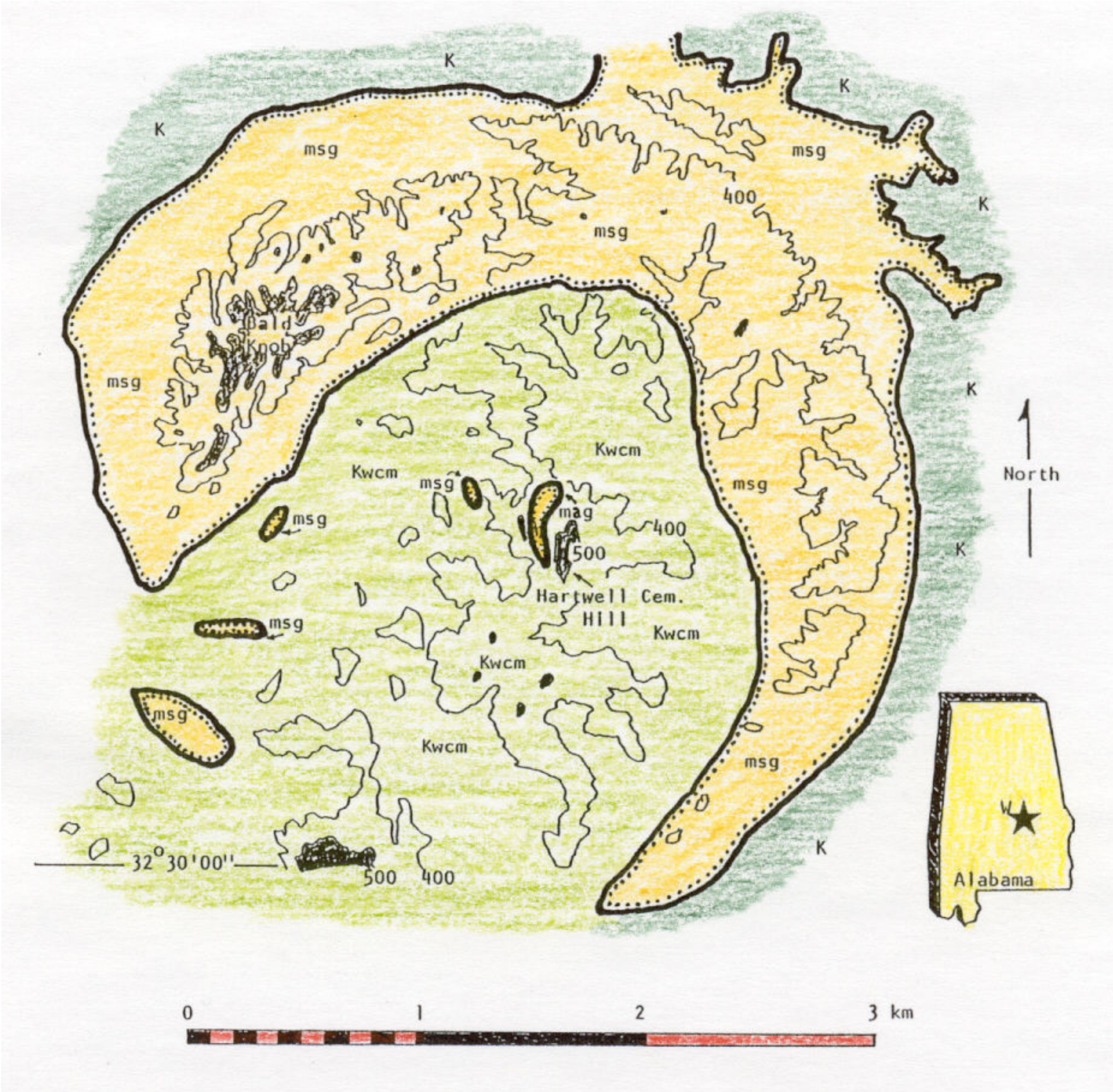
Manicouagan, Canada

Pingualuit, Quebec Canada

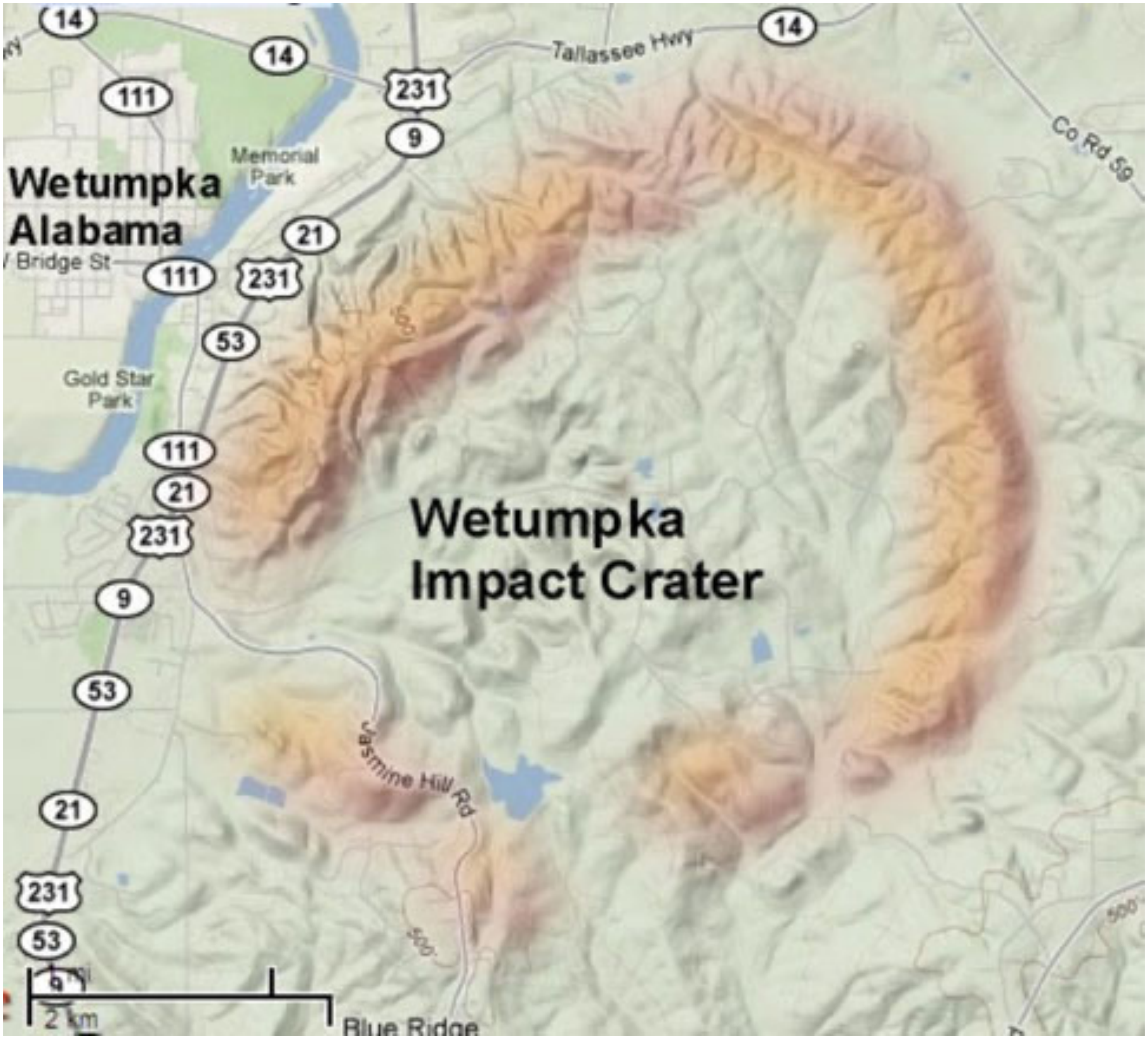
Lonar Crater Lake, Maharashtra, India

Kaali crater, Estonian island of Saaremaa

Wetumpka Crater – impact 83 million years ago



Wetumpka Crater



At high tide on the beach, you see the Moon high in the sky. About how long till the next high tide at that location?

1. 6 hours, a quarter of a day
2. 12 hours, half a day
3. 24 hours, one day
4. One week
5. One month
6. other

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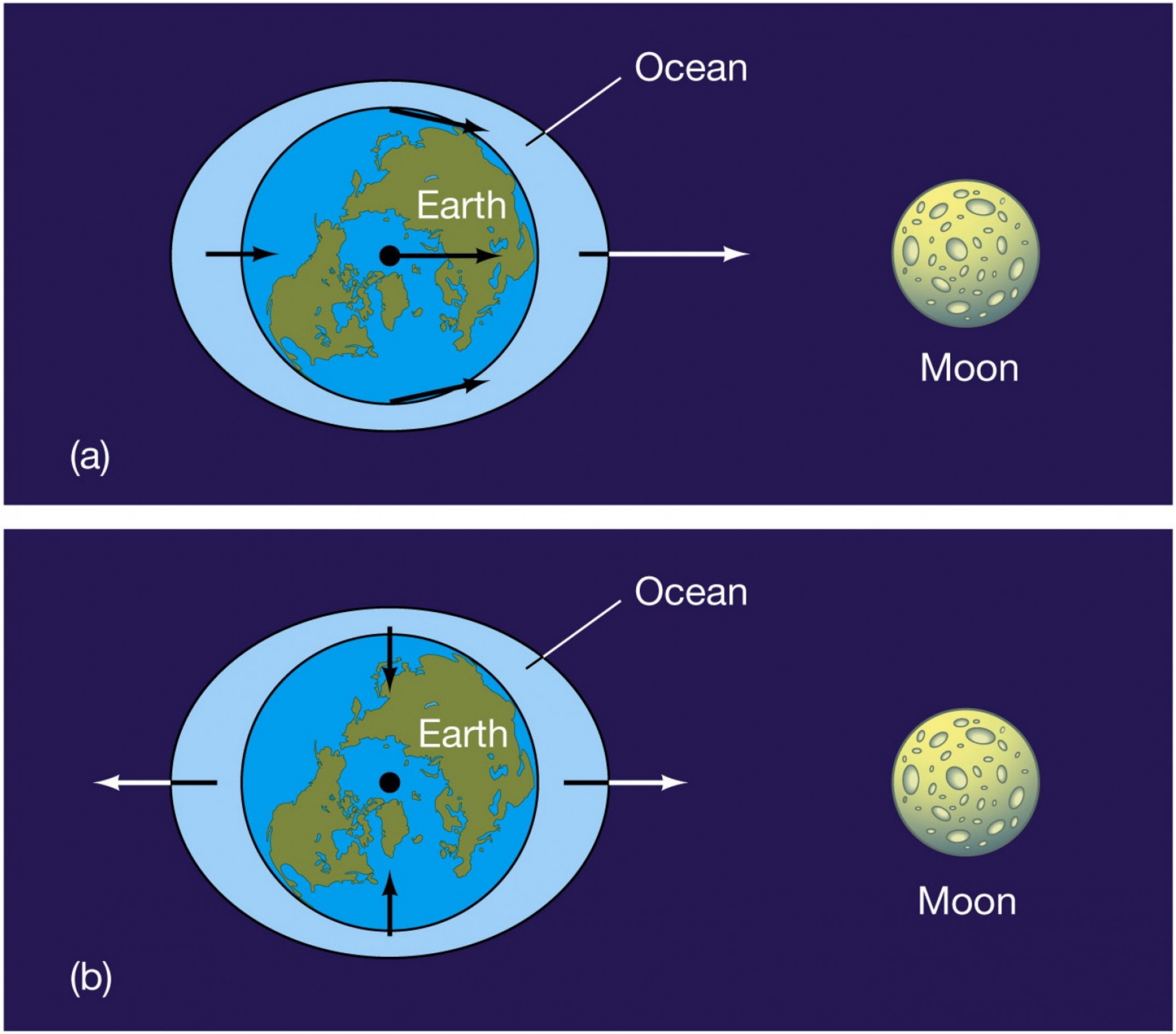
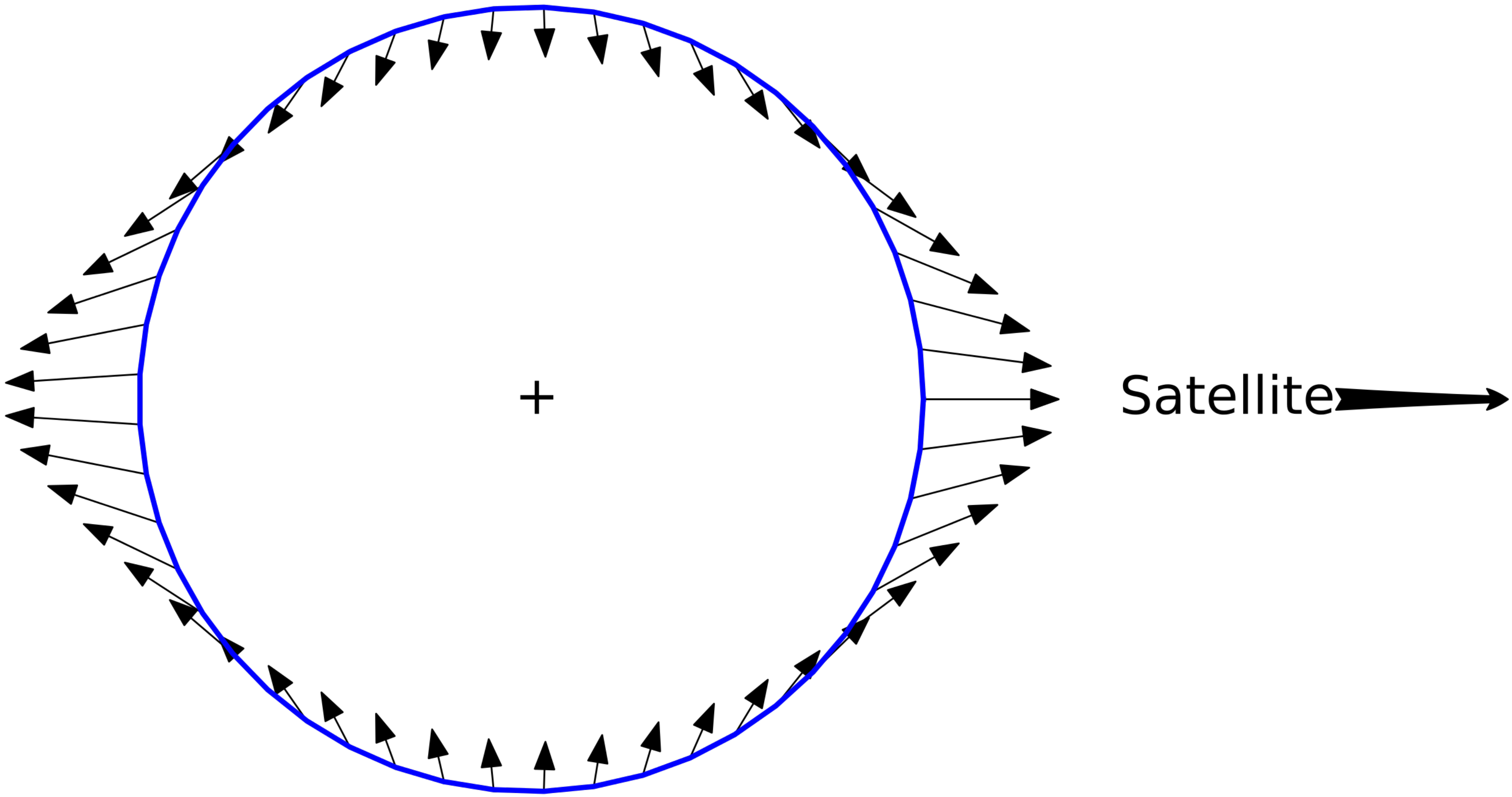
Tidal forces



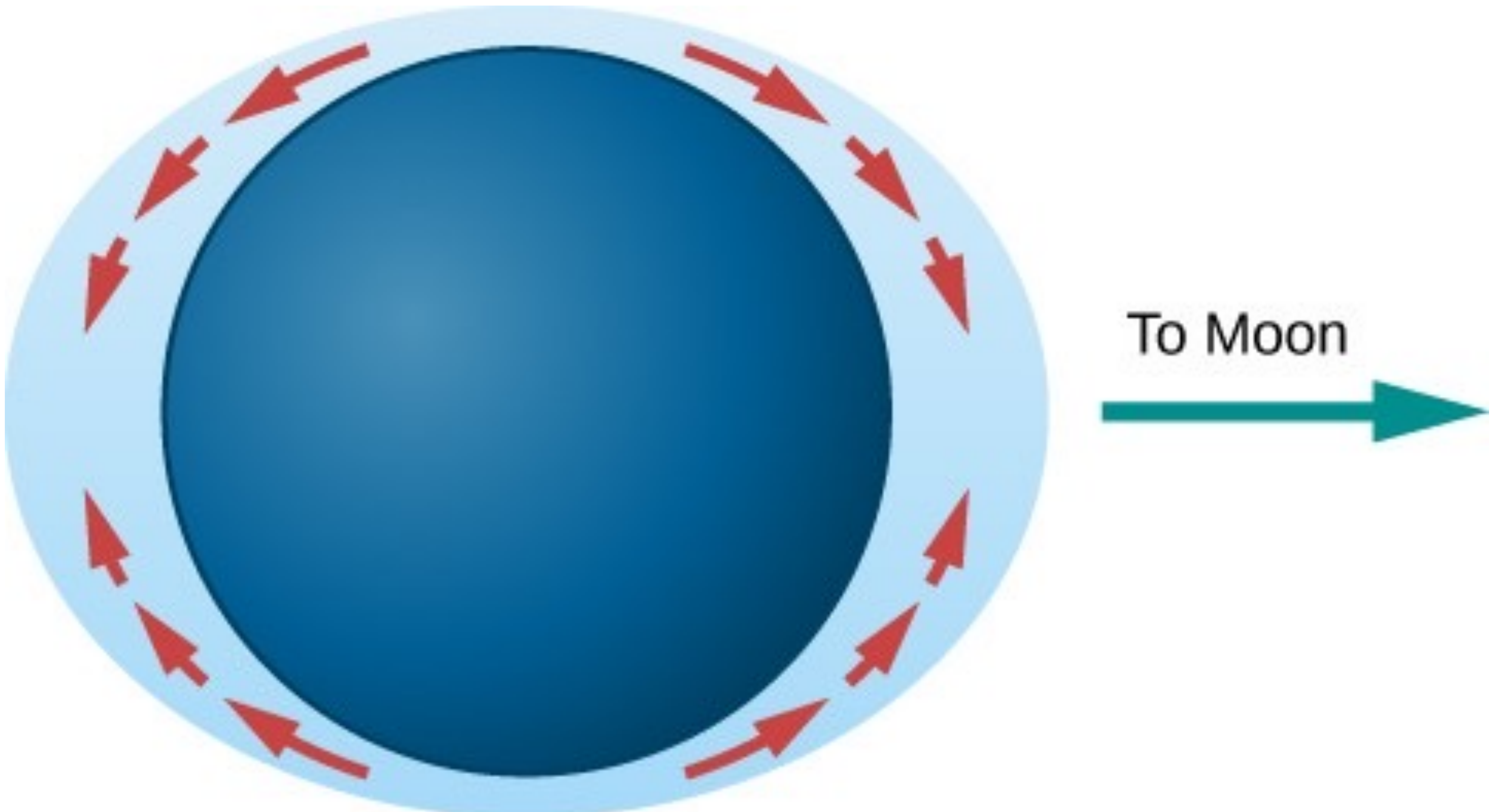
Tides are cause by how the Moon's gravity differs across Earth's surface

- At any point on Earth, the Moon's gravity pulls toward its center, so those directions vary with location
- By subtracting off the average direction, the remainder is
  - Strictly upward along the Earth-Moon line
  - Strictly downward 90° away from there
  - At other locations, there is a component that is tangential to the surface
- That tangential component is what pulls water in the oceans and causes the tidal bulges

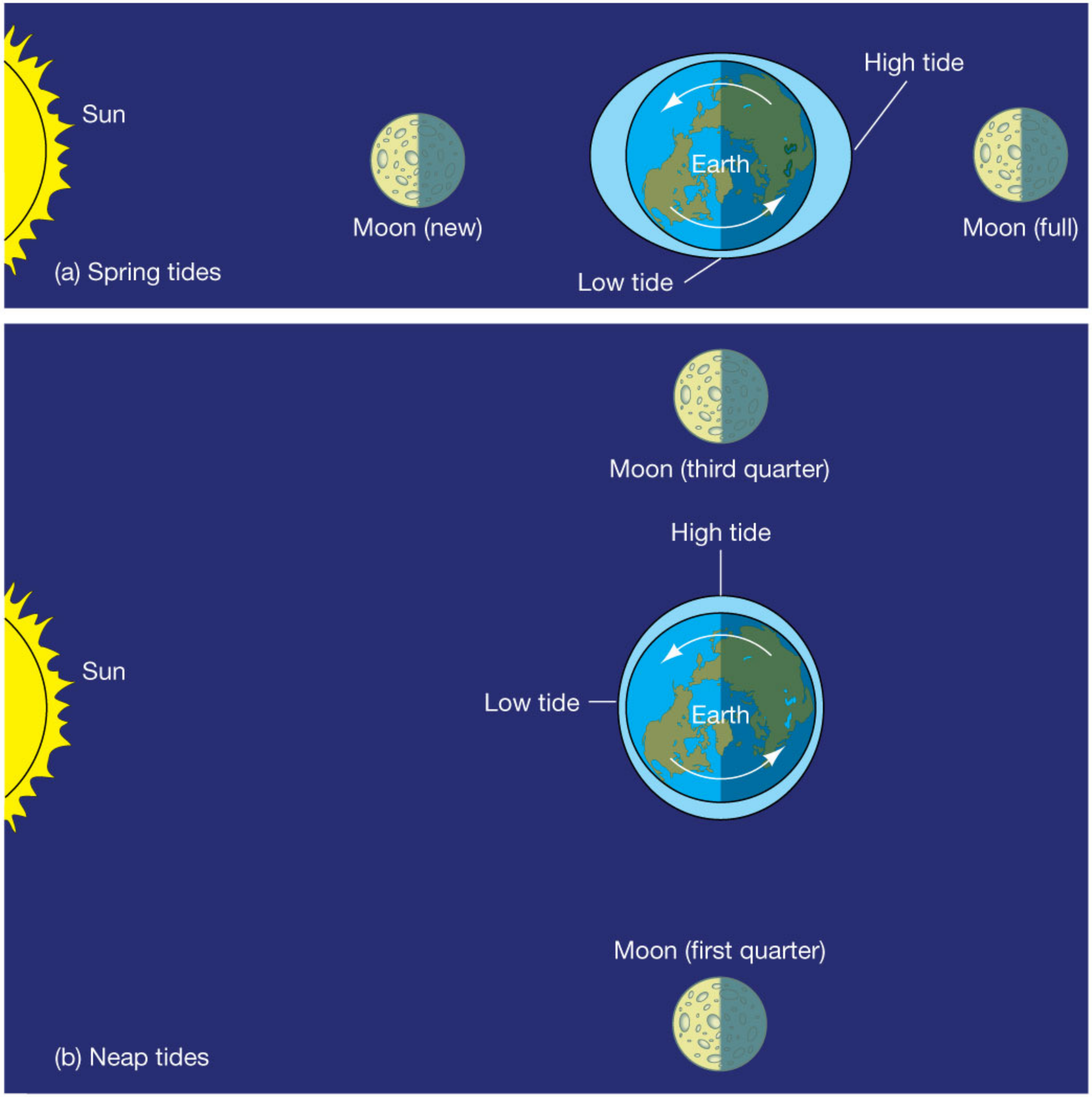
The differential gravitational field - Tidal forces



Tidal bulges



Spring tides and Neap tides



For a single planet orbiting the Sun, which of these can change?

1. Eccentricity of the orbit
2. Tilt of the axis from the ecliptic
3. Perihelion angle around the Sun
4. 1 & 2
5. 2 & 3
6. 3 & 1
7. All of the above
8. None of the above

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5. 2 & 3
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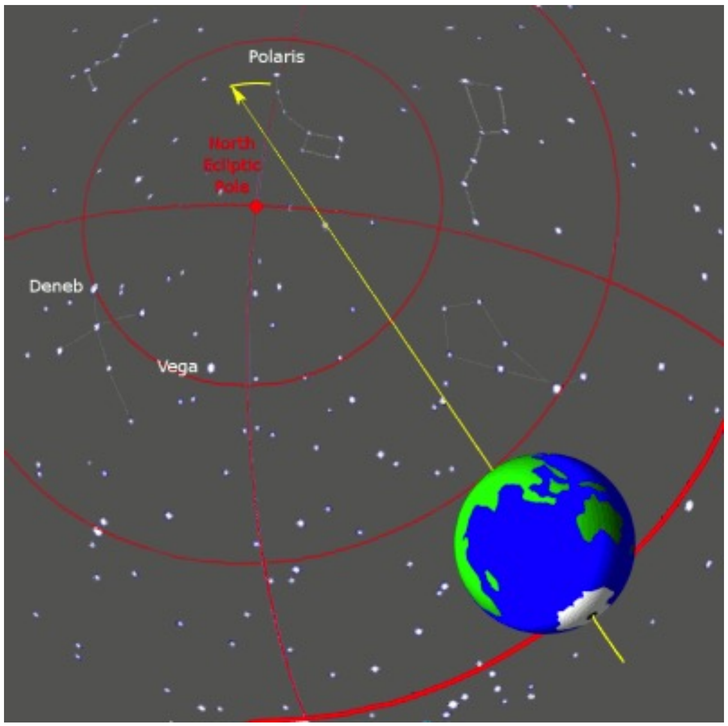
Additional effects on tides

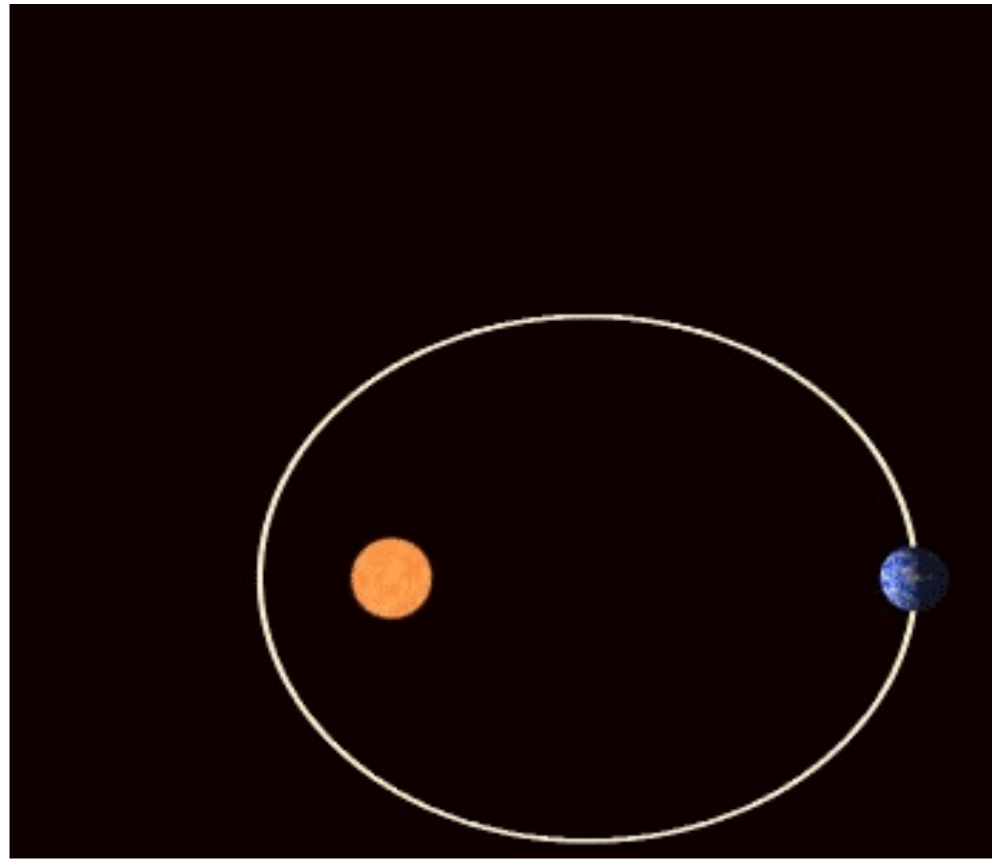
- For two-body orbits, these are fixed:
  - Eccentricity of the orbit
  - Tilt of the axis from the ecliptic
  - Perihelion angle around Sun
- If there are three or more bodies, these can change very slowly
- The resulting variations in tides can be studied in geological strata

Milutin Milankovitch (1941) calculated how the amount of sunlight varies in time at northern latitudes depending on small variations in Earth's orbital characteristics

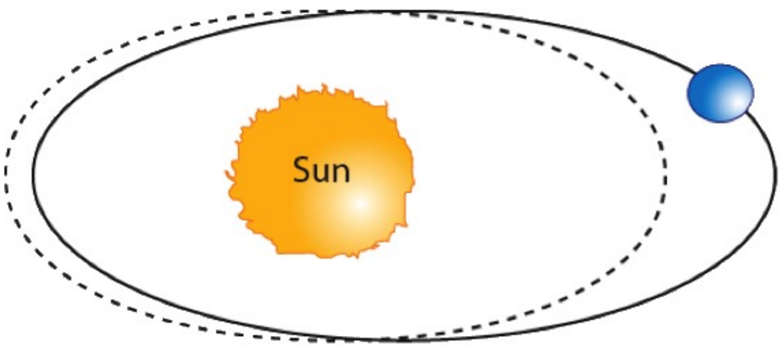
Important factors

- The 26,000–year period of the precession of the equinox, which combines with the 11,300 year perihelion advance to produce a 21,000–year cycle
- The 40,000–year cycle of variations in the tilt of the Earth's rotation axis to the ecliptic (called "obliquity") ranging from 22° to 24.5°
- The 90,000 to 100,000–year cycle of variation of the eccentricity of the Earth's orbit

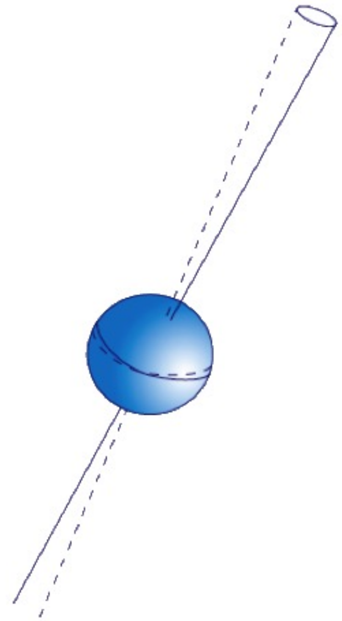

Polaris
North
Ecliptic
Pole
Deneb
Vega



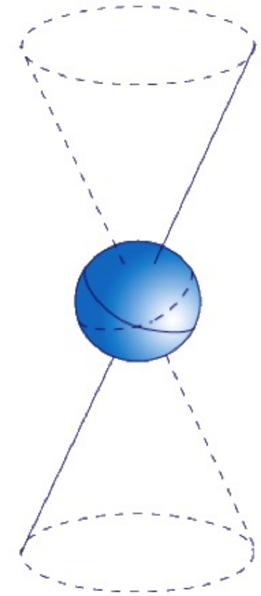
Astronomical variations influencing climate on earth



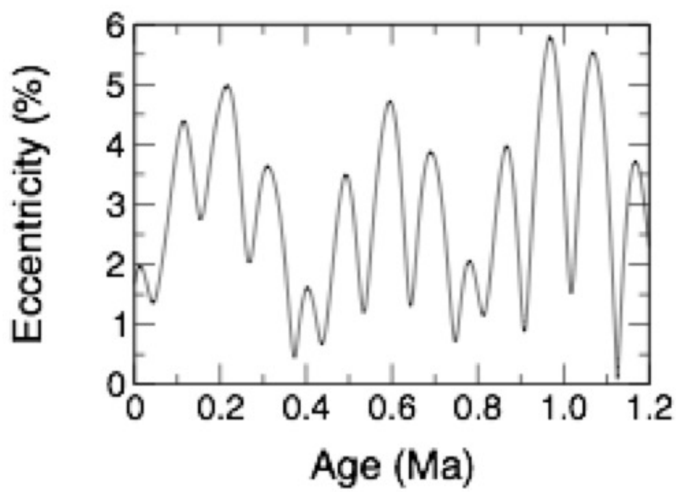
Eccentricity 110,000 years

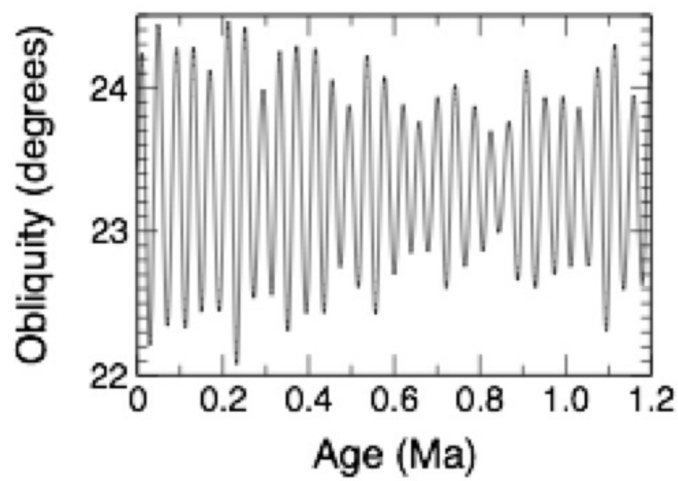


Obliquity 41,000 years

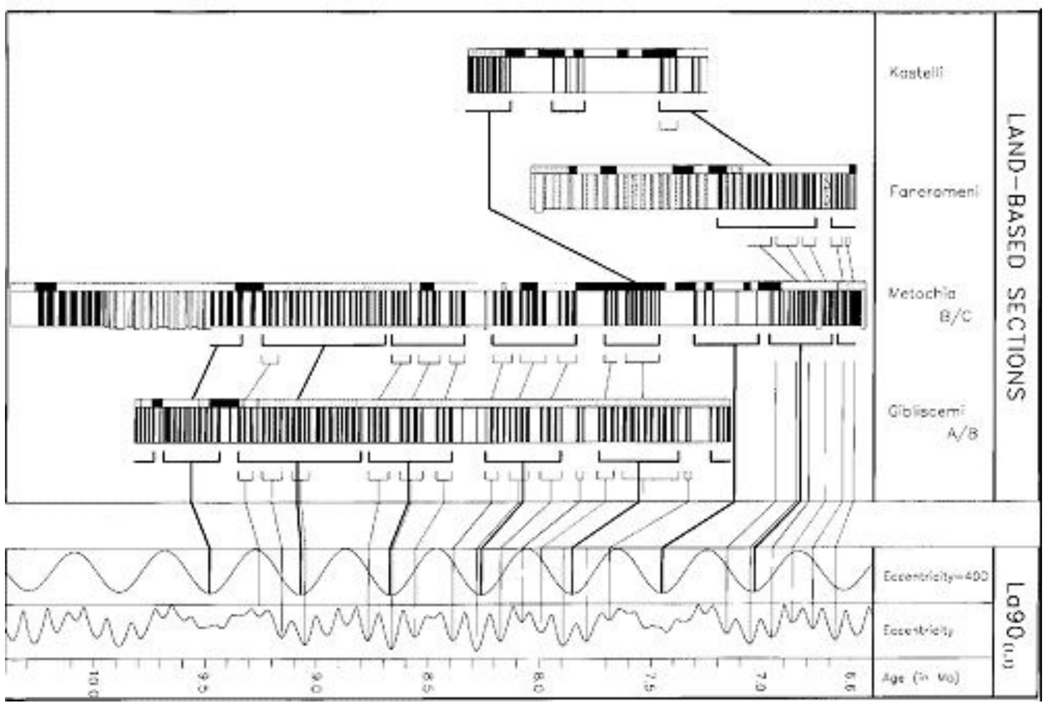


Precession 19-23,000 years





Variations of moon’s orbit affects tides and resulting strata



Milankovitch Cycles apparent in strata - Punta di Maiata, Sicily, Italy

Photo by Frits Hilgen/Luc Lourens

Miocene shallow lake deposits

Example of orbital forcing in a classic nonmarine sequence. These ~12-million-year-old (Miocene) cyclic shallow lake sediments reflect astronomically controlled variations in lake level. Individual cycles (alternations between dark mudstone and white carbonate) reflect the precession cycle. Thick-thin alternations of carbonate beds in successive mudstone-carbonate cycles in the central, regular part of the section reflect the obliquity cycle. The ~400,000-year eccentricity cycle is visible in the lowermost part of the section (dark interval). Photograph taken near the village Orera, northeastern Spain.

From: Crowley T.J, (2002) Cycle, cycles, everywhere. Science, v. 295, p.1473-1474. Photo originally by HAYFAA ABDUL AZIZ Reprinted with permission from AAAS.