BHARATHIDASAN UNIVERSITY

Tiruchirappalli - 620 024
Tamil Nadu, India

Programme : 6 year Integrated M.Tech in Geological Technology and Geoinformatics

Course title : Marine Geology and Geoinformatics in Sea bed Exploration

Course code : MTIGT 0607

UNIT - II

Physical Phenomena and Features of the Ocean

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Ocean circulation

Ocean circulation is the large scale movement of waters in the ocean basins. Sun’s energy doesn't fall equally all over the Earth. Most of the Sun's energy enters the Earth at the equator. This leads to large temperature gradients between the equator and the Poles.

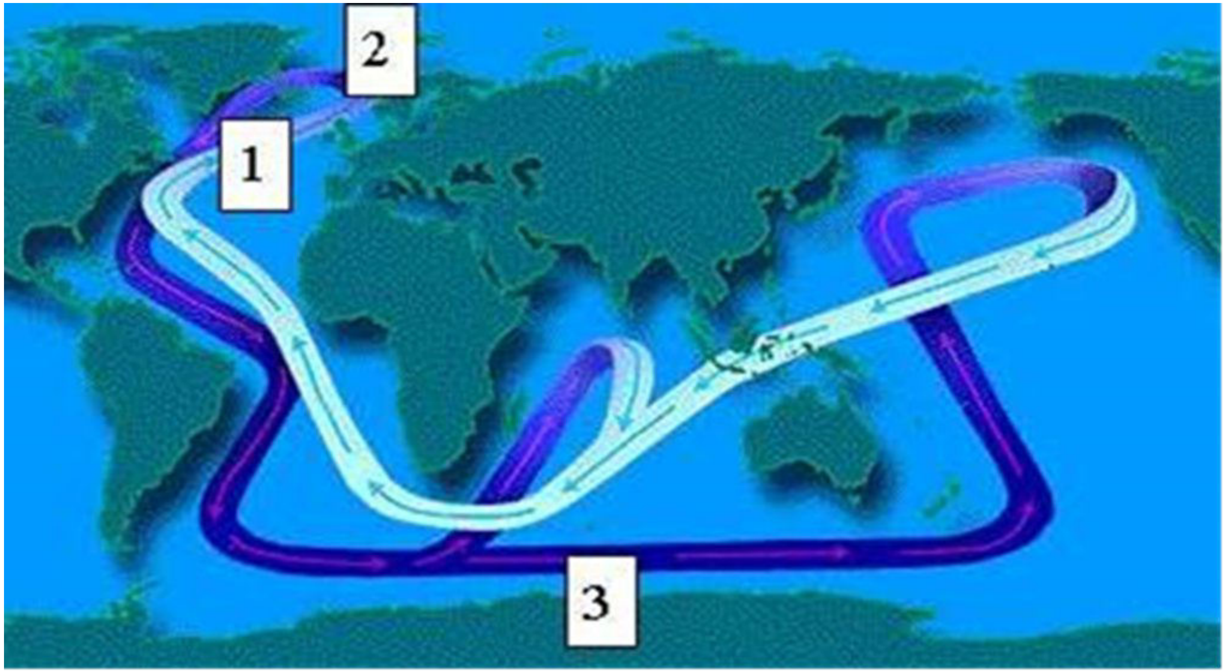
Movement of both the air and the sea water is controlled by these temperature differences and the result is a transfer of heat from the equator to the poles. Generally, half the heat transport around the planet is done by the oceans so the oceans are an extremely important part of the Earth's climate control system. If ocean circulation is changed by global warming, major changes in climate are therefore likely. Ocean circulation also transports oxygen from the air into the ocean making marine life possible.

Seawater continuously moves around the globe as if it is on a huge conveyor belt, moving from the surface to the deep waters and back. Because the distance the water has to travel is so large, it takes approximately 1000 years for seawater to go all the way around the Earth.

Broadly, two different types of Ocean circulation are recognised:

- **density driven circulation** driven by the differences in the density of seawater at different locations. As the density of seawater depends on its temperature and its salt content. This movement is known as the **thermohaline circulation** (thermo - heat, haline - salt).

- **wind driven circulation** which results in huge surface currents like the Gulf Stream.

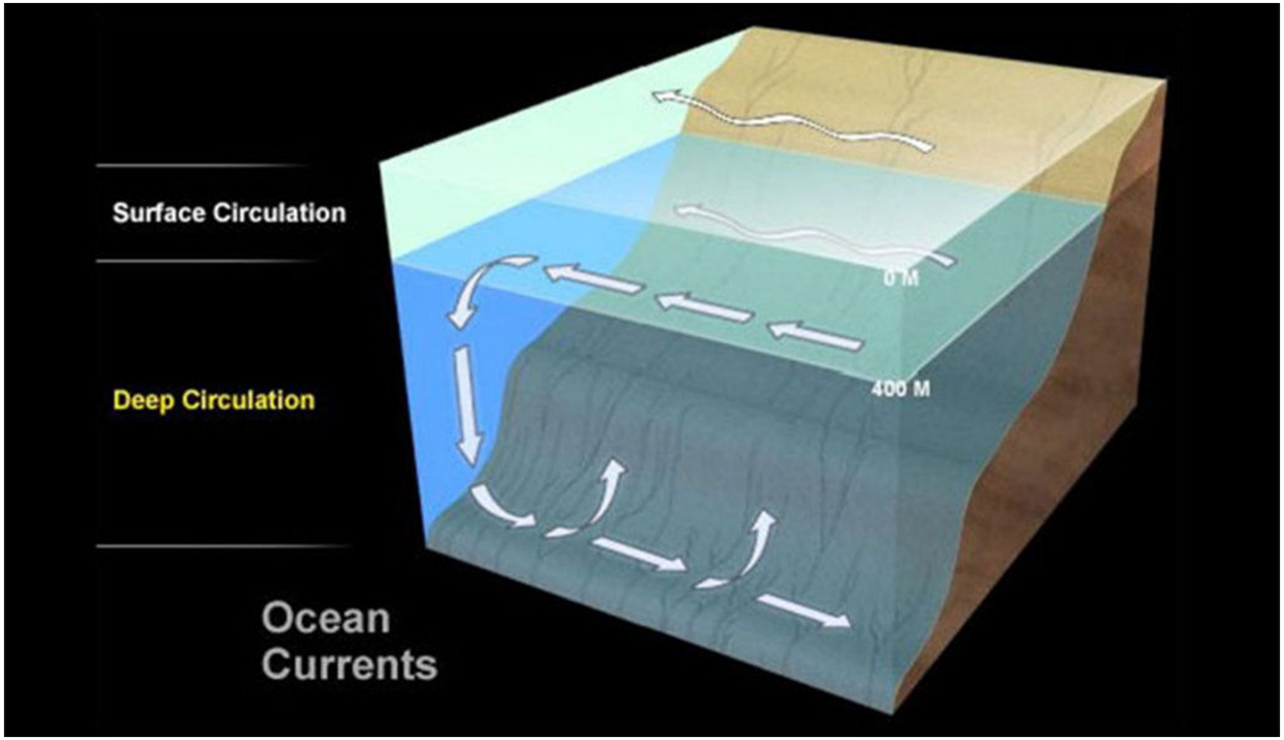


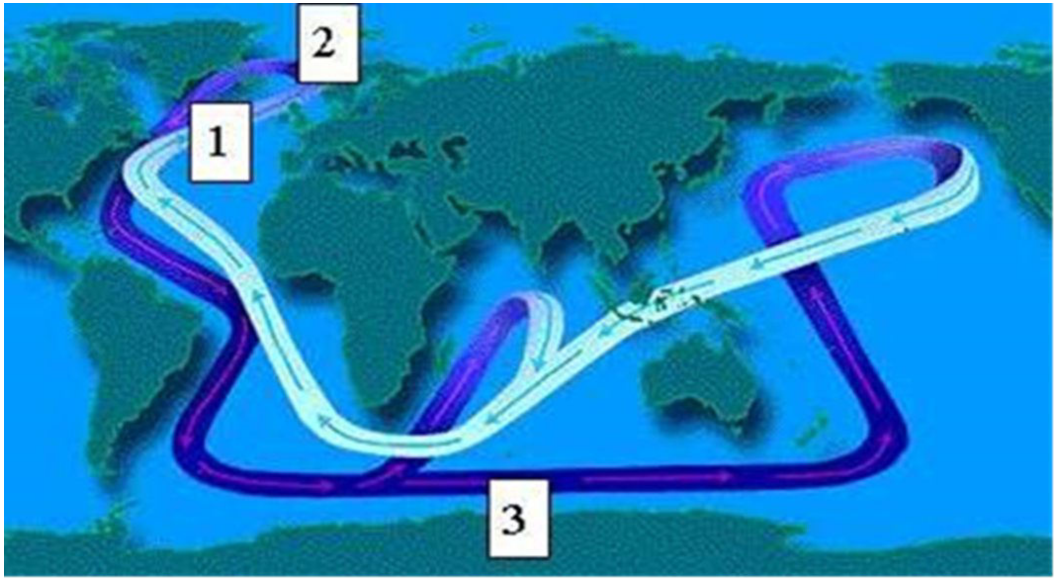
The light colored path shows the general movement of the surface waters and the dark colored path shows the movement of water at depth. The numbers show the position of:

1. The Gulf Stream which transports heat from the tropics to northern Europe.
2. North Atlantic Deep Water formation which results from strong cooling.
3. Antarctic Bottom Water formation due to sea ice production around Antarctica.

Wind driven circulation (Surface currents)
(Primarily horizontal motion)

Density driven circulation (Deep currents)
Driven by differences in density caused by differences in temperature and salinity (Vertical and horizontal motions) These currents move water masses through the deep ocean - taking nutrients, oxygen, and heat with them.





Ocean circulation transports surface seawater to the polar region where it cools. This cooling releases heat which warms the air and makes the water cold and, therefore, dense enough to sink to the bottom of the ocean.

This results in the formation of new deep water which displaces existing deep water pushing it towards the equator. The major regions for this deep water formation are the Labrador and Greenland Seas in the northern North Atlantic Ocean.

This North Atlantic Deep Water then flows south along the ocean floor allowing more warm surface water to flow into the region to replace it. Strong cooling also occurs in the Bering Sea in the North Pacific, but the structure of the ocean floor here prevents the deep water that forms from entering the ocean circulation.

Antarctica

Deep water formation also occurs around Antarctica during the production of sea ice. This ice contains very little salt and so, as the ice forms, the surrounding water becomes saltier and denser. This very dense water slides down the edge of the Antarctic continent to form Antarctic Bottom Water. This water then spreads out and moves around most of the ocean floor.

Earlier, it has been thought that the deep waters that formed at the poles moved towards the equator, slowly warming and rising to the surface over the whole ocean, and that this water then returned to the poles in warm surface currents to complete the cycle. However, recent studies have shown that this gradual upwelling process is too slow to explain the age of seawater.

Currently, many are of the opinion that as deep water circulates around the bottom of the ocean, it meets the mid ocean ridges which are mountainous areas on the sea floor. The roughness of these causes strong mixing which forces the deep water to rise to the surface. The wind also causes strong mixing in the Southern Ocean and this also brings the deep water back to the surface. Once at the surface, the water returns to the poles in wind driven surface currents to complete its cycle.

Surface Currents

Controlled by three factors

- Global winds
- Coriolis Effect
- Continental Deflections

Coriolis Effect

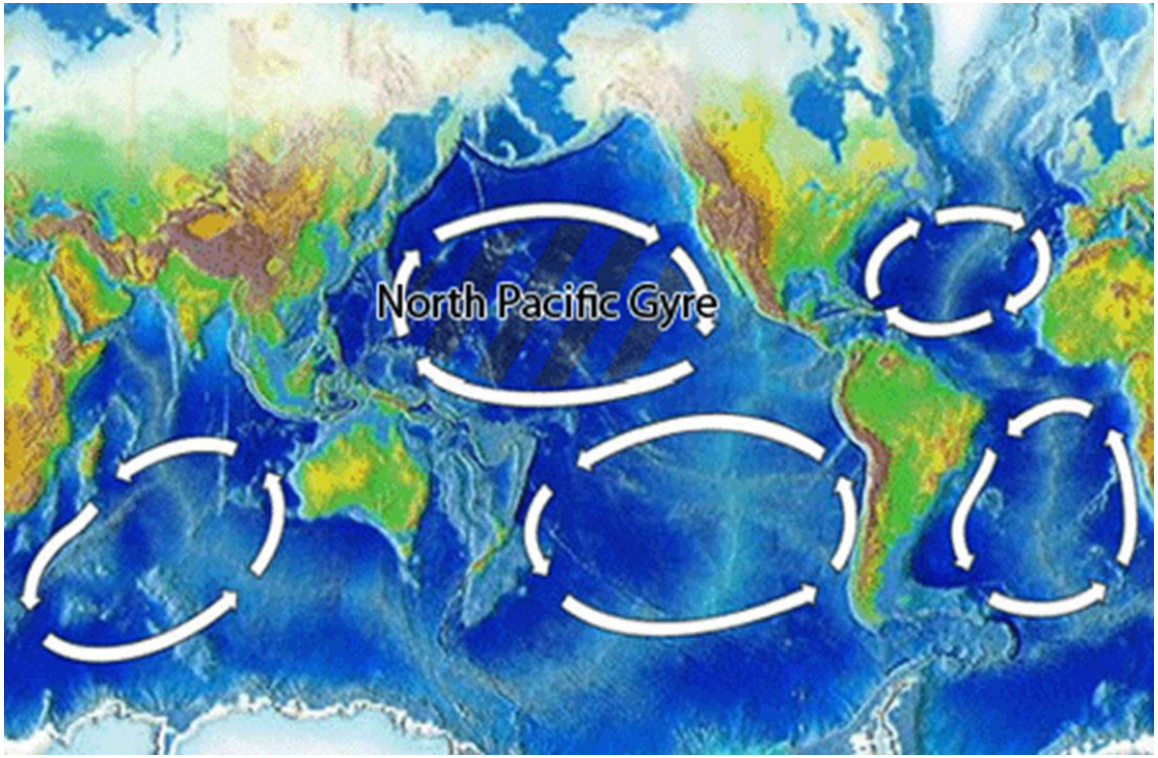
Apparent curving of moving objects (i.e. Water) due to the Earth's rotation

Continental Deflections

Shape of continents change the direction of current flow

Ocean Currents Vocabulary

Gyre: Nearly closed current system in the open ocean

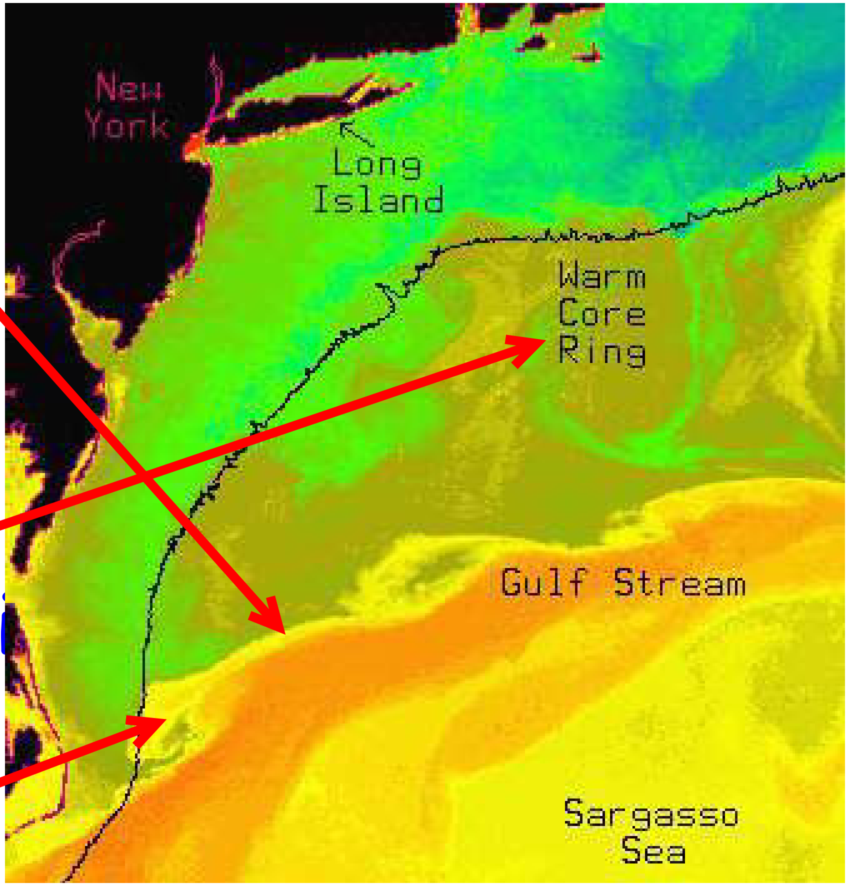


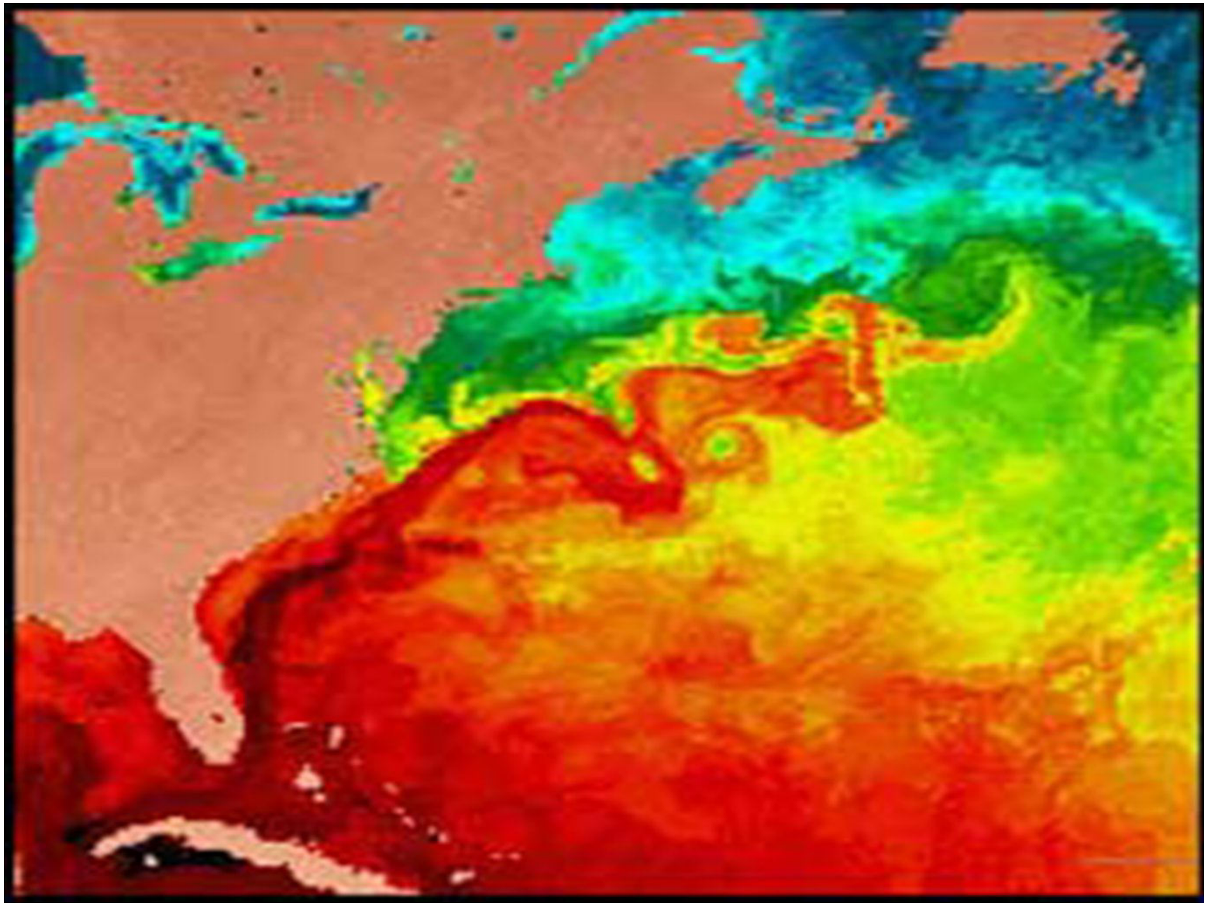
- Clockwise pattern in N. Hemisphere
- Counter-clockwise pattern in S. Hemisphere

- **Meander** – Bend in a current's flow

- **Ring** – Large, whirl-like pattern (when a meander is cut off)

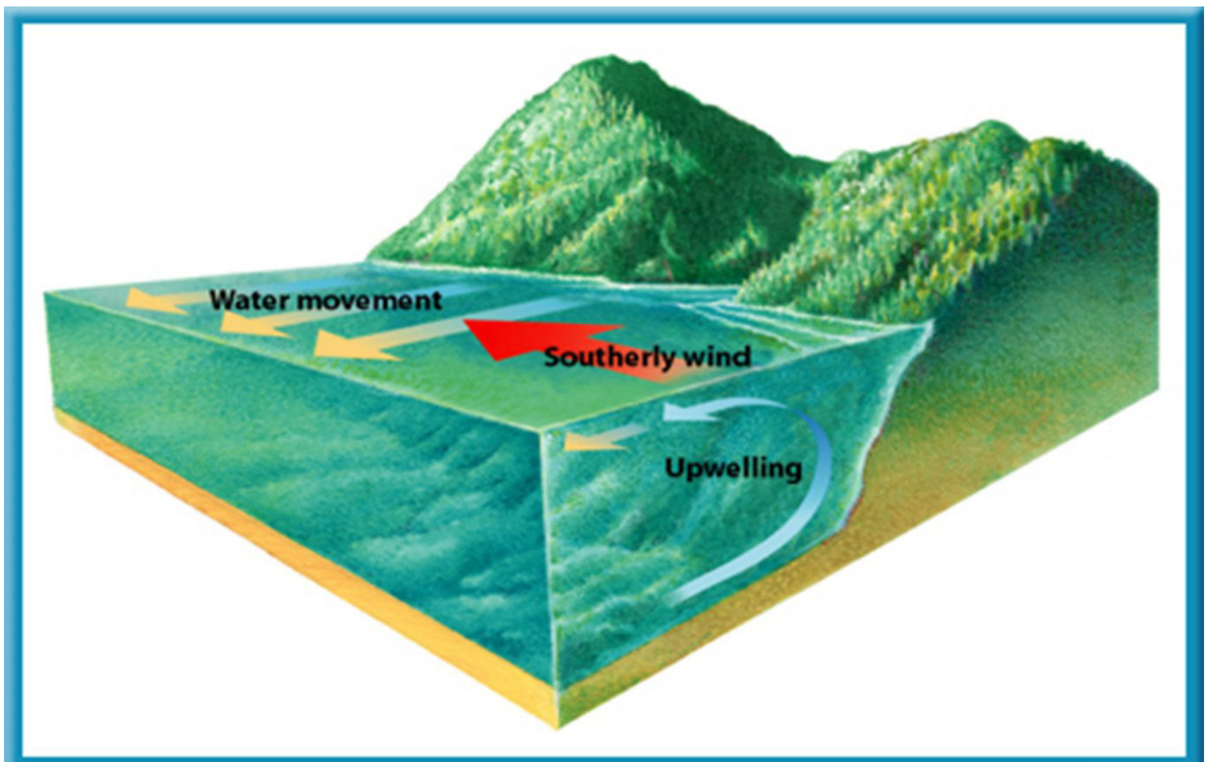
- **Eddy** – Small current Ring





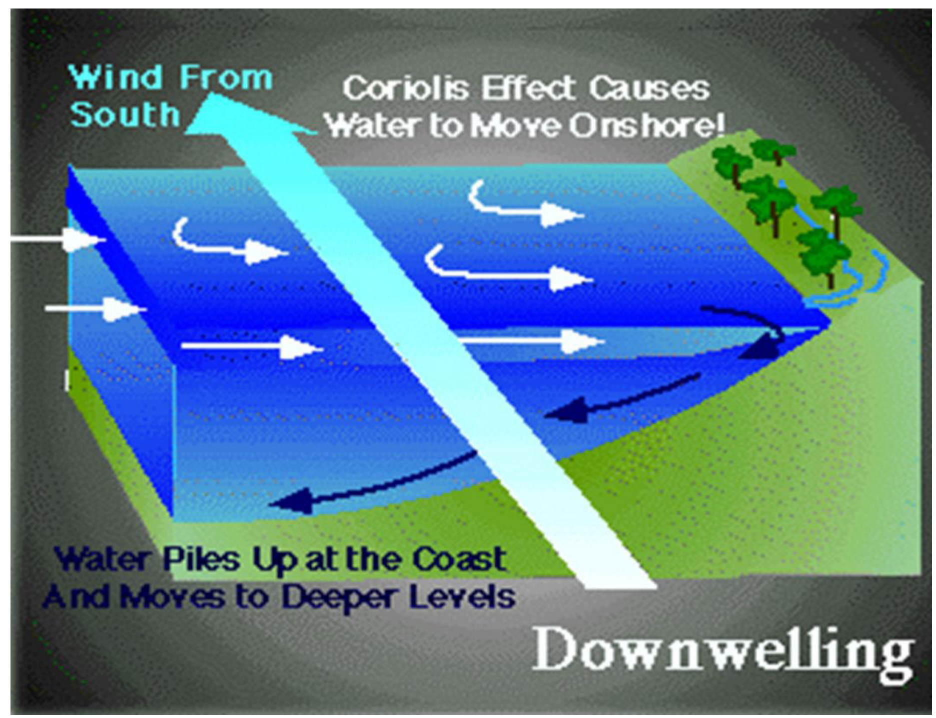
Upwelling

- The movement of deep, cold, nutrient rich water to the surface
- Nutrients promote growth of fish and plants
- Areas are important fishing grounds



Downwelling (Sinking)

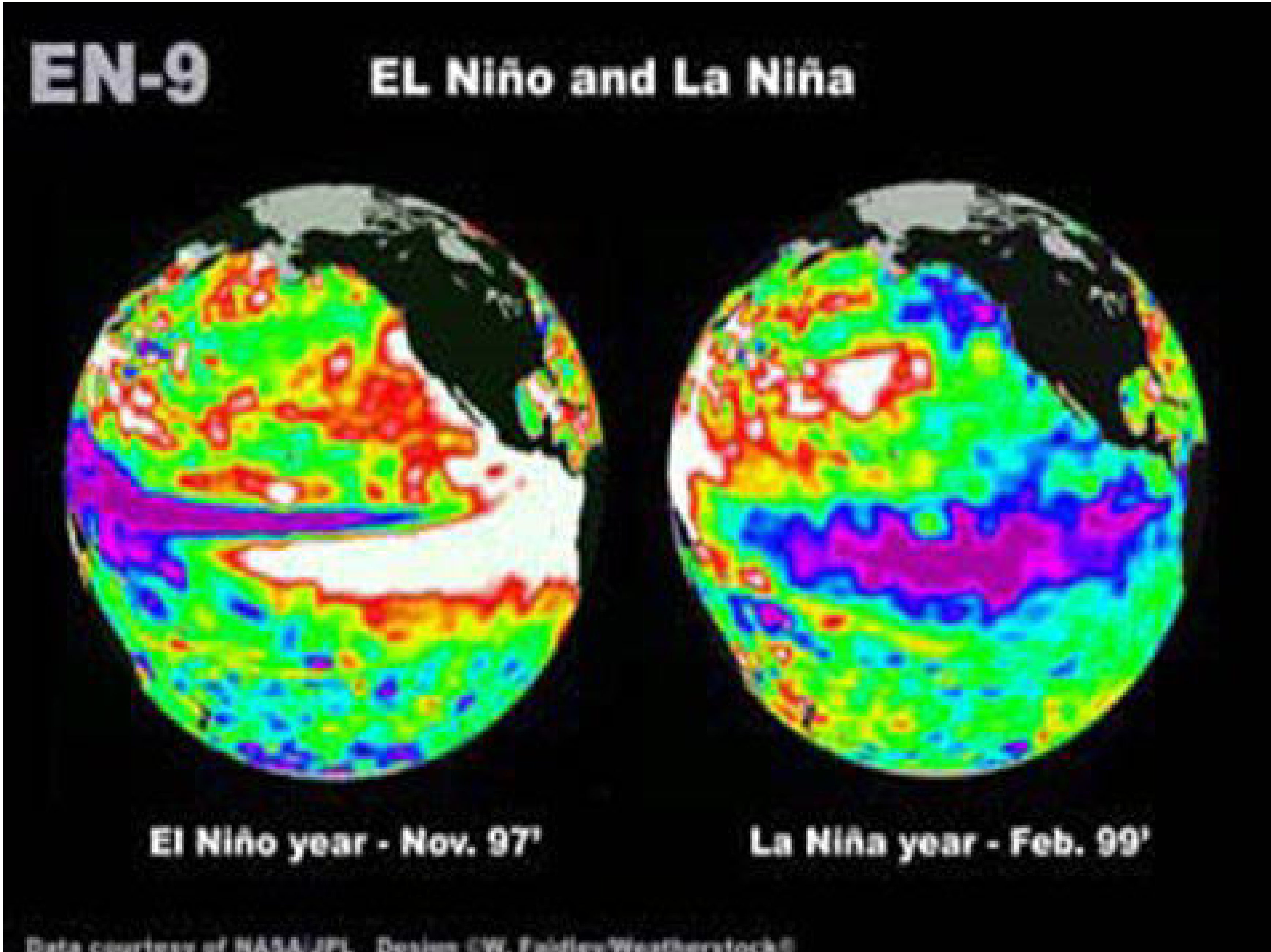
- The movement of warm surface waters towards the coast
- Causes a thickening of the surface waters which causes them to sink



Causes of warm and cold currents

- **El Niño**
  - Change in the water temperature in the Pacific Ocean that produces a warm current.

- **La Niña**
  - Change in the eastern Pacific Ocean in which the surface water temperature becomes unusually cool.


EN-9
EL Niño and La Niña
El Niño year - Nov. 97'
La Niña year - Feb. 99'
Data courtesy of NASA/JPL Design ©W. Faidley/Weatherstock©

Variations in the ocean's circulation can lead to variations in heat transport and to variations in weather patterns. One important variation in the circulation is the change in the equatorial circulation known as **El Niño** which occurs with an irregular period of two to five years. The most recent El Niños have been observed with unprecedented accuracy by TOPEX/Poseidon.

El Niño is a condition that sometimes occurs in the Pacific Ocean and it is so big that it affects weather all over the world.

Weather depends a lot on ocean temperatures. Where the ocean is warm, more clouds form, and more rain falls in that part of the world. In the Pacific Ocean, near the equator, the Sun makes the water especially warm on the surface.

Normally, strong winds along the equator push the warm surface water near South America westward toward Indonesia. When this happens, the cooler water underneath rises up toward the surface of the ocean near South America.

Due to the rotation of the earth, currents are deflected to the right in the northern hemisphere and to the left in the southern hemisphere. This effect is known as the "**Coriolis force**." The deflection leads to highs and lows of sea level directly proportional to the speed of the surface currents. The changes in sea level due to currents are the ocean topography that is observed by TOPEX/Poseidon.

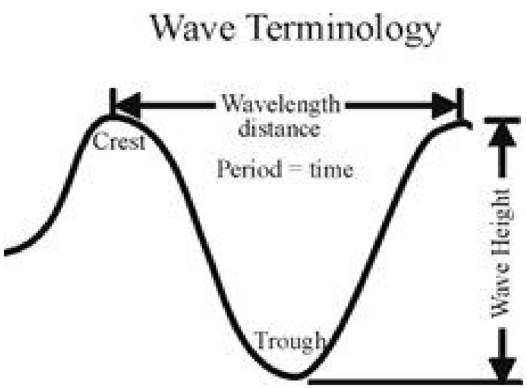
Observations of ocean topography and a knowledge of the Coriolis force permit scientists to map ocean currents using data from the satellite. Every ten days TOPEX/Poseidon produces maps of the currents everywhere in the ocean.

WAVE ENERGY

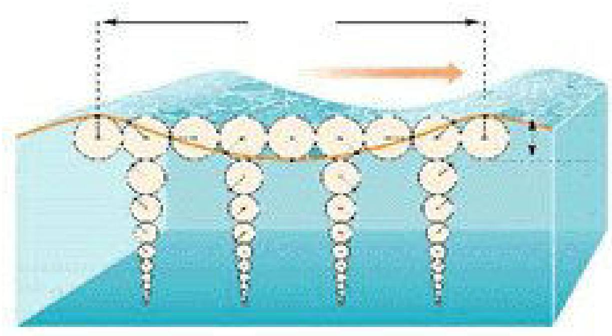
When energy from the wind is transferred to the water, waves are produced. The waves then carry that energy as they travel for hundreds or thousands of kms. This is possible because it is energy that is moving, not water.

For ex. if we float a ball on waves in an area free of wind. The ball will move up as the wave passes under it. The ball then returns nearly to its original location.

Each wave moves the ball around in a circular orbit, and since the ball is in contact with the water, the water must be moving in the same way. Waves represent energy passing along the surface of the water in much the same way that "waves" of energy can pass through a rug or a rope as one end is shaken up and down.

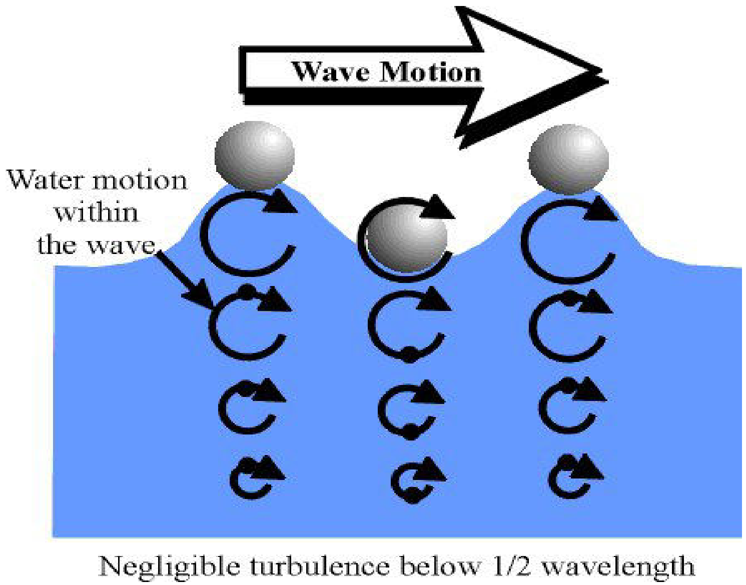


Height (H) , Period (T) - time between successive crests, Wavelength (L) - distance between successive crests.



Causes of Waves

- When wind blows across a body of water, wind energy is transferred to the water
- If the wind speed is great enough, the water begins to pile up, forming a wave.
- The height of a wave depends on:
  - The speed of the wind
  - The distance over which the wind blows
  - The length of time the wind blows

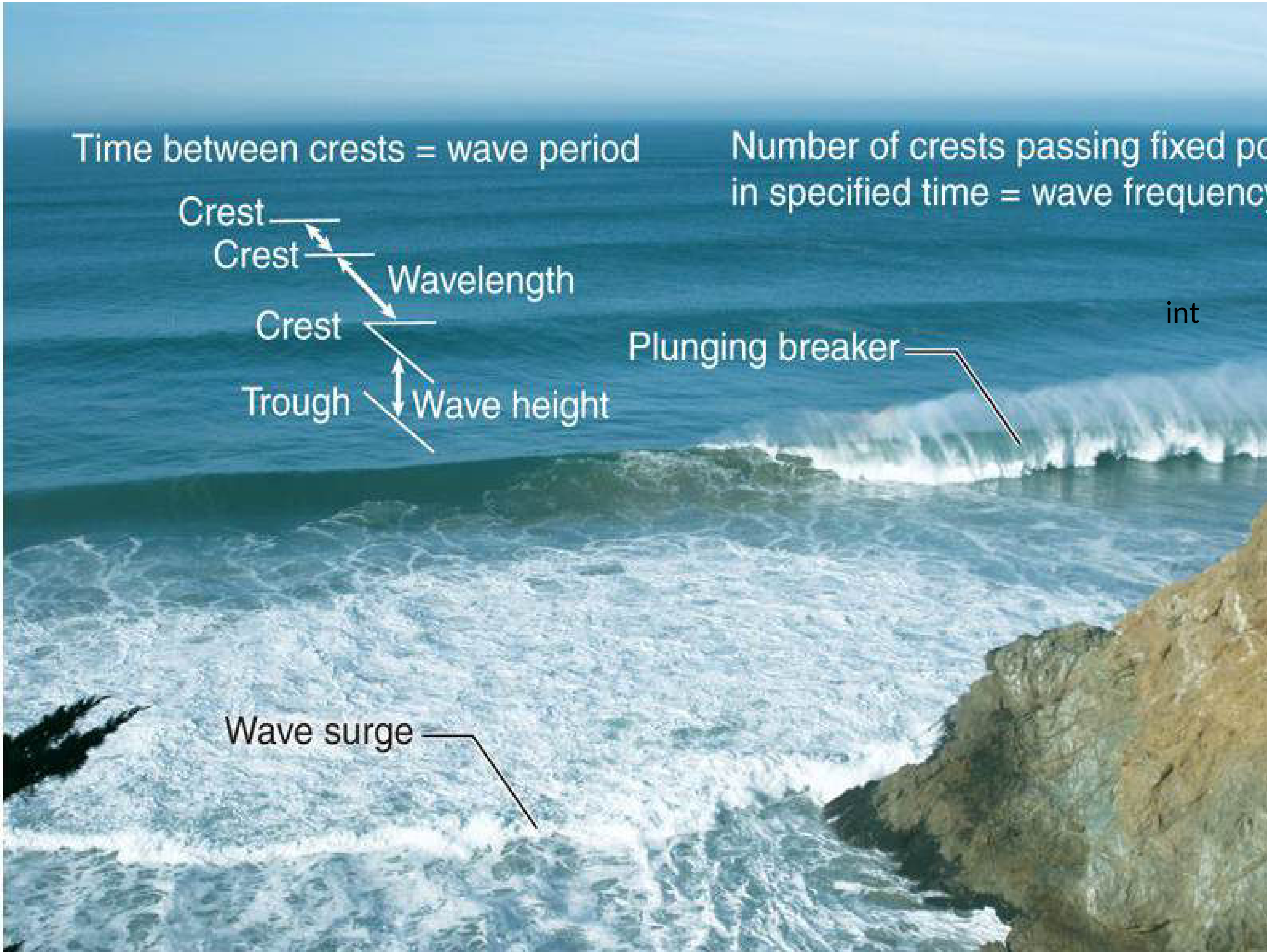


This circular orbit is confined largely to the upper layers. Observation indicates that the waves' motion decreases with depth and nearly dies out at a distance below the waves **equal to one half of their wavelength** (the distance from one crest to the next). Thus, if waves were found to have wavelengths of about 13 m, we would know that they are disturbing the water to a depth of about seven meters. This depth is known as the "**wave base**."

Waves can pass fairly easily from one place to the next without a significant loss of energy. Thus the world's oceans become great collectors of energy that is steadily transported toward the coastlines. When the "waves of energy" reach the coast, they can accomplish a great deal of work by expending this energy over a small area in a short period of time.

As waves approach shallow water, they eventually reach the point at which the wave base is equal to the water's depth. As the sea floor begins to interfere with the circular orbit of the waves, friction causes the waves to slow down. When the leading waves slow down, the following waves push in behind.

The result is that the waves are squeezed together and pushed upward to become taller. As the waves become taller, they become unstable. Eventually the waves will fall forward and "break" on the beach. Each breaking wave can pick up a sizable load of sand, silt or whatever is available and move it forcefully up onto the beach.


Time between crests = wave period
Number of crests passing fixed po
in specified time = wave frequency
int
Crest
Crest
Wavelength
Crest
Trough
Wave height
Plunging breaker
Wave surge

The shoreline is often divided into distinct zones by the nature of the wave erosional forces present:

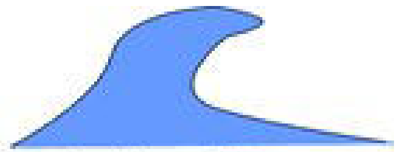
1. **Offshore** - that portion of the shoreline beyond the breaker zone where water depths exceed 6 meters.

2. **Inshore** - includes the breaker zone and surf zone. In the former, waves crest and break. The surf zone is characterized by foam and turbulence from the breaking waves.

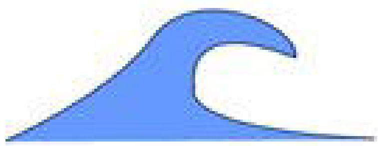
3. **Foreshore** - the swash zone where breaking waves surge up onto the beach. Top of the swash zone is marked by a berm or ridge of sand created by wave erosion and surge.

4. **Backshore** - that portion of the beach not affected by present day wave activity.

Types of breaking waves



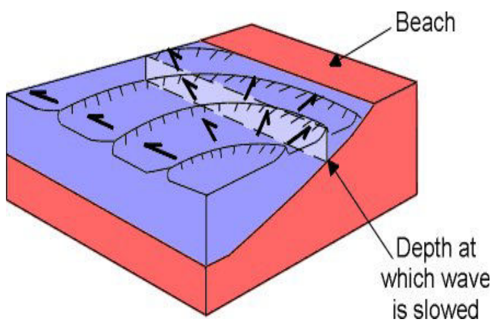
Spilling waves - typical breaking wave.



Plunging waves - top of the wave curls over trapping an air pocket. Trapped air generates foam when the wave breaks. (Storm-generated waves)

Reflected Wave

A water wave that reflects off the shore or another obstacle and is redirected towards the sea or lake.



Refraction and Longshore Currents

Refraction - change in a waves direction as it approaches a coastline. Due to drag on waves approaching a coast obliquely. Effect is to cause waves to approach nearly parallel to the shore.

Tides are the rise and fall of sea levels caused by the combined effects of the gravitational forces exerted by the Moon and the Sun, and the rotation of the Earth.

They are very long waves that travel across the oceans and are transmitted into bays, inlets, estuaries or lagoons around the world's coastline.

The lunar cycle produces

Semidiurnal tides (two high and two low tides in approximately 25 hours), well displayed around the Atlantic Ocean.

The solar cycle produces diurnal tides (one high and one low tide every 24 hours), as registered in the Caribbean, northern Java and the Philippines, and on the Antarctic coast.

Elsewhere the two are mixed, yielding unequal high and low tides (e.g. high high, low low, low high and high low), as around much of the Pacific and Indian Ocean coasts.

The rise and fall of the tide (tide range) on a coast is measured by tide gauges, located chiefly at ports. The highest and lowest astronomical tides are those that occur at a particular point on the coast in calm weather over a period of at least a year.

Tides recorded shortly after each new moon and full moon, when earth, sun and moon are in alignment, and have combined gravitational effects, are relatively large, and are known as spring tides.

The highest spring tides occur fortnightly (actually at intervals of about 14.6 days). Maximum spring tide ranges occur about the equinoxes (late March and late September), when the sun is overhead at the equator.

At half-moon (**first and last quarter**) the sun and moon are at right angles in relation the earth, so that their gravitational effects are not combined; tide ranges recorded shortly after this are reduced, and are known as neap tides.

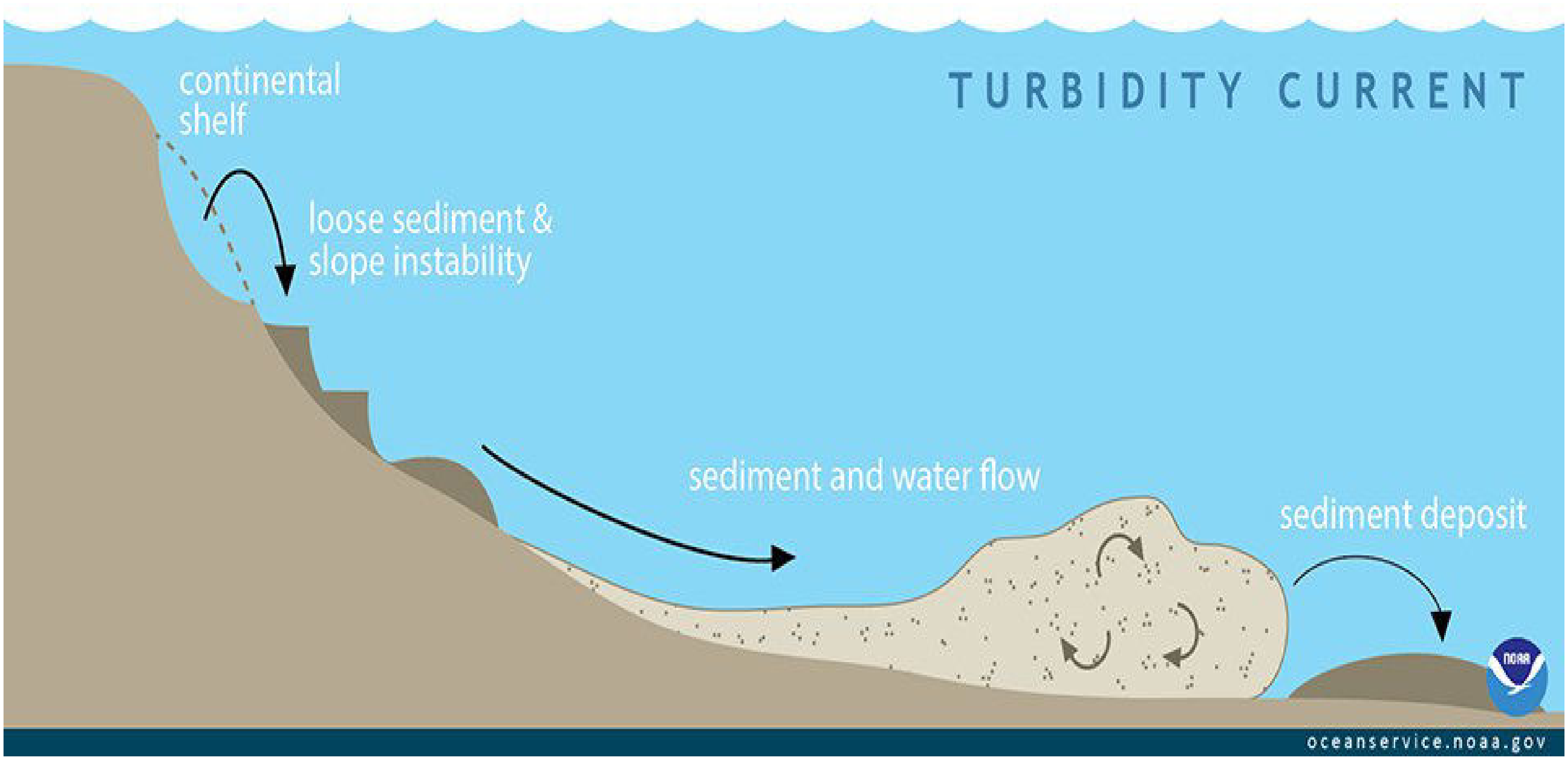
Turbidity is a measure of the level of particles such as sediment, plankton, or organic by-products, in a body of water. As the turbidity of water increases, it becomes denser and less clear due to a higher concentration of these light-blocking particles.

Turbidity currents can be set into motion when mud and sand on the continental shelf are loosened by earthquakes, collapsing slopes, and other geological disturbances. The turbid water then rushes downward like an avalanche, picking up sediment and increasing in speed as it flows.

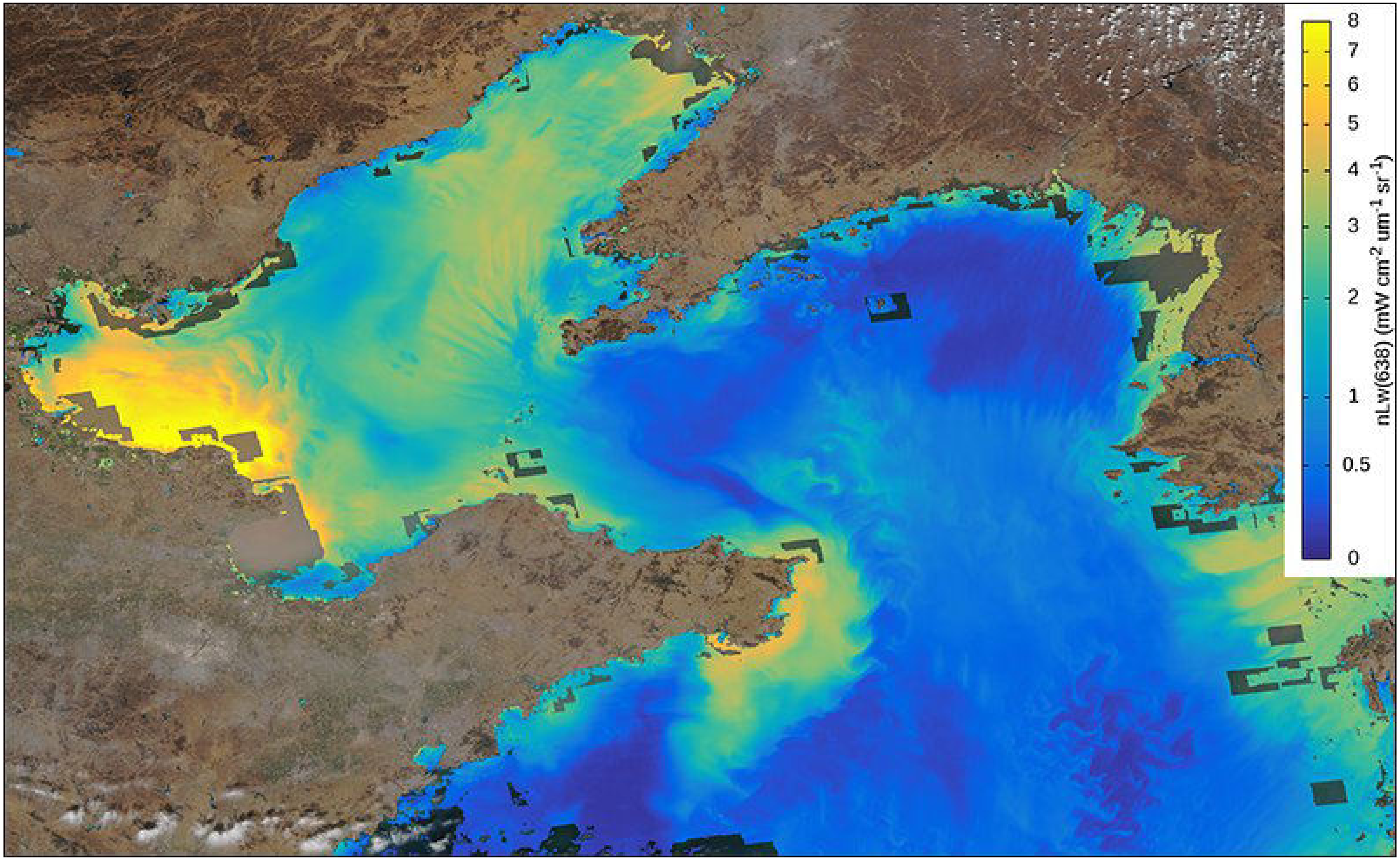
Turbidity currents can change the physical shape of the seafloor by eroding large areas and creating underwater canyons. These currents also deposit huge amounts of sediment wherever they flow, usually in a gradient or fan pattern, with the largest particles at the bottom and the smallest ones on top.

Scientists use current meters attached with turbidity sensors to gather data near underwater volcanoes and other highly active geological sites. Also, satellite imagery is used to observe turbidity by measuring the amount of light that is reflected by a section of water.

A turbidity current is a rapid, downhill flow of water caused by increased density due to high amounts of sediment.


TURBIDITY CURRENT
continental shelf
loose sediment & slope instability
sediment and water flow
sediment deposit
oceanservice.noaa.gov

Color-coded satellite data map of turbid waters in the Bohai Sea and Yellow Sea

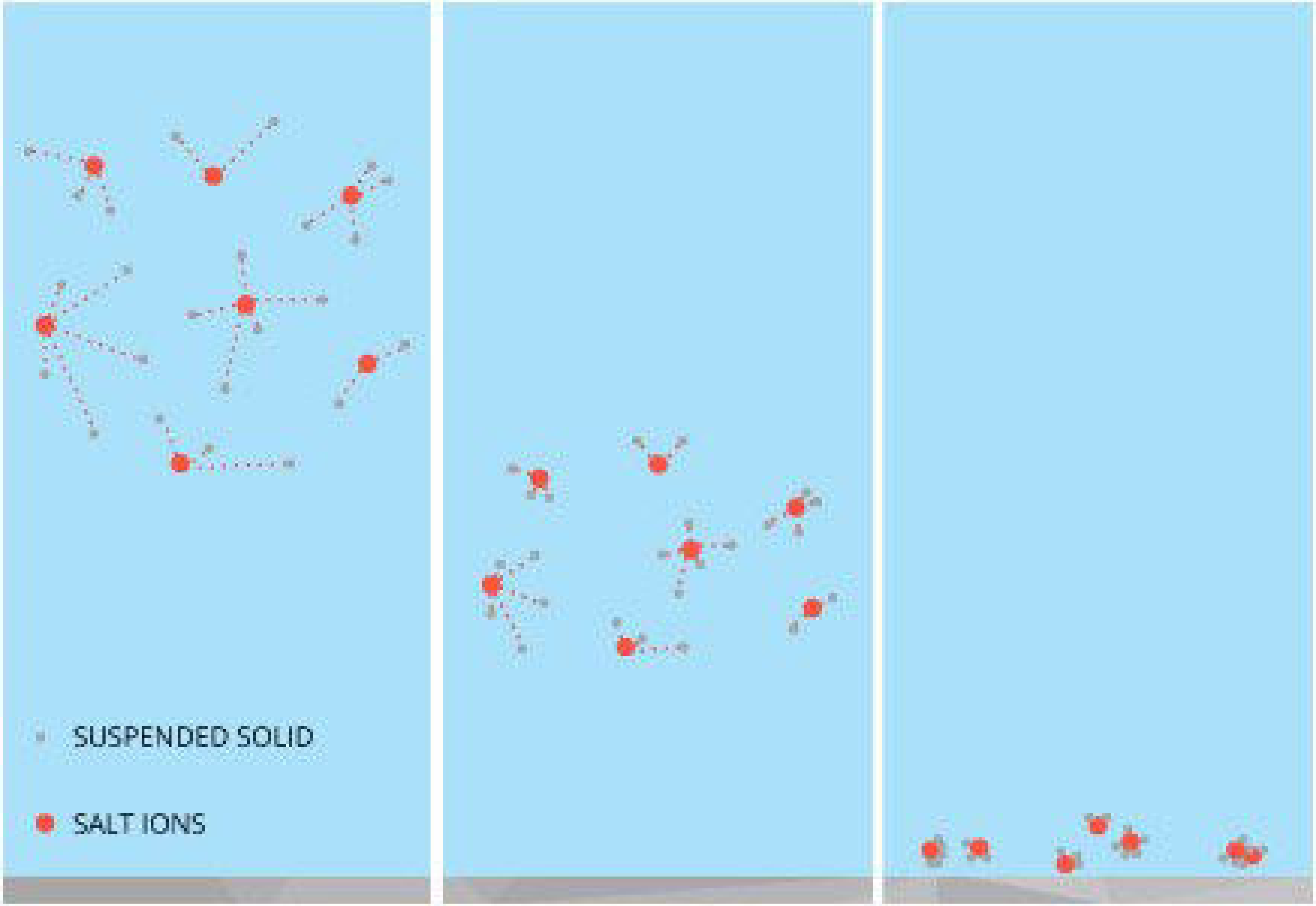


What is Water Clarity?

Water clarity is a physical characteristic defined by how clear or transparent water is. Clarity is determined by the depth that sunlight penetrates in water. The further sunlight can reach, the higher the water clarity. The depth sunlight reaches is also known as the **photic zone**. The clearer the water, the deeper the photic zone and the greater the potential for photosynthetic action. The photic zone has a maximum depth of 200 m based on the light absorption properties of water.

Water clarity is directly related to turbidity, as turbidity is a measure of water clarity. The transparency of water is affected by the amount of sunlight available, suspended particles in the water column and dissolved solids such as colored dissolved organic material (CDOM) present in the water.

Salinity also affects water clarity. This is due to the effect of salt on the aggregation and settling velocity of suspended particles. In other words, salt ions collect suspended particles and bind them together, increasing their weights and thus their likelihood of settling to the bottom. Due to this mechanism, oceans and estuaries tend to have a higher clarity (and lower average turbidity) than lakes and rivers.



Salt ions can cause suspended particle to aggregate and settle at the bottom of a body of water.

Turbidity vs Suspended sediments

Turbidity and total suspended solids refer to particles present in the water column.

Turbidity is determined by the amount of light scattered off of these particles. While this measurement can then be used to estimate the total dissolved solids concentration, it will not be exact. Turbidity **does not include any settled solids or bedload** (sediment that "rolls" along the riverbed).

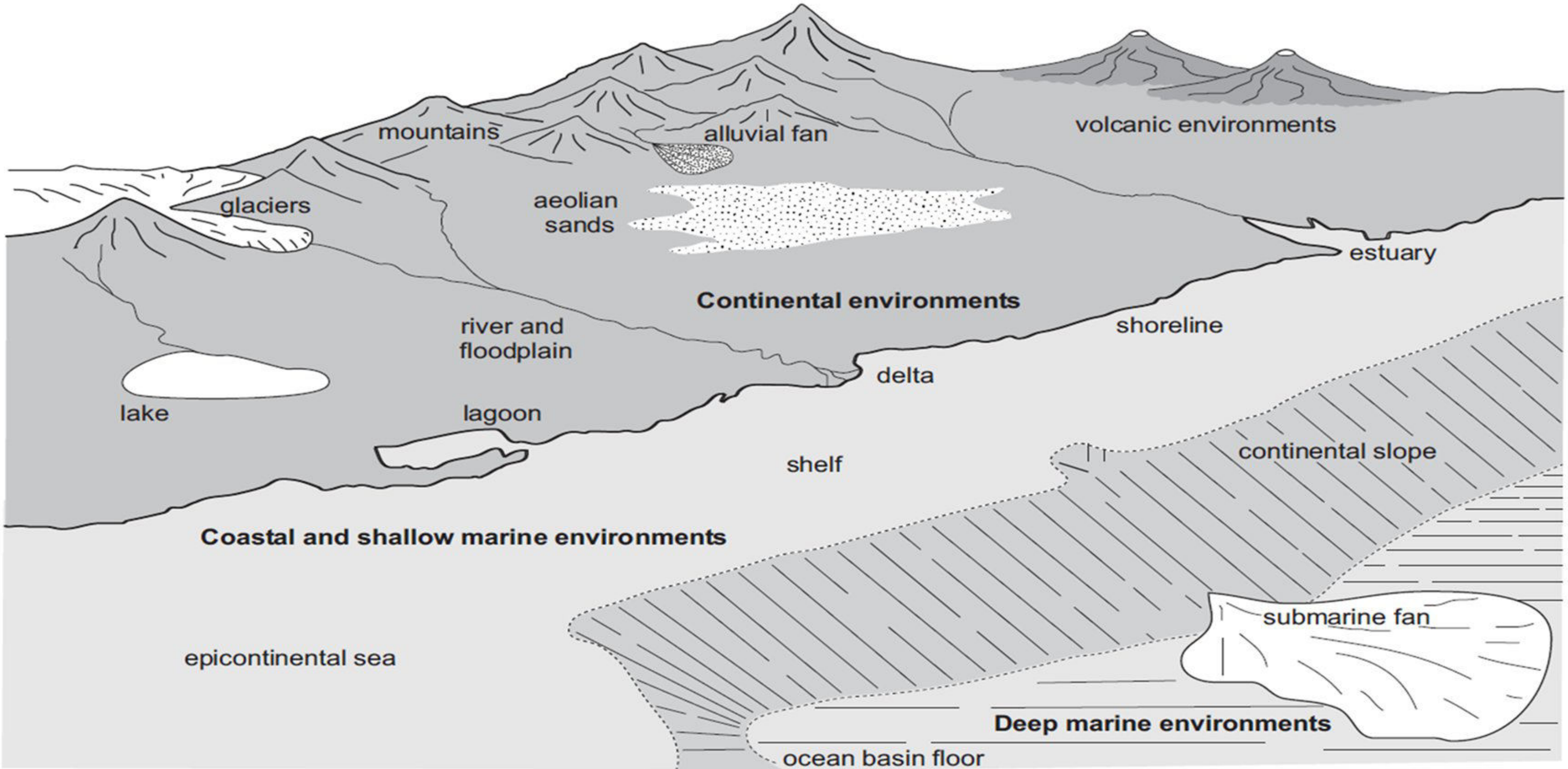
Total suspended sediments, on the other hand, are a total quantity measurement of solid material per volume of water. TSS includes settled solids, and is the direct measurement of the total solids present in a water body. As such, TSS can be used to calculate sedimentation rates, while turbidity cannot.

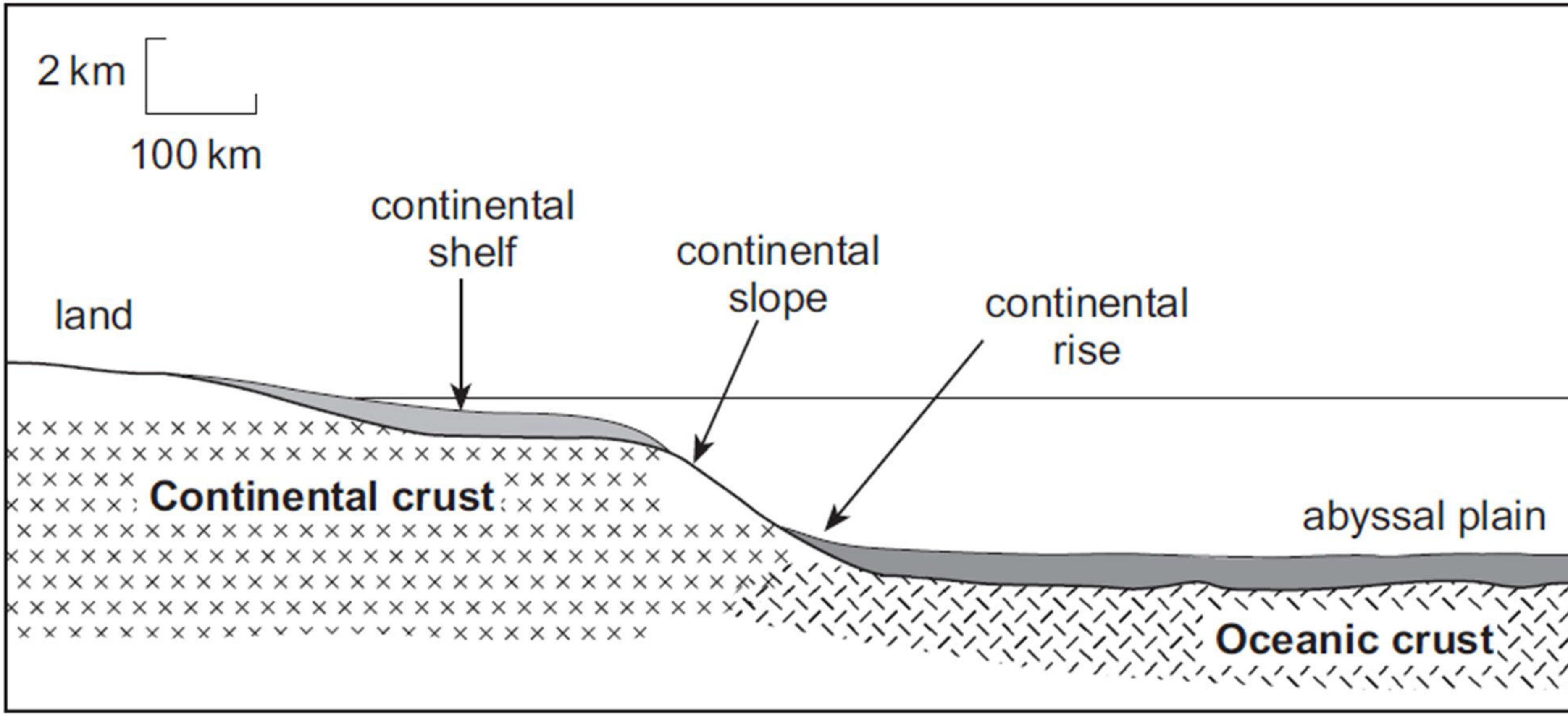
Why Turbidity is Important?

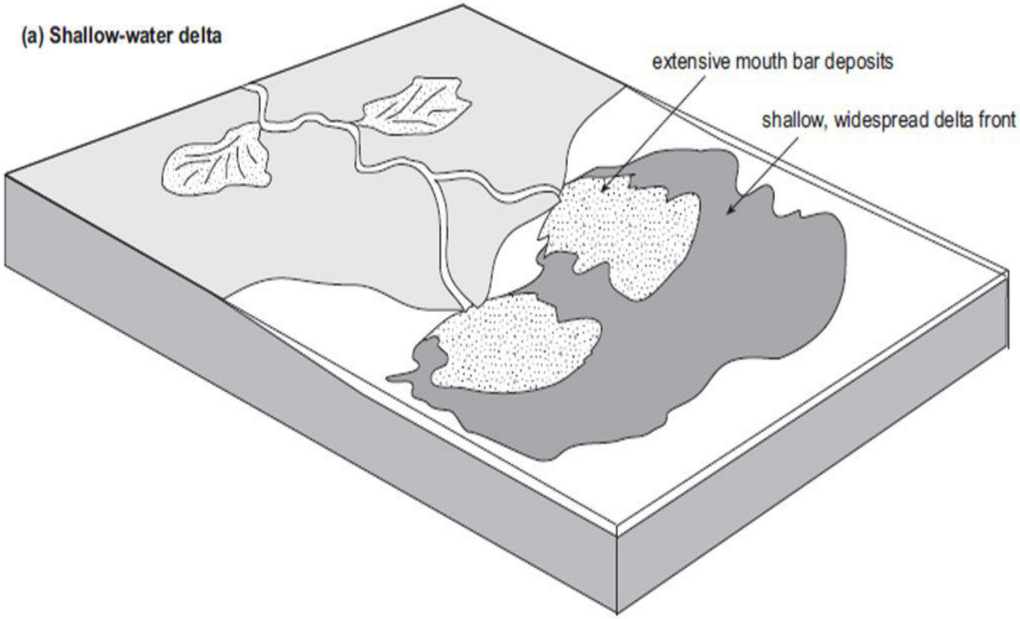
Turbidity the most visible indicator of water quality. These suspended particles can come from soil erosion, runoff, discharges, stirred bottom sediments or algal blooms. Clear water is usually considered an indicator of healthy water.

A sudden increase in turbidity in a previously clear body of water is a cause for concern. Excessive suspended sediment can impair water quality for aquatic and human life.

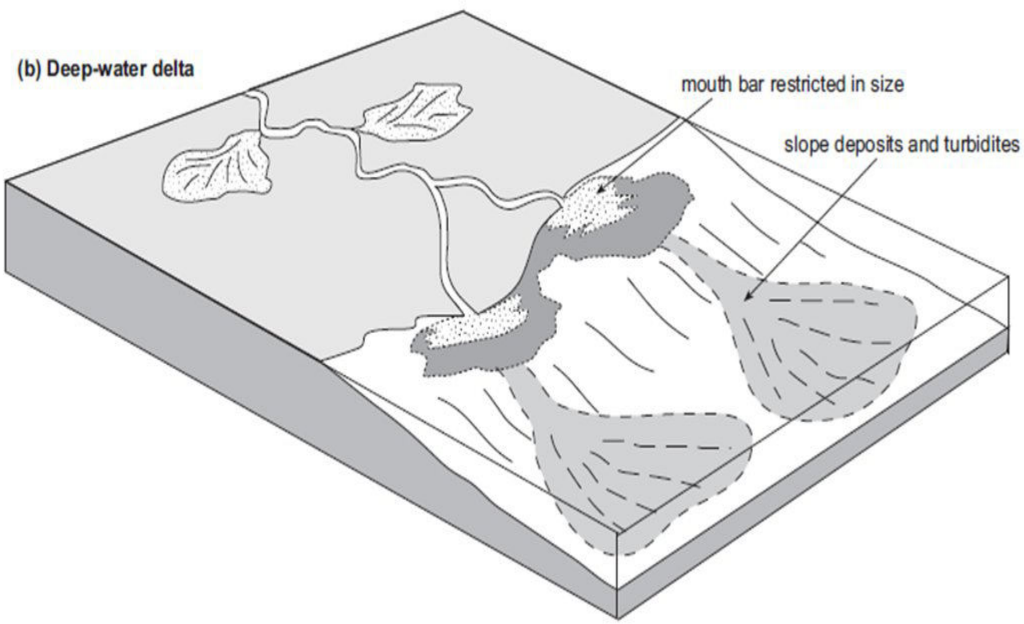
Turbidity can also halt photosynthesis by blocking sunlight. Halted or reduced photosynthesis means a decrease in plant survival and decreased dissolved oxygen output. The higher the turbidity levels, the less light that can reach the lower levels of water. This reduces plant productivity at the bottom of an ocean. Without the needed sunlight, seaweed and grasses below the water's surface will not be able to continue photosynthesis and may die.


mountains
alluvial fan
volcanic environments
glaciers
aeolian
sands
estuary
Continental environments
shoreline
river and
floodplain
delta
lake
lagoon
shelf
continental slope
Coastal and shallow marine environments
submarine fan
epicontinental sea
Deep marine environments
ocean basin floor

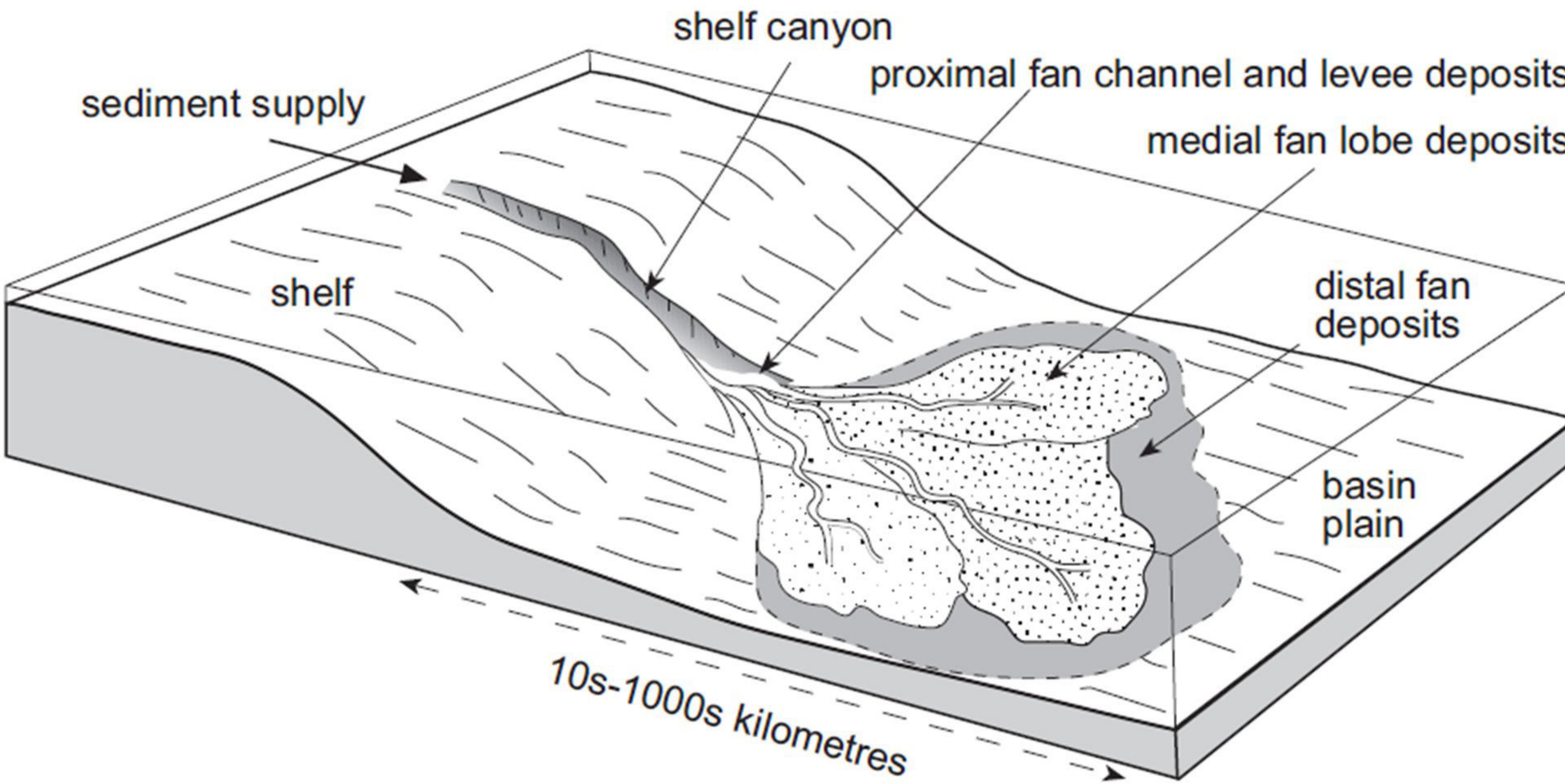

2 km
100 km
continental shelf
continental slope
continental rise
land
abyssal plain
Continental crust
Oceanic crust



a. A delta prograding into shallow water will spread out as the sediment is redistributed by shallow-water processes to form extensive mouth-bar and delta-front facies.



b. In deeper water the mouth bar is restricted to an area close to the river mouth and much of the sediment is deposited by mass-flow processes in deeper water.


shelf canyon
proximal fan channel and levee deposits
sediment supply
medial fan lobe deposits
shelf
distal fan
deposits
basin
plain
10s-1000s kilometres

The Bengal Fan is the largest submarine fan in the world, with a length of about 3000 km, a width of about 1000 km and a maximum thickness of 16.5 km.

It has been formed as a direct result of the India-Asia collision and uplift of the Himalayas and the Tibetan Plateau.

It is currently supplied mainly by the confluent Ganges and Brahmaputra Rivers, with smaller contributions of sediment from several other large rivers in Bangladesh and India.

Marine sediments contain a record of Earth history. Marine sediments provide a variety of important resources. Marine sediments have a variety of origins.

Marine Sediment Classification - Classified by origin

- Lithogenous – derived from land
- Biogenous – derived from organisms
- Hydrogenous or Authigenic – derived from water
- Cosmogenous – derived from outer space

Lithogenous Sediments

- Small particles eroded and transported

- Carried to ocean by the
- – Streams
- – Wind
- – Glaciers
- – Gravity

- Greatest quantity around continental margins

Biogenous Sediment

- Hard remains of once-living organisms
- Two major types:
- **–Macroscopic**
- Visible to naked eye
- Shells, bones, teeth
- **–Microscopic**
- Tiny shells or tests
- Biogenic ooze
- Mainly algae and protozoans

Hydrogenous Marine Sediments

• Minerals precipitate directly from seawater
- Manganese nodules
- Phosphates
- Carbonates
- Metal sulfides

• Small proportion of marine sediments
• Distributed in diverse environments

Cosmogenous Marine Sediments

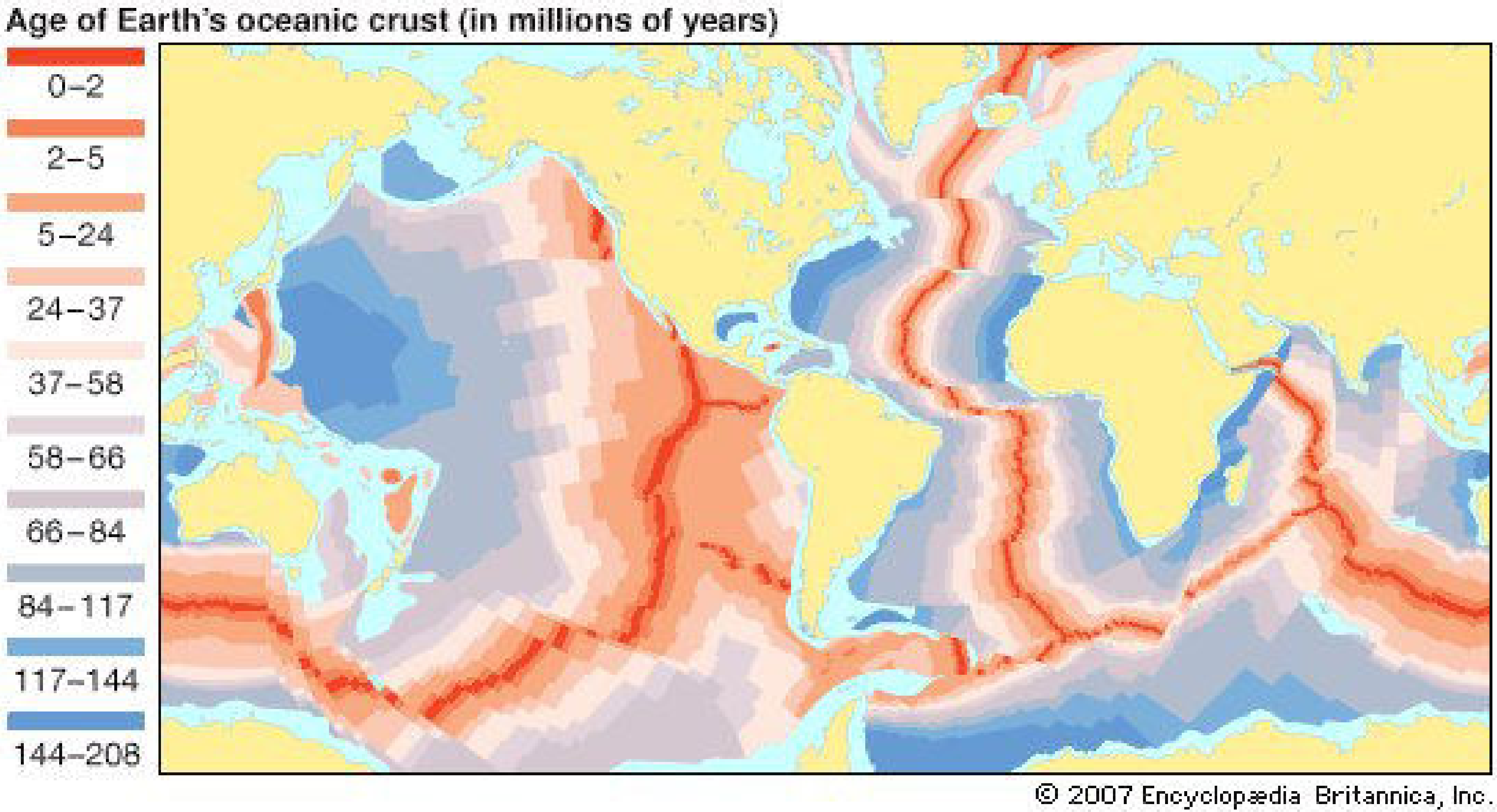
• Macroscopic meteor debris
• Microscopic iron nickel and silicate spherules (small globular masses)
- Tektites
- Space dust

• Overall, insignificant proportion of marine sediments

Through most of geologic time, probably extending back 2 billion years, the ocean basins have both grown and been consumed as plate tectonics continued on Earth.

The latest phase of ocean basin growth began just less than 200 million years ago with the breakup of the supercontinent Pangea, the enormous landmass composed of nearly all the present-day continents.

Since that time the major developments have included a shrinking of the Pacific basin at the expense of the growing Atlantic and Arctic basins, the opening of the Tethys seaway circling the globe in tropical latitudes and its subsequent closing, and the opening of the Southern Ocean as the southern continents moved north away from Antarctica.



The oldest known oceanic crust (estimated to be about 200 million years old) is located in the western equatorial Pacific, east of the Mariana Island arc. The Pacific ocean floor at this site was generated during seafloor spreading.

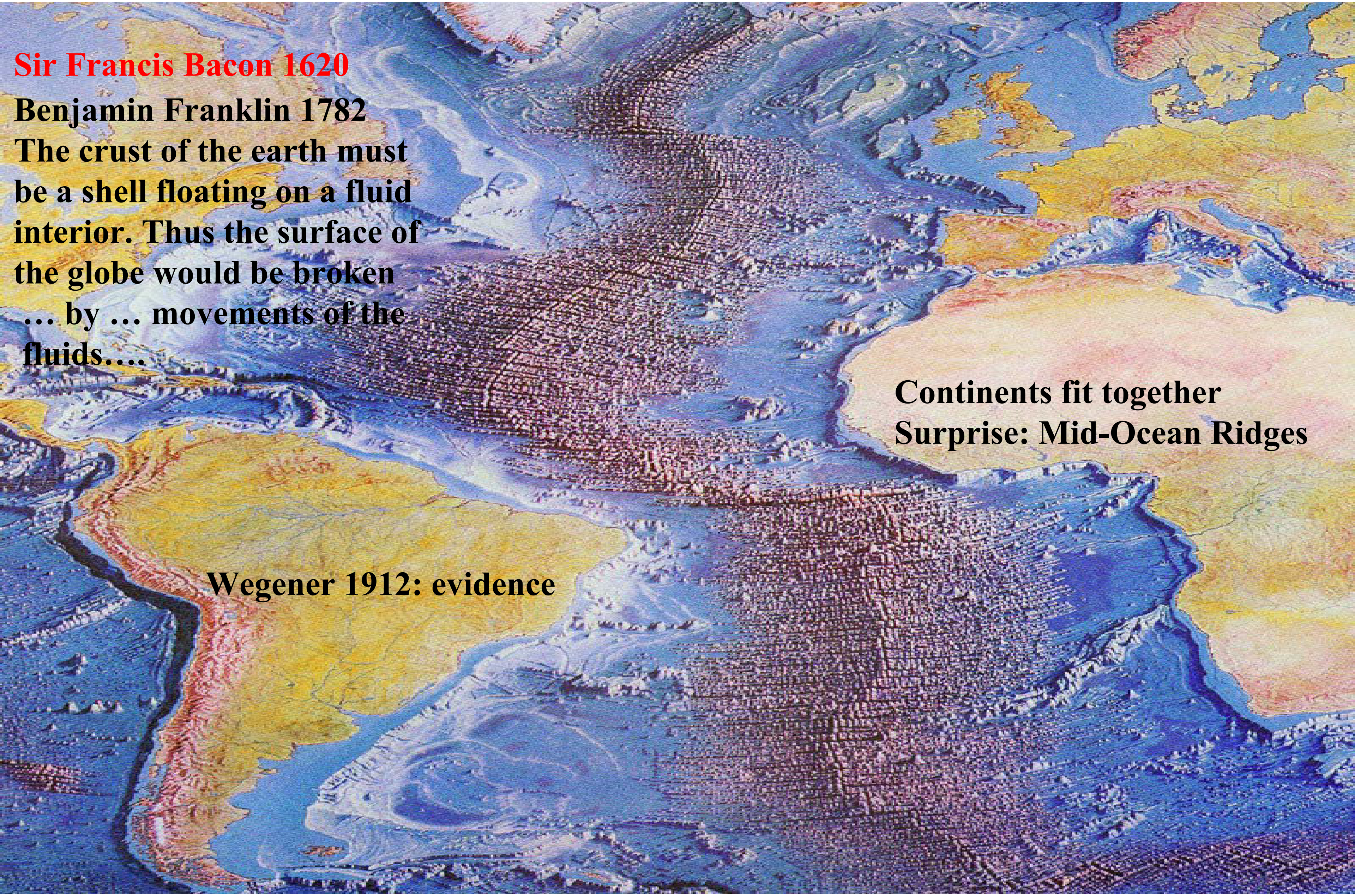
In the Indian Ocean the oldest segment of seafloor was formed about 165 to 145 million years ago by the rifting away of Africa and South America from Gondwana, a supercontinent consisting largely of the present-day continents of the Southern Hemisphere.

At this time Africa was joined to South America, Eurasia, and North America. Today this old seafloor is found along the east coast of Africa from the Somali Basin to the east coast of South Africa and adjacent to Queen Maud Land and Enderby Land in East Antarctica.

Close to 180 million years ago (but before 165 million years ago), North America and Eurasia, which together made up most of the large northern continent of Laurasia, began drifting away from Africa and South America, creating the first seafloor in the central region of the North Atlantic and opening the Gulf of Mexico.

The Tethys sea also opened during this rifting phase as Europe pulled away from Africa. Shortly after this time continental fragments, including possibly Tibet, Myanmar and Malaya, rifted away from the northwest coast of Australia and moved northward, thereby creating the oldest seafloor in the Timor Sea. During this period spreading continued in the Pacific basin with the growth of the Pacific Plate and the consumption by subduction of its bordering plates, including the Izanagi, Farallon, and Phoenix. The Pacific Plate moved northward during this phase and continues to do so today.

Plate Tectonics



Sir Francis Bacon 1620

Benjamin Franklin 1782
The crust of the earth must be a shell floating on a fluid interior. Thus the surface of the globe would be broken … by … movements of the fluids….

Continents fit together
Surprise: Mid-Ocean Ridges

Wegener 1912: evidence

Continental drift: An idea before its time

- **Alfred Wegener**
  - **Proposed hypothesis in 1915**
  - **Published *The Origin of Continents and Oceans***
- **Continental drift hypothesis**
  - **Supercontinent Pangaea began breaking apart about 200 million years**

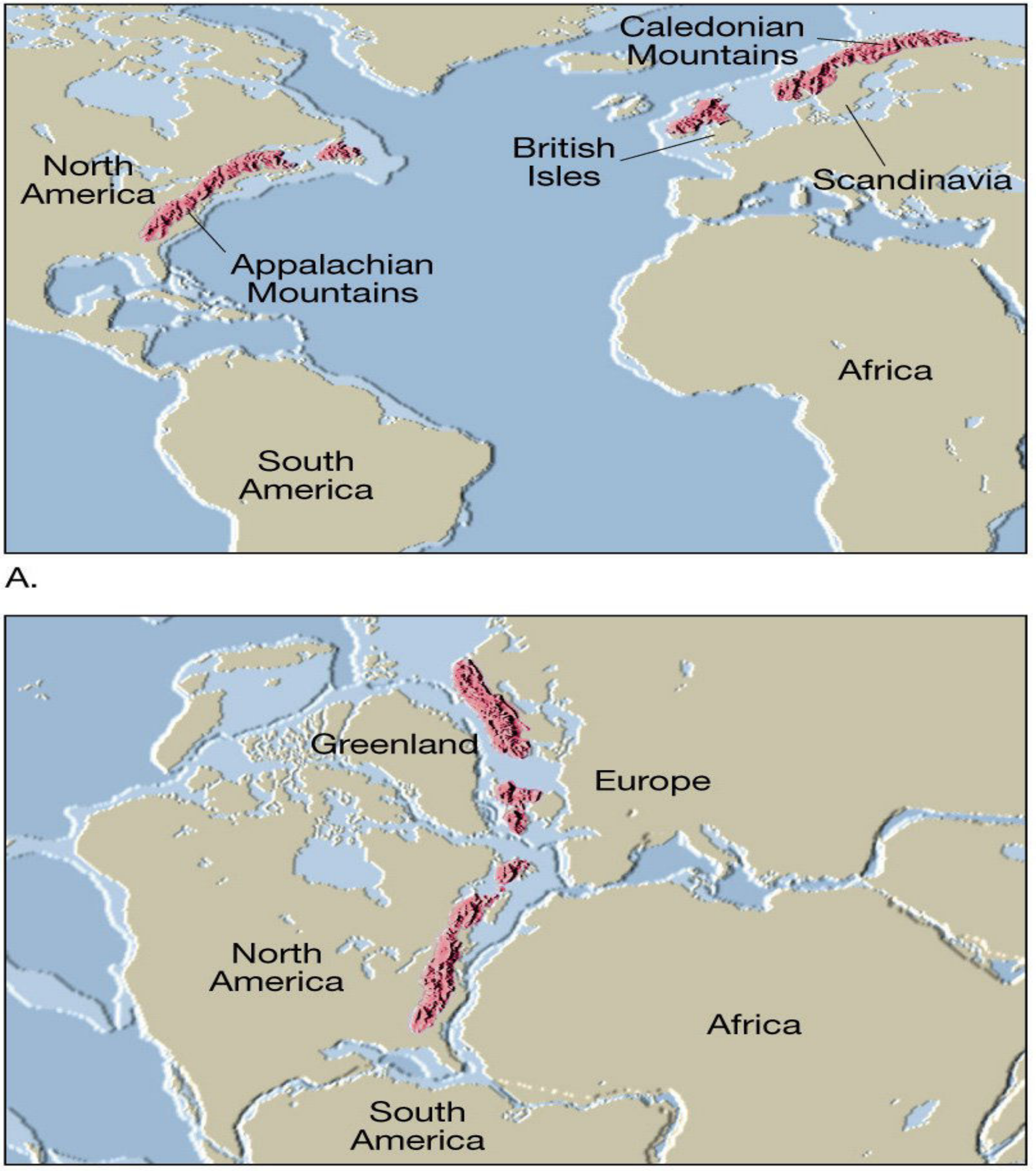
Fit of continents, fossil evidence, continuation of rock types and mountain belts , paleoclimatic evidence

Fit of Continents: Pangaea approximately 200 million years ago

Especially good agreement if continental shelf is included.

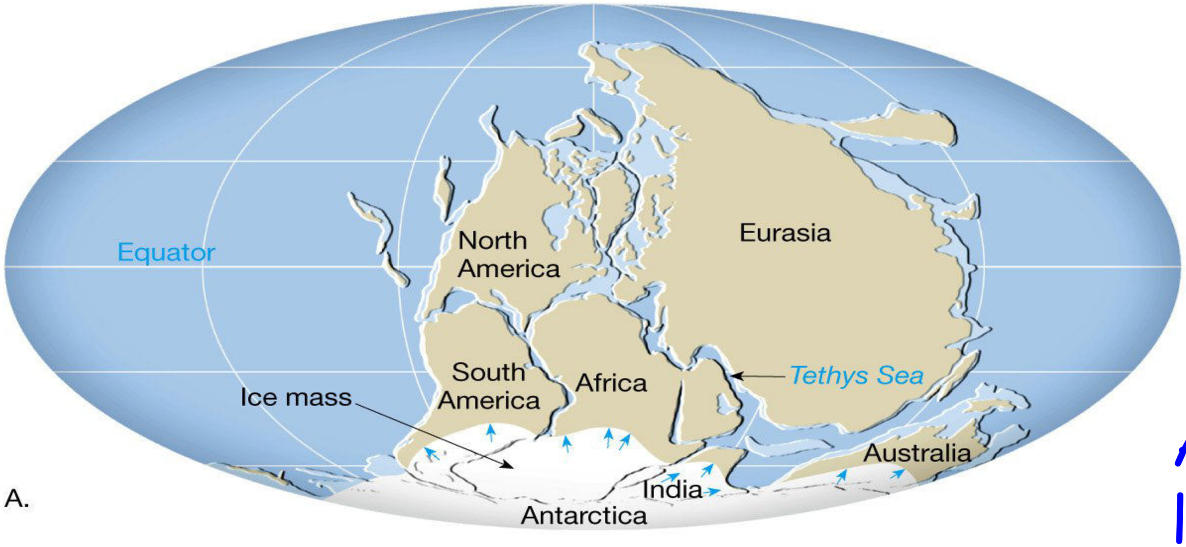
Coastlines Fit
Mountain Ranges line up

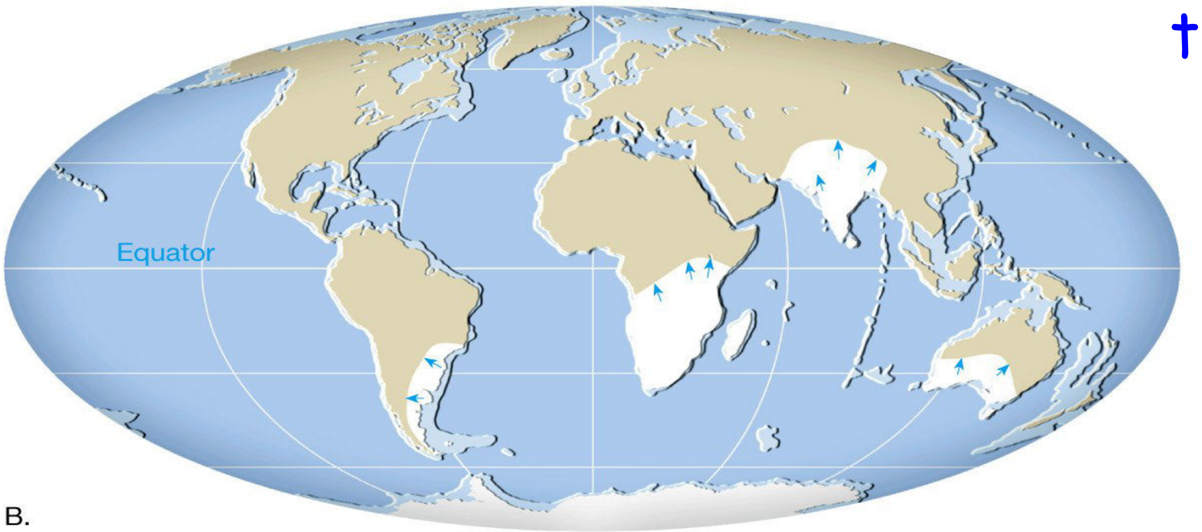
matching of mountain ranges on continents



A.
B.

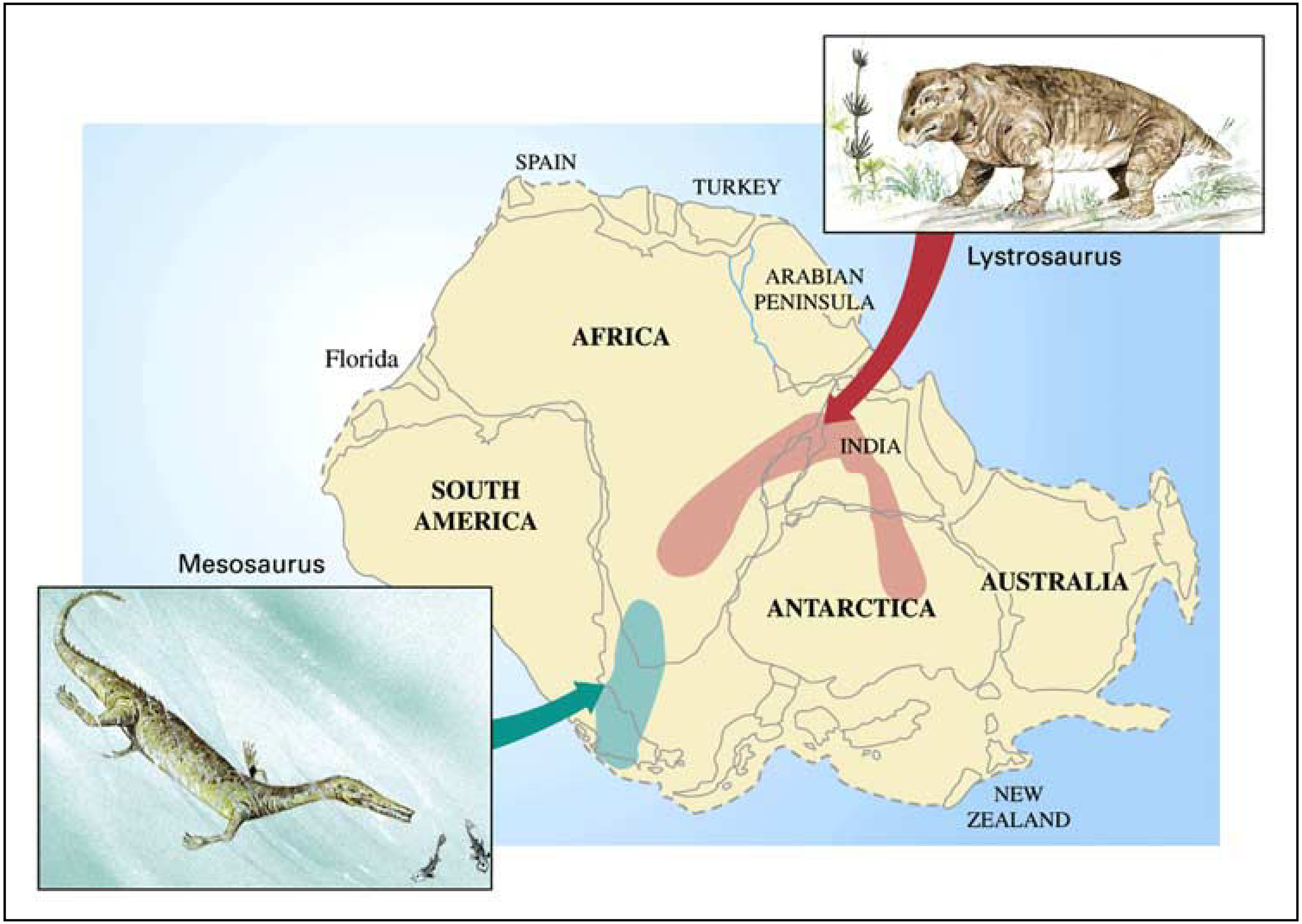
Paleoclimatic evidence for Continental Drift





Ancient glaciers line up if continents together

Ranges of Triassic Reptiles

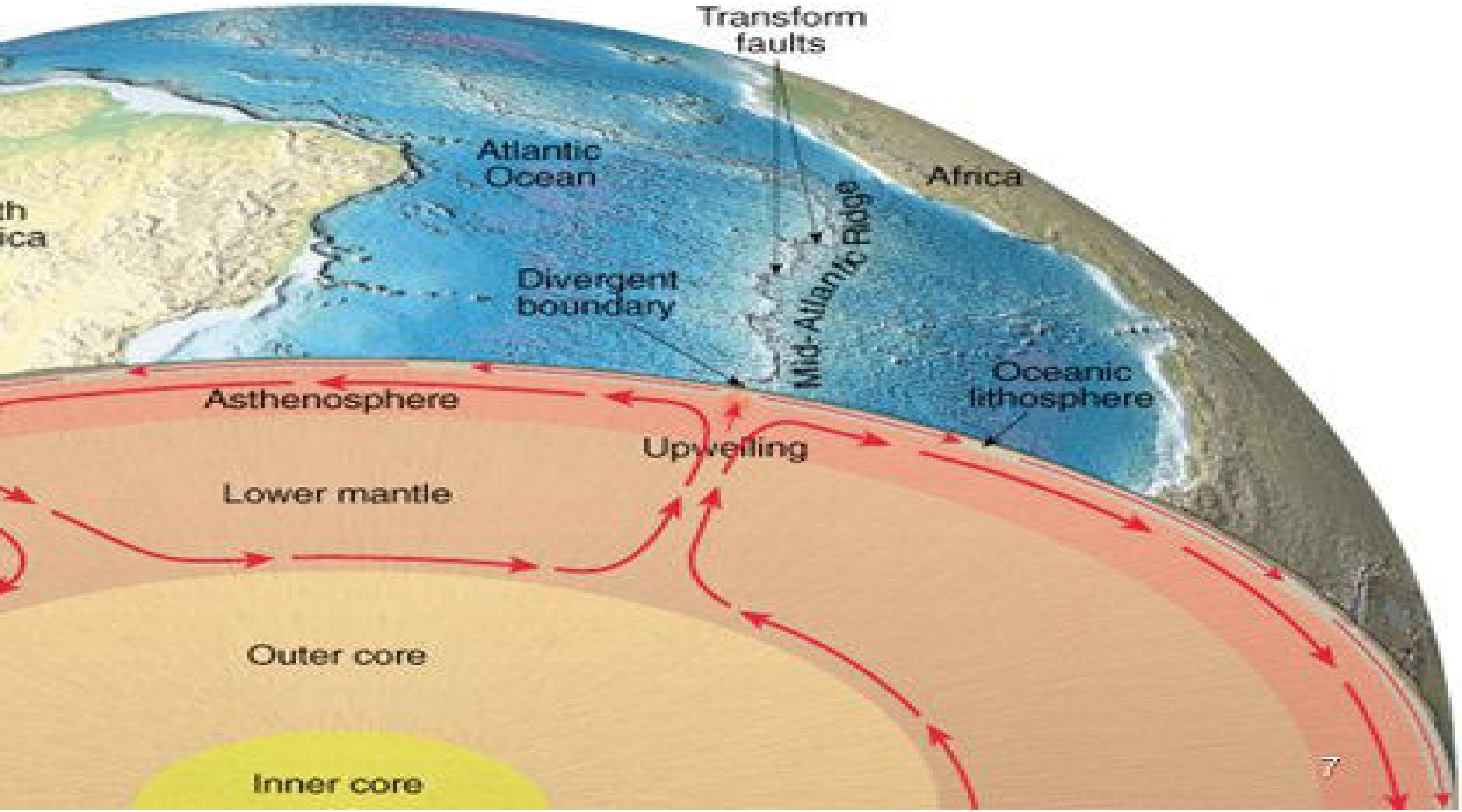


Seafloor spreading hypothesis was proposed by Harry Hess in the early 1960s.

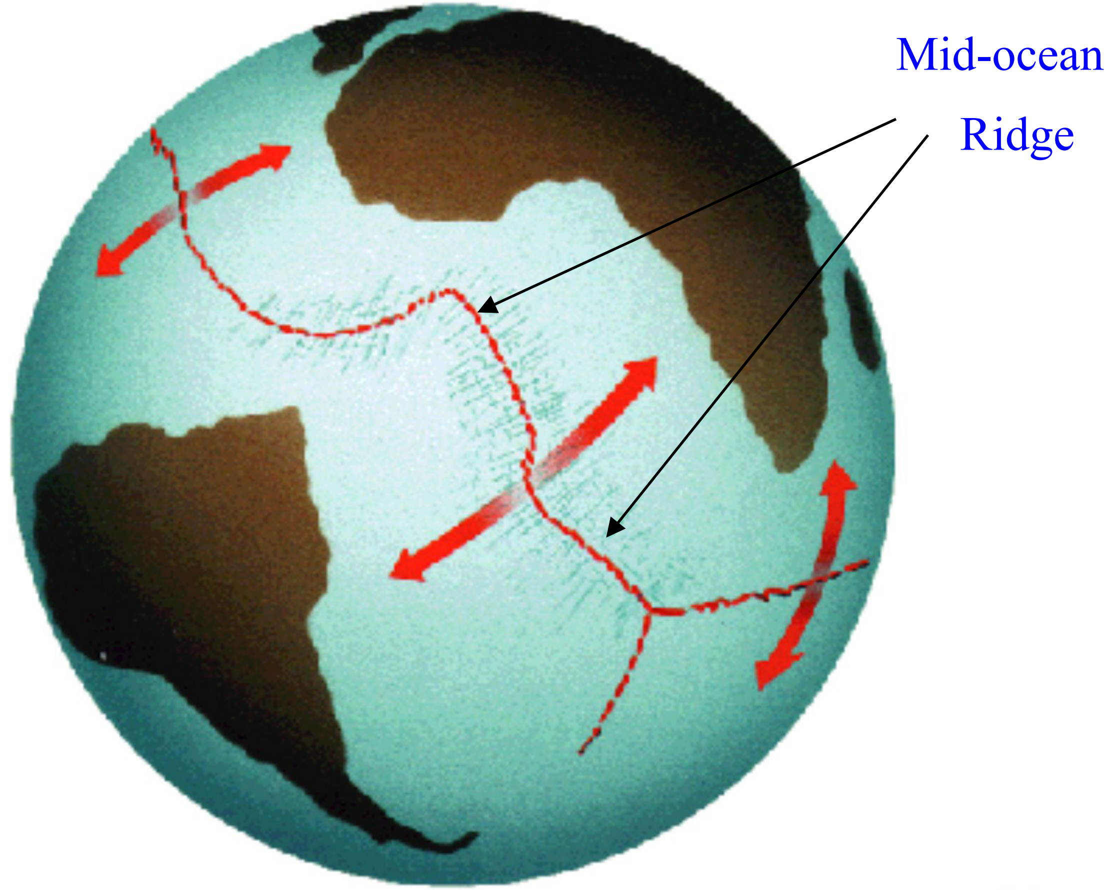
During WWII, Harry kept his depth sounder on, collected huge amounts of data. Together with data from other ships, the data show mid-ocean ridges.

Harry: The earth's internal heat, and the flow it causes in the mantle, is responsible for sea-floor spreading at the mid-ocean ridges.

Harry Hess: Mid-ocean ridges are spreading apart due to heat flow in the mantle. Crust moves apart as if on conveyer belts. New lava fills the cracks due spreading, new ocean floor from frozen lava



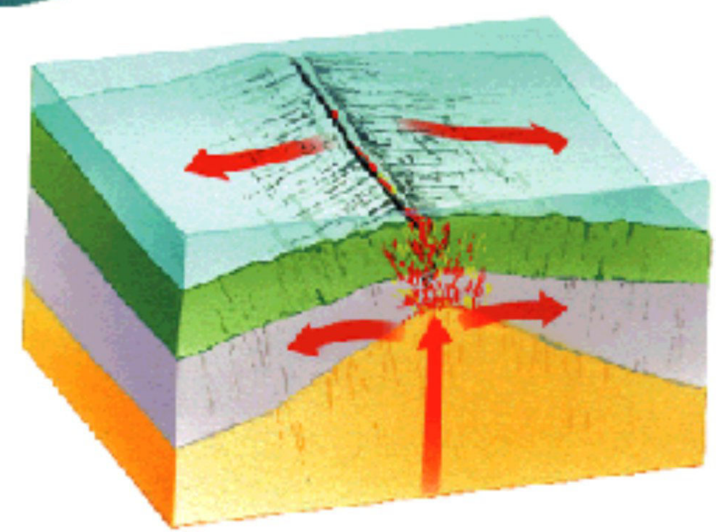
Origin of new Ocean Floor At the Mid-Ocean Ridge



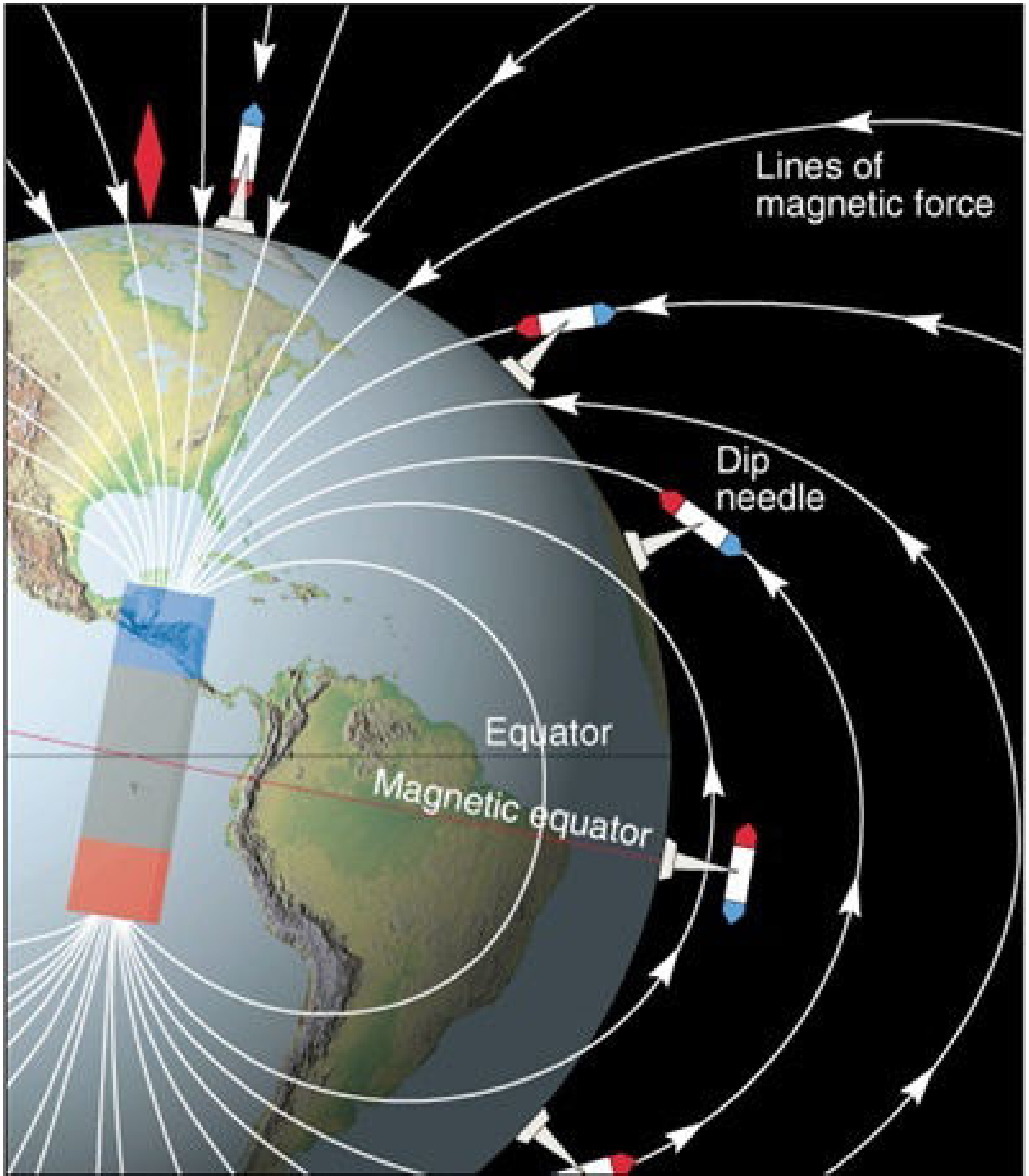
Lithosphere (Crust + Upper Mantle) bulges into a mid-ocean ridge.

Added heat causes lithosphere to expand. It cracks, exposing the mantle to low pressures Some of the Mantle minerals are unstable at atmospheric pressures.

The unstable minerals melt forming lavas, which cool into basalt, the main rock of ocean lithosphere.



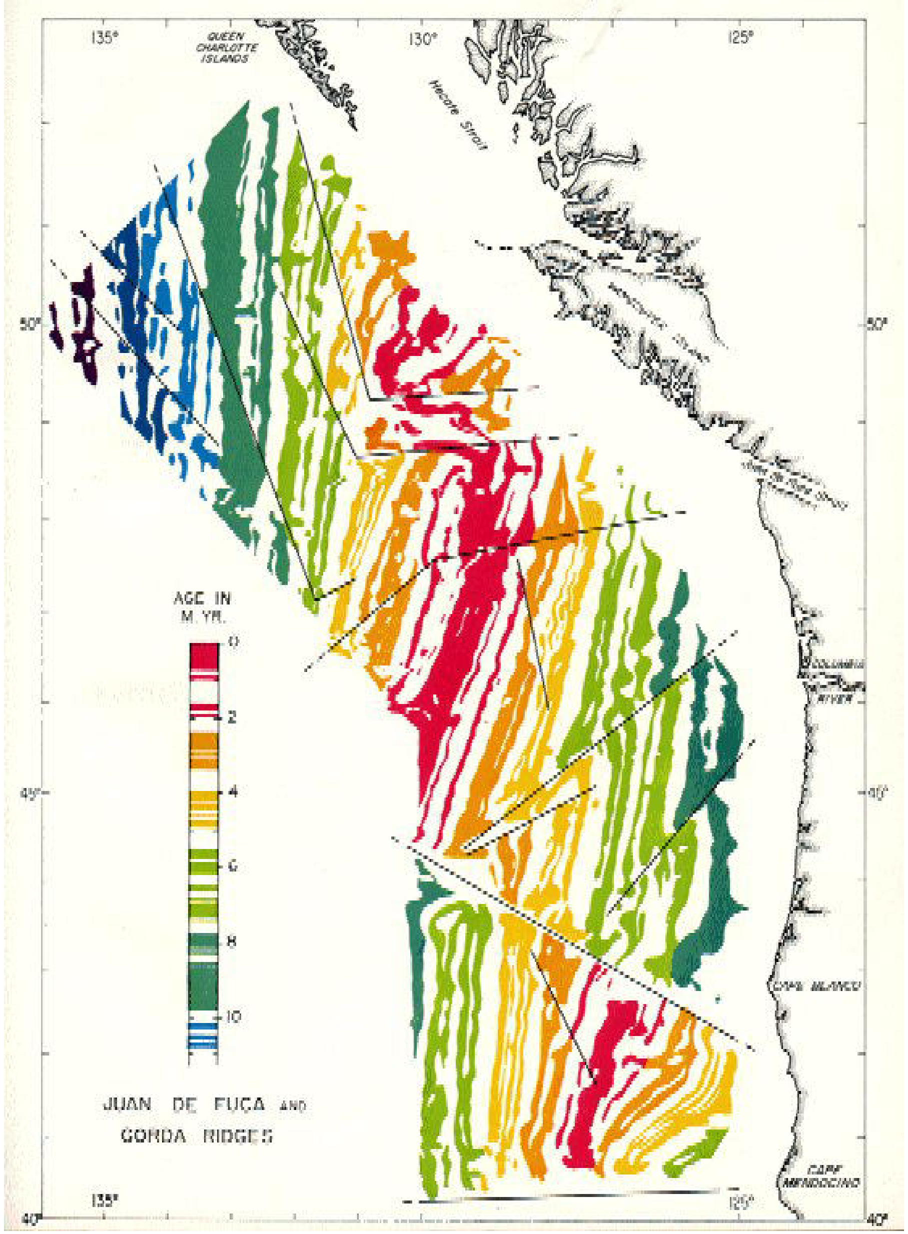
Testing the Hess Hypothesis

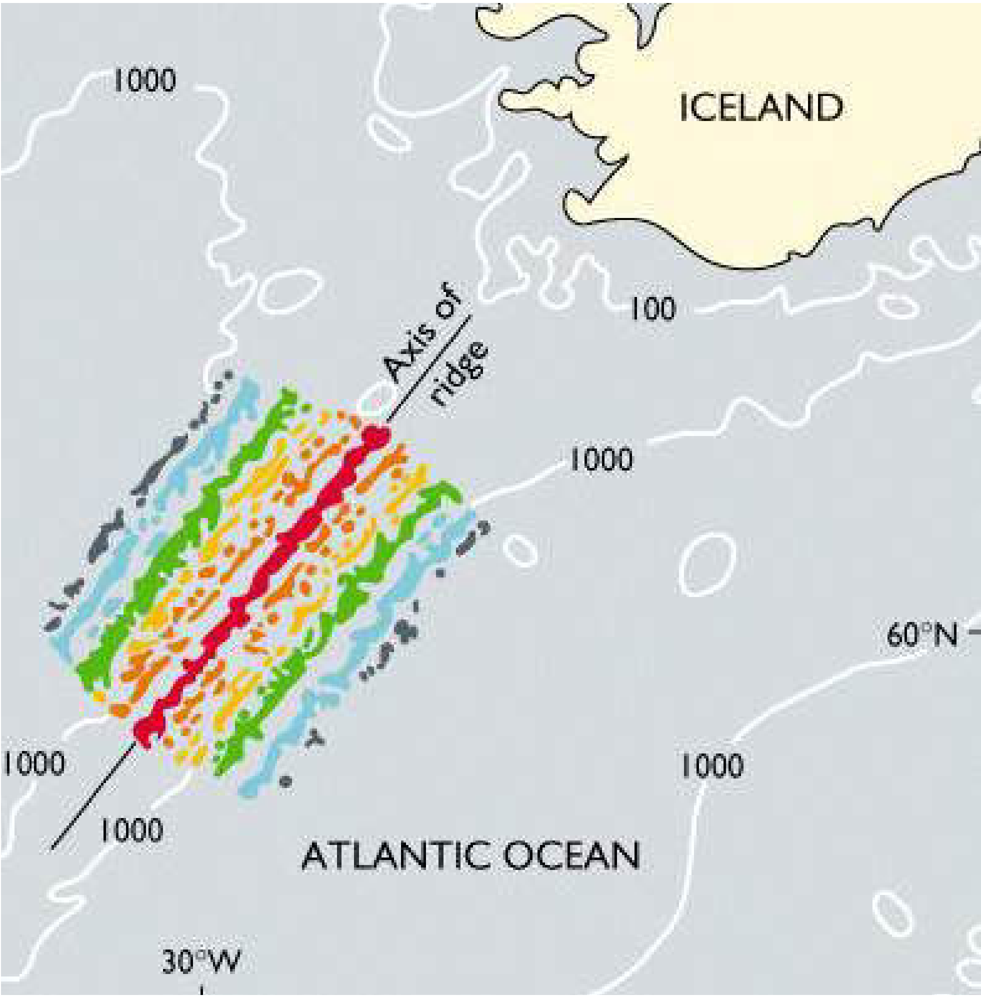


- **Magnetized minerals in seafloor lavas show direction to Earth's magnetic poles**
- **Provide a means of determining the original latitude of the rocks when they formed.**
- **Testable consequences: If continents moved, old lavas should show different latitude**

Some Tests:

So, they checked. Symmetrical, **NOT FALSE**





Another test: Oceanic Crust youngest at ridges?

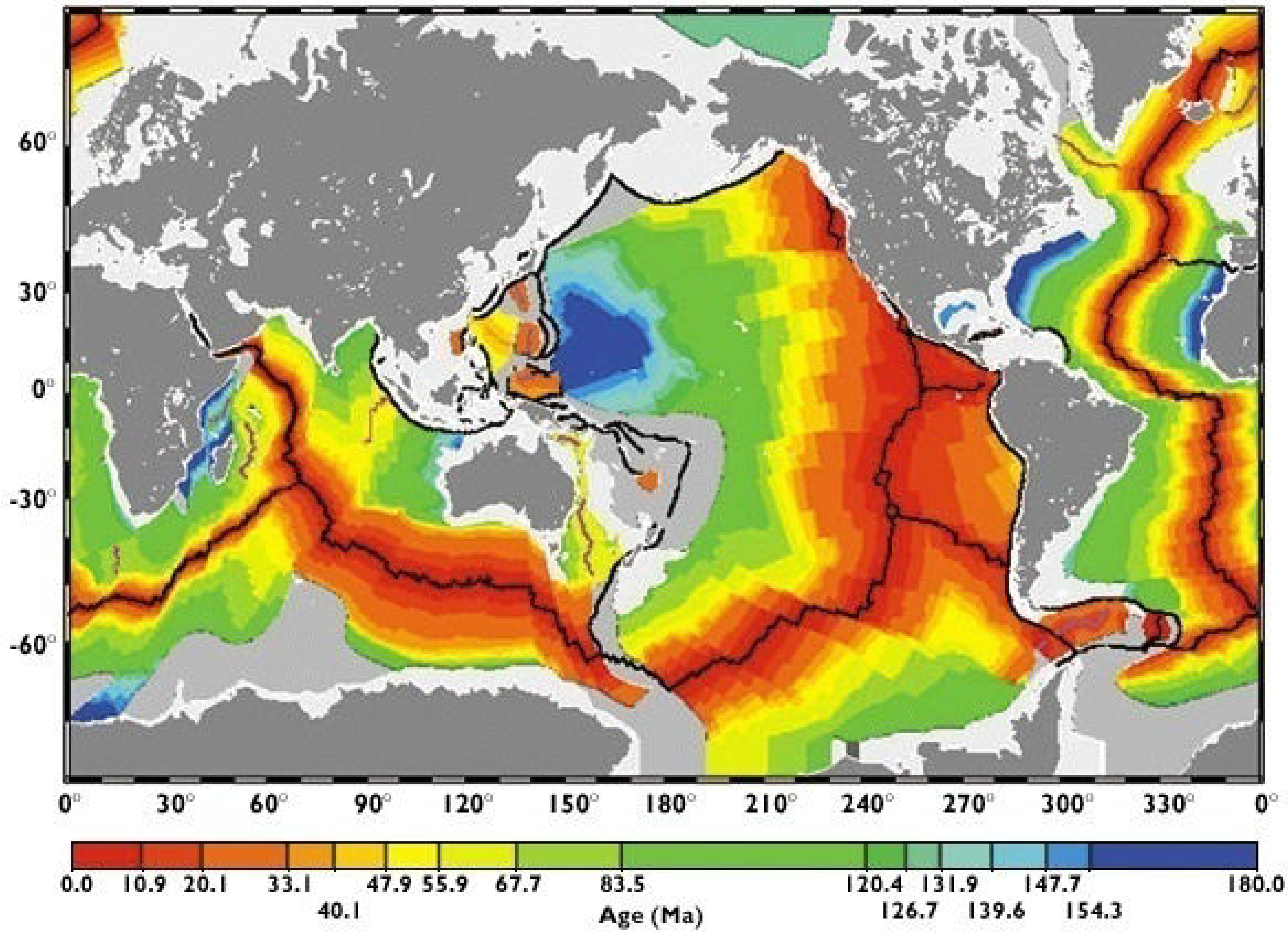
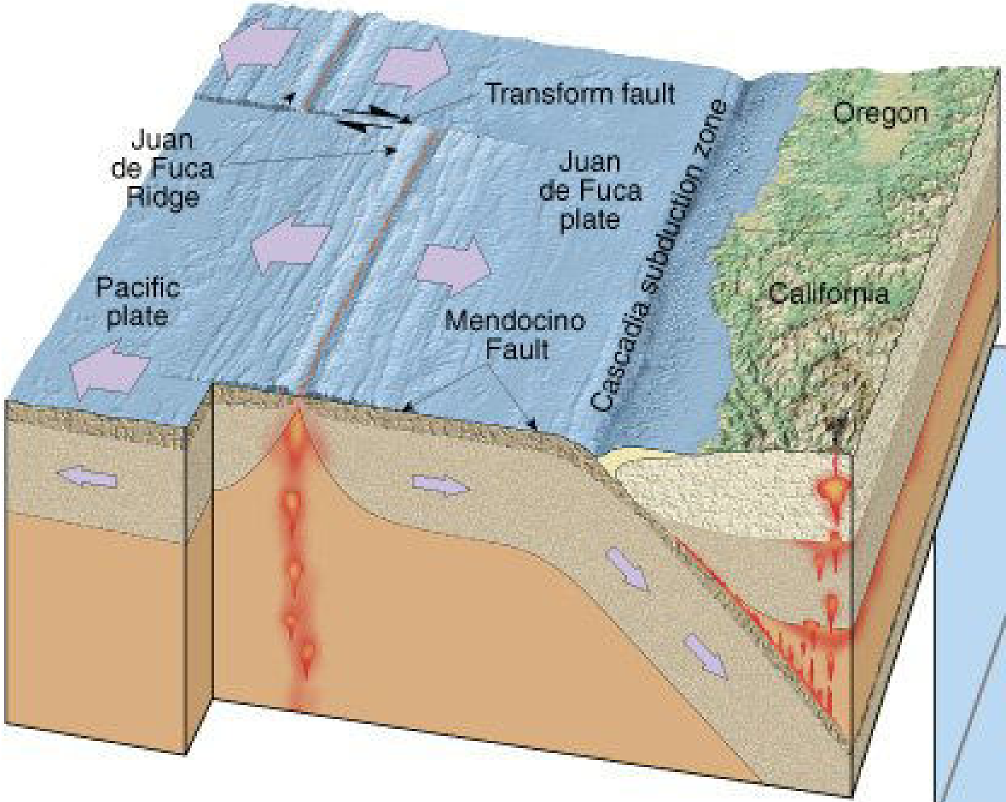
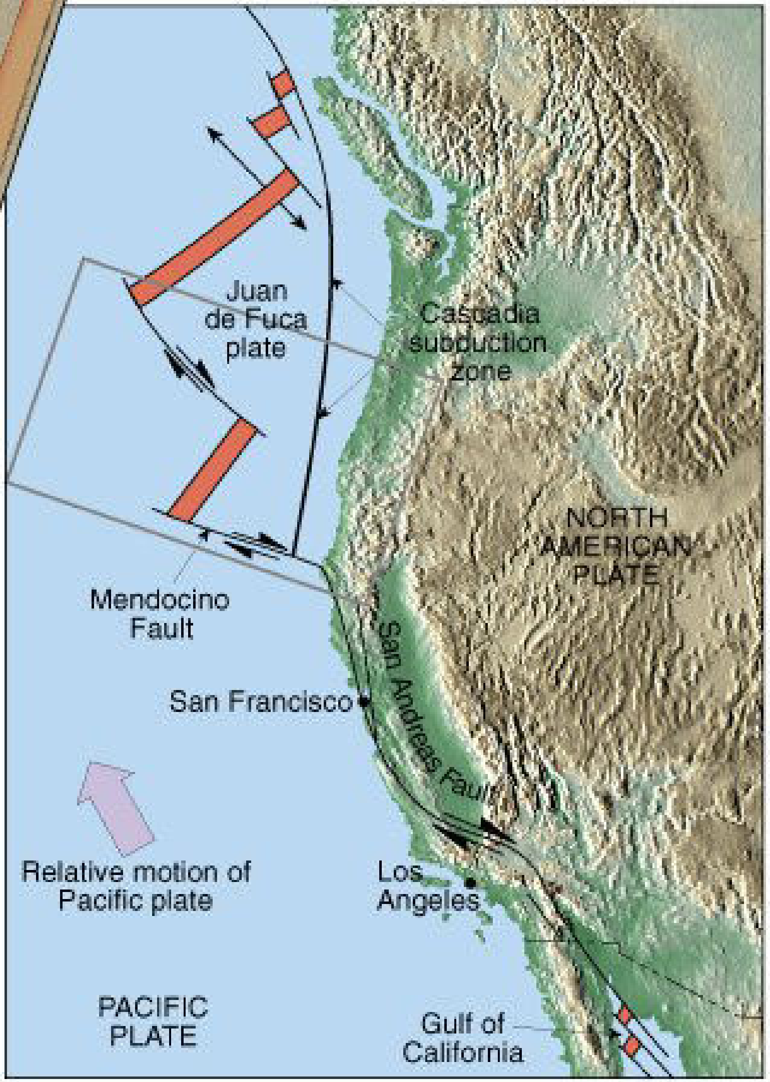


Plate tectonics: The new paradigm

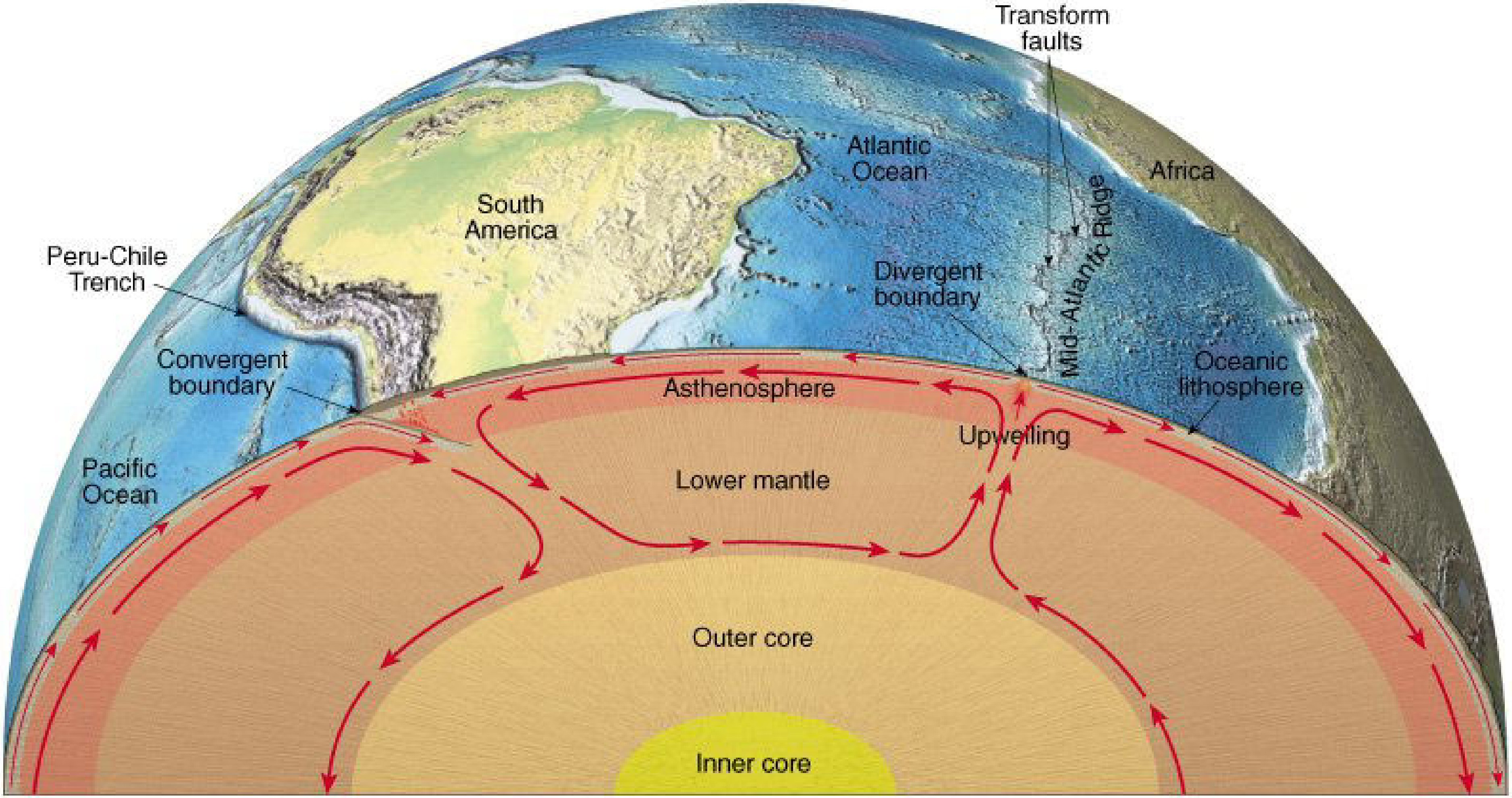
- **Earth's major plates**
  - Associated with Earth's strong, rigid outer layer
    - Known as the lithosphere
    - Consists of uppermost mantle and overlying crust
    - Overlies a weaker region in the mantle called the aesthenosphere. The Aesthenosphere is hot and plastic, and sheds heat via convective currents.

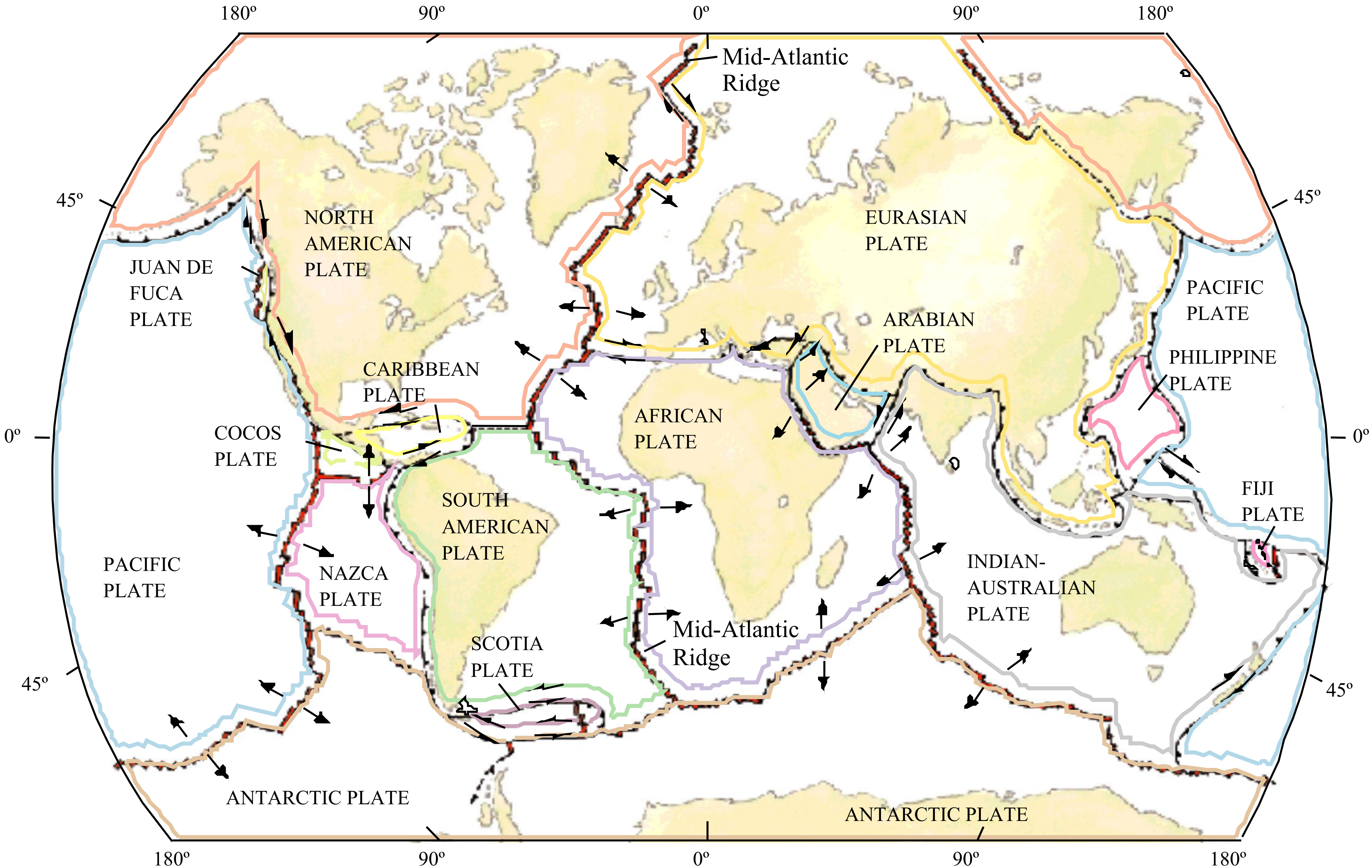


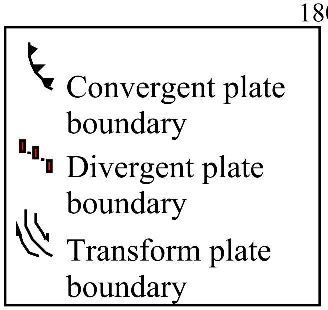


Structure of three boundary types

Mantle circulations are an example of convection, heat transfer by moving fluids



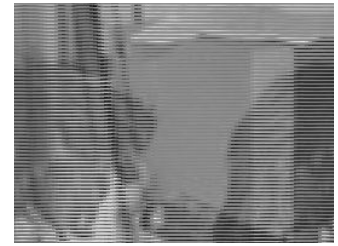


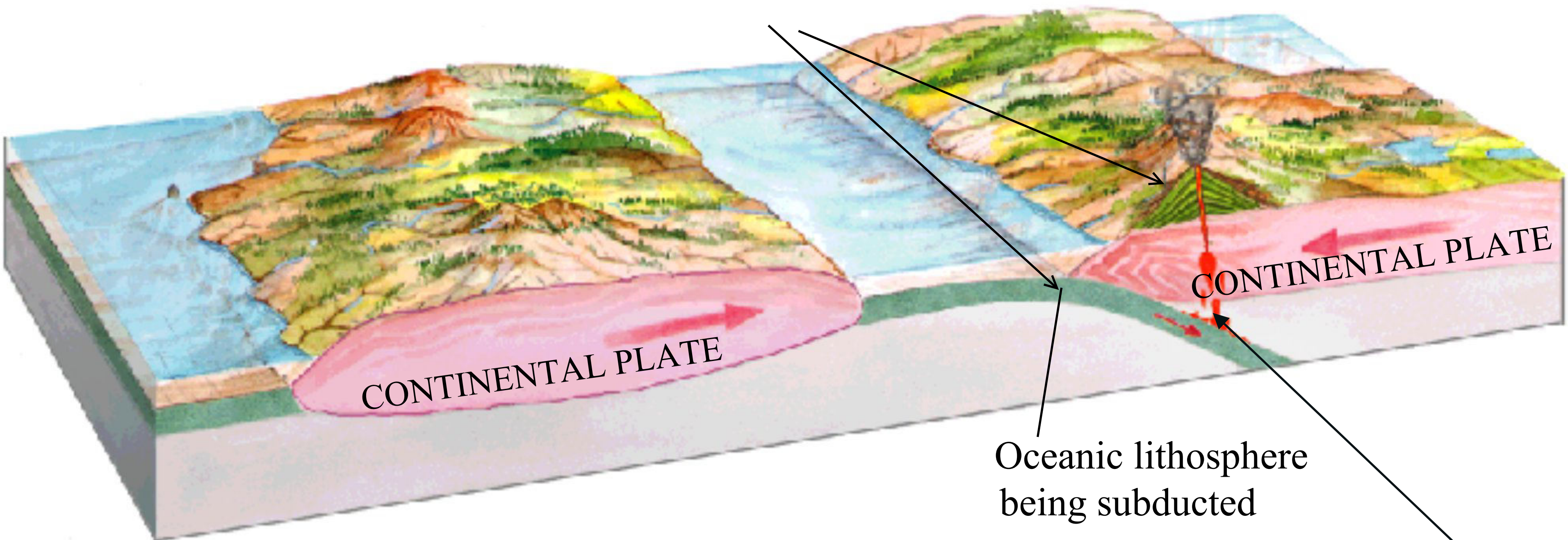


Average about 5 centimeters (2 inches) per year

Seven major lithospheric plates
Seven or so smaller ones.
Plates are in motion and change in shape and size
Largest plate is the Pacific plate
Several plates include an entire continent plus a large area of seafloor

Assistant Professor Dirk Vogel, teaching Petrology at Rutgers, about 1971. It was Dr. Vogel who let the Plate Tectonics cat out of the bag at Rutgers. Concept caused revelation. Yes, revelation. Earth’s many features were all caused by the same process.



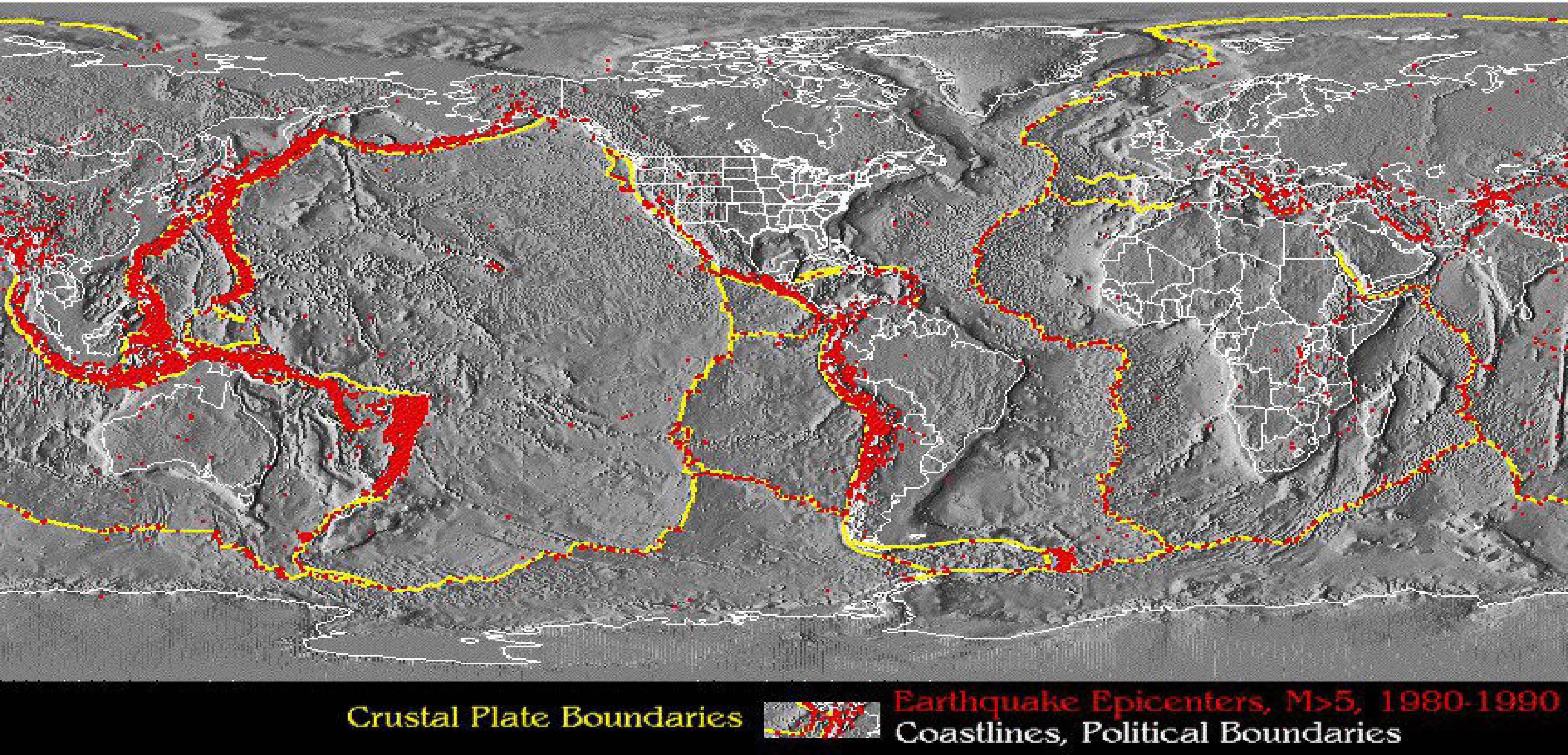


(a)

Fundamental Paradigm

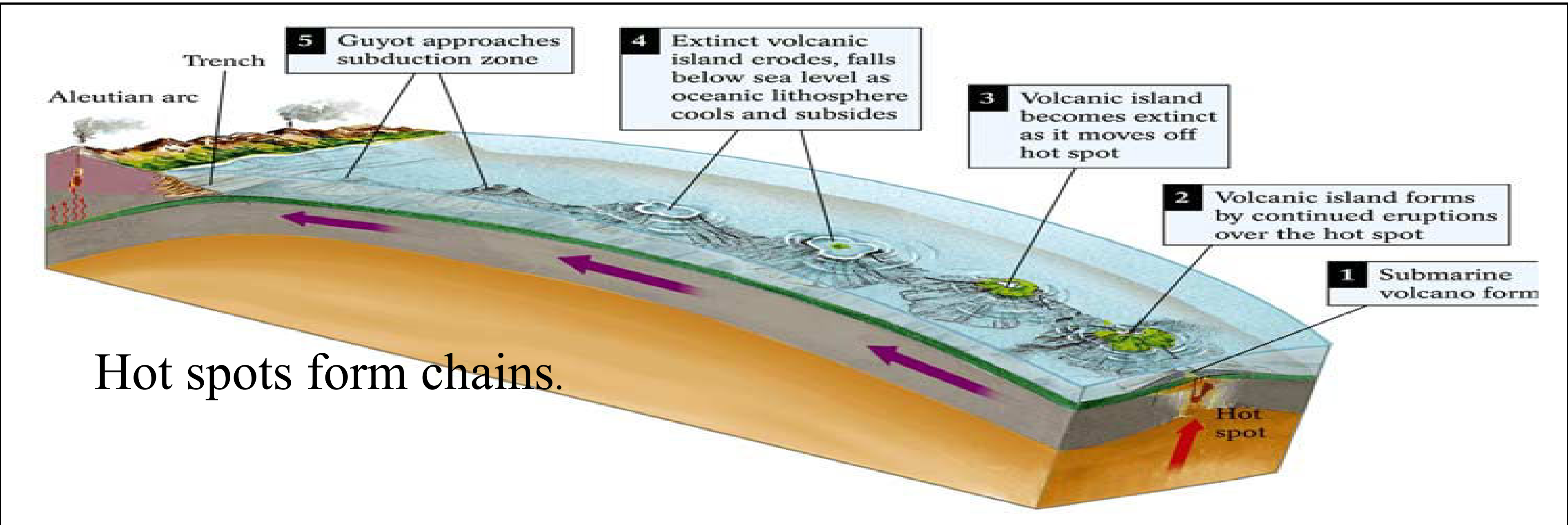
Water driven out of ocean lithosphere
Water hits mantle, which partially melts.
Forms a deep basaltic magma

Each plate bounded by combination of all three boundary types: divergent, convergent, transform



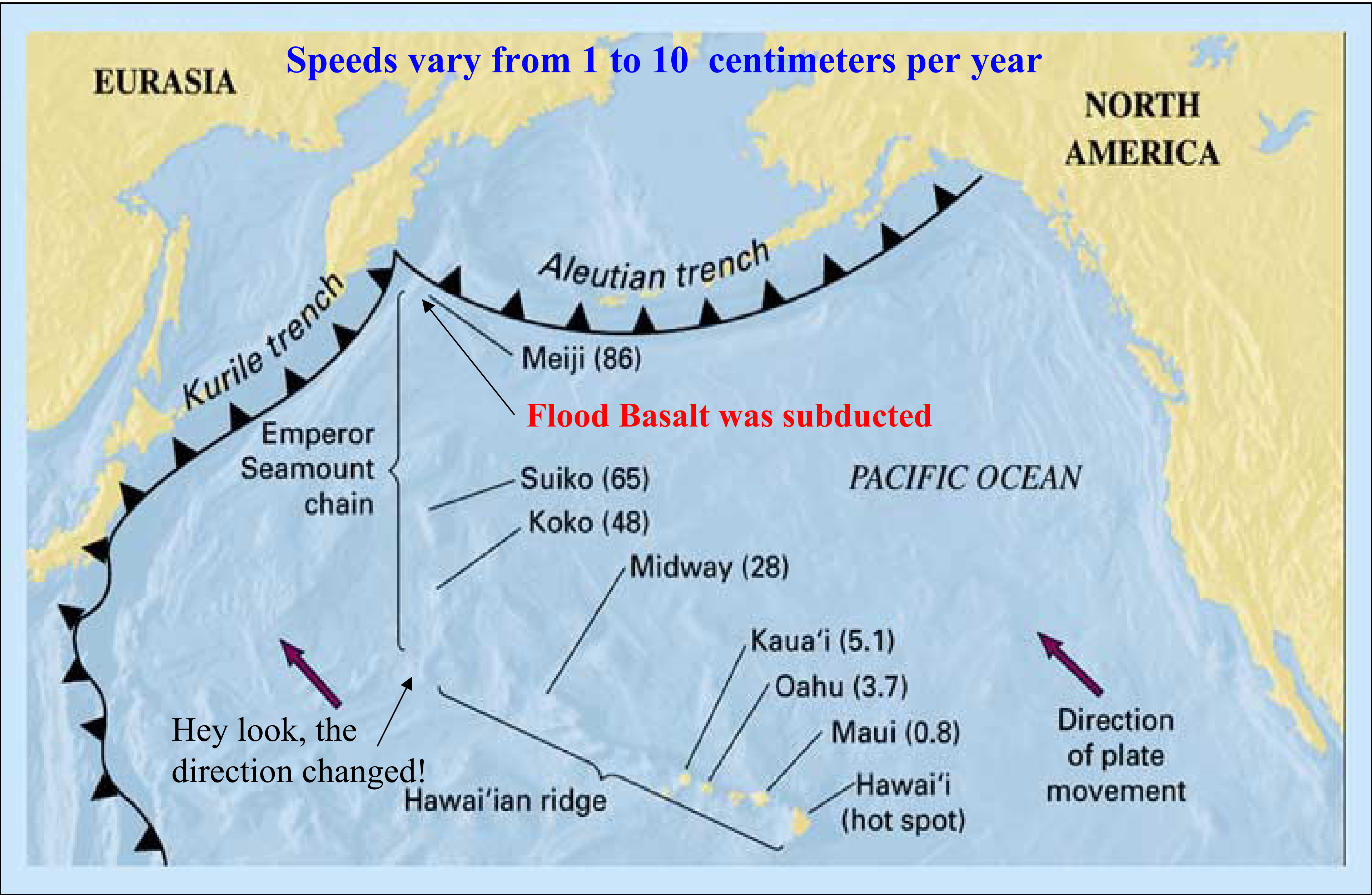
How fast do Plates Move?

- Hot Spots are magmas from rising plumes from the deep mantle, probably heated by the liquid outer core. Their lavas are datable
- As plates move over them, new volcanic seamounts and islands are formed. Eventually any subaerial (exposed to the air) parts are eroded away, and as they move away from the Hot Spot, they cool, contract, and submerge. Called Guyots

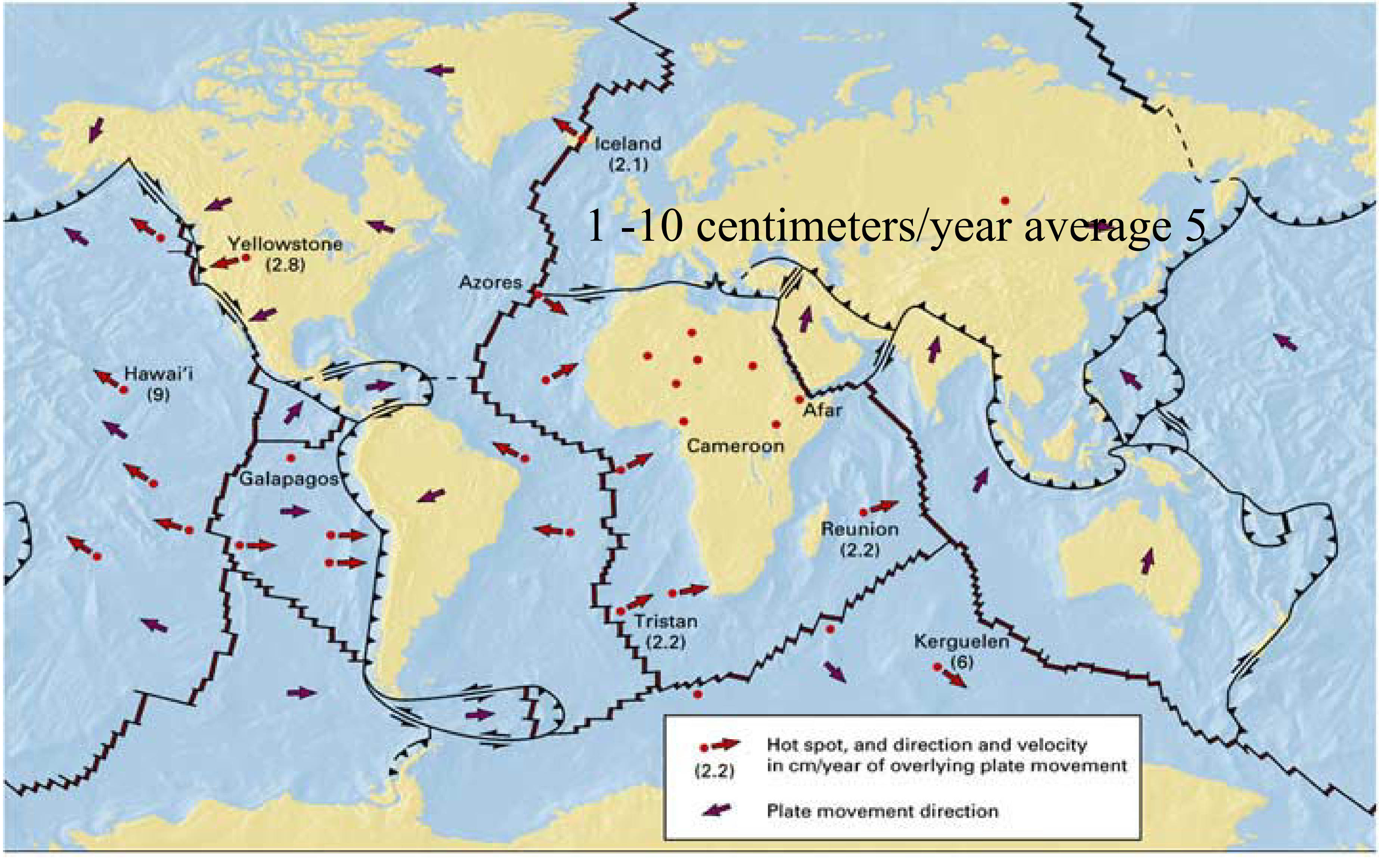


Hot spots form chains.

Hot Spots and Hawaii

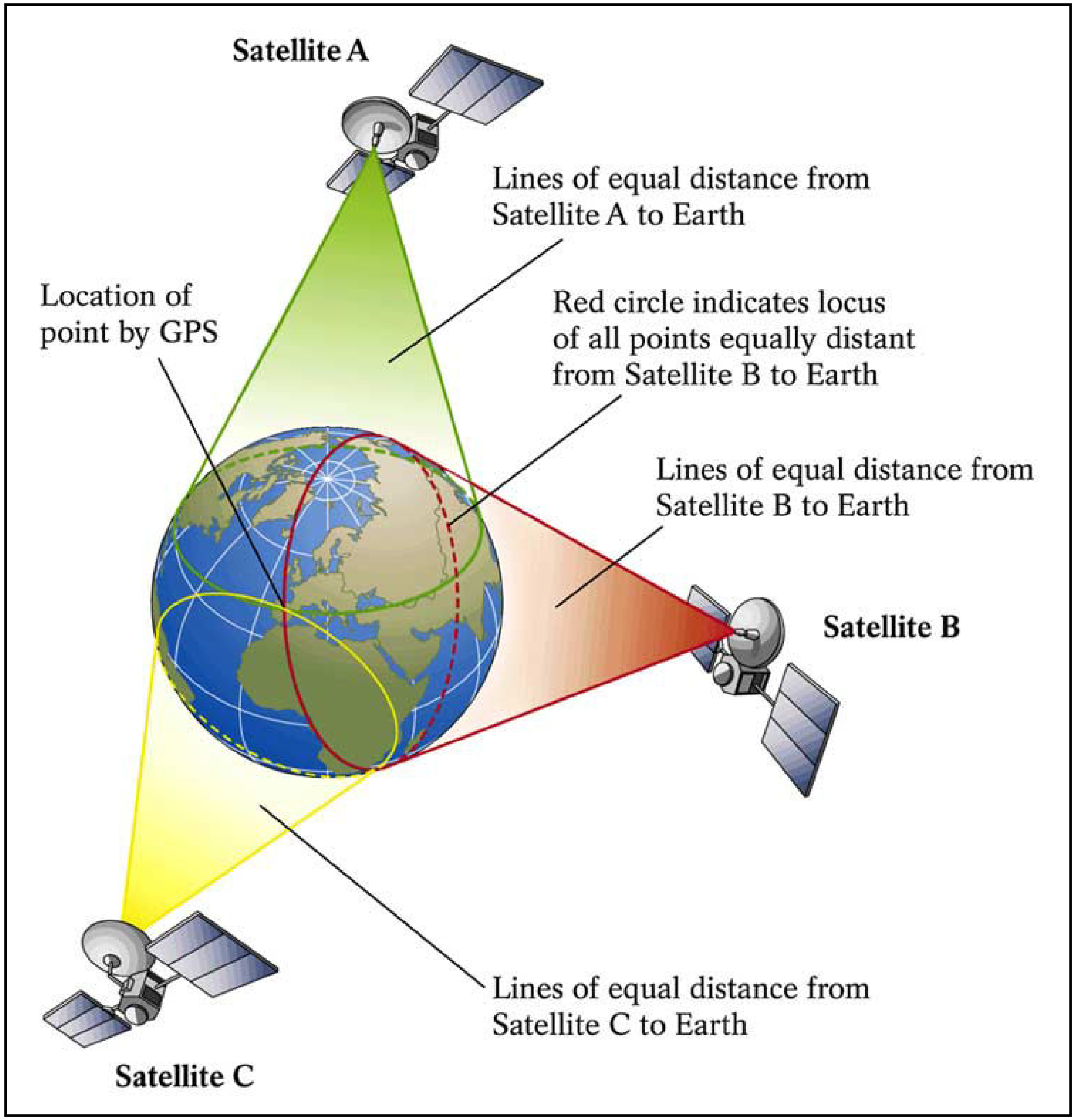


Hot Spots & Plate Motions



New ways of determining spreading rate

LAGEOS and GPS satellites determine that plates move 1-10 cm per year, avg 5



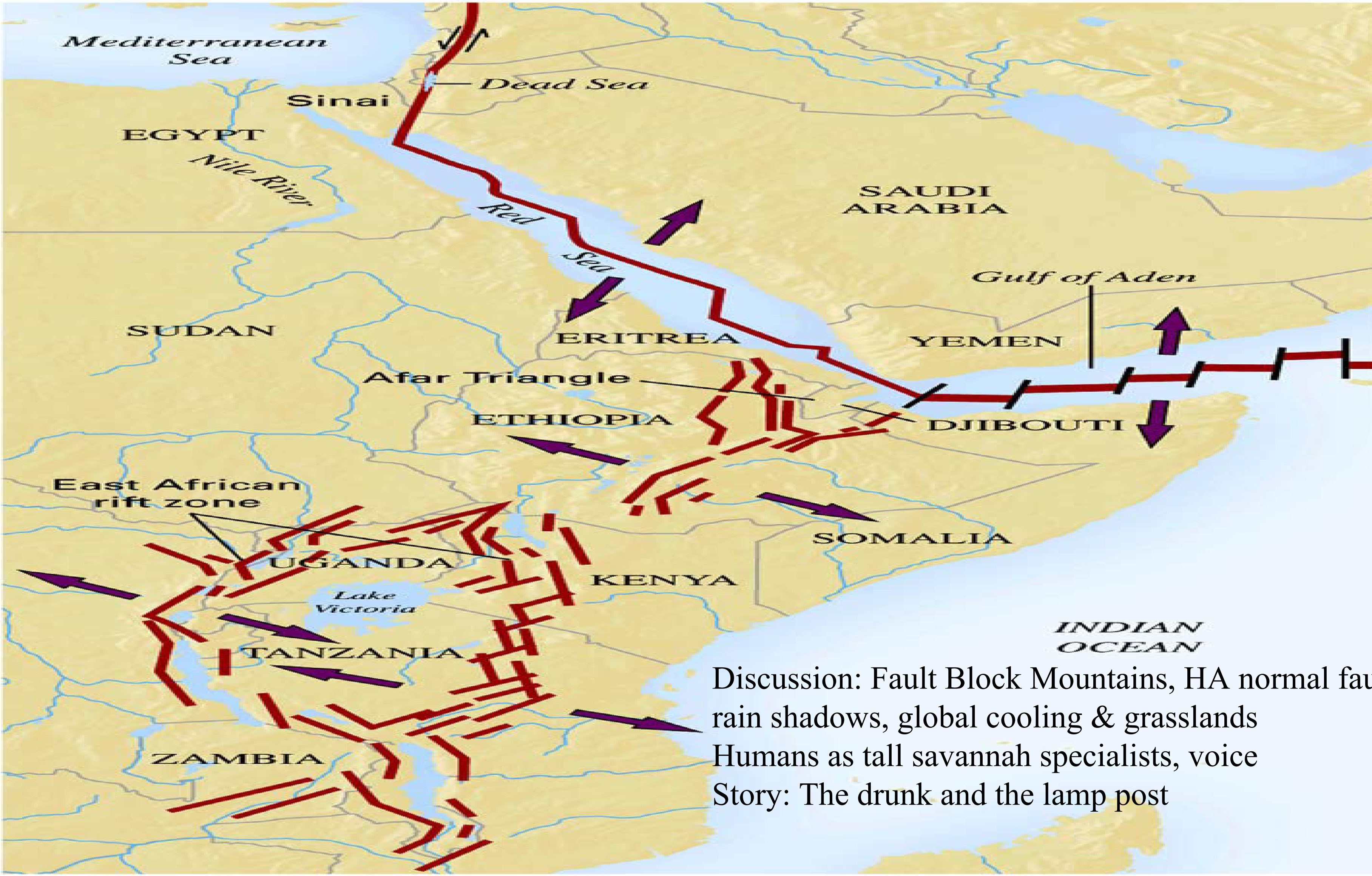
Just find position wrt distant stars, then watch fixed objects on earth move .

Paleogeography Reconstructions

- Orientation of magnetic minerals gives latitude (north or south of equator)
- Radiometric dates of ocean floor basalts, plus distance from ridge, gives paleolongitude since 200 million years ago, when Pangaea began to break apart.

East African Rift Zone

Active: Red Sea and Gulf of Aden Failed Arm: Great Rift Valley (aulocogen)

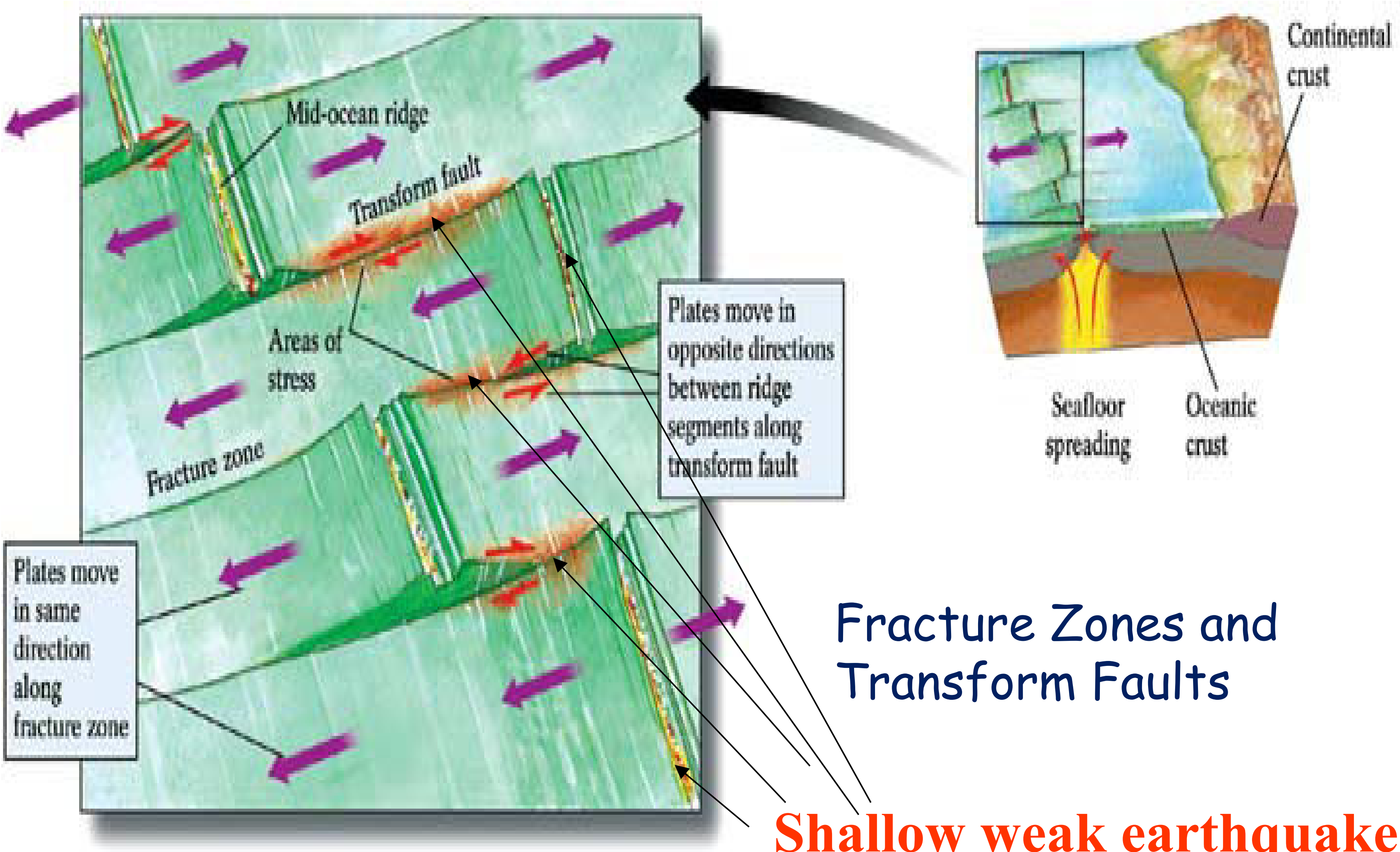


Discussion: Fault Block Mountains, HA normal fault
rain shadows, global cooling & grasslands
Humans as tall savannah specialists, voice
Story: The drunk and the lamp post

Mid-Ocean Ridge dimensions

- Total 65,000 kilometers long
- As wide as 1,500 km
- Some more than 3 km high above ocean floor.

Mid-Ocean Ridge System Motion

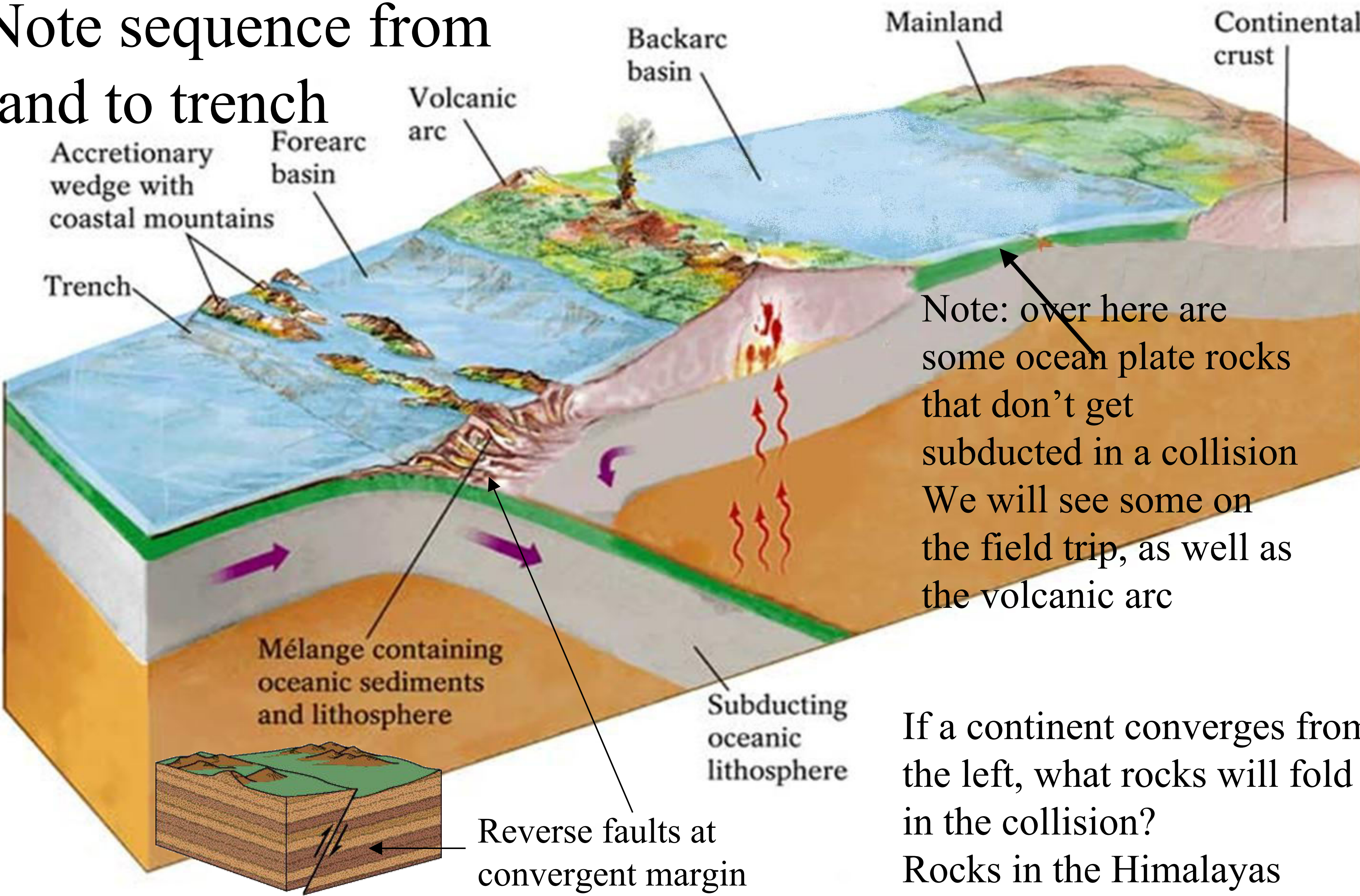


Fracture Zones and Transform Faults

Shallow weak earthquakes

Subduction-Zone Features

Note sequence from land to trench

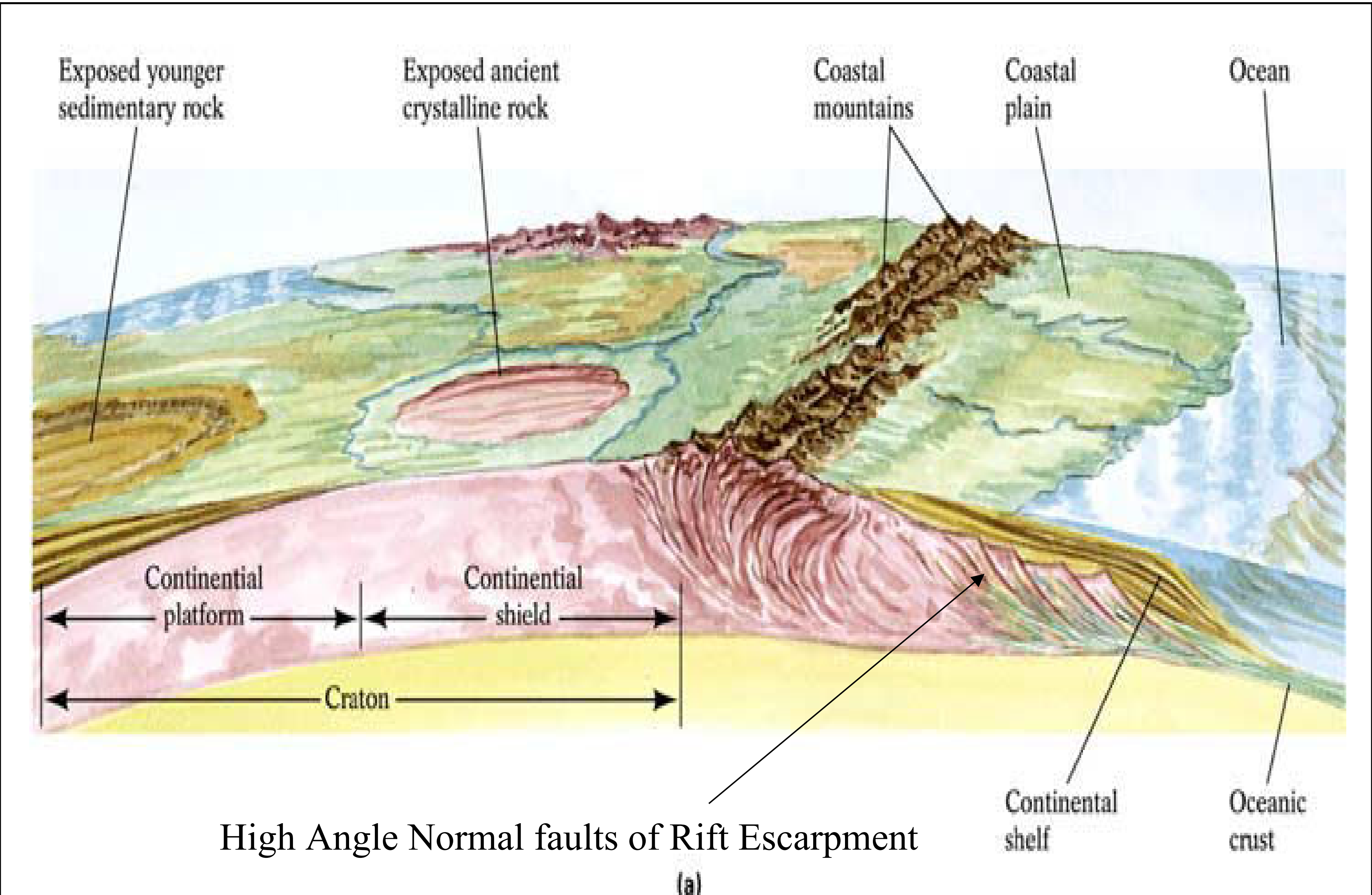


Note: over here are some ocean plate rocks that don't get subducted in a collision
We will see some on the field trip, as well as the volcanic arc

If a continent converges from the left, what rocks will fold in the collision?
Rocks in the Himalayas

Anatomy of a Continent

Shield + Platform = Craton



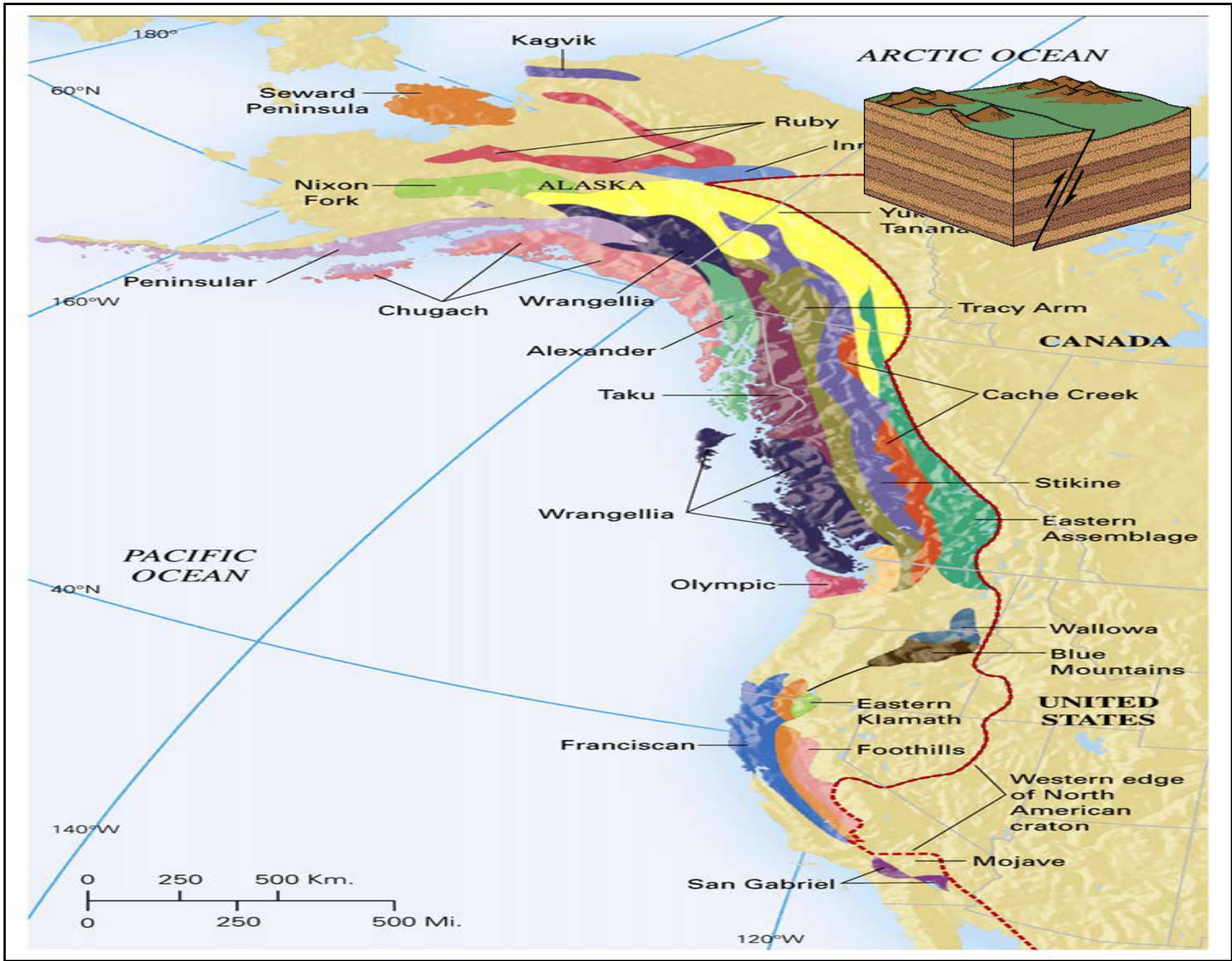
Exotic (Displaced) Terrains

Collisions with Volcanic Island Arcs and microcontinents

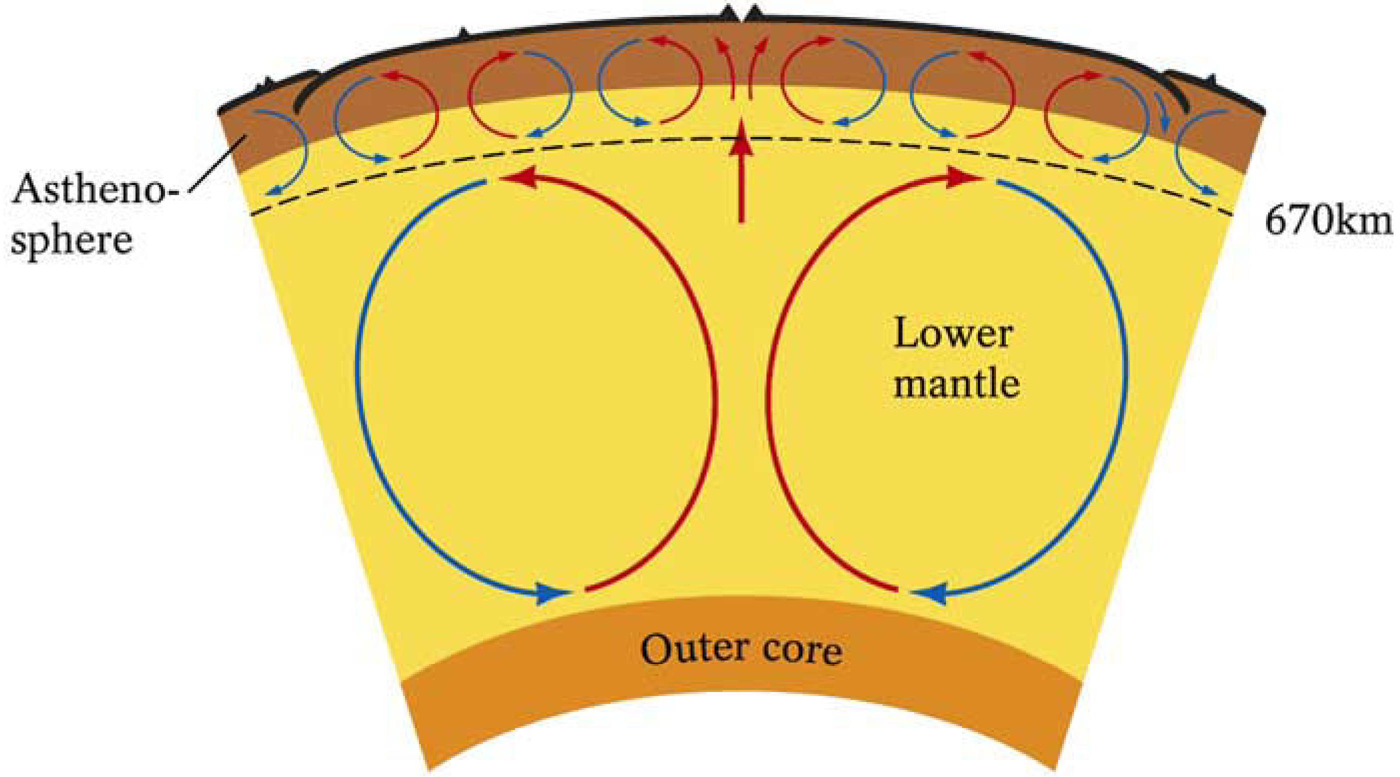
Continental Crust buoyant hard to subduct. Erosion resistant parts

Suture Zones

Pieces are volcanic island arcs, and microcontinents Accreted or moved by transform faults Anecdote Western California



Ideas: Earth's Convection Cells



(c) Two-tiered convection-cell hypothesis

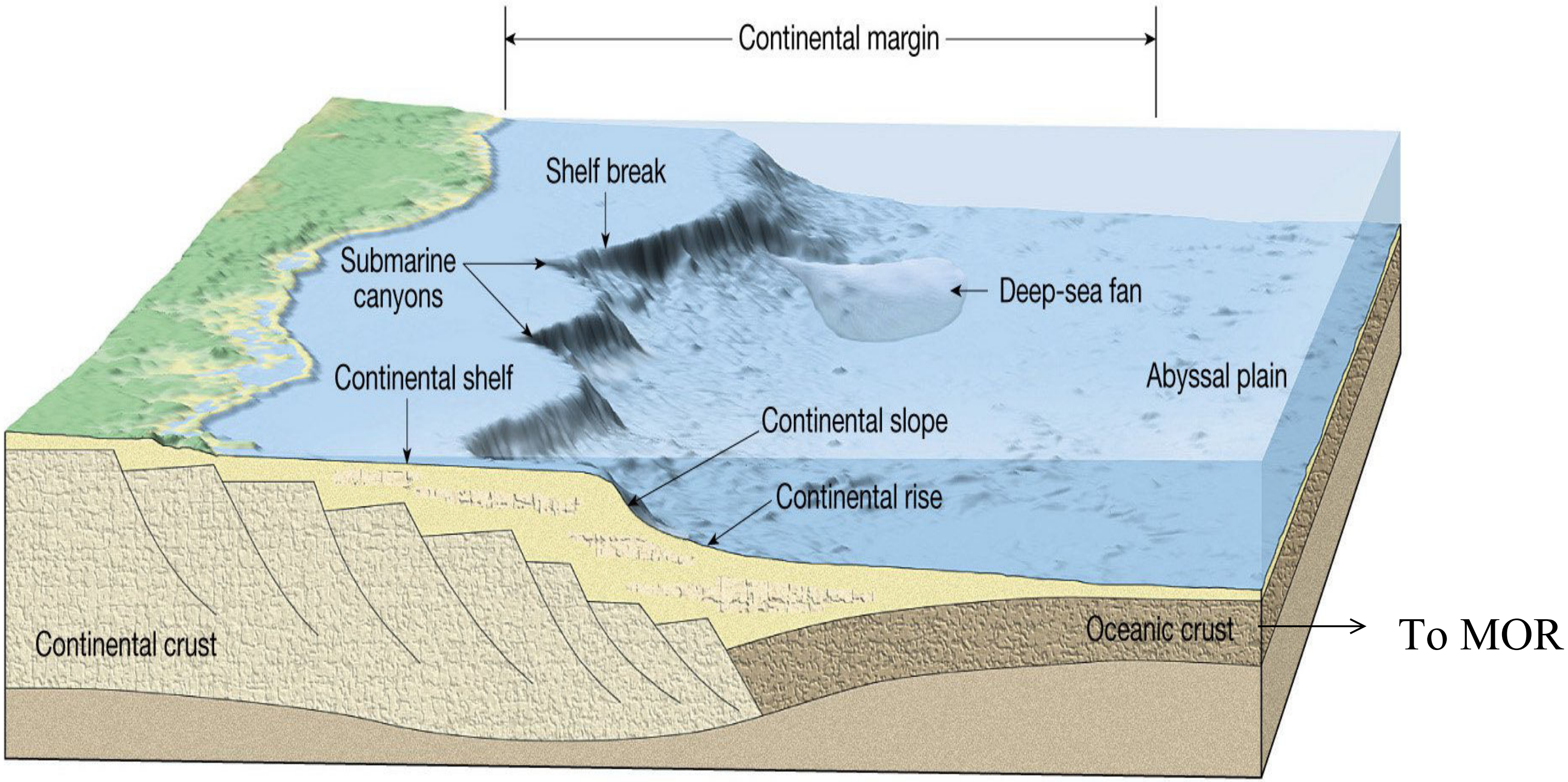
Combination

Mapping the ocean floor

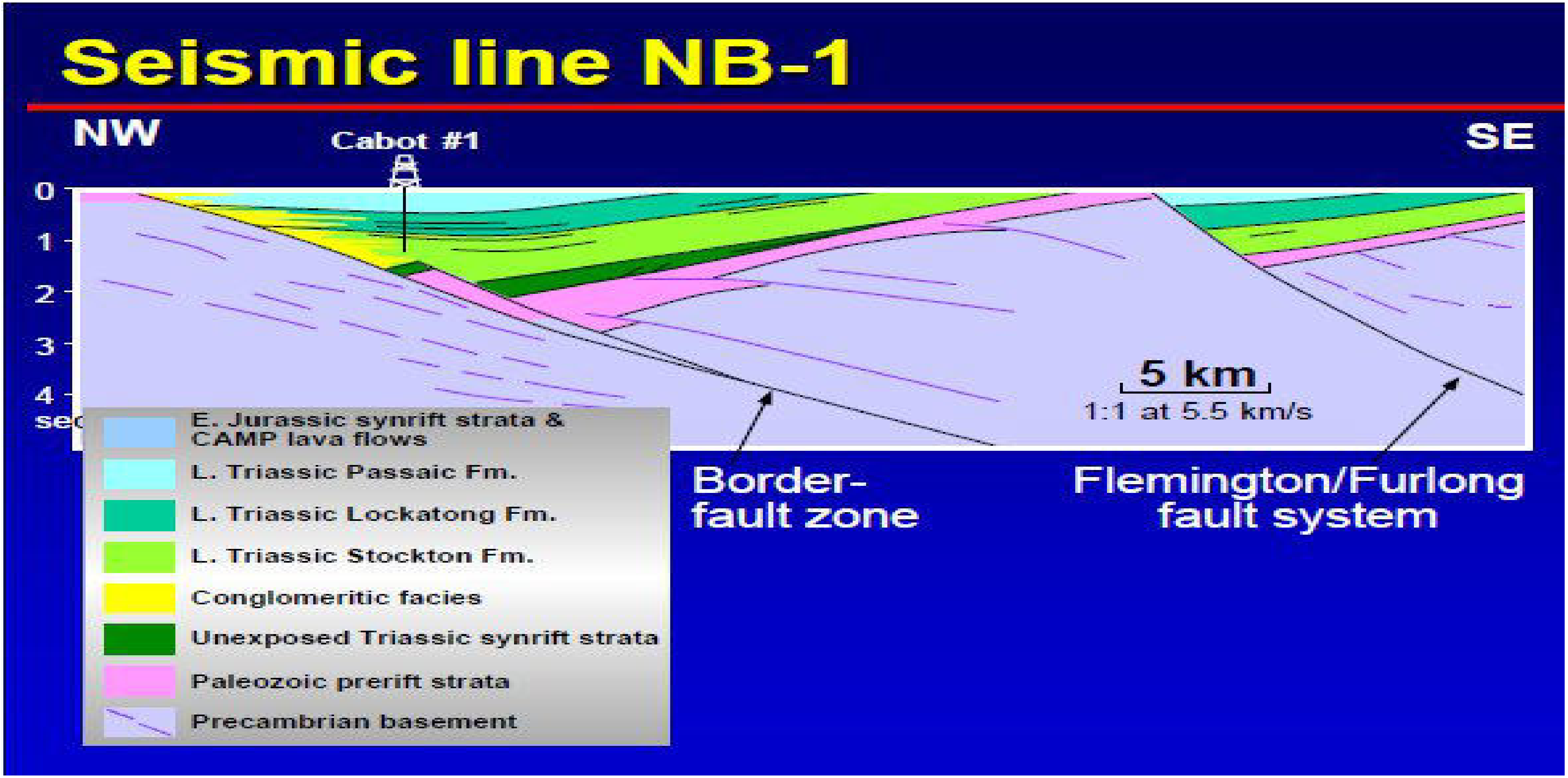
- **Three major topographic units of the ocean floor**
  - **Continental margins**
  - **Deep-ocean basins**
  - **Mid-ocean ridges**

A passive continental margin

- Found along coastal areas that surround oceans w central MOR
- Not near active plate boundaries
- Little volcanism and few earthquakes
- East Coast of US an example

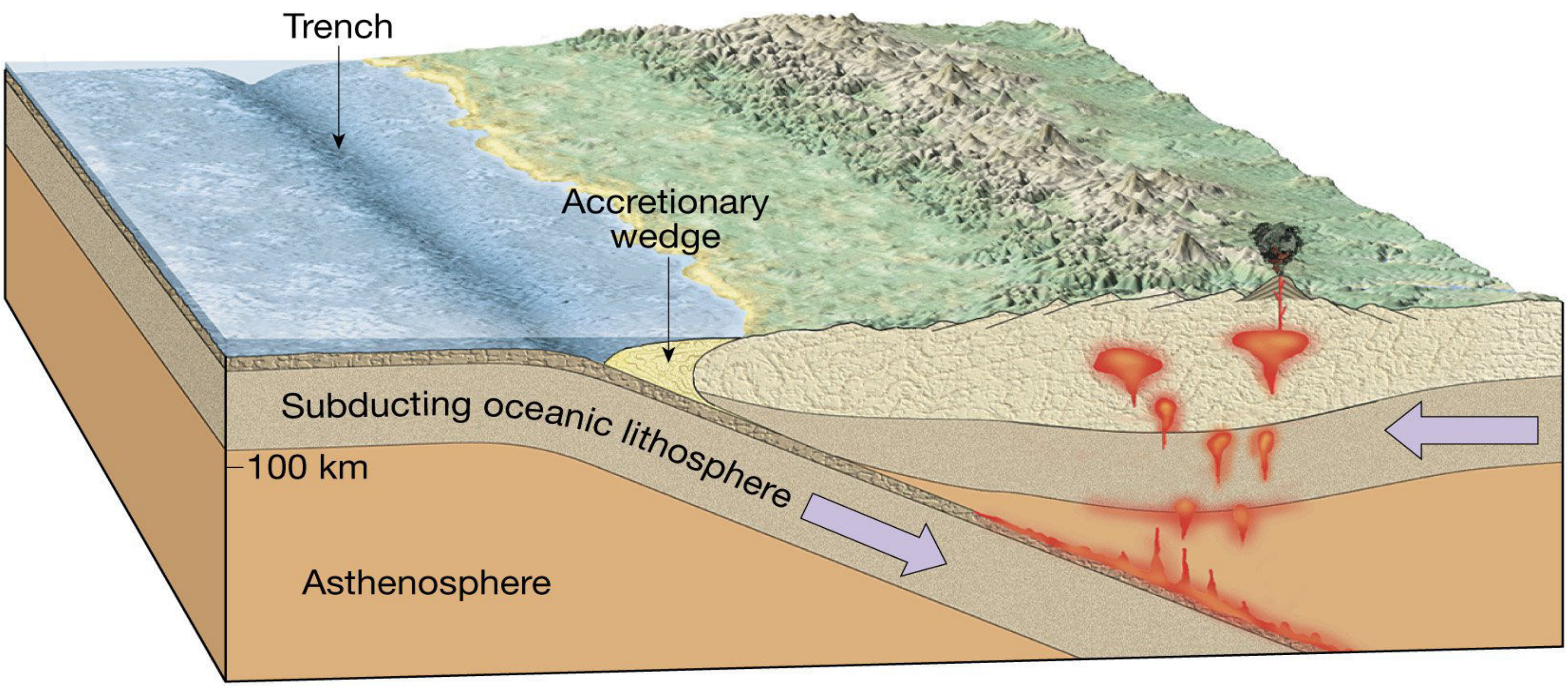


Rifts and MOR's the same divergent process, diff. place and/or age

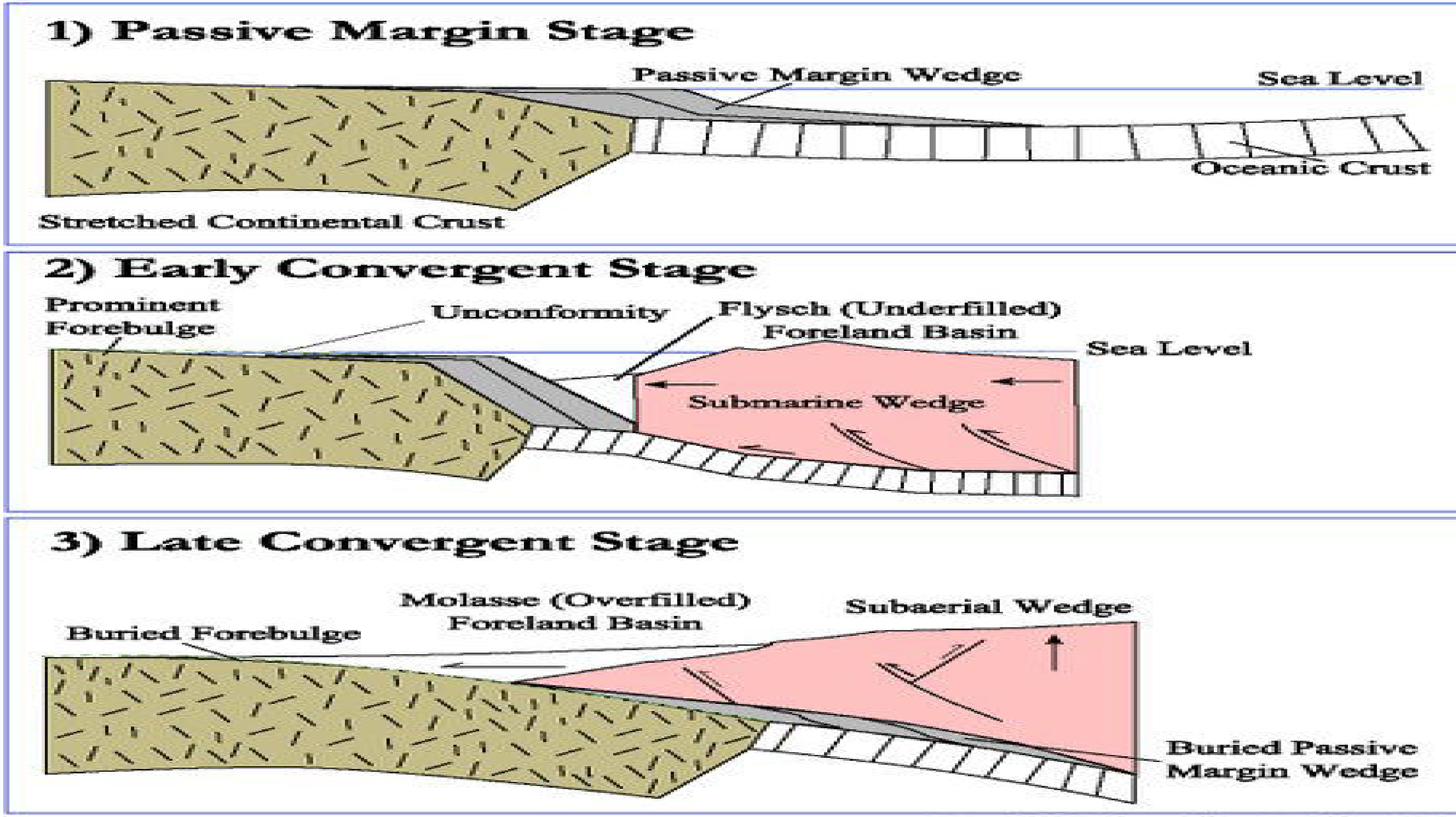


An active continental margin

- Continental slope descends abruptly into a deep-oceanic trench
- Located primarily around the Pacific Ocean
- Sediment and oceanic crust scraped off ocean crust to form accretionary wedges

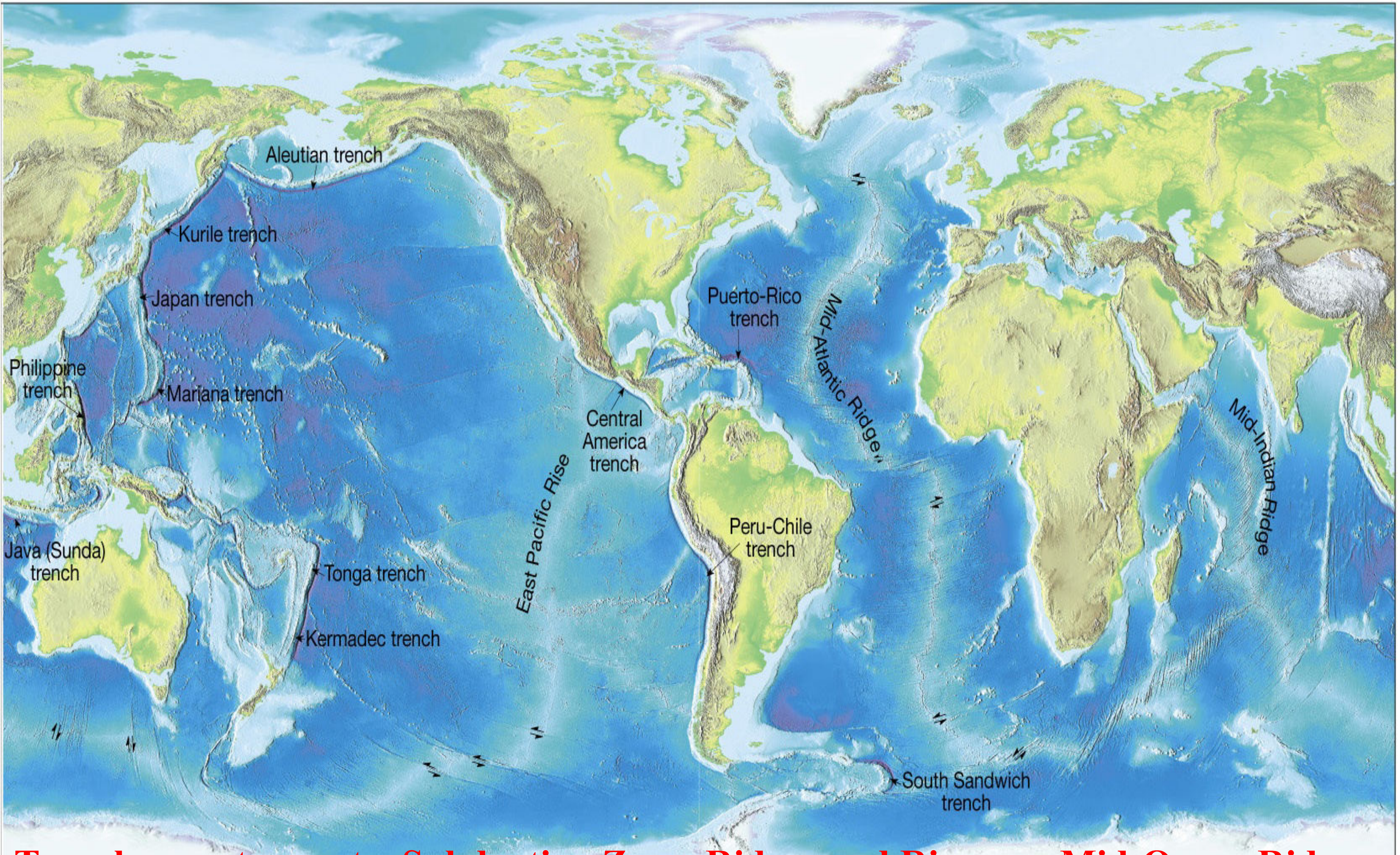


How are these related?

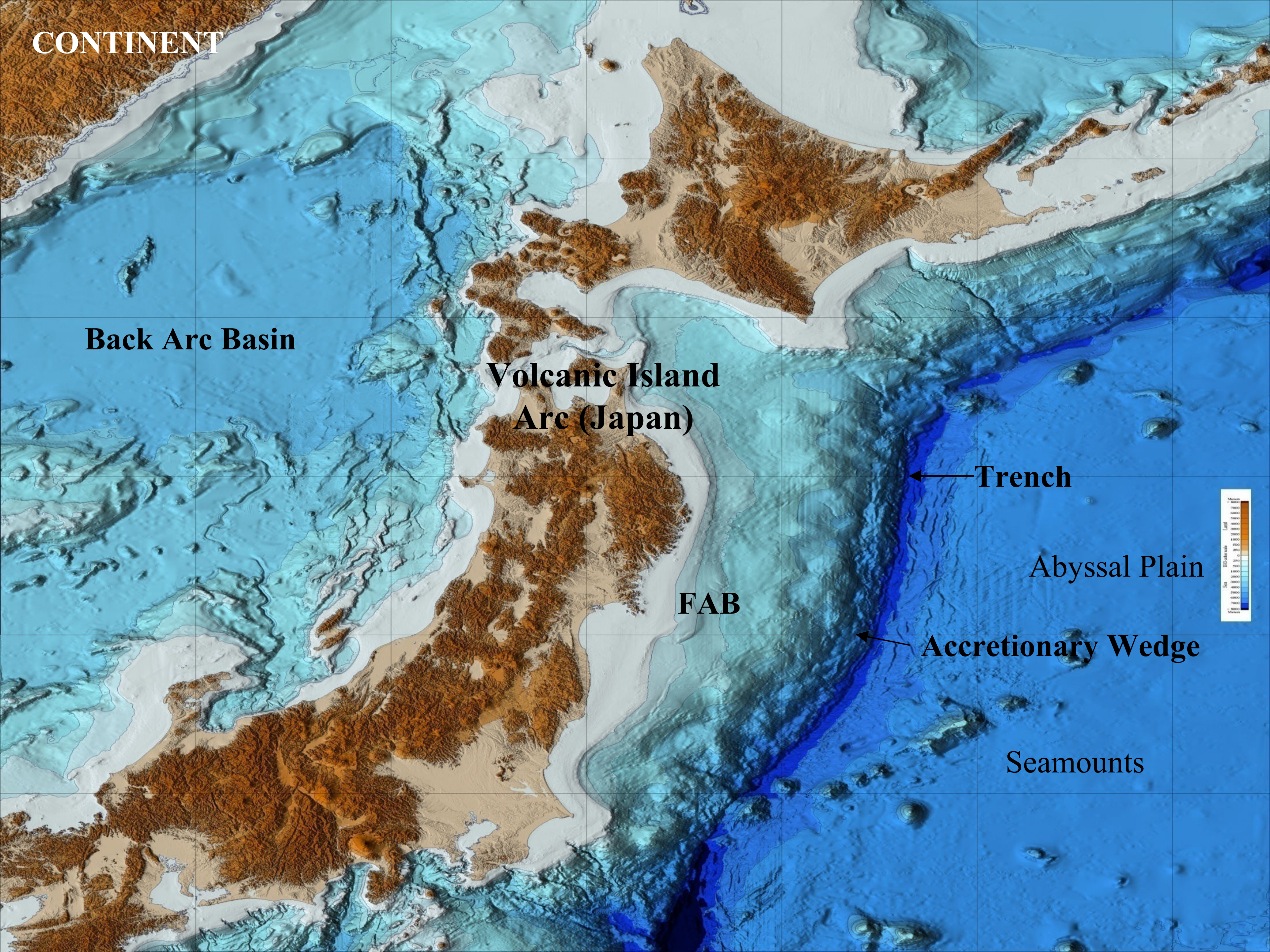


Modified after Allen & Allen 2005

The world's trenches and ridges



Trench an entrance to Subduction Zone, Ridges and Rises are Mid-Ocean Ridges


CONTINENT
Back Arc Basin
Volcanic Island
Arc (Japan)
Trench
Abyssal Plain
FAB
Accretionary Wedge
Seamounts

Features of the deep-ocean basin

- Abyssal plains
  - Can be sites of thick accumulations of sediment
  - Found in all oceans
  - Studded by old cold seamounts and ridges

Seafloor sediments

Ocean floor is mantled with sediments

- Sources
  - Turbidity currents on continent margins
  - Sediment that slowly settles to the bottom from above – fine mud and plankton
- Thickness varies
  - Thickest in trenches – accumulations may exceed 9 km

- Types of sediments
  - Biogenous sediment
    - Shells and skeletons of marine animals and plants
    - Calcareous oozes from microscopic organisms (only in shallow water)
    - Siliceous oozes composed of opaline skeletons of diatoms and radiolarians (only in deep water)
    - Carbonate compensation depth - 4km

Foraminifera (a.k.a. Forams)

Form deepwater carbonate oozes, depths less than 4 km

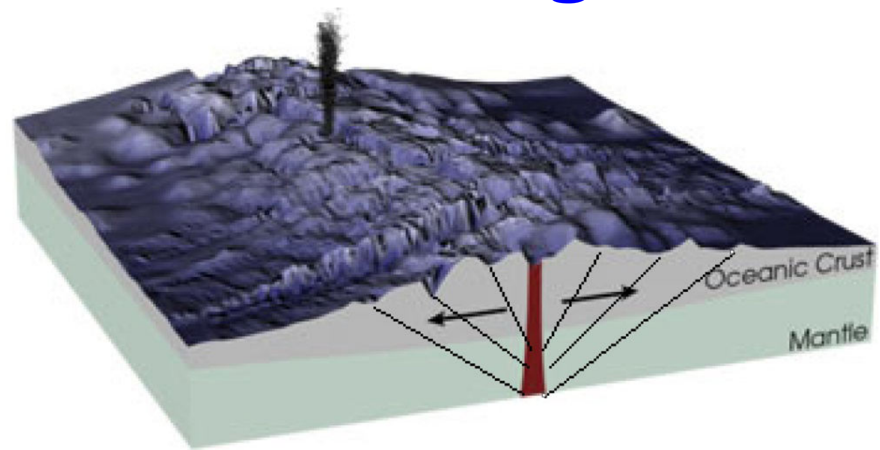
Chert sample

below carbonate line

>4 km

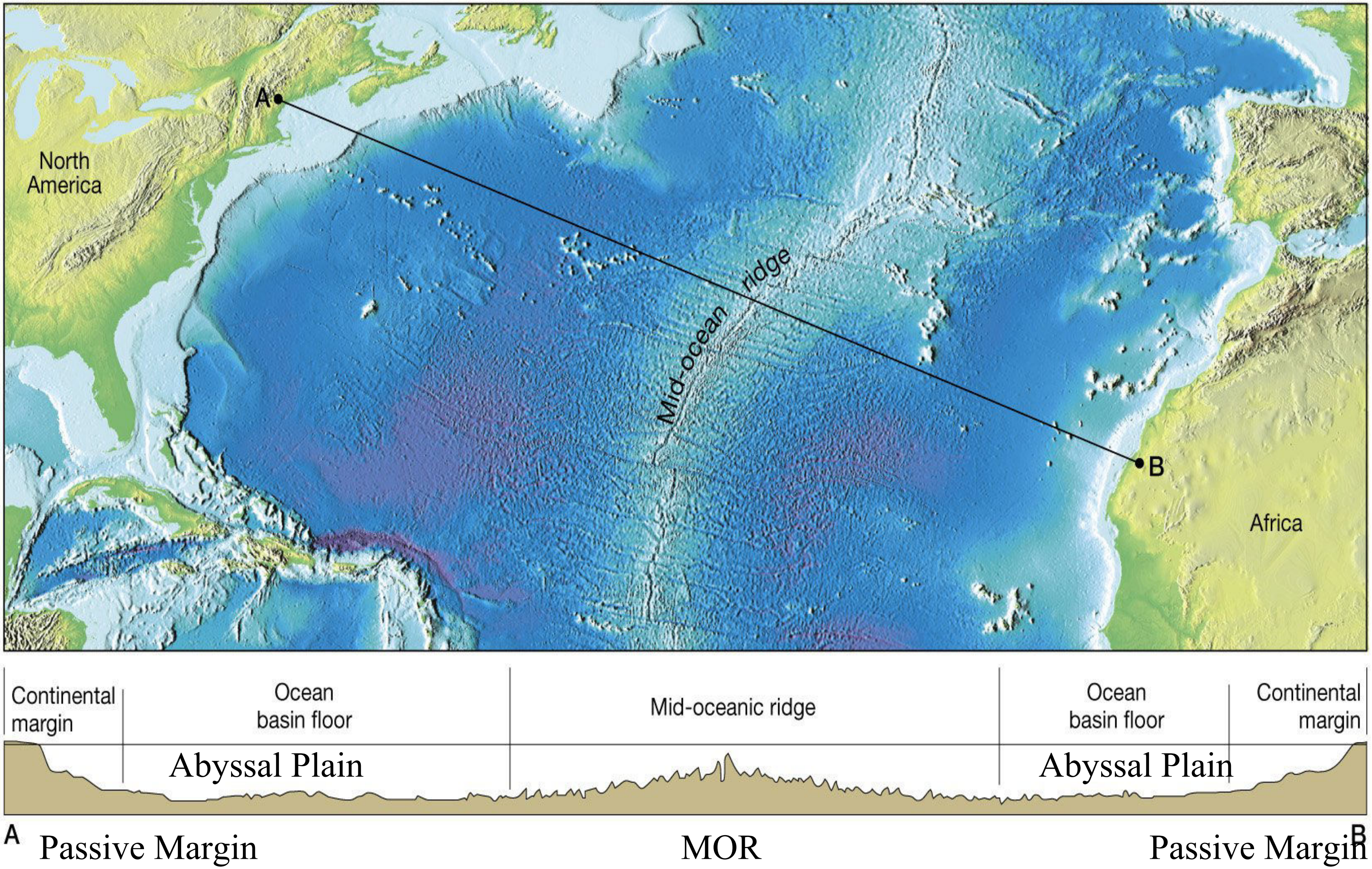
Diatoms (siliceous ooze)

Mid -oceanic ridges

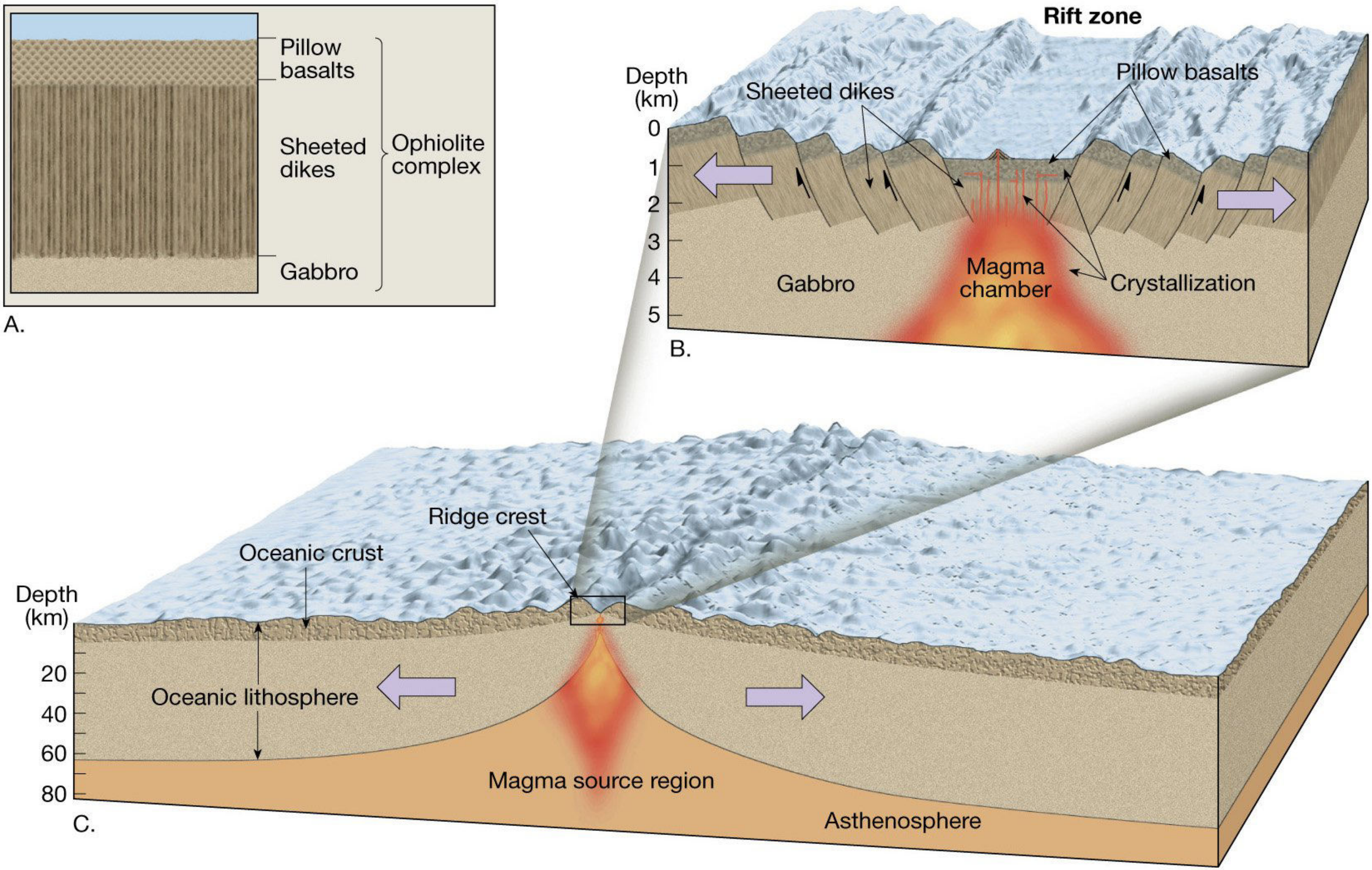


- Characterized by
  - Heating => elevated ridge w/ radial cracks
  - Closely spaced normal faulting: HW down
  - Mantle flow below pulls the crust apart – High Angle Normal Faults steeper than cartoon
  - Newly formed basalt ocean floor fills in cracks

Bathymetry of the Atlantic Ocean

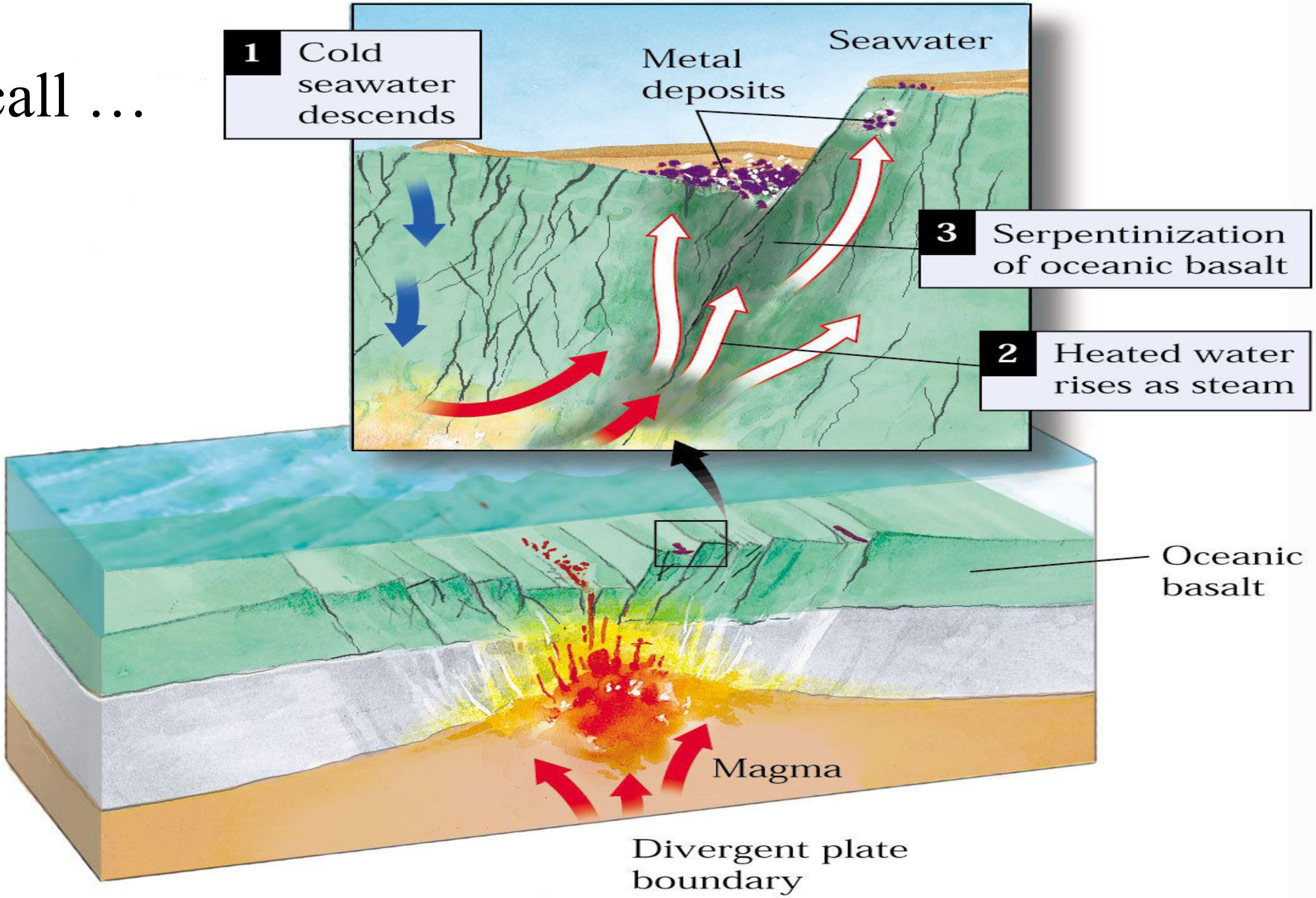


The structure of oceanic crust



Hydrothermal Metamorphism

Recall …



Black Smokers

http://collections.ic.gc.ca/geoscience/images/detail/F92S0220.jpg

Circulation of hot water in cracks at mid-ocean ridge dissolves metals (Copper, Iron, Zinc, Lead, Barium) which are re-precipitated as sulphide ores. Hydrothermal waters are capable of metamorphism.

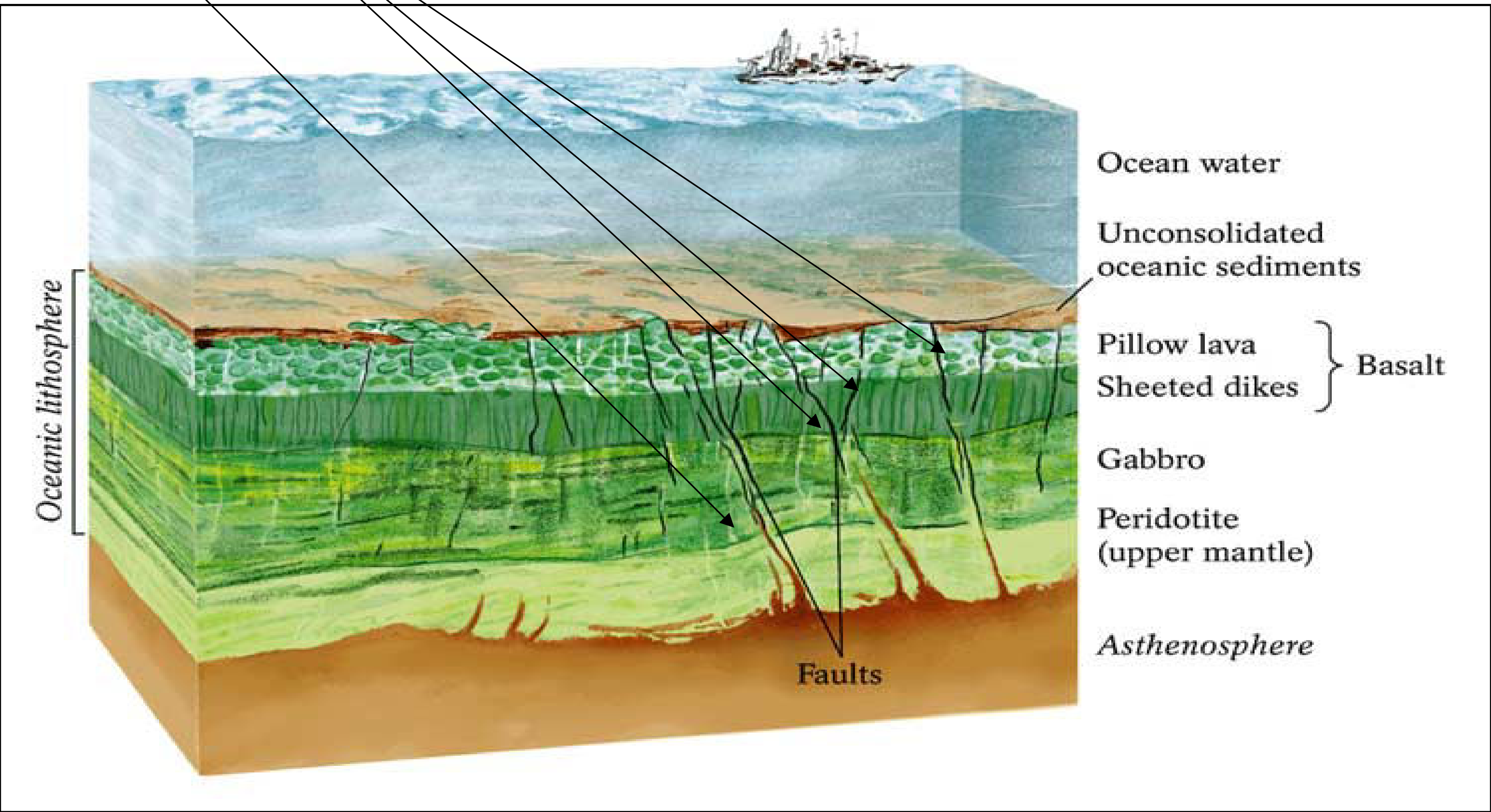
Ocean Floor layers:Ophiolite Suite

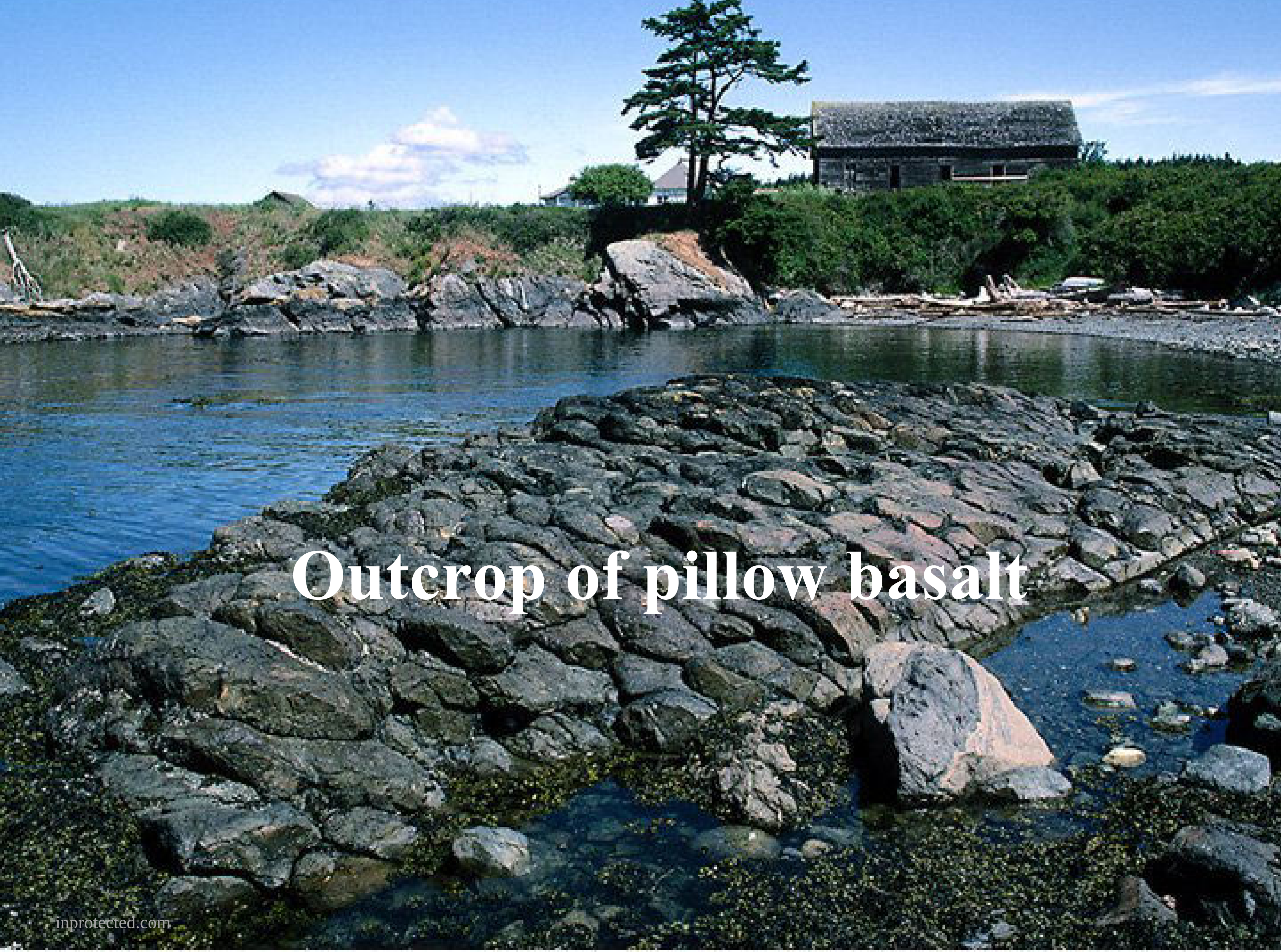
- **Structure of oceanic crust**
  - **Three layers in crust**
    - **Upper layer – consists of sediments over pillow lavas**
    - **Middle layer – numerous interconnected dikes called sheeted dikes**
    - **Lower layer – gabbro formed in basaltic magma chambers**
  - **Layer in mantle also part of the Ophiolite complex**

    - Magma that creates new ocean floor originates from partially melted mantle rock (peridotite) in the asthenosphere

Ophiolite Suite

Some **Serpentine is formed** due to hot water circulation (called Hydrothermal)




Outcrop of pillow basalt
inprotected.com