GEM 102
Plate Tectonics

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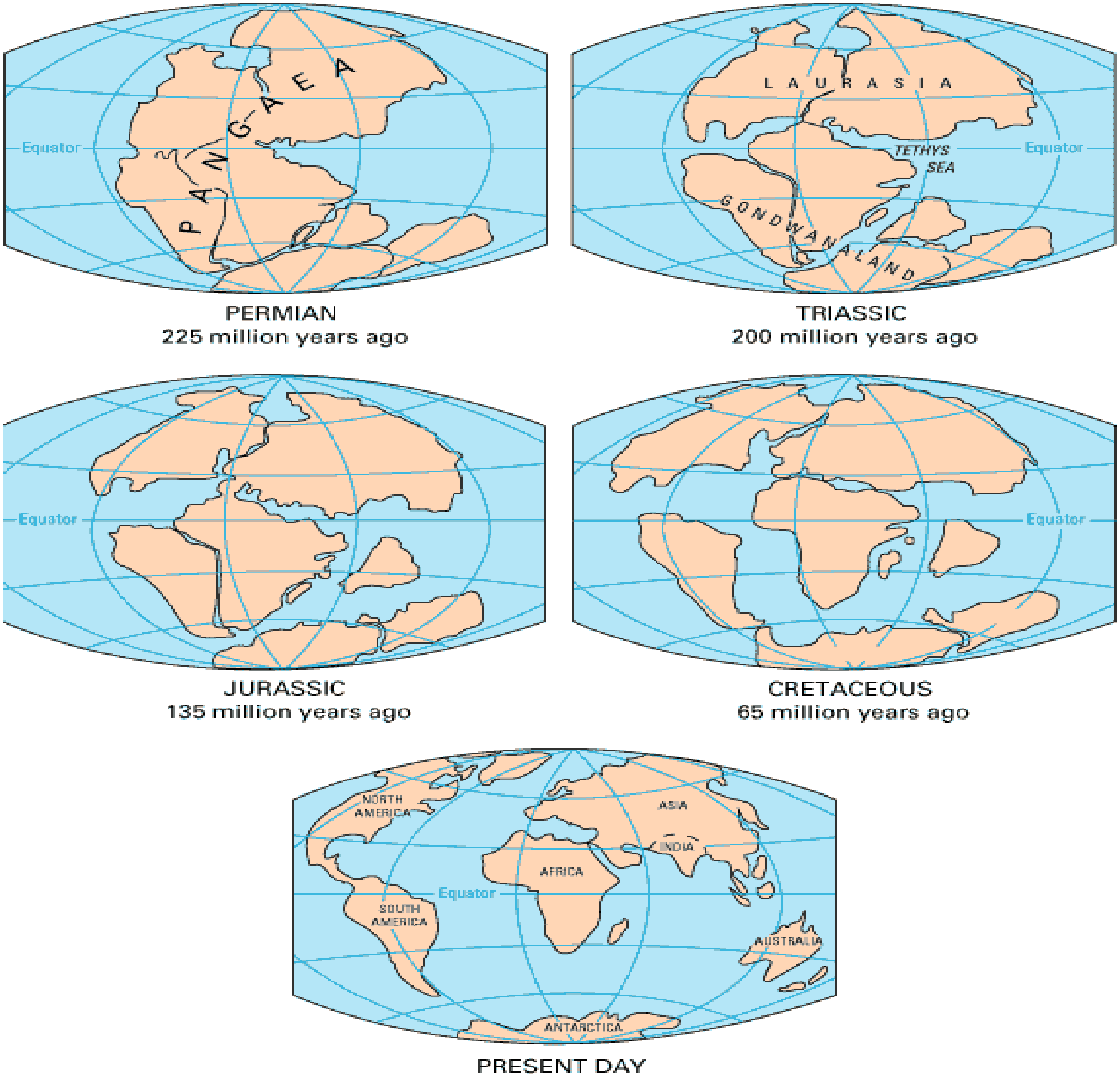
Introduction

- Plate Tectonics is a theory developed in the late 1960s, to explain how the outer layers of the Earth move and deform.
- The theory has caused a revolution in the way we think about the Earth.
- Plate tectonics has proven to be so useful that it can predict geologic events and explain almost all aspects of what we see on the Earth today.

Tectonic Theories

- Tectonic theories attempt to explain why these geological events occur and where they do occur:
  - ✓ mountains,
  - ✓ earthquakes, and
  - ✓ volcanoes.
- The ages of deformational events,
- The ages and shapes of continents and
- Ocean basins.

Historical Geology



Wegner's Theory of Continental Drift

- Alfred Wegner was a German Meteorologist in the early 1900s who studied ancient climates.
- Like most people, the jigsaw puzzle appearance of the Atlantic continental margins caught his attention.
- He proposed that prior to about 200 million years ago all of the continents formed one large land mass that he called ***Pangea***.
- He proposed that the continents slide over ocean floor which was rejected by Geologists.

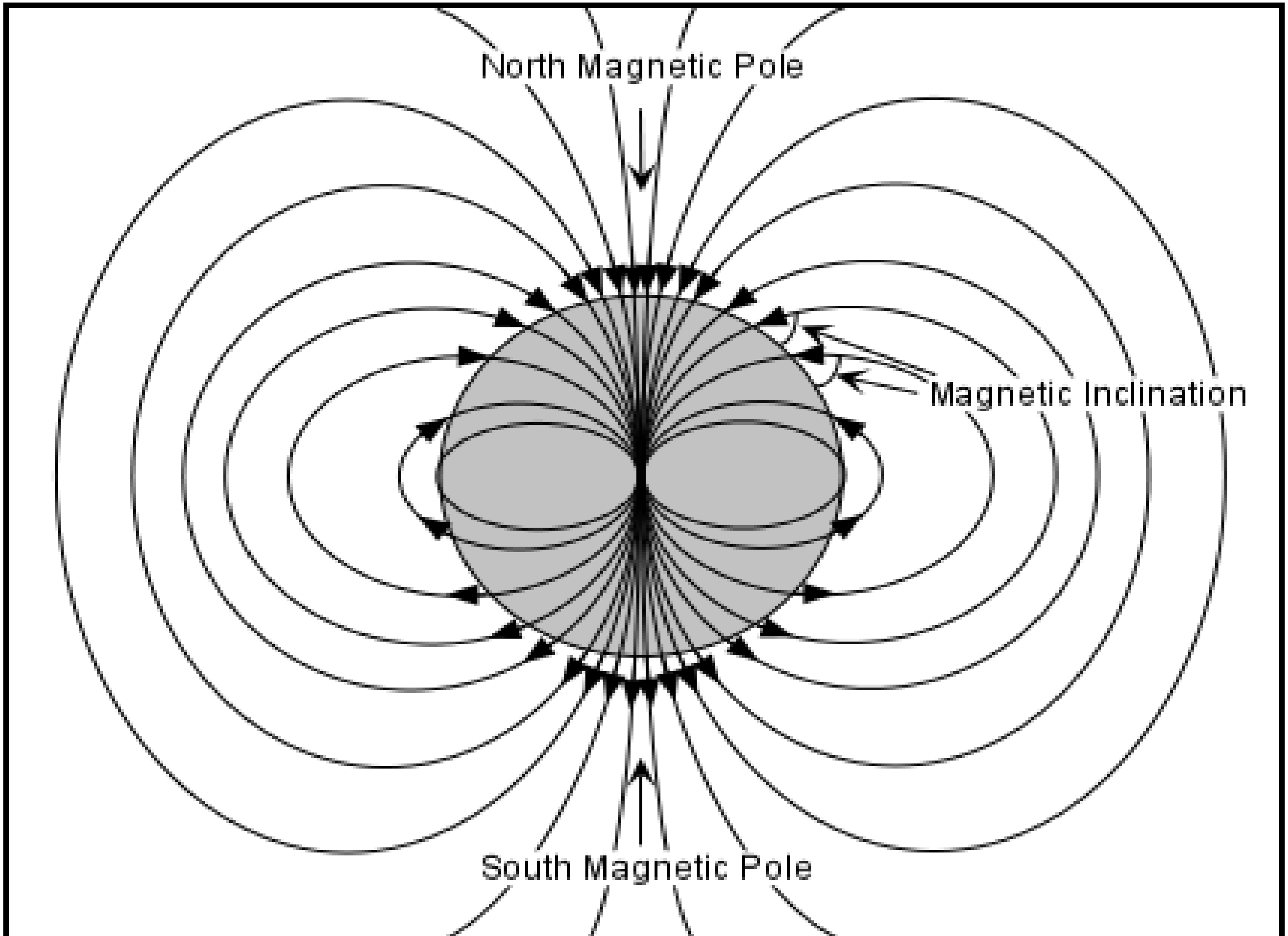
The Earth's Magnetic Field and Paleomagnetism

- In 1950s and 1960s, studies of the Earth's magnetic field and how it varied through time (***paleomagnetism)*** provided new evidence that would prove that the continents do indeed drift.
- In order to understand these developments, we must first discuss the Earth's magnetic field and the study of Paleomagnetism.

The Earth's Magnetic Field and Paleomagnetism, Cont.

- The Earth has a magnetic field that causes a compass needle to always point toward the North magnetic pole, currently located near the rotation pole.
- The Earth's magnetic field is what would be expected if there were a large bar magnet located at the center of the Earth.
- The magnetic field is composed of lines of force as shown in the next diagram.

The Earth's Magnetic Field and Paleomagnetism



The Earth's Magnetic Field and Paleomagnetism, Cont.

- A compass needle or a magnetic weight suspended from a string, points along these lines of force.
- Note that the lines of force intersect the surface of the Earth at various angles that depend on position on the Earth's surface.
- This angle is called the ***magnetic inclination.***
- The inclination is 0^0 at the magnetic equator and 90^0 at the magnetic poles.
- Thus, by measuring the inclination and the angle to the magnetic pole, one can tell position on the Earth relative to the magnetic poles.

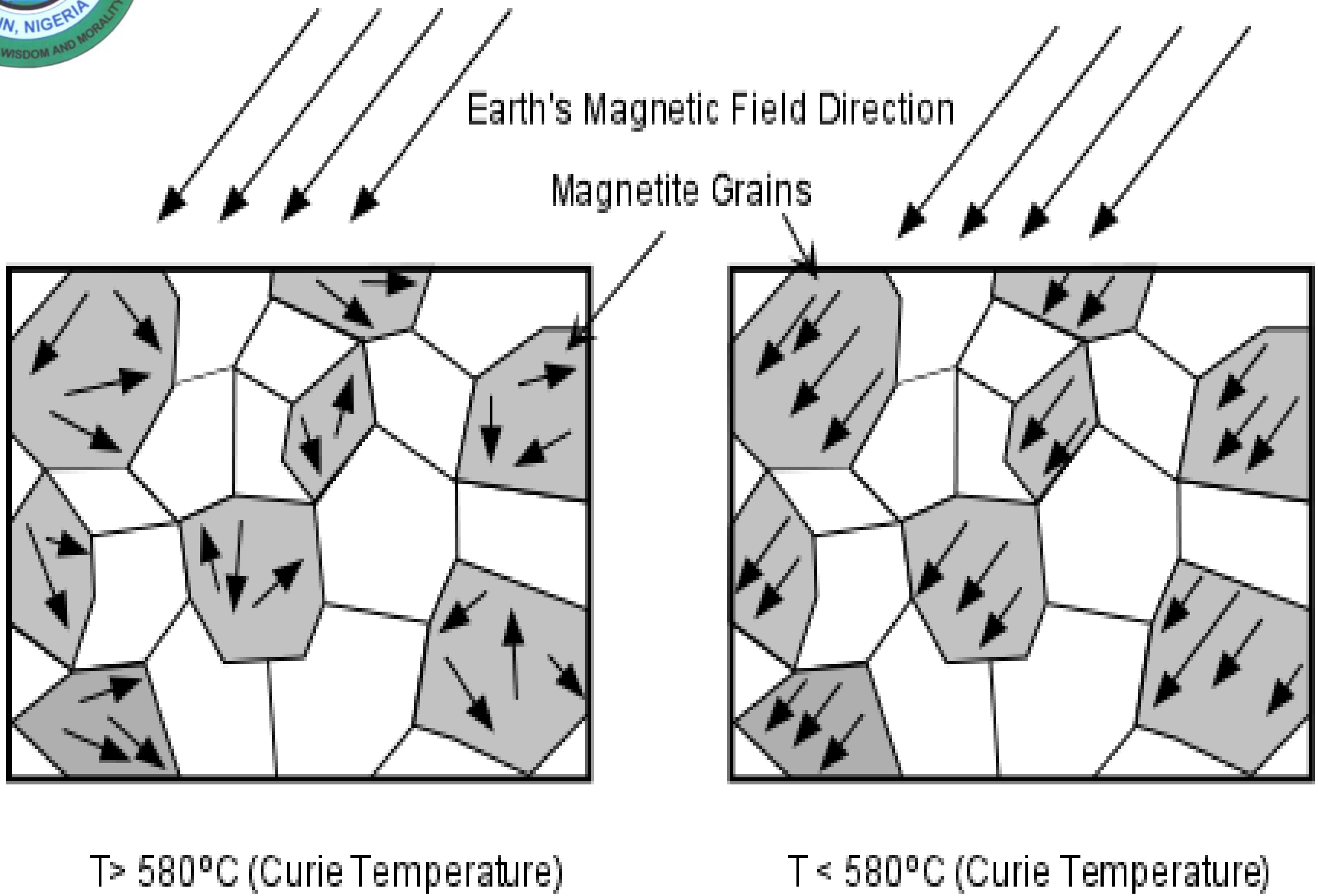
Curie Temperature

- In the 1950s it was discovered that when magnetic minerals cool below a temperature called the ***Curie Temperature,*** domains within the magnetic mineral take on an orientation parallel to any external magnetic field present at the time they cooled below this temperature.
- At temperatures above the Curie Temperature, permanent magnetization of materials is not possible.

Curie Temperature, Cont.

- Since the magnetic minerals take on the orientation of the magnetic field present during cooling, we can determine the orientation of the magnetic field present at the time the rock containing the mineral cooled below the Curie Temperature, and
- thus, be able to determine the position of the magnetic pole at that time.
- This made possible the study of Paleomagnetism (the history of the Earth's magnetic field).
- Magnetite is the most common magnetic mineral in the Earth's crust and has a Curie Temperature of 580^0C.

Curie Temperature



Changing Earth's magnetic pole

- Initial studies of the how the position of the Earth's magnetic pole varied with time were conducted in Europe.
- These studies showed that the magnetic pole had apparently moved through time.
- That the different continents have moved relative to each other over time.
- Studies of ancient pole positions for other continents confirmed the hypothesis, and seemed to confirm the theory of Continental Drift.

Sea-Floor Spreading

- During World War II (1936 – 1945), geologists employed by the military carried out studies of the sea floor, a part of the Earth that had received little scientific study.
- The purpose of these studies was to understand the topography of the sea floor to find hiding places for both Allied forces (USA, France, UK, USSR, Canada) and enemy (Germany) submarines.
- The topographic studies involved measuring the depth to the sea floor.
- These studies revealed the presence of two important topographic features of the ocean floor:

Sea-Floor Spreading –

Topography of the sea floor, Cont.

- ***Oceanic Ridges –***

  long sinuous ridges that occupy the middle of the Atlantic Ocean and the eastern part of the Pacific Ocean.

- ***Oceanic Trenches –***

  deep trenches along the margins of continents, particularly surrounding the Pacific Ocean.

Sea-Floor Spreading –
measuring magnetic materials

- Another type of study involved towing a magnetometer (for measuring magnetic materials) behind ships to detect submarines.
- The records from the magnetometers, however, revealed that there were magnetic anomalies on the sea floor:
- ✓ With magnetic high areas running along the oceanic ridges, and
- ✓ Parallel bands of alternating high and low magnetism on either side of the oceanic ridges.

Reversals of the Earth's Magnetic Field

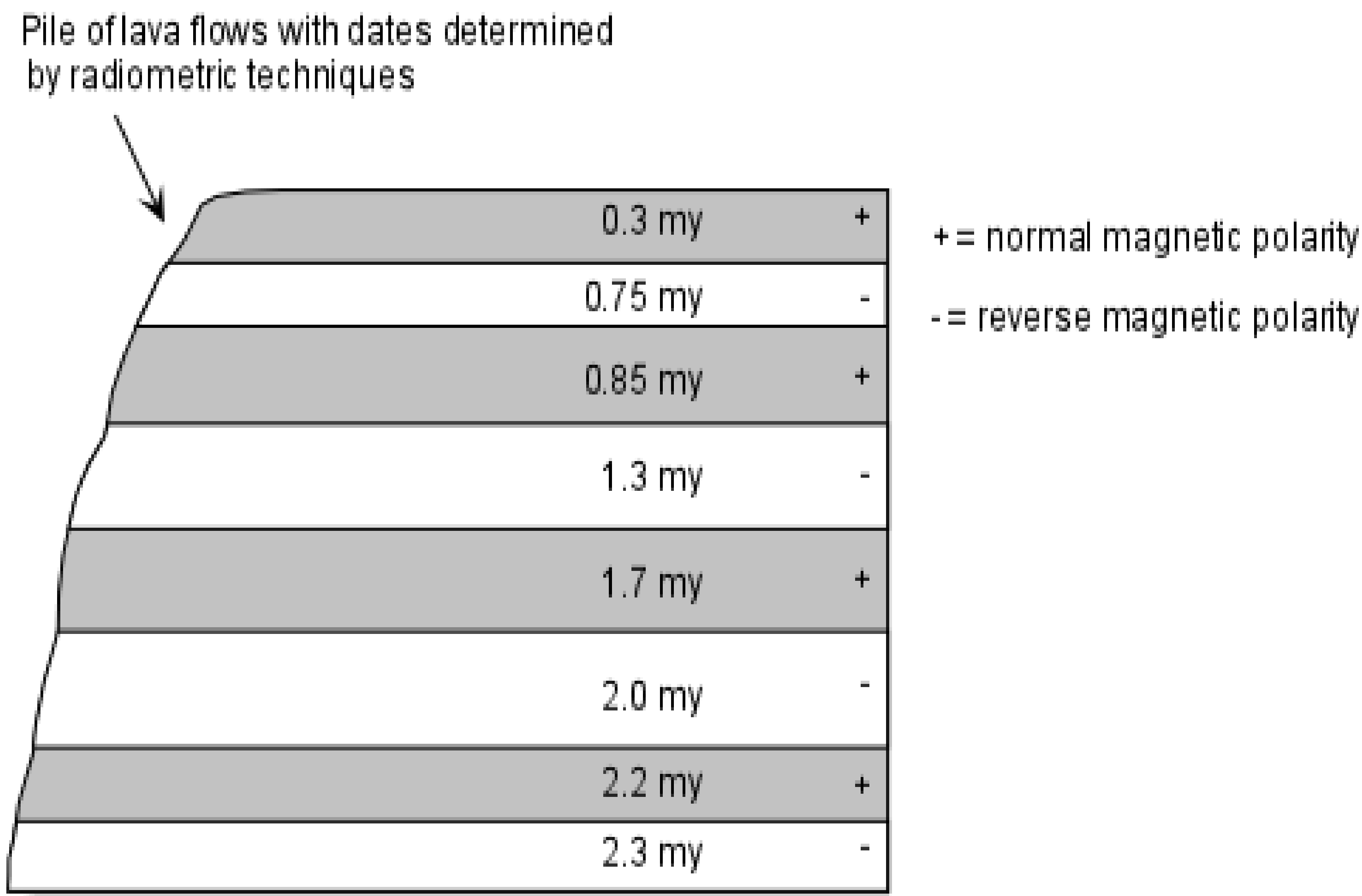
Studying piles of lava flows on the continents geophysicists found that over short time scales the Earth's magnetic field undergoes polarity reversals (The north magnetic pole becomes the south magnetic pole).

- By dating the rocks using radiometric dating techniques and correlating the reversals throughout the world they were able to establish the magnetic time scale.

Reversals of the Earth's Magnetic Field - Sea-Floor Spreading

- New oceanic crust and lithosphere were created at the oceanic ridge by eruption and intrusion of magma.
- As this magma cooled it took on the magnetism of the magnetic field at the time.
- When the polarity of the field changed new crust and lithosphere created at the ridge would take on the different polarity.
- **This hypothesis lead to the theory of sea floor spreading.**

Reversals of the Earth's Magnetic Field



Reversals of the Earth's Magnetic Field - Sea-Floor Spreading

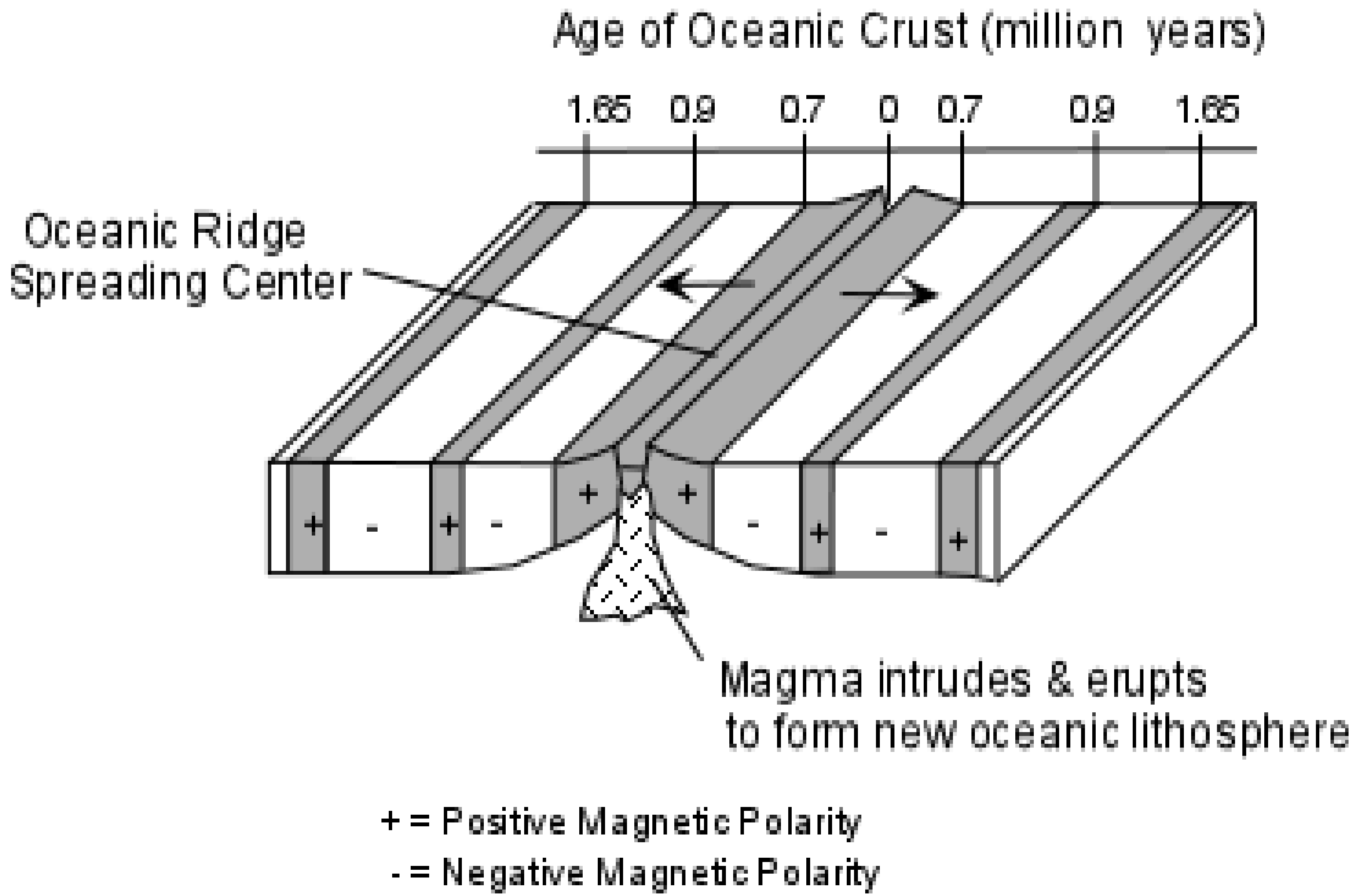


Plate Tectonics

- ➢ The new theory of Plate Tectonics became a coherent theory to explain crustal movements.
- ✓ By combining the sea floor spreading theory
- ✓ With continental drift and
- ✓ Information on global seismicity (Zones along which earthquakes occur).

Plate Tectonics

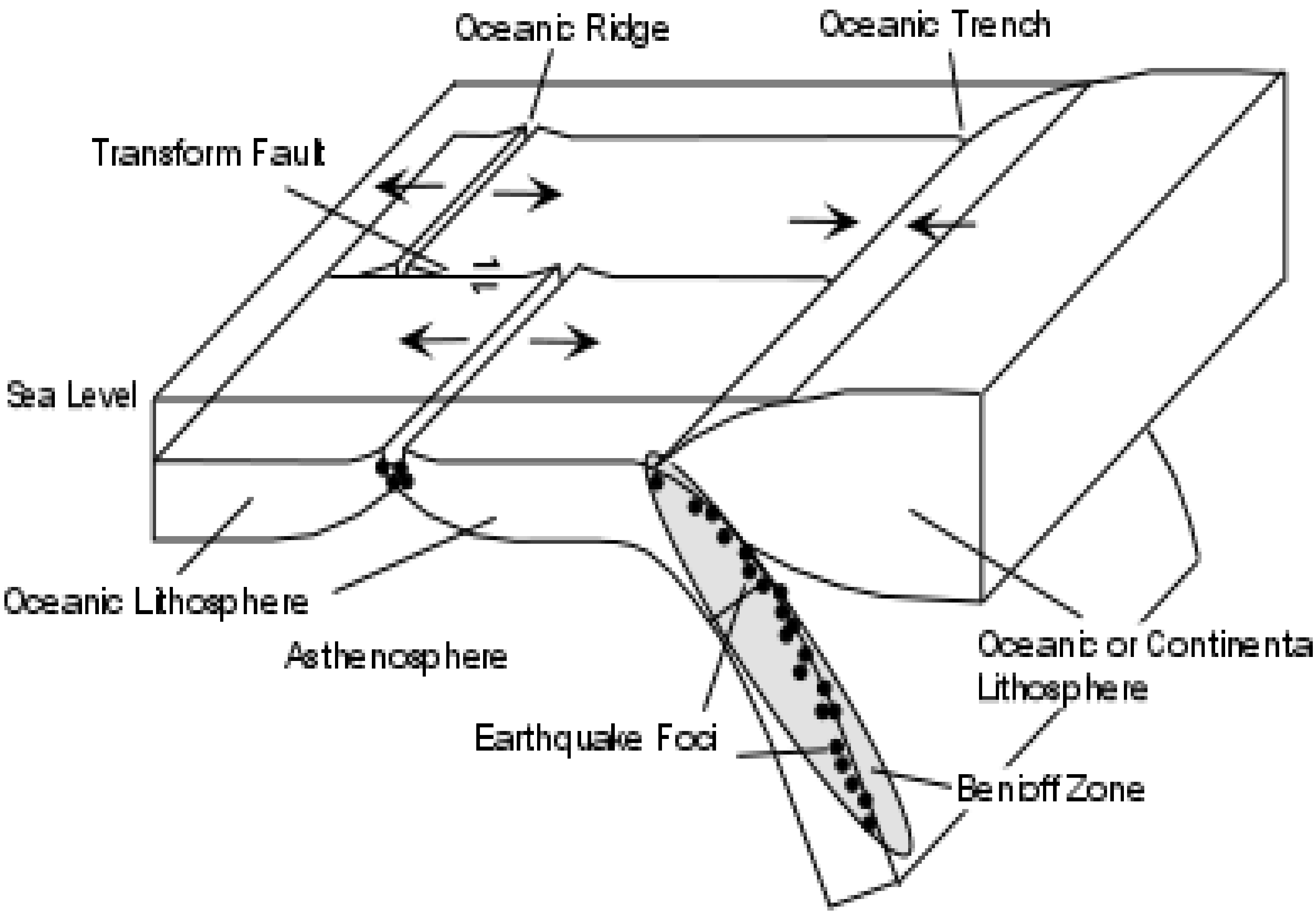
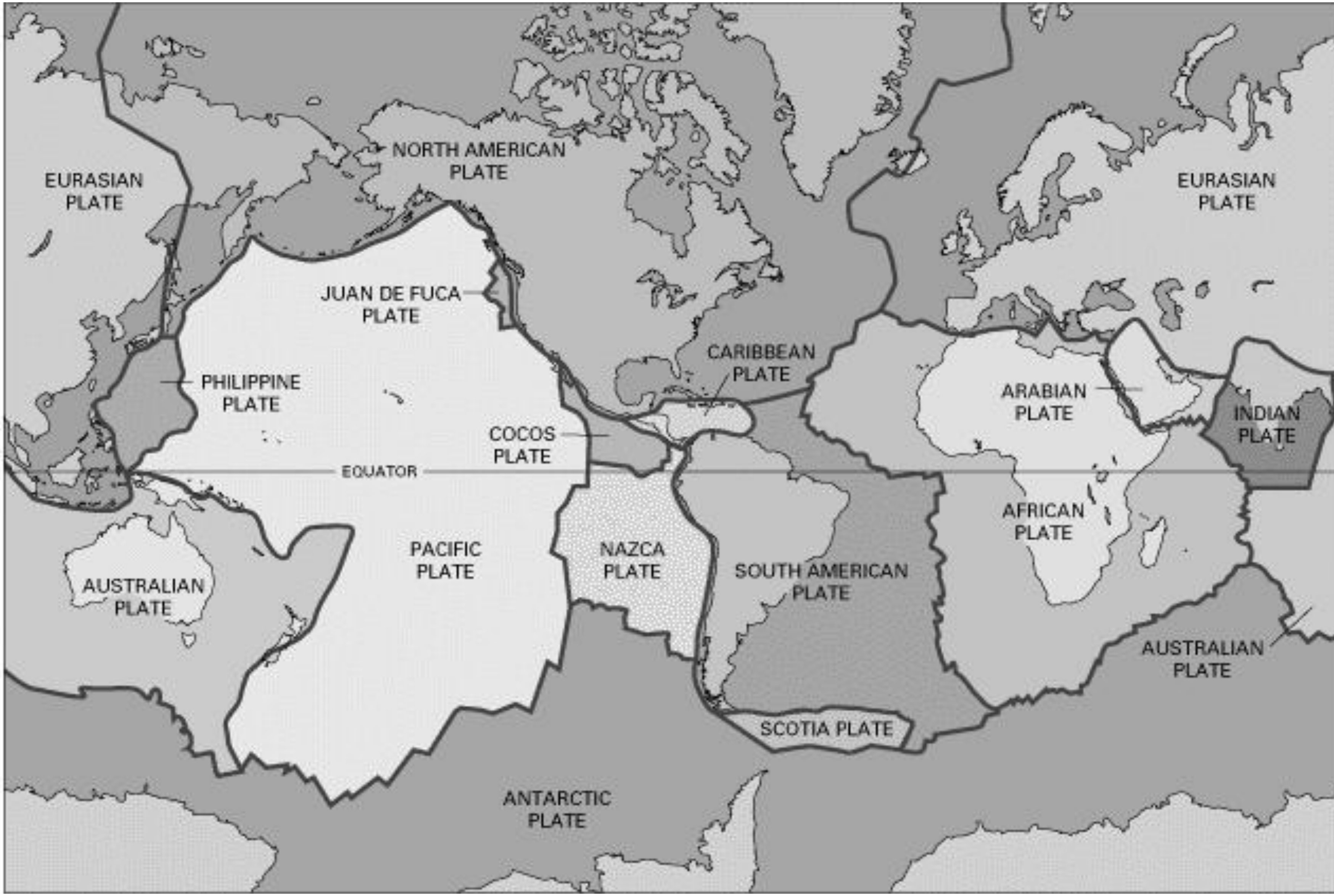


Plate Tectonics, Cont.

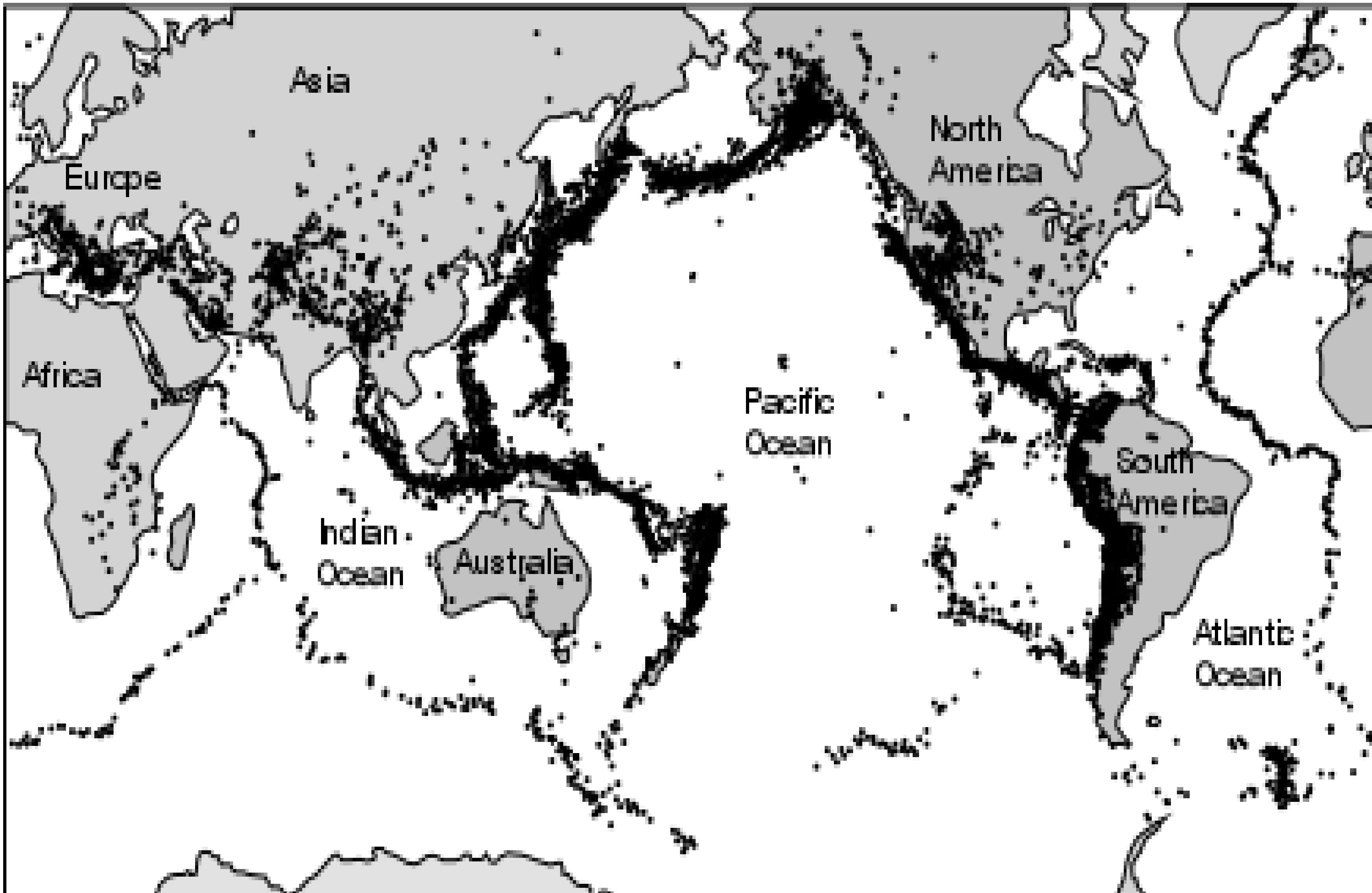
- Plates are composed of lithosphere, about 100 km thick, that "float" on the ductile asthenosphere (upper mantle).
- The continents do indeed drift, because they are part of larger plates that float and move horizontally on the upper mantle asthenosphere.
- The plates behave as rigid bodies with some ability to flex, but deformation occurs mainly along the boundaries between plates.

Plate Boundaries



Zones Along Which Earthquakes Occur

World Seismicity 1961 - 1967



Types of Plate Boundaries

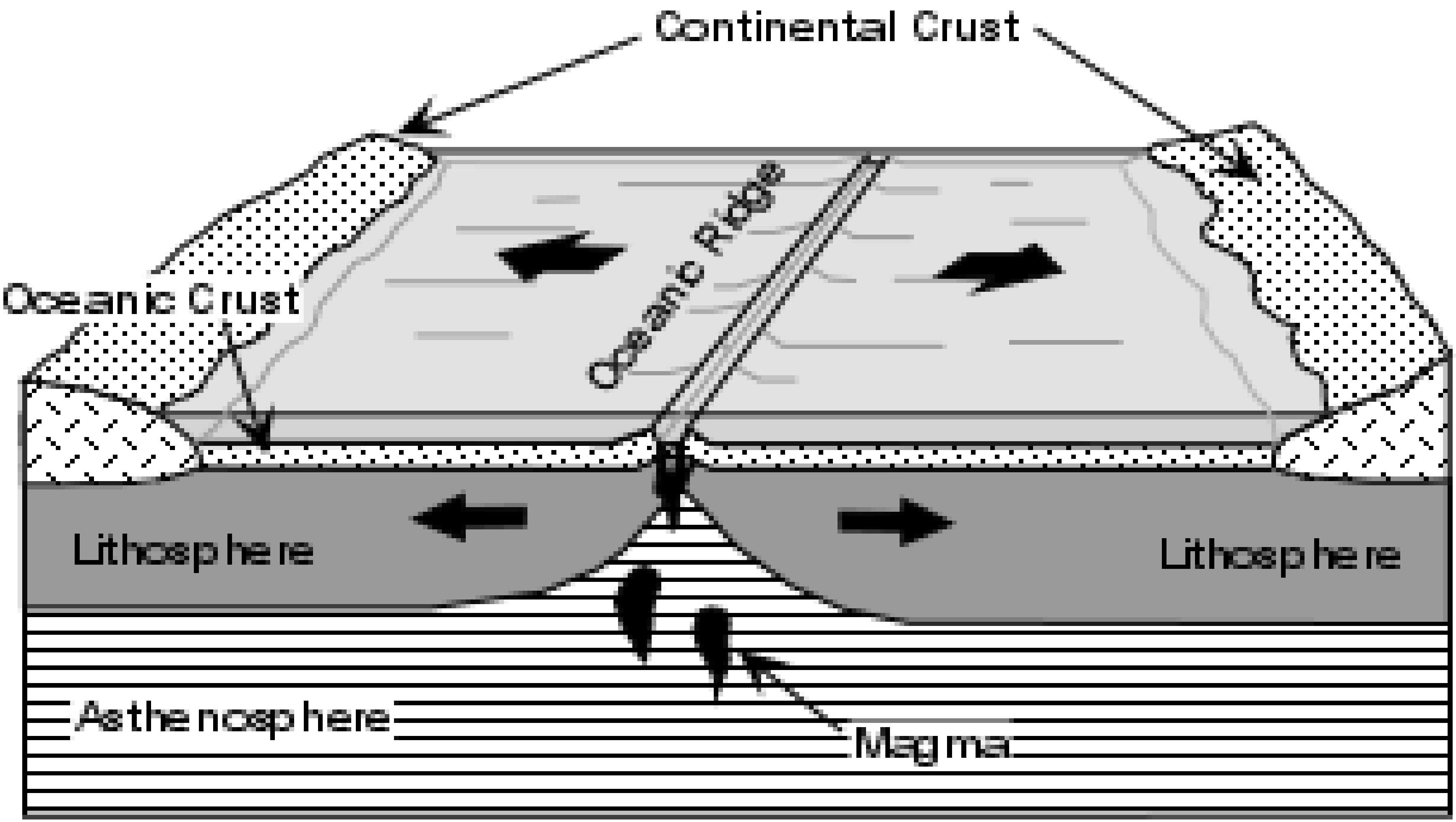
❑Three Types are Classified:

- Divergent Plate Boundaries
- Convergent Plate Boundaries
- Transform Plate Boundaries

Types of Plate Boundaries –
1. Divergent Plate Boundaries

- These are oceanic ridges where new oceanic lithosphere is created by upwelling mantle that melts, resulting in basaltic magmas which intrude and erupt at the oceanic ridge to create new oceanic lithosphere and crust.
- As new oceanic lithosphere is created, it is pushed aside in opposite directions. Thus, the age of the oceanic crust becomes progressively older in both directions away from the ridge.

Divergent Plate Boundaries



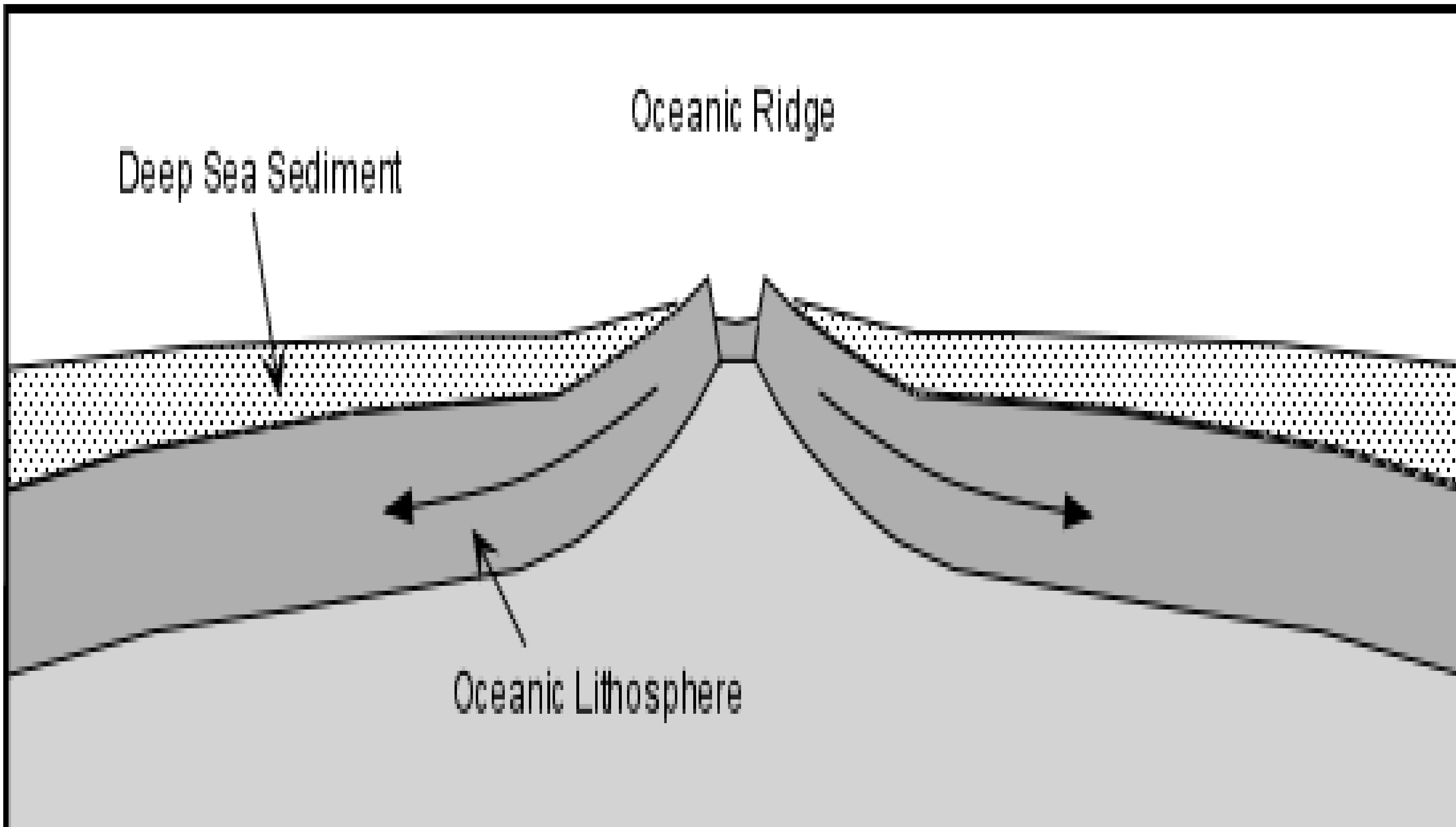
Diverging Plate Boundary
Oceanic Ridge - Spreading Center

Underwater volcano

Divergent Plate Boundaries, Cont.

- Because the oceanic ridges are areas of young crust, there is very little sediment accumulation on the ridges.
- Sediment thickness increases in both directions away of the ridge, and is thickest where the oceanic crust is the oldest.
- ✓ In the Atlantic Ocean, the oldest oceanic crust occurs next to the North American and African continents and is about 180 million years old (Jurassic).

Sediment Thickness Increases In Both Directions Away Of The Ridge



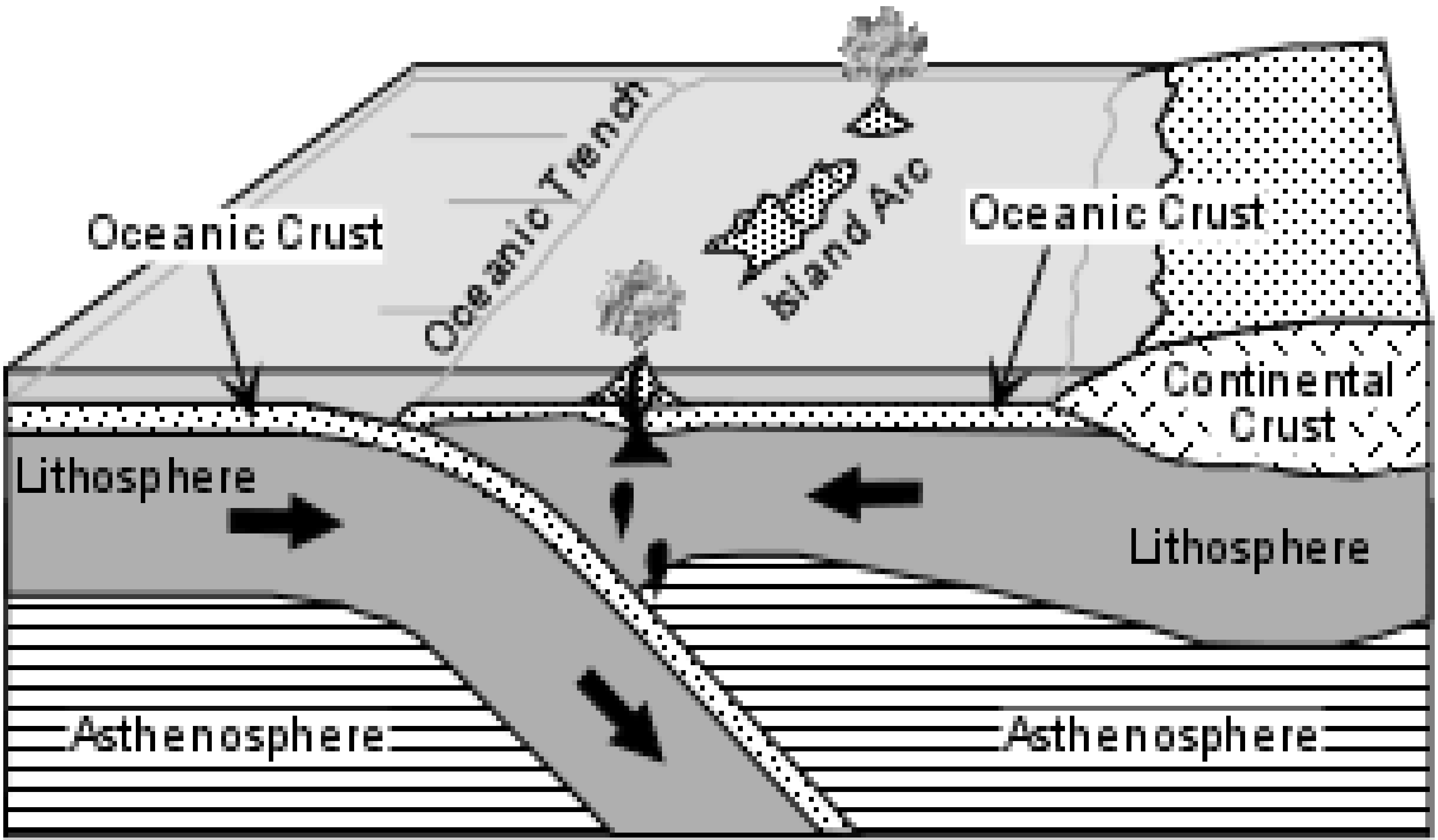
Divergent Plate Boundaries, Cont.

- Knowing the age of the crust and the distance from the ridge, the relative velocity of the plates can be determined.
- Relative plate velocities vary both for individual plates and for different plates.
- Variations in individual plate velocities occur because spreading of the sea floor takes place on a spherical surface rather than on a flat surface.
- Velocities are greatest at large distances away from the spreading pole

Types of Plate Boundaries –
2. Convergent Plate Boundaries

- When a plate of dense oceanic lithosphere moving in one direction collides with a plate moving in the opposite direction, one of the plates subducts beneath the other.
- Where this occurs an oceanic trench forms on the sea floor and the sinking plate becomes a subduction zone.
- The Benioff zone identifies a subduction zone.
- The earthquakes may extend down to depths of 700 km before the subducting plate heats up and loses its ability to deform in a brittle fashion.

Convergent Plate Boundaries
- Island Arc -



Ocean - Ocean Convergence

Convergent Plate Boundaries

- As the oceanic plate subducts, it begins to heat up and metamorphose.
- As it does so, dehydration reactions release water into the overlying mantle asthenosphere, causing a reduction in the melting temperature and the production of andesitic magmas.
- These magmas rise to the surface and create a volcanic arc parallel to the trench.

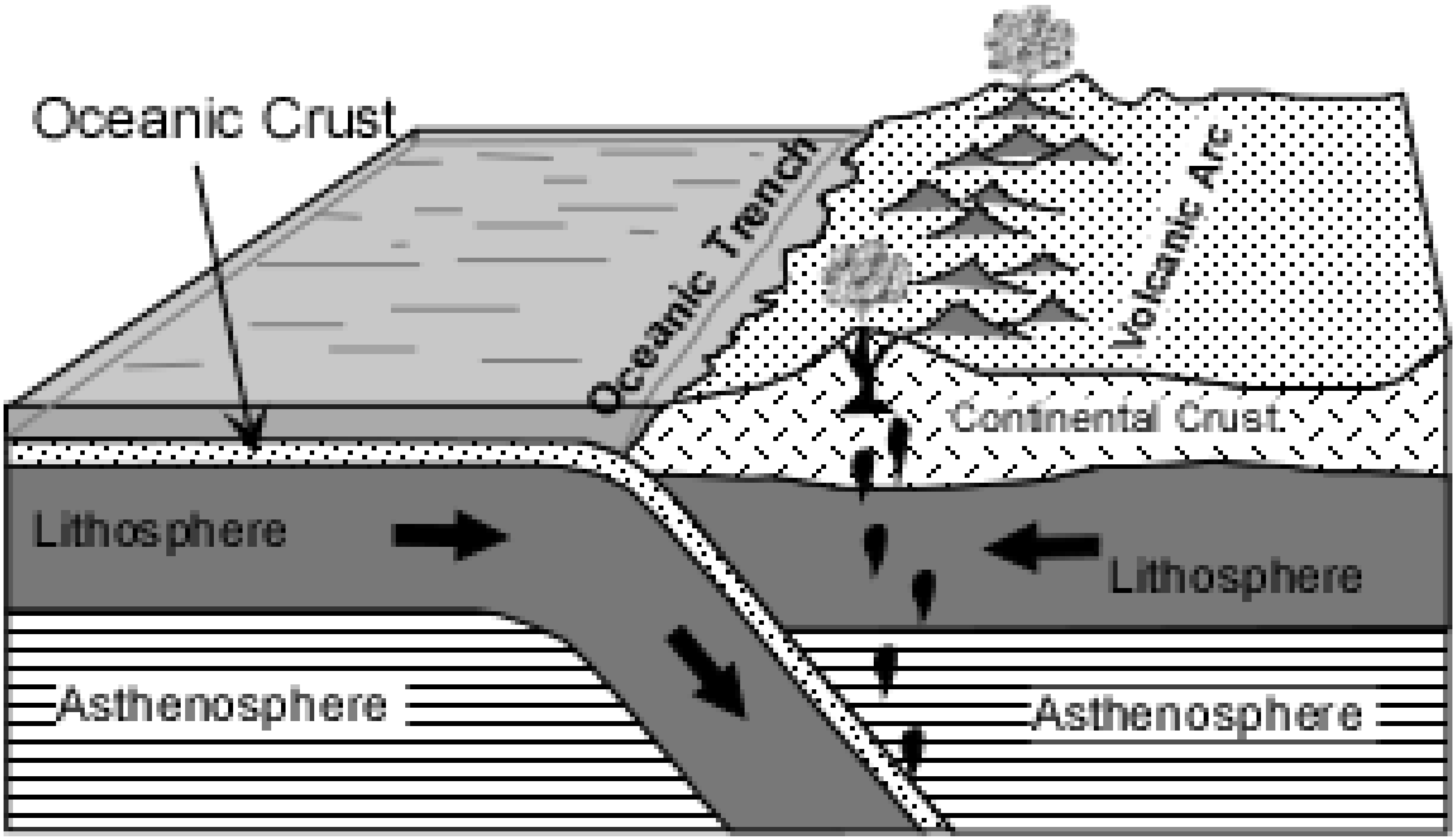
Convergent Plate Boundaries

- If the subduction occurs beneath oceanic lithosphere, an island arc is produced at the surface (such as the Japanese islands, the Aleutian Islands, the Philippine islands, or the Caribbean islands.
- If the subduction occurs beneath continental crust, a continental volcanic arc is produced (such as the Cascades of the western U.S., or the Andes mountains of the South America).

Convergent Plate Boundaries

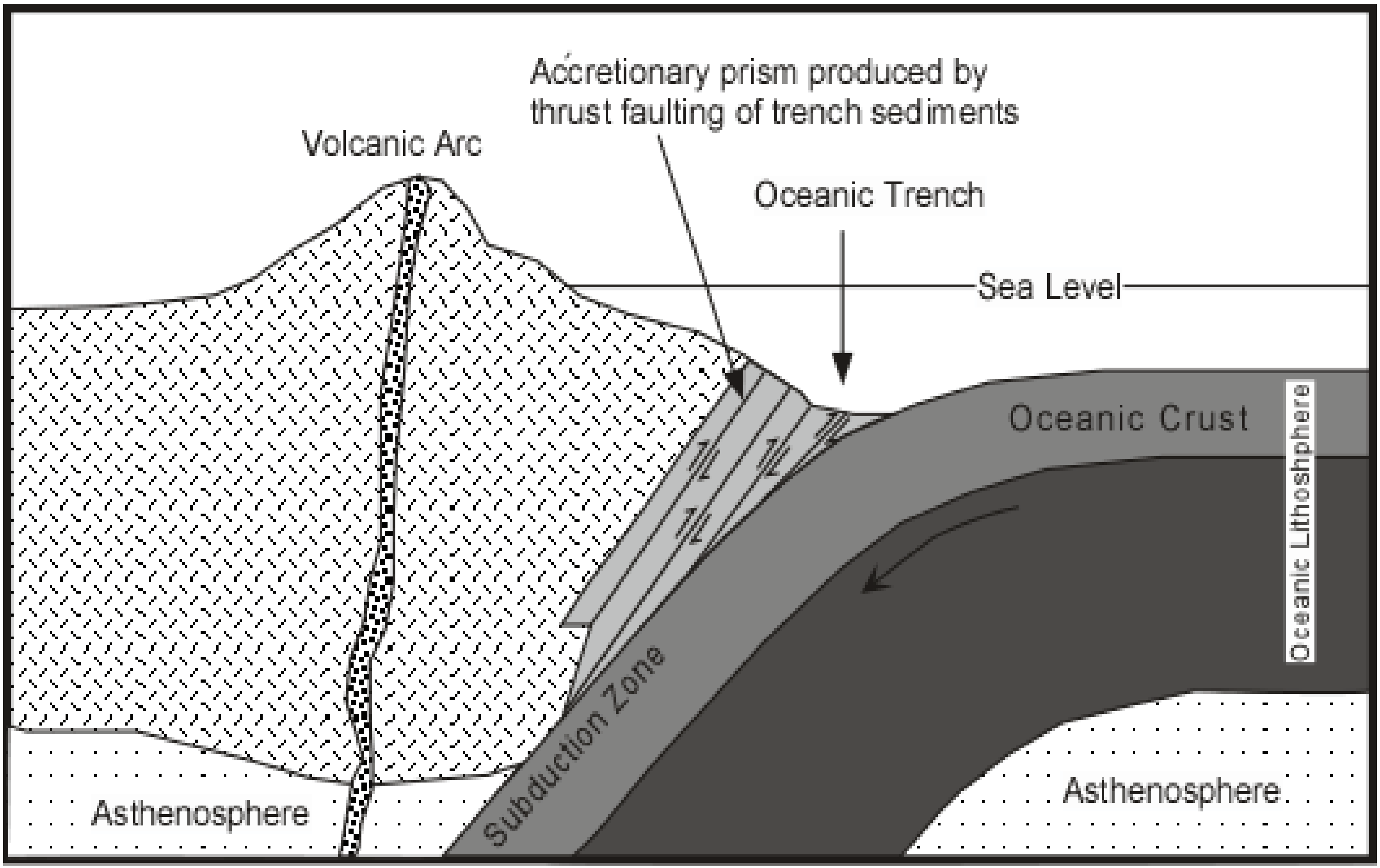
- If one of the plates has continental lithosphere on its margin, the oceanic plate will subduct because oceanic lithosphere has a higher density than continental lithosphere.
- Sediment deposited along the convergent margin, and particularly that in the trench will be deformed by thrust faulting.
- ✓ This will break the rocks up into a chaotic mixture of broken, jumbled, and thrust faulted rock know as a ***mélange.***

Convergent Plate Boundaries
- *Continental Volcanic Arc* -



Ocean - Continent Convergence

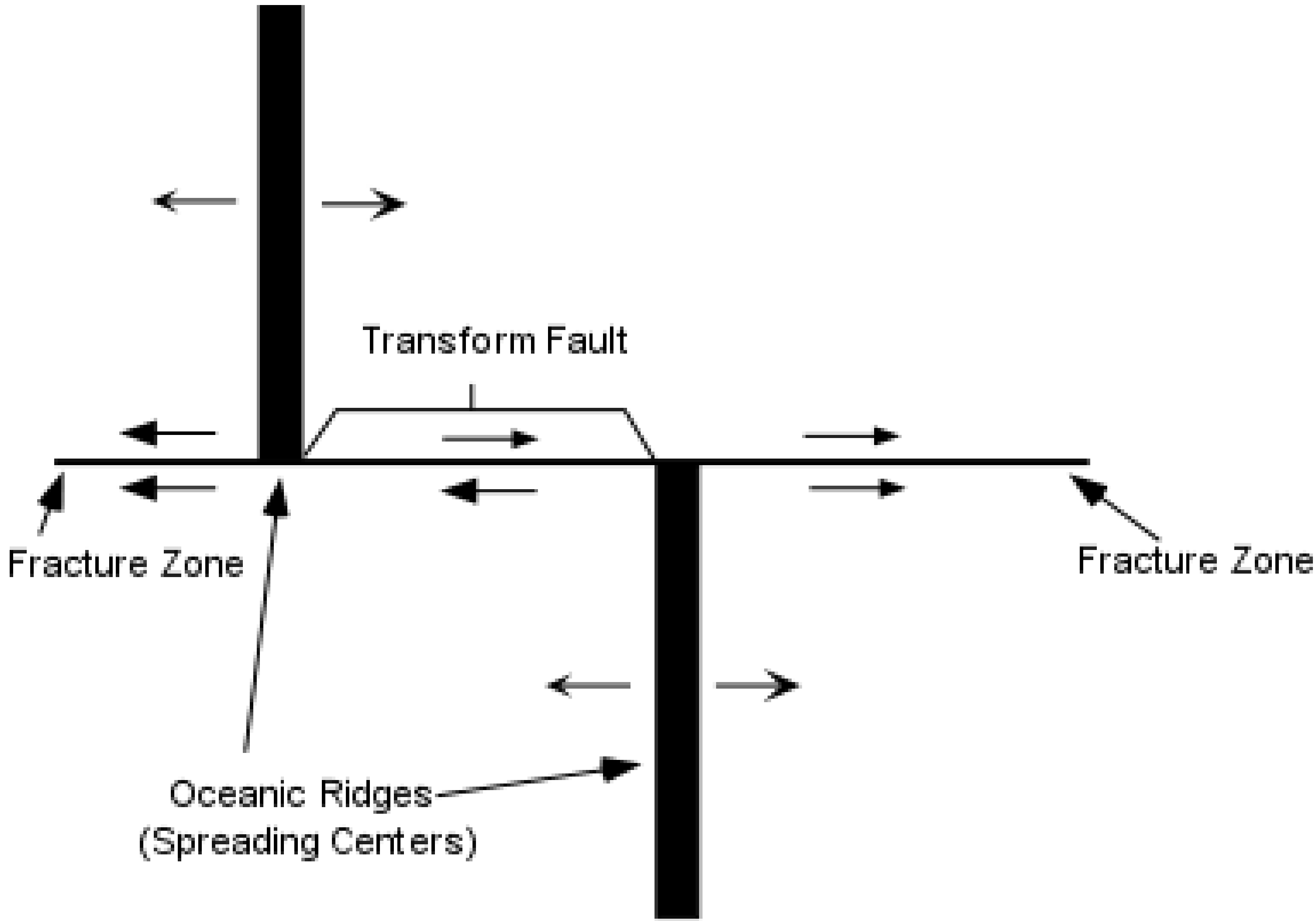
Convergent Plate Boundaries
- *Accretionary Prism* -



3. Transform Plate Boundaries

- Where lithospheric plates slide past one another in a horizontal manner, a transform fault is created. Earthquakes along such transform faults are shallow focus earthquakes.
- Most transform faults occur where oceanic ridges are offset on the sea floor. Such offset occurs because spreading takes place on the spherical surface of the Earth, and some parts of a plate must be moving at a higher relative velocity than other parts.

Transform Plate Boundaries



Hot Spots and Absolute Plate Velocities

- Plate velocities determined from the rate of sea floor spreading or by making measurements across a plate boundary are only relative velocities.
- That is we know the velocity of one plate only if we can assume that the adjacent plate is not moving.
- In order to determine absolute plate velocities, we need some fixed reference point that we know is not moving.

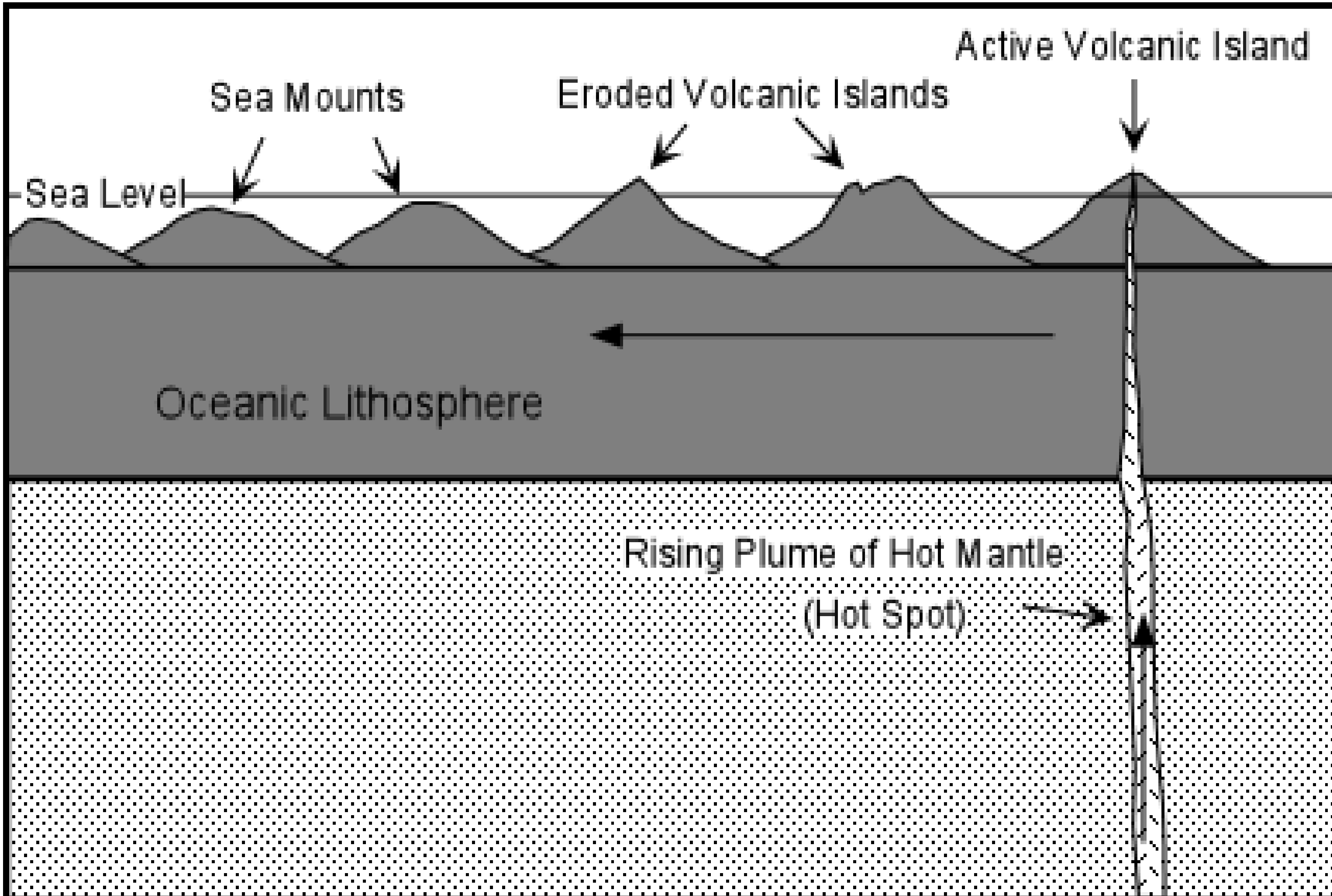
Hot Spots and Absolute Plate Velocities, Cont.

- The island chain appears to have formed as the Pacific plate moved over a ***Hot Spot,*** an area in the Earth's mantle where hot material from the Earth's interior is moving upward.
- If we can assume that such a hot spot is stationary, then we can calculate the absolute velocity of the Pacific Plate as it has moved over the hot spot.

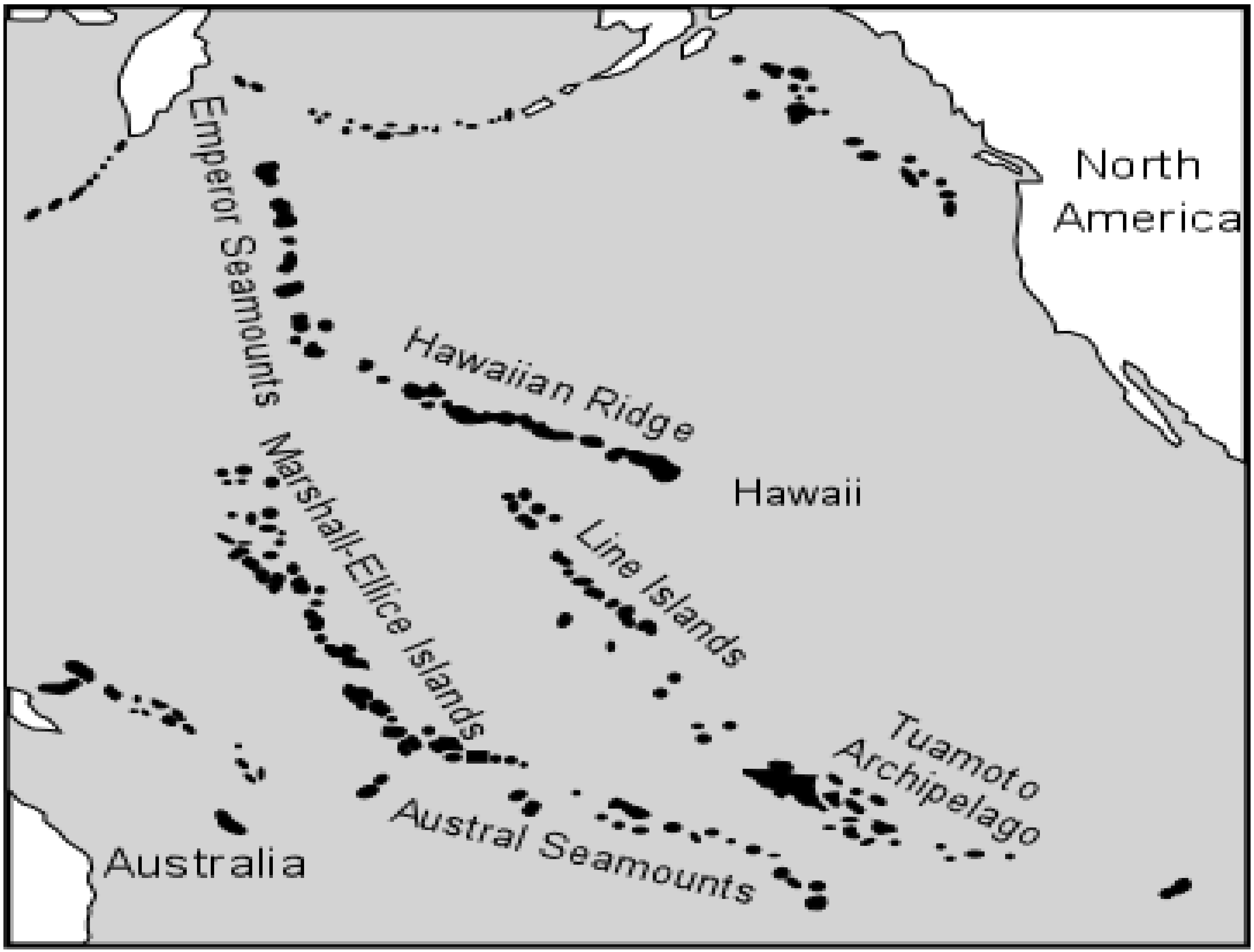
Hot Spots and Absolute Plate Velocities, Cont.

- By using these hot spots to determine absolute velocities, we find that the African Plate is almost stationary (expected because the African Plate is surrounded by oceanic ridges, and the Mid- Atlantic Ridge is moving toward the west.
- Furthermore, the Atlantic Ocean is getting bigger and the Pacific Ocean is getting smaller.

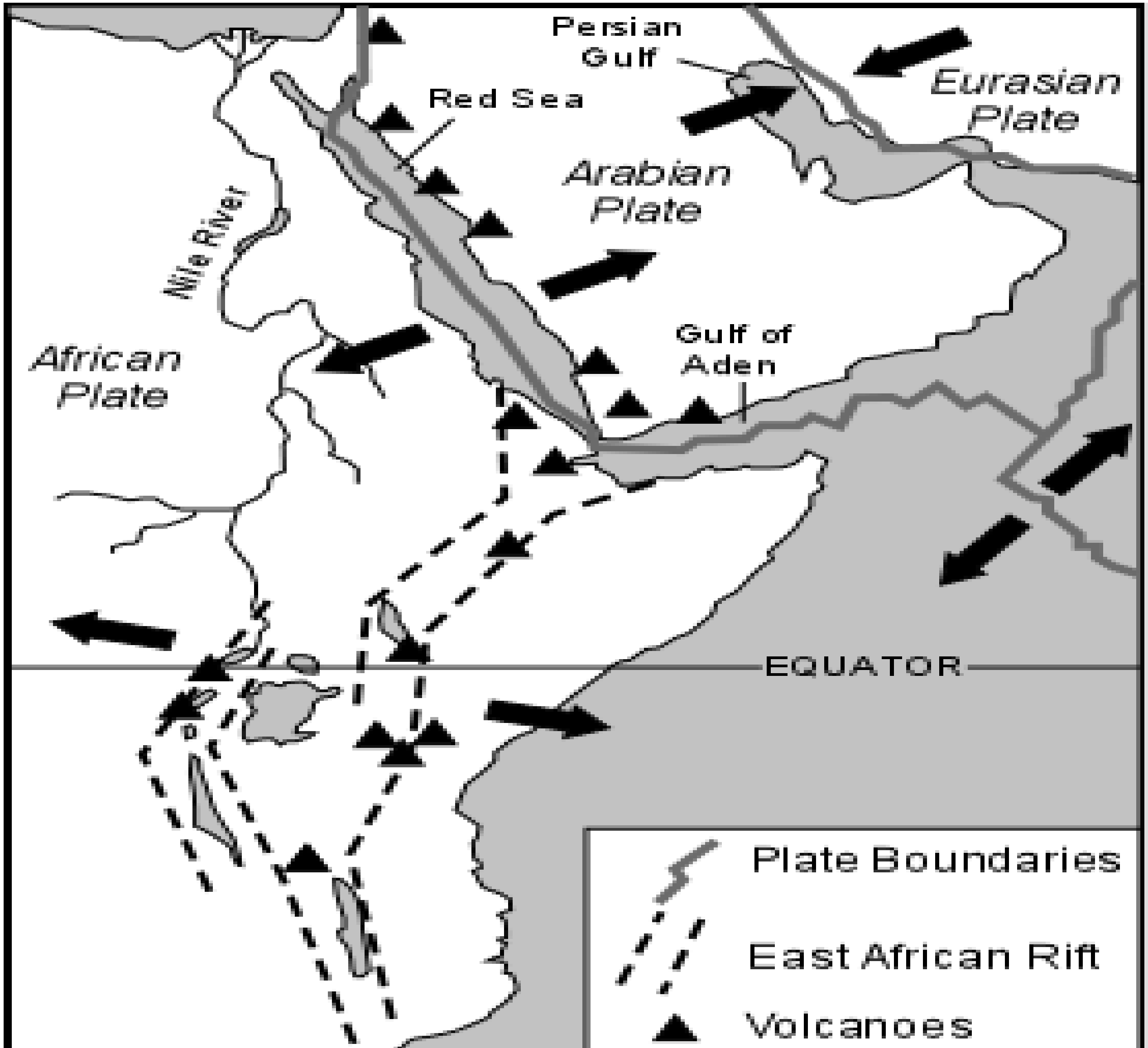
Hot Spots


Active Volcanic Island
Sea Mounts
Eroded Volcanic Islands
Sea Level
Oceanic Lithosphere
Rising Plume of Hot Mantle
(Hot Spot)

Hot Spots
-Linear Chains Of Islands And Seamounts-

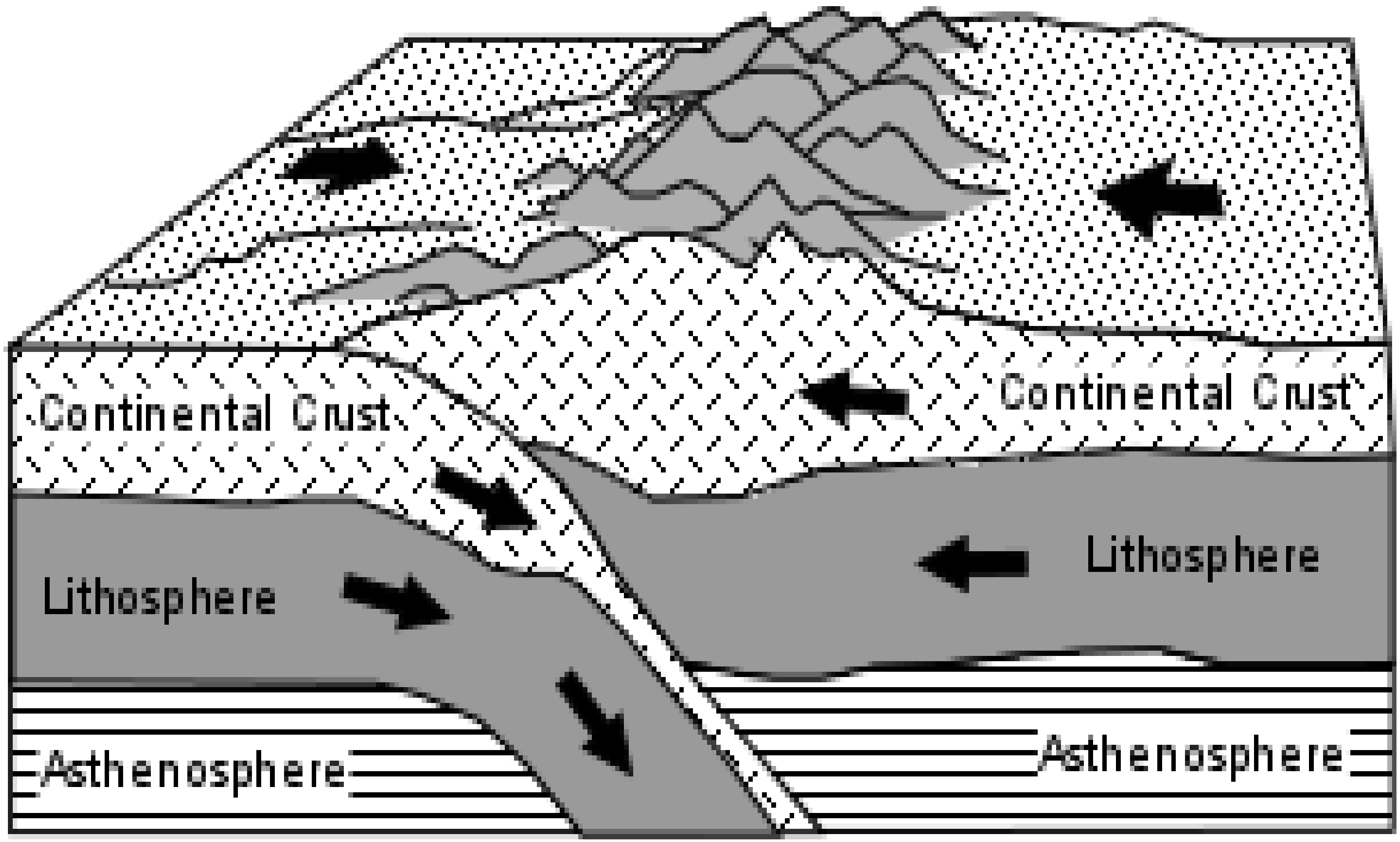


Evolving Plate Boundaries
-Continental Rifting-



Evolving Plate Boundaries

-Continental Collisions-



Continent- Continent Convergence

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THANK YOU

NEXT

GEOTIME