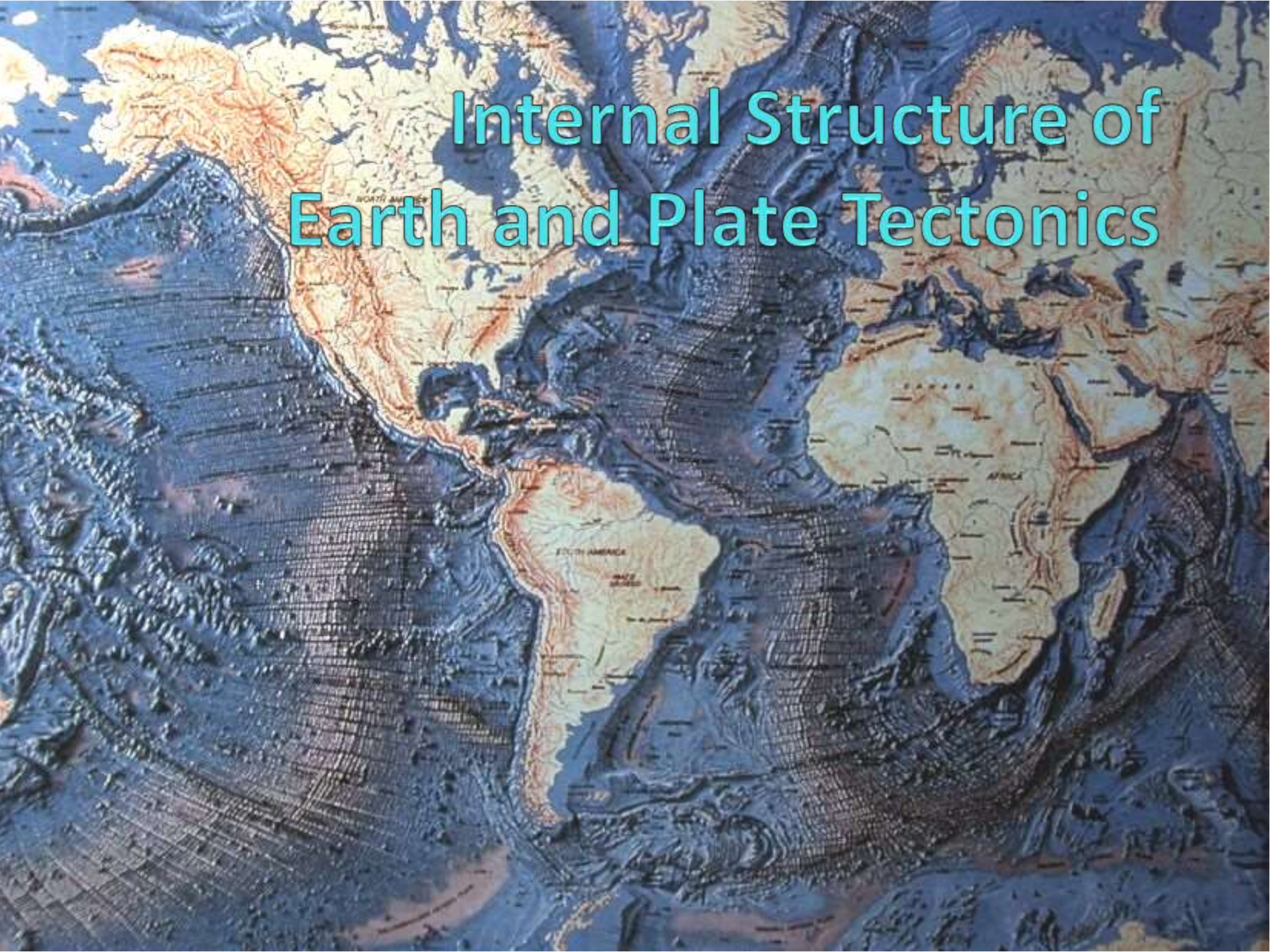
ANNOUNCEMENTS

- Remember to check Avenue Calendar for quiz schedule
- Plate Tectonics

ANNOUNCEMENTS

- Readings required
- https://www.theguardian.com/world/2018/dec/24/sunda-strait-tsunami-volcano-indonesia
- https://www.cnn.com/2018/12/23/asia/indonesia-pop-band-tsunami-video/index.html

Internal Structure of Earth and Plate Tectonics



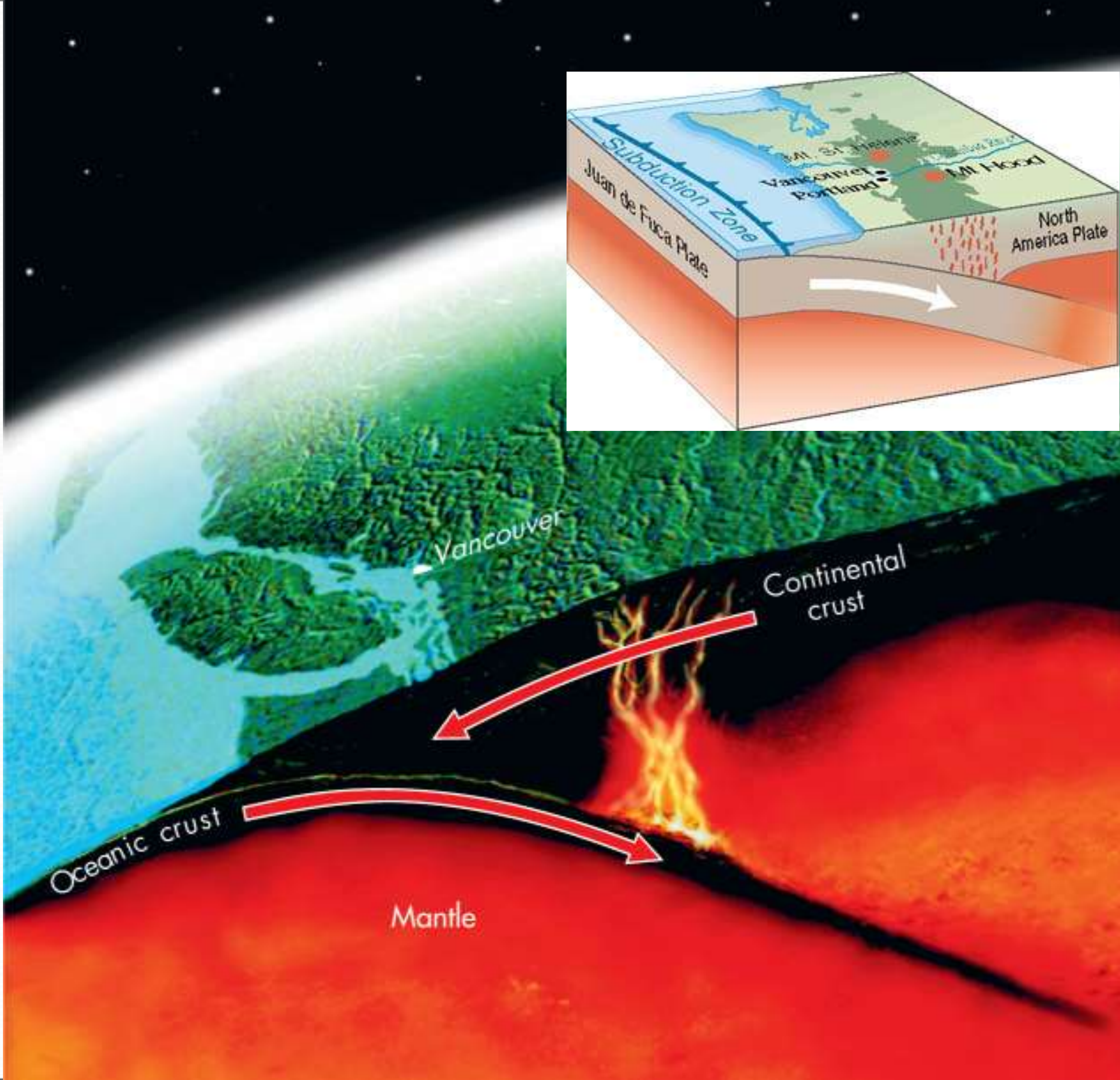
Learning Objectives

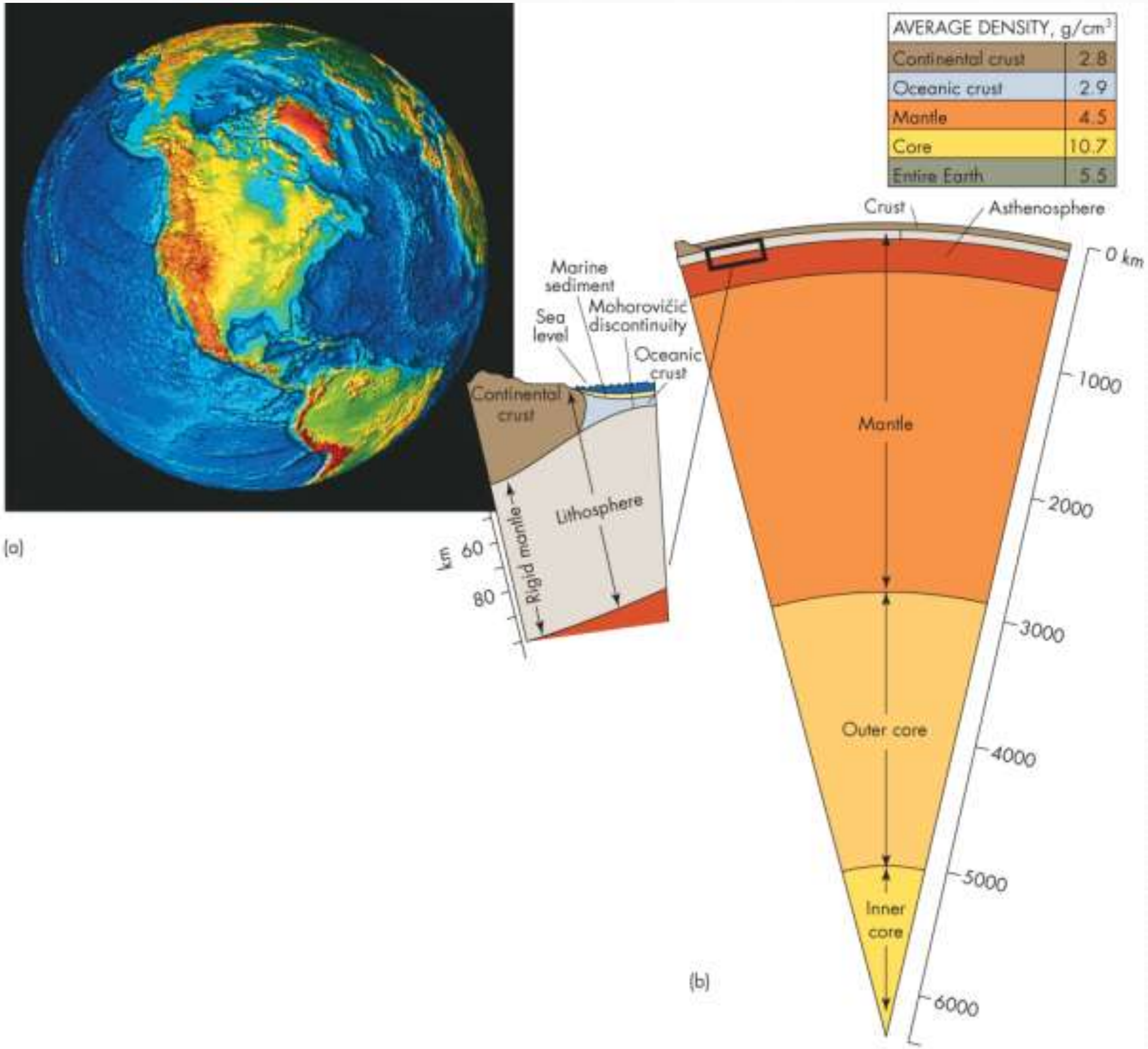
- Understand the structure of Earth and its internal processes
- Know the ideas behind, and the evidence for, the theory of plate tectonics
- Understand the mechanisms that cause plates to move
- Understand the relationship between plate tectonics and natural hazards

Internal Structure of Earth

- Earth is layered and dynamic

- The internal structure of Earth can be considered in two fundamental ways:
    - By composition, state, and density
    - By strength


Subduction Zone
Juan de Fuca Plate
Vancouver
Portland
Mt. Hood
North America Plate
Vancouver
Continental crust
Oceanic crust
Mantle

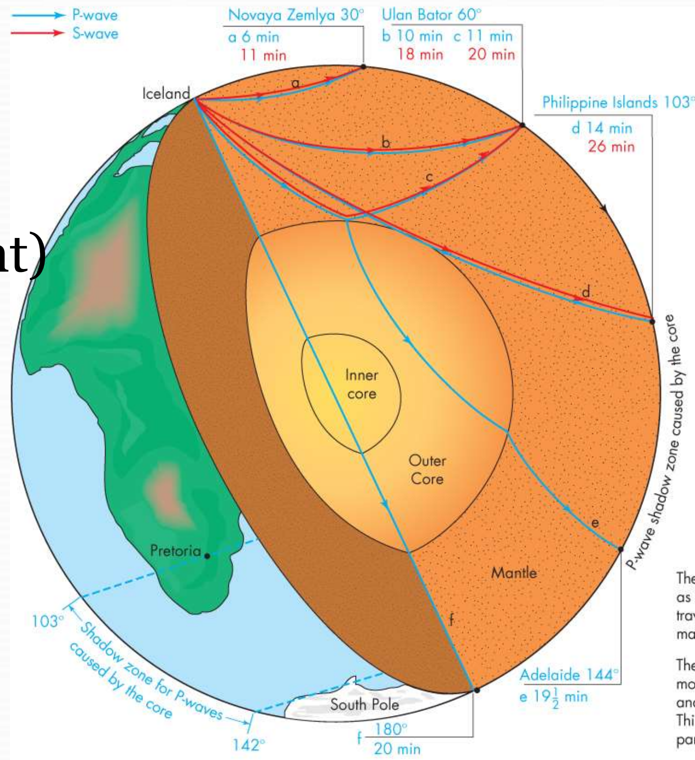


▲ **FIGURE 2.2 EARTH AND ITS INTERIOR** (a) A relief map of Earth as viewed from space. Land elevation increases as colour changes from green to yellow to red. The depths of the ocean floor increase as colour changes from lighter to darker shades of blue. (b) An idealized diagram showing the structure of Earth from its centre to its surface. Notice that the lithosphere consists of the crust and part of the mantle, and that the asthenosphere is located entirely within the mantle. Densities and thicknesses of the different layers have been estimated from the patterns and velocities of earthquake waves within Earth, from rocks formed within the lithosphere that have reached Earth's surface by tectonic processes, and from meteorites, thought to be pieces of old Earth-like planets. *((a) National Geophysical Data Center, National Oceanic and Atmospheric Administration; (b) From Levin, H. L. 1986.* Contemporary Physical Geology, 2nd ed. *Philadelphia: Saunders).*

Structural Layers of Earth

- Inner core
  - Solid
  - 1300 km radius
  - High temperature
  - Composed of iron (90% by weight) and other elements (sulphur, oxygen, and nickel)

- Outer core
  - Liquid
  - 2000 km in thickness
  - Composition similar to the inner core



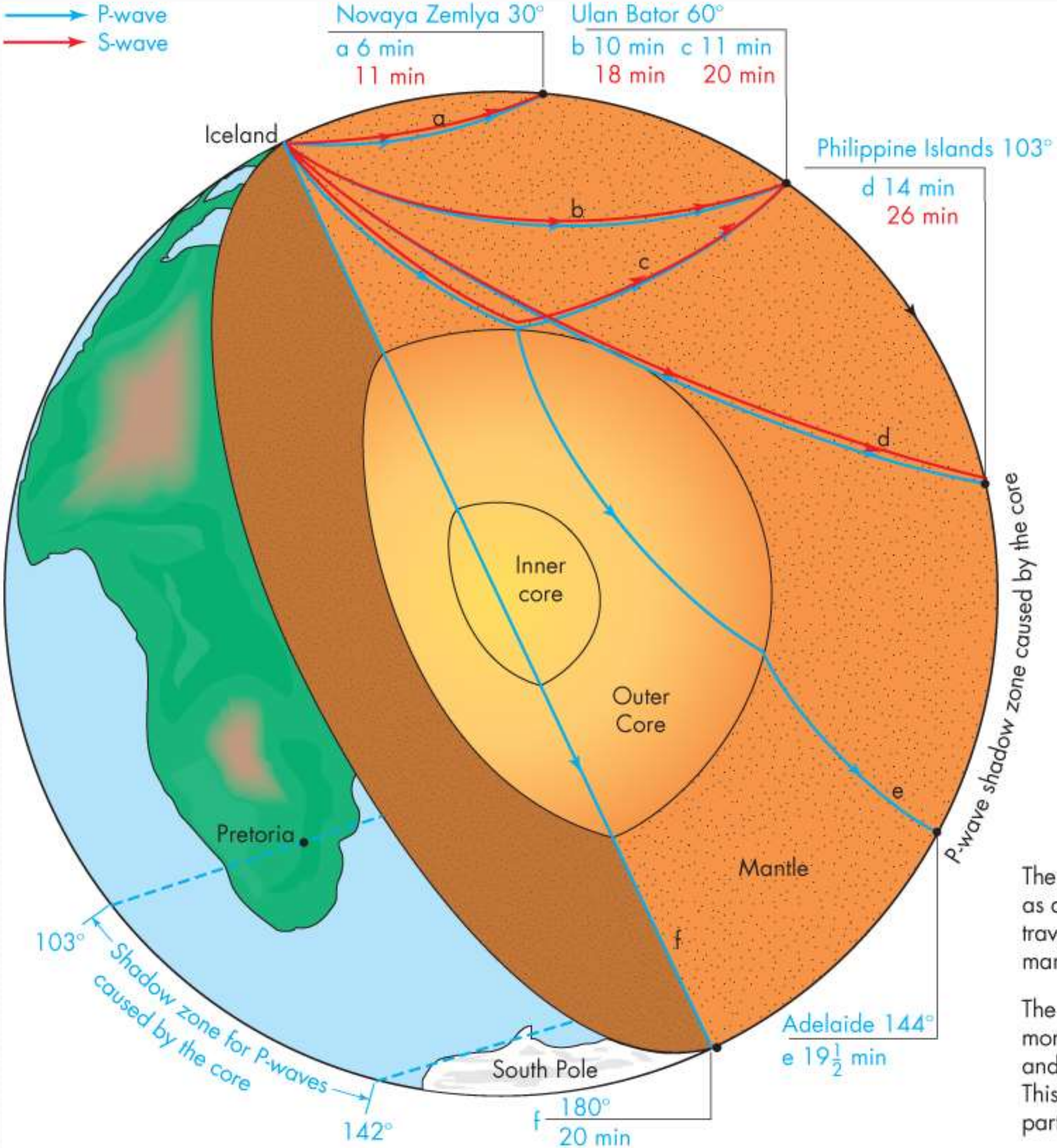
The mantle. Travel times for pathways such as a, b, and c indicate that seismic waves travel faster the deeper they penetrate the mantle.

The core. P-waves travel considerably more slowly in the core than in the mantle, and S-waves are not transmitted at all. This indicates that at least the outer part of the core is liquid.

Structural Layers of Earth

- Mantle
  - Solid
  - 3000 km in thickness
  - Composed of iron-rich and magnesium-rich silicate rocks

- Crust
  - Outer rock layer of Earth
  - Mohorovicic discontinuity
    - Separates lighter crustal rocks from the more dense mantle



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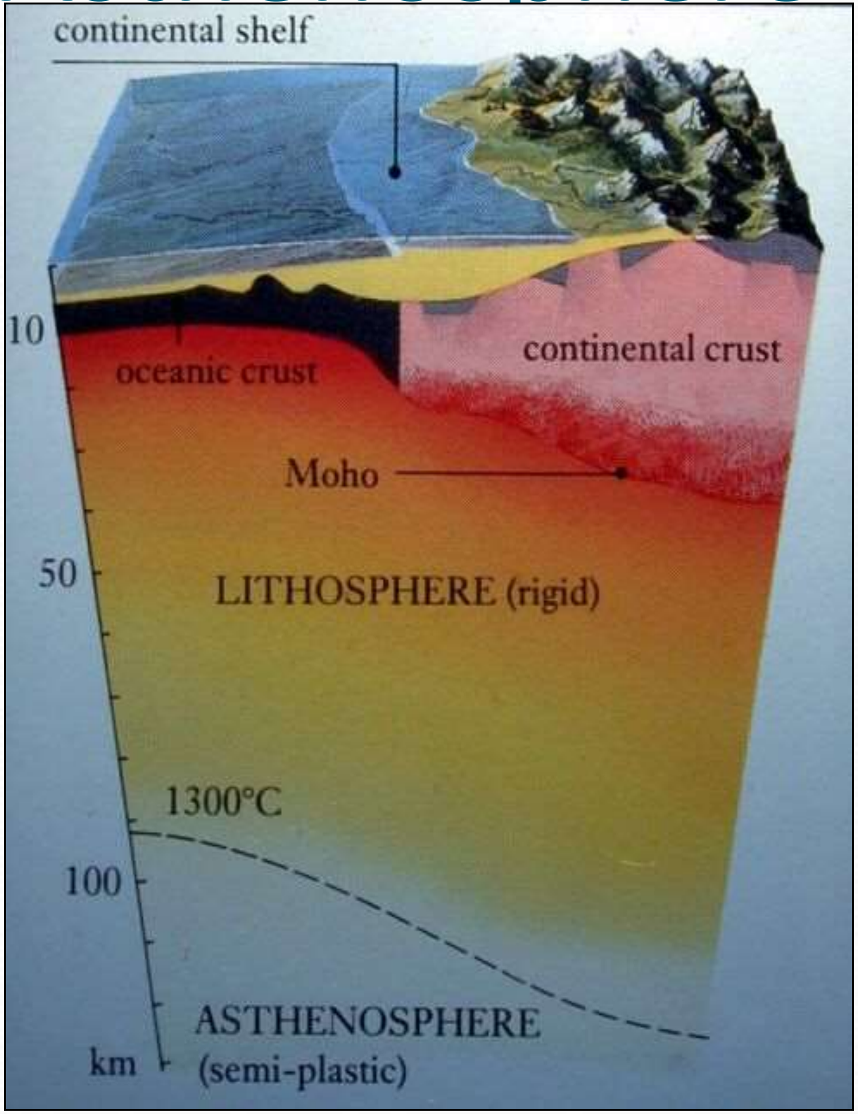
Lithosphere and Asthenosphere

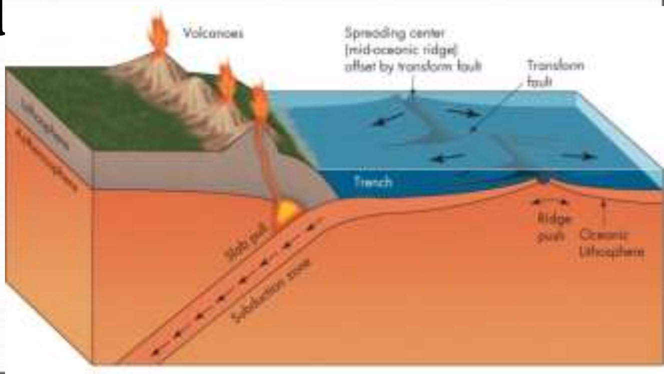
- Lithosphere
  - Cool, strong outermost layer of Earth
- Asthenosphere
  - Constitutes all but the uppermost part of the mantle
  - Hot, slowly flowing layer of relatively weak rock



Continents and Ocean Basins

- Crustal rocks are less dense than the mantle rocks below
    - Continental crust is less dense than oceanic crust
    - Oceanic crust is relatively thinner

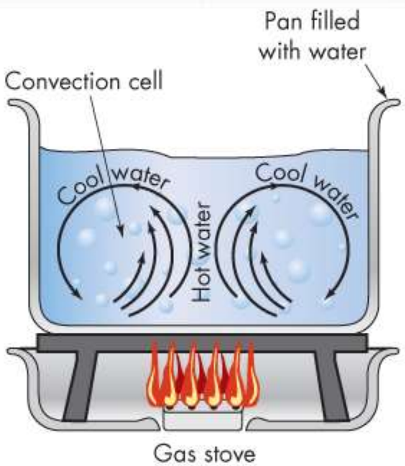
- Oceanic crust underlying today's ocean basins is less than 200 million years old, whereas some continental crust is up to several billion years old



Convection

- Earth's internal heat causes magma to heat up and become less dense

- The less dense magma rises
  - Cooler magma falls back downward

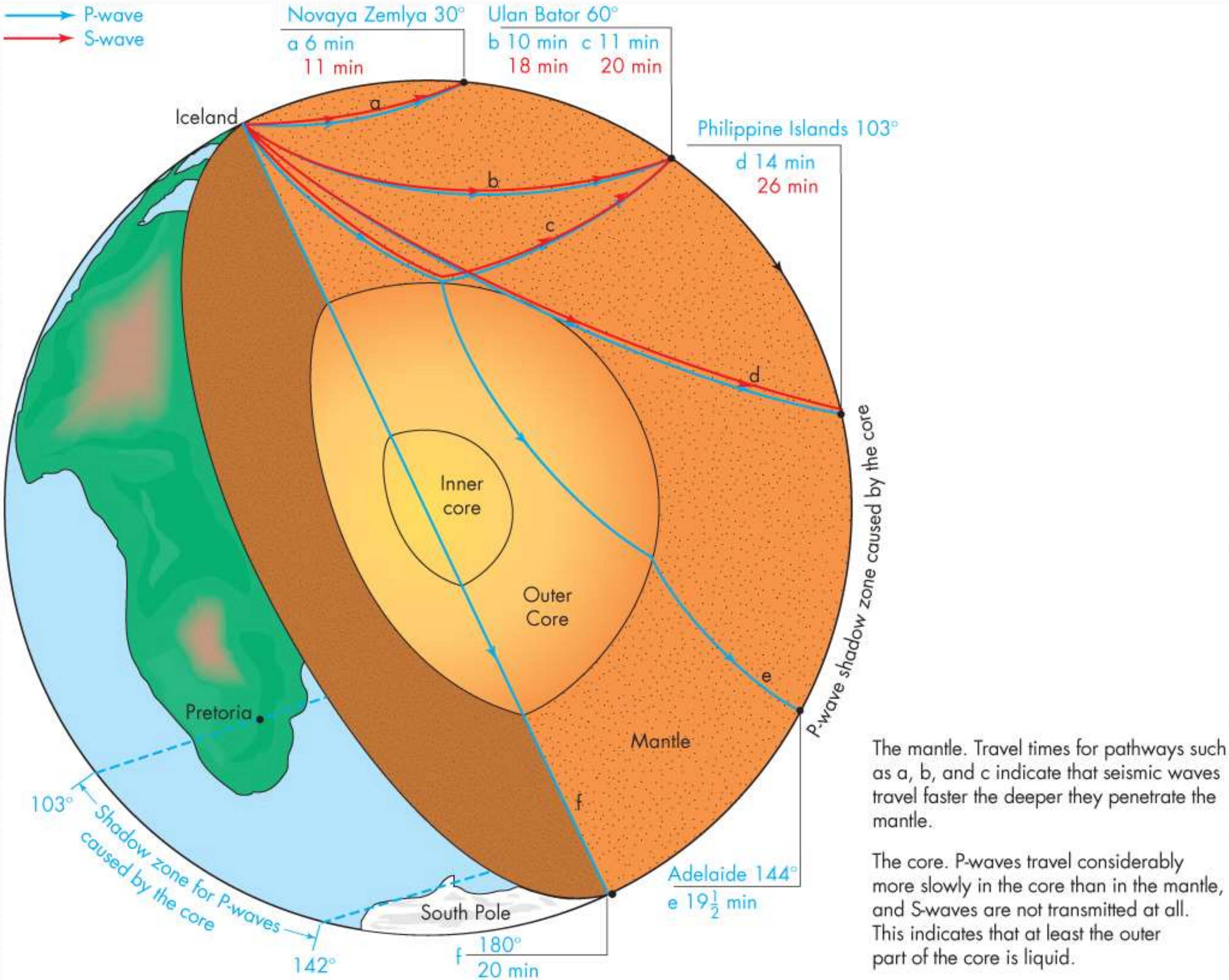


▲ **FIGURE 2.3 CONVECTION** Idealized diagram showing the concept of convection. As the pan of water is heated, less dense hot water rises from the bottom and displaces denser cooler water at the top, which then sinks down to the bottom. This process of mass transport is called convection, and each loop of rising and falling water is a convection cell.

How We Know about Earth's Internal Structure

- Most of our knowledge of Earth's structure comes from seismology
  - Study of earthquakes

- Earthquakes cause seismic energy to move through Earth
  - Some waves move through solid, but not liquids
  - Some waves are reflected
  - Some waves are refracted (they change direction)
  - Information on wave movement has allowed scientists to deduce the structure of Earth's interior and the properties of its layers



▲ **FIGURE 2.4 STRUCTURE OF EARTH INFERRED FROM SEISMIC WAVES** Scientists have inferred the physical properties and composition of Earth by studying the travel times and paths of seismic waves.

How We Know about Earth's Internal Structure

- What have we learned about Earth from earthquakes?
  - Where magma is generated in the asthenosphere
  - The existence of slabs of lithosphere that have sunk deep into the mantle
  - The variability of lithospheric thickness, reflecting differences in its age and history
  - What is liquid and what is solid (we will come back to this)

Plate Tectonics

- Tectonic refers to the large-scale geologic processes that deform Earth's lithosphere
  - Produce ocean basins, continents, and mountains
  - Driven by forces deep within Earth

- The lithosphere is broken into pieces
  - Lithospheric plates

- Plates move relative to one another

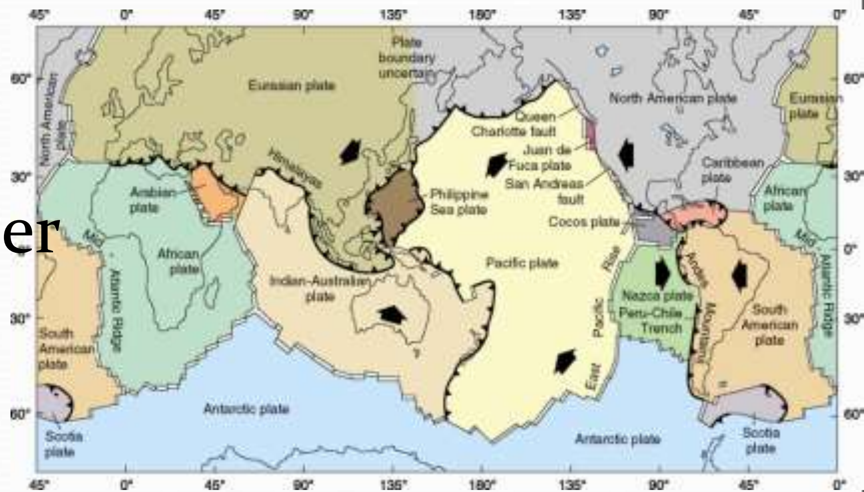
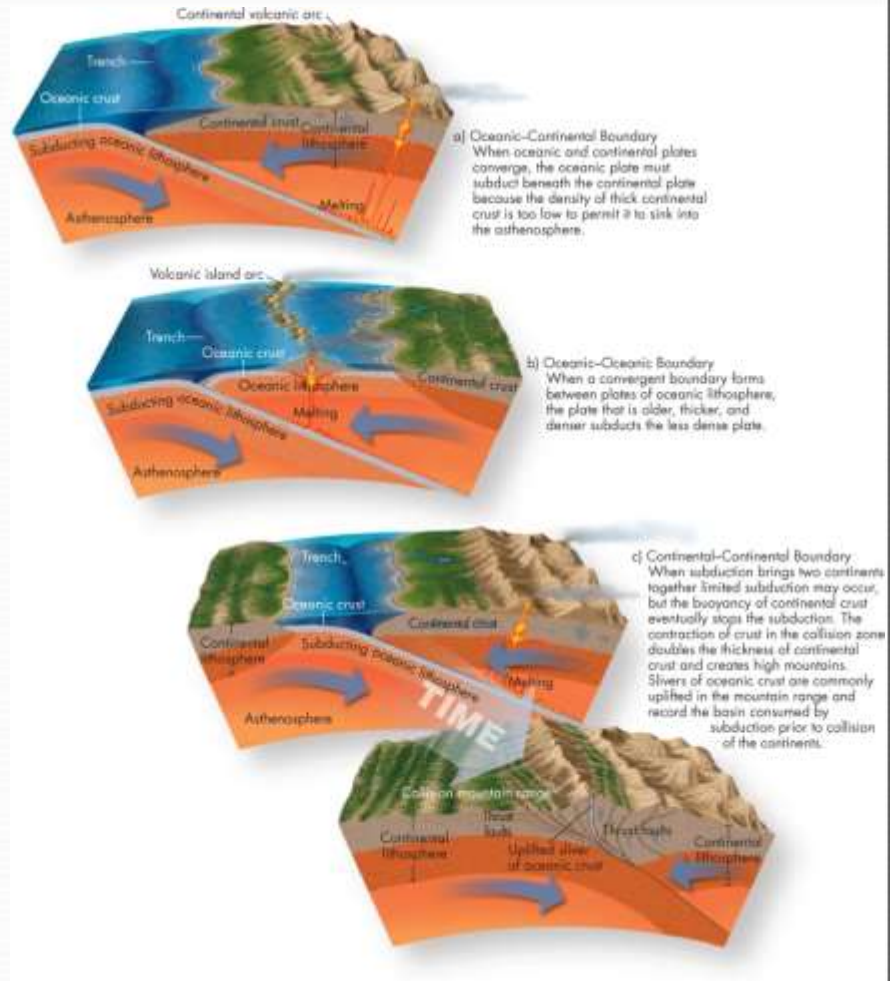
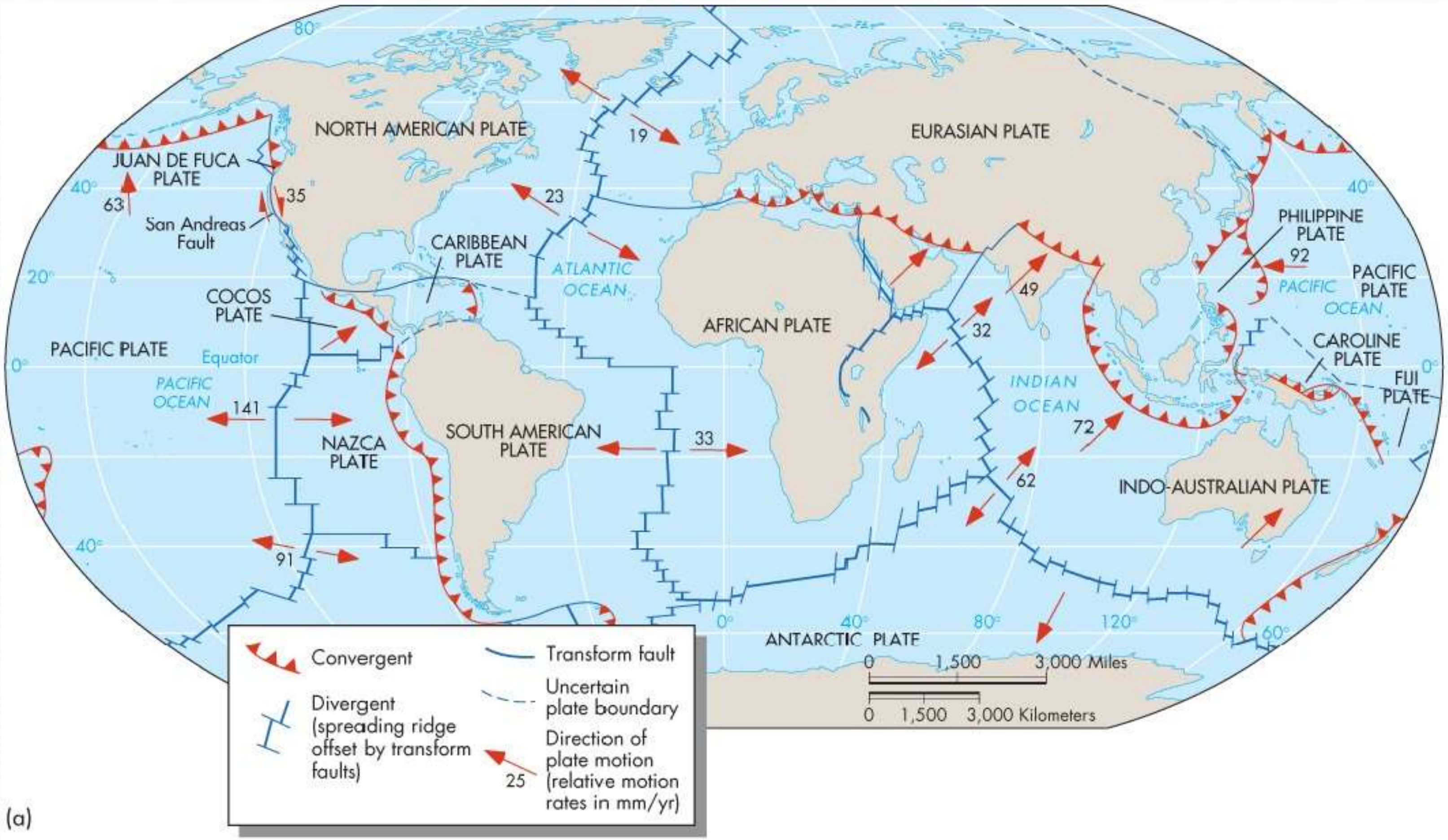


Plate Boundaries

- These are delineated by earthquakes and active volcanoes
    - Geologically active areas
- Plate boundaries are defined by areas of seismic activity
- Dynamic events on the Earth’s surface occur when plates move.
    - Diverge, converge, or slide past each other (transform)

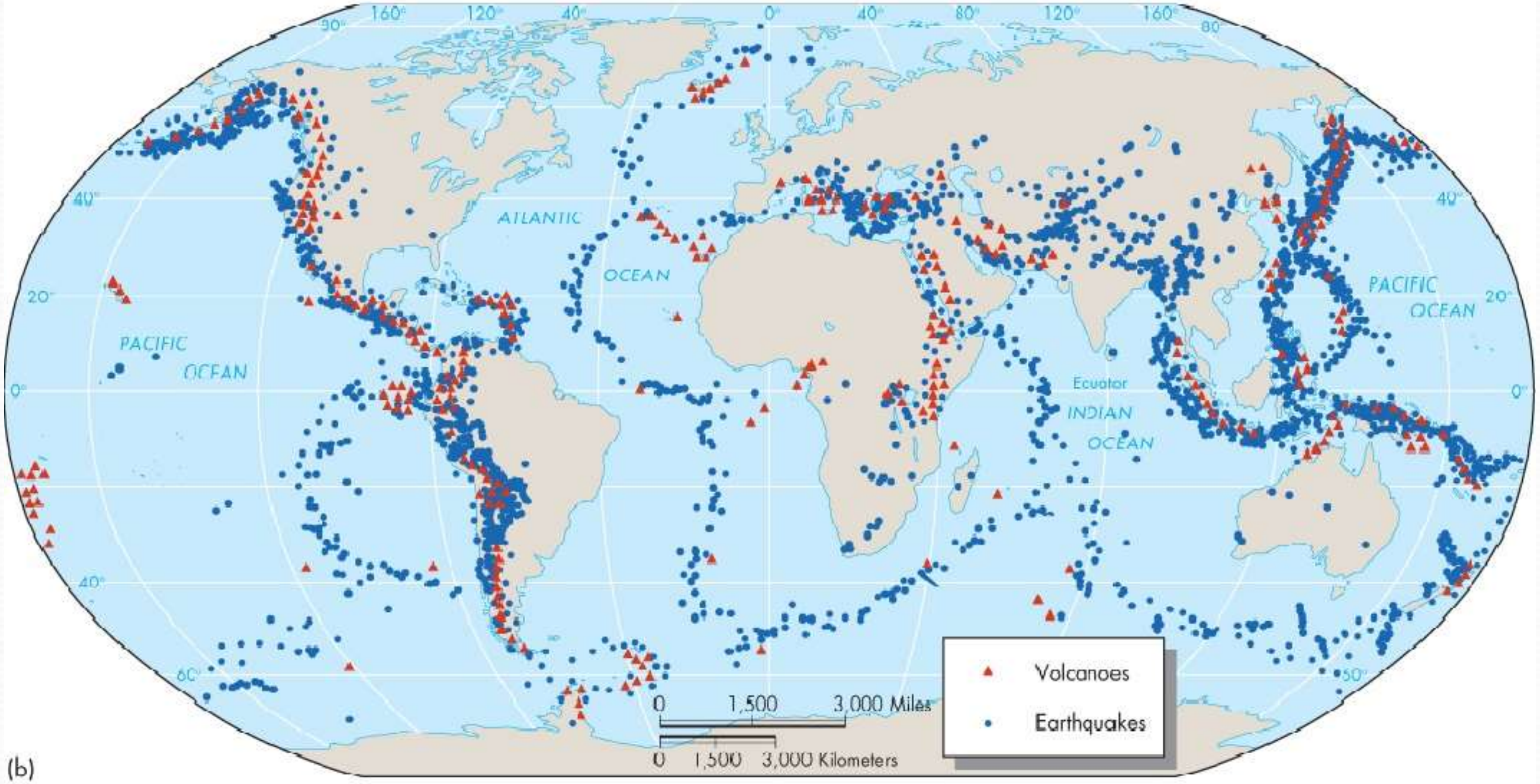


▲ FIGURE 2.11 **CONVERGENT PLATE BOUNDARIES** Idealized diagram illustrating characteristics of convergent plate boundaries: (a) continental–oceanic plate boundary; (b) oceanic–oceanic plate boundary; (c) continental–continental plate boundary.



NORTH AMERICAN PLATE
EURASIAN PLATE
JUAN DE FUCA PLATE
San Andreas Fault
CARIBBEAN PLATE
ATLANTIC OCEAN
COCOS PLATE
PACIFIC PLATE
Equator
PACIFIC OCEAN
AFRICAN PLATE
PHILIPPINE PLATE
PACIFIC PLATE
PACIFIC OCEAN
CAROLINE PLATE
FIJI PLATE
INDIAN OCEAN
NAZCA PLATE
SOUTH AMERICAN PLATE
INDO-AUSTRALIAN PLATE
ANTARCTIC PLATE
19
23
35
63
141
91
33
49
32
72
62
92
80°
40°
20°
0°
60°
120°
0 1,500 3,000 Miles
0 1,500 3,000 Kilometers
Convergent
Transform fault
Divergent (spreading ridge offset by transform faults)
Uncertain plate boundary
Direction of plate motion
25 (relative motion rates in mm/yr)

(a)



▲ **FIGURE 2.5 EARTH'S TECTONIC PLATES** (a) A map showing the major tectonic plates, plate boundaries, and directions of plate movement. (b) Map showing the locations of volcanoes and earthquakes. Note the correspondence between this map and the plate boundaries in (a). *(Based on Christopherson, R. W. 1994.* Geosystems, 2nd ed. *New York: Macmillan; Press, F., R. Siever, J. Grotzinger, and T. H. Jordan. 2003.* Understanding Earth, 4th ed. *New York: W.H. Freeman)*

Seafloor Spreading

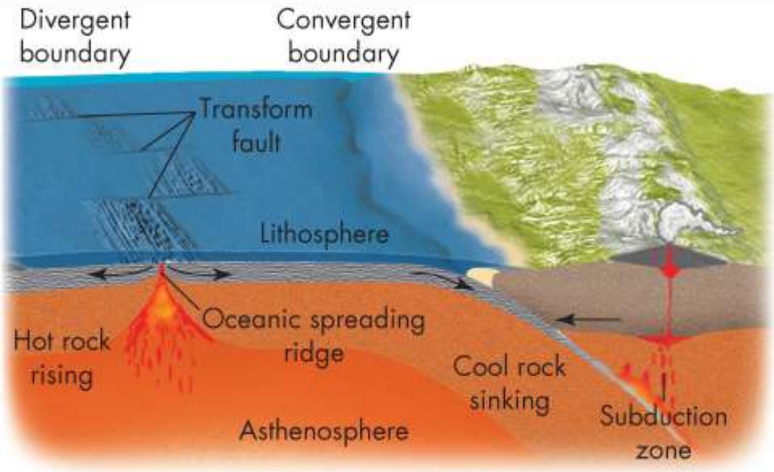
- This is the mechanism for plate tectonics
- At mid-ocean ridges new crust is added to edges of lithospheric plates
  - Continents are carried along plates
- Crust is destroyed along other plate edges
  - Subduction zones
- The rate of production of new lithosphere at spreading centres is balanced by consumption of lithosphere at subduction zones

Sinking Plates Generate Earthquakes

- Sinking ocean plates come in contact with the hot asthenosphere
- Plates melt to generate magma
- Magma rises to produce volcanoes
- Earthquakes occur along the path of the descending plate

Plate Tectonics is a Unifying Theory

- Explains a variety of phenomena
- Convection within Earth’s mantle likely drives plate tectonics

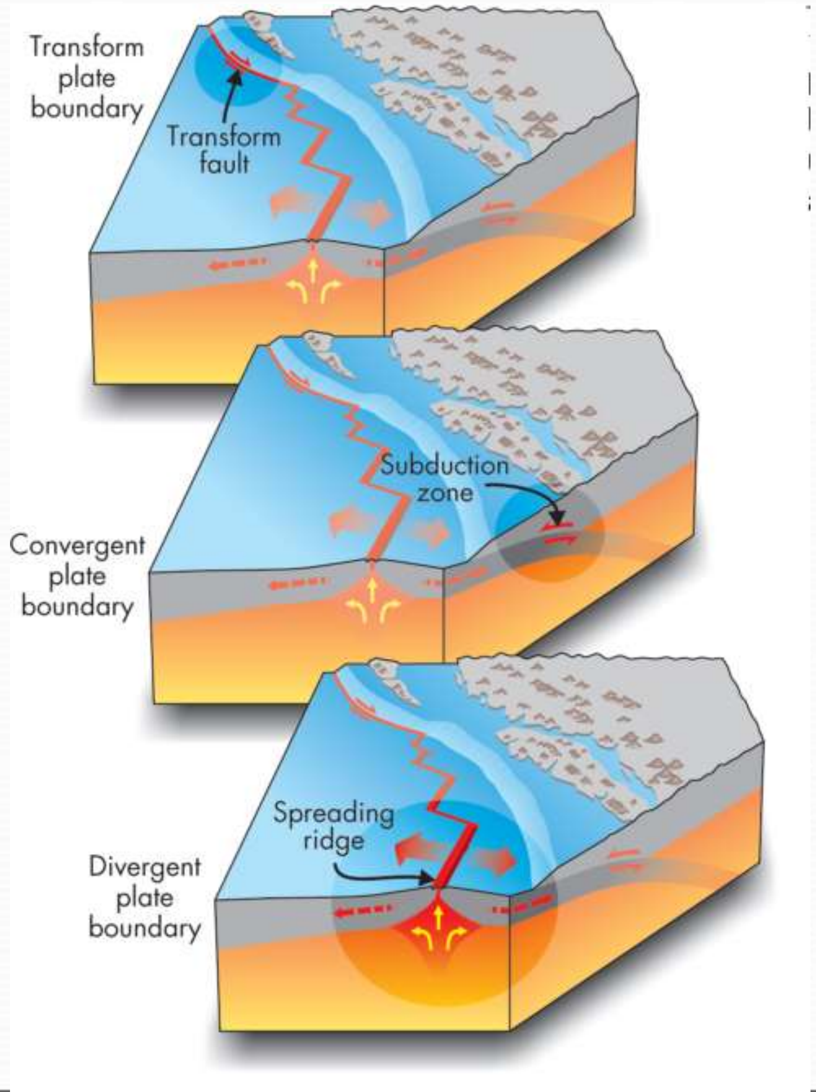


◀ **FIGURE 2.8 MODEL OF PLATE TECTONICS** New oceanic lithosphere is produced at a spreading ridge (divergent plate boundary). It returns to the mantle at a convergent plate boundary (subduction zone). *(Based on Lutgens, F., and E. Tarbuck. 1992.* Essentials of Geology. *New York: Macmillan)*

Types of Plate Boundaries

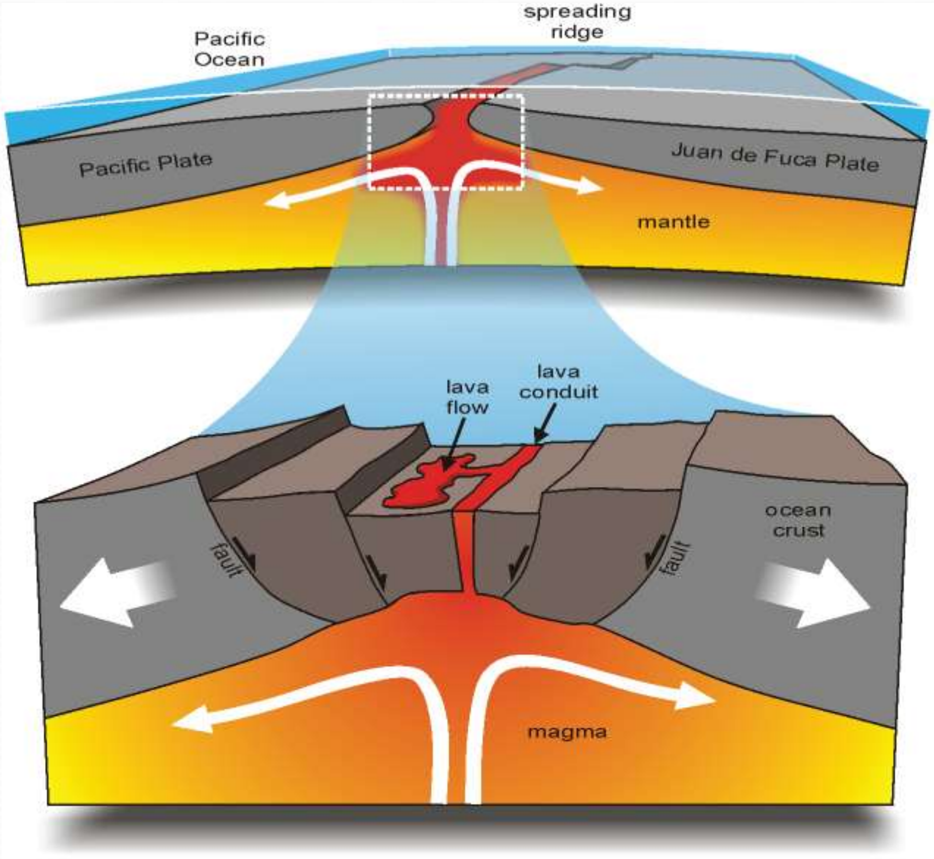
- Three basic types
  - divergent, convergent, and transform

- The boundaries are broad zones of intense deformation



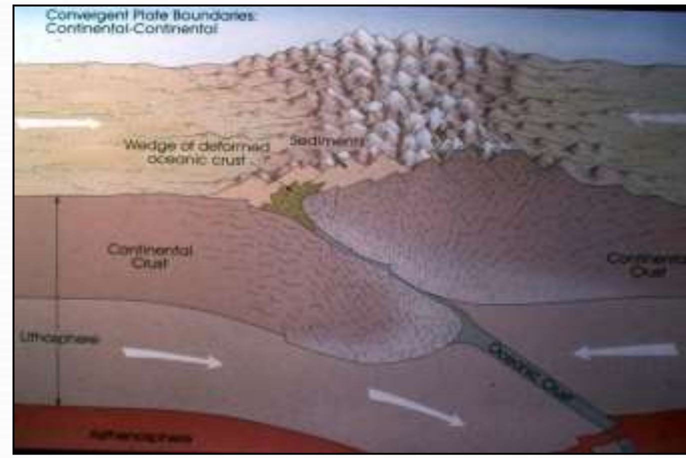
Divergent Plate Boundaries

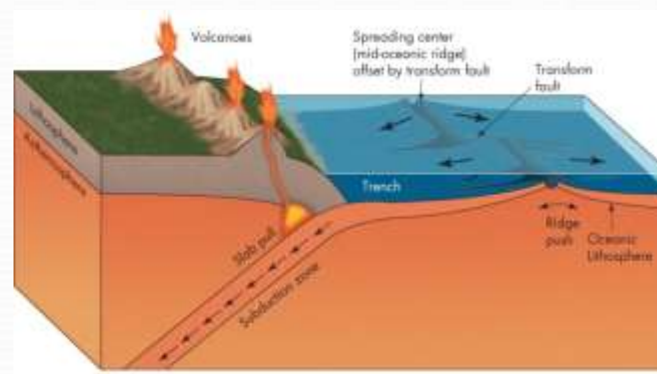
- Where two plates move away from one another
- New lithosphere is created at these boundaries
- Divergence between two ocean plates:
  - Causes mid-ocean ridges
  - Seafloor spreading
  - Ex: Mid-Atlantic Ridge



Convergent Plate Boundaries

- Where two plates collide head-on
- Oceanic-continental collisions result in subduction zones
  - More dense ocean plates sink and melt
  - Melted magma rises to form volcanoes
- Collisions between two continental plates results in a continental collision boundary
  - Neither plate subducts, instead the plates crumple together
  - Large mountains form such as the Himalayas

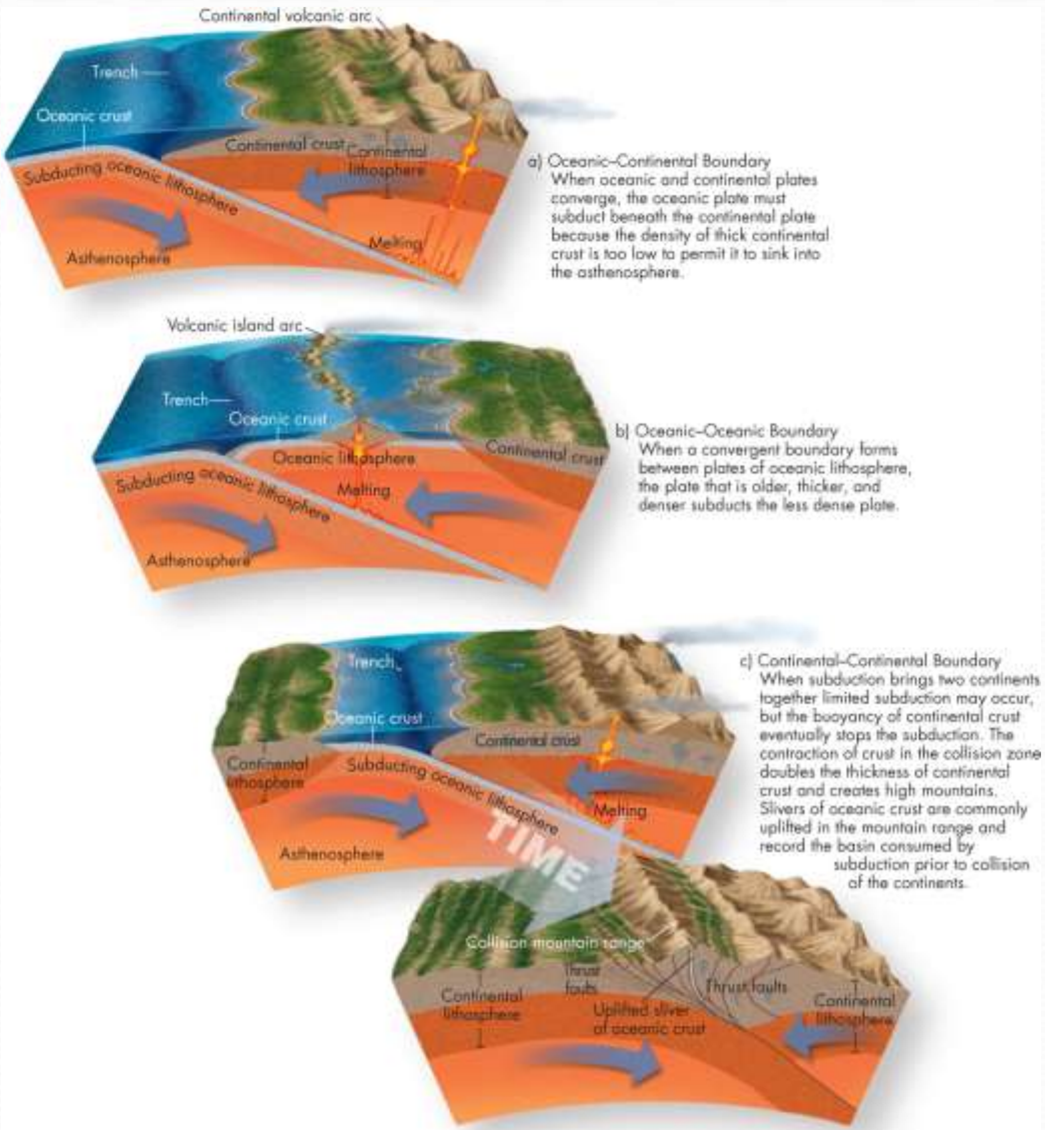




▲ FIGURE 2.21 **PUSH AND PULL IN MOVING PLATES** Diagram showing the mechanisms of ridge push and slab pull in facilitating the movement of lithospheric plates. Both are gravity-driven processes. The heavy lithosphere moves down the slope of the mid-ocean ridge and is pulled down through the lighter, hotter mantle at the subduction zone. *(Cox, A., and R. B. Hart. 1986. Plate Tectonics. Boston, MA: Blackwell Scientific Publications)*

Transform Plate Boundaries

- Where the edges of two plates slide horizontally past one another
- Most common on the ocean floor but some occur within continents
- Ex: San Andreas Fault
  - Separates the Pacific plate and the North American plate



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Rates of Plate Motion

- Plates move a few centimetres per year
- Although the central portions of plates move at a steady slow rate, movement may not be steady at plate boundaries
- Plates can displace by several metres during a great earthquake

A Detailed Look at Seafloor Spreading

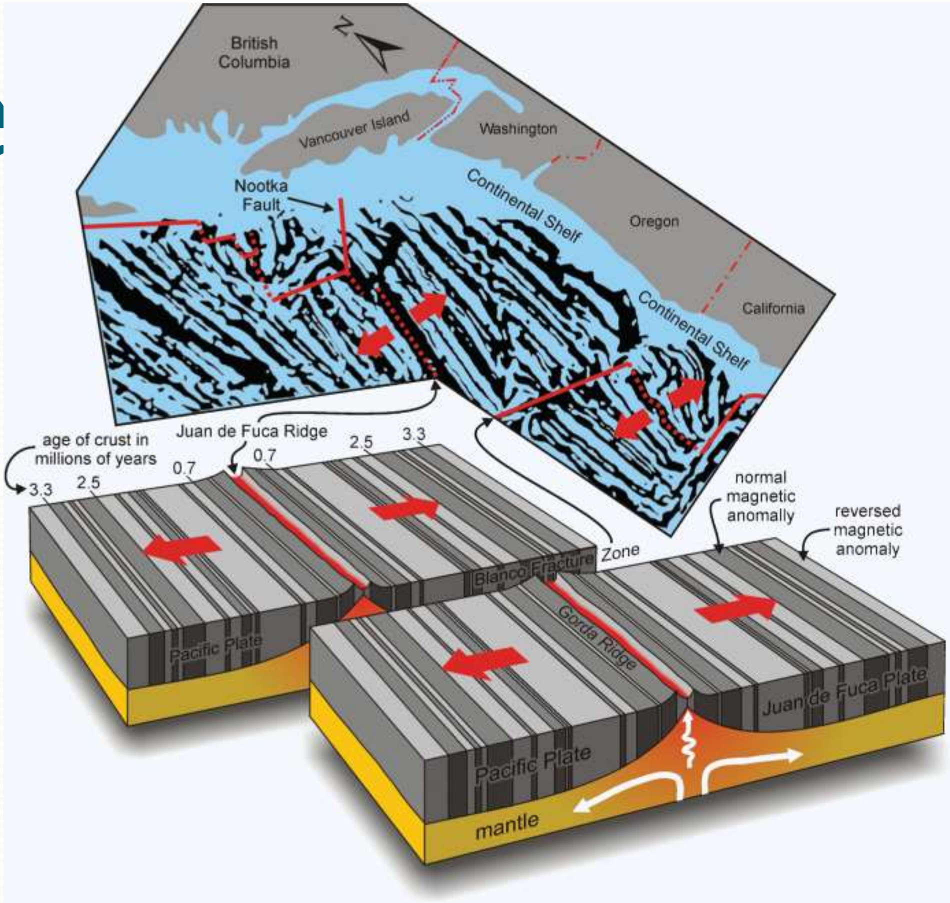
- Mid-ocean ridges were discovered by Harry H. Hess

- Validity of seafloor spreading was established by:
  - Identification and mapping of ocean ridges
  - Dating of volcanic rocks on the floor of the ocean
  - Understanding and mapping of the paleomagnetic history of ocean basins

▲ **FIGURE 2.7 MID-ATLANTIC RIDGE** Image of the Atlantic Ocean basin showing details of the seafloor. Notice that the width of the Mid-Atlantic Ridge is about one-half the width of the ocean basin. *(Heinrich C. Berann/National Geographic Image collection)*

Magnetic Stripe

- Scientists used ships to tow magnetometers along the ocean floor
  - These are instruments that measure magnetic properties of rocks
- Rocks on the ocean floor are magnetically striped parallel to mid-ocean ridges
  - Areas of normal and reversed magnetism



▲ FIGURE 2.17 **MAGNETIC STRIPING ON THE SEAFLOOR** (Top) Map showing the results of a magnetic survey of the seafloor in the eastern North Pacific Ocean, published in 1961. The black stripes record intervals of normal magnetic polarity, like today, and the intervening blue stripes represent intervals when Earth's magnetic field was reversed. (Bottom) An idealized diagram showing the formation of magnetic stripes by the conveyor-like movement of new crust away from the Juan de Fuca spreading ridge. The small red arrows are directions of motion along transform faults, which connect segments of the spreading ridge. *(Reprinted with permission of Tricouni Press)*

Driving Mechanisms

- Two possible driving mechanisms for plate tectonics
  - ridge push and slab pull

- Ridge push is a gravitational push away from crests of mid-ocean ridges

- Slab pull occurs when cool, dense ocean plates sinks into the hotter, less dense asthenosphere
  - Weight of the plate pulls the plate along

- Evidence suggests that slab pull is the more important process

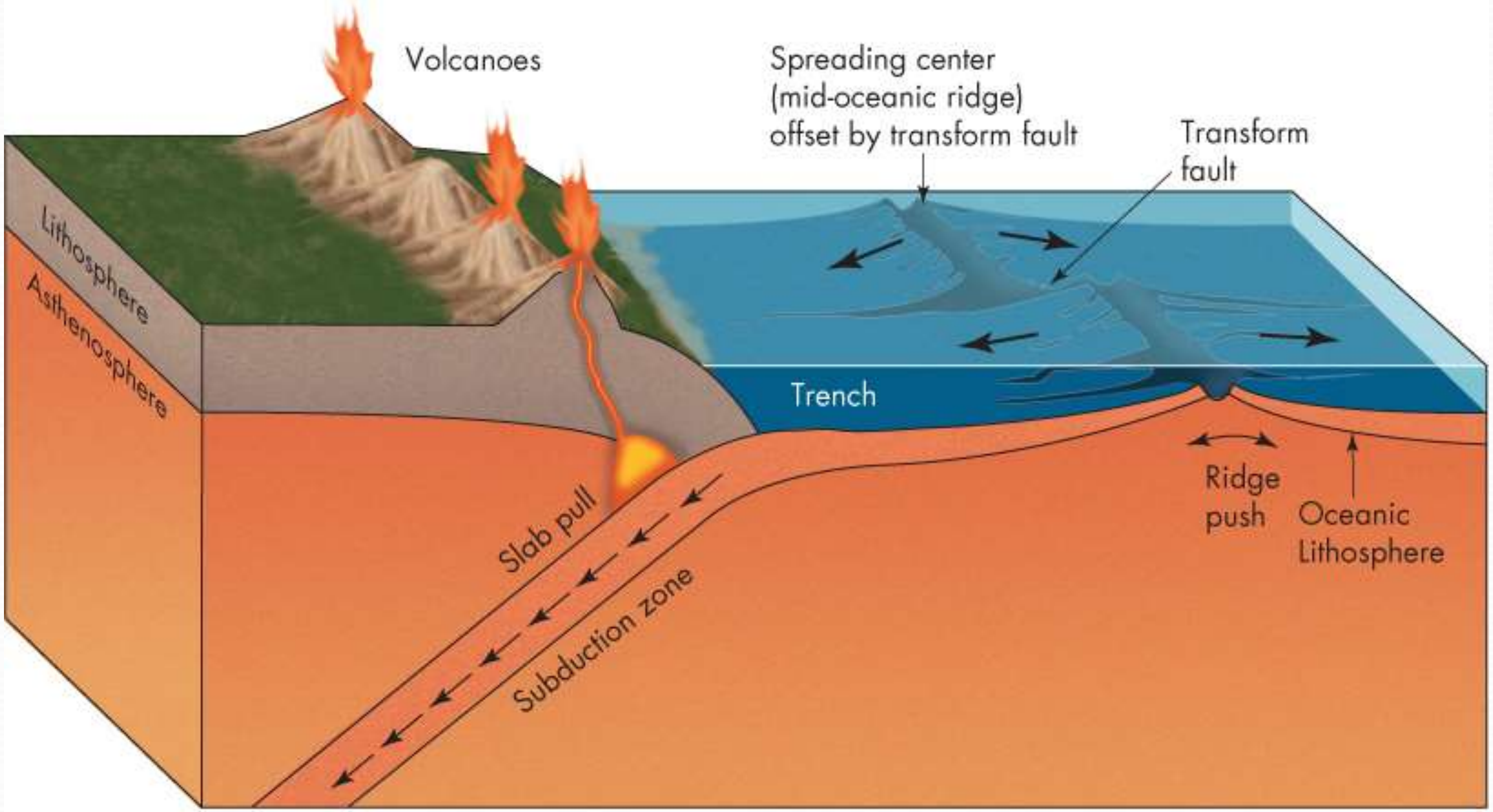


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Plate Tectonics and Hazards

- Divergent plate boundaries (Mid-Atlantic Ridge) exhibit earthquakes and volcanic eruptions

- Boundaries that slide past each other (San Andreas Fault) have appreciable earthquake hazards
- Convergent plate boundaries where one plate sinks (subduction zones) contain explosive volcano and earthquake hazards

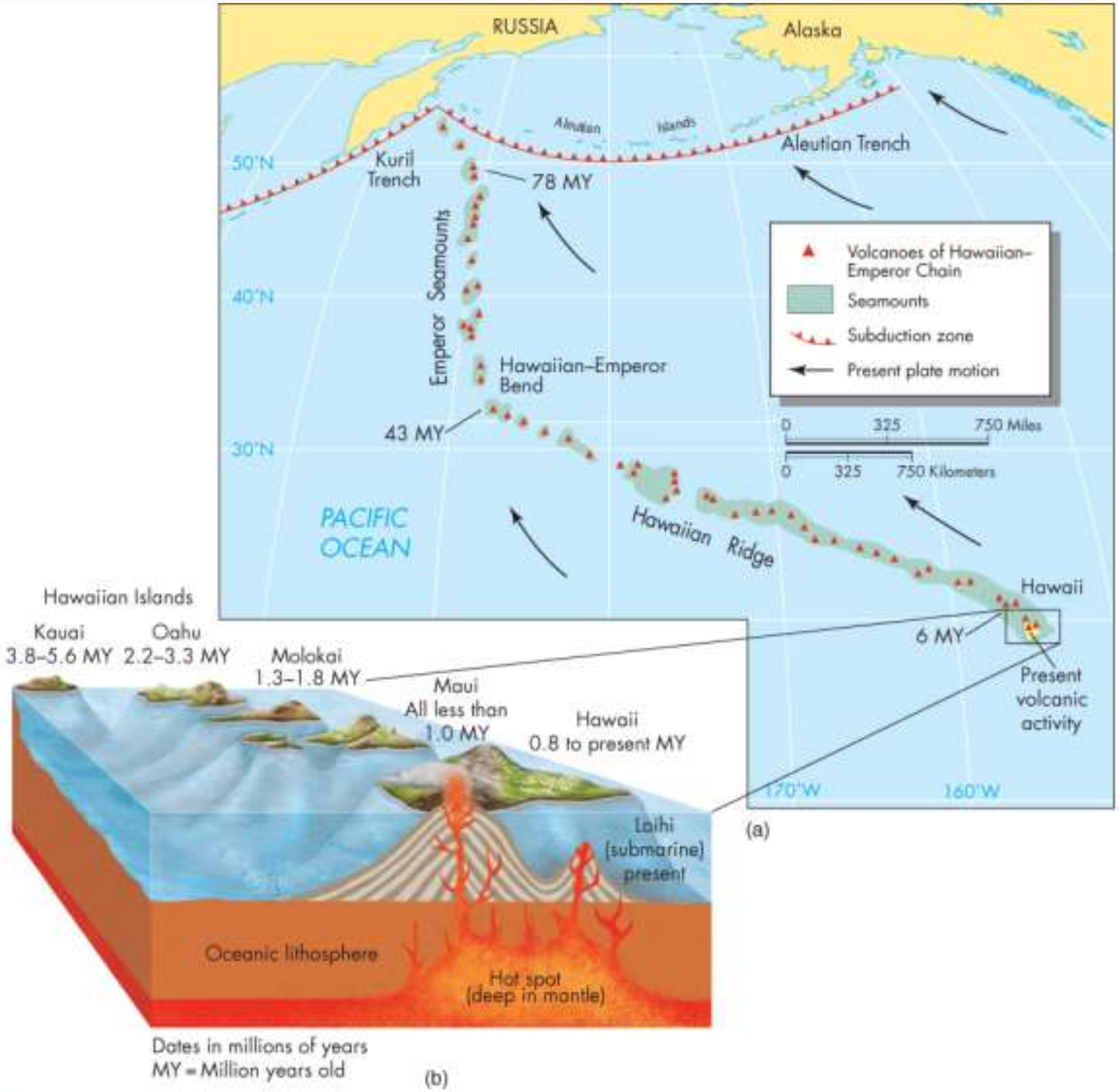
- Convergent plate boundaries where continents collide (Himalayas) have high topography and earthquakes

Hot Spots

- Concept developed by Canadian geophysicist J. Tuzo Wilson
- Volcanic centres away from plate boundaries resulting from hot material from deep in the mantle
- Magma moves up through the mantle and overlying plates
  - Found under both oceanic and continental crust

▲ FIGURE 2.20 J. TUZO WILSON A leader in the development of the plate tectonic theory in the early 1960s was J. Tuzo Wilson, a Canadian geophysicist and professor at the University of Toronto. Wilson theorized that the Hawaiian Islands formed by the movement of an oceanic lithospheric plate over a mantle hot spot. He also was the first scientist to recognize transform faults, one of the three main types of plate boundaries. (Courtesy Ontario Science Centre)

- Plates move over hot spots creating a chain of volcanoes
  - Ex: Hawaiian Islands, Yellowstone National Park



▲ **FIGURE 2.19 HAWAIIAN HOT SPOT** (a) Map showing the Hawaiian-Emperor chain of volcanic islands and seamounts. The Hawaiian Islands are the only volcanoes of the chain that reach above the ocean surface. The other volcanoes are seamounts. (b) Sketch map showing the Hawaiian Islands, which range in age from present-day to almost 6 million years. Notice that most of the mass of the volcanoes is below the ocean surface. *((a) From The Geological Society of America; (b) From Thurman, H. V. 1995.* Essentials of Oceanography 5th ed. *Upper Saddle River, NJ: Prentice Hall. Reprinted and Electronically reproduced by permission of Pearson Education, Inc., Upper Saddle River, New Jersey.)*

To Do

- Read Chapters 1-3
- Complete short quiz