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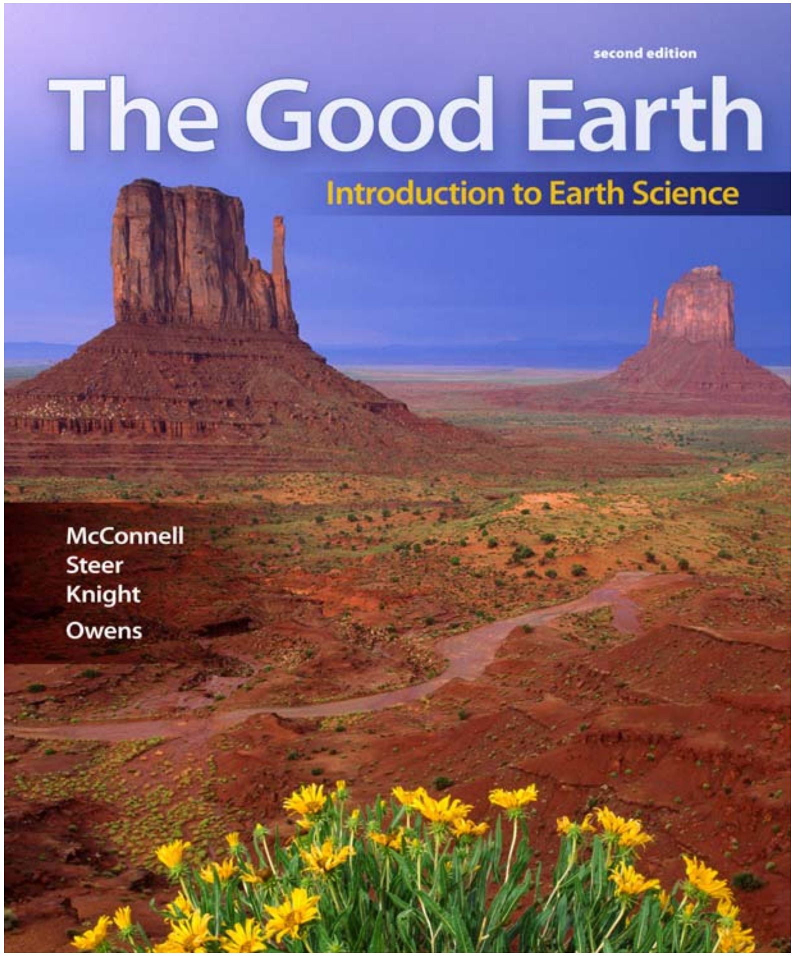
Chapter 4: Plate Tectonics



1. Science and Santa Claus
2. Continental Drift
3. Evidence from the Seafloor
4. Plate Tectonics
5. Plate Boundaries

Science and Santa Claus

Paradigm

- Models or patterns for thinking about or valuing a situation

Paradigm Shift

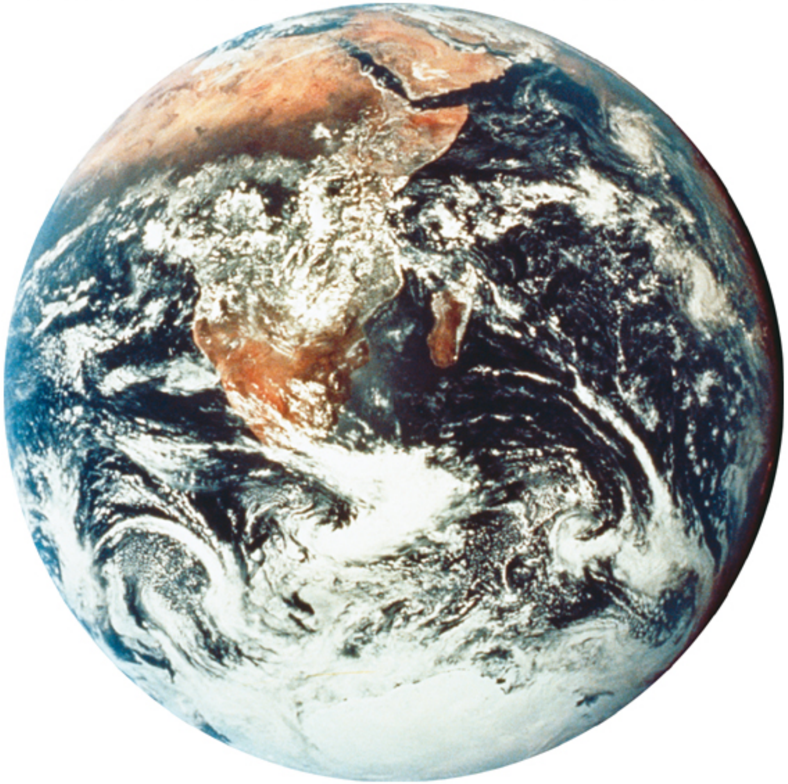
- A fundamental change in an accepted view or understanding of a concept
  - Example: Santa Claus vs. parents as a source of Christmas gifts

Plate Tectonics Concept Survey

Using examples that are not described in this chapter; identify and briefly describe:

1. A personal paradigm shift.
2. A cultural or social paradigm shift
3. A scientific paradigm shift

Science and Santa Claus



© PhotoLink/Getty Images

- Plate tectonics represents a paradigm shift in our view of the Earth and how it works
  - Change of views occurred over several decades
- Earth's surface divided into two major elevation zones
  - Land and shallow oceans
  - Deep ocean floor

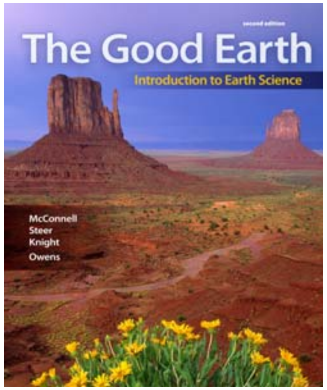


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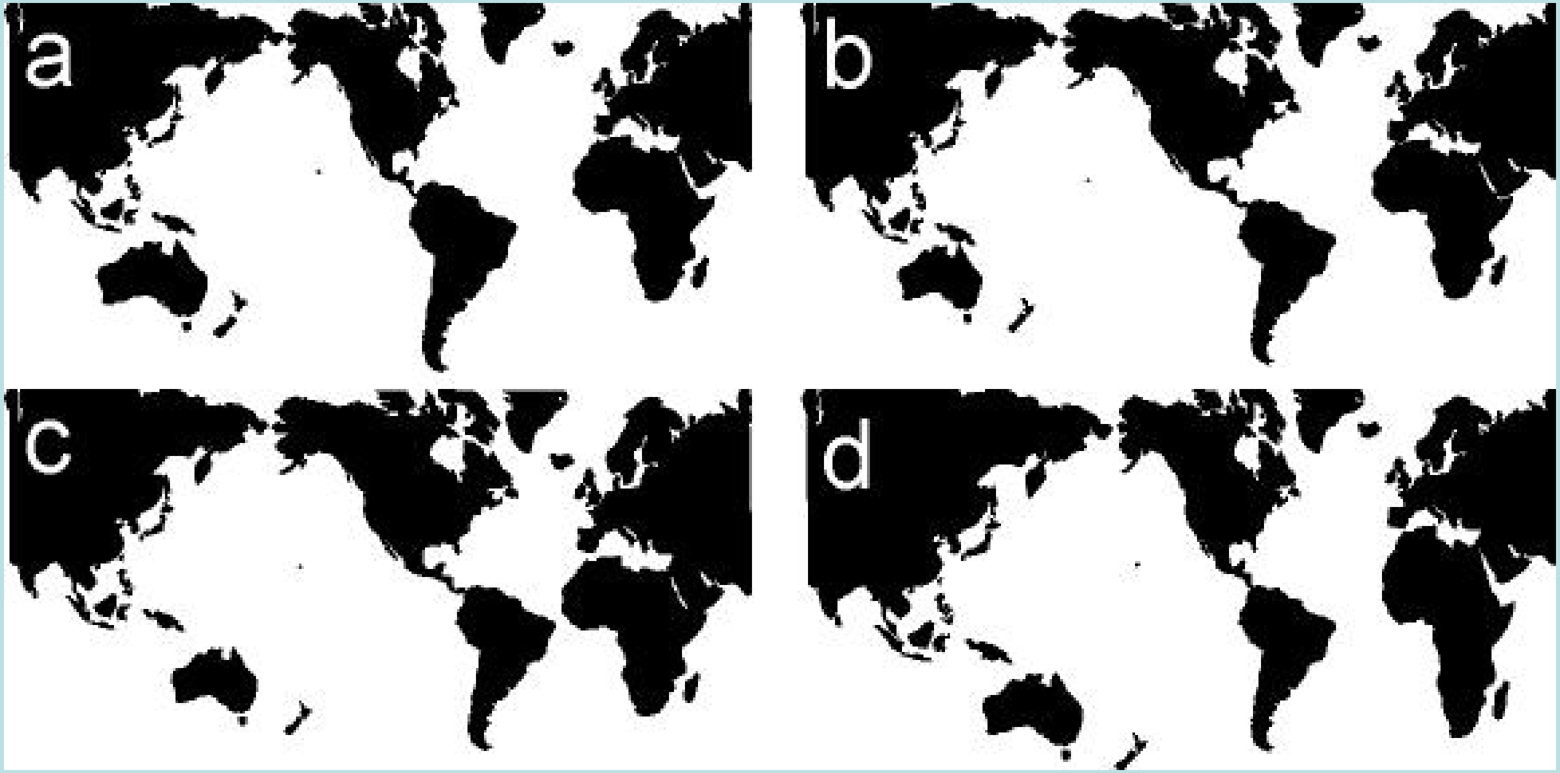
Plate Tectonics Conceptest

Which is the actual map of Earth's features?



Continental Drift

Early 20th Century Paradigm:

- **Contracting Earth**: Planet is slowly cooling and contracting as heat of formation is lost
  - Mountains represent “wrinkles” formed by the contraction of the surface
  - Collapse of surface formed ocean basins
  - Continents, oceans effectively fixed in place
  - Vertical crustal movements dominate

Continental Drift

Pangaea, 250 MYA

Laurasia and Gondwana, 210 MYA

Most modern continents had formed by 65 MYA

Wegener's Alternative Paradigm:

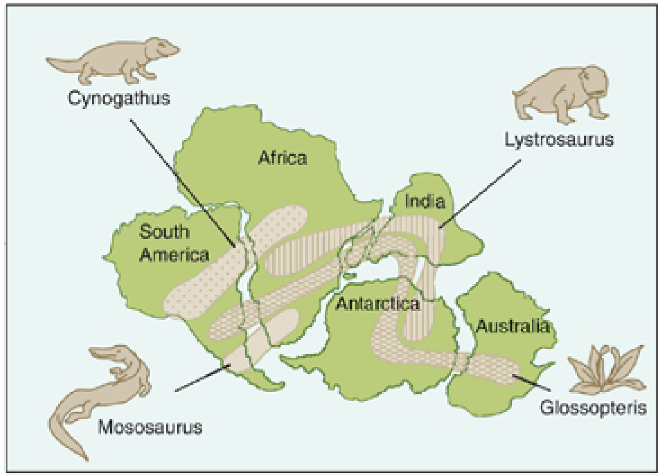
- **Continental Drift**: continents have occupied different locations on Earth's surface in the geologic past
  - 250 million years ago the continents were all together in a "supercontinent", **Pangaea**
  - Continents "drifted" across surface of Earth to their present locations

Continental Drift

Wegener's Observations:

Matching features

- Distribution of plant and animal fossils matched between continents



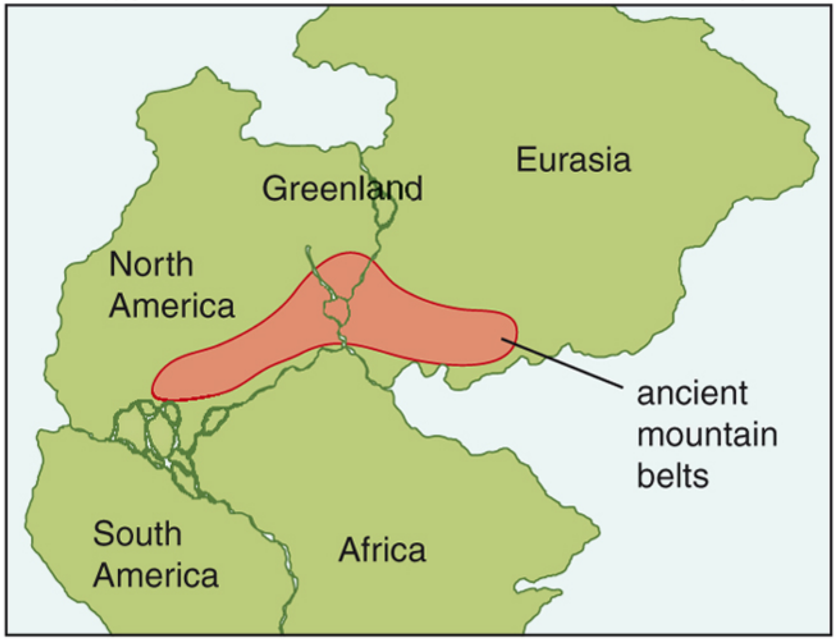
a. Fossil distribution

Continental Drift

Wegener's Observations:

Matching features

- A continuous mountain belt can be formed when Pangaea is reassembled



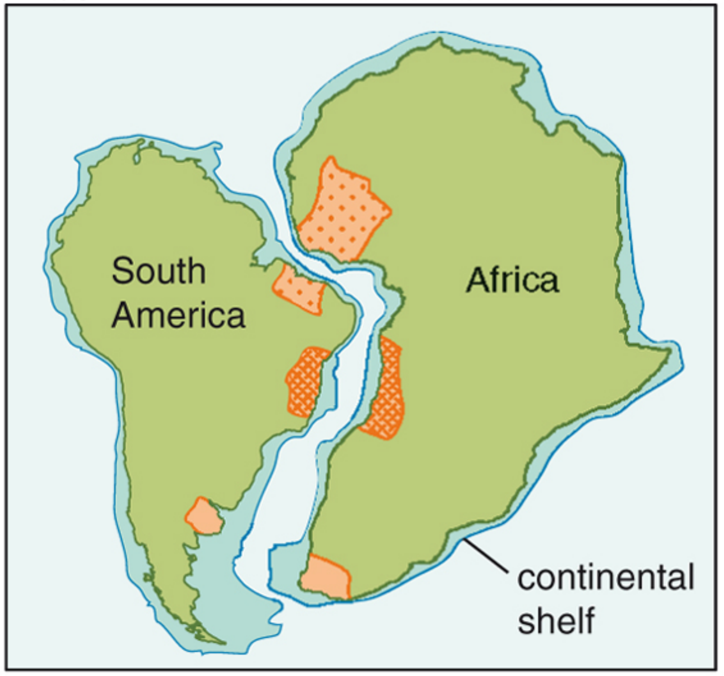
b. Match of mountain belts among North America, Europe, and Greenland

Continental Drift

Wegener's Observations:

Matching features

- Opposing edges of continents fit together along the shallow continental shelf
- Unusual rock sequences match between Africa and South America



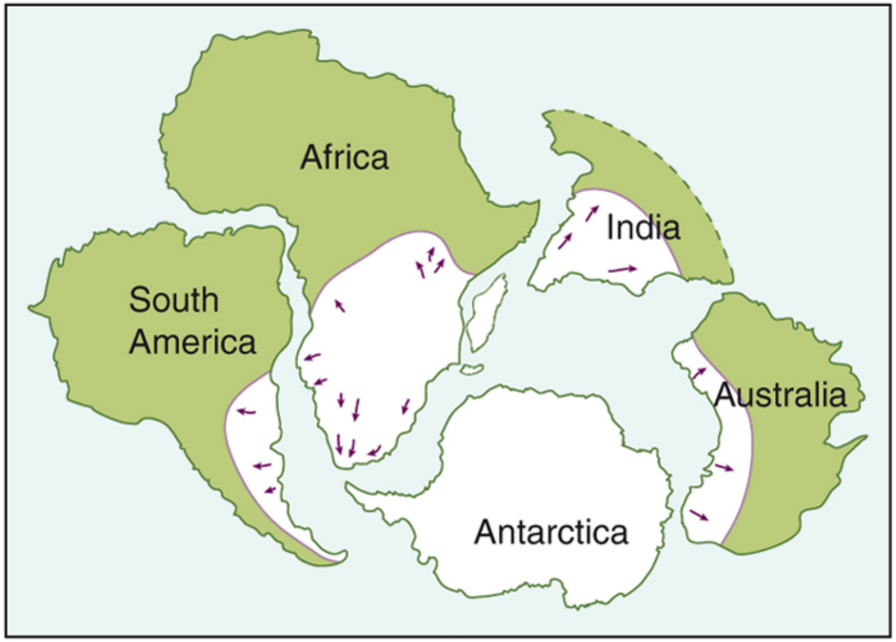
c. Fit of continents, matching rock units

Continental Drift

Wegener's Observations:

Paleoclimates

- Evidence of a thick ice sheet throughout the southern continents
- Rocks formed in tropical conditions (e.g., coal swamps) in North America near (paleo)equator



d. Glacial deposits. Arrows illustrate direction of ice movement.

Continental Drift

Wegner's Continental Drift hypothesis was not widely accepted because:

1. Wegener could not explain **how** the continents moved
2. Supporters of the contracting Earth hypotheses came up with alternative explanations for some of Wegener's observations
   - e.g., land bridges allowed fossil organisms to move between continents

Plate Tectonics Concept Survey

How is fixing this plate analogous to Wegener's methods of assembling the continents into Pangaea?

Plate Tectonics Conceptest

Which of the lines of evidence were <u>not</u> used to support Wegener's continental drift hypothesis?

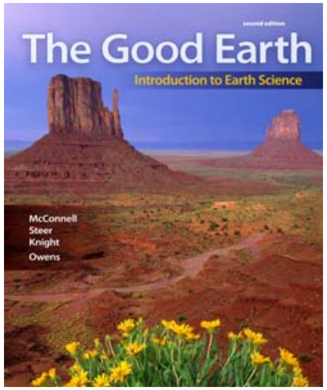
A. The distribution of fossils.
B. Fit of continents.
C. Match of mountain belts.
D. Earthquake locations.
E. Paleoclimate data.

Plate Tectonics Concept Survey

Science follows some basic rules. Science . . .

- is tentative
- is based on observations or experiments
- is predictable
- offers a natural cause for a natural phenomenon

Was the development of Wegener's Continental Drift hypothesis consistent with the characteristics of good science?



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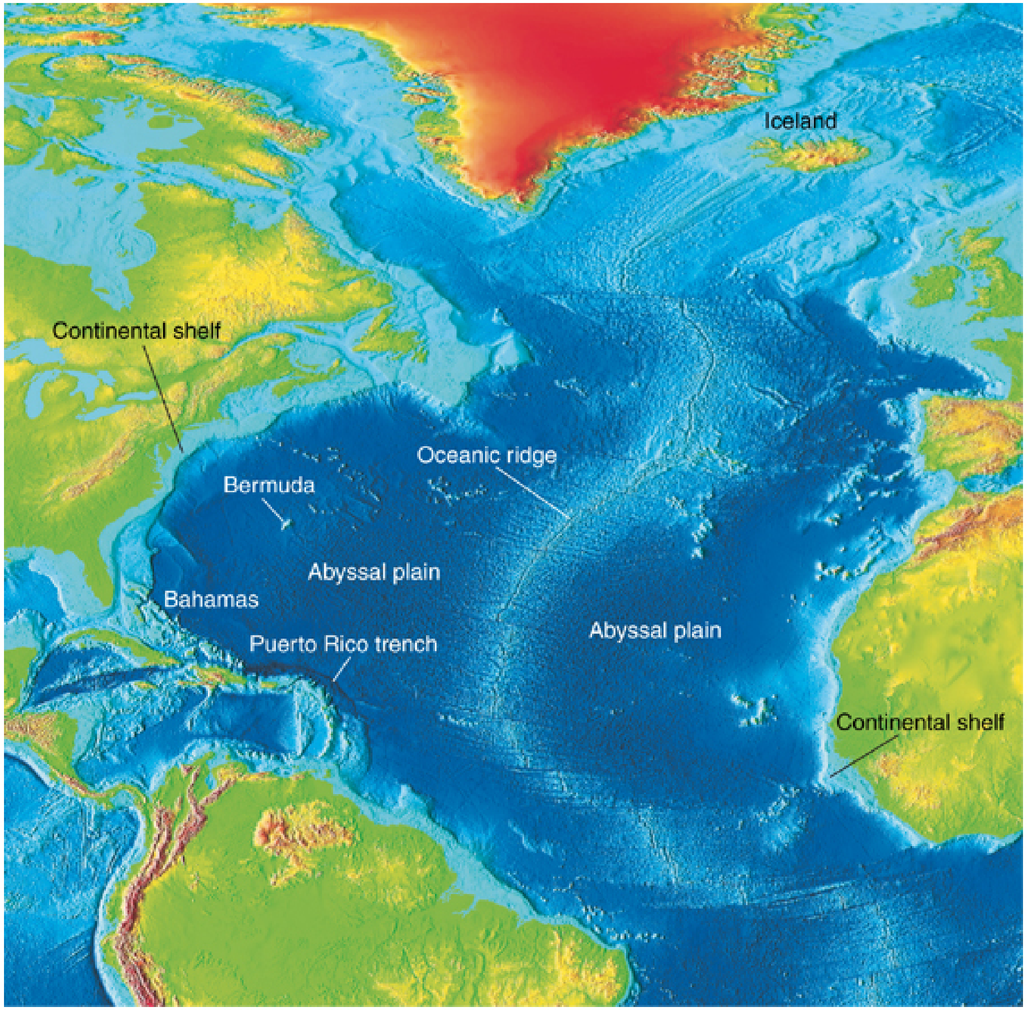
Evidence from the Seafloor

In the decades following Wegener's research, key observations about the seafloor contributed to a new understanding of Earth processes

- Seafloor topography
- Age of the seafloor
- Heat flow
- Volcanoes
- Earthquakes

Evidence from the Seafloor



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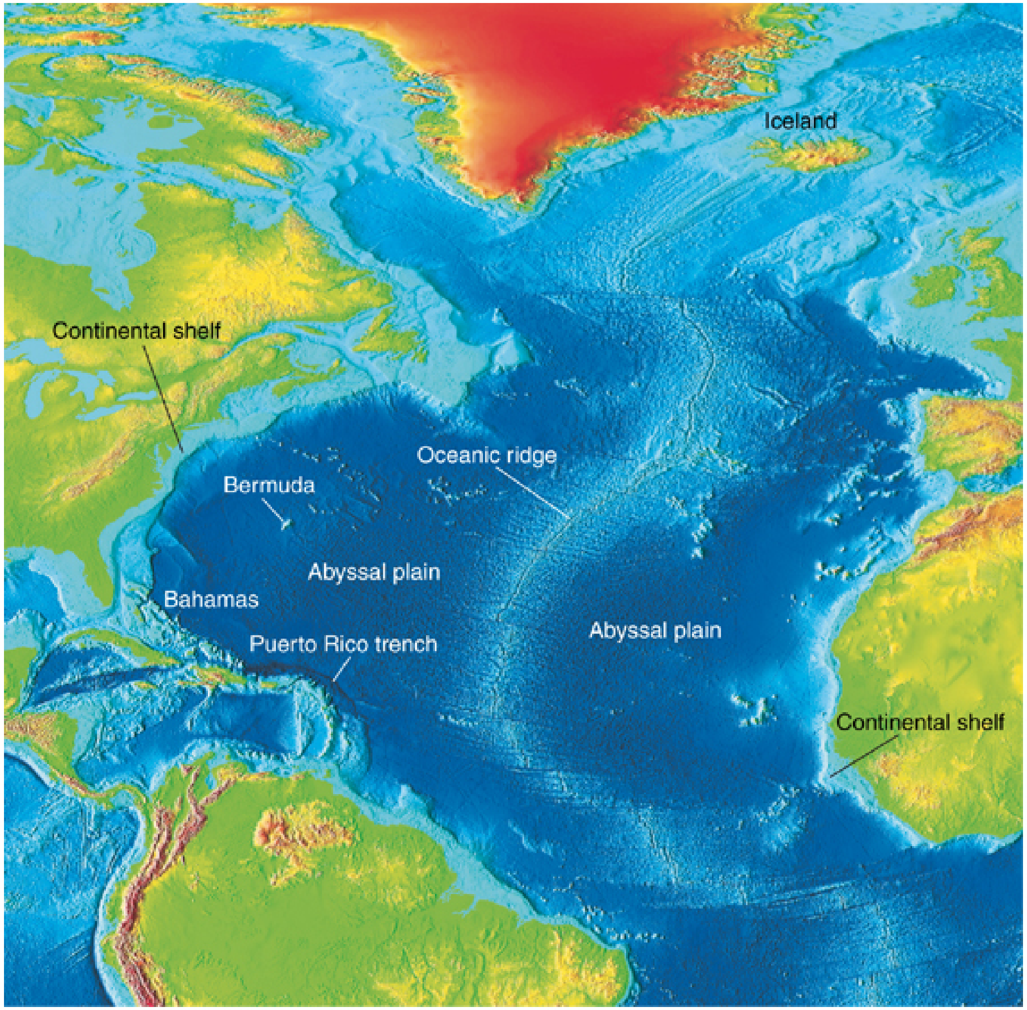
Seafloor Topography

Key features

- Continental shelf
  - Narrow, shallow ocean surrounding continents
- Abyssal plain
  - Relatively level seafloor, often with volcanoes (Bermuda)

Evidence from the Seafloor



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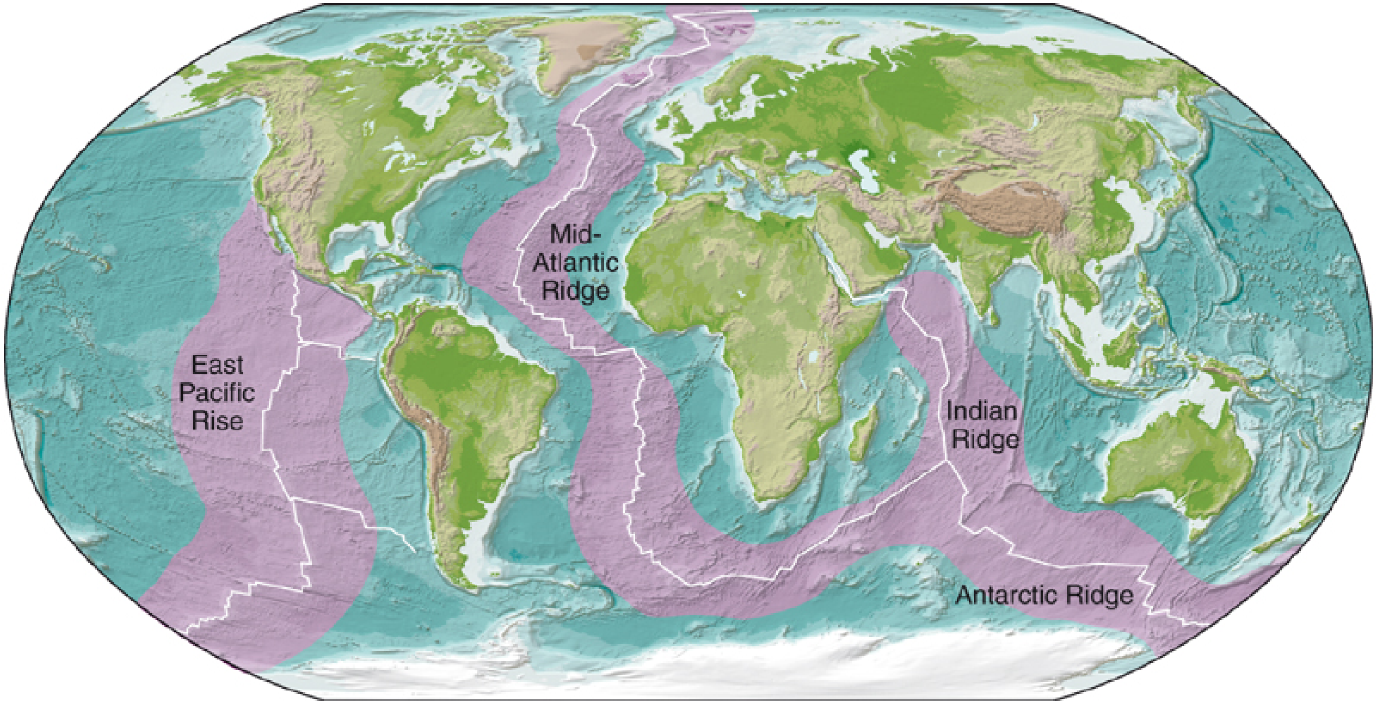
Seafloor Topography

Key features

- Oceanic ridge
  - Submarine mountain range that is a source of volcanic activity
  - May reach surface (Iceland)
- Oceanic trench
  - Narrow, deepest portion of ocean floor (Puerto Rico trench)

Evidence from the Seafloor

- Seafloor Topography: Oceanic ridges
  - Oceanic ridge system occupies much of the seafloor in all the world's ocean basins
  - Often found toward center of oceans

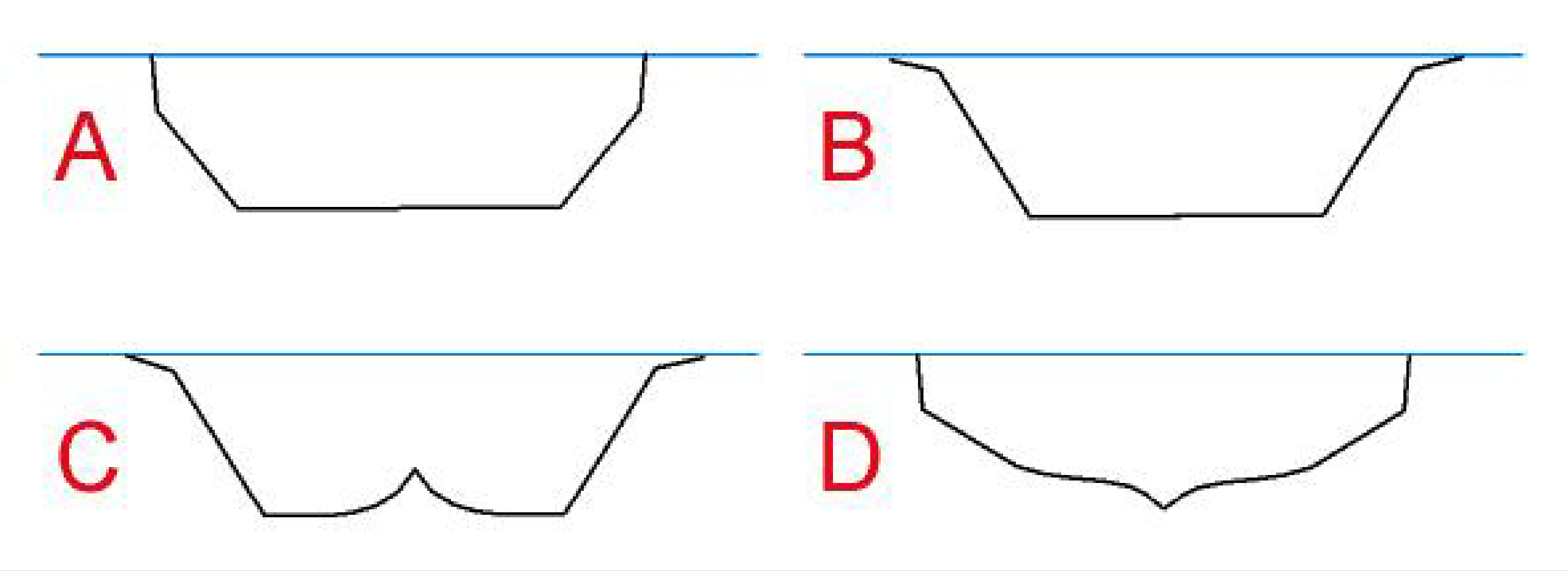


Evidence from the Seafloor

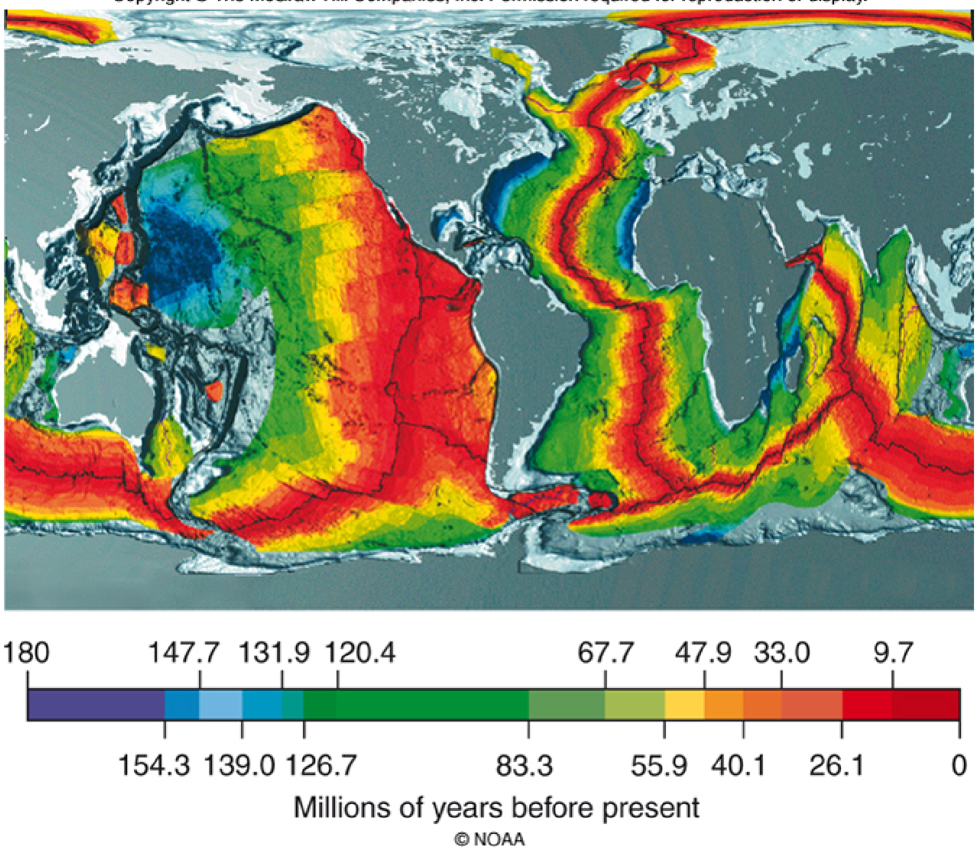
- Seafloor Topography: Oceanic trenches
  - Found adjacent to some continents or island chains and along the margins of oceans
  - Most common around Pacific Ocean

Plate Tectonics Concepttest

Which image best approximates the shape of the ocean floor in the Atlantic Ocean?



Evidence from the Seafloor



Age of the Ocean Floor

- Age of seafloor rocks varies systematically
- Rocks of the seafloor are young compared to most rocks on the continents
  - Rocks on ocean floor younger than 200 million years old
  - Rocks on continents as old as 4,000 million years

Evidence from the Seafloor

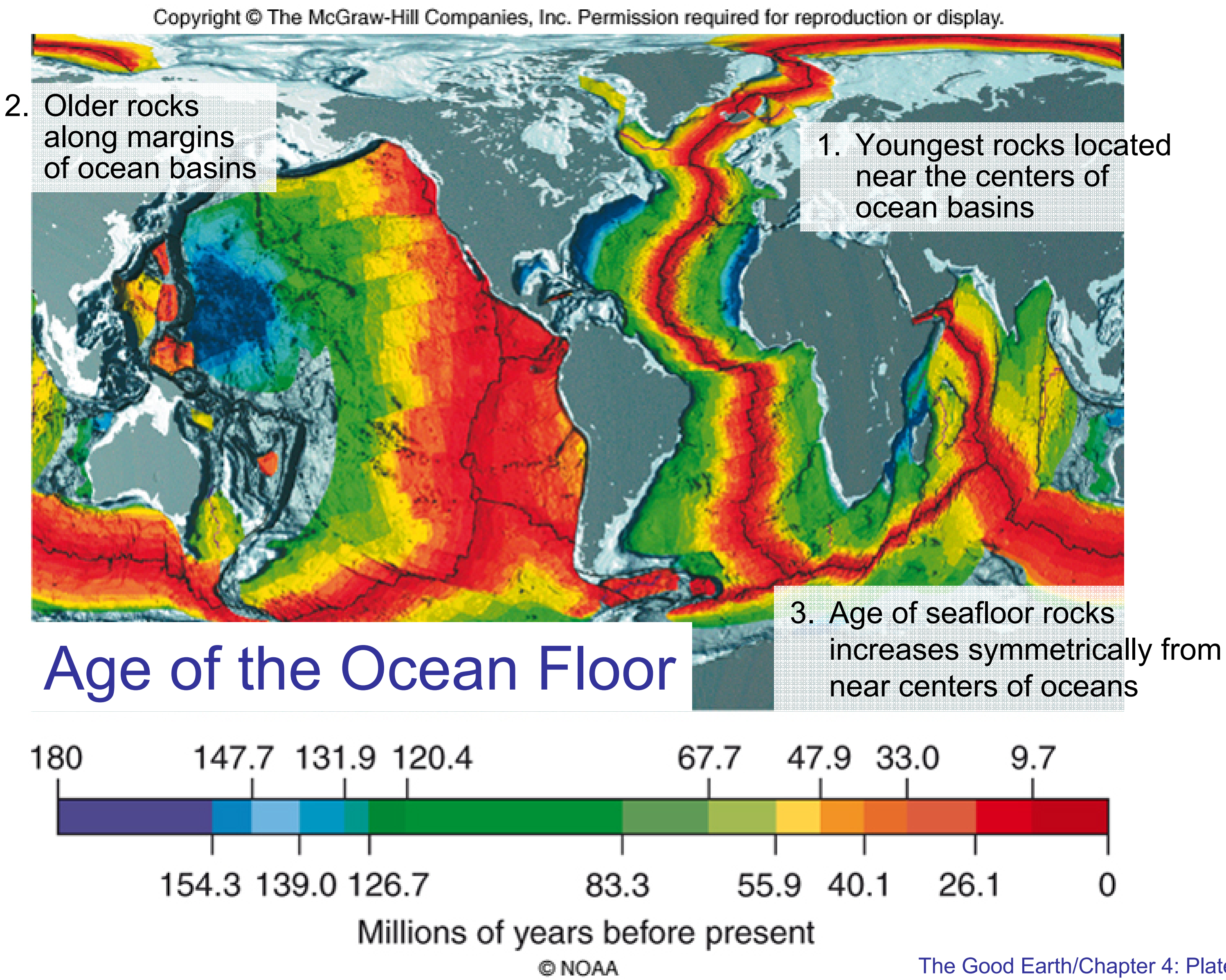


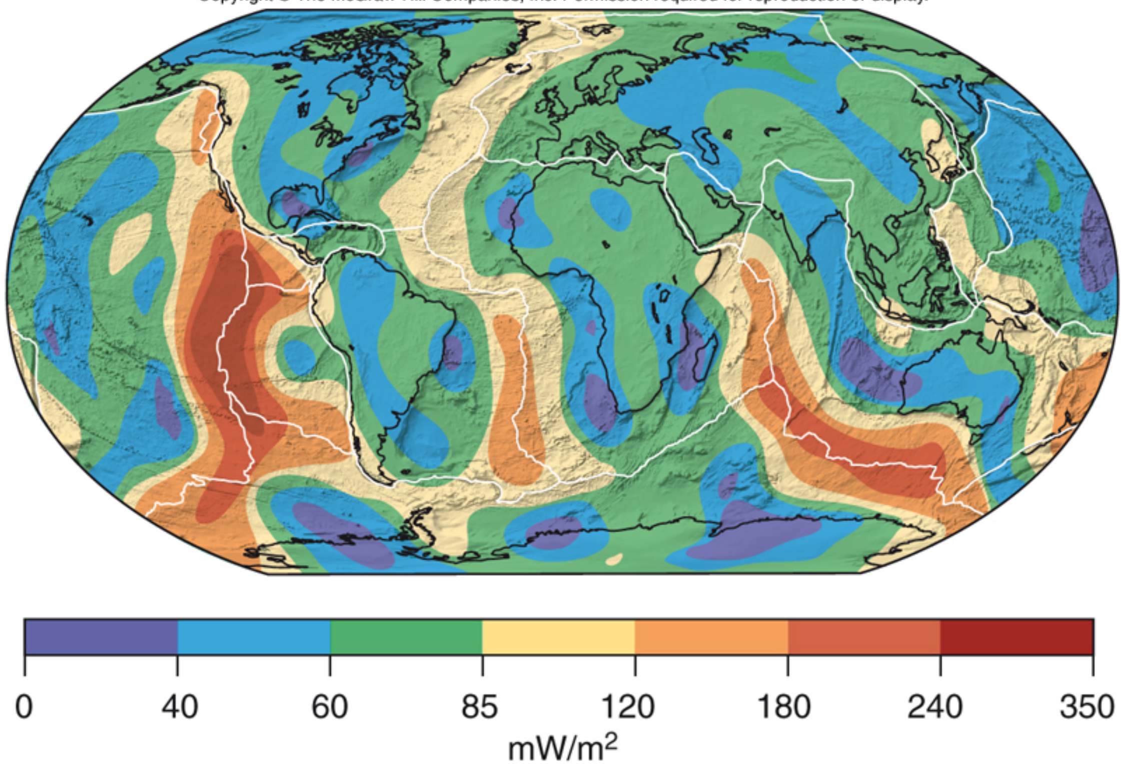
Plate Tectonics Conceptest

Which statement is TRUE about the relationship between age and topography of the ocean floor?

A. Deeper regions of the ocean floor are younger
B. The Pacific Ocean is larger than the Atlantic Ocean because it contains older oceanic floor
C. Oldest oceanic crust is only present near trenches
D. Youngest seafloor rocks occur near oceanic ridges

Evidence from the Seafloor

Heat Flow, Volcanoes, and Earthquakes



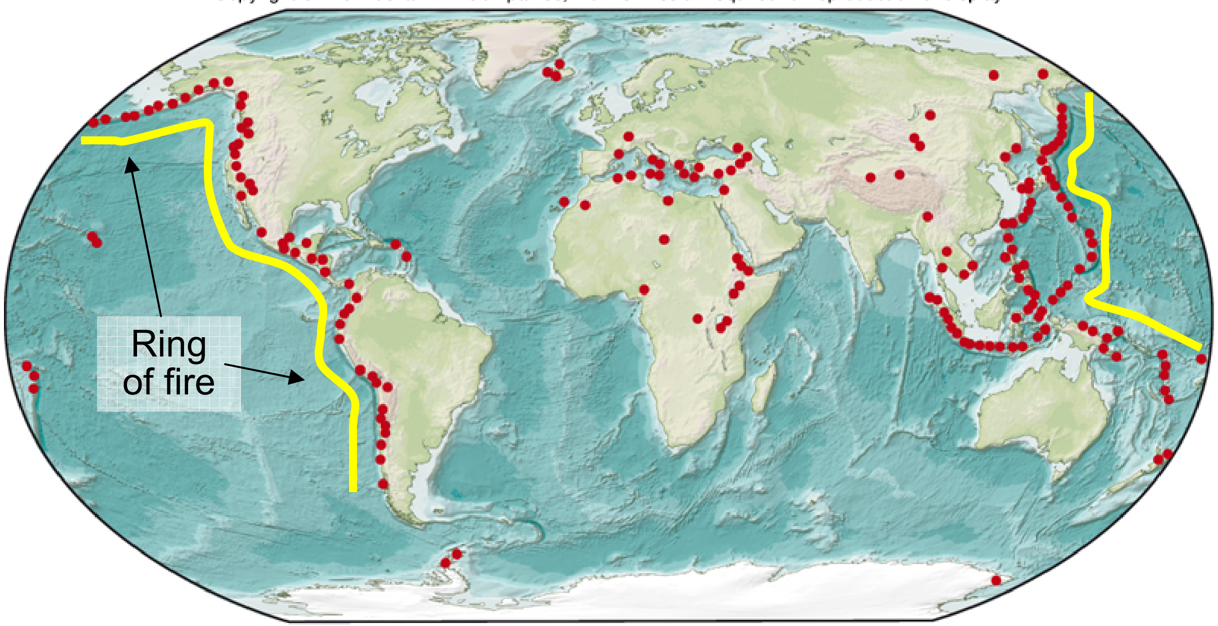
a.

cooler → *hotter*

- Heat flow varies systematically around the world
  - Highest along oceanic ridges
  - Lowest on continents and in ocean far from ridges

Evidence from the Seafloor

Heat Flow, Volcanoes, and Earthquakes

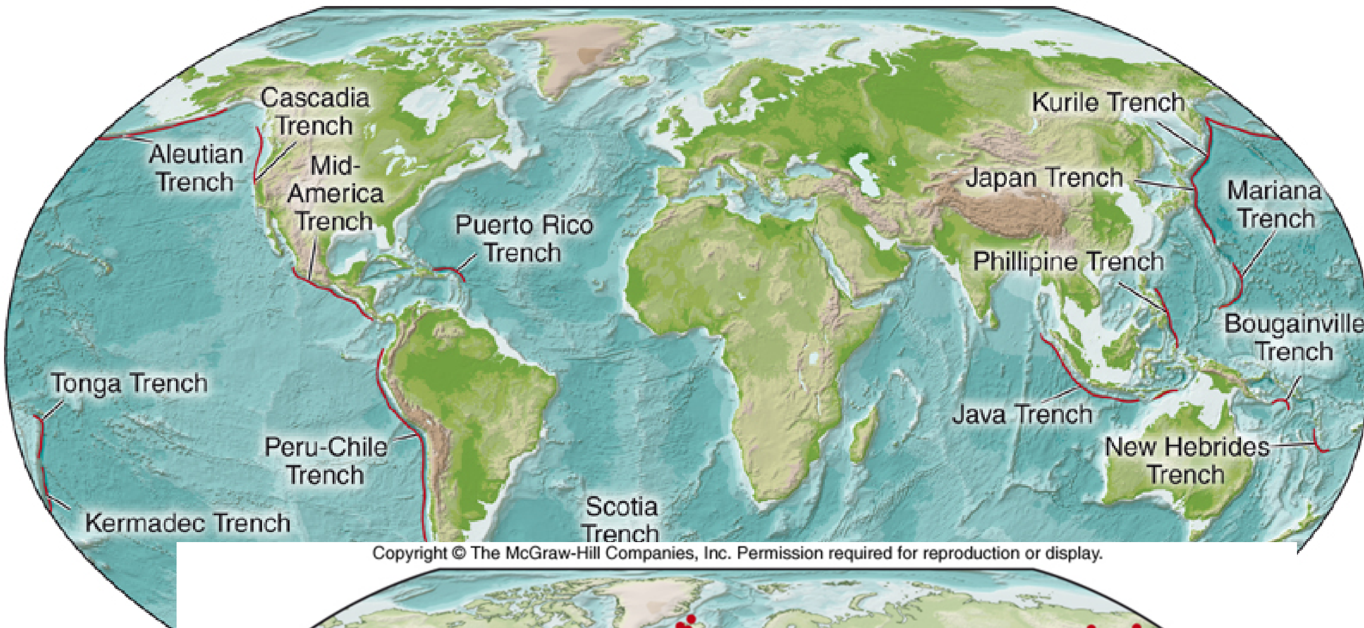


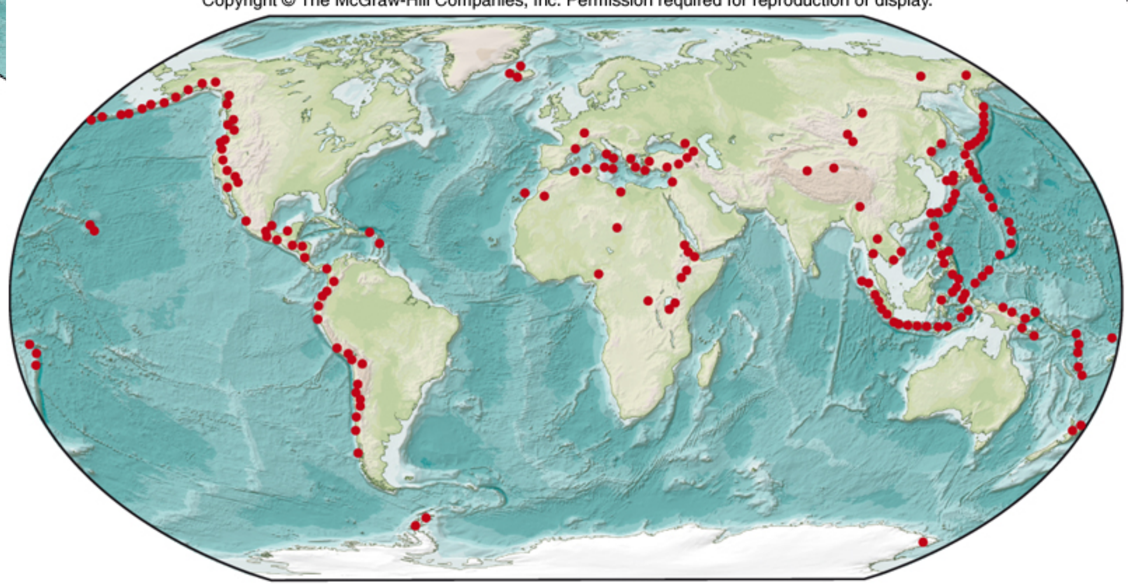
b.

Global distribution of active volcanoes

- Most active volcanoes are located around the Pacific rim (Ring of Fire)
  - Found near oceanic trenches

Evidence from the Seafloor



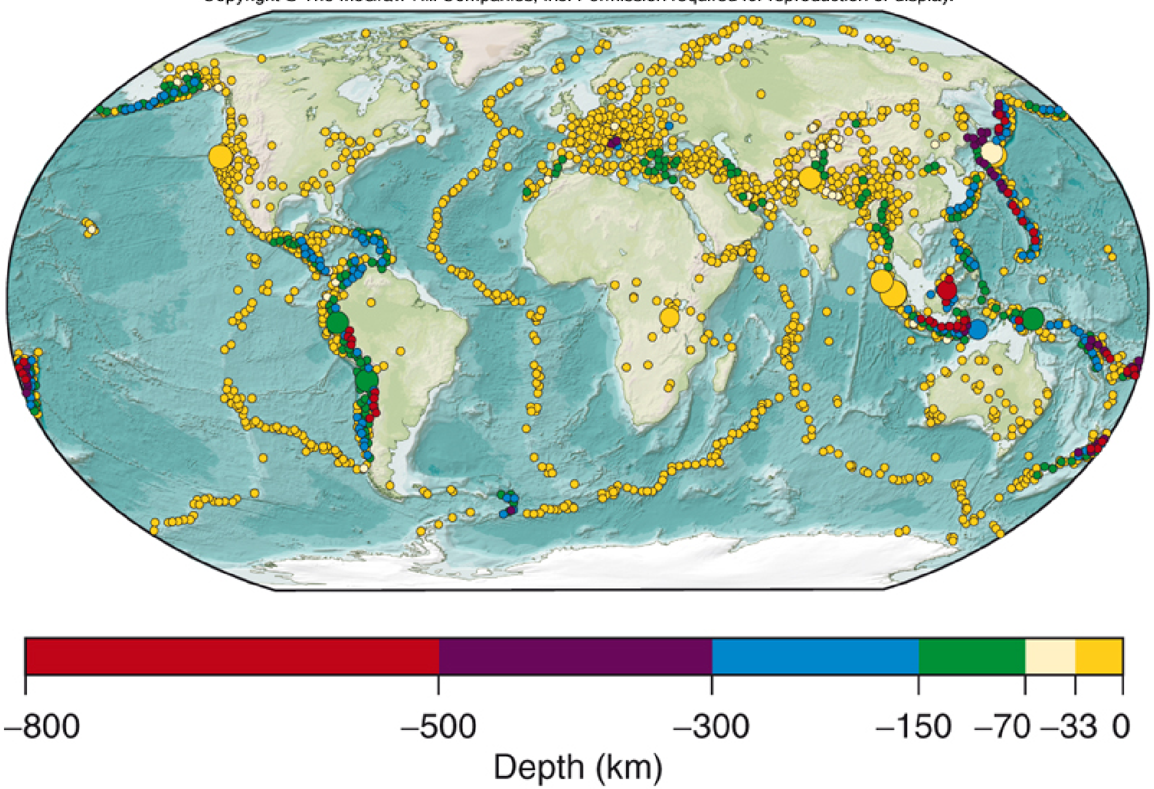


b.

- Most active volcanoes are found near oceanic trenches

Evidence from the Seafloor

Heat Flow, Volcanoes, and Earthquakes



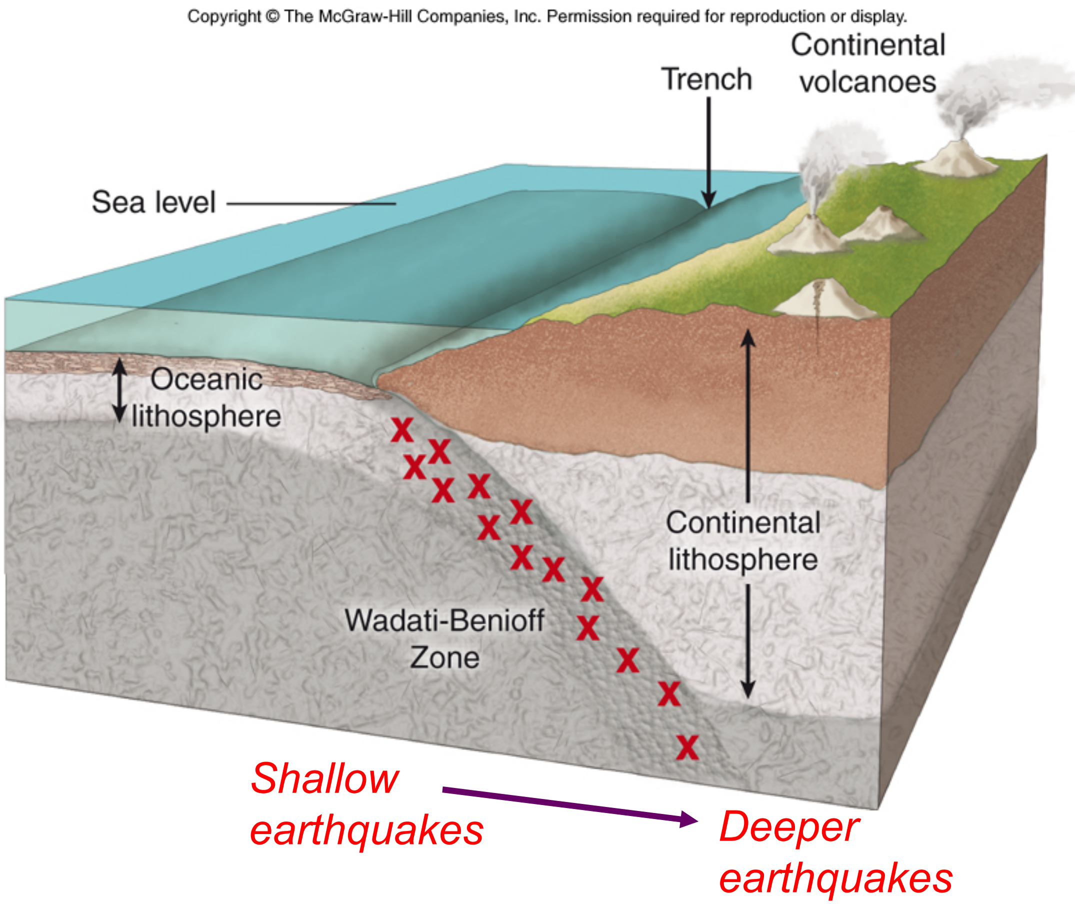
c.

Global distribution of earthquakes, 2005

- Earthquakes found near oceanic ridges and trenches
  - Earthquakes recorded to 800 km depth
  - Deep earthquakes found only near oceanic trenches
  - Largest earthquakes near trenches

Evidence from the Seafloor

Heat Flow, Volcanoes, and Earthquakes



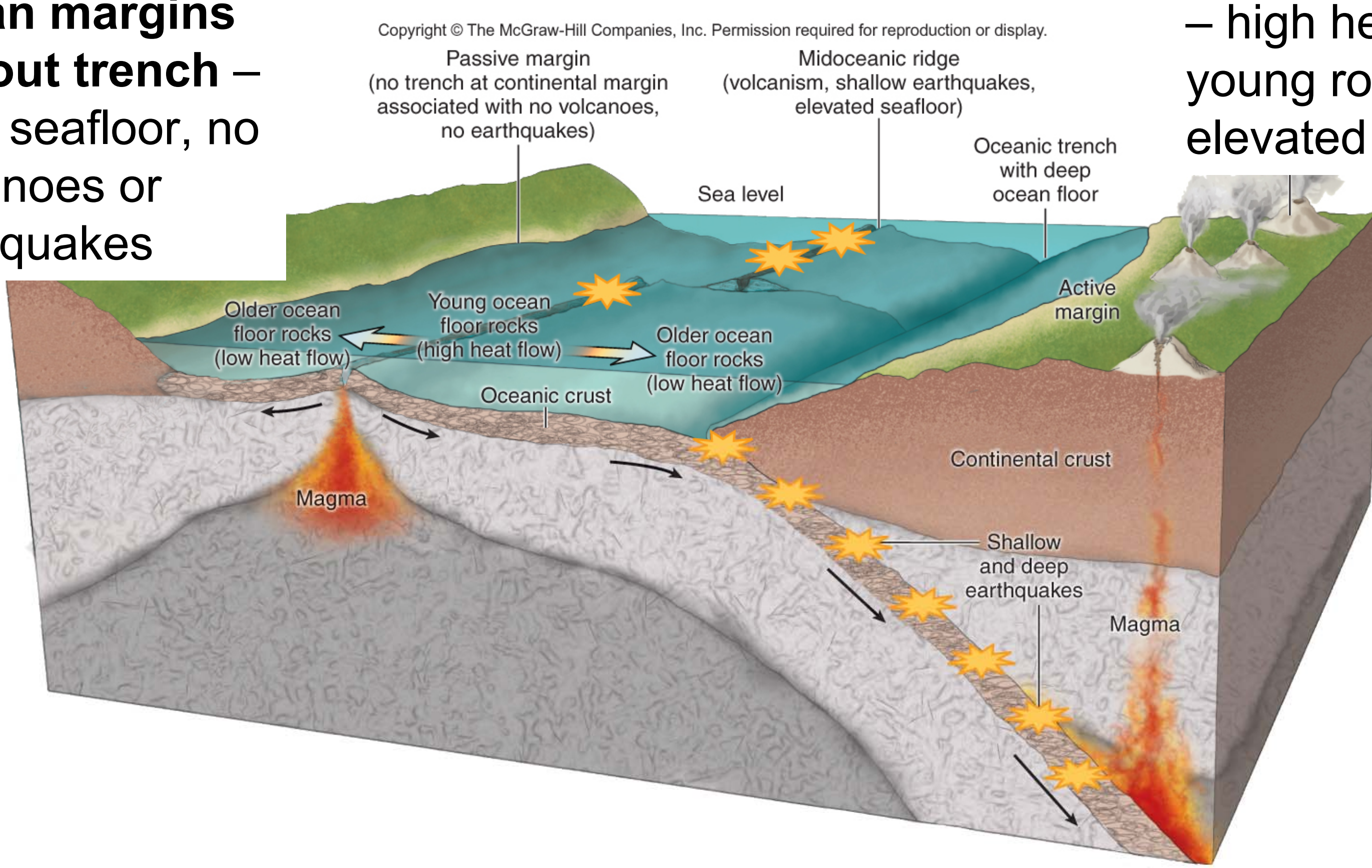
- Earthquakes become deeper with distance from trenches
  - Define Wadati-Benioff zones that slope away from ocean
  - Often occur in association with volcanoes

Evidence from the Seafloor

Seafloor Spreading Hypothesis: **Observations**

Ocean margins without trench – older seafloor, no volcanoes or earthquakes

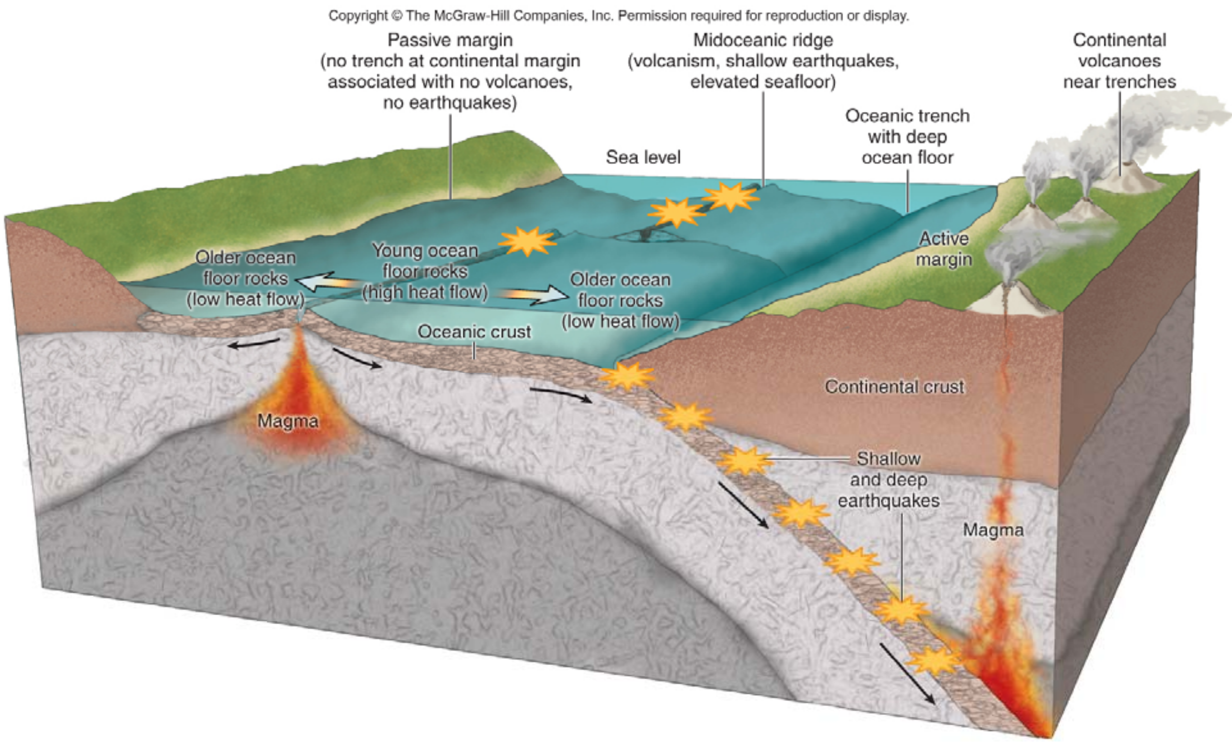
Oceanic ridges – high heat flow, young rocks, elevated seafloor



Ocean margins with trench – older seafloor, volcanism and earthquakes

Evidence from the Seafloor

Seafloor Spreading Hypothesis: **Interpretations**

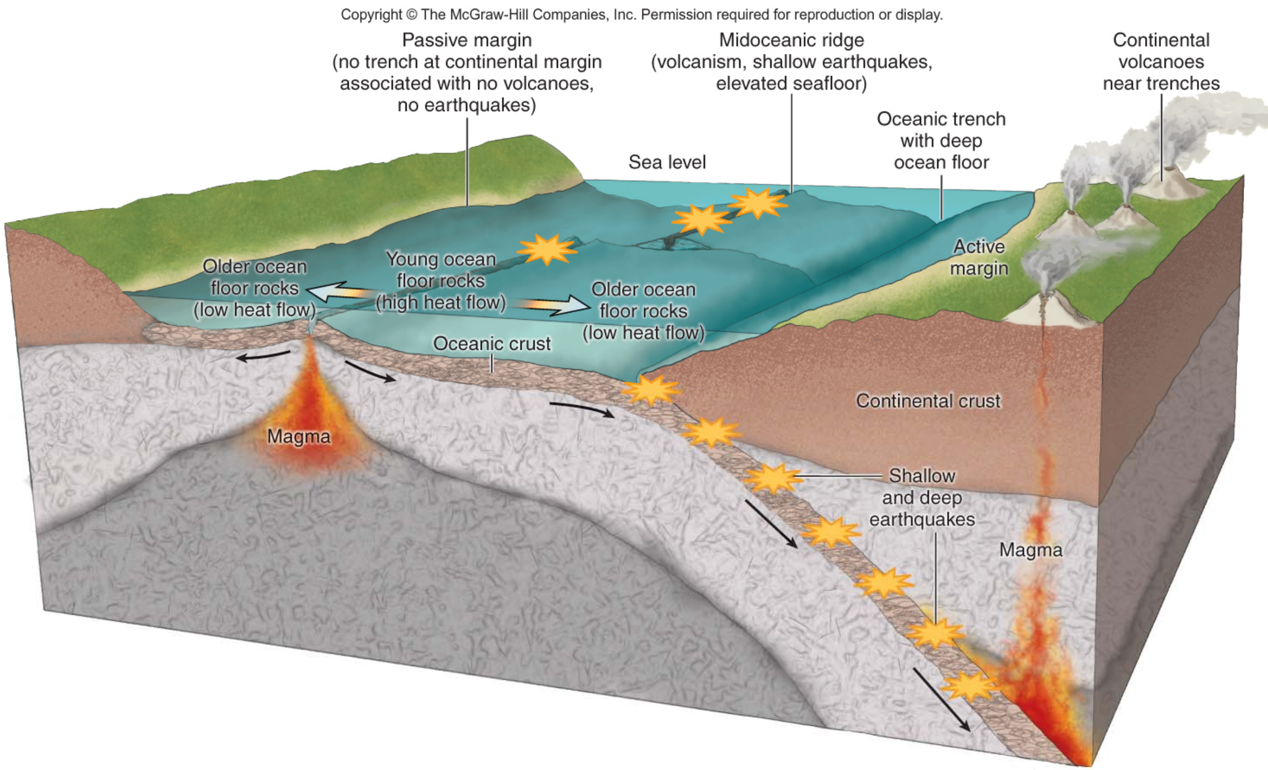


Oceanic ridges

- Magma rises from mantle, forms new oceanic crust
- Expansion of seafloor results in high elevations
- Seafloor moves away from ridge (conveyer belt) creating a gap for new material

Evidence from the Seafloor

Seafloor Spreading Hypothesis: **Interpretations**



Oceanic trench

- Older seafloor descends into mantle at **active margin**
- Melting of rocks forms magma, volcanism
- Earthquakes where old seafloor consumed

Passive margin

- Continent/ocean transition

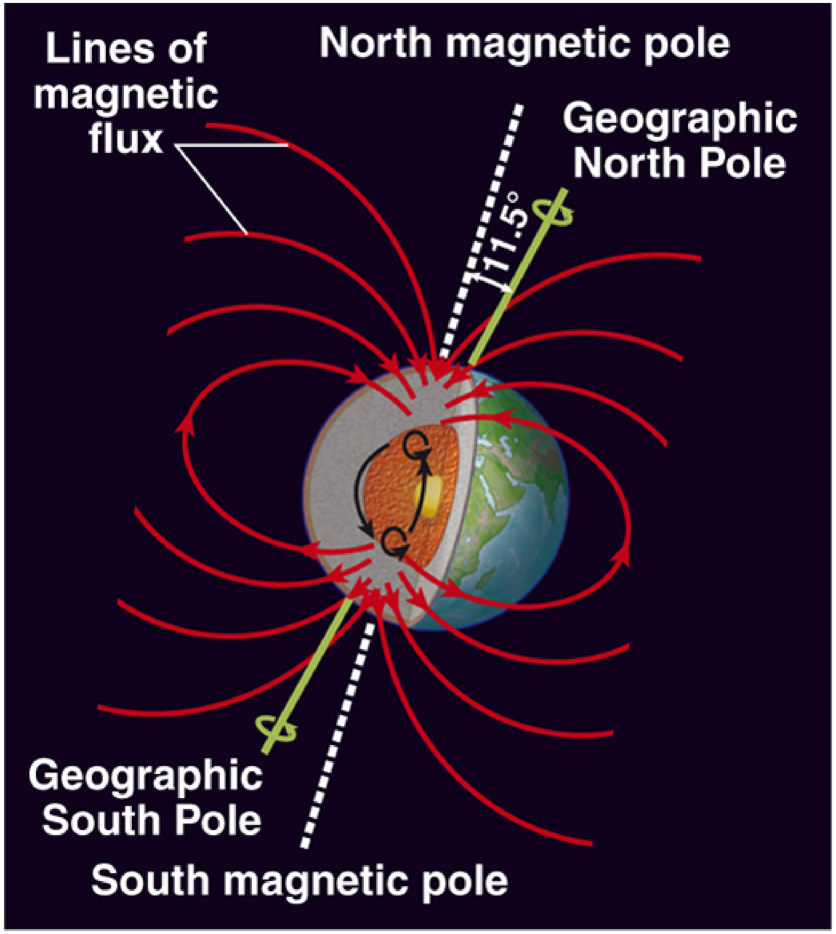
Evidence from the Seafloor

Additional observations about the magnetic properties of seafloor rocks supported the seafloor spreading hypothesis

Earth has a magnetic field because it has:

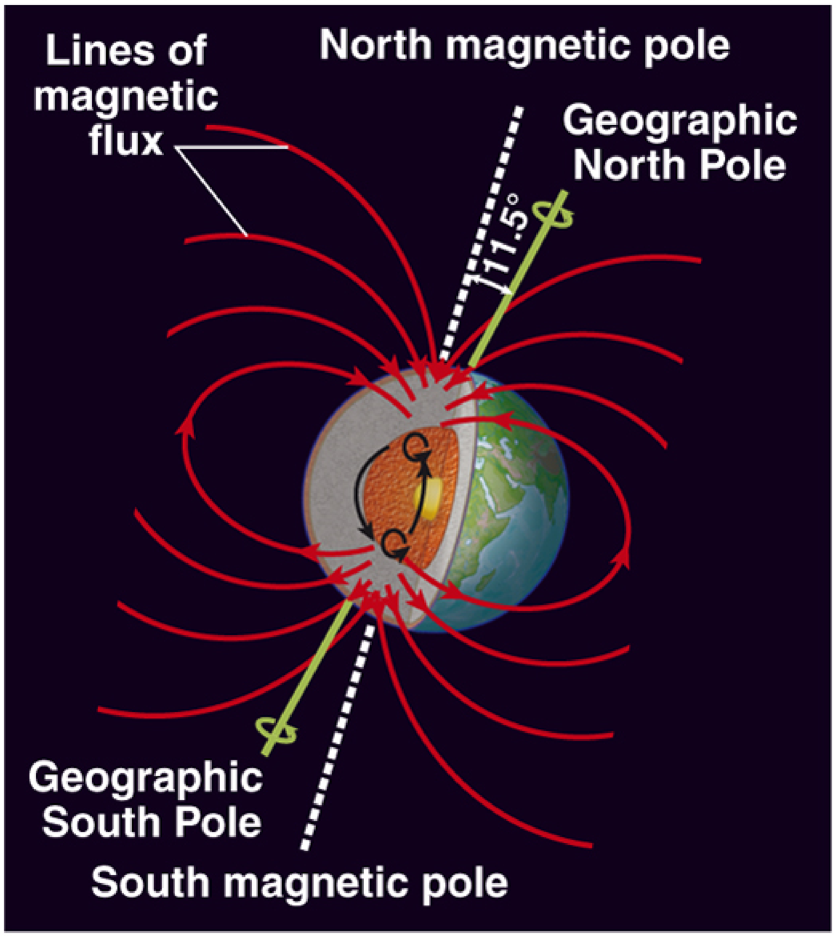
1. Molten rock in the outer core
2. Heat to generate currents in outer core
3. Rotation to mix the currents

Evidence from the Seafloor



- Earth's magnetic field has negative and positive poles located near the North and South poles
- A compass needle lines up along lines of magnetic force (flux)

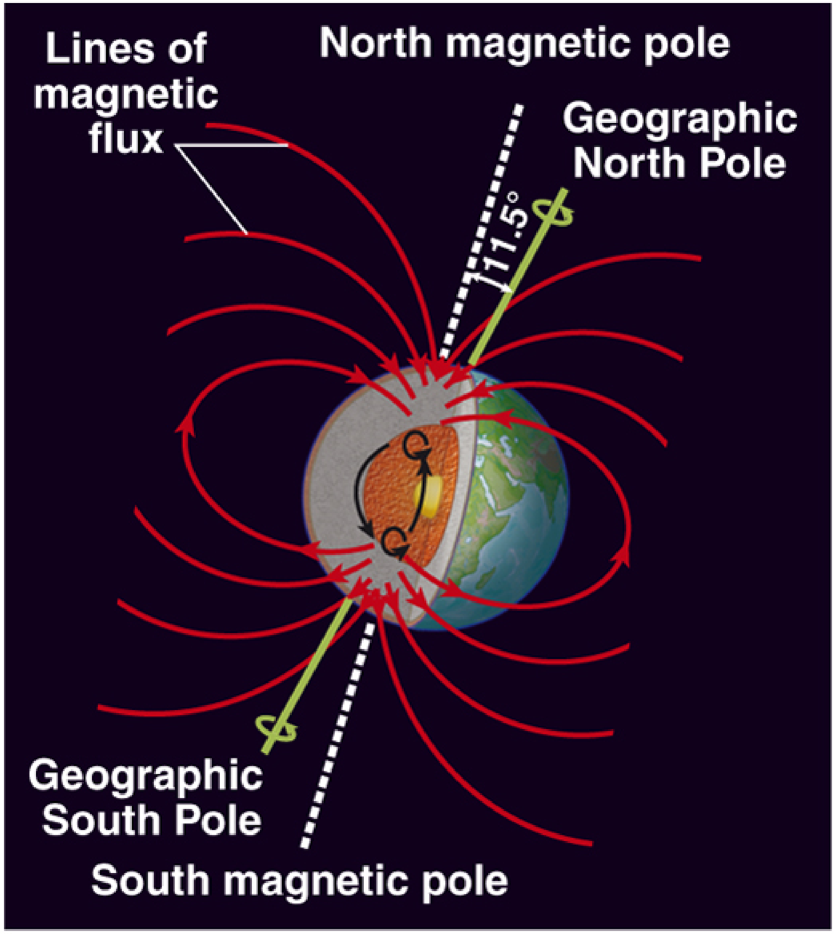
Evidence from the Seafloor



Earth's magnetic field for can be defined by:

- Direction
  - the field "points" toward the magnetic poles
- Inclination
  - the field "points" down in the Northern Hemisphere, up in the Southern Hemisphere
  - Inclination greatest (vertical) at magnetic poles
  - Field horizontal at the (magnetic) equator

Evidence from the Seafloor



- Atoms in magnetic minerals aligned parallel to the magnetic field when magma cooled to form seafloor rocks
  - Preserves ancient magnetic field - **paleomagnetism**
  - Analysis reveals the inclination of the field where they formed – a proxy for latitude

Plate Tectonics Conceptest

Which United States location has the greatest magnetic inclination value (that is, closest to vertical)?

A. Anchorage, Alaska
B. New York, New York
C. Miami, Florida

Plate Tectonics Conceptest

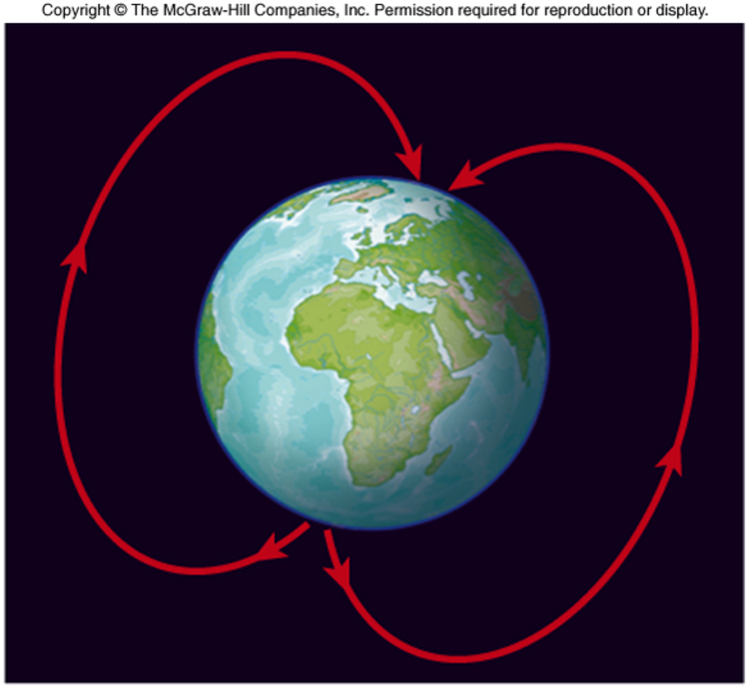
The magnetic North Pole has migrated northward over the last century, so how did magnetic inclination readings at Chicago change between 1900 and 2000?

A. Inclination increased
B. Inclination decreased
C. Inclination remained constant

Evidence from the Seafloor

Magnetic Field Reversals

- Paleomagnetic records indicate that magnetic poles have switched positions many times



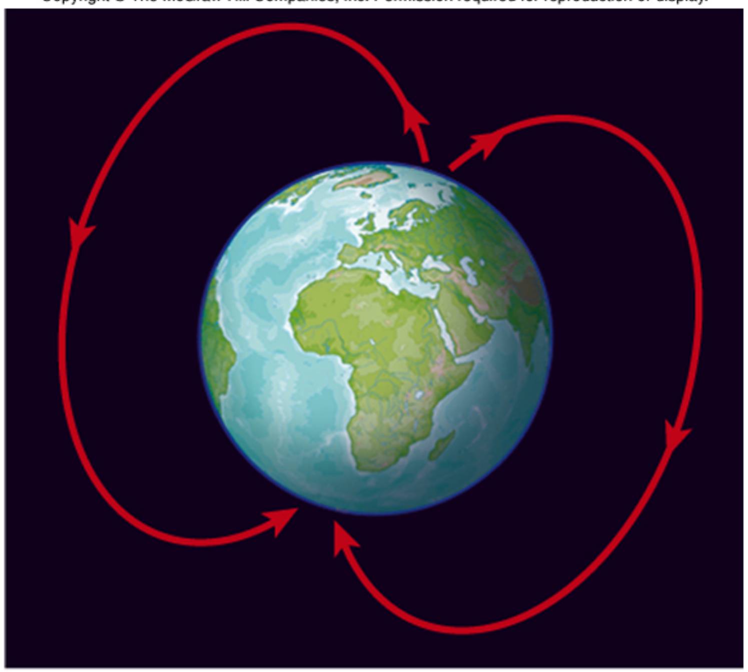
a. Normal polarity

- **Normal polarity** when negative magnetic pole is near geographic North Pole (current status)
- Lines of magnetic flux inclined downward in Northern Hemisphere, upward in Southern Hemisphere

Evidence from the Seafloor

Magnetic Field Reversals

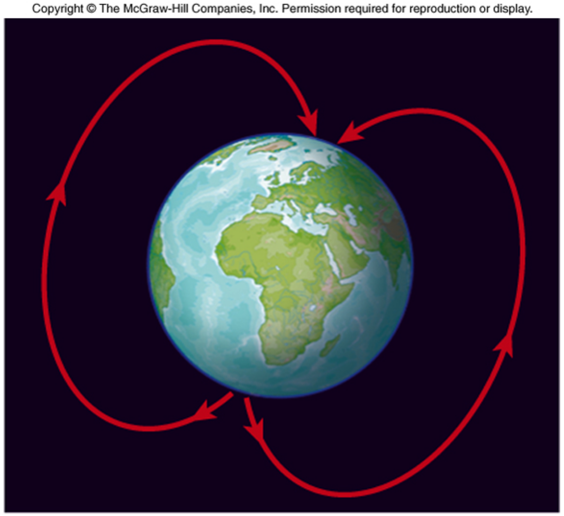
- Paleomagnetic records indicate that magnetic poles have switched positions many times



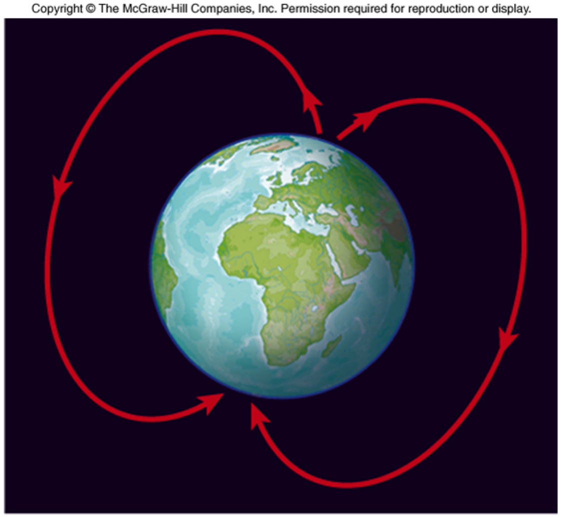
b. Reversed polarity

  - **Reverse polarity** when positive magnetic pole is near geographic North Pole
  - Lines of magnetic flux inclined upward in Northern Hemisphere, downward in Southern Hemisphere

Evidence from the Seafloor



a. Normal polarity



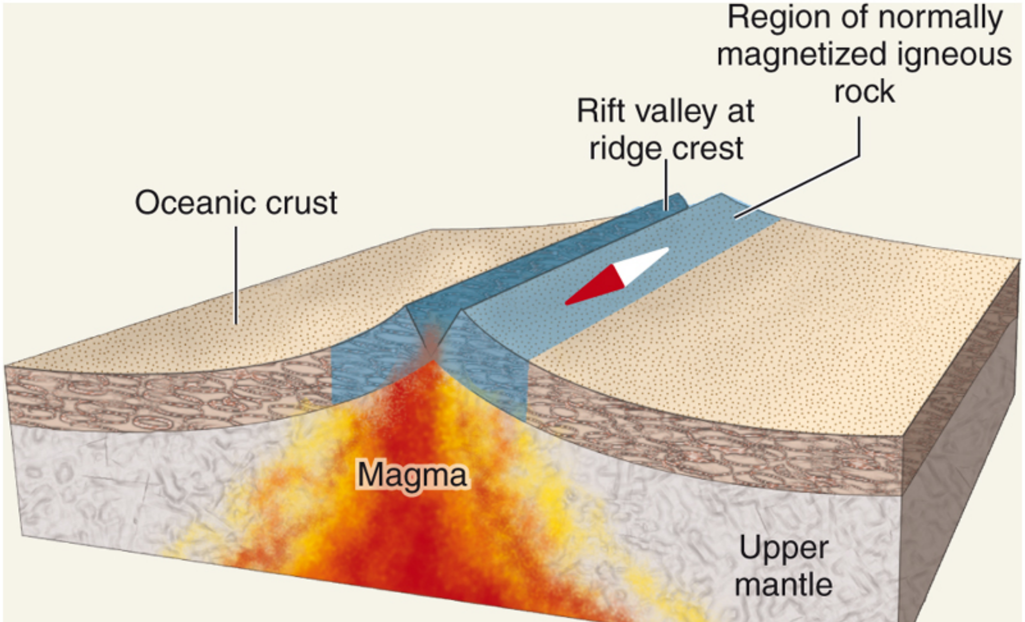
b. Reversed polarity

Magnetic Field Reversals

- Each period of normal or reversed polarity averages 250,000 years
- Longest = 10's of millions of years
- Shortest = 10's of thousands of years
- Few thousand years to change polarity (normal → reverse or reverse → normal)

Evidence from the Seafloor

Paleomagnetism & Seafloor Spreading

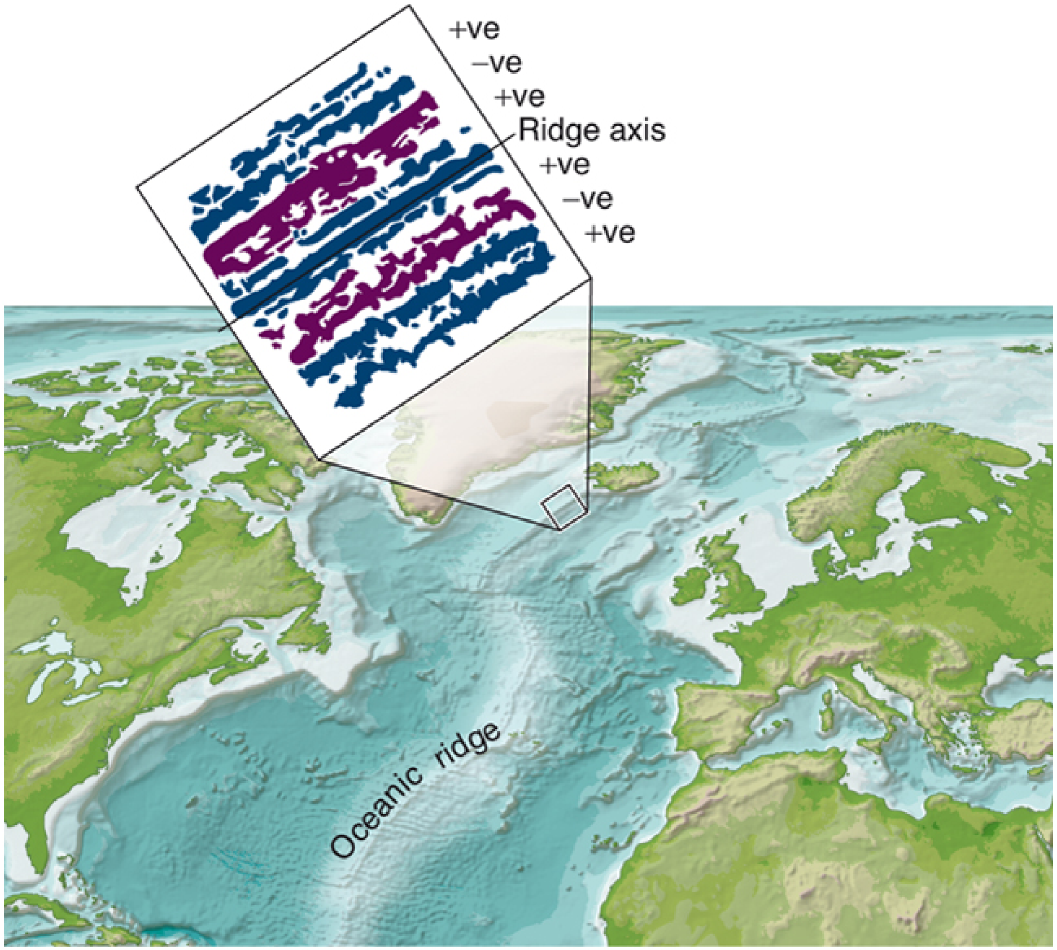


a. Time of normal magnetism

- Normal polarity rocks currently forming from magma along oceanic ridge
  - Marine surveys measure strength of Earth's magnetic field
  - Strength higher in regions of normal polarity, lower where there is reverse polarity

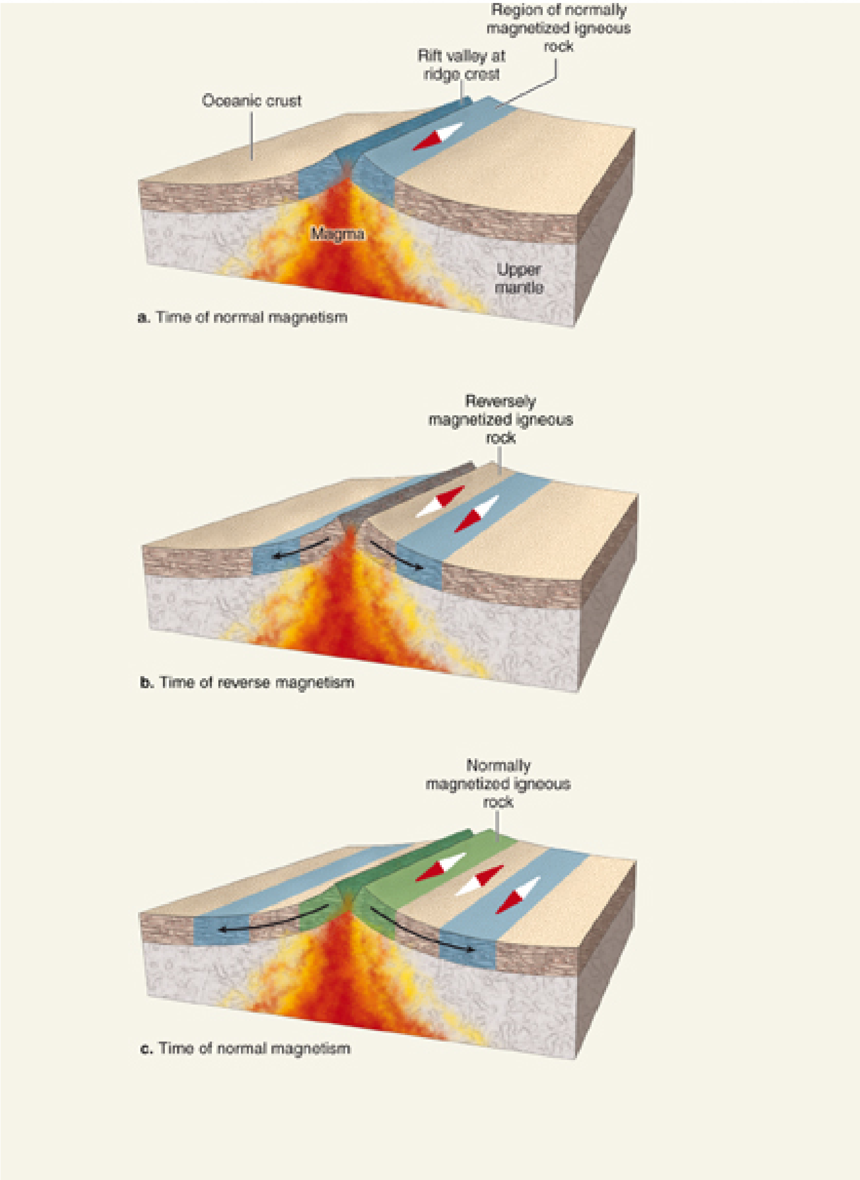
Evidence from the Seafloor

Paleomagnetism & Seafloor Spreading

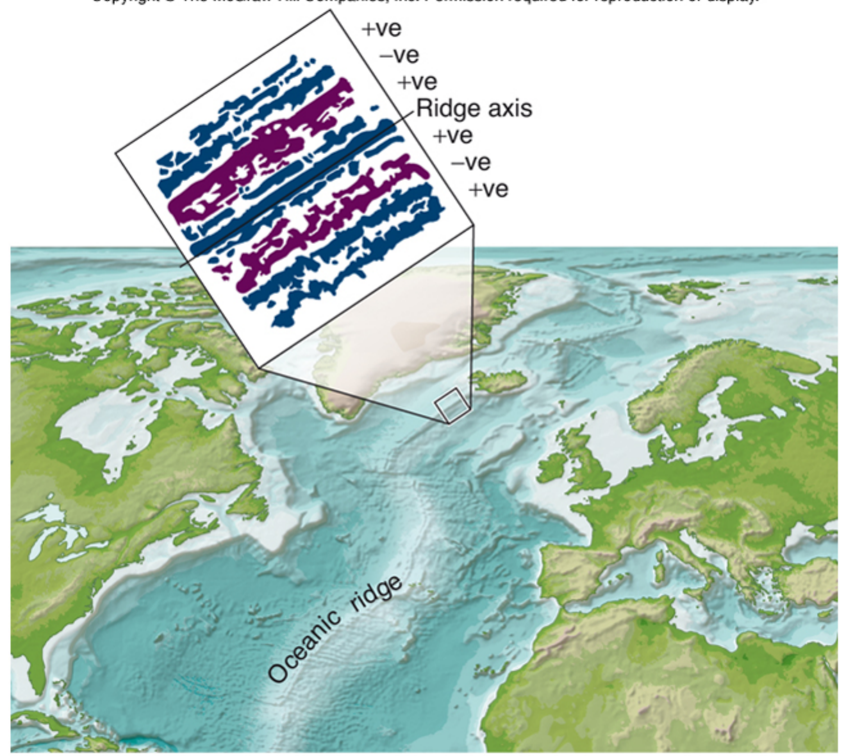


- Polarity of seafloor alternates between normal (+ve) and reverse (-ve) on either side of oceanic ridge
  - Symmetrical pattern on either side of ridge
  - “stripes” of similar width and polarity

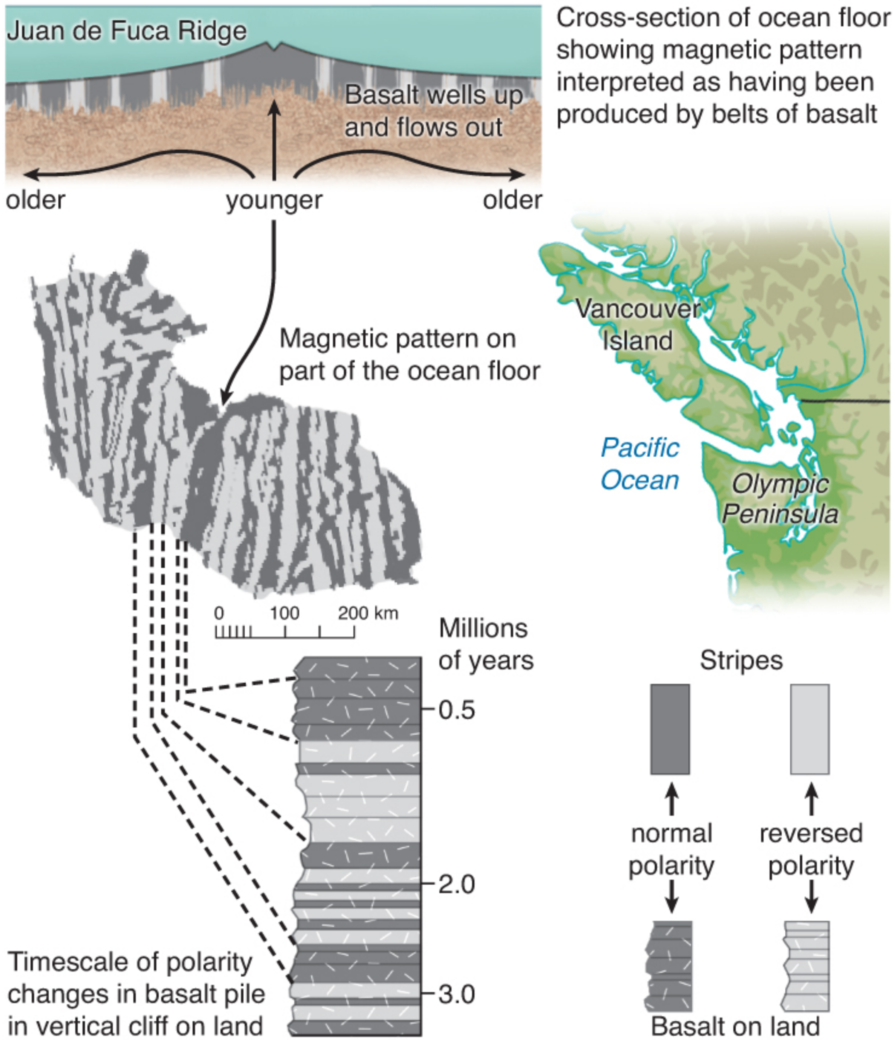
Evidence from the Seafloor



Polarity of seafloor alternates between normal (+ve) and reverse (-ve) on either side of oceanic ridge



The process in action: Juan de Fuca plate



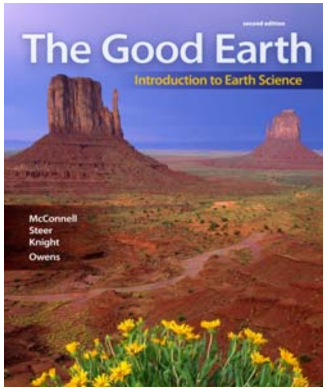


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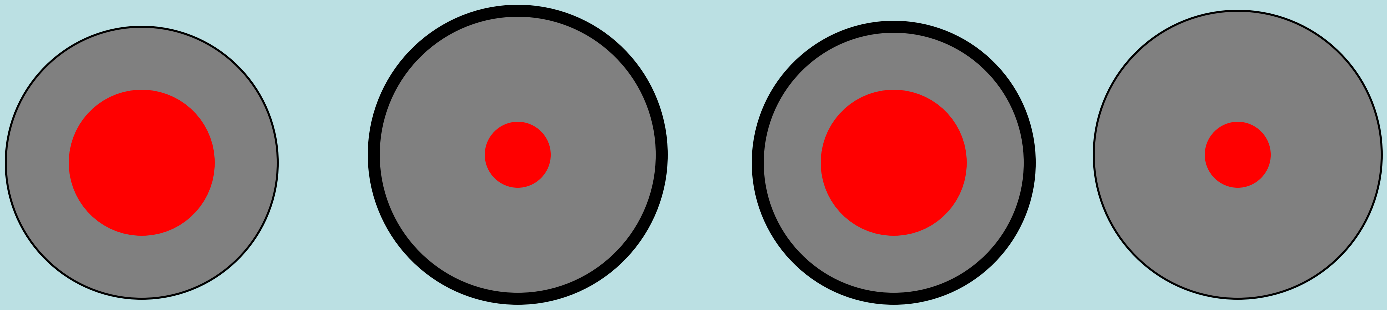
Plate Tectonics Conceptest

Which of the images below best approximates the relative distribution of Earth’s core, mantle and crust?

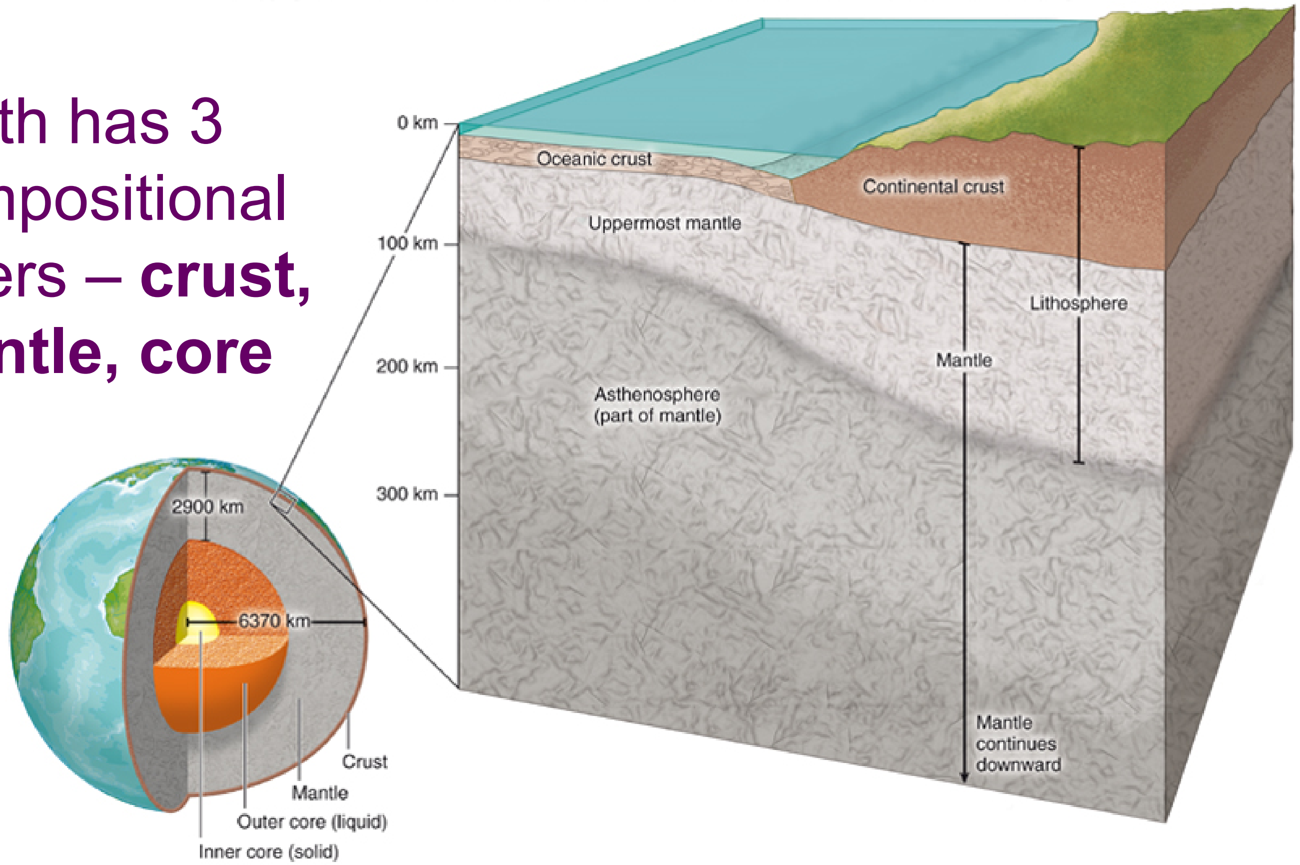
a) b) c) d)



Big core, thin crust | Small core, thick crust | Big core, thick crust | Small core, thin crust

Plate Tectonics

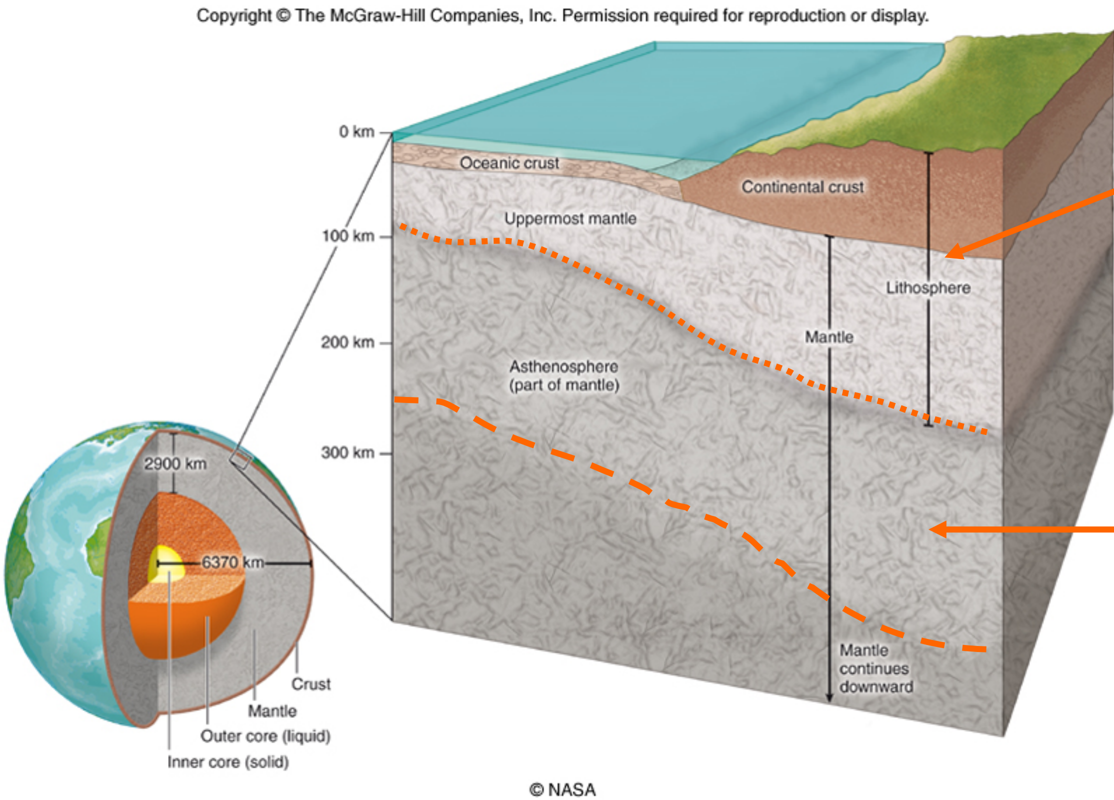
Earth has 3 compositional layers – **crust, mantle, core**



The major features on Earth's surface are the result of processes in the upper few hundred kilometers

Plate Tectonics

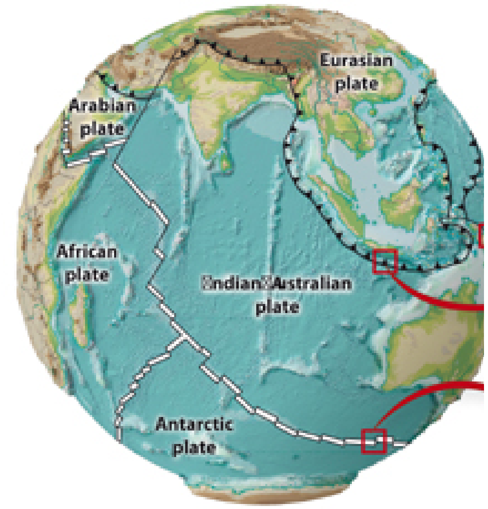
Two key layers in crust and upper mantle



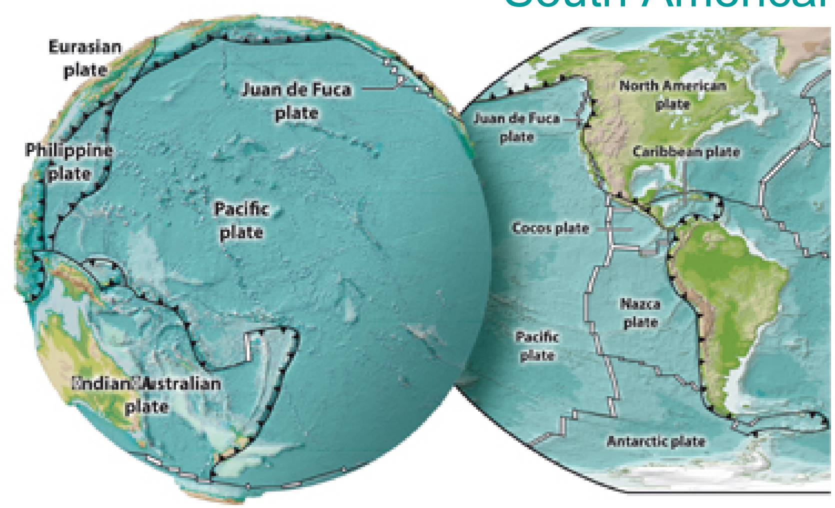
- Lithosphere
  - Rigid layer composed of crust & uppermost mantle
  - Divided into mobile **tectonic plates**
- Asthenosphere
  - Weaker layer found in upper part of mantle
  - Flows due to small proportion (1%) of melted minerals

Plate Tectonics

PLATES OF THE WORLD

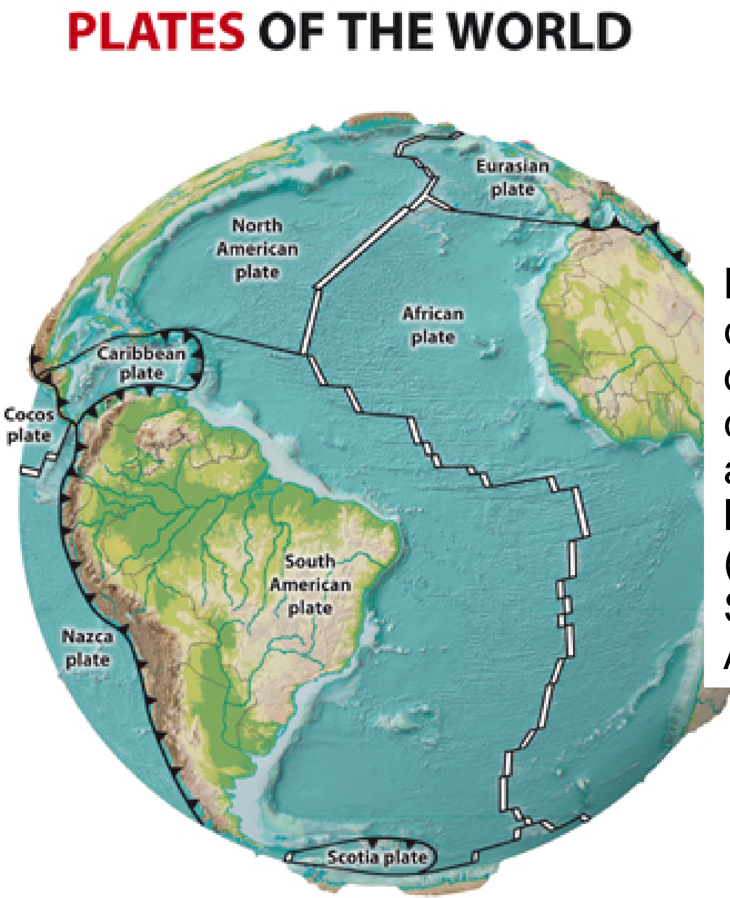


8 Major Plates:
- African
- Antarctic
- Eurasian
- Indian-Australian
- Nazca
- North American
- Pacific
- South American

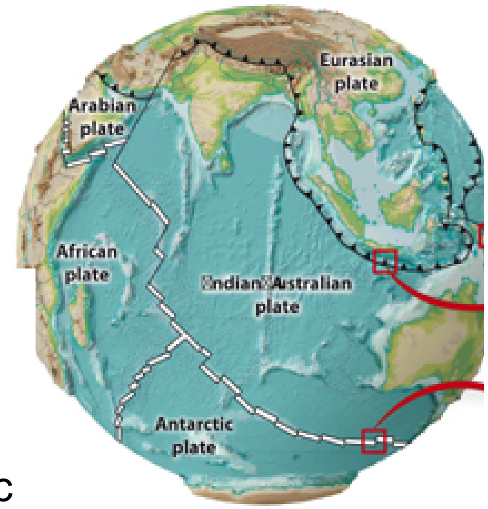


Rigid lithosphere is divided into mobile **tectonic plates**

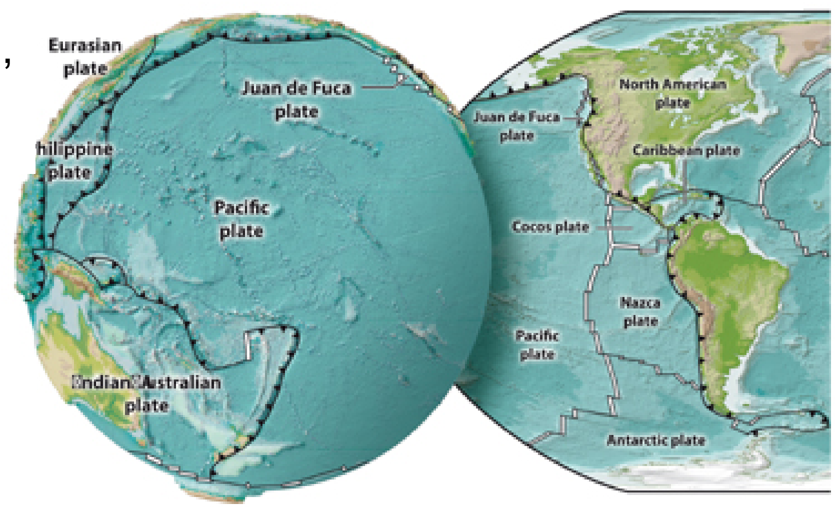
Plate Tectonics



Most plates composed of both continental and oceanic lithosphere (e.g., Africa, South America)

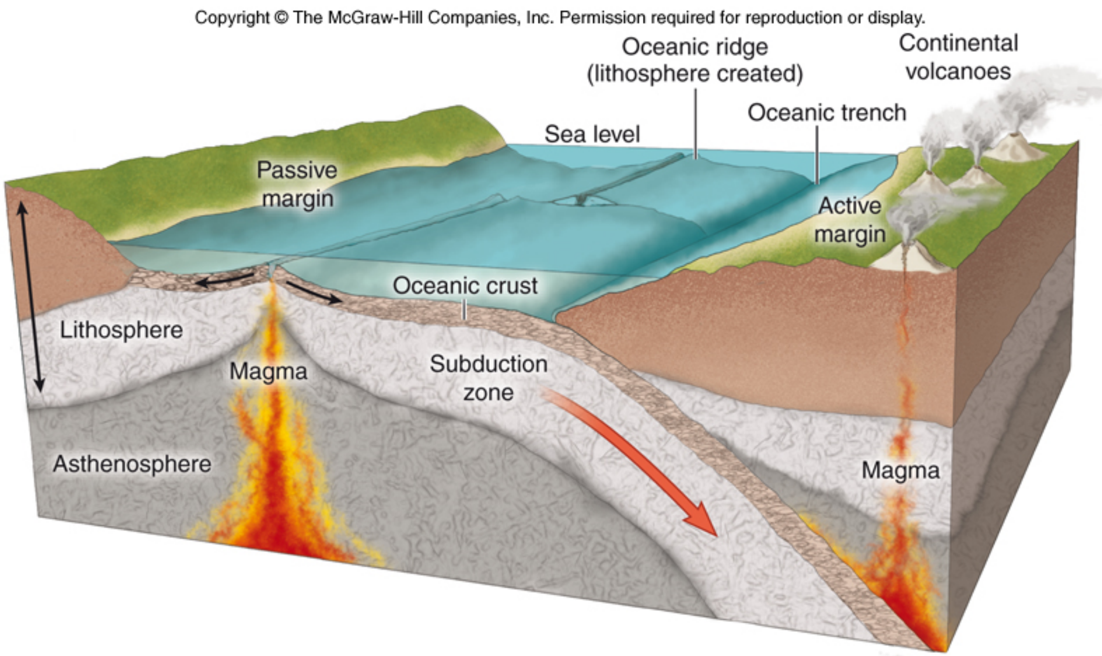


Oceanic ridges and trenches represent most plate boundaries



Numerous smaller plates (e.g., Arabian, Caribbean, Cocos, Juan de Fuca, Philippine, Scotia)

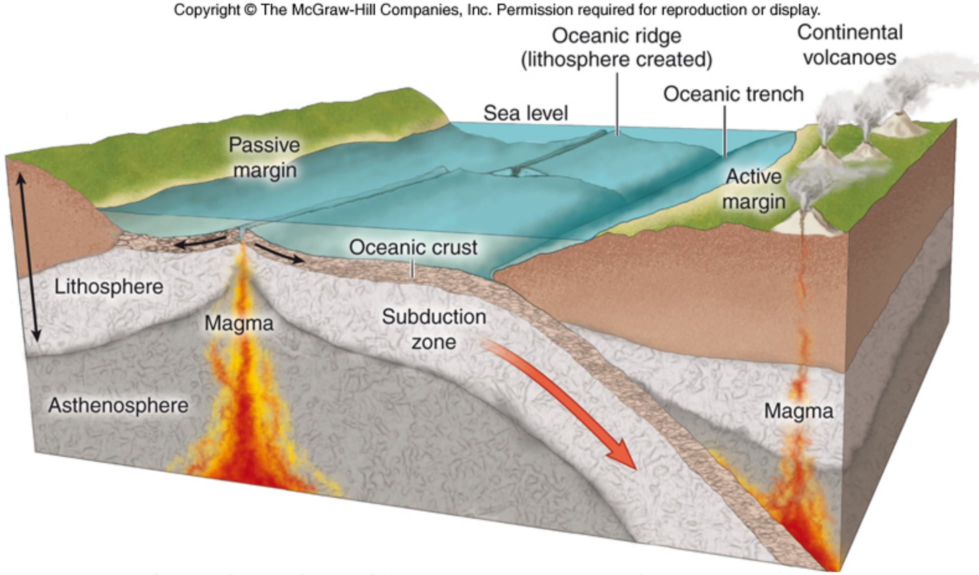
Plate Tectonics

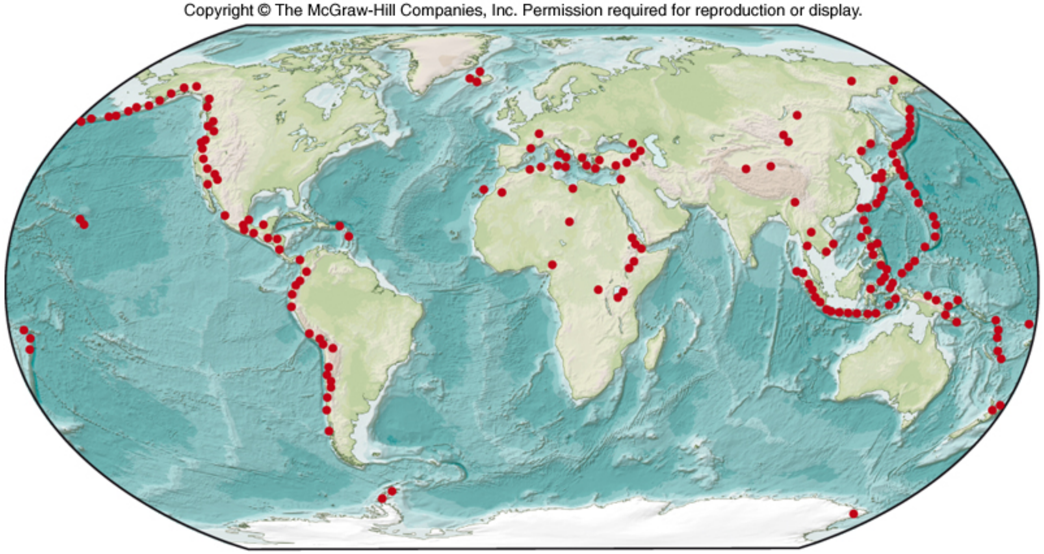


Interactions of plates along their boundaries accounts for the formation of new lithosphere, earthquakes, volcanoes, and the gradual movement of continents

Many of these processes involve the melting of rocks

Plate Tectonics



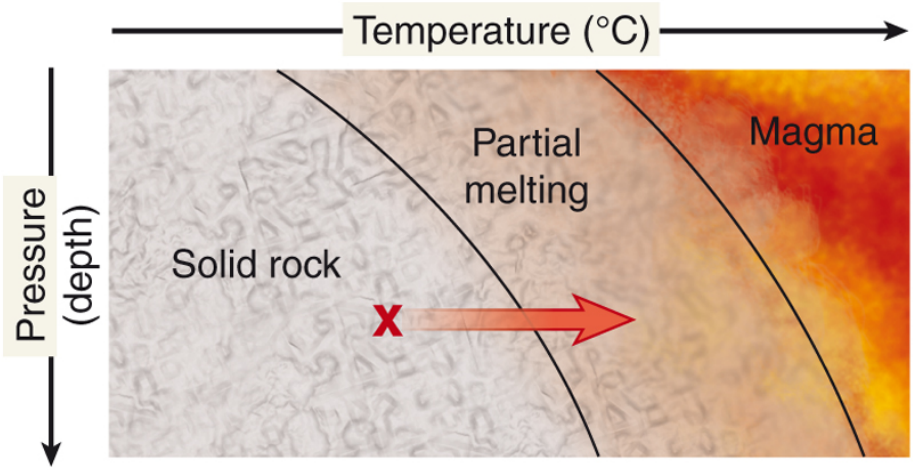


b.

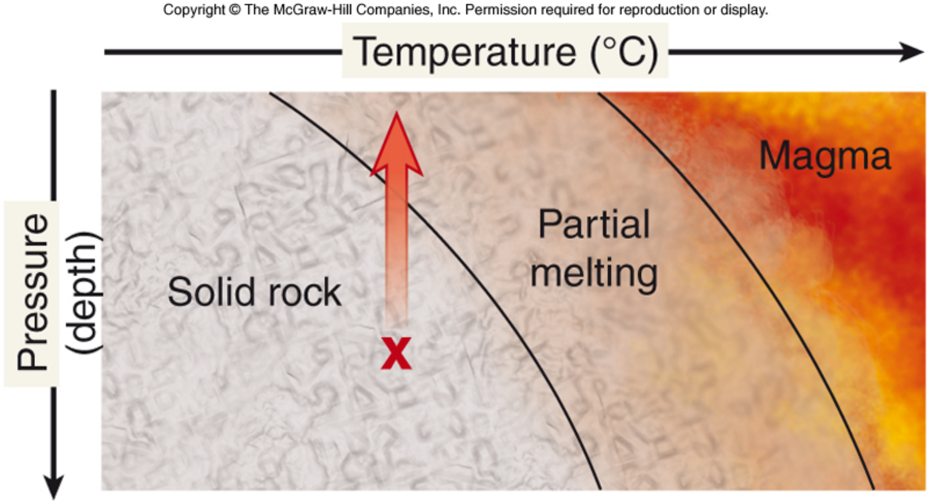
Melting of rocks produces magma associated with the formation of lithosphere at oceanic ridges and the generation of volcanoes near oceanic trenches

- Three changes lead to partial melting
  - Increasing temperature
  - Decreasing pressure
  - Addition of water

Plate Tectonics



a. Melting due to increasing temperature

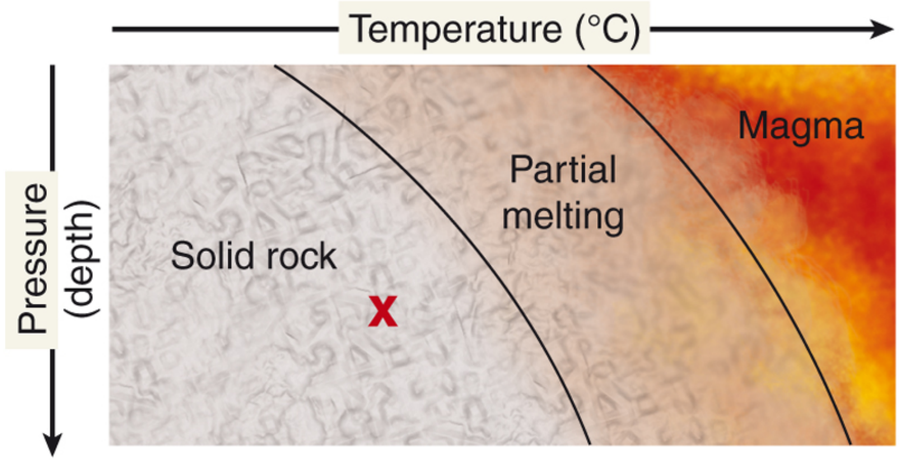


b. Melting due to decreasing pressure

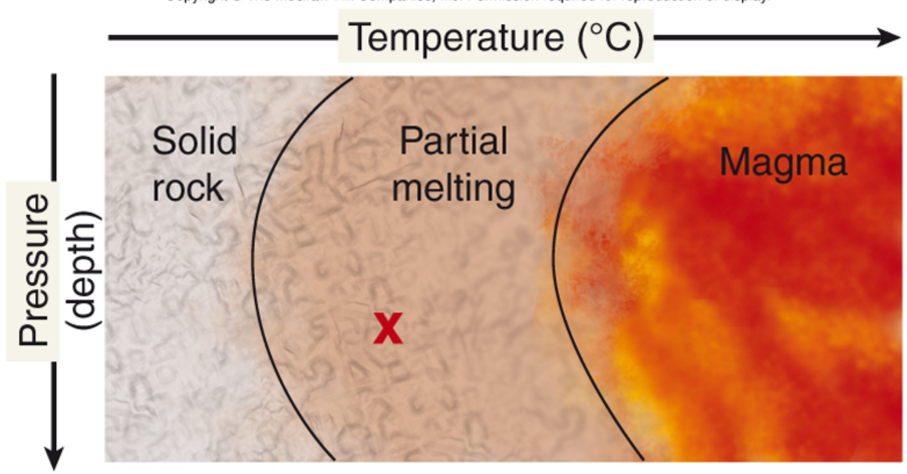
Why rocks (partially) melt:

1. Increasing temperature
   - Temperature increases with depth but increasing pressure impedes melting
   - Proximity to magma raises temperatures locally
2. Decreasing pressure
   - **Decompression melting** occurs as rocks rise toward surface
   - Example: below oceanic ridges

Plate Tectonics



c. No melting at X before the addition of water



d. Melting occurs at X after the addition of water

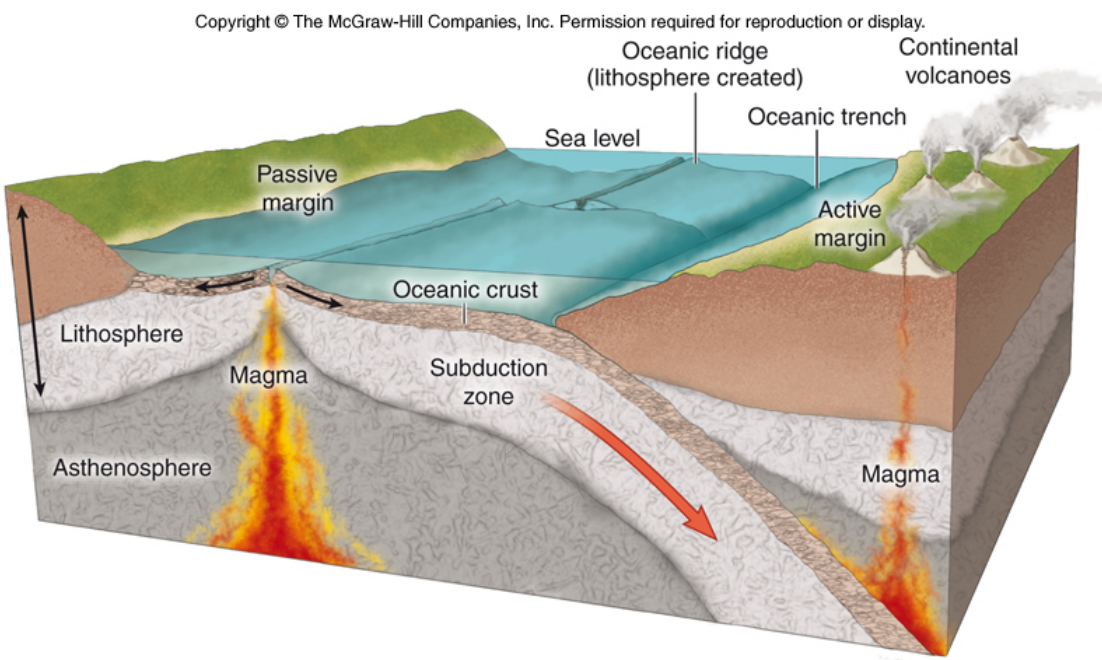
Why rocks (partially) melt:

3. Addition of water

   - Chemical reactions in the presence of water lower the temperature necessary for melting of some minerals

Plate Tectonics

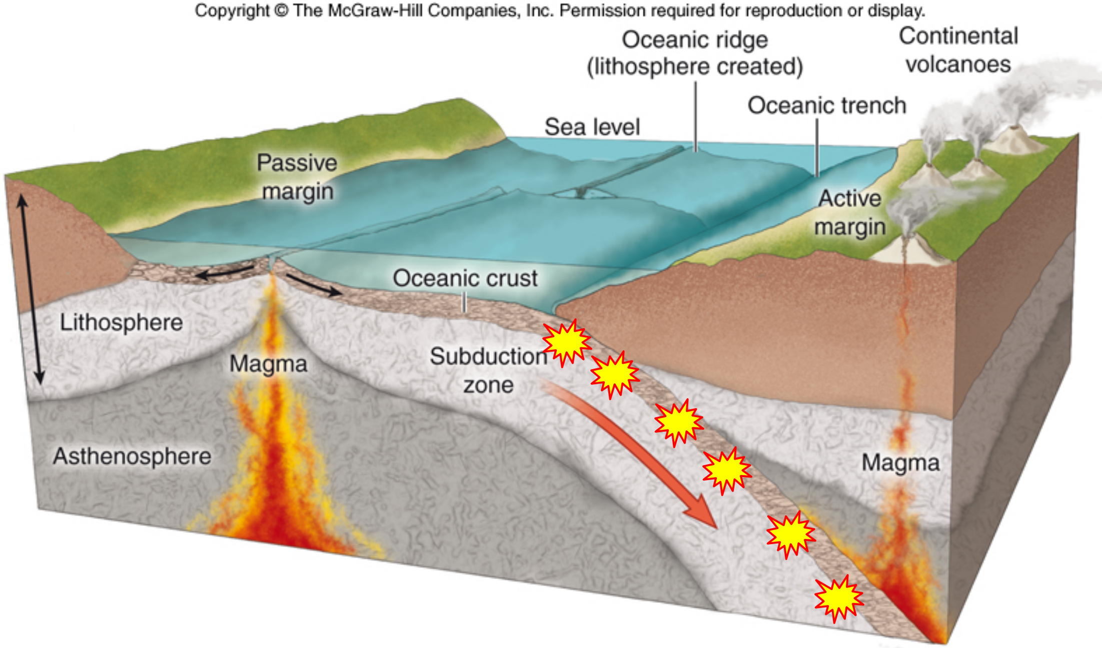
Formation of new lithosphere at oceanic ridges



- New oceanic lithosphere added along edges of two plates that move away from ridge
  - Lithosphere formed from magma generated by decompression melting of asthenosphere

Plate Tectonics

Generation of earthquakes and volcanoes

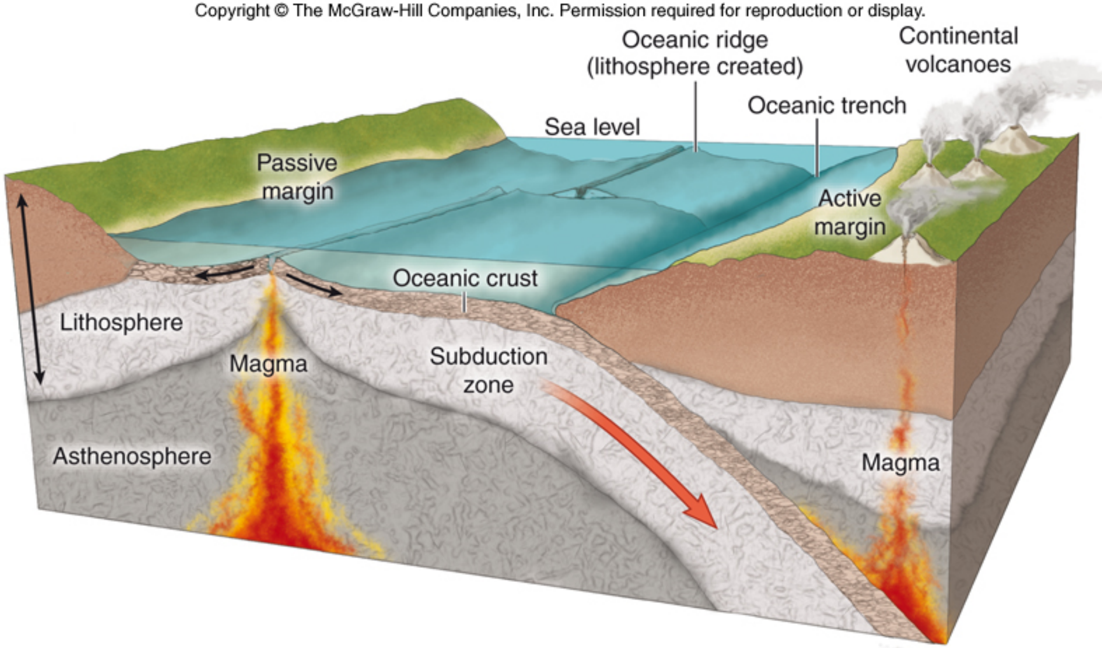


- Older oceanic lithosphere is destroyed at subduction zone to balance formation of new material
  - Earthquakes ( ) occur from surface to ~800 km depth in descending plate

Continental lithosphere is **not** consumed in subduction zones. Continents can break up or combine but total volume remains the same.

Plate Tectonics

Generation of earthquakes and volcanoes

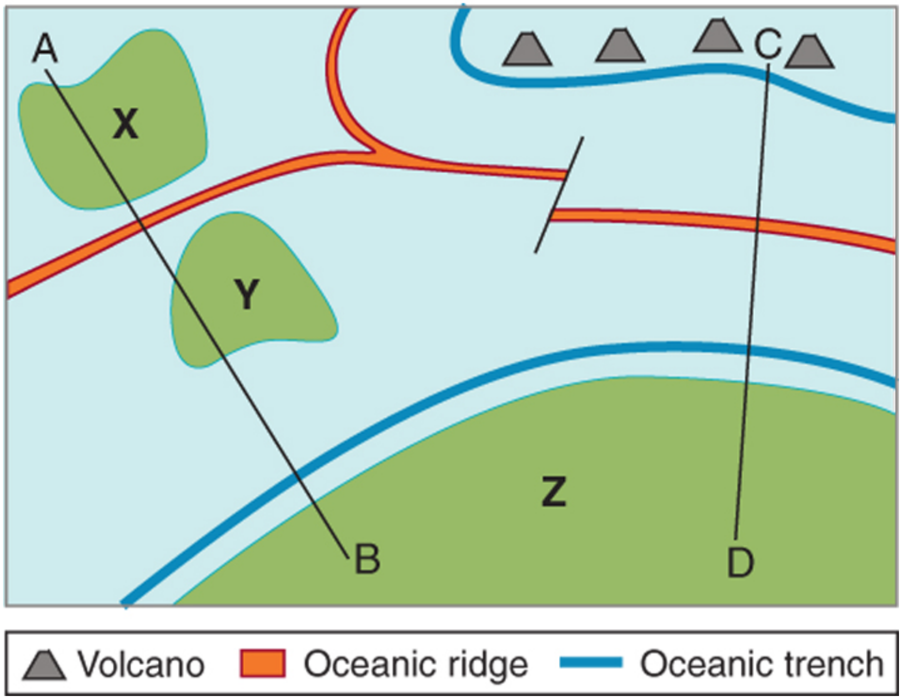


Most continental margins are **not** plate boundaries (e.g., Atlantic coast of North America) = ***passive margins***

- Older oceanic lithosphere destroyed at subduction zone
  - Chemical reactions in descending plate release water
  - Water causes partial melting in overlying plate
  - Magma rises to form volcanoes

Plate Tectonics Conceptest

How many plates are in this image?



A. 3

B. 4

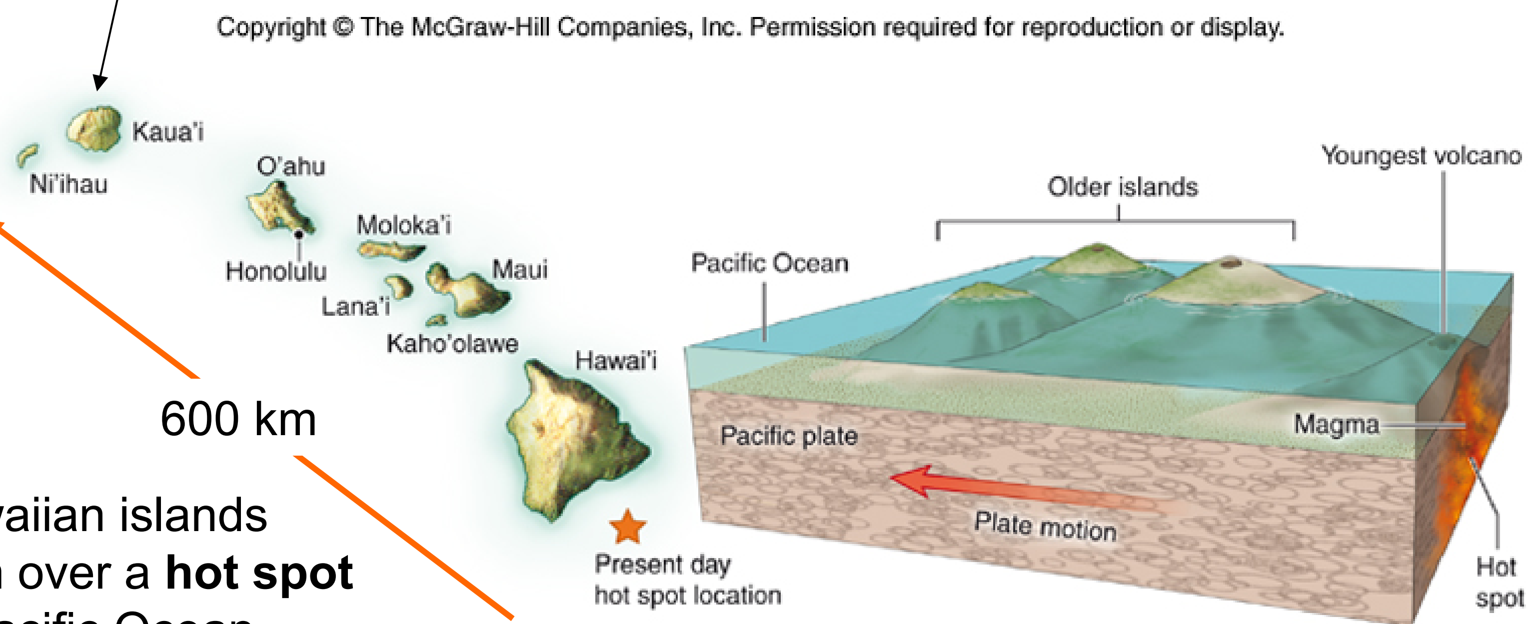
C. 5

D. 6

Plate Tectonics

Rate of Plate Movements

1. Kaua’i formed 5,000,000 years old
2. Kaua’i has moved 600 km (600,000 meters) since its formation
3. Kaua’i moved 600,000/5,000,000 meters per year = 0.12 m/yr = 12 cm/yr



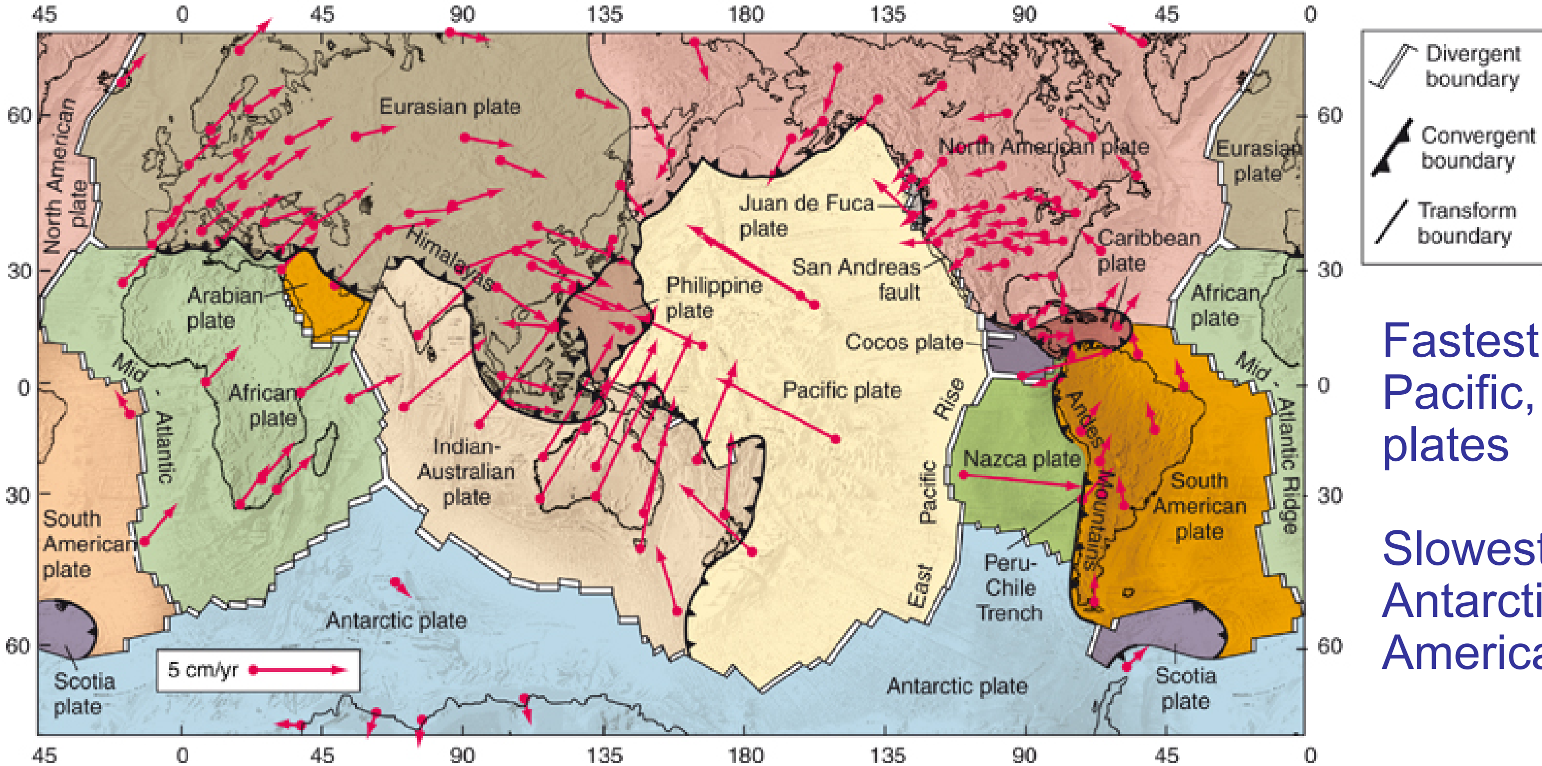
600 km

Hawaiian islands form over a **hot spot** in Pacific Ocean

Plate Tectonics

Rate of Plate Movements

Modern satellite measurements reveal that plates move at rates of ~1-15 centimeters per year



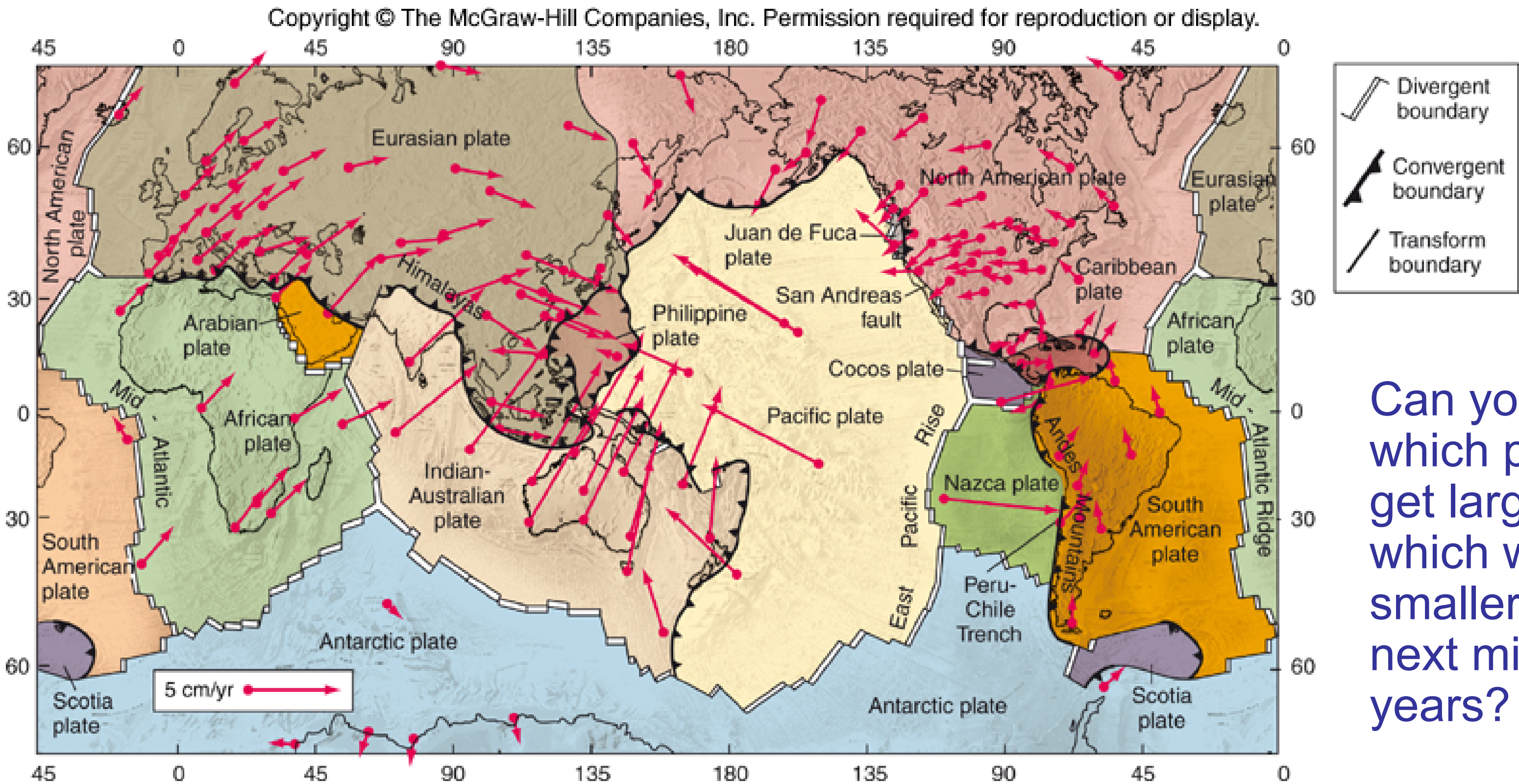
Fastest rates - Pacific, Nazca plates

Slowest rates - Antarctic, North American plates

Plate Tectonics

Directions of Plate Movements

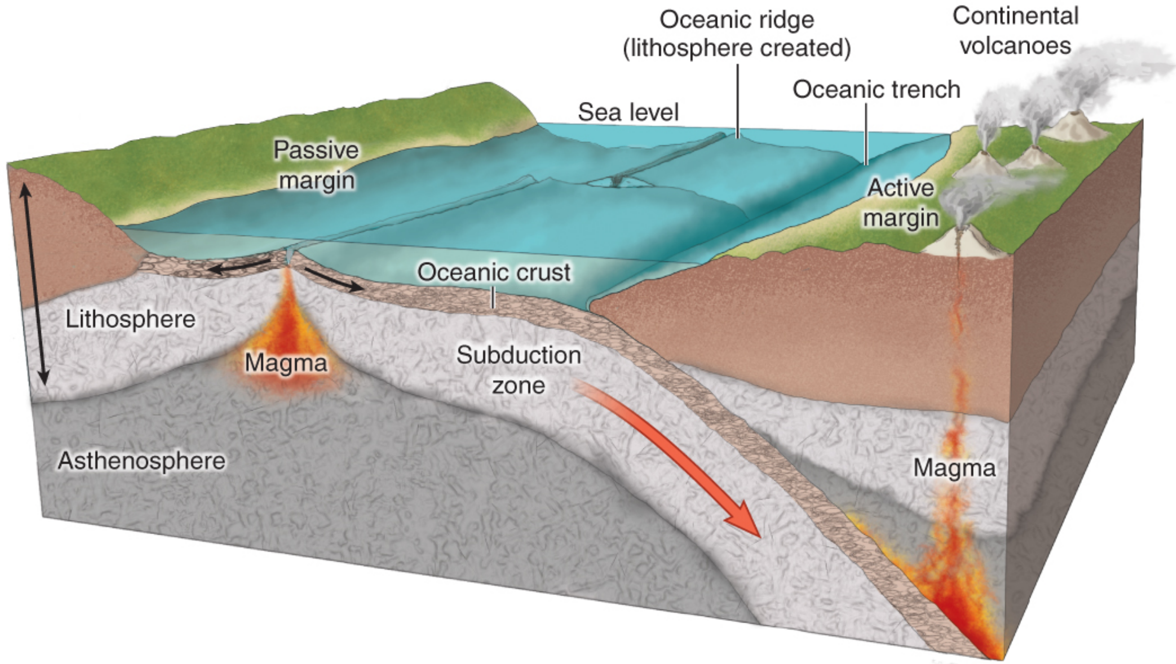
Plates move away from oceanic ridges and toward oceanic trenches (subduction zones).



Can you predict which plates will get larger and which will grow smaller over the next millions of years?

Plate Tectonics Conceptest

How many plates are in this image?



A. 1

B. 2

C. 3

D. 4

E. 5

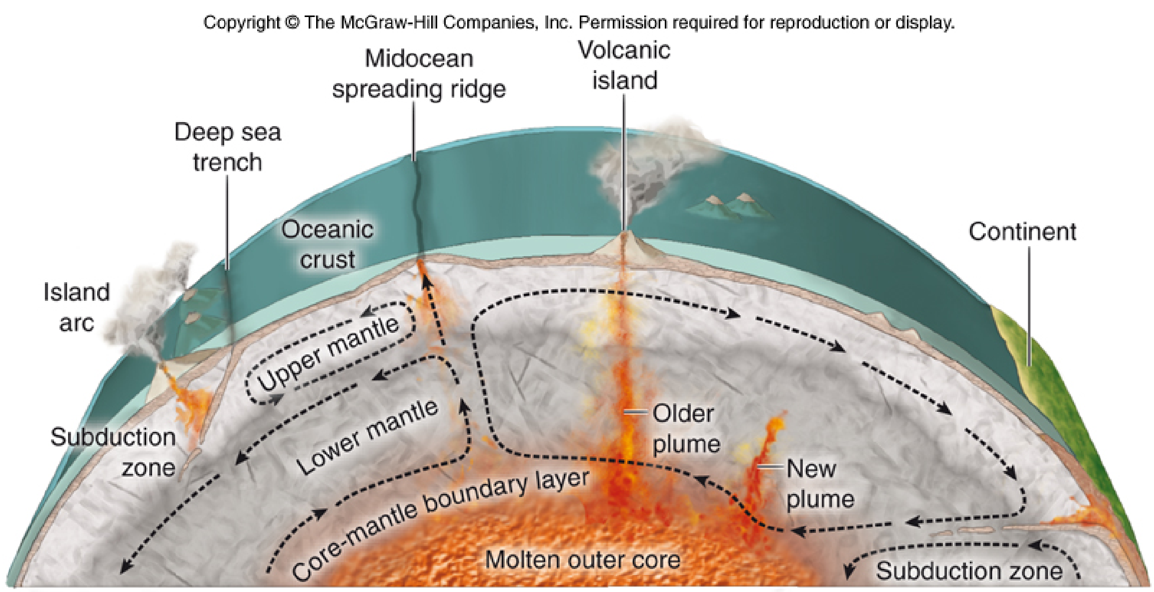
Plate Tectonics

Energy for Plate Movements

Mantle convection cells carry hot material from Earths interior toward the surface and transport cold material to depth

Two potential hypotheses interpret plate tectonics to be driven by upper mantle or whole mantle convection

Upper-mantle convection model



Whole-mantle convection model

Plate Tectonics Conceptest

The continental crust at Y is moving toward the …

A. Southeast
B. Southwest
C. Northeast
D. Northwest

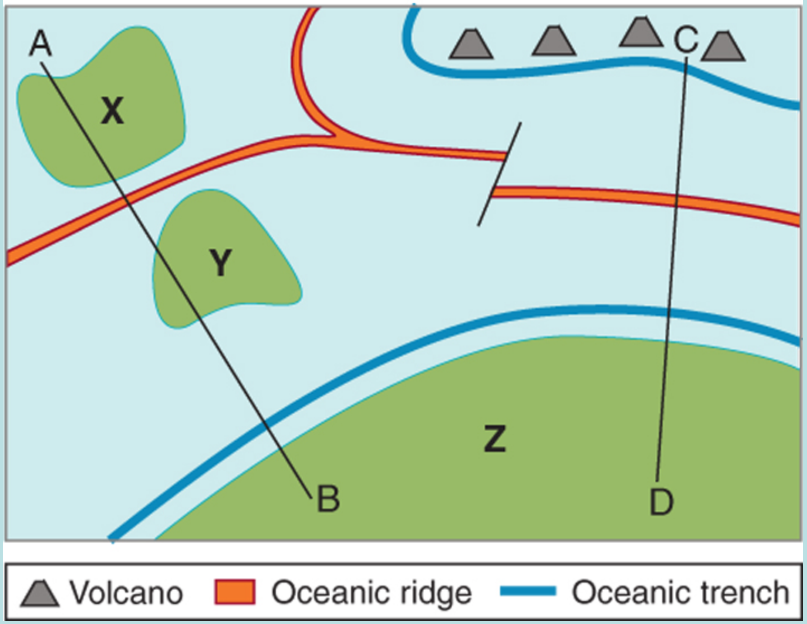
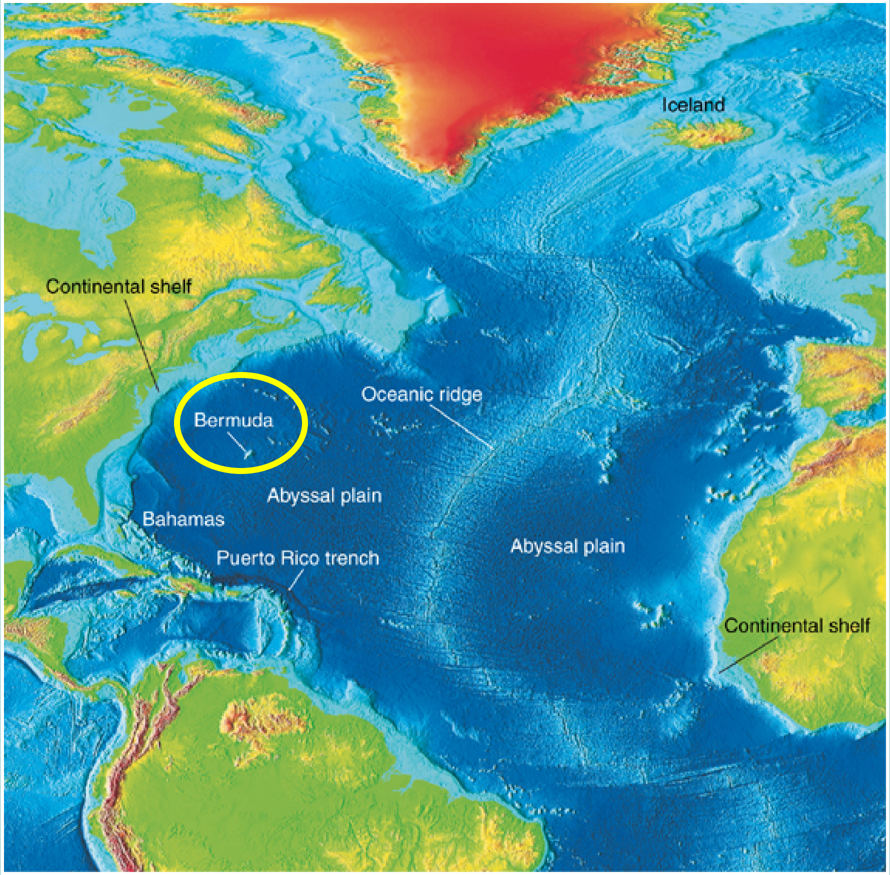


Plate Tectonics Conceptest



© Phil Degginger

The island of Bermuda is a former volcano on the floor of the western Atlantic Ocean. Approximately how far and in what direction would the island travel in 100 years?

A. 20 centimeters to the west

B. 20 centimeters to the east

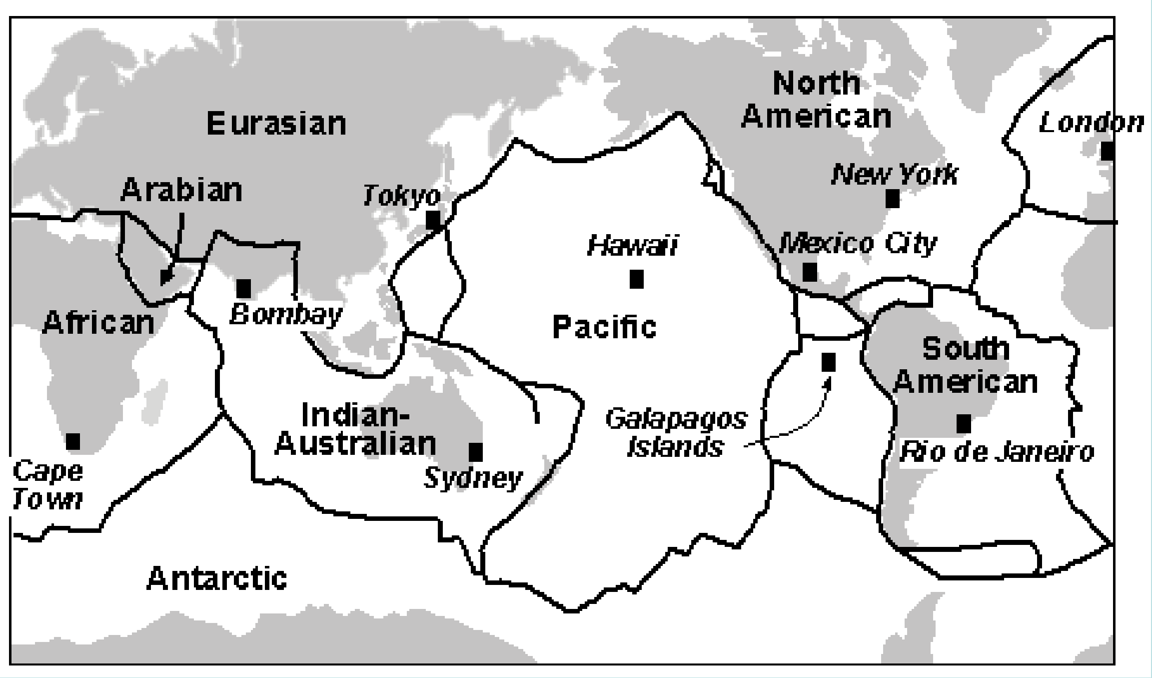
C. 200 centimeters to the west

D. 200 centimeters to the east

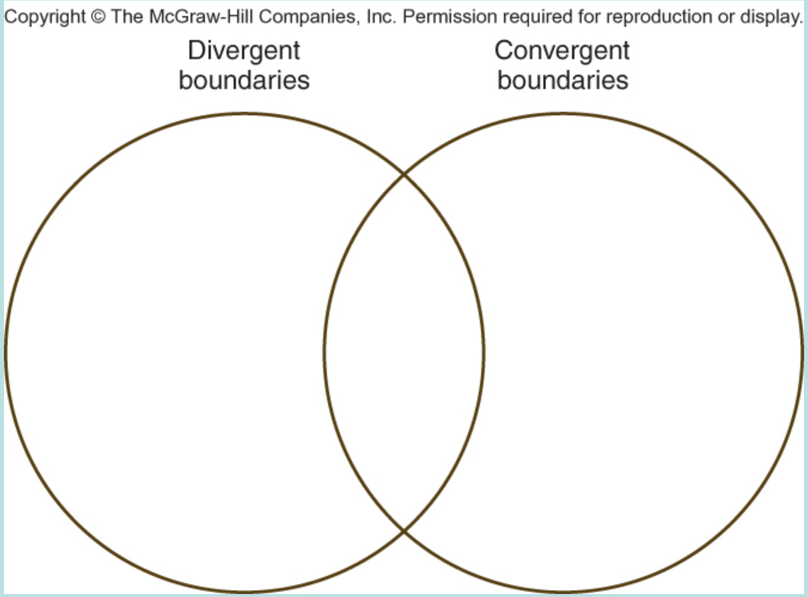
Plate Tectonics Conceptest

Review the map below and identify which pair of locations is moving closer together as a result of plate tectonics?

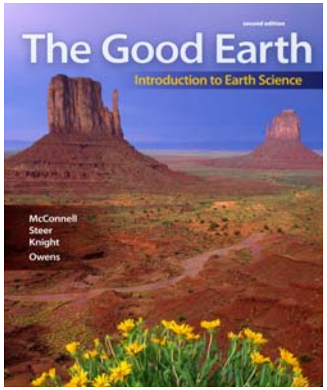
A. Bombay and Sydney
B. Hawaii and Tokyo
C. New York and London
D. Cape Town and Sydney



Place the phrases is the most appropriate location on the Venn diagram.



1. Rocks on either side of boundary are typically of different ages.
2. Example: Nazca and South American plate boundary.
3. Associated with oceanic trenches.
4. Oceanic lithosphere may be present on both sides of the plate boundary.
5. Only young ocean lithosphere present.
6. Plates move away from each other (divergent boundary).
7. Plates move toward each other (convergent boundary).
8. Often associated with volcanoes.
9. Magma rises to surface at or near the boundary.
10. Causes continents to divide.
11. Causes continents to combine.
12. Mountains present where continental lithosphere involved.
13. Chains of volcanic islands form (island arcs).

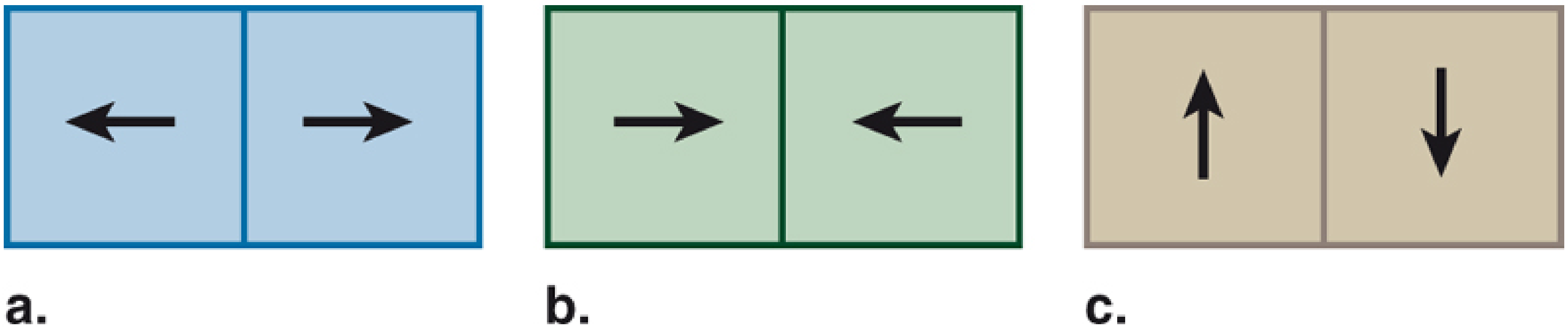


Go back to the **Table of Contents**

Go to the next section: ***Plate Boundaries***

Plate Boundaries

Three types of plate boundaries



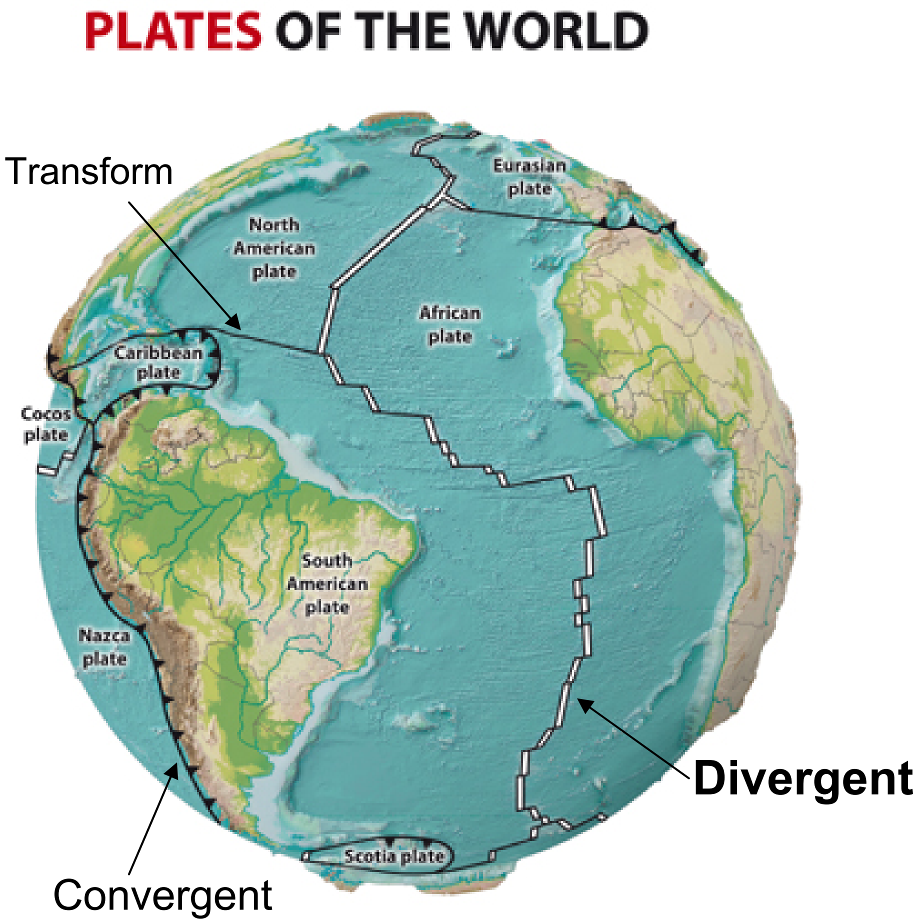
Divergent
- plates move apart (e.g. oceanic ridges)

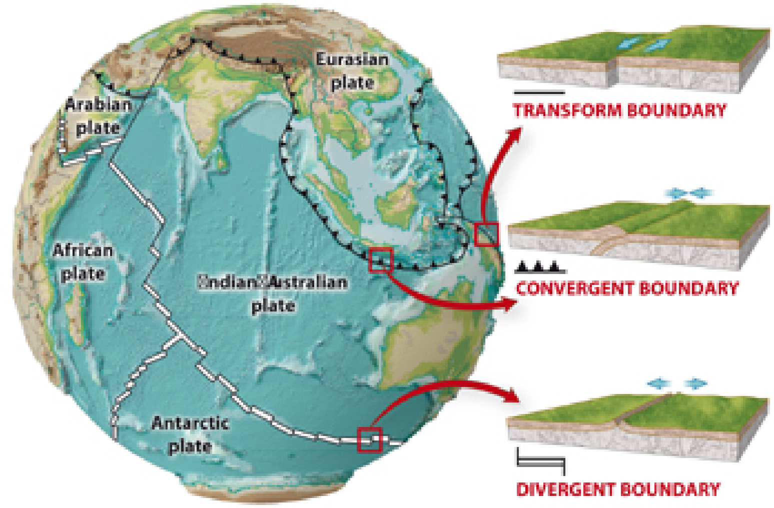
Convergent
- plates move toward each other (e.g. subduction zones)

Transform
- plates slide past each other (e.g. San Andreas fault, CA)

Plate Boundaries

Three types of plate boundaries





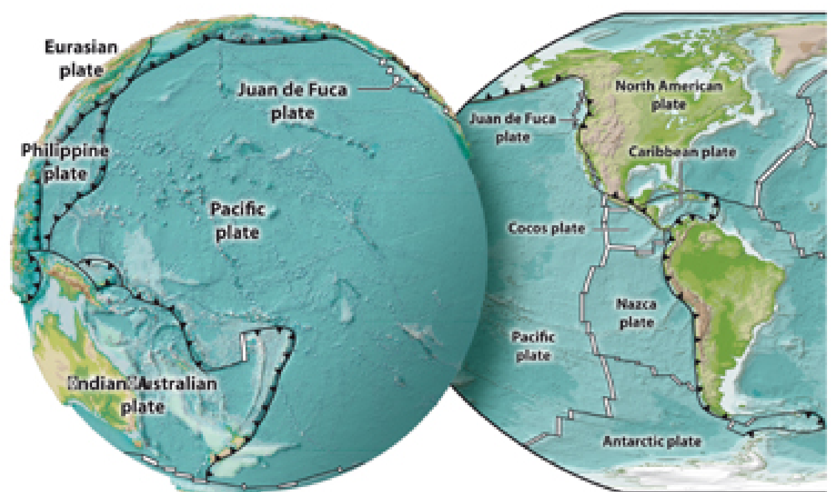


Plate Boundaries

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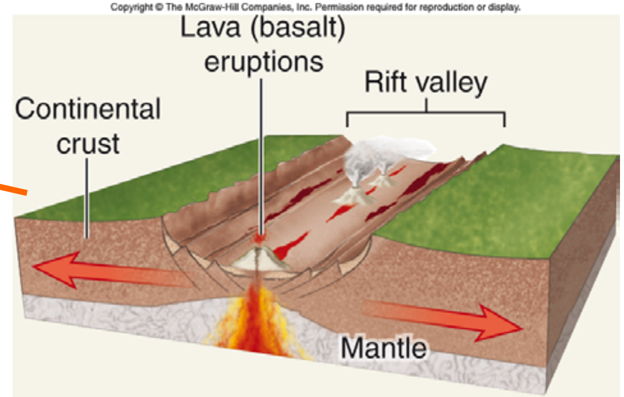
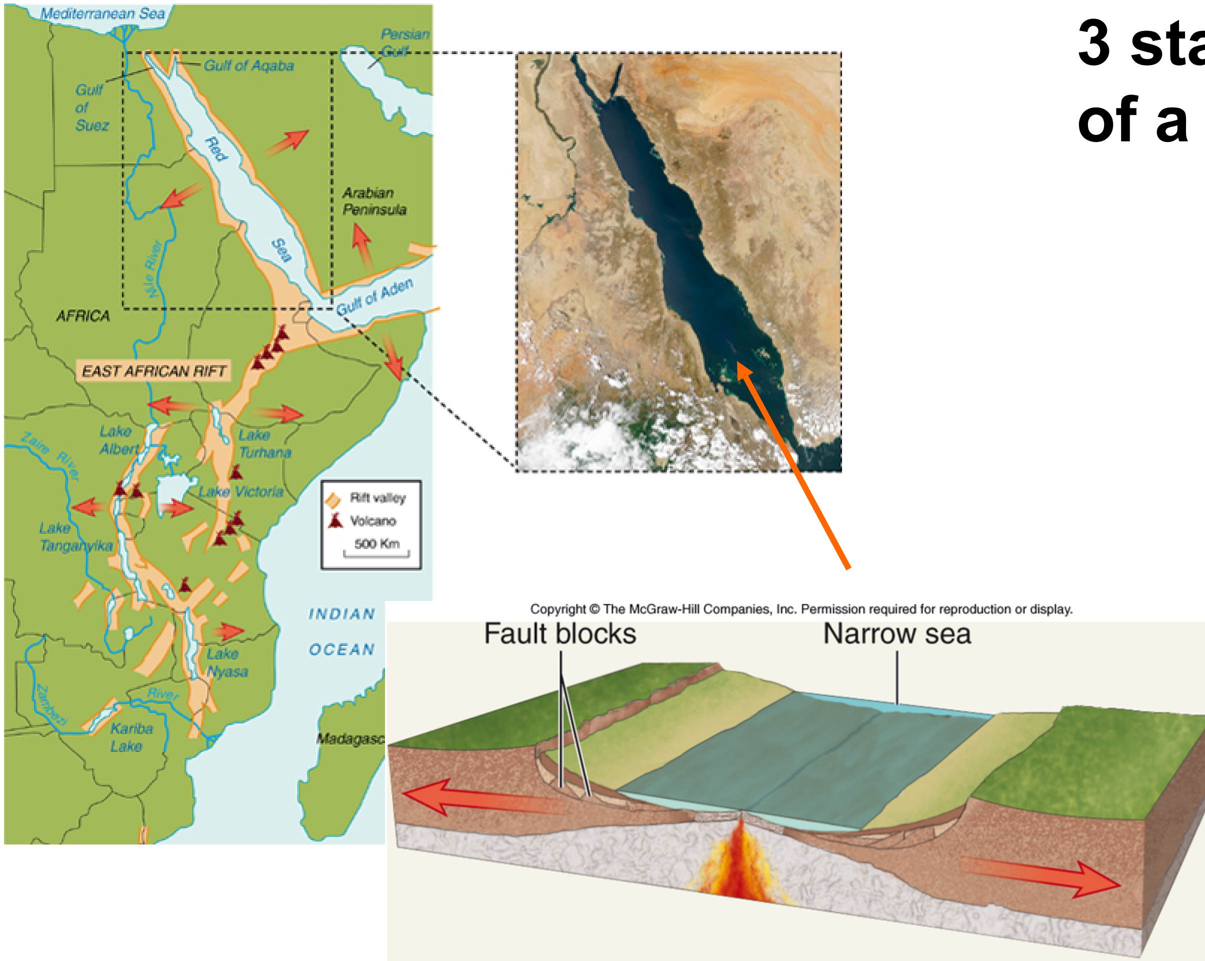


a. Continent undergoes extension. The crust is thinned and a rift valley forms.

3 stages in the evolution of a Divergent Boundary

1. Birth - break up of continental lithosphere
   - One continental plate in process or breaking in half (e.g., East Africa)
   - Thin crust, volcanoes, rift valley

Plate Boundaries



b. Continent tears in two. Continent edges are faulted and uplifted. Basalt eruptions form oceanic crust.

3 stages in the evolution of a Divergent Boundary

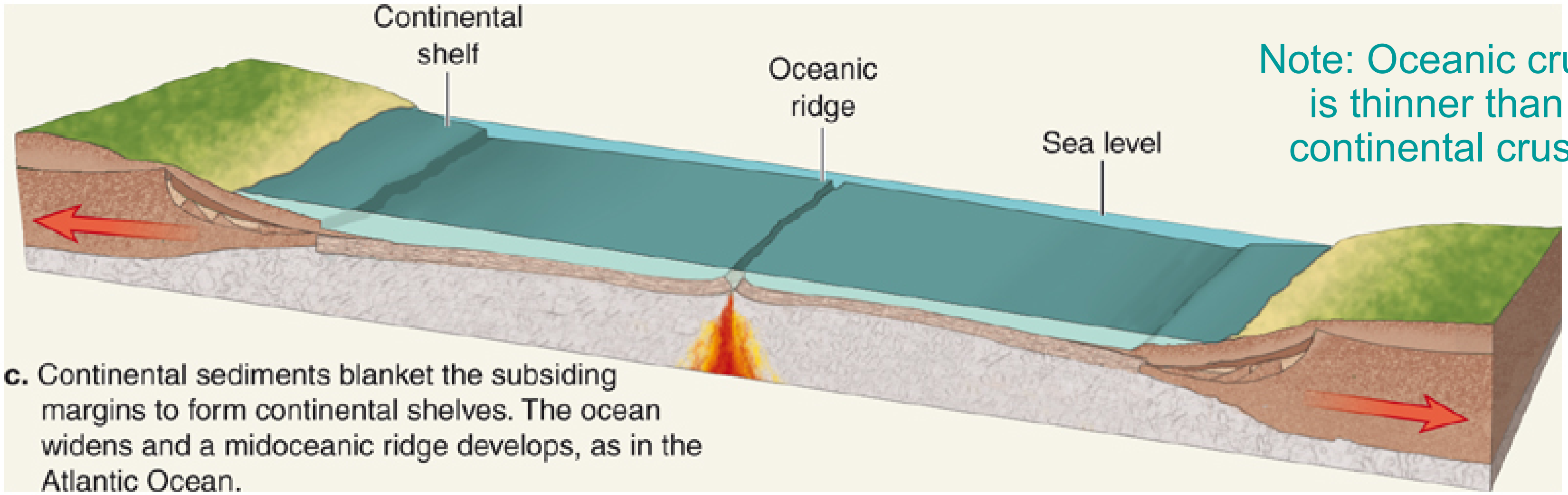
2. Youth – narrow ocean forms
   - Two passive margins form on opposing coasts (e.g., Red Sea)
   - Oceanic ridge, relatively shallow seafloor

Plate Boundaries

3 stages in the evolution of a Divergent Boundary

3. Maturity – wide ocean

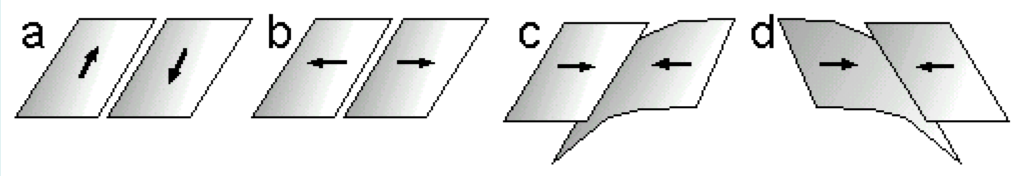
   - Two passive margins, each with broad continental shelf, on opposing coasts (e.g., North America, Africa)
   - Fully developed ridge system, abyssal plain



c. Continental sediments blanket the subsiding margins to form continental shelves. The ocean widens and a midoceanic ridge develops, as in the Atlantic Ocean.

Plate Tectonics Conceptest

Which of the 4 diagrams best represents a divergent plate boundary configuration?



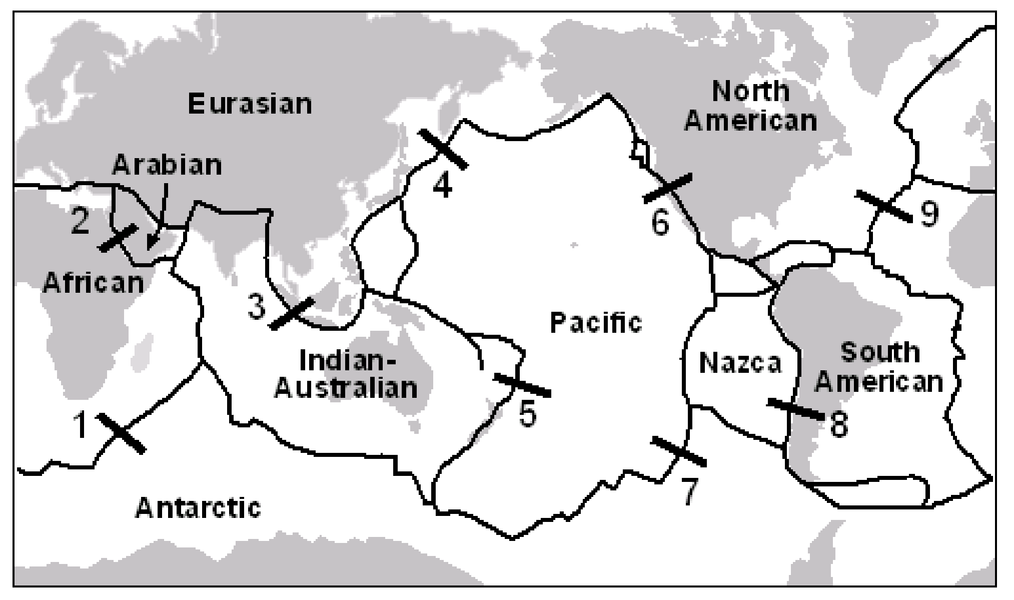
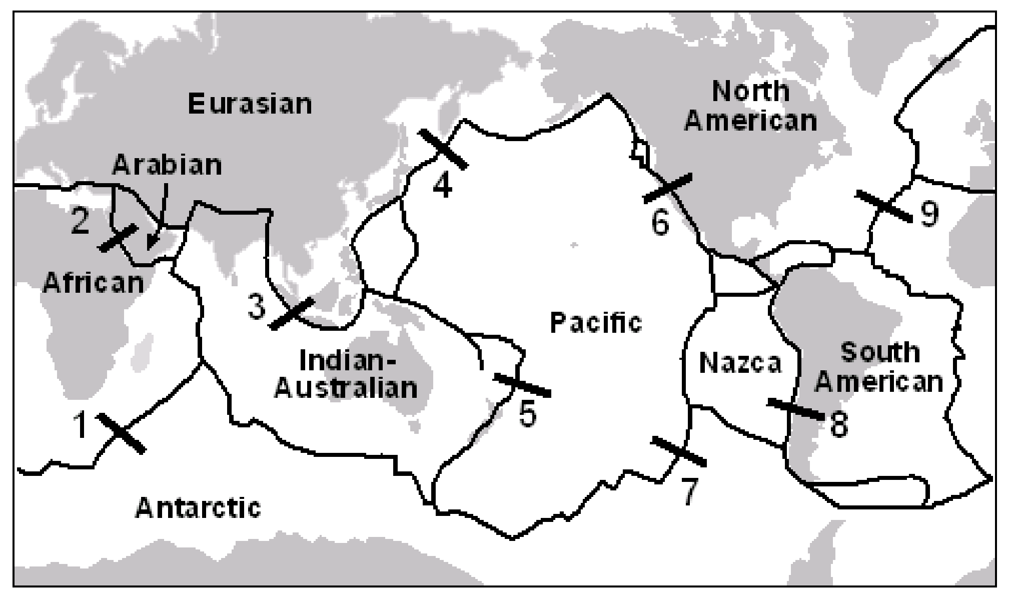


Plate Tectonics Conceptest

Which of the locations on the map represent examples of divergent plate boundaries?



A. 1, 6, 8

B. 3, 4, 5

C. 2, 7, 9

D. 2, 5, 6

E. 3, 7, 8

Plate Boundaries

Three types of plate boundaries

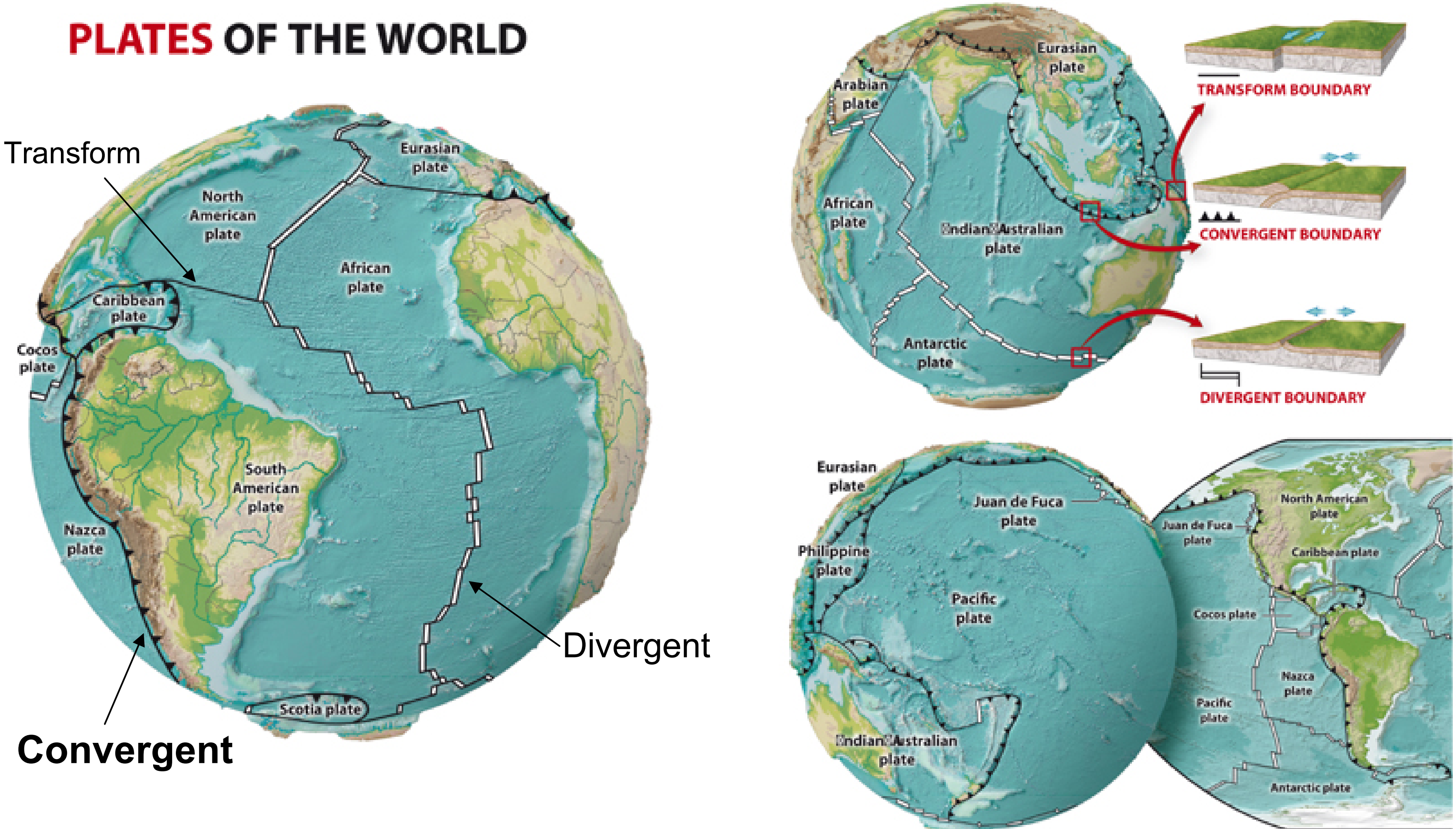
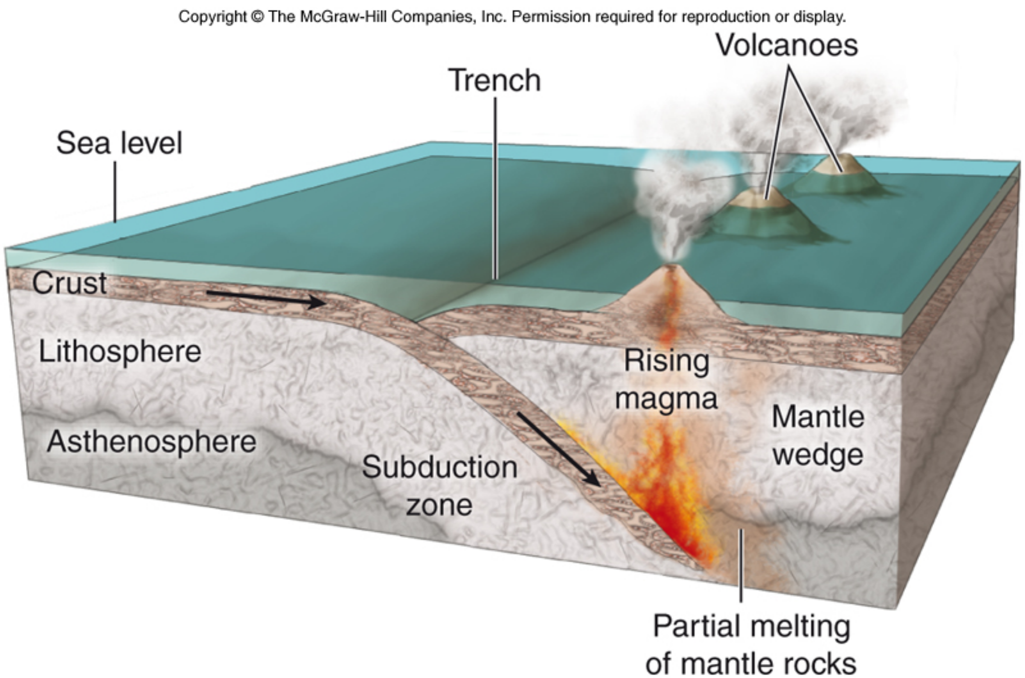


Plate Boundaries

Magma Generation at a Convergent Boundary

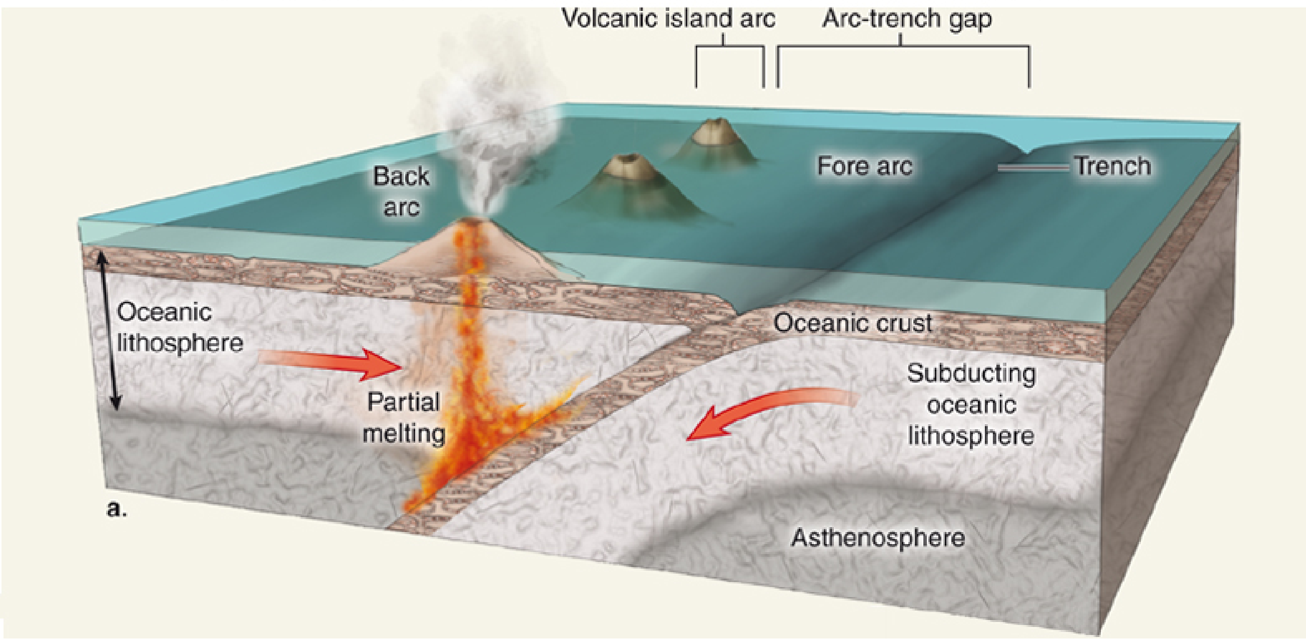


- Older (colder) oceanic lithosphere consumed at subduction zone
  - Denser plate descends down subduction zone
  - Water in descending plate expelled into hot rocks of overlying mantle wedge
  - Magma from partial melting of mantle wedge supplies overlying volcanoes

Plate Boundaries

Convergent Boundary: 1. Ocean/Ocean

- When 2 oceanic plates collide, the older lithosphere is consumed in the subduction zone

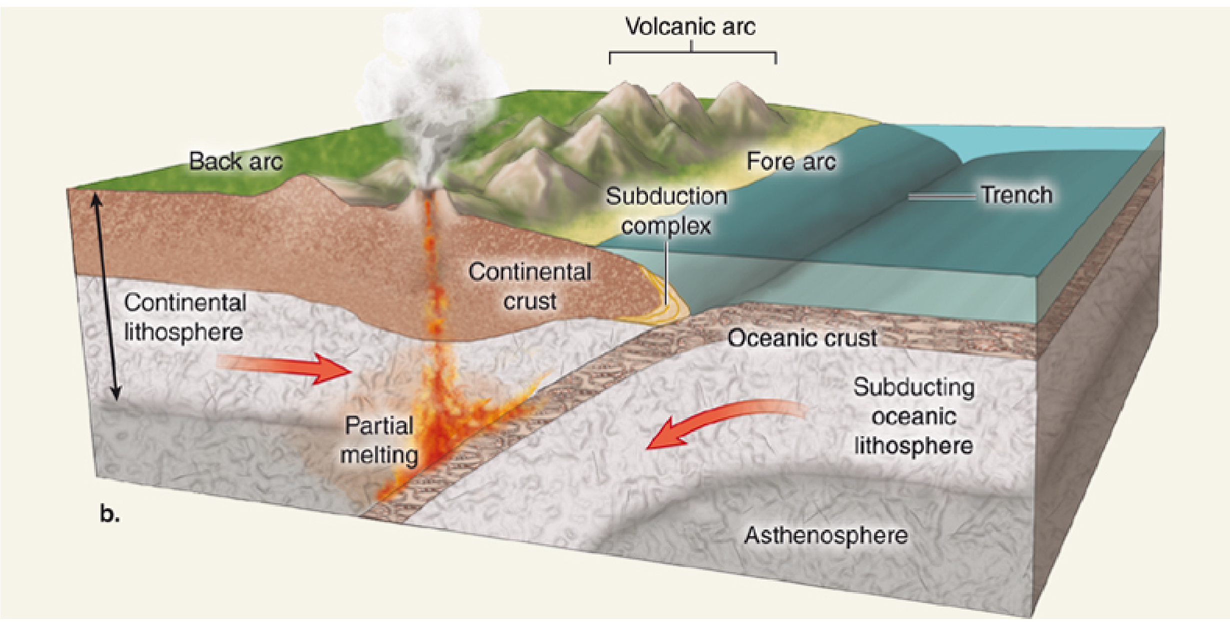


- Volcanic island arc forms behind trench on over-riding plate
- Arc-trench gap depends on angle of subduction zone
- Steeper slope = smaller gap

Plate Boundaries

Convergent Boundary: 2. Ocean/Continent

- When an oceanic plate collides with a continental plate, the oceanic plate is consumed in the subduction zone



- Example: Nazca plate descends below western South America
- Mountain ranges form along active margin

Plate Boundaries

Convergent Boundary: 3. Continent/Continent

- Thickening of continental crust forms tallest mountain ranges
  - Example: Himalayas formed where India collided with Eurasia
  - Only type of convergent boundary without oceanic trench
  - No current volcanic activity

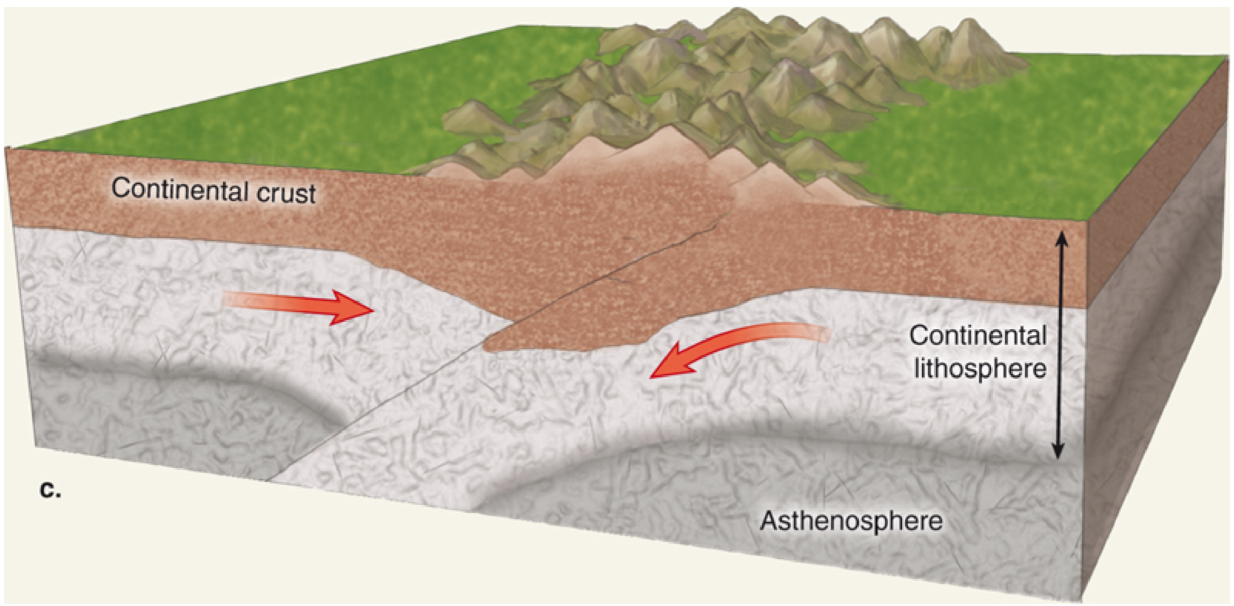
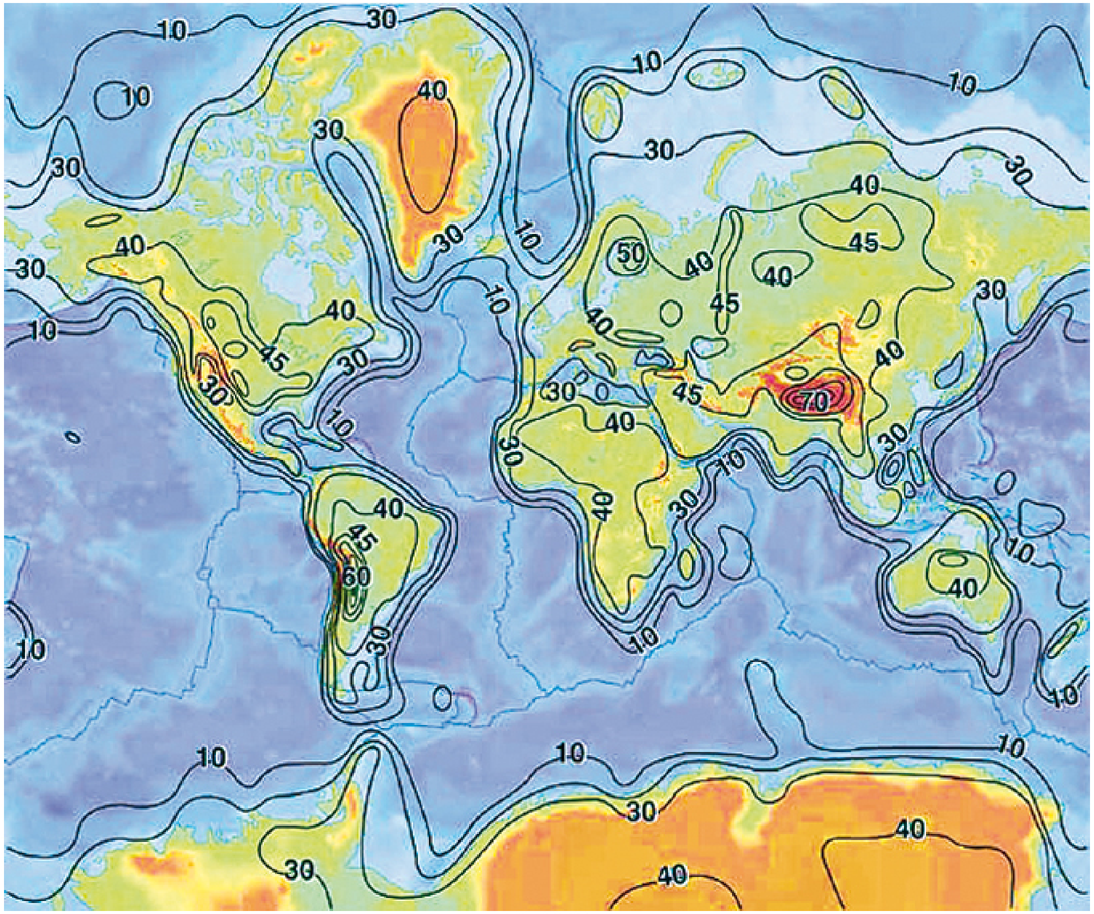


Plate Boundaries

Convergent Boundary vs. Crustal Thickness

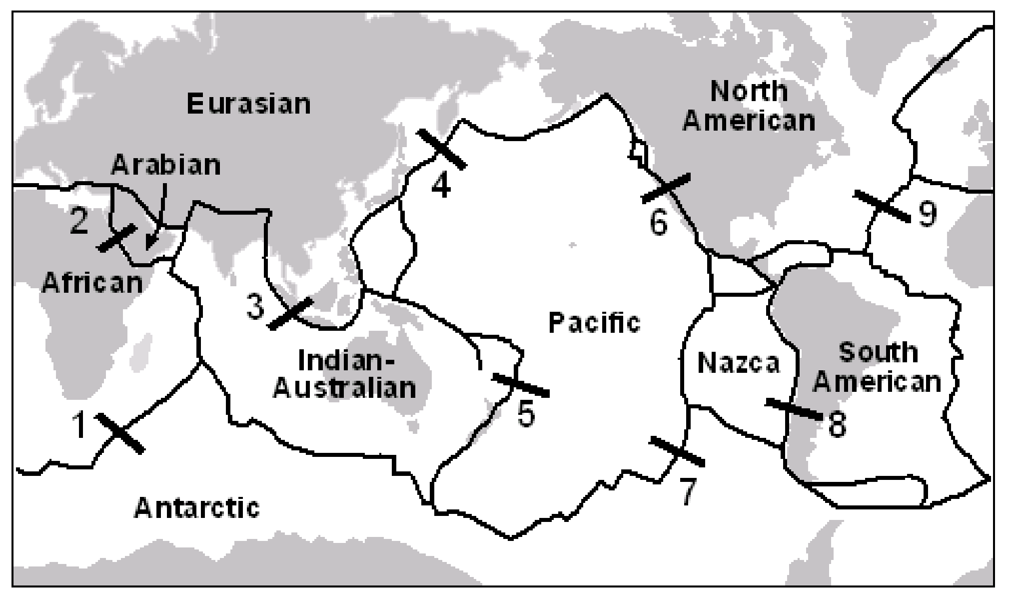


© USGS

- Thickest crust found along convergent boundaries
  - Himalayas, 70 km thick
  - Andes, up to 60 km thick
  - Most continental interiors, 30-40 km thick

Plate Tectonics Concepttest

Which of the locations on the map all represent examples of convergent plate boundaries?



A. 1, 6, 8

B. 3, 4, 5

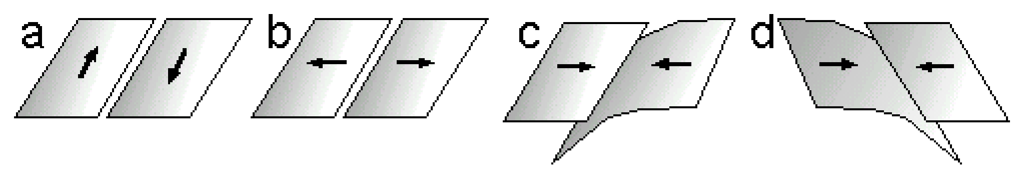
C. 2, 7, 9

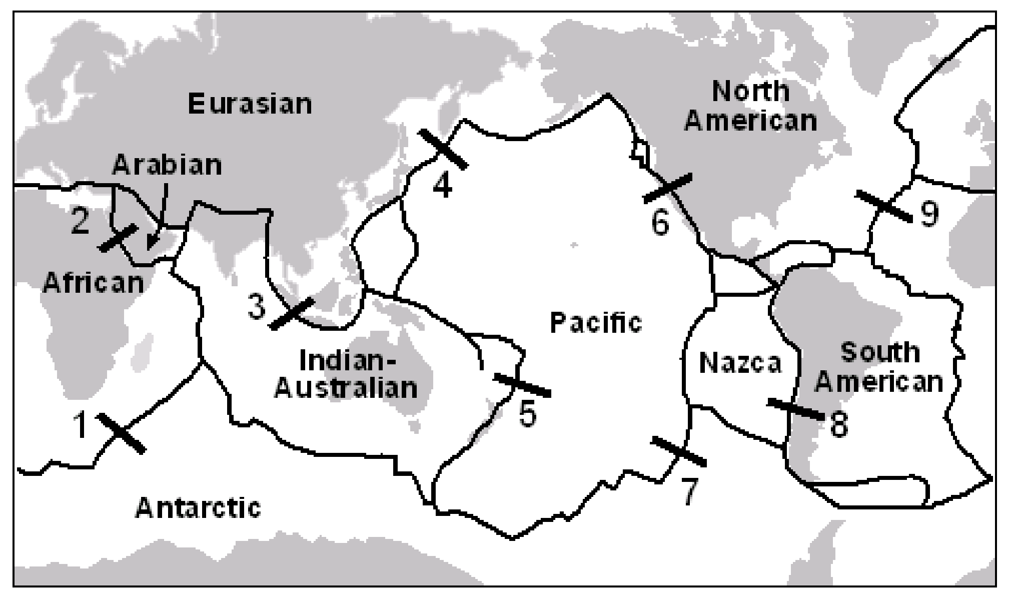
D. 2, 5, 6

E. 3, 7, 8

Plate Tectonics Conceptest

Which of the numbered locations best represents a plate boundary configuration similar to “c”?





A. 1, 7

B. 3, 8

C. 4, 5

D. 6, 9

Plate Boundaries

Three types of plate boundaries

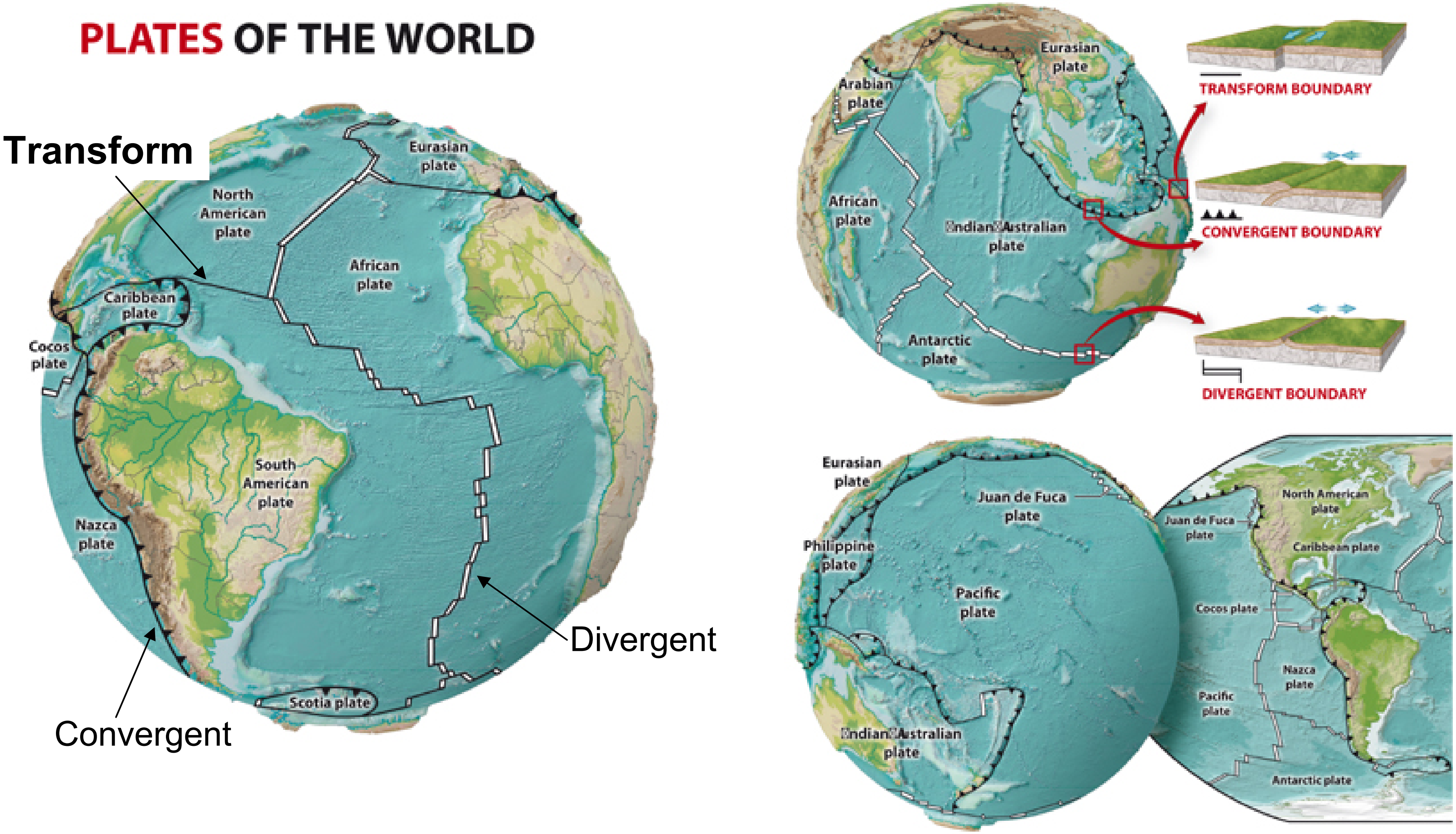


Plate Boundaries

Transform Boundaries

- Link sections of ridge or trench systems
- Plates move in opposite directions
- No lithosphere created, no lithosphere destroyed

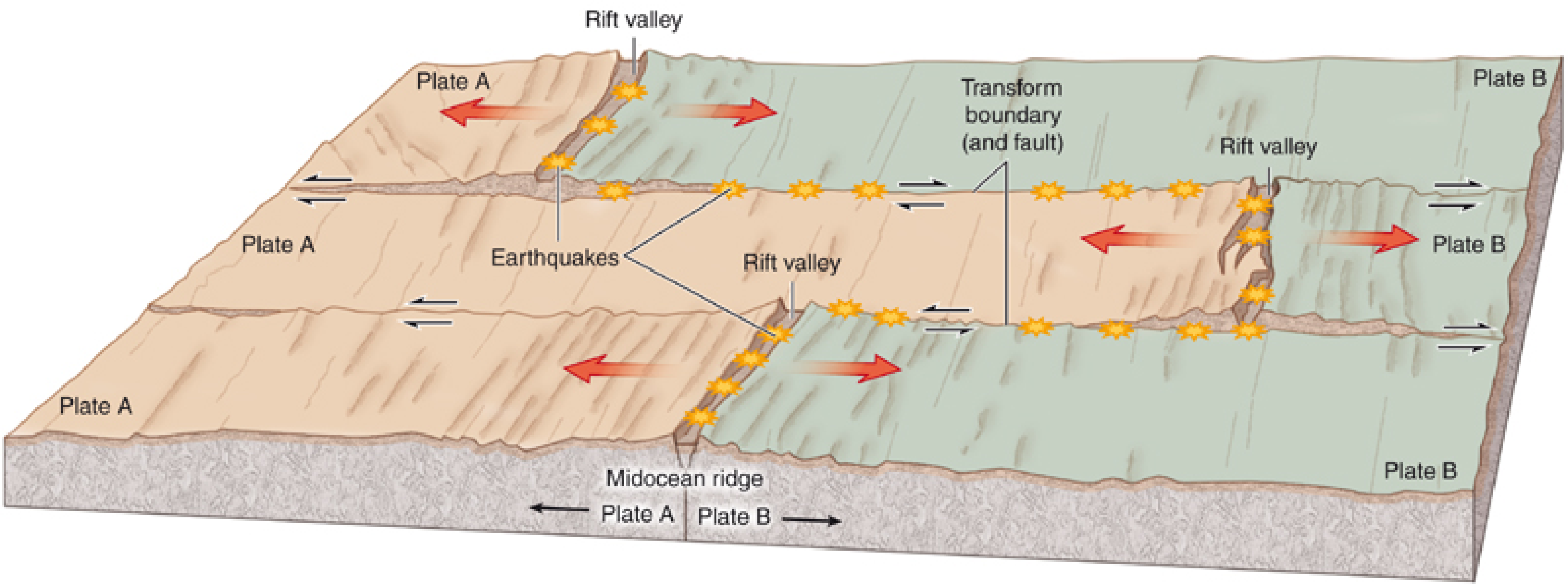


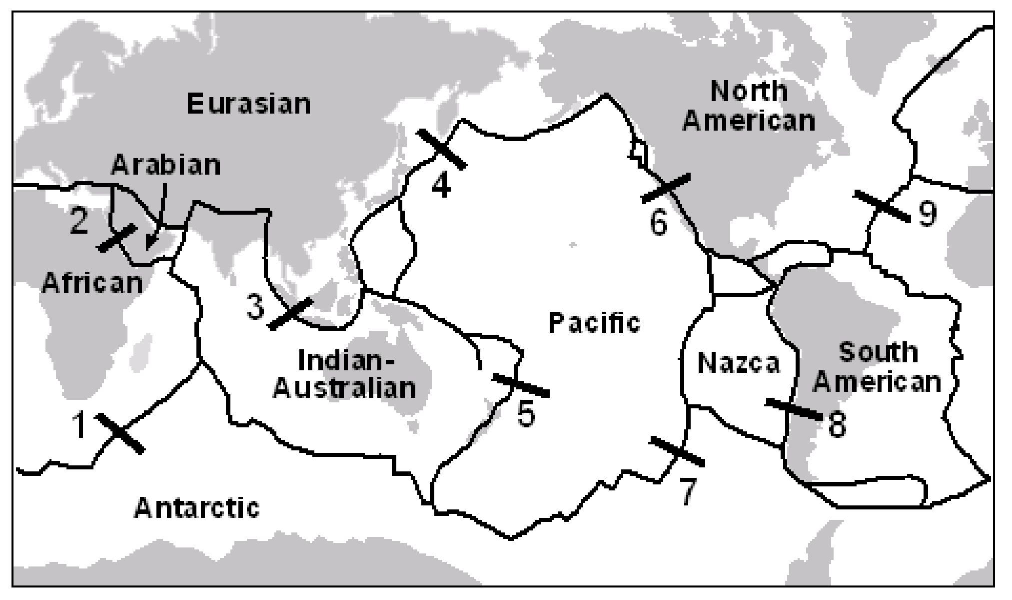
Plate Boundaries

San Andreas Fault, CA

- Links oceanic ridge systems in Gulf of California and Juan de Fuca plate
  - San Francisco and most of U.S. on North American plate
  - Western California, including Los Angeles, on Pacific plate
  - Moving north → collide with Alaska

Plate Tectonics Conceptest

Which location on the map represents an example of a transform plate boundary?



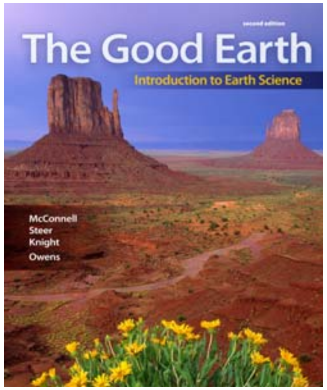
A. 1

B. 3

C. 5

D. 6

E. 8



The End

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