Introduction to Geology

Geology literally means "study of the Earth."

Physical geology examines the materials and processes of the Earth.
Historical geology examines the origin and evolution of our planet through time.

Geology seeks to understand the origin of our planet and our place in the Universe – answers to these questions are also posed outside of the realm of science

The Earth System: **From space, Earth looks small, finite and fragile.**

The Earth is composed of several integrated parts (spheres) that interact with one another:

- atmosphere
- hydrosphere
- solid earth (lithosphere)
- biosphere

Hydrosphere: the global ocean is the most prominent feature of our (blue) planet. The oceans cover ~71% of our planet and represent 97% of all the water on our planet.

Atmosphere: the swirling clouds of the atmosphere represent the very thin blanket of air that covers our planet. It is not only the air we breathe, but protects us from harmful radiation from the sun.

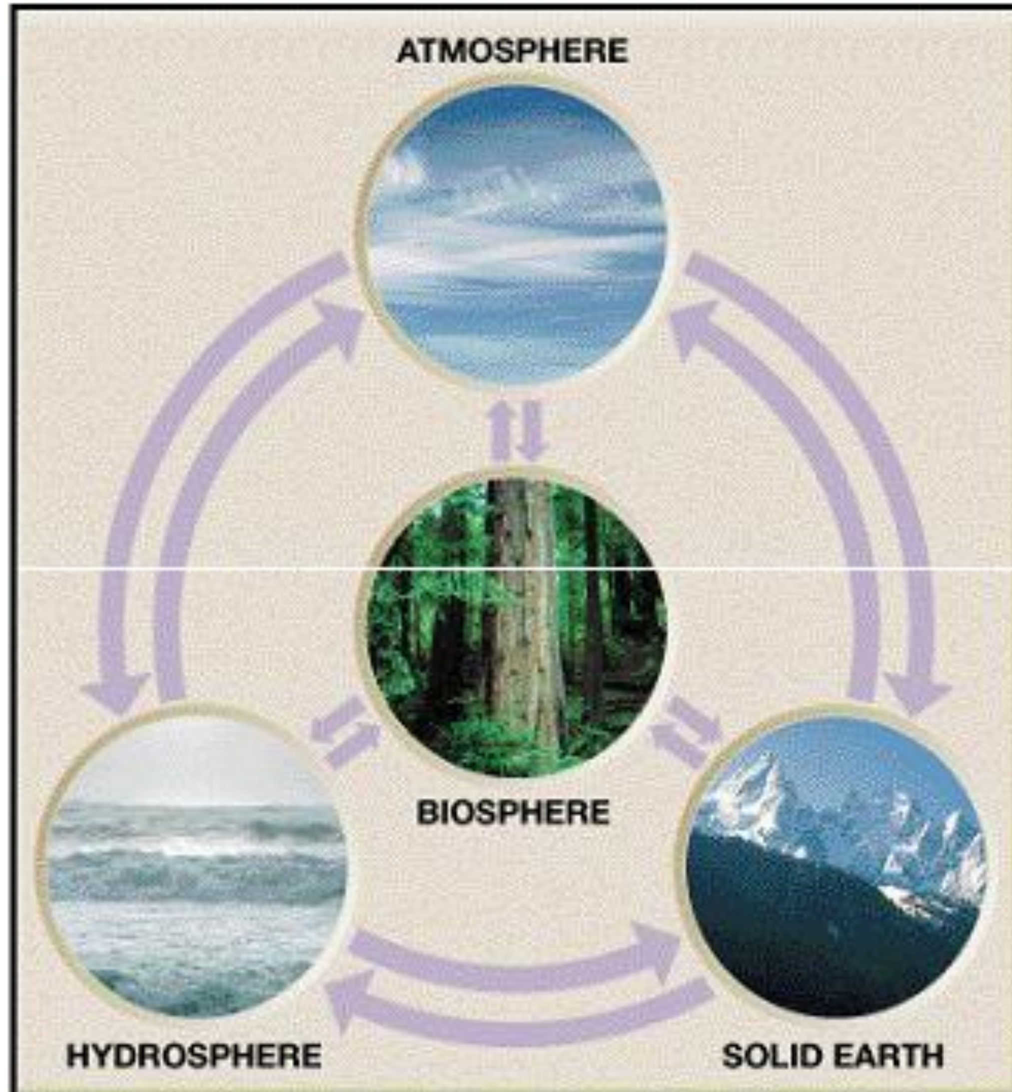
Biosphere: includes all life on Earth - concentrated at the surface. Plants and animals don't only respond the their environment but also exercise a very strong control over the other parts of the planet.

Solid Earth: represents the majority of the Earth system. Most of the Earth lies at inaccessible depths. However, the solid Earth exerts a strong influence on all other parts (ex. magnetic field).

This figure shows the dynamic interaction between the major spheres.

As humans, we desire to divide the natural world into artificial portions to make it easier. It should be stressed that these divisions are artificial.

What are some of the interactions between these spheres?



The Rock Cycle

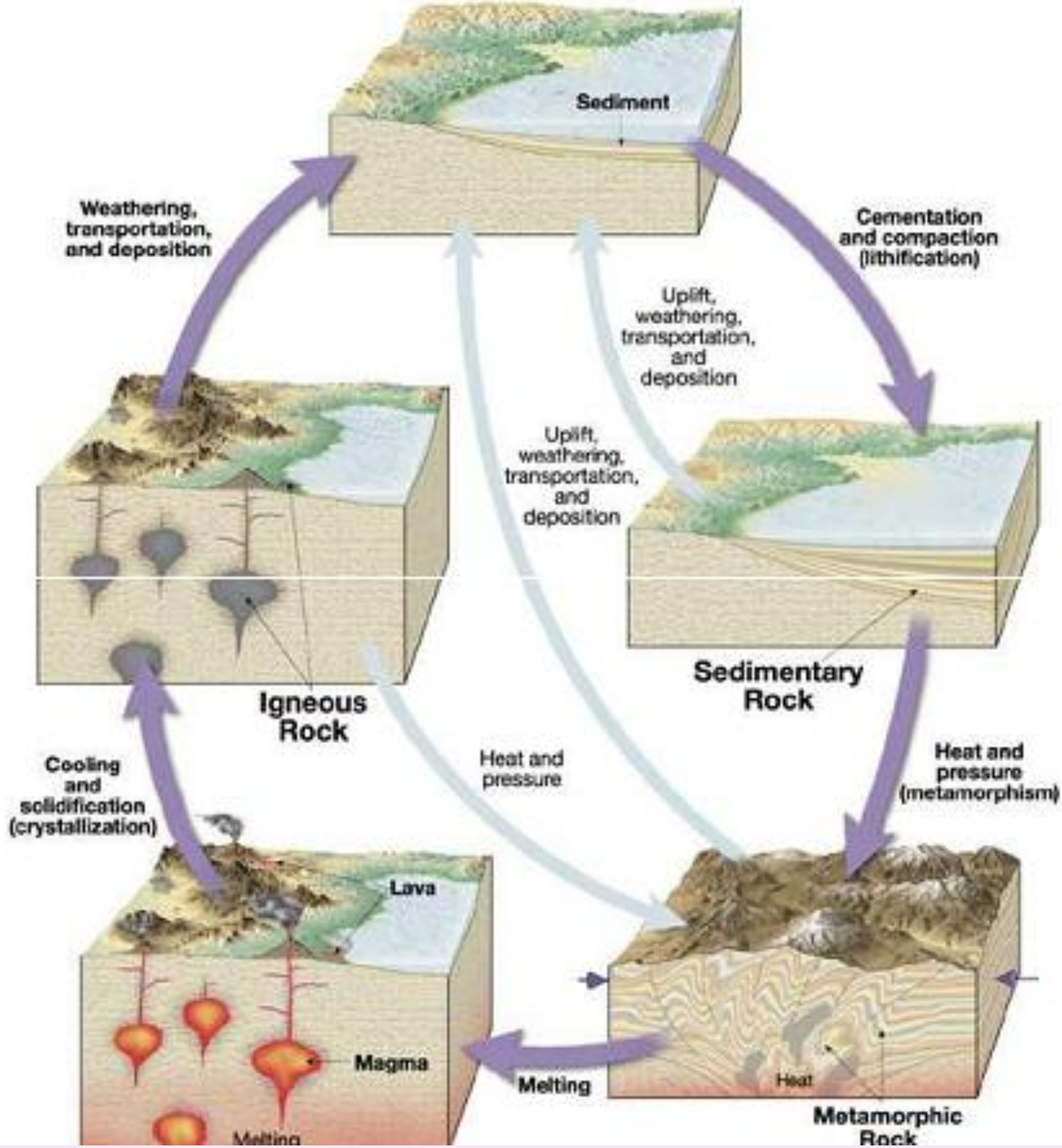
Three basic rock types:

igneous - form from magma/lava

sedimentary - form from sediment and chemical precipitation from seawater

metamorphic - form from other rocks that recrystallize under higher pressures and/or temperatures.

A number of geological processes can transform one rock type into another.



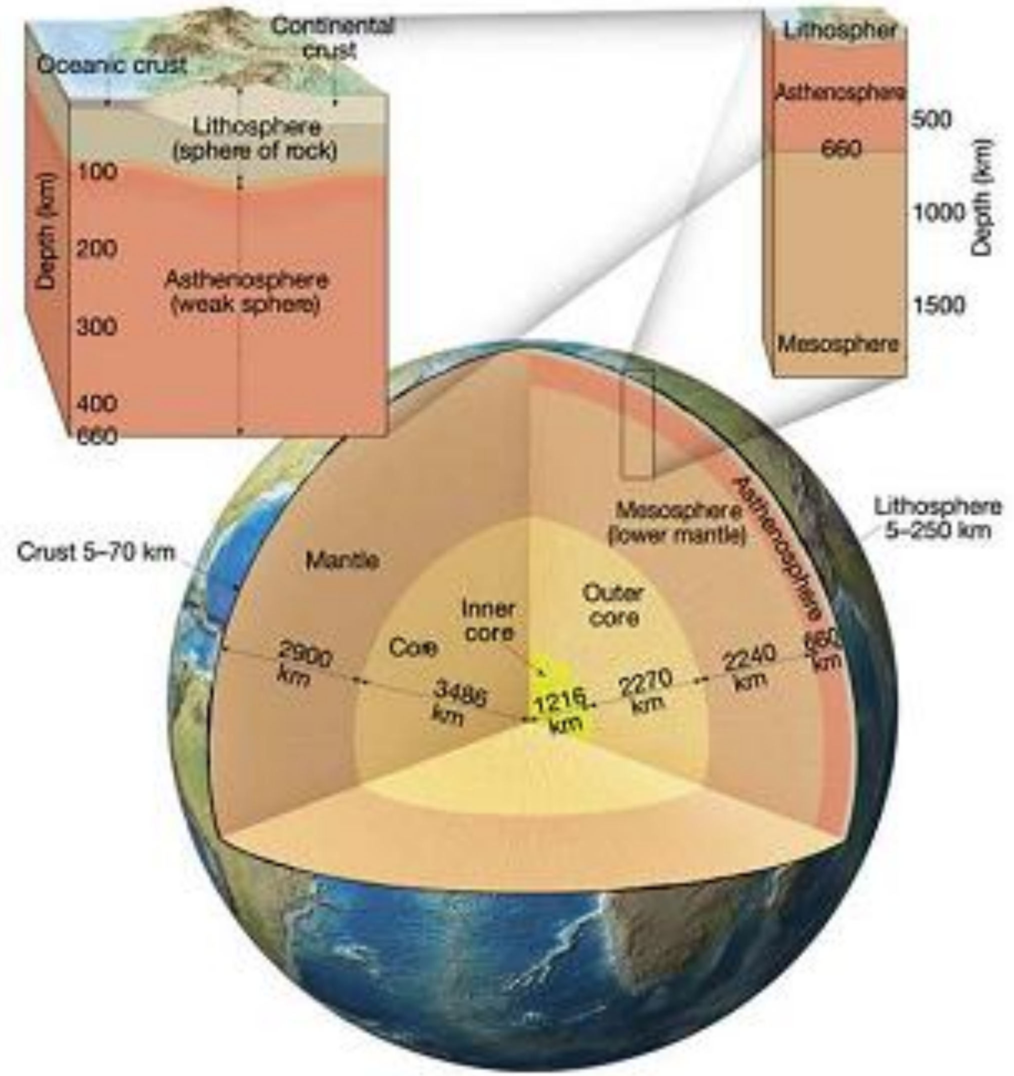
Earth's Internal Structure

The Earth's interior is characterized by a gradual increase in temperature, pressure and density with depth.

At only 100 km depth, the temp is ~1300°C.

At the Earth's center, the temperature is >6700°C.

The pressure in the crust increases ~280 bars for every kilometer depth.



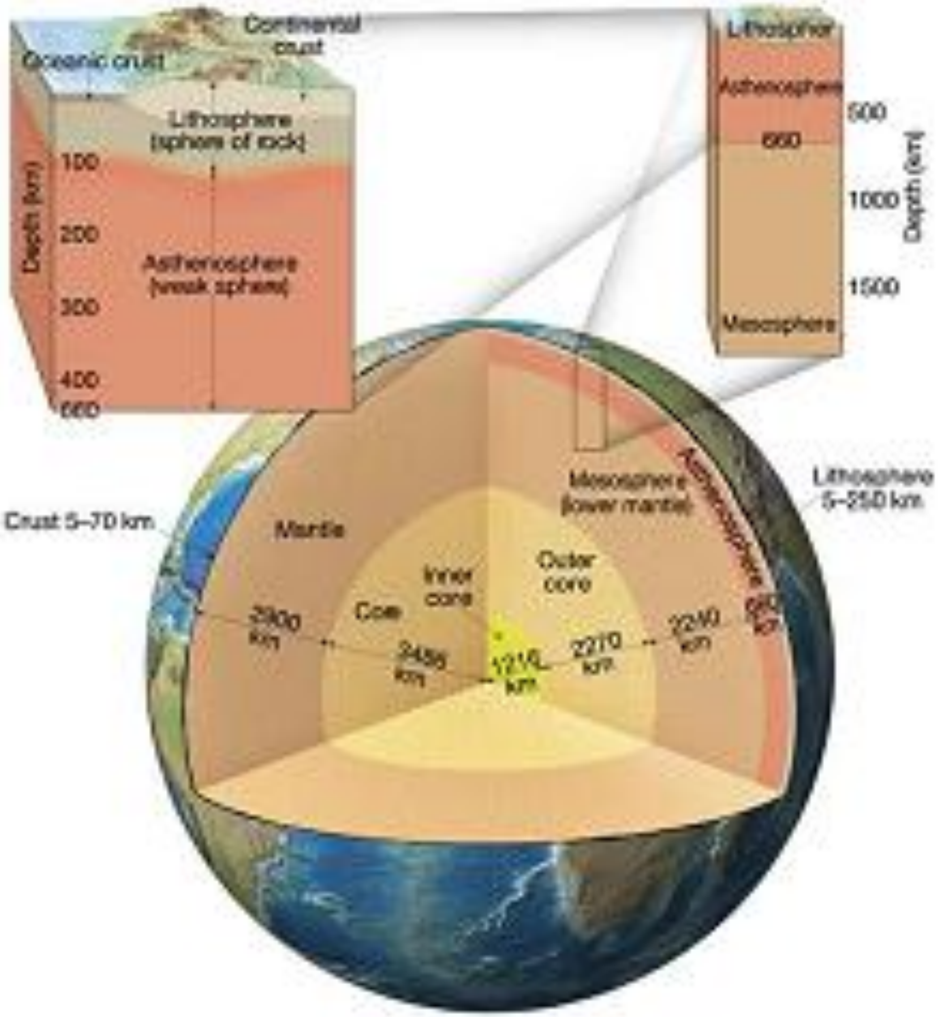
Earth's Internal Structure

The Earth consists of 3 major regions marked by differences in chemical composition.

Crust: rigid outermost layer of the Earth. Consists of two types:

1. **oceanic** - 3-15 km thick and is composed of *basalt* (igneous). Young (<180 million years old).

2. **continental** - up to 70 km thick and composed of a wide variety of rock types (ave. *granodiorite*). Ranges from young to old (>3.8 billion years old).



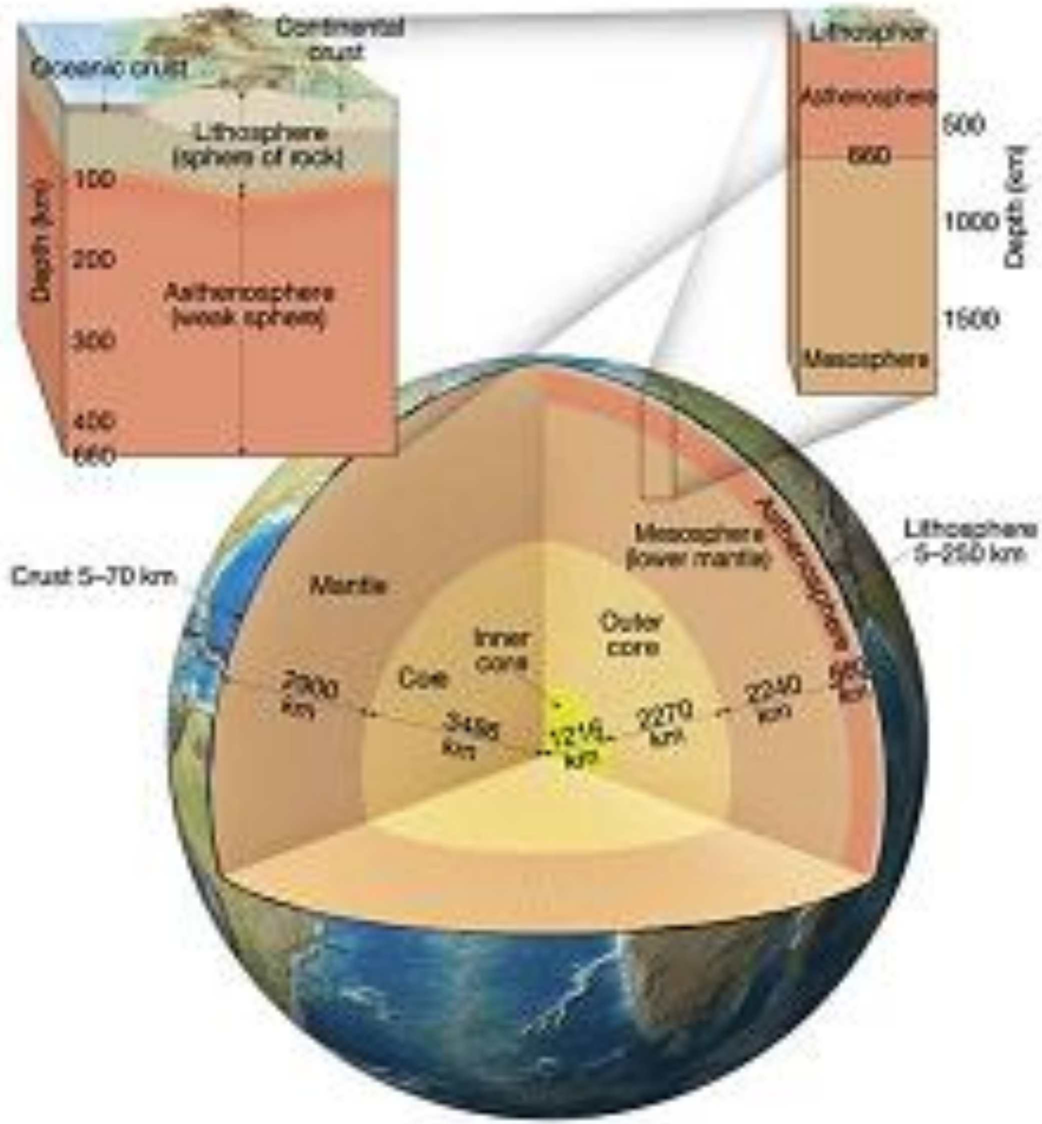
Earth's Internal Structure

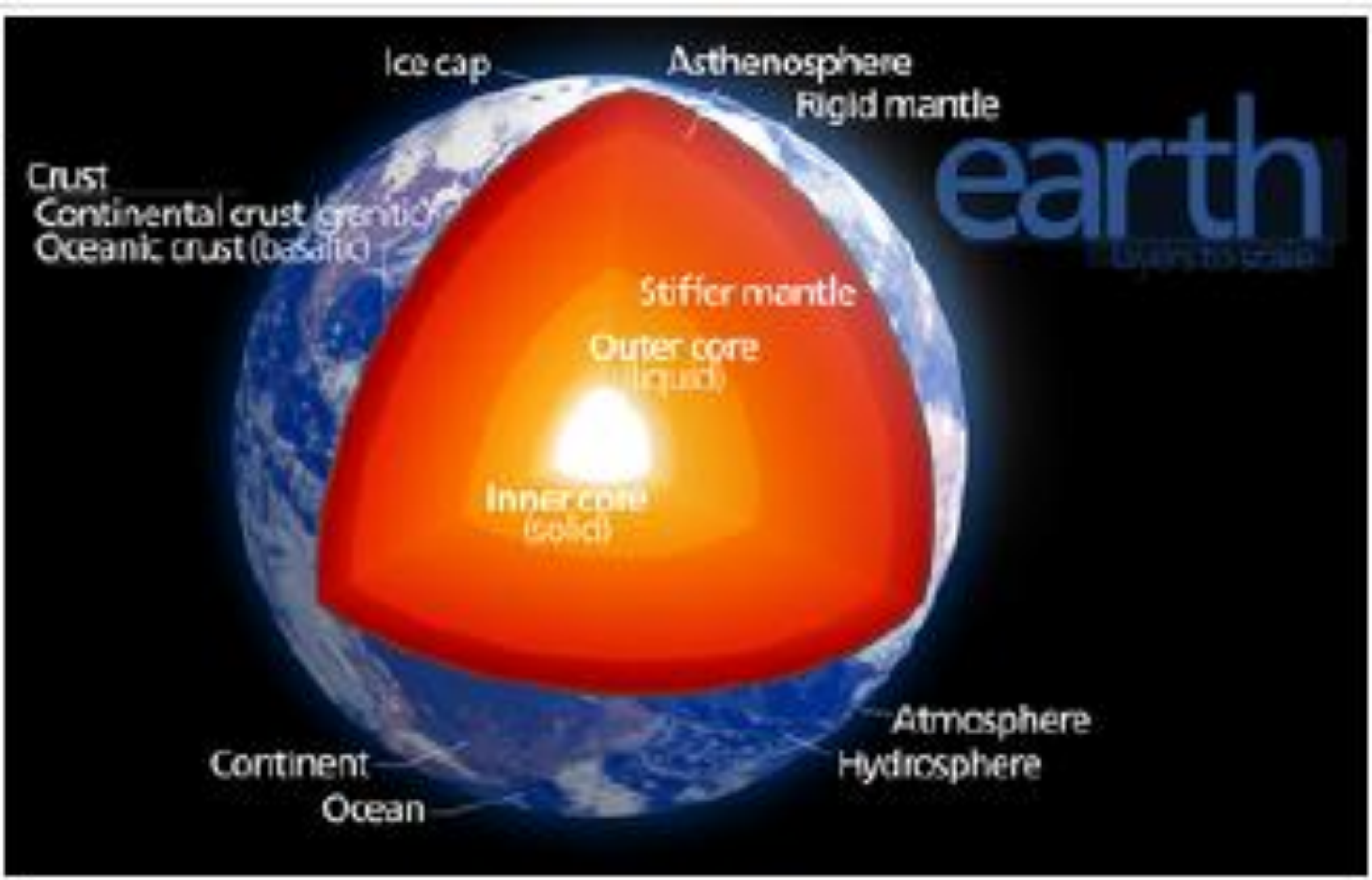
Mantle: comprises ~82% of the Earth by volume and is ~2900 km thick.

- The mantle is characterized by a change in composition from the crust.
- The mantle is able to flow (plastically) at very slow rates.

Core: composed of iron, nickel and other minor elements.

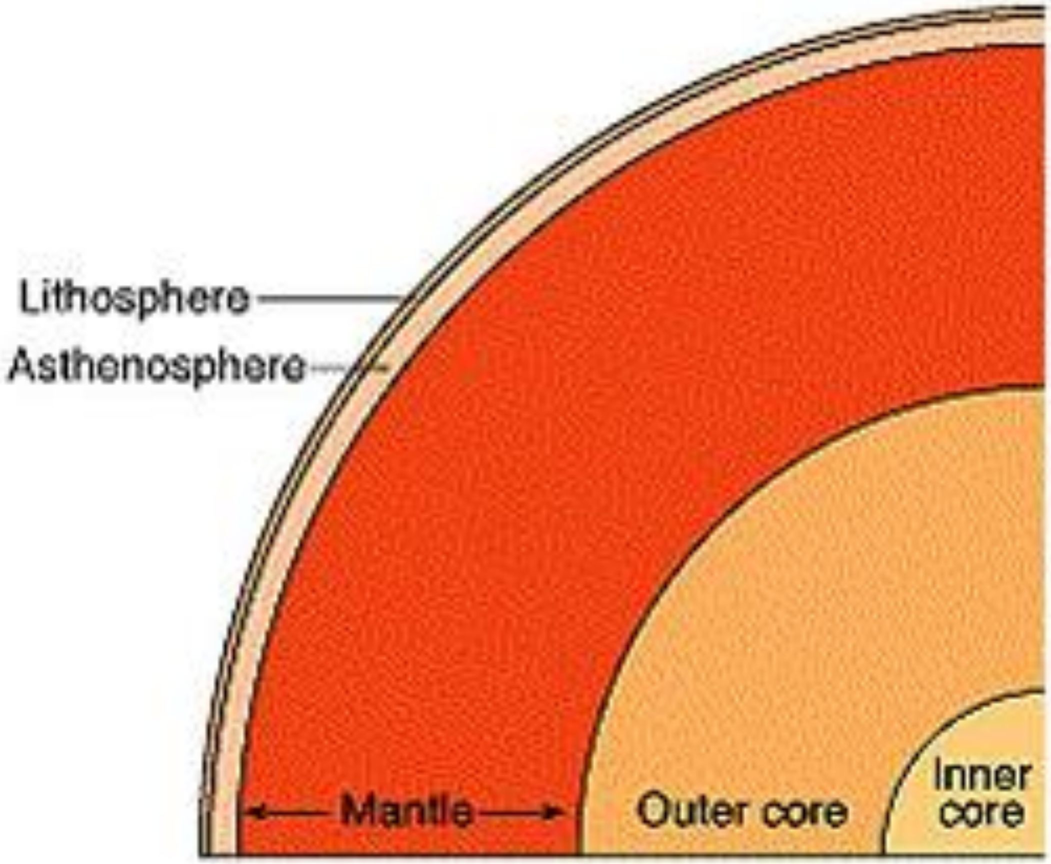
- The outer core is liquid — capable of flow and source of the Earth's magnetic field.
- The inner core is solid Fe-Ni. There is no major chemical difference between the outer and inner core.




Ice cap
Asthenosphere
Rigid mantle
earth
Crust
Continental crust
Oceanic crust (basaltic)
Stiffer mantle
Outer core
(liquid)
Inner core
(solid)
Atmosphere
Hydrosphere
Continent
Ocean

Lithosphere (0 to ~100 km)

The outer 75 km (with big variations between 10 and 300km) of the earth is a region which does not get heated up to near-melting because it is losing heat rapidly to the surface. This relatively cool shell is called the *lithosphere*. The lithosphere is fractured into a few large plates - just enough so that the movement of the plates can deliver interior heat to the surface particularly near the spreading boundaries, where two plates are moving apart, and new material wells up from depth.



1. Continental
2. Oceanic

Asthenosphere (~100 to 660 km)

- Radioactive decay causes the Earth to heat up on time scales of millions of years. In the course of tens/hundreds of millions of years, this heat production is enough to warm the interior by hundreds of °C.

- This heat is carried away by the convective circulation of the earth's interior. The convection delivers heat to the surface, so it can eventually be lost into space (The average geothermal heat flux through the earth surface is 70 mW/m^2)

- Most of the earth's interior is heated to a temperature > 300°C which makes it ductile, so that it is soft, and can flow like a viscous liquid. You have seen this behavior as glass is heated to near its melting point. The soft region (just below the lithospheric plates) is called the asthenosphere

Mesosphere / Lower Mantle (660 to 2900 km)

- Rock in the lower mantle gradually strengthens with depth, but it is still capable of flow.

Outer (2900 to 5170 km) and Inner Core (5170 to 6386 km)

- Outer core is liquid and composed of an iron-nickel alloy. Convective flow of this fluid generates much of the Earth's magnetic field.
- Inner core is solid iron-nickel alloy. It is hotter than the outer core, but the intense pressure keeps it solid.

Plate Tectonics

A relatively recent theory that the Earth's crust is composed ***of rigid plates that move relative to one another.***

Plate movements are on the order of a few centimeters /year -about the same rate as about the same rate as fingernails grow!

Major & Minor Plates

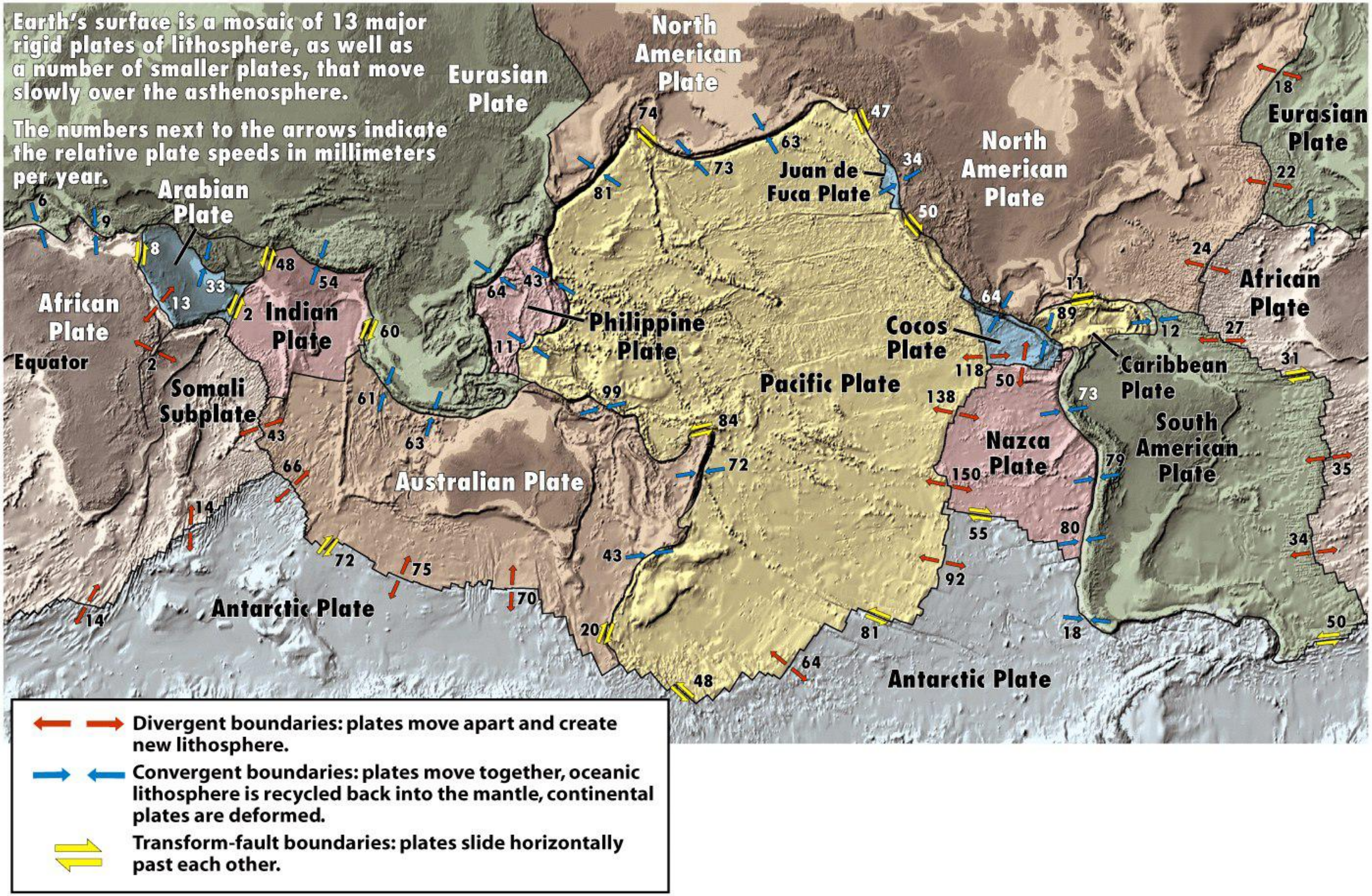


Figure 2-5

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Pacific Basin & Plate Boundaries

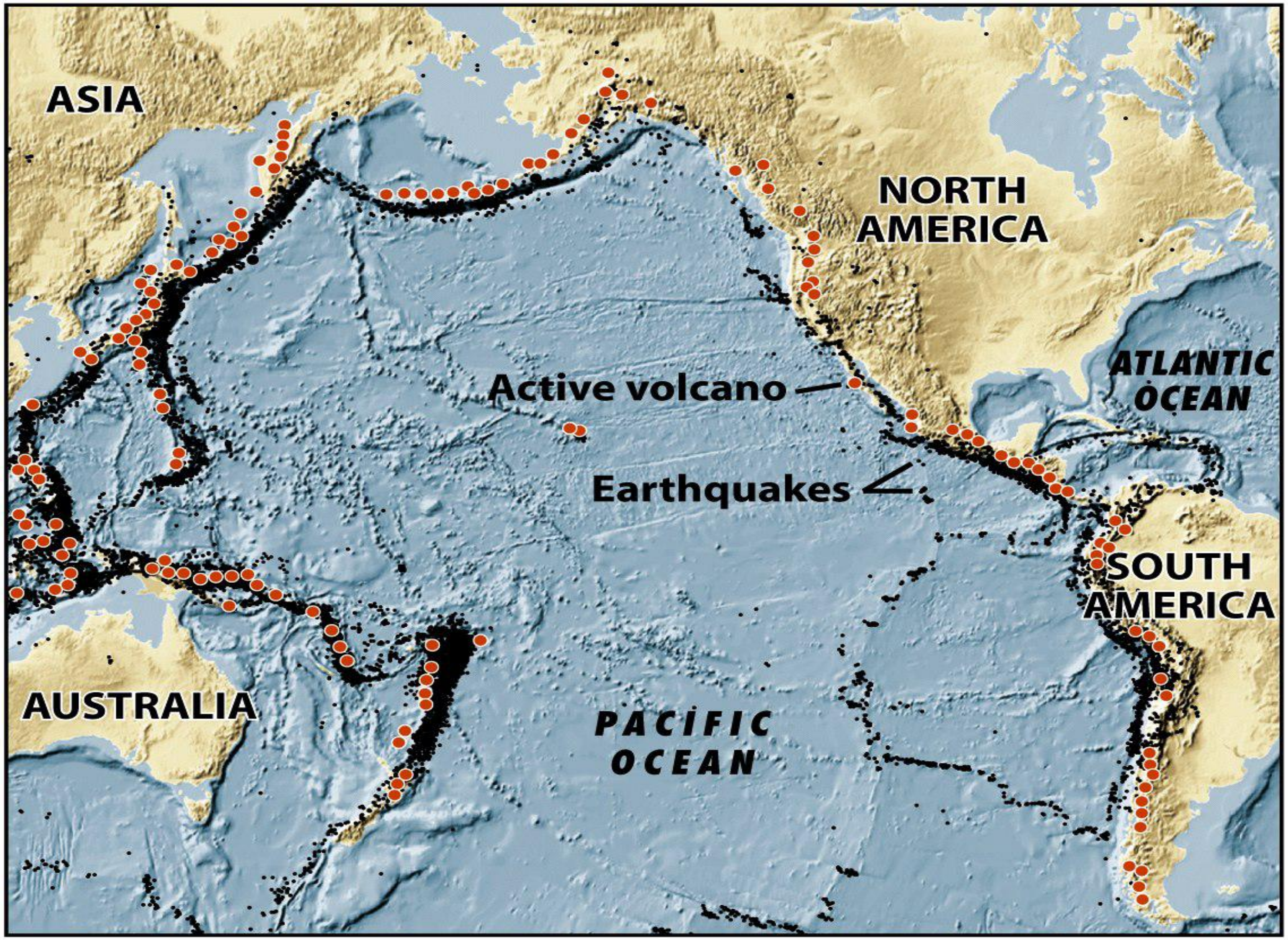

Figure 2-4
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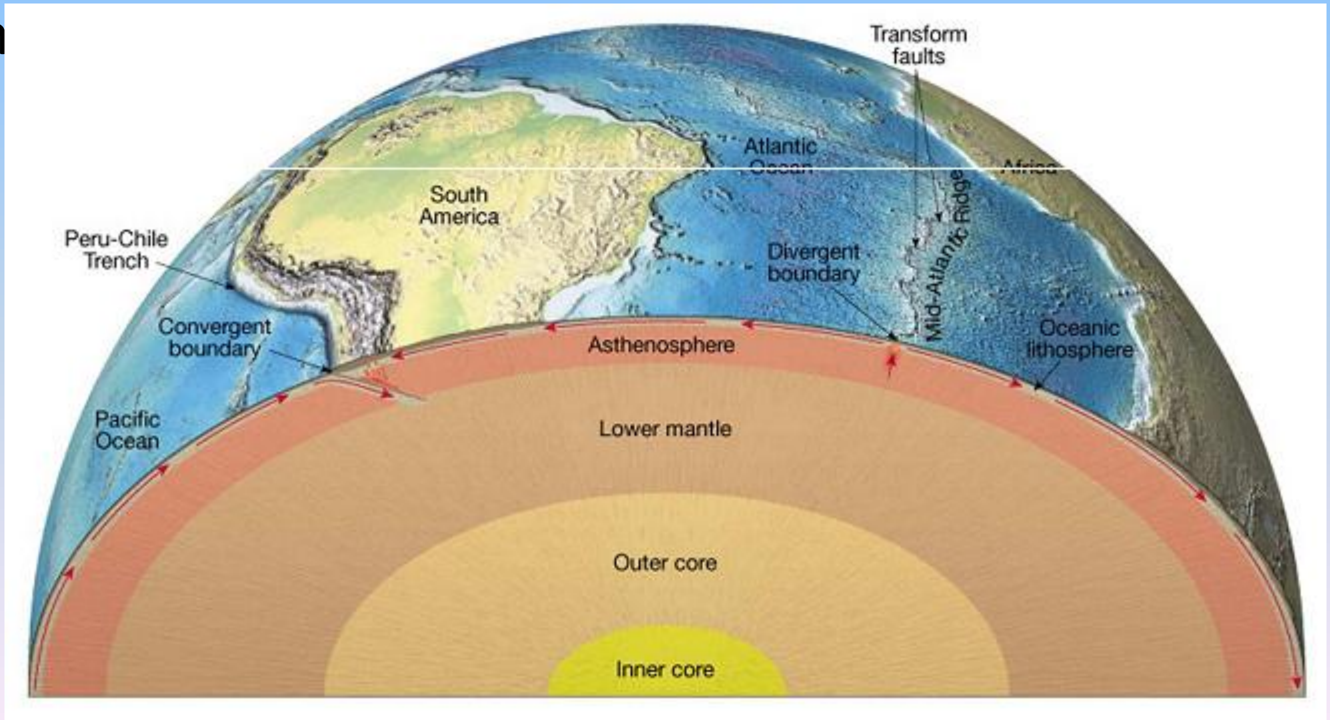
1. **Pacific plate boundary is often termed the "Ring of Fire".**
2. **Pacific is the only large plate that lacks a continent.**
3. **Although the east-Pacific ocean ridge has the fastest spreading rate, overall the Pacific plate is decreasing in area as the Atlantic ocean basin grows.**

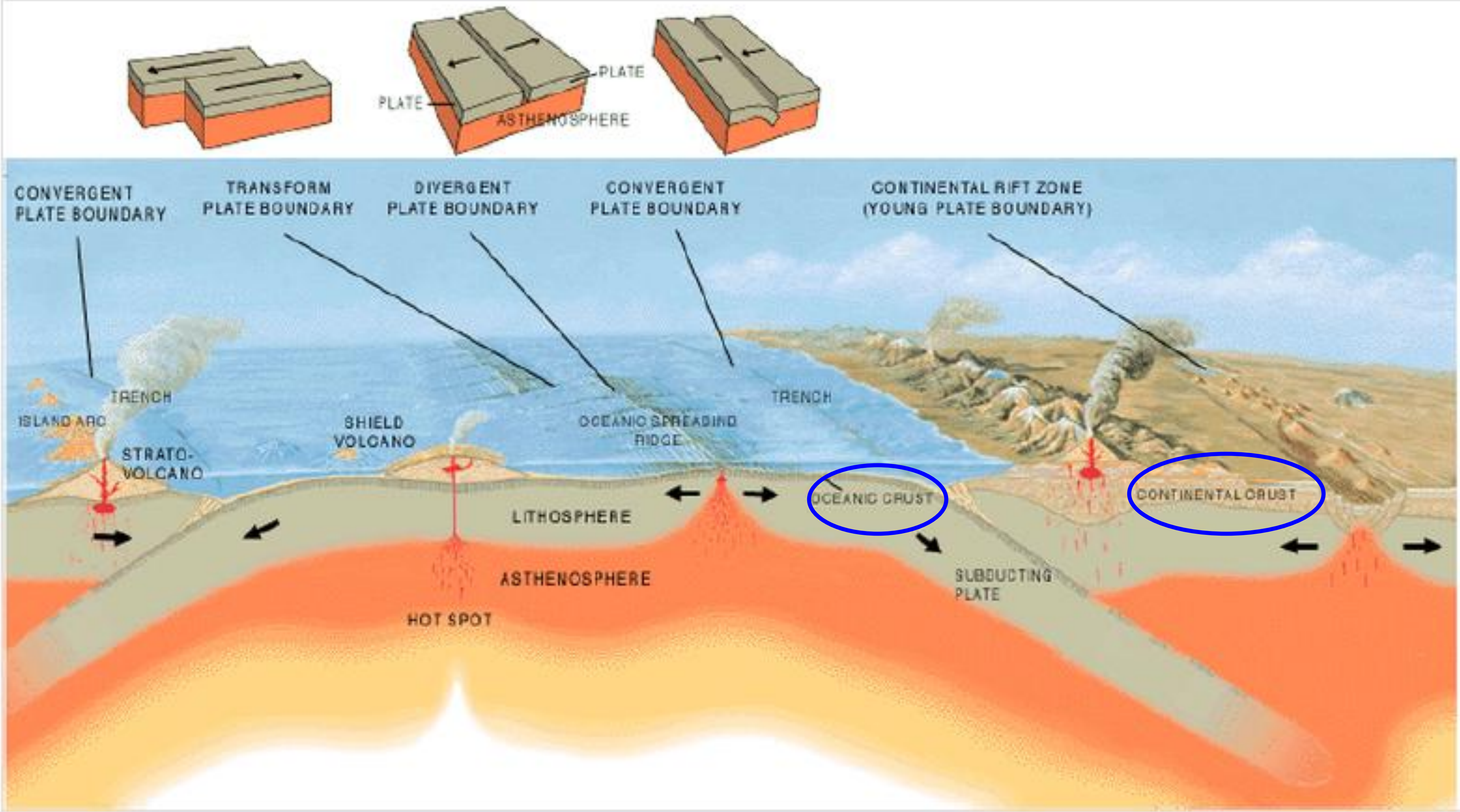
There are 3 types of plate Boundaries:

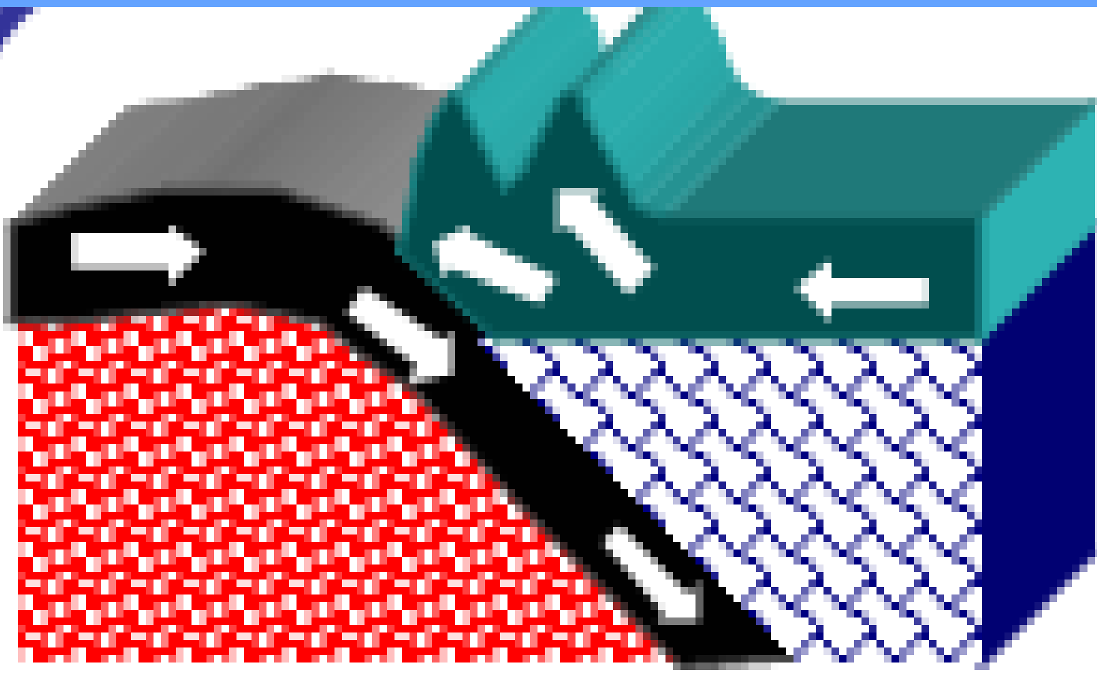
1. Divergent 2. convergent 3. transform

- **Convergent boundaries** - plates move together forming a subduction zone and mountain chains.
- **Divergent boundaries** - plates move apart forming the mid-ocean ridge and seafloor spreading.
- **Transform boundaries** - plates grind past one another. These boundaries subdivide the mid-ocean ridge and also form the San Andreas fault system

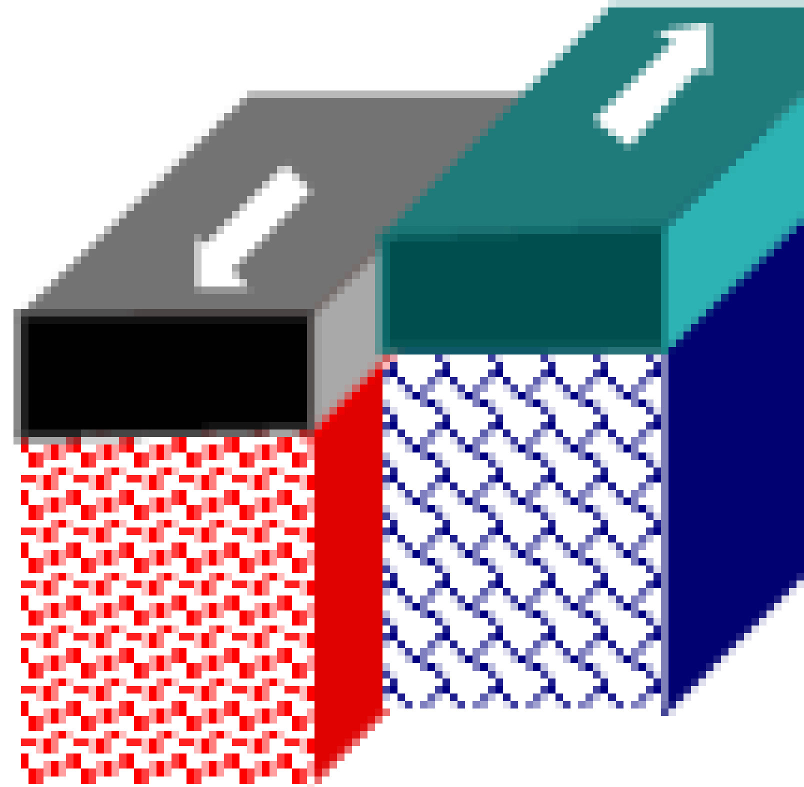


Tectonic Plate Boundaries

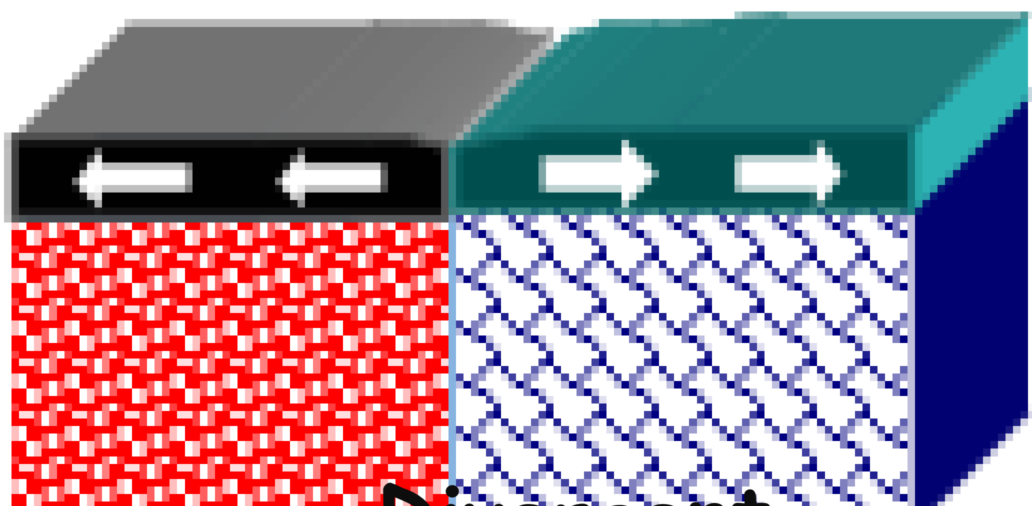




Convergent Boundary



Transform Boundary



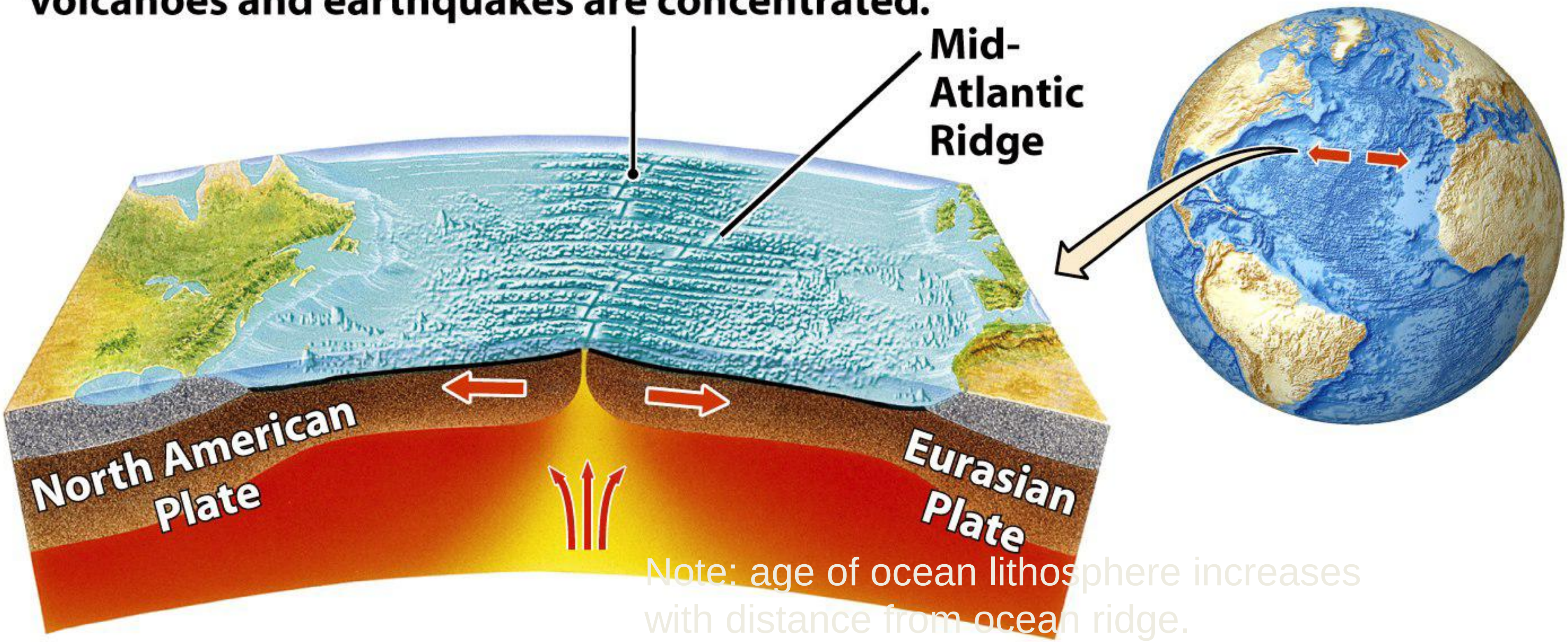
Divergent

Divergent Boundary Cross-Section

DIVERGENT BOUNDARIES

Oceanic Plate Separation

Rifting and spreading along a narrow zone have created the Mid-Atlantic Ridge, a mid-ocean mountain chain where volcanoes and earthquakes are concentrated.



Note: age of ocean lithosphere increases with distance from ocean ridge.

Figure 2-6a
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Divergent Continental Rift

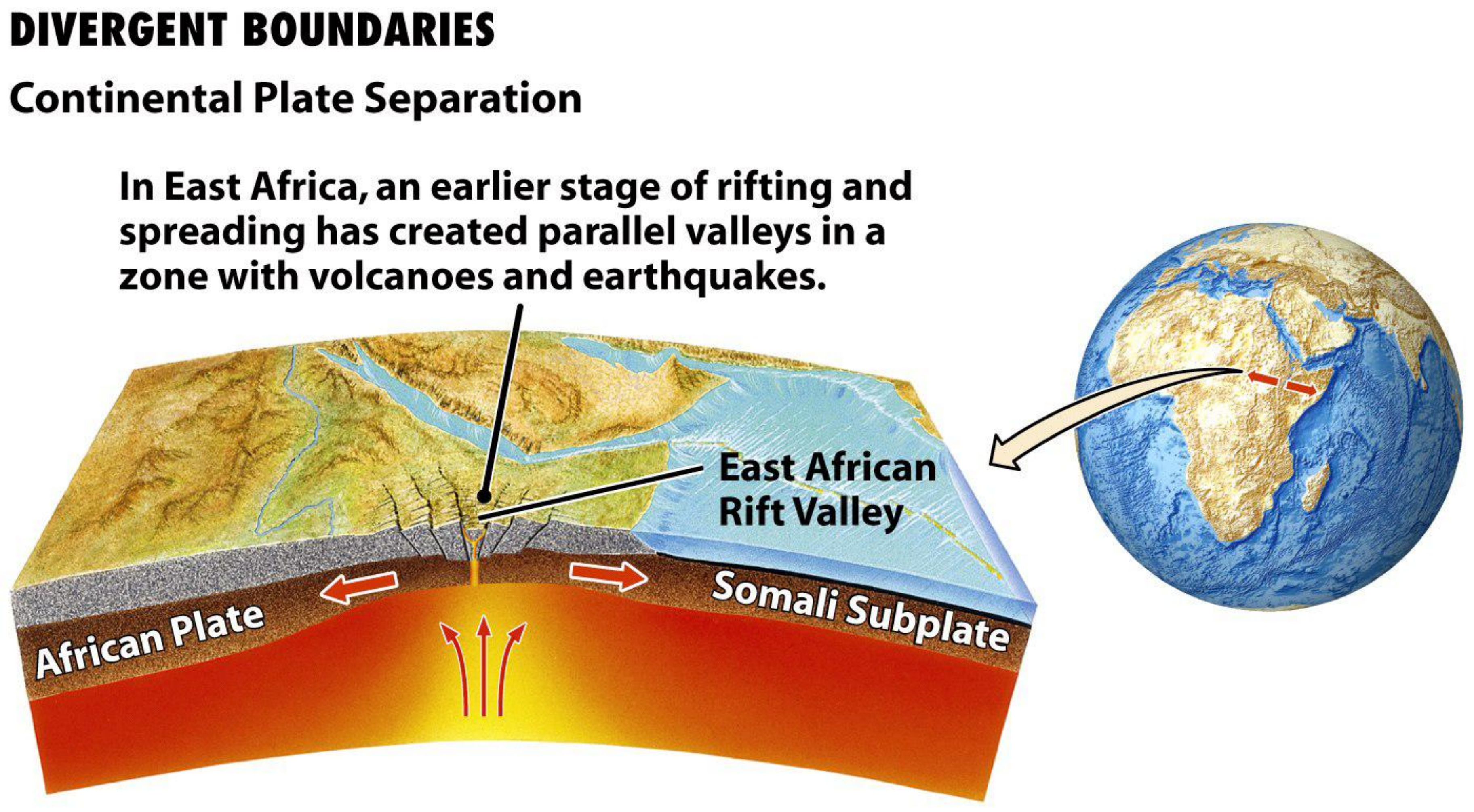

Figure 2-6b
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Convergent: Oceanic-to-Oceanic

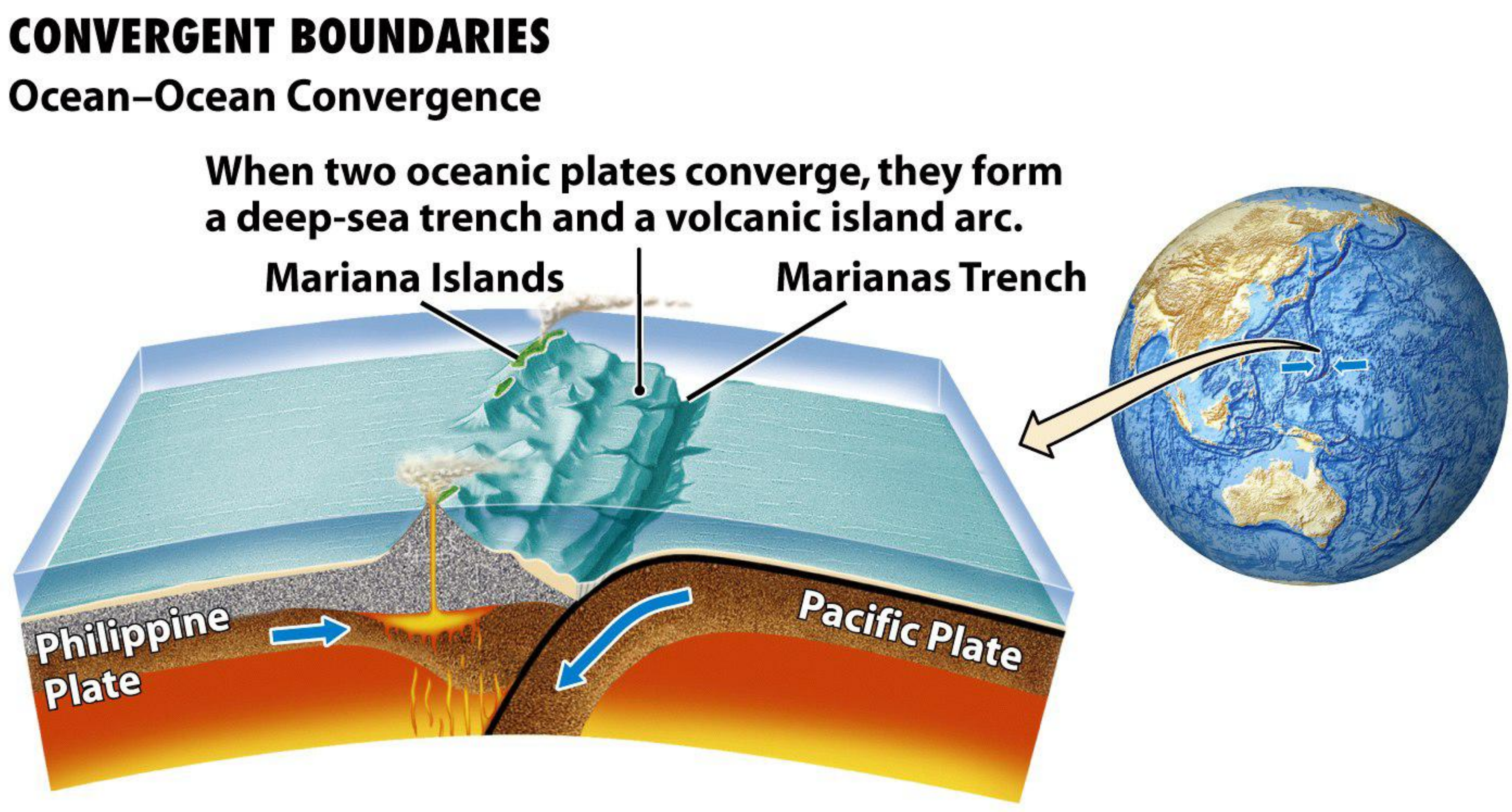

Figure 2-6c
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Andean-type: Oceanic-to-Continental

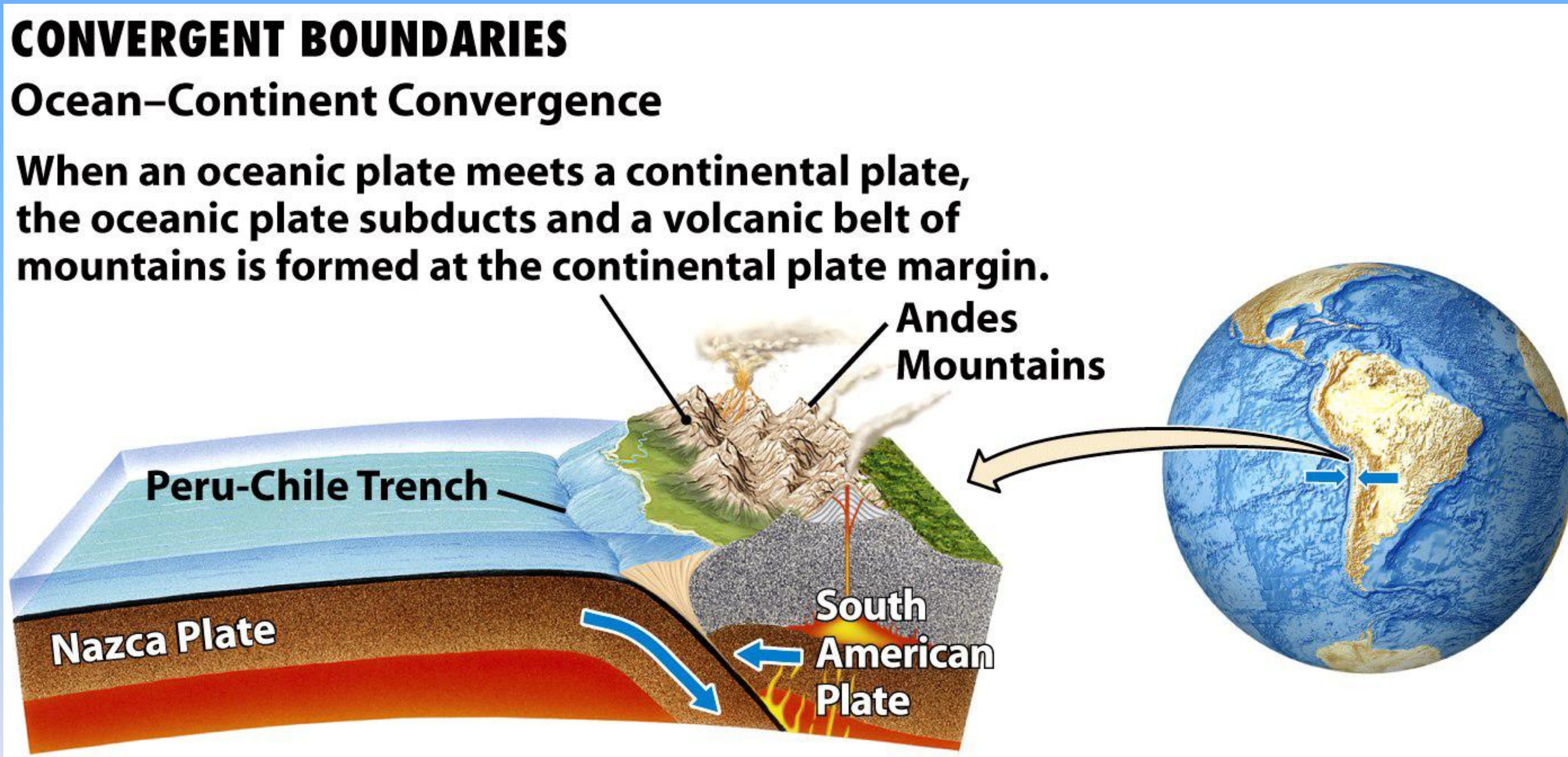

Figure 2-6d
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Transforms: Oceanic

TRANSFORM-FAULT BOUNDARIES

Mid-Ocean Ridge Transform Fault

Spreading centers are offset by mid-ocean ridge transform faults, where the two oceanic plates slide horizontally past each other.

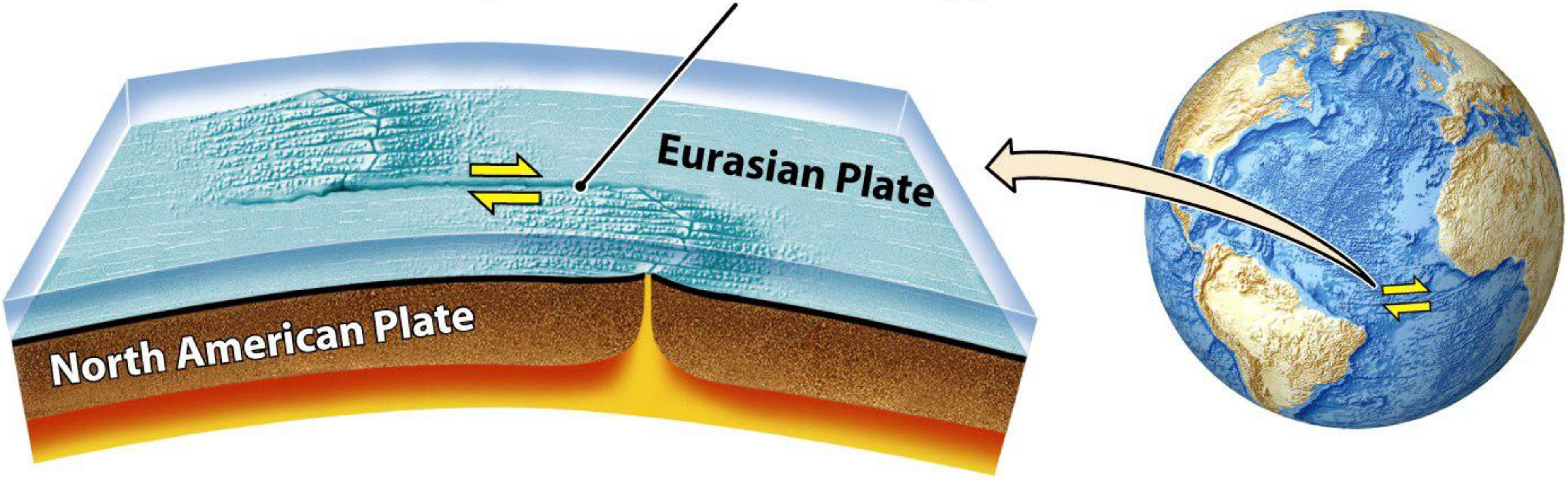

Figure 2-6f
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Transforms: Continental

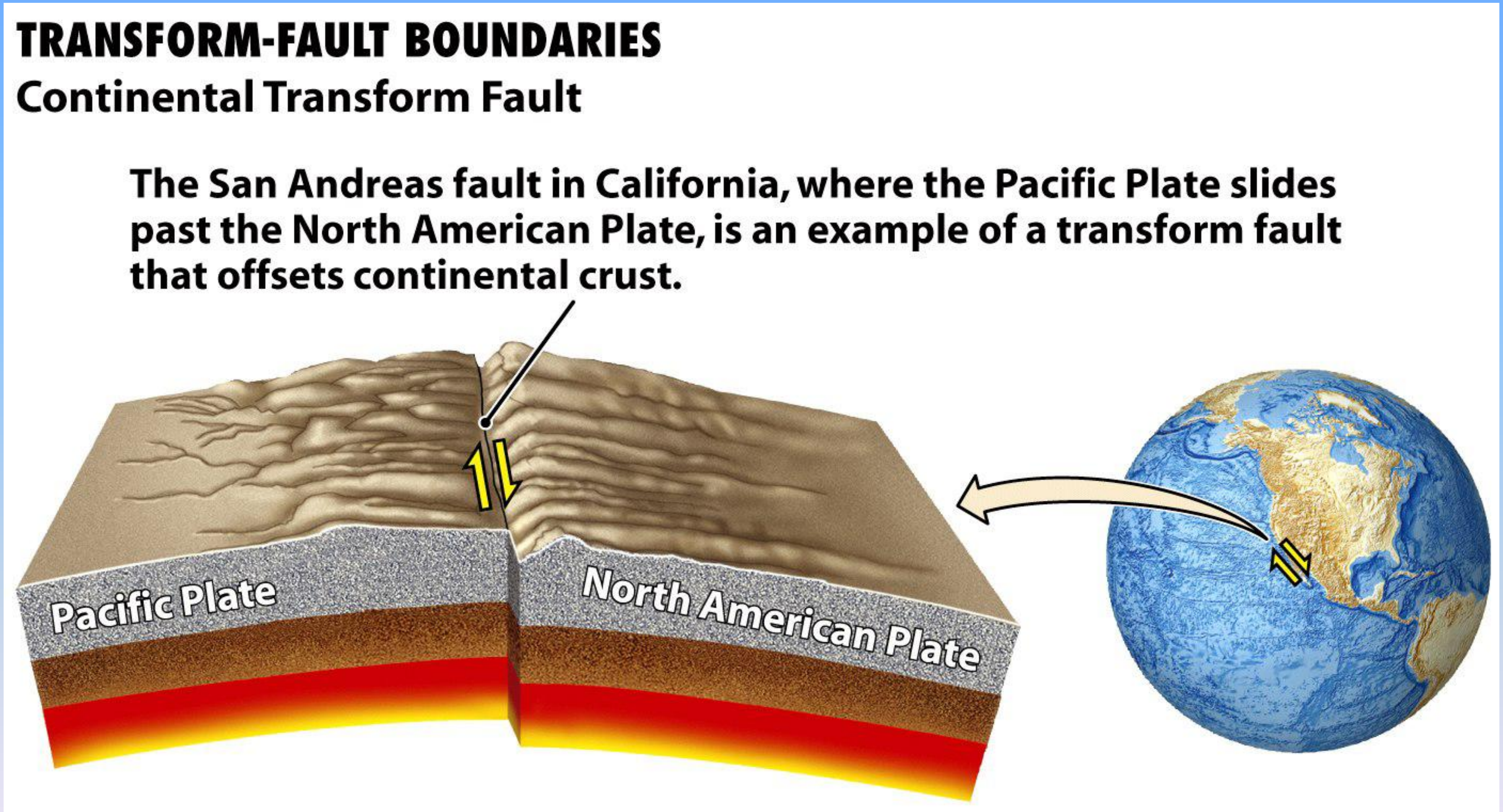

Figure 2-6g
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Plate Tectonics

- **Plate Tectonics: The Beginning**
  - Layers of the Earth
  - What are Tectonic Plates- movement?
  - **Tectonic Plate boundaries**
    1. Convergent boundary
       - Ocean-continent
       - Continent-continent
       - Oceanic-oceanic
       - Volcanism
    2. Divergent boundary
       - Sea-floor spreading
       - The Mid-Atlantic Ridge
       - Sea-floor Exploration and Age Dating
    3. Transform Boundary (San Andreas Fault, J. Tuzo Wilson)
- **Faults and Folds**
- **Plate movement over Geologic Time**
- **Creation and change of Landforms**
  - Volcanic eruptions (Mt. St. Helens)
  - Mountain building events (Appalachian vs. Himalayas)
- **Tectonics and the Ocean Floor**
  - Continental margins
    - Passive
    - Active

Plate Tectonics: The Beginning

Background

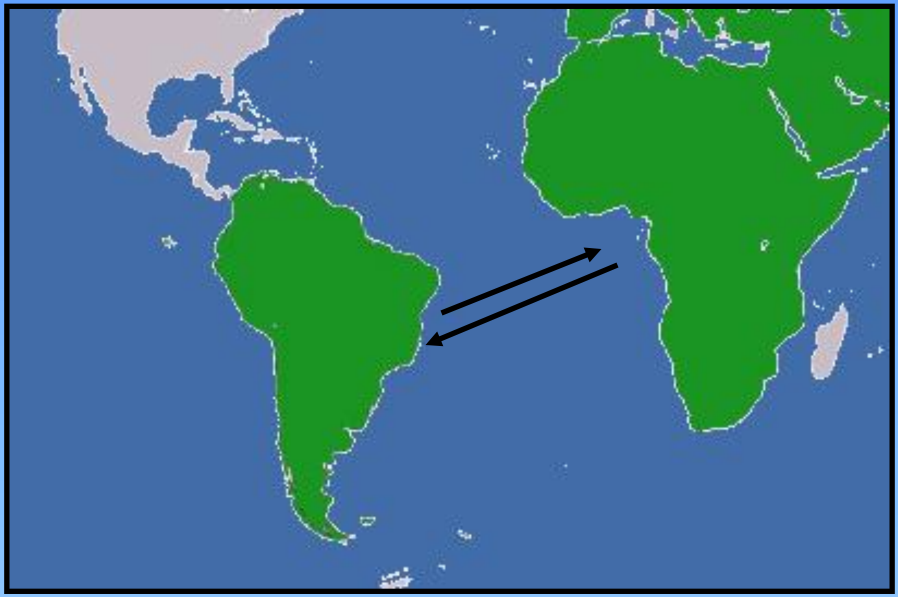
❖ At the beginning of the 20th Century, scientists realized that that they could not explain many of the Earth's structures and processes with a single theory. Many scientific hypotheses were developed to try and support the conflicting observations. One hypotheses was ***continental drift***, which was proposed by Alfred Wegener in a series of papers from 1910 to 1928.

❖ The principal thought of continental drift theory is that the continents are situated on slabs of rock, or plates, and they have drifted across the surface of the Earth over time; however, originally, they were all joined together as a huge super-continent at one time.

❖ In the 1960's, the theory of continental drift was combined with the theory of sea-floor spreading to create the theory of **plate tectonics**.

Plate Tectonics: The Beginning

❖ The idea for Wegener's theory was sparked by his observation of the nearly perfect **"fit"** of the South American and African continents.



The "fit" of two continents.

Additional evidence supporting the continental drift theory:

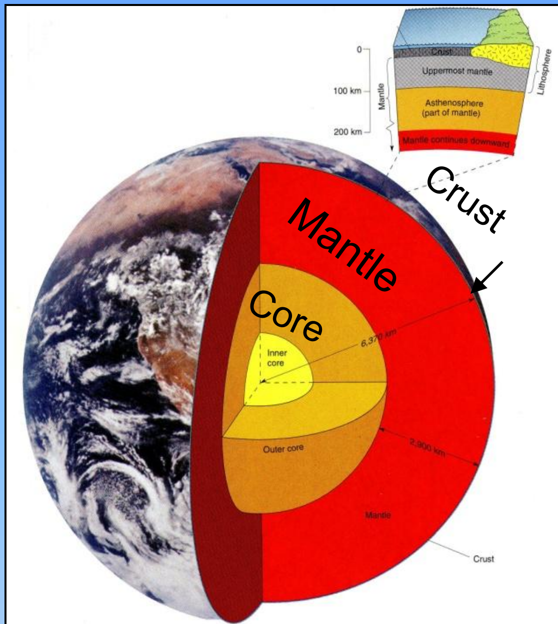
1. Fossils of the same plant (Glossopteris) found in Australia, India, Antarctica and South America.

2. Fossils of same reptile (Mesosaurus) found in Africa and South America. This animal could not have swum across the existing Atlantic Ocean!

3. Glacial deposits found in current warm climates and warm climate plant fossils found in what is now the Arctic.

4. Nearly identical rock formations found on the east coast of U.S. and the west coast of Europe and eastern South America and western Africa.

What are Tectonic Plates?



The layers of the earth.
Modified after Plummer/McGeary, 7th ed., pg. 14

The Earth is made up of three main layers:

1. The **Core** is at the center of the Earth. It is divided into an inner and outer core.
2. The **Mantle** is the layer surrounding the core. The upper mantle is partially molten and called the asthenosphere.
3. The **Crust**, or lithosphere, is the rigid outer-most layer. Thick continental crust underlies continents, and thin, very dense oceanic crust underlies oceans.

	Inner Core	**Outer Core**	**Mantle**	**Crust**
Thickness	1,216 km	2,270 km	2,900 km	Continental 35-90 km Oceanic 7-8 km
Physical Properties	Solid Iron; extremely dense (17 g/cm^3)	Molten Iron, very dense (12 g/cm^3)	Made mostly of silicates of magnesium and iron; moderately dense. Behaves like melted plastic in upper-most section (5.5 g/cm^3)	Made of silicate rocks and oxides; slightly dense; rigid. (2.67-3.3 g/cm^3)
Percentage of Earths' Mass	30%		65%	5%

What are Tectonic Plates? (continued)

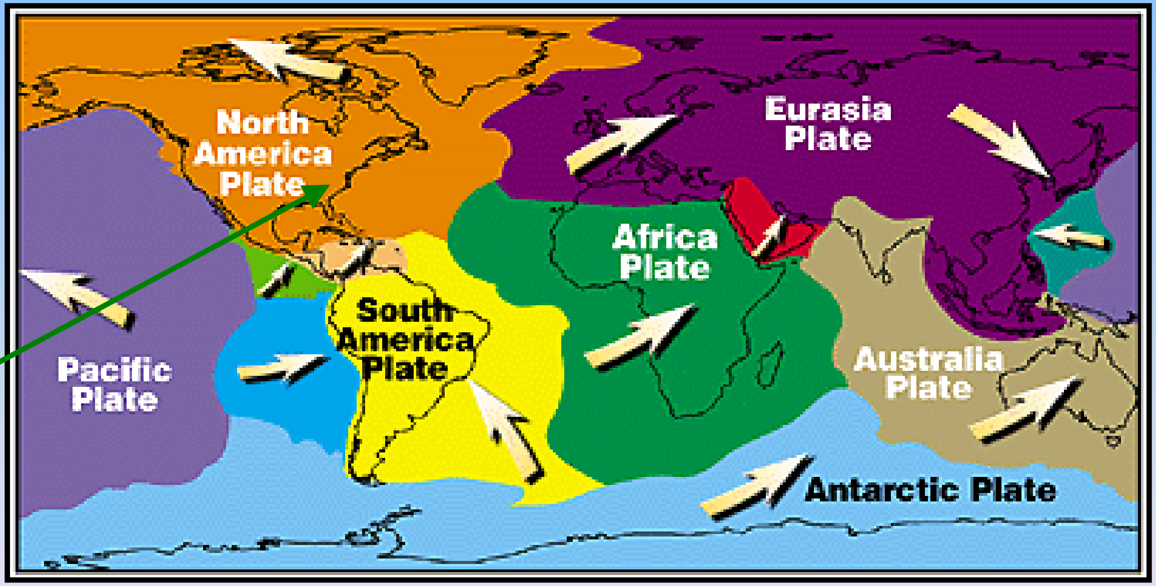
❖ The Earth's crust consists of about a dozen large slabs of rock, or **PLATES**, that the continents and oceans rest on. These tectonic plates can move centimeters per year— about as fast as your fingernails grow up to 15cm/yr in some places.

❖ Tectonic plates are also called **lithospheric plates** because the crust and the upper-most mantle make up a sub-layer of the earth called the lithosphere. The plates can move about because the uppermost mantle, or the asthenosphere, is partially molten and possesses a physical property called plasticity, allowing the strong, rigid plates of the crust to move over the weaker, softer asthenosphere.

Plates and relative plate motion.

Modified after NOAA

South Carolina is located on the North American plate



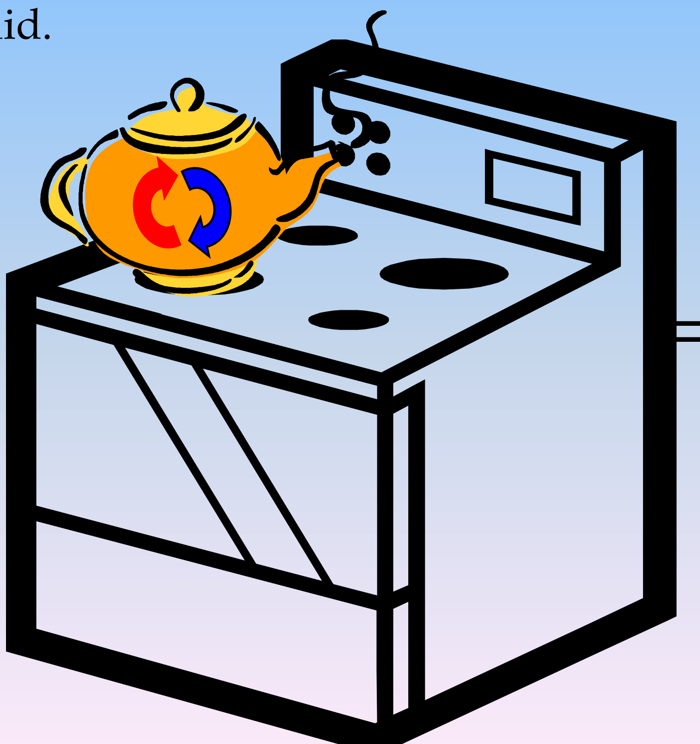
❖ The word TECTONICS is of Greek origin and it means "to build." The word "tectonism" refers to the deformation of the lithosphere. This deformation most notably includes mountain building.

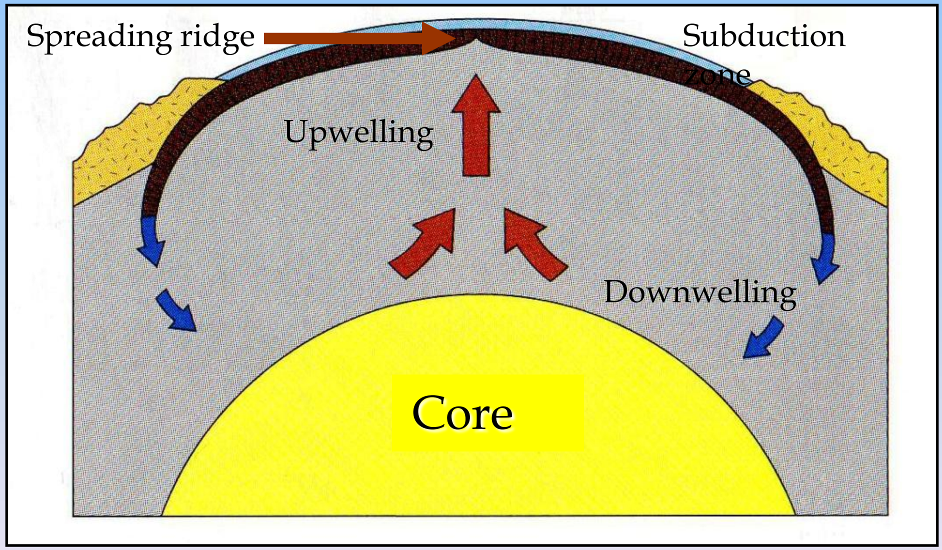
What are Tectonic Plates? (continued)

❖ Tectonic plates, or lithospheric plates, are constantly moving, being created, and consumed simultaneously. The motion sometimes results in earthquakes, volcanoes, and mountain ranges at the plate boundaries.

❖ Plate motion is driven by heat escaping from the mantle. The constant movement of heat in the mantle leads to circular convection currents. These hot convective cells are similar to the rolling boil that occurs when water is heated on a stovetop. The flowing mantle has also been compared to a "conveyor belt," moving the rigid plates in different directions.

❖ Fundamentally, convection occurs due to uneven heating and different densities within the liquid.





Convection currents within the mantle.
Modified after Plummer/McGeary, 7th ed., pg. 15

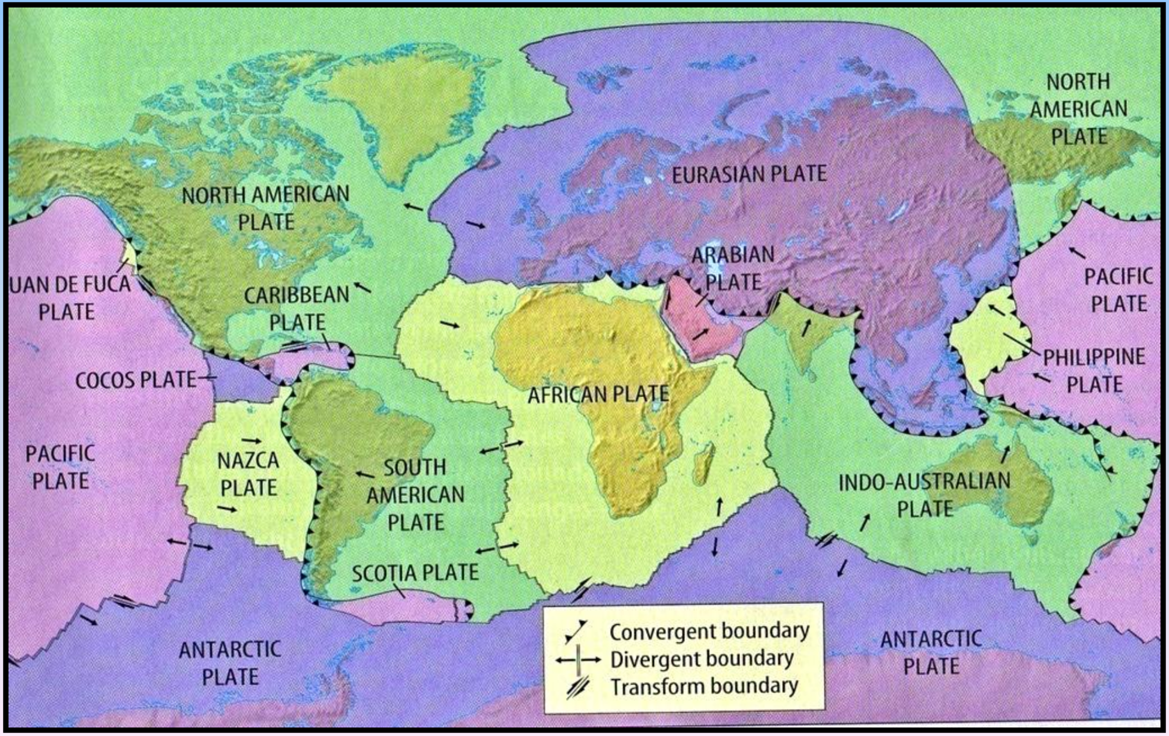
Plate Boundaries

There are three basic ways that plates interact with one another. Each of these plate boundaries has the potential to create different geological features.

1. When plates **collide** with each other **= Convergent boundary**

2. When plates **separate** from each other **= Divergent boundary**

3. When plates **slide** along side each other **= Transform boundary**



The tectonic plates and plate boundaries.

McGraw Hill/Glencoe, 1st ed., pg 143

1. Convergent Boundary:
Ocean-Continent Collision

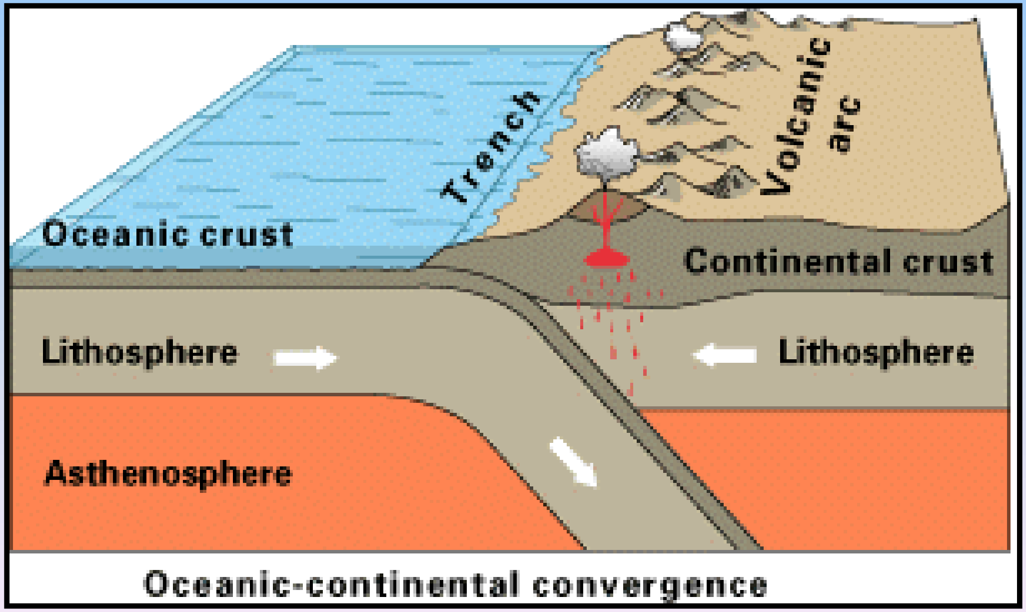
❖ Because the oceanic crust is more dense than continental crust, when these two collide, the continental crust rides up over the oceanic crust and the oceanic crust is bent down and subducted beneath the continental crust. This is called a subduction zone, where the old oceanic crust is dragged downward and "recycled."

❖ Deep-sea trenches are created at subduction zones. Trenches are narrow, deep troughs parallel to the edge of a continent or island arc. They typically have slopes of 4-5 degrees, and they are often 8-10 km deep. The deepest spots on earth are found in oceanic trenches. The Mariana Trench is the deepest ocean depth at 11 km (35,798 ft) below sea level.

Figure depicting oceanic crust subducting beneath continental crust, creating volcanoes on the land surface above, and a deep-sea trench off of the coast.

Credit: U.S. Geological Survey

Department of the Interior/USGS

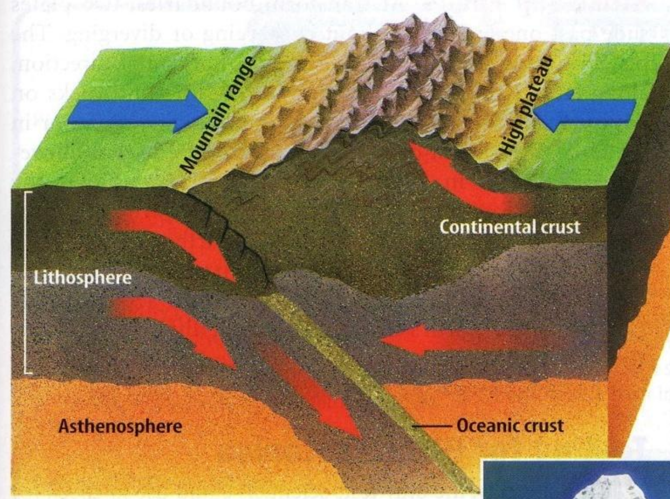


Convergent Boundary:
Continent-Continent Collision

❖ If two continental plates collide, mountain building usually takes place because they are both relatively low in density.

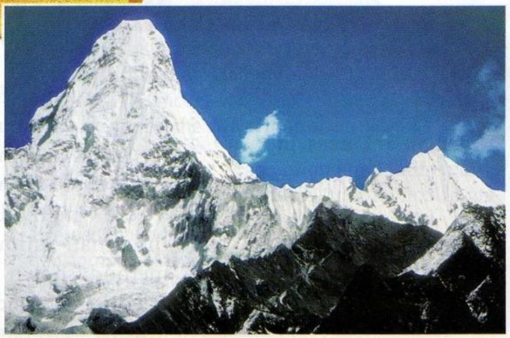
❖ Earthquake activity at these boundaries is common; however, because igneous activity is different from ocean-continent collisions, volcanoes are rare.

❖ Examples: The Himalayan and the Appalachian mountain chains.



Constructive mountain building during continent-continent collision.

McGraw Hill/Glencoe, 1st ed., pg 149



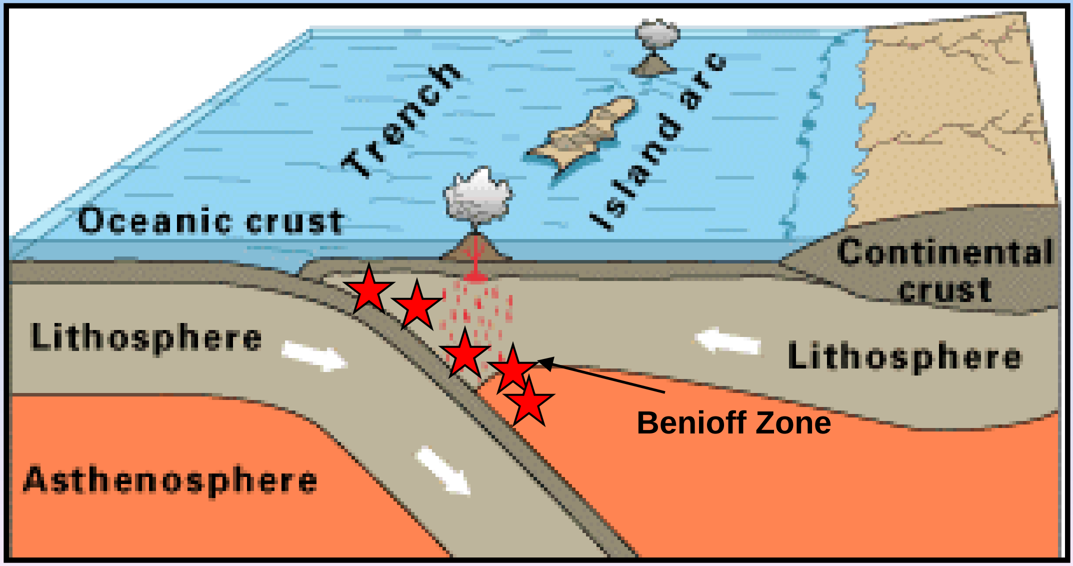
The Himalaya mountains are still forming today as the Ind-Australian Plate collides with the Eurasian Plate

Convergent Boundary:
Ocean-Ocean Collision

❖ If 2 oceanic plates collide, the older, denser one is subducted downward into the mantle and a chain of volcanic islands can form, called a volcanic arc.

❖ Example: Mariana Islands (Mariana Trench). It is deeper than the earth's tallest mountain is tall. Mariana Trench: 11,000 meters deep. Mt. Everest: 8850 meters high.

❖ The interaction of the descending oceanic plate causes incredible amounts of stress between the plates. This usually causes frequent earthquakes along the top of the descending plate known as the "Benioff Zone." The focii of Benioff earthquakes can be as deep as 700 km below sea level.



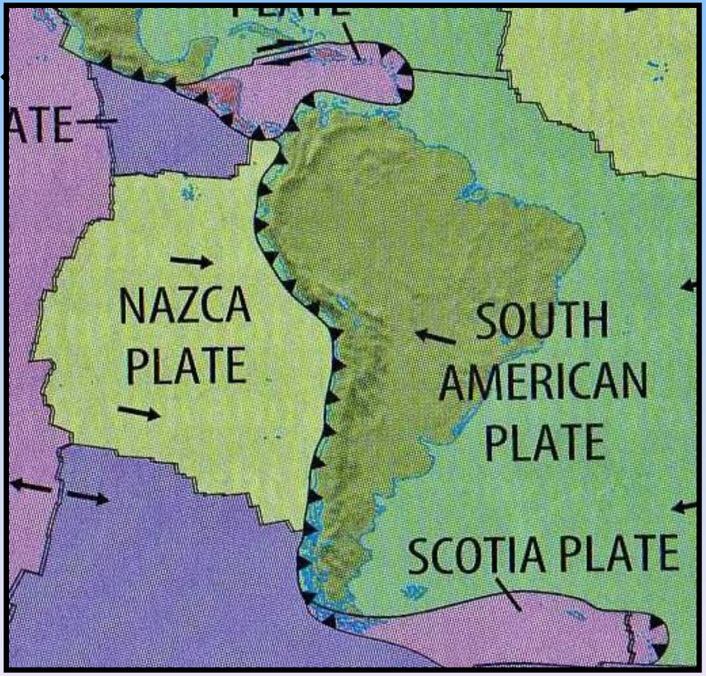
Oceanic/oceanic collision resulting in a chain of island arcs.

Credit: U.S. Geological Survey Department of the Interior/USGS

Convergent Boundary: Volcanism

❖ Most volcanoes form above subduction zones because as one slab is subducted beneath the other, the interaction of fluids and geothermal heat form new magma. The new magma then rises upward through the overlying plate to create volcanoes at the surface.

❖ The Andes Mountains are home to many volcanoes that were formed at the convergent boundary of the Nazca and South American Plates.



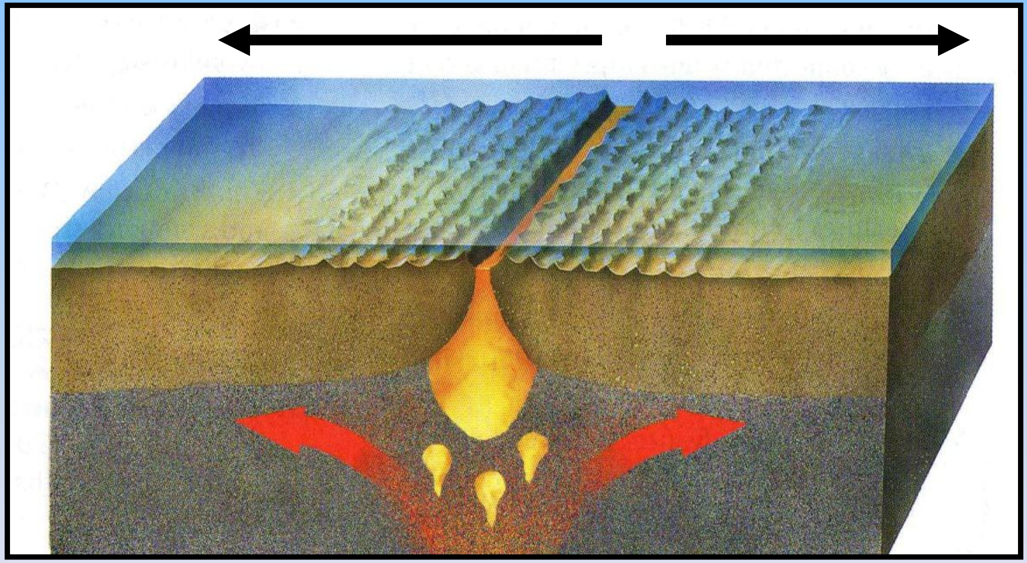
Left: Image of the Nazca Plate subducting beneath the South American Plate.
Modified after McGraw Hill/Glencoe, 1st ed., pg. 143

Right: Red dots indicate general locations of volcanoes along western coast of South America.

2. Divergent Boundary: Sea-floor Spreading

❖ At a divergent boundary, two oceanic plates pull apart from each other through a process called **sea-floor spreading**.

❖ Sea-floor spreading was proposed by Harry Hess in the early 1960's. Hess proposed that hot magma rises from the asthenosphere and up into existing ocean crust through fractures. The crust spreads apart making room for new magma to flow up through it. The magma cools, forming new sea floor and resulting in a build-up of basaltic rock around the crack, which is called a mid-ocean ridge.



Sea-floor spreading at an oceanic divergent boundary.

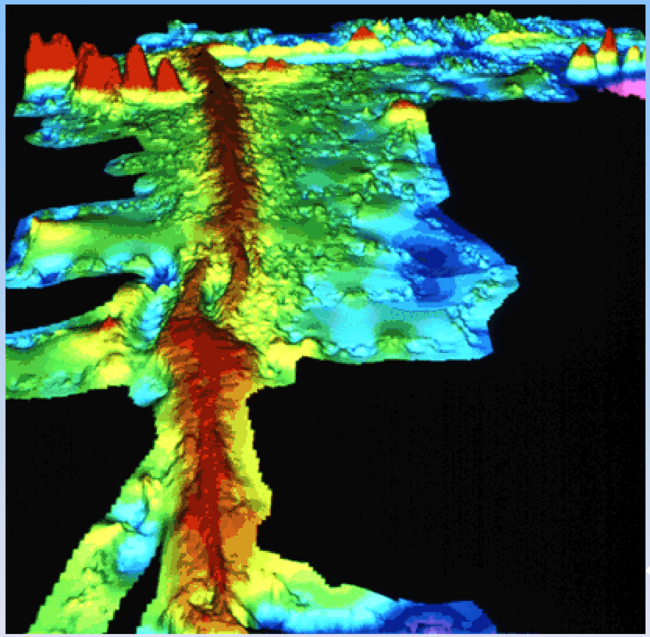
Modified after McGraw Hill/ Glencoe, 1st ed., pg. 138 (with permission)

❖ New material is constantly being created. This is the opposite of a convergent boundary, where material is constantly being destroyed.

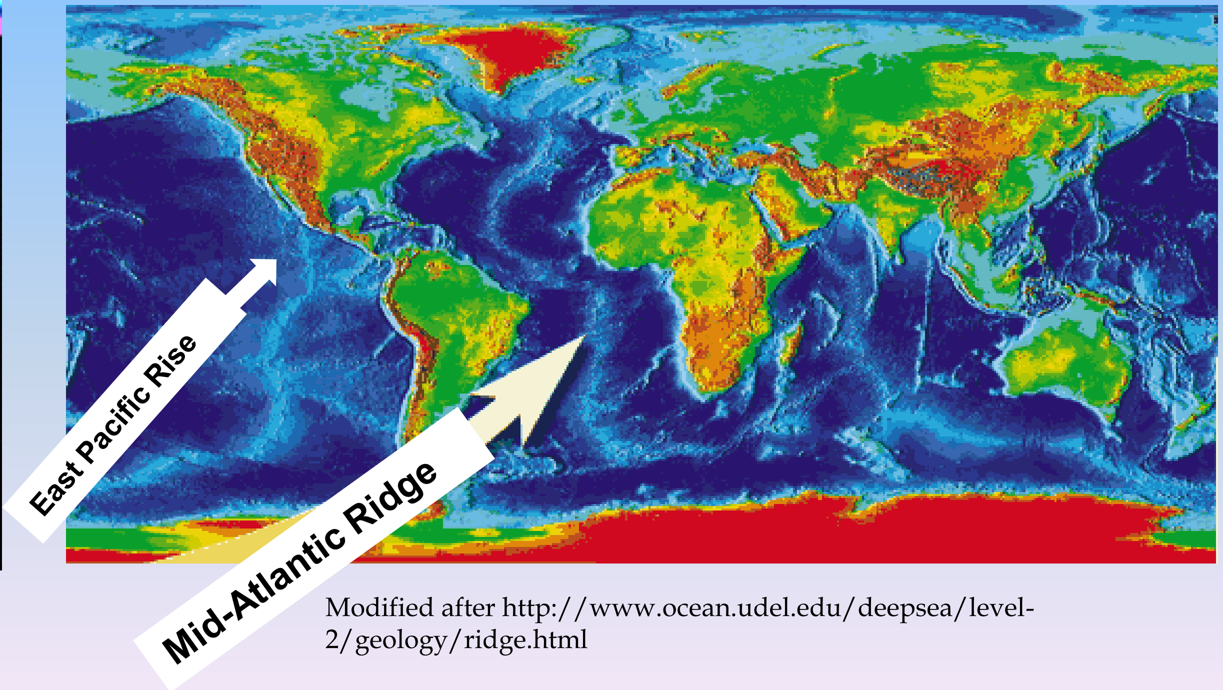
Divergent Boundary: Mid-Atlantic Ridge

❖ The world's longest mountain chain is underwater. It is 56,000 km long and is called the Mid-Atlantic Ridge.

❖ The Mid-Atlantic Ridge is considered a slow-spreading ridge, spreading at about 1-2 centimeters per year. An example of a fast-spreading ridge is the East Pacific Rise, which spreads at about 6-8 centimeters per year.



Satellite bathymetry of the East Pacific Rise spreading ridge. *Credit: U.S. Geological Survey Department of the Interior/USGS*



Modified after http://www.ocean.udel.edu/deepsea/level-2/geology/ridge.html

Sea-floor Exploration

❖ The Deep Sea Drilling Project (DSDP) began in 1968 aboard the research vessel Glomar Challenger. This ship was outfitted with a drill rig capable of drilling into the ocean floor beneath many kilometers of water.

❖ Before this type of research was available, scientists had to rely on dredging or grabbing single rock samples from line weights on boats.

❖ Scientists quickly determined that continental crust is thicker than oceanic crust, that continental crust is less dense than oceanic crust, and that the youngest seafloor is located at mid-ocean ridges and increases in age with distance from the ridge.

❖ Before technology like this, most people thought the ocean floor was flat and smooth. This is understandable as 2/3 of the Earth's surface lies under oceans.

The Glomar Challenger (1968)

Credit: U.S. Geological Survey
Department of the Interior/USGS

Sea-floor Exploration

❖ In the mid-1960's, magnetometer surveys at sea indicated that alternating magnetic anomalies existed within marine rock. These anomalies were aligned parallel to the Mid-Atlantic Ridge forming stripe-like patterns on the sea floor, and they were symmetrically distributed on either side of the Mid-Atlantic Ridge.

❖ Geologists Fred Vine and Drummond Matthews first noticed these symmetric patterns of magnetic "stripes" and concluded that this pattern of magnetic anomalies at sea matched the pattern of magnetic reversals over time.

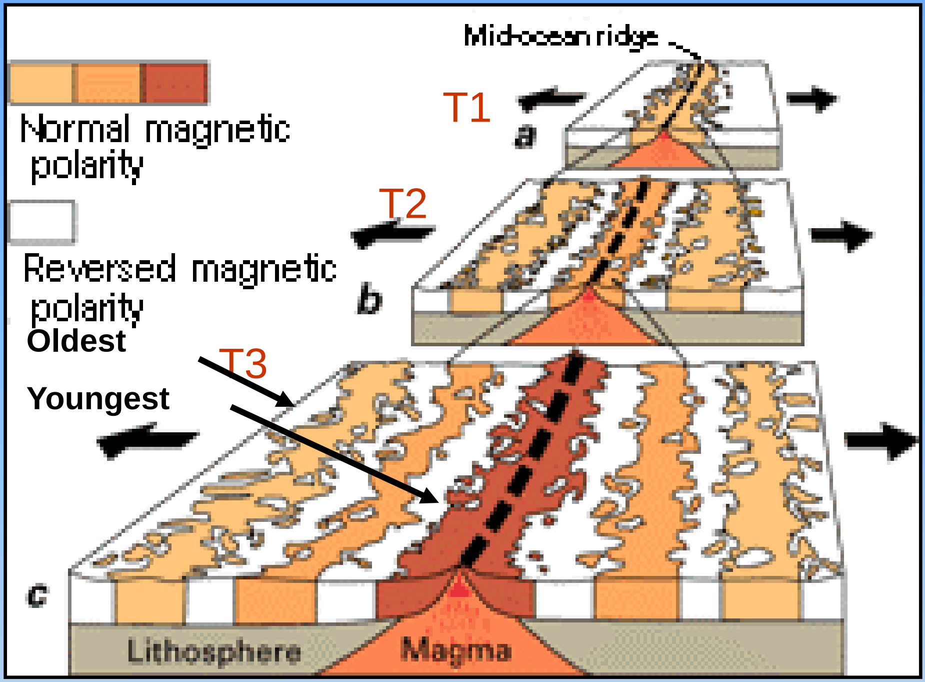
❖ The Earth's magnetic field flows from a southerly direction to northerly direction. This is what makes the arrow on our compasses point towards north.

❖ The Earth's magnetic field has changed over the past 100 million years approximately once every 250,000 years. When the magnetic field "reverses" from today's "normal" N-S direction it becomes a period of magnetic reversal. The normal magnetic field is considered a positive anomaly, and, when the magnetic field is reversed, it is considered a negative anomaly.

Sea-floor Exploration: Age-dating

- The relative age of the sea floor can be determined by changes in magnetic polarities of the earth.

- These periods of normal and reversed polarity are recorded in the magnetic minerals within the newly formed sea floor at mid-ocean ridges. Scientists can see a clear pattern of normal and reversed magnetization in the rock record that shows up as "magnetic stripes" on either side of mid-ocean ridges, which gives them a relative time of how old the sea floor is and lets them compare ocean basins to each other.



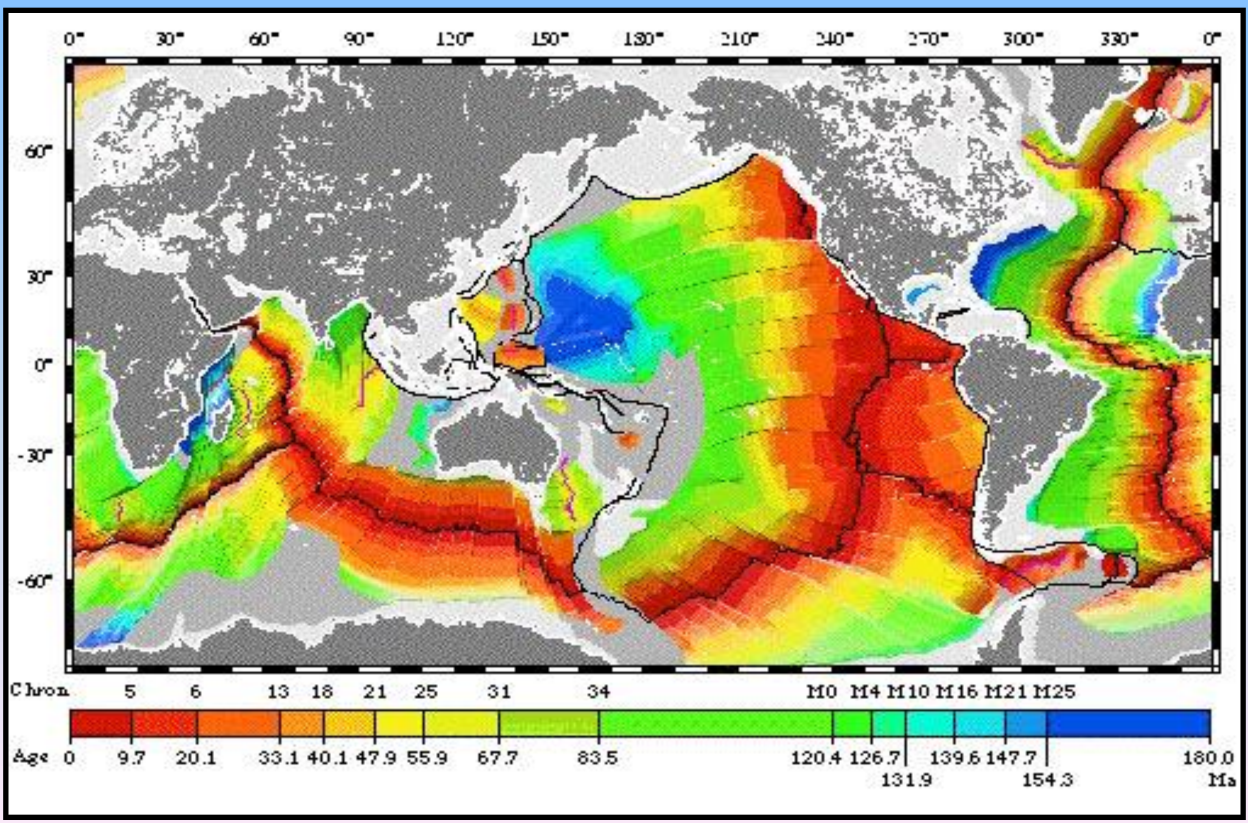
Above: Figure depicting magma flowing out from a spreading ridge, cooling and spreading out symmetrically about the ridge to produce successively older rock as you travel in either direction from the ridge. The magnetized minerals within the rock "tell" how old it is.

Credit: U.S. Geological Survey
Department of the Interior/USGS

Sea-floor Exploration: Age-dating

❖ The oldest oceanic crust found is ~ 180 million years old.

❖ Because the age of the earth is ~4,600 million years, we know that oceanic crust is continually being formed at spreading ridges and being destroyed at subduction zones. The ocean floor is constantly changing shape and size through the processes of sea-floor spreading and subduction.



❖ Because no older ocean crust has been found, recycling of the ocean crust takes place about every 180 million years.

The relative ages of the ocean floor.

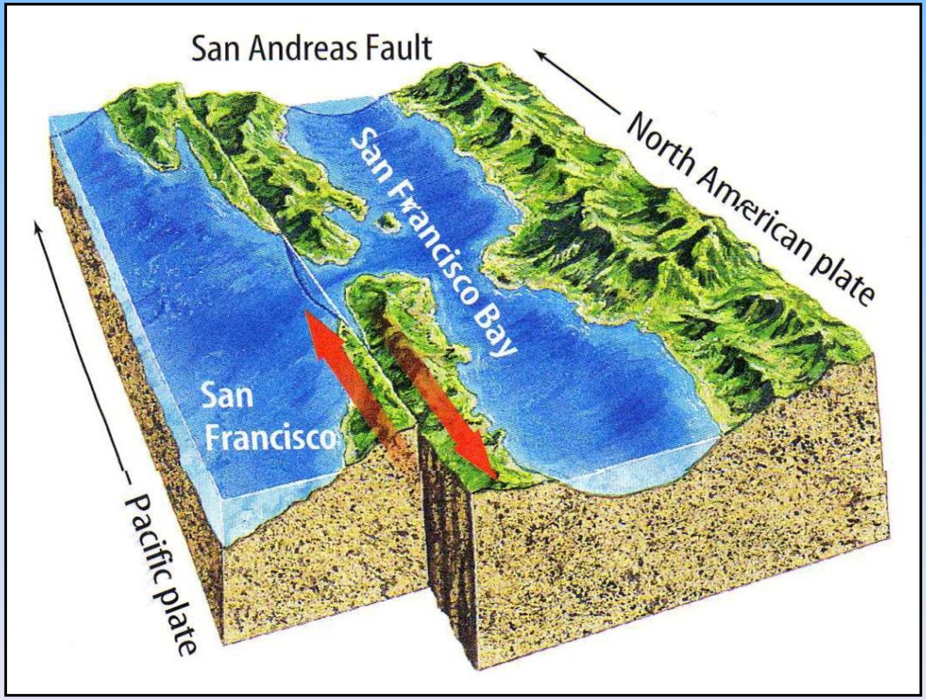
Credit: Nova.

3. Transform Boundary

❖ When two plates slide past each other moving in different directions or the same direction, it is termed a transform boundary and is characterized by a transform fault and earthquake activity.

❖ An example of a transform fault is the San Andreas Fault in California. Here the North American Plate joins the Pacific Plate. The difference in plate motion along the contact (fault) leads to a buildup of strain energy that sometimes slips releasing a huge amount of energy and causing an earthquake.

An aerial photo of the San Andreas fault line. *McGraw Hill/Glencoe, 1st ed., pg. 146 (with permission)*



Movement between the 2 plates at the San Andreas Transform Fault. *McGraw Hill/Glencoe, 1st ed., pg. 146 (with permission).*

Transform Boundary (continued)

- ❖ J. Tuzo Wilson was a geophysicist who was fascinated by Wegener's theory of continental drifting. He was also inspired by Harry Hess, whom he studied under at Princeton University in the 1930's.

- ❖ Wilson is recognized today for advancing plate-tectonic theory by introducing three major concepts:

  1. Wilson (1963) introduced the concept of a "stationary hotspot", where the heat from the mantle could affect the thin crust, forming volcanic islands such as Hawaii.

  2. Wilson (1965) proposed the "transform" boundary as the third type of plate boundary. They commonly offset ocean ridges and trenches, and transform the motion between the offset. Unlike ridges and trenches, transform faults offset the crust horizontally, without creating or destroying crust.

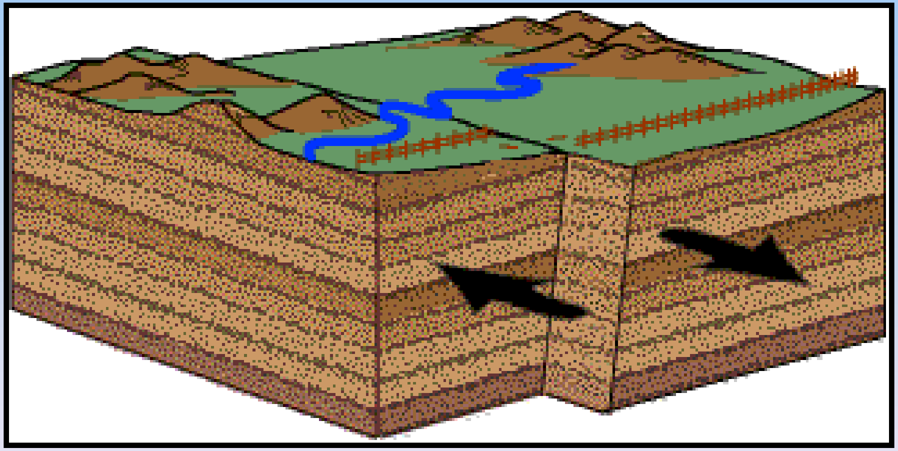
  3. Wilson proposed what is known today as the Wilson Cycle. This concept explains the origin for the Appalachian Mountains. The "cycle" goes through the sequence:
     1. The splitting of a supercontinent,
     2. the opening of an ocean basin,
     3. the closing of the ocean basin,
     4. the collision of continents and formation of mountains.

Mountain building processes, faults and folds

❖ Plate tectonics cause many of the physical features that we see on earth today like volcanoes and earthquakes, but also many other geological features like faults. **Faults** are planar rock fractures along which movement has occurred.

❖ A transform fault occurs at a transform plate boundary like the San Andreas Fault in California. It connects two of the other plate boundaries.

❖ Similar in movement, a strike-slip fault occurs through **shearing** when two blocks move in horizontal but opposite directions of each other. Depending on the direction of offset, it can be a "right-lateral offset" or a "left-lateral offset."



In the example above, it is obvious that the fence has been offset to the right, therefore it is called a right lateral strike-slip fault *(Credit: U.S. Geological Survey Department of the Interior/USGS)*

The photograph above displays a light-colored pegmatite vein offset to the right in a schistose matrix. ***Photo courtesy of K. McCarney-Castle.***

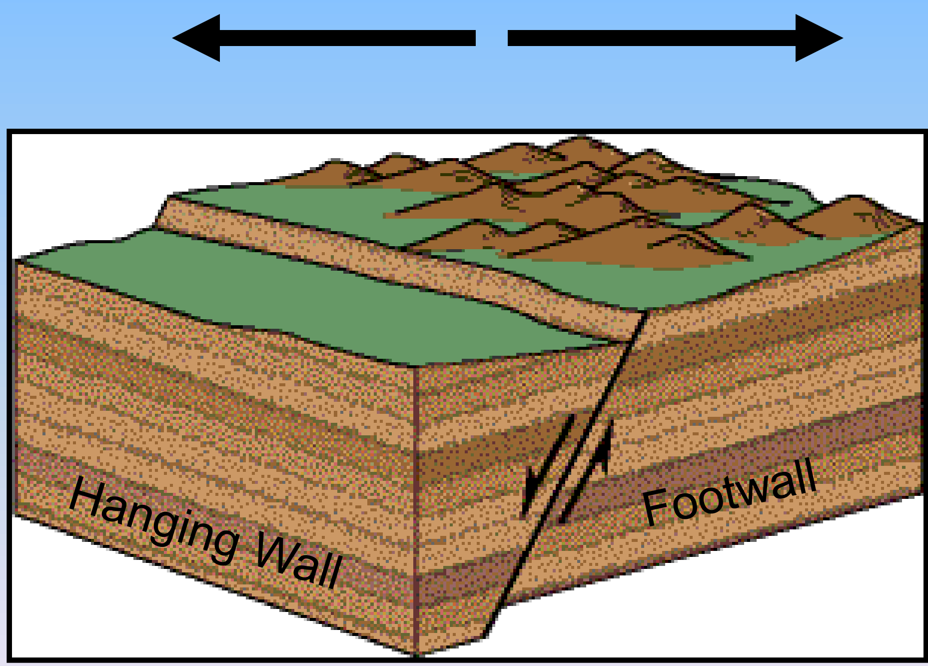
Faults: Normal Faults

❖ Faults caused by blocks of crust pulling apart under the forces of tension are called **normal faults.** Entire mountain ranges can form through these processes and are known as fault block mountains (examples: Basin and Range Province, Tetons).

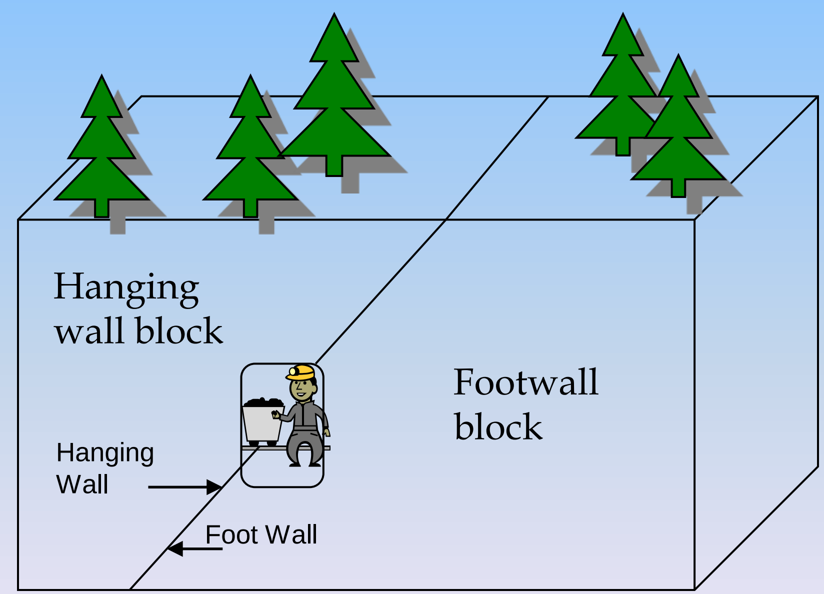
❖ In a normal fault, the hanging-wall block moves down relative to the foot-wall block.

❖ The footwall is the underlying surface of an inclined fault plane.

❖ The hanging wall is the overlying surface of an inclined fault plane.



Relative movement of two blocks indicating a normal fault. *(Credit: Modified after U.S. Geological Survey Department of the Interior/USGS)*



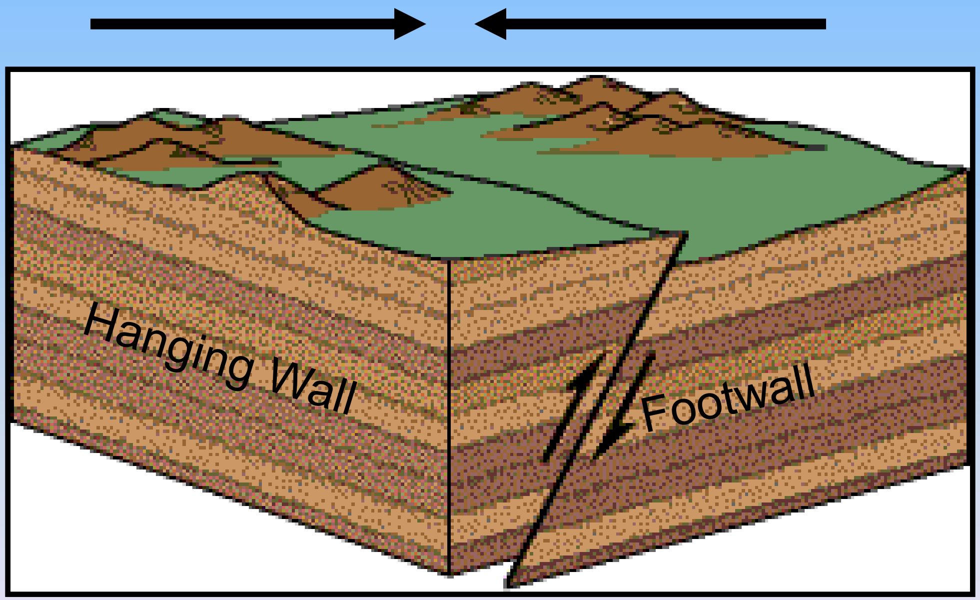
Diagrammatic sketch of the two types of blocks used in identifying normal faults.

Faults: Reverse Faults

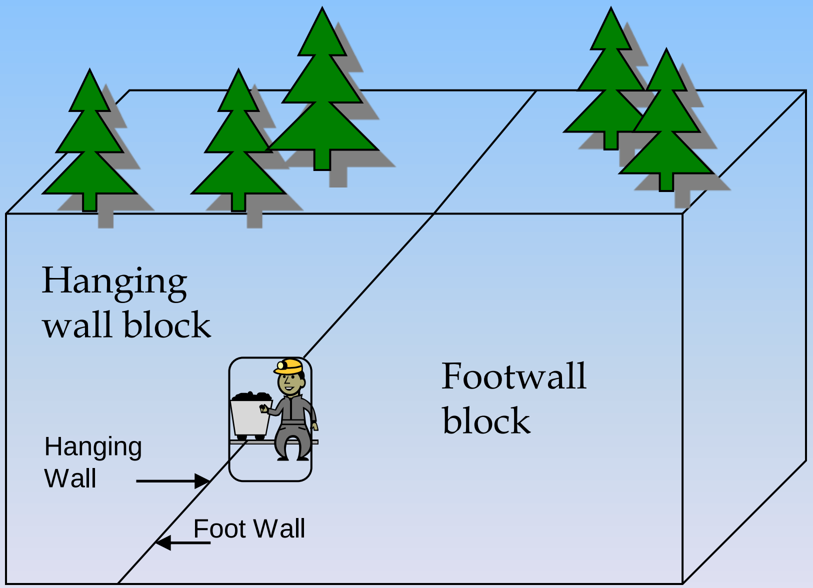
❖ Faults caused by blocks of crust colliding under the forces of compression are called reverse faults.

❖ Reverse faults form during continent-continent collision. Usually, there is also accompanying folding of rocks.

❖ During reverse faulting, the hanging wall block moves upward (and over) relative to the footwall block.



Relative movement of two blocks indicating a reverse fault. *(Credit: U.S. Geological Survey Department of the Interior/USGS)*



Diagrammatic sketch of the two types of blocks used in identifying reverse faults.

Folding

❖ During mountain building processes, rocks can undergo folding as well as faulting.

❖ Sometimes rocks deform ductilely, particularly if they are subjected to heat and pressure. At elevated temperature and pressure within the crust, folds can form from compressional forces.

❖ Entire mountain rages, like the Appalachians, have extensive fold systems.

Z-fold in schist with white felsic dike (hammer for scale). Near Lake Murray, South Carolina.
Photo courtesy of K. McCarney-Castle

Large fold in outcrop (geologists for scale). Near Oakridge, Tennessee, Appalachian Mtns. *Photo courtesy of K. McCarney-Castle.*

Plate Movement Over Geologic Time

❖ Alfred Wegener proposed that all of the continents once formed a “supercontinent” called Pangaea.

❖ From the Greek language, ‘*pan*’ meaning ALL and ‘*gaea*’ meaning EARTH. It was thought to have come together and formed approximately 200 million years ago.

❖ Evidence for a supercontinent included:

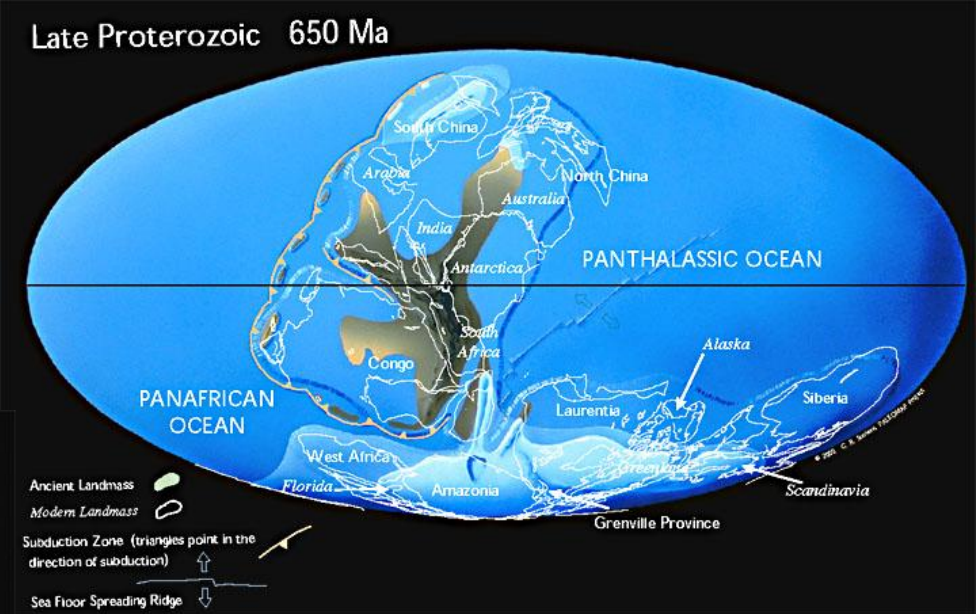
1. Fossils of the same plant (Glossopteris) found in Australia, India, Antarctica, and South America.

2. Fossils of same reptile (Mesosaurus) found in Africa and South America. This animal could not have swum across the existing Atlantic Ocean!

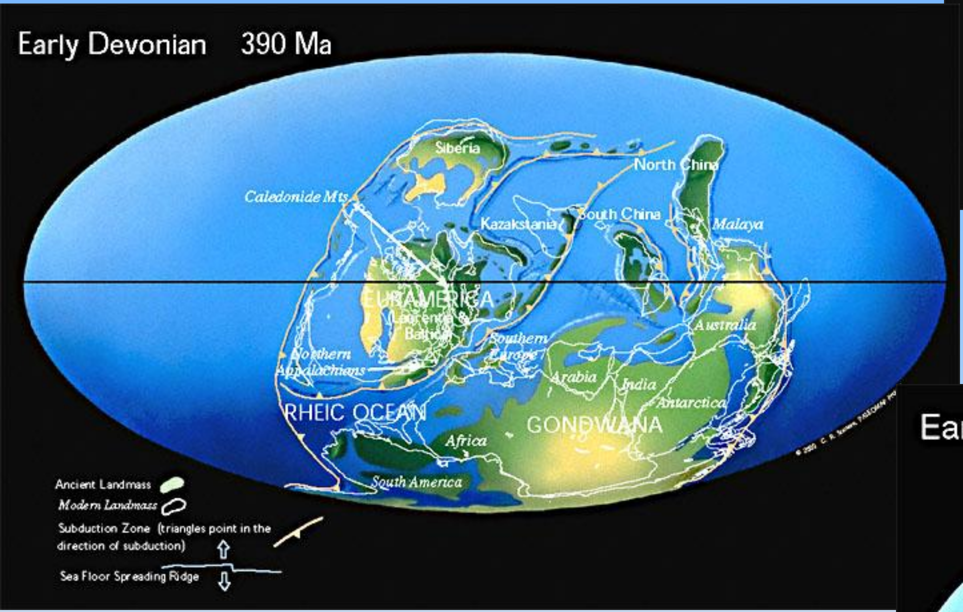
3. Glacial deposits found in current warm climates and warm-climate plant fossils found in what is now the Arctic.

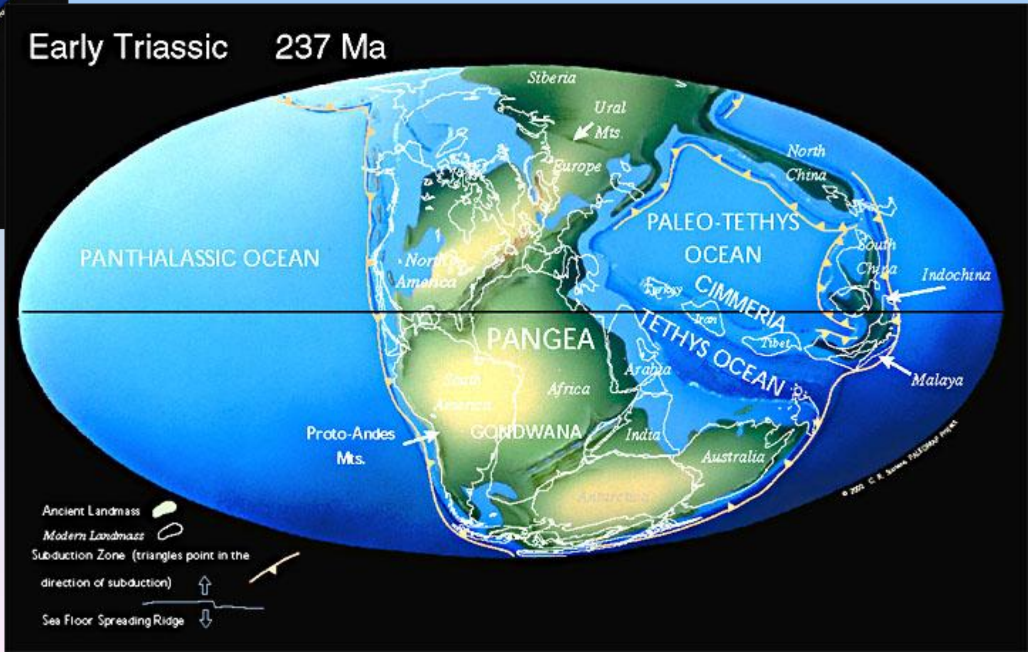
4. Nearly identical rock formations found on the east coast of U.S. and the west coast of Europe and on eastern South America and western Africa.

1. About 1,100 million years ago, a super-continent called Rodinia existed (pre-Cambrian).



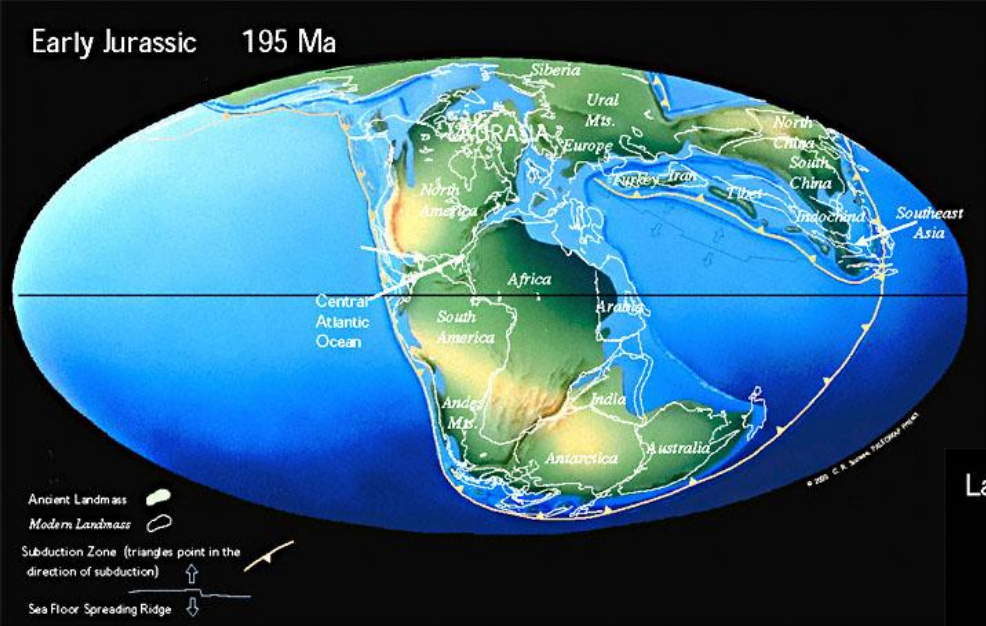
2. Rodinia broke apart, and about 400 million years ago, the oceans began to close up to form a pre-Pangea (early Devonian).





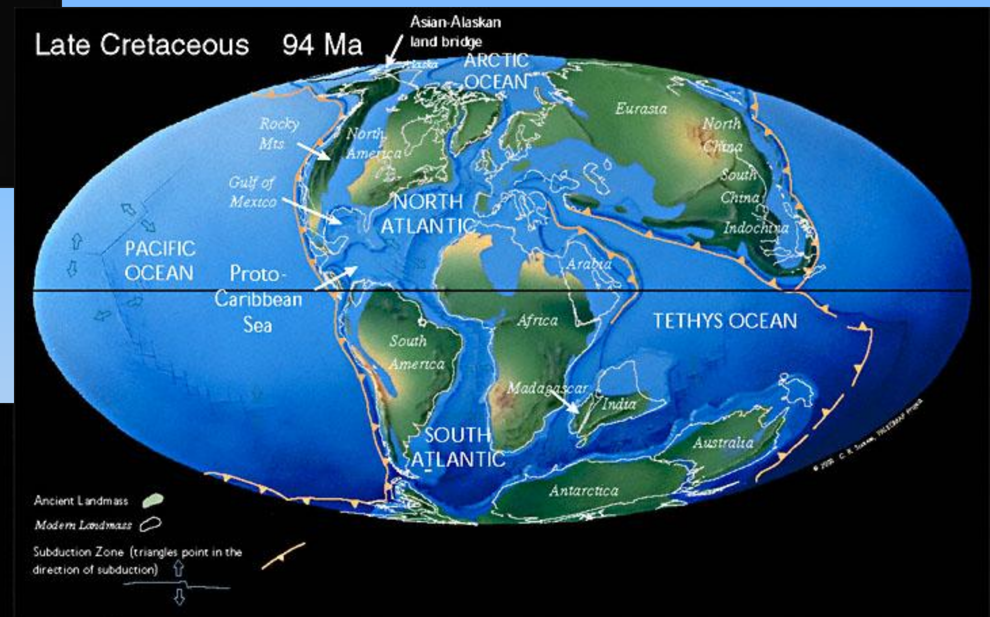
3. Pangea formed around 250 million years ago and animals could migrate from the north to the south pole (Early Triassic).

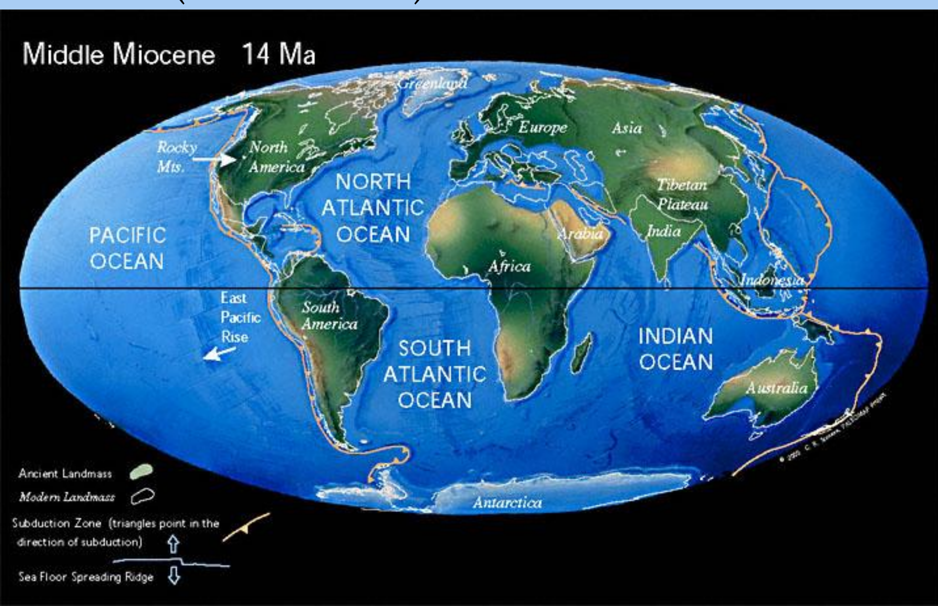
PaleoMaps used with permission from Christopher Scotese and are under copyright of C.R. Scotese, 2002



4. Pangaea began to break apart into 2 halves approximately 200 million years ago (Early Jurassic). The northern half is called Laurasia and the southern half is called Gondwanaland. These two huge continents were separated by a body of water called the Tethys Sea.

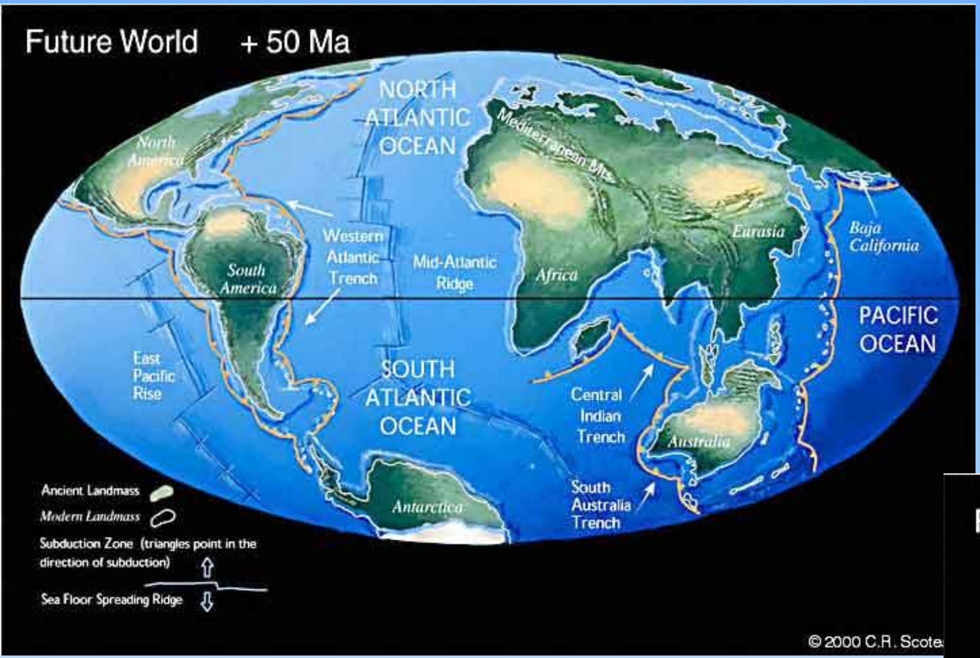
5. Gondwananland split to form Africa, South America, Antarctica, Australia and India. Laurasia split to form North America, Eurasia (minus India) and Greenland.



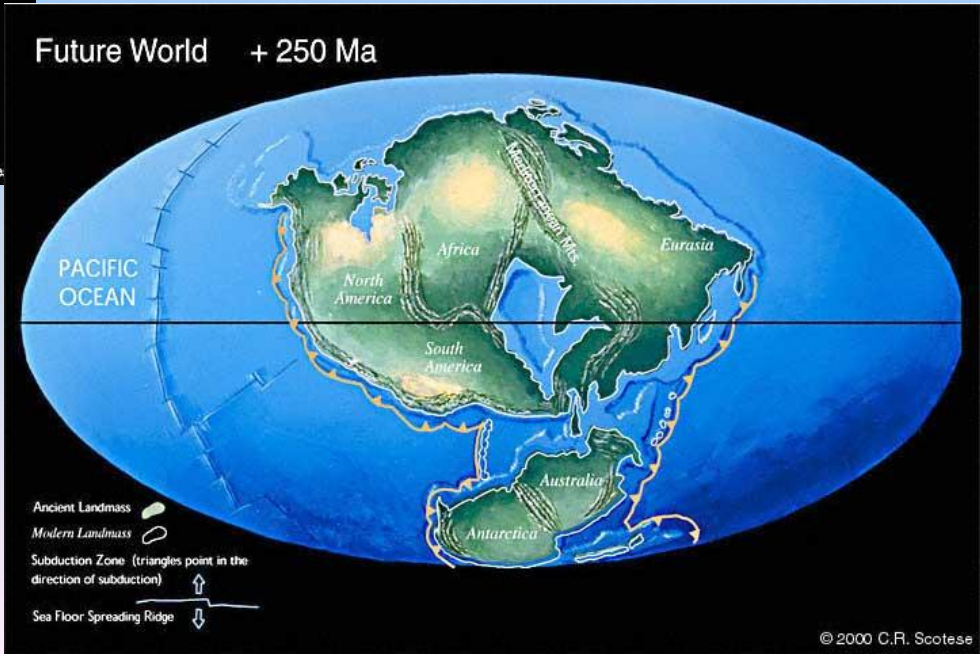


6. Around 15 million years ago, the continents finally looked like they do today

Continents in the future?



In 50 million years, it is possible that the Mediterranean could close due to the collision of Africa with Europe. Australia may eventually join Asia.



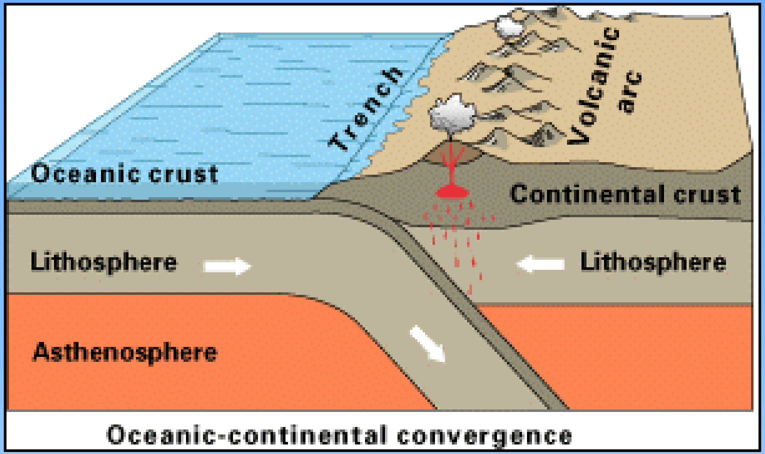
It is though that in another 250 million years, another Pangea will form.

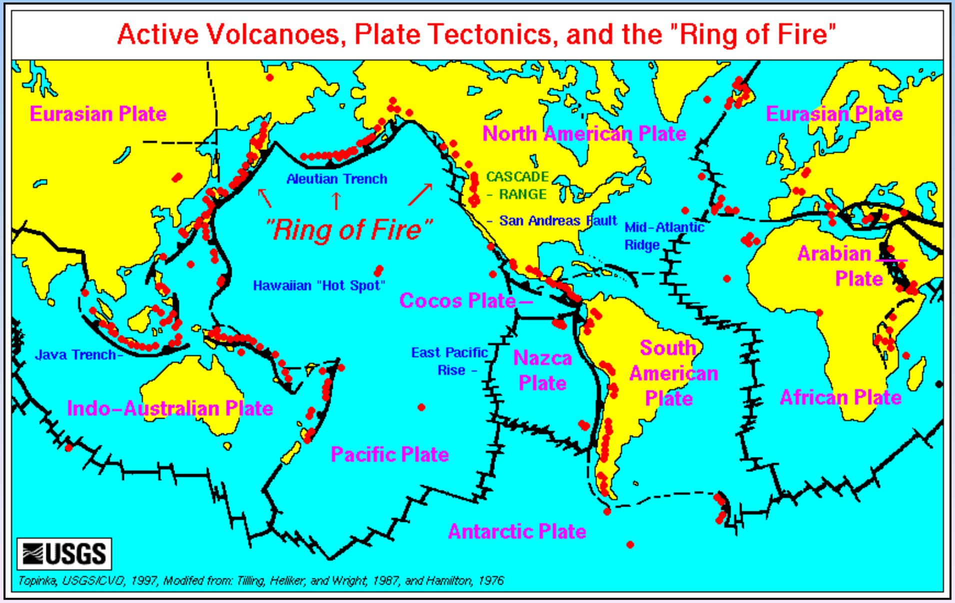
Creation and Change of Landforms

Volcanoes

❖ Most volcanoes form above subduction zones because as one slab is subducted beneath the other, it causes melting, forming new magma, which then rises upward. This is why most volcanoes are found near plate boundaries.

❖ Volcanoes are constructive because they add new rock, form new islands, and create new land masses. However, they are also destructive when they erupt and change the landscape (possibly even the climate).





<u>Above:</u> Diagrammatic sketch of a volcanic arc located above a subduction zone

<u>Left:</u> Active volcanoes found along plate boundaries

(Credit: U.S. Geological Survey Department of the Interior/USGS)

Volcanic Eruptions:

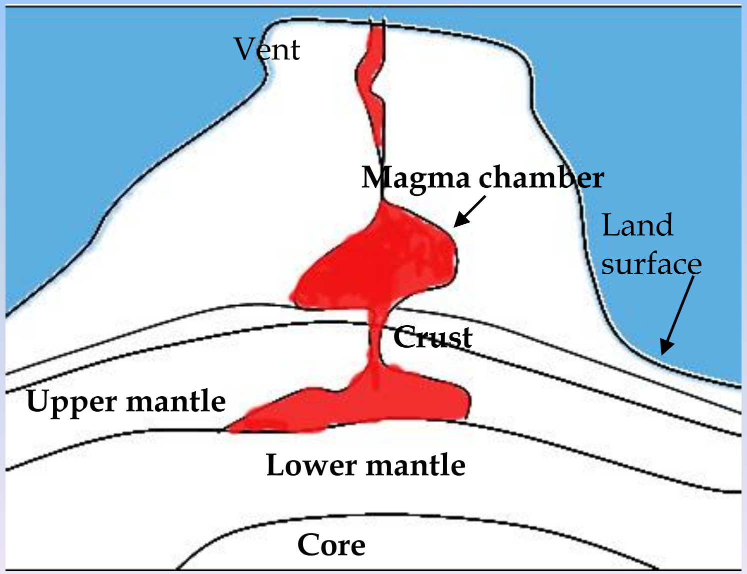
❖ Most volcanoes form above subduction zones because as one slab is subducted beneath the other, melting occurs, forming new magma, which then rises upward along the plate boundary.

❖ Being hot, magma is less dense than the solid rock surrounding it. This enables the liquid magma to rise up through cracks in the solid rock and collect in pockets within the earth, called magma chambers. Eventually some of the magma pushes through vents and fissures in Earth's surface, causing an eruption that may be violent or quiet. Once the magma reaches the earth's surface, it is called lava.

❖ The explosiveness of an eruption depends on the viscosity of the magma. Viscosity is the resistance of a liquid to flow. If the magma is very thick and viscous, gases can build up within the magma. Finally, when threshold is reached, there is a violent eruption from the built up pressure of the gases in the magma chamber.

❖ If magma is less viscous, or more fluid, gases can escape easily from it. When this type of magma erupts, it flows out of the volcano and violent explosions are rare.

❖ Sometimes, huge clouds of ash race down mountainsides destroying almost everything in their path. These are pyroclastic clouds. They can travel faster than a high-speed train. The ash produced from an eruption will fall back to the ground and suffocate humans, animals, and plants.



Cross-sectional view looking through the side of a volcano

Volcanoes: Mount St. Helens

❖ A famous volcano that erupted in the U.S. nearly 30 years ago was Mt. St. Helens in the Cascade Range of Washington.

❖ The volcanic activity of Mt. St. Helens is caused by the ongoing subduction of the Juan de Fuca plate under the North American plate. It is part of the Cascade Volcanic arc, which includes some 160 active volcanoes along the west coast.

❖ On May 18, 1980 Mount St. Helens erupted in what was the most economically destructive volcanic event in U.S. history. Nearly 60 people lost their lives and 250 homes were destroyed.

❖ Before the volcano exploded, it was 2,950 m tall. Afterwards, it was 2,550 m tall, and instead of a sharp peak at the summit, a mile-wide horseshoe shaped crater was left. The debris avalanche associated with the eruption was nearly 3 cubic kilometers in volume.

Before eruption…

After eruption…

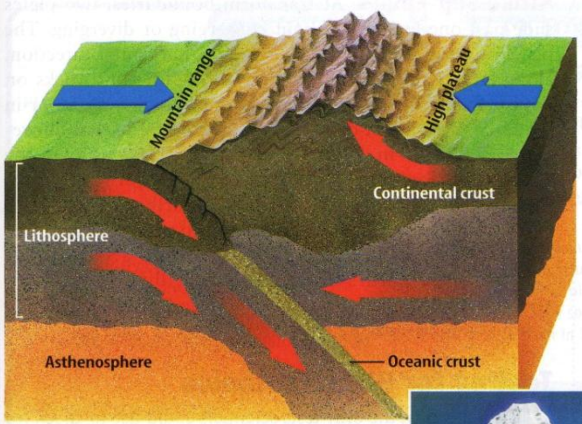
❖ When Mount St. Helens exploded, it had not erupted for 123 years. Most people thought Mount St. Helens was a beautiful, peaceful mountain and not a dangerous volcano.

Credit: Wikimedia Commons

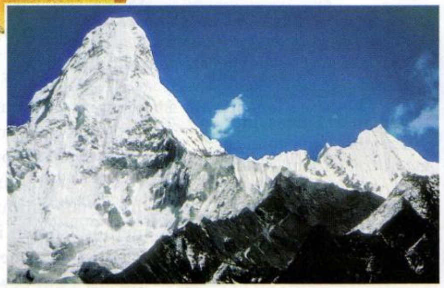
Mountain-building forces

❖ When two continental plates collide at a convergent boundary, the process produces a mountain range. Compressional forces drive the mountain building process.

❖ The Appalachians, the Alps, and the Himalayas were formed through compression.



Continent/ continent convergence



The Matterhorn, Alps

❖ The Himalayan mountain chain was formed approximately 150 million years ago. When we think of the Himalayas, we think of very high, steep mountains, cliffs, and, of course, Mt. Everest.

❖ In contrast, when we consider our own Appalachians, which formed about 400 million years ago, we see more subdued topography than in the Himalayas. This is because the process of wind and water erosion have eroded hundreds of vertical feet of land surface from the area and reduced high jagged mountains into the rolling hills present today.

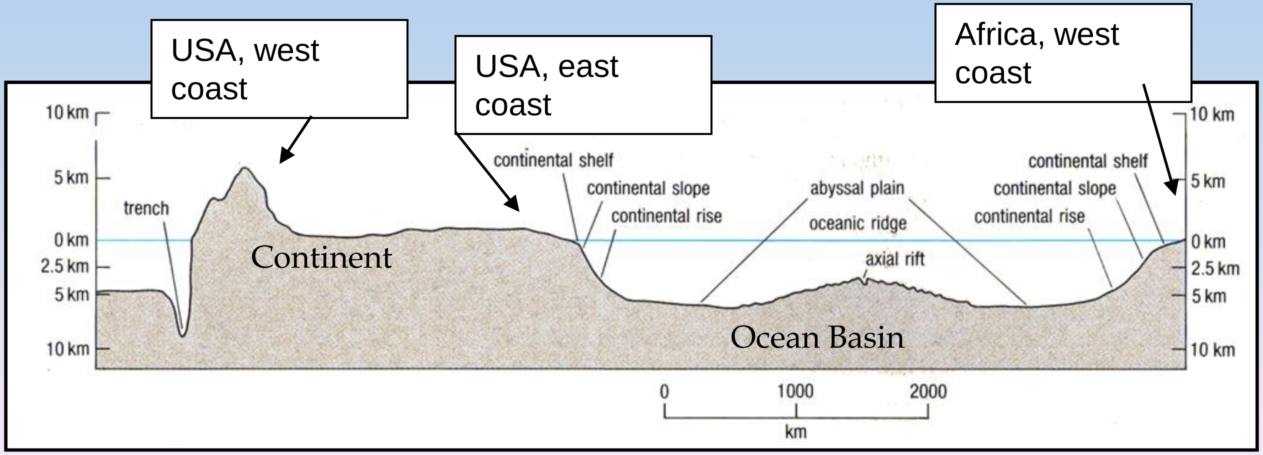
The Appalachian Mountains. *Photo courtesy of K. McCarney-Castle*

Continental margins and deep-sea landforms

❖ Even though approximately 70% of the earth's surface is covered by water, it is the study of sea-floor rocks, sediment, and topography that provide most of the information used to validate the theory of plate tectonics. Ongoing research on the sea floor continues to provide clues to the Earth's dynamic structural processes.

❖ Research and technology have granted us access to study both the shallow **continental shelves** as well as the deep **abyssal plains** of the ocean basins. These include rock dredging, coring, drilling, geophysical studies (seismic and magnetic), and age dating.

❖ One advancement in technology is the use echo sounders, which are used to draw profiles of submarine topography. Seismic profilers also use acoustic echoes but can penetrate the bottom of the seafloor. These profilers allow us to see a "picture" of the layered structure under the sea floor.



Cross-sectional view of continents grading into deep ocean basins. Note change in topography.

Continental Margins: Continental Shelves and Slopes

❖ All continents are surrounded by a shallow, relatively flat platform called a **continental shelf** and a sloping surface called a **continental slope** that gently descends down to the deep ocean floor.

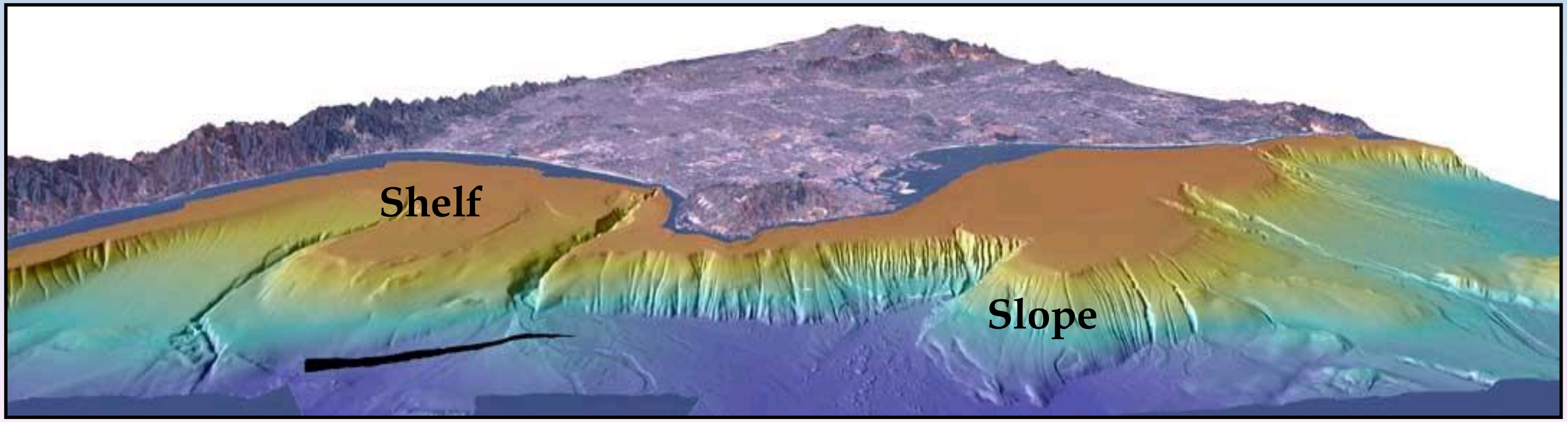
❖ Continental shelves vary in width depending on the type of continental margin. On the U.S. Pacific coast, it is only a few km wide, but off of the Atlantic Coast it is up to 500 km wide.

❖ The continental shelf area has thick accumulations of young sediment and has water depths less than 200 meters.

❖ The continental slope has a relatively steep slope (4-5 degrees) and it joins the edge of the shelf to the deep ocean floor. Relatively little is known about the slopes, as it is difficult to drill on the steep surfaces.

❖ Beyond the continental shelf is the continental break where flat shelf ends and the steep continental slope begins. Although typical continental slopes have an incline of around 4 degrees, some active margins, like the Gulf of California, slope at about 20 degrees.

❖ The continental slope may be marked by channels called submarine canyons that transport sediment from the shelf to the sea floor, sometimes in violent events called turbidity currents. The continental rise has been built up by these thick deposits of sediment.



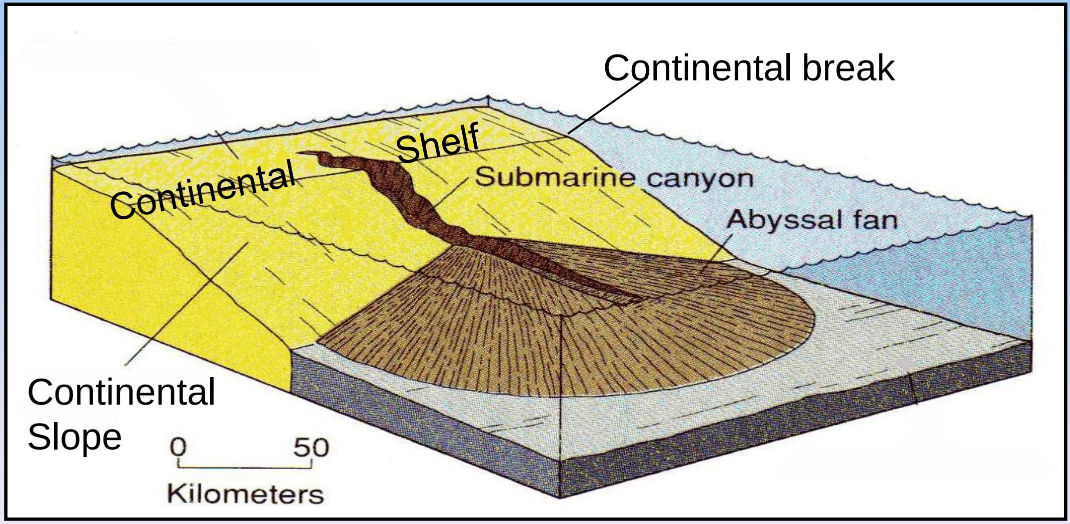
California Continental Margin looking east towards Los Angeles.

(Credit: U.S. Geological Survey Department of the Interior/USGS)

1. **Passive Continental Margins**

- A passive continental margin includes a continental shelf, slope, and rise and these margins gently grade into a deep abyssal plain.
- The ocean floor and continent usually belong to the same continental plate.
- Passive margins form on "geologically quiet" coasts, also called trailing margins, where there is no tectonic or volcanic activity, such as the eastern seaboard of the U.S.
- The **continental rise** is a wedge of sediment that extends from the lower part of the slope to the deep sea floor sloping at about 0.5 degrees. It grades into a flat abyssal plain at around 5km in depth.
- Abyssal plains are found at the base of the continental rise and are the flattest features on earth. Abyssal plains form where turbidity currents carry amounts of sediment large enough to bury and obscure the rugged relief normal found on the sea floor.

Sketch of an abyssal fan forming on the sea floor. Sediment for the fan is carried from the shelf through the canyon in violent turbidity currents and are deposited, forming a fan .

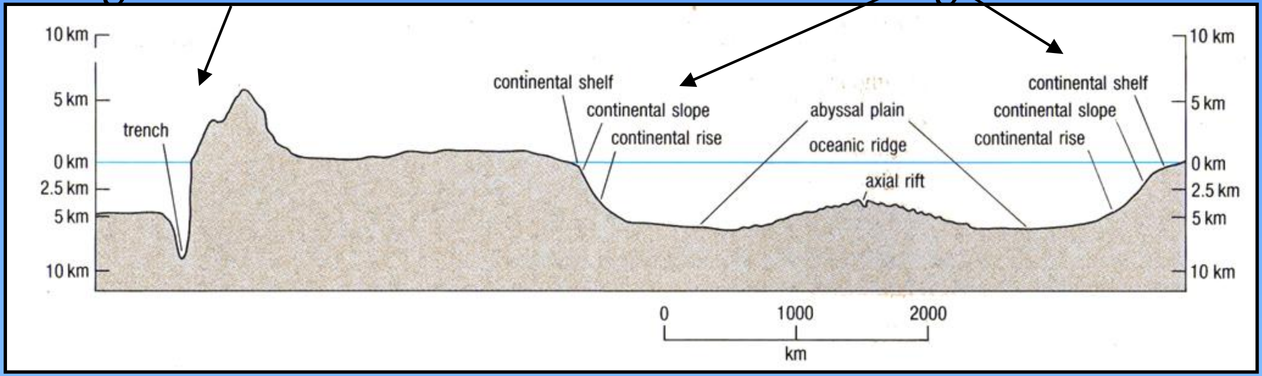


Modified after Plummer/McGeary, 7th ed., pg. 400.

Active continental margin with trench

Passive continental margin

Cross-sectional sketch showing the trench off the active continental margin and the rise off of the passive continental margin.



2. <u>Active continental margin:</u>

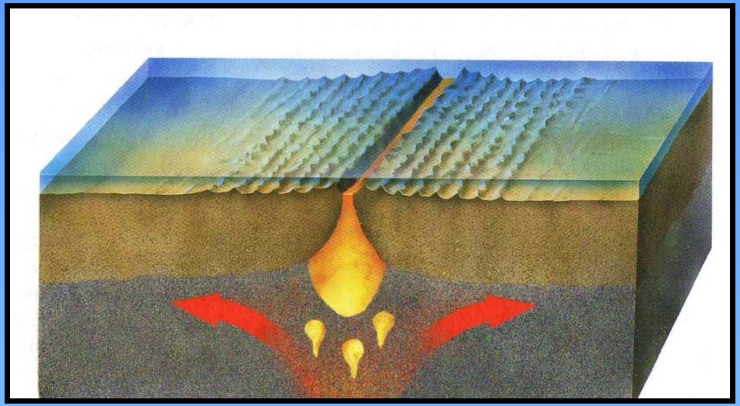
❖ An active continental margin includes a continental shelf, slope, and an ocean trench. It is the result of an ocean plate colliding with a continental plate.

❖ Active margins are tectonically active, characterized by earthquakes, volcanoes, and mountain belts. Tectonically active margins may have a deep **trench** instead of a continental rise where the oceanic plate is subducted beneath the continental plate.

❖ The west coast of the U.S. and South America are examples of active margins.

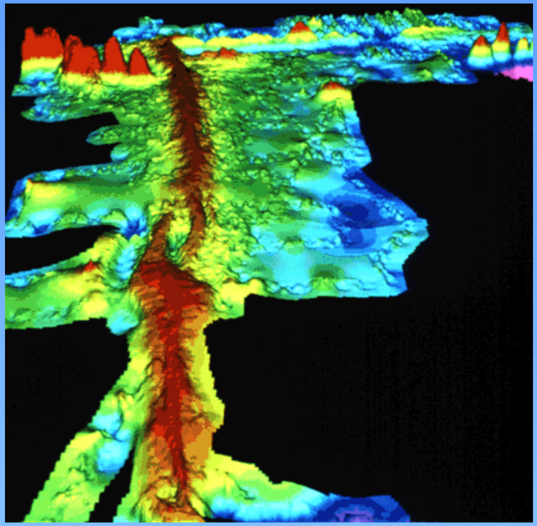
❖ Ocean trenches are elongate features parallel to the edge of the continent and are the deepest regions on earth at over 11 km below sea level.

❖ Ocean trenches are associated with seismic Benioff Zones, which begin at the trench and dip underneath the continent as part of the subduction zone. Earthquakes are prevalent along the Benioff Zone, which is the site of one tectonic plate descending underneath another.



Sea floor spreading at the mid-ocean ridge and rift valley. *Modified after McGraw Hill/ Glencoe, 1st ed., pg. 138 (with permission)*

Satellite bathymetry of the East Pacific Rise spreading ridge.
Credit: U.S. Geological Survey
Department of the Interior/USGS



❖ The Mid-Atlantic Ridge is an example of a divergent boundary found extending around the world dividing the world's ocean basins. It spreads at about 1-2 centimeters per year and is made of basalt. It is 56,000 km long and 2,500 km wide, and it rises 2 –3 km above the sea floor.

❖ The spreading of the ridge creates a rift valley running down the crest of the ridge. The valley is about 1-2 km deep and several kilometers wide- similar to the dimensions of the Grand Canyon!

❖ Shallow earthquakes are frequent along these ridges and long deep fractures run perpendicular to the ridge.

❖ Seamounts, guyots, and black smokers are other geological features that can be found on the deep sea floor.