The Dynamic Earth – Plate Tectonics

The Dynamic Earth :

Plate Tectonics & Sea floor Spreading

(UG Hons. 1st Year)

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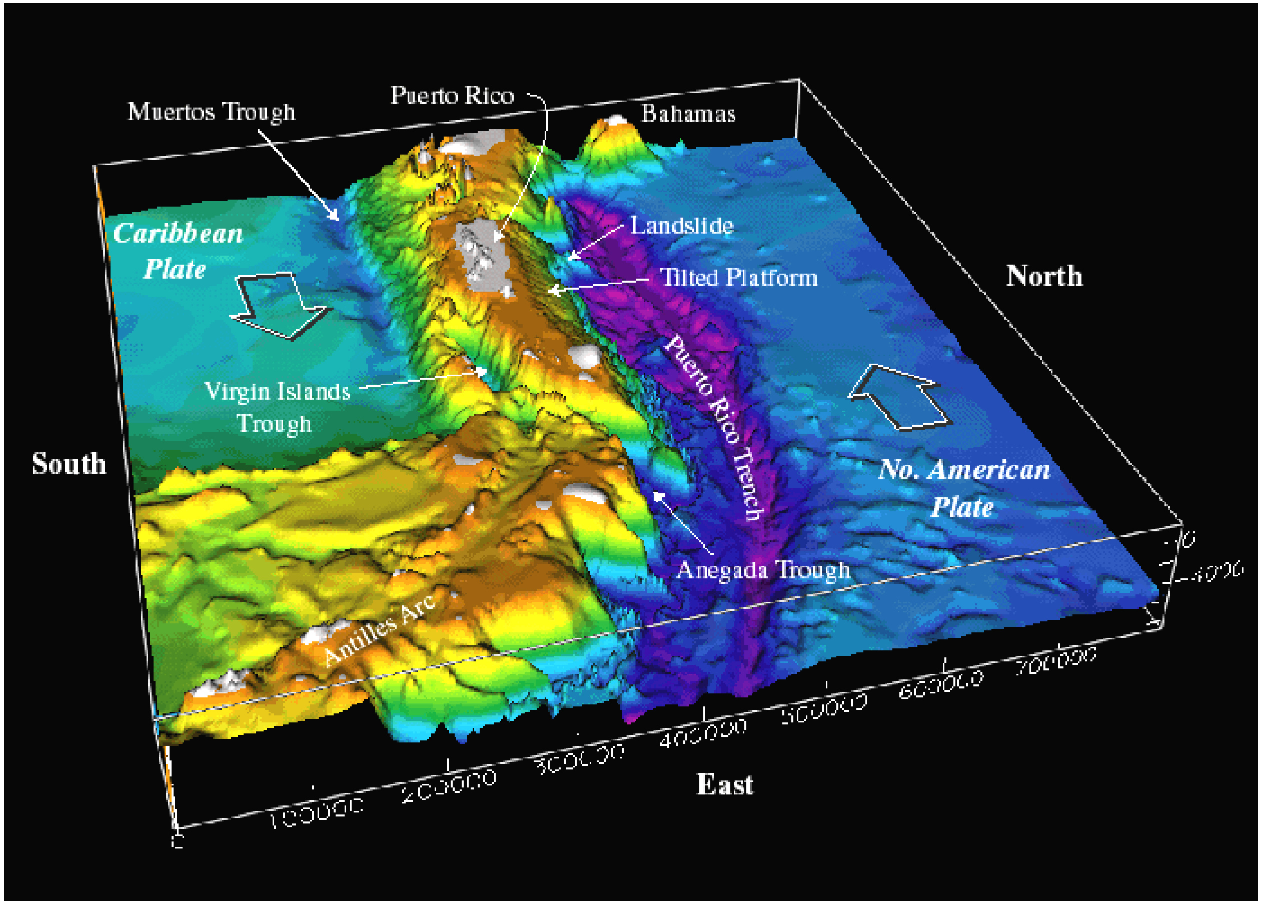
Why?

Why is Mount Everest 29,035 feet (8850 meters) high?

Why?

Why do we have deep ocean trenches?

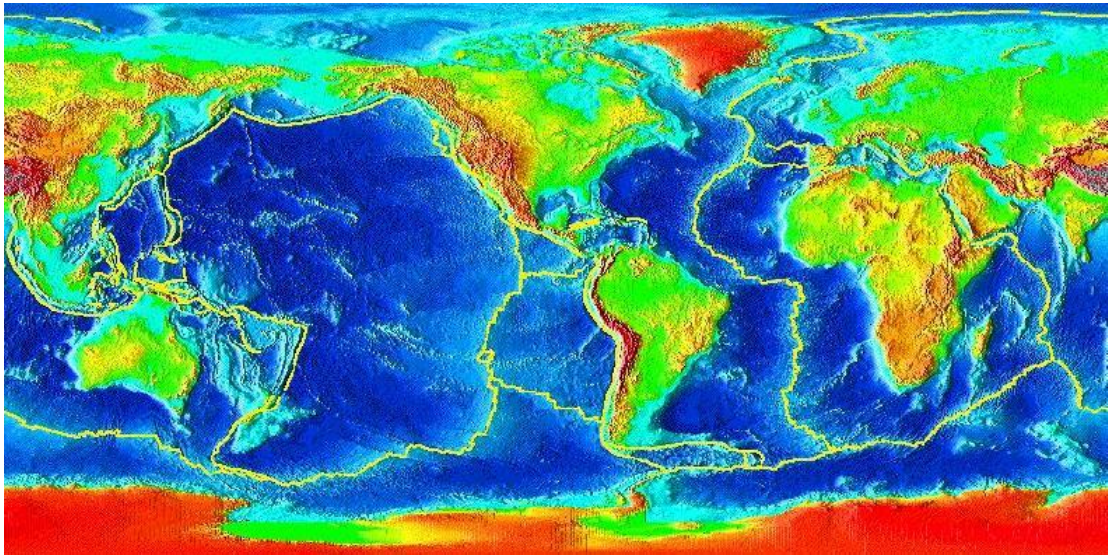


Dynamic Earth

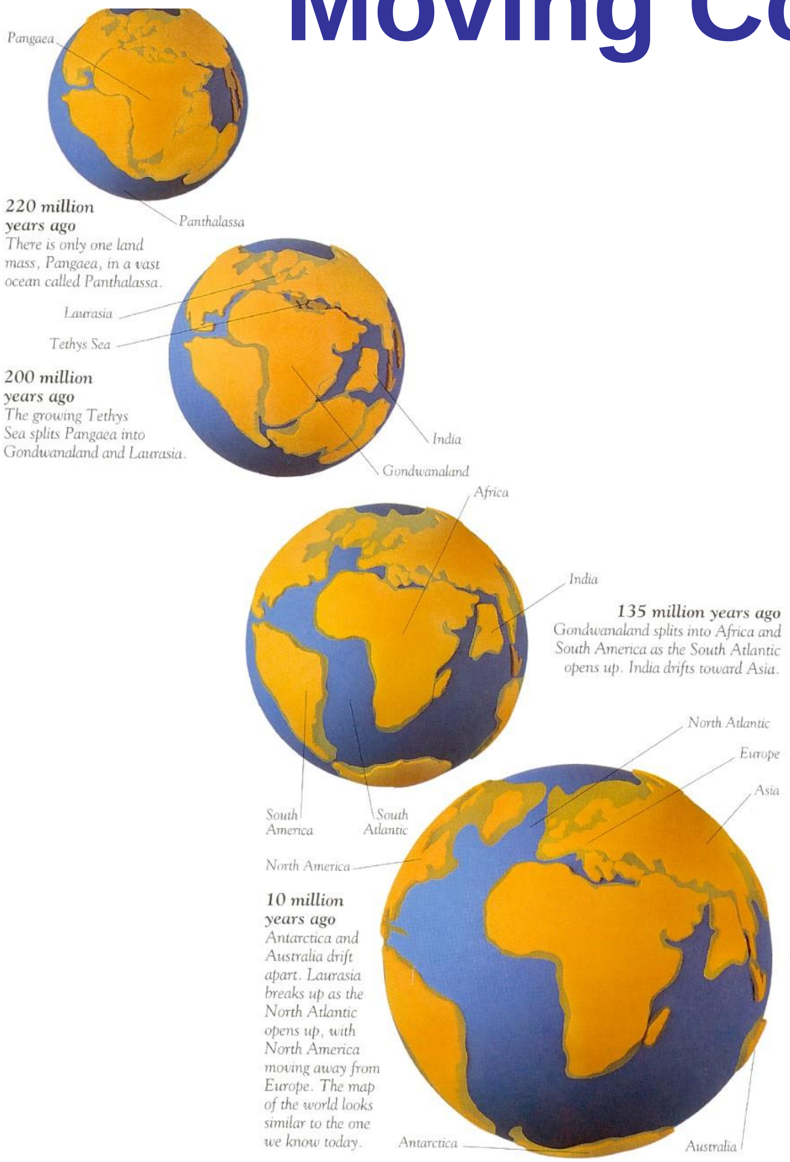
Because the Earth is a dynamic planet

Historically, over long geologic time periods, the Earth has under gone tremendous change

It turns out that the outer crust of the Earth is composed of about 20 distinct "plates", which move relative to each other



Moving Continents



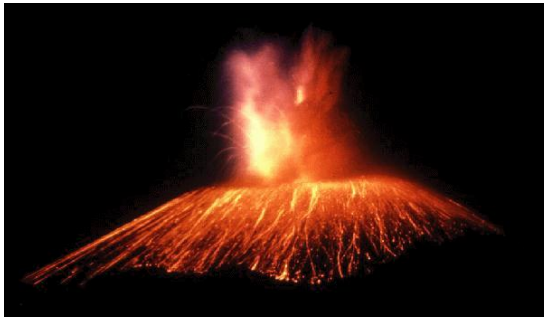
Simply put, we now understand that the continents move over time with respect to each other

Plate tectonics causes this continental drift

Plate Tectonics

Plate tectonics is the unifying concept of the Earth sciences

Plate tectonics explains:

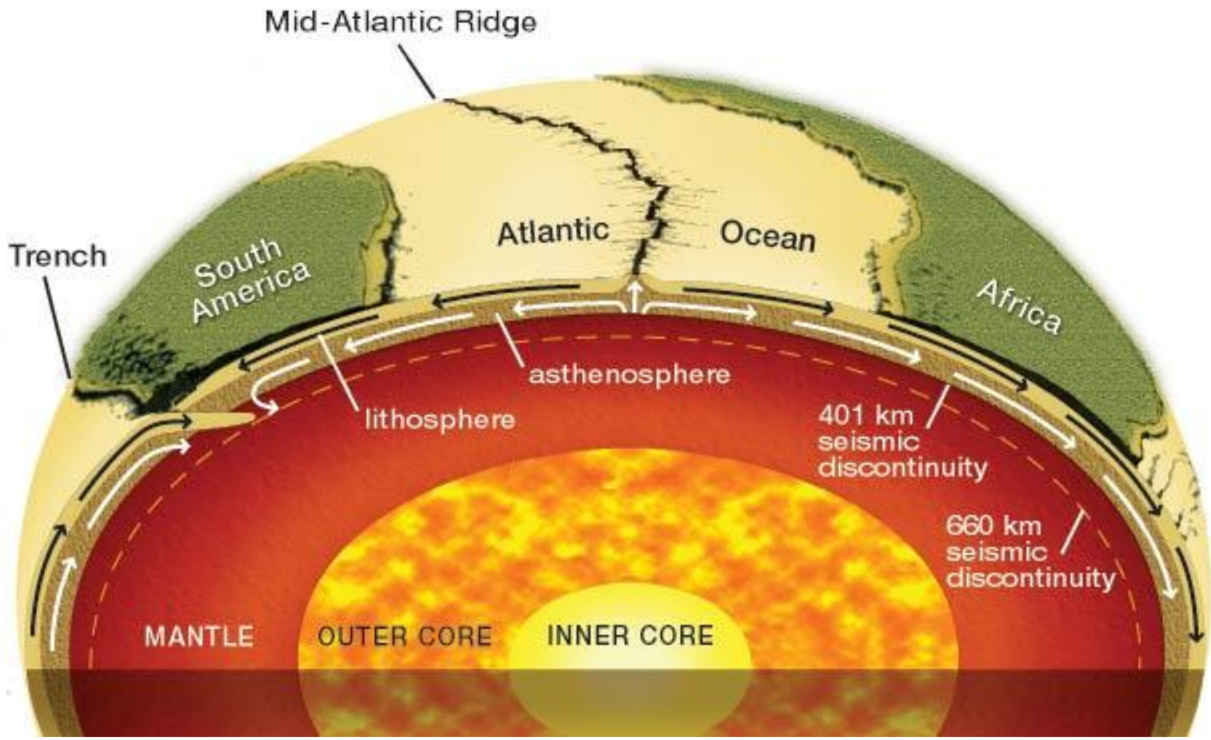


Volcanoes
Earthquakes
Mountain chains
Sea floor spreading
Deep ocean trenches
Occurrence of same fossils on different continents

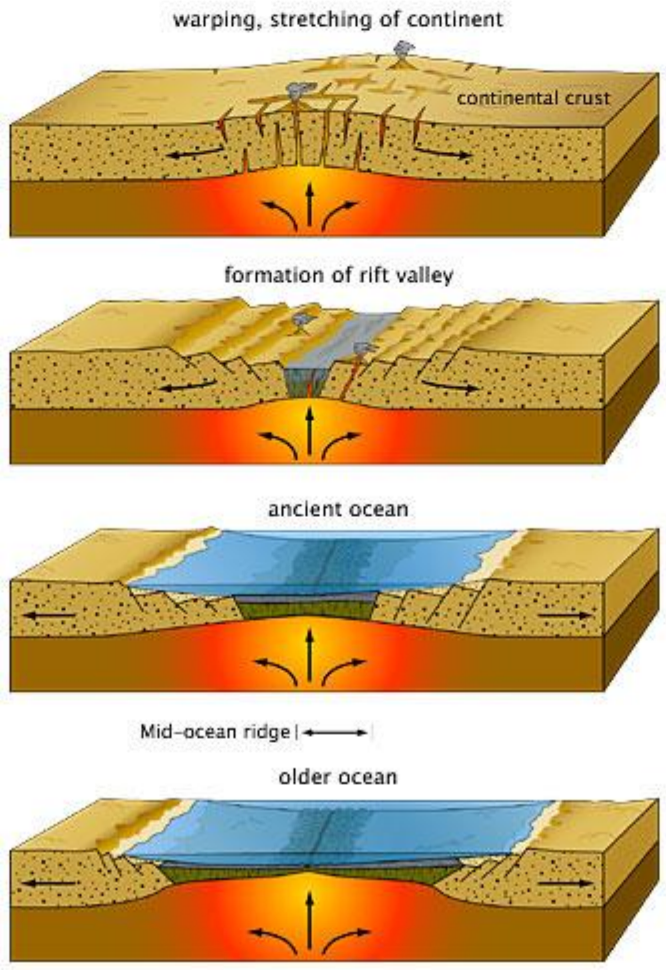
Plate Tectonics

First suggested based on evidence from cartography, geology and paleontology

Fully embraced after evidence from geophysical measurements



Accumulating Evidence



Fossil record

Magnetism and the Earth's magnetic field

Paleomagnetism

Magnetic reversals

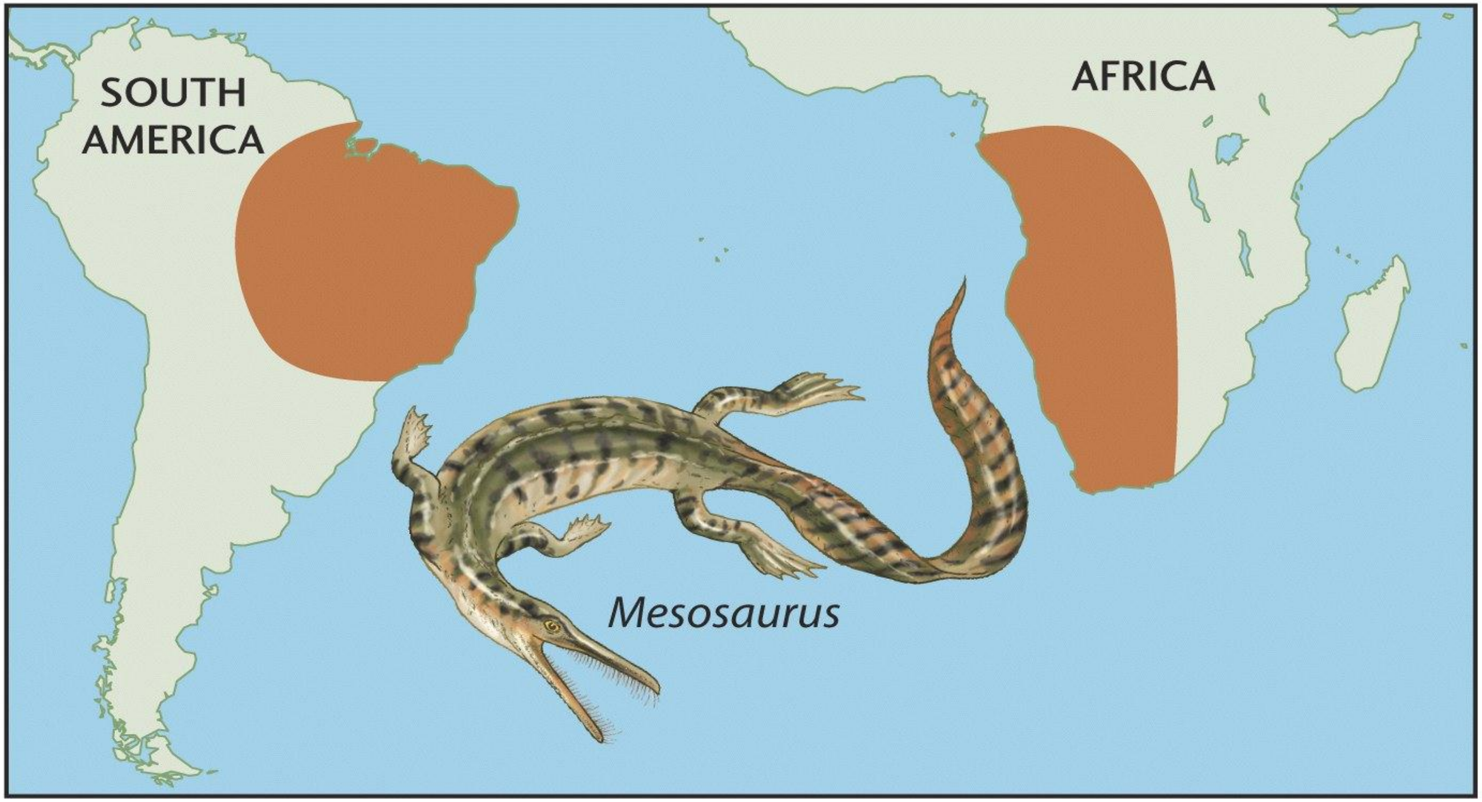
The topography of the seafloor

Age of the seafloor

Seafloor spreading

Fossil Record

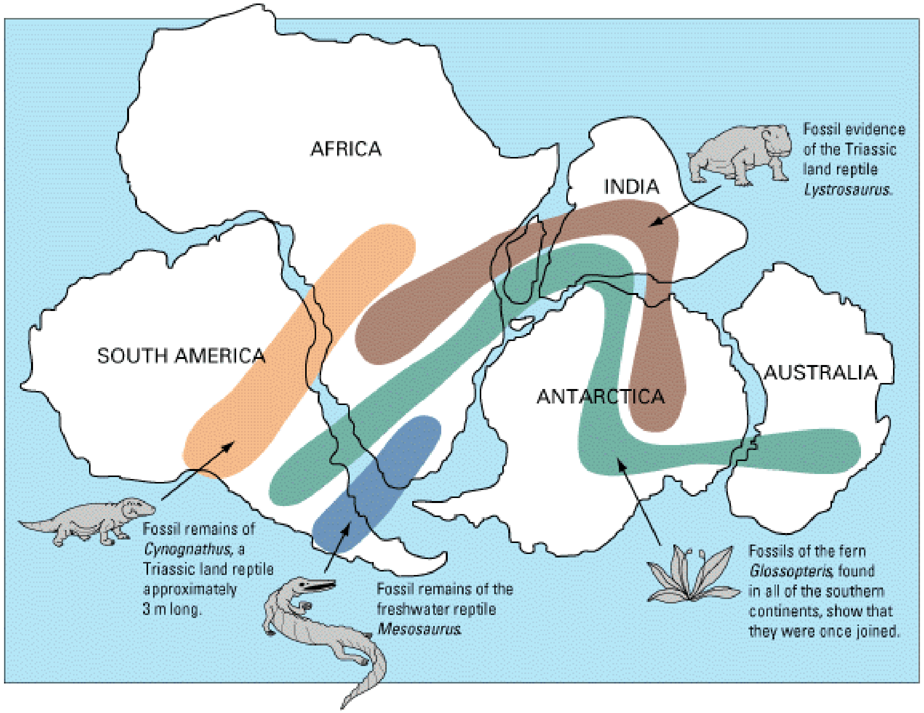
The fossil record had revealed that the geology and paleontology match on opposite sides of the Atlantic Ocean



Fossil Record

In fact, there are matching fossil records that span across all of the continents

Without plate tectonics, this is hard to explain



Magnetism

Most iron-bearing minerals are at least weakly magnetic

Each magnetic mineral has a **Curie temperature**, the temperature below which it remains magnetic

Above the Curie temperature the mineral is not magnetic

The Curie temperature varies from mineral to mineral, but it is always below the melting temperature of the mineral

Earth’s Magnetic Field

The Earth has a magnetic field

This why a compass points to the north

The simple presence of iron in the Earth’s core is not enough to account for the Earth’s magnetic field

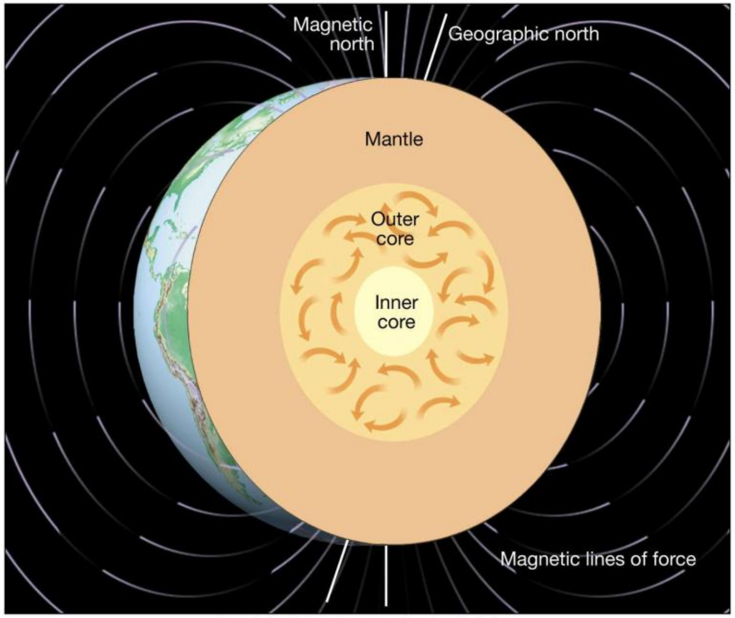
The high temperatures in the Earth’s core are far above the Curie temperature for any magnetic mineral

Earth’s Magnetic Field

It is believed that the Earth’s magnetic field originates in a layer called the outer core

The outer core is a metallic fluid consisting mainly of iron

This metallic fluid is in motion and the convection currents act like a giant dynamo, converting mechanical energy into magnetic energy

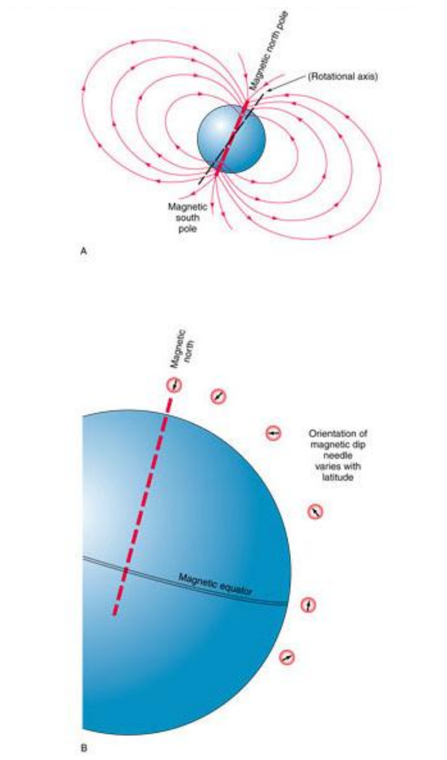


Paleomagnetism

A hot magma is not magnetic

As a magma cools and solidifies, the iron-bearing minerals (such as ferromagnesian silicates) crystallize

Eventually, the minerals cool below the Curie temperature and the iron-bearing minerals become magnetic

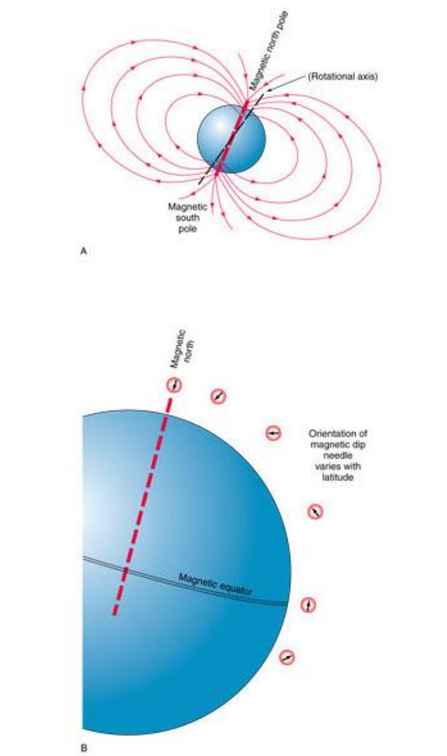


Paleomagnetism

Like tiny compass needles, these magnetic minerals align themselves parallel to the lines of force of the Earth's magnetic field

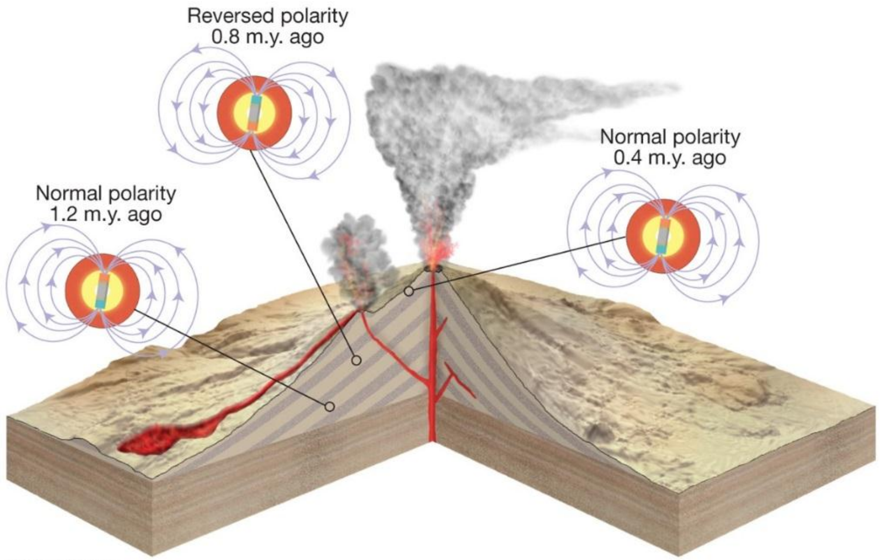
This remnant magnetism, which is also called paleomagnetism, points to the north pole like a sign post

But...



Magnetic Reversals

About a century ago, a sequence of lava flows were found in France where some of the flows had the north and south poles reversed

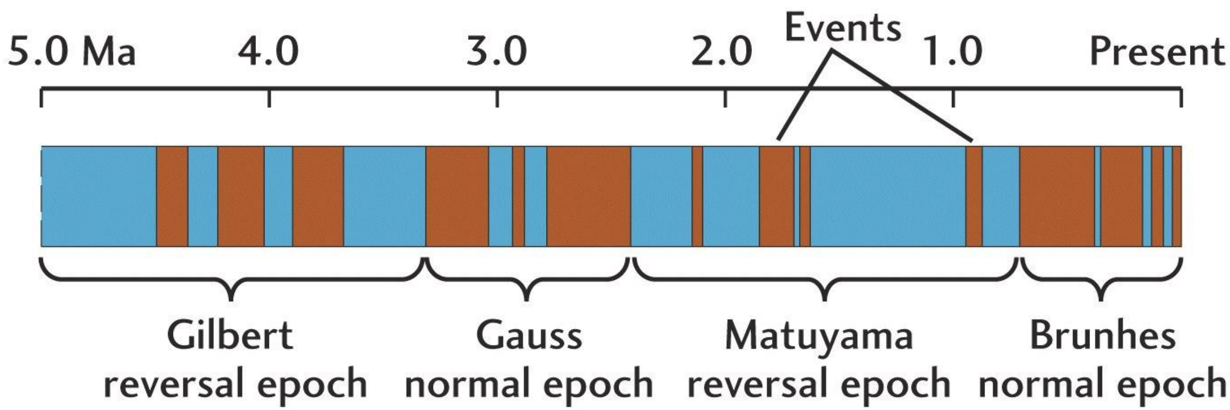


Therefore, the north pole and south pole must have repeatedly swapped positions

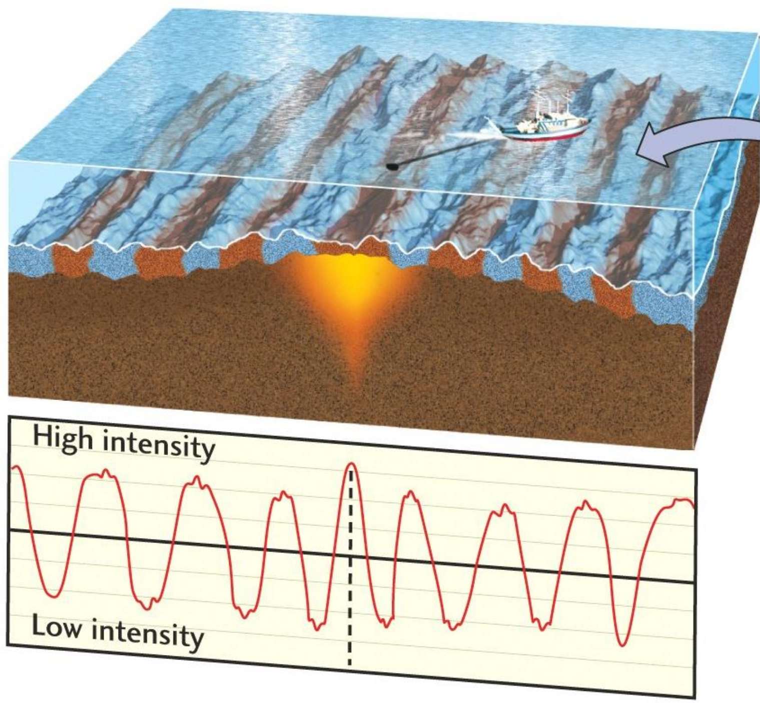
Magnetic Reversals

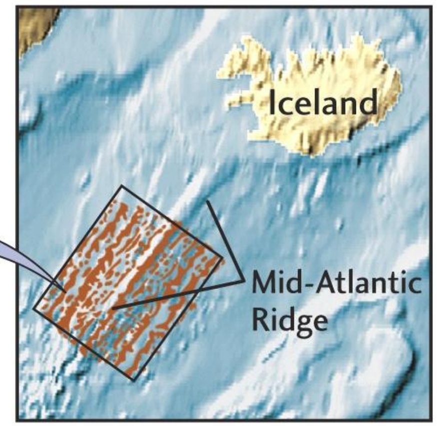
These magnetic reversals have occurred though out the history of the Earth

They occur on an irregular basis ranging in time from tens of thousands of years to millions of years



Magnetic Striping on Seafloor





In the 1950s, the Atlantic Ocean seafloor was found to consist of alternating stripes of normal and reversely magnetized rocks

Topography of the Atlantic

Also, in the 1950s, it was discovered that an underwater mountain range ran north-south in the middle of the Atlantic Ocean

The Mid-Atlantic Ridge rises as high as 2 kilometers above the abyssal plain

Atlantic Ocean Sea Floor

- In the 1960s, samples were collected from the Atlantic seafloor using special ships with drill rigs
- The rocks of the Atlantic seafloor were discovered to be basalt
- Basalt contains radioactive isotopes (such as U^{235}) which can be dated

Atlantic Ocean Sea Floor

It was discovered that the youngest rocks of the Atlantic Ocean seafloor are found along the mid-oceanic ridge

And that farther you move away from the ridge, the older the rocks become on either side of the ridge

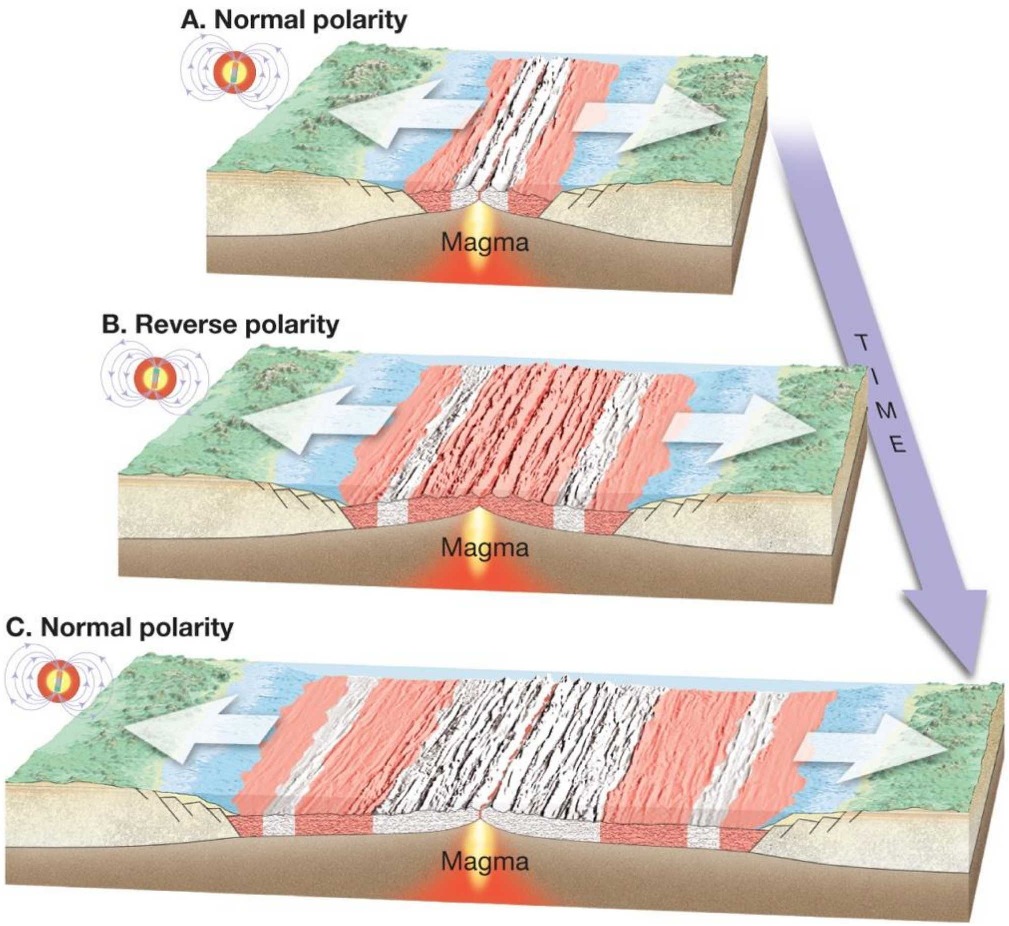
The oldest rocks are along the continental boundaries

Seafloor Spreading

By 1962, Harry Hess at Princeton University and a Naval Reserve Rear Admiral, and Robert S. Dietz had coined the term "seafloor spreading"

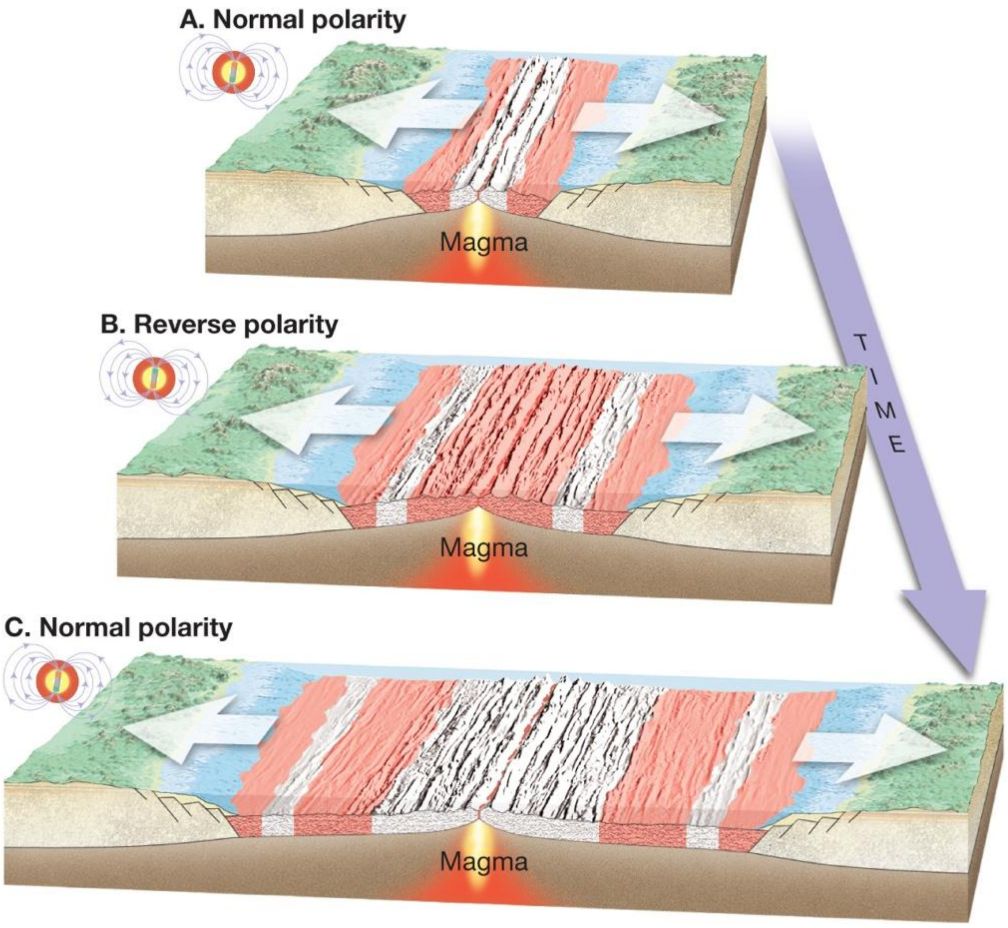
And in 1963, the team of F. J. Vine and D. H. Matthews (and independently L. W. Morley) proposed that seafloor spreading could explain the observed magnetic reversal striping on the Atlantic and Pacific seafloors

Seafloor Spreading



The Mid-Atlantic Ridge is a great fault zone where hot magma rises up, cools and solidifies, forming new basalt

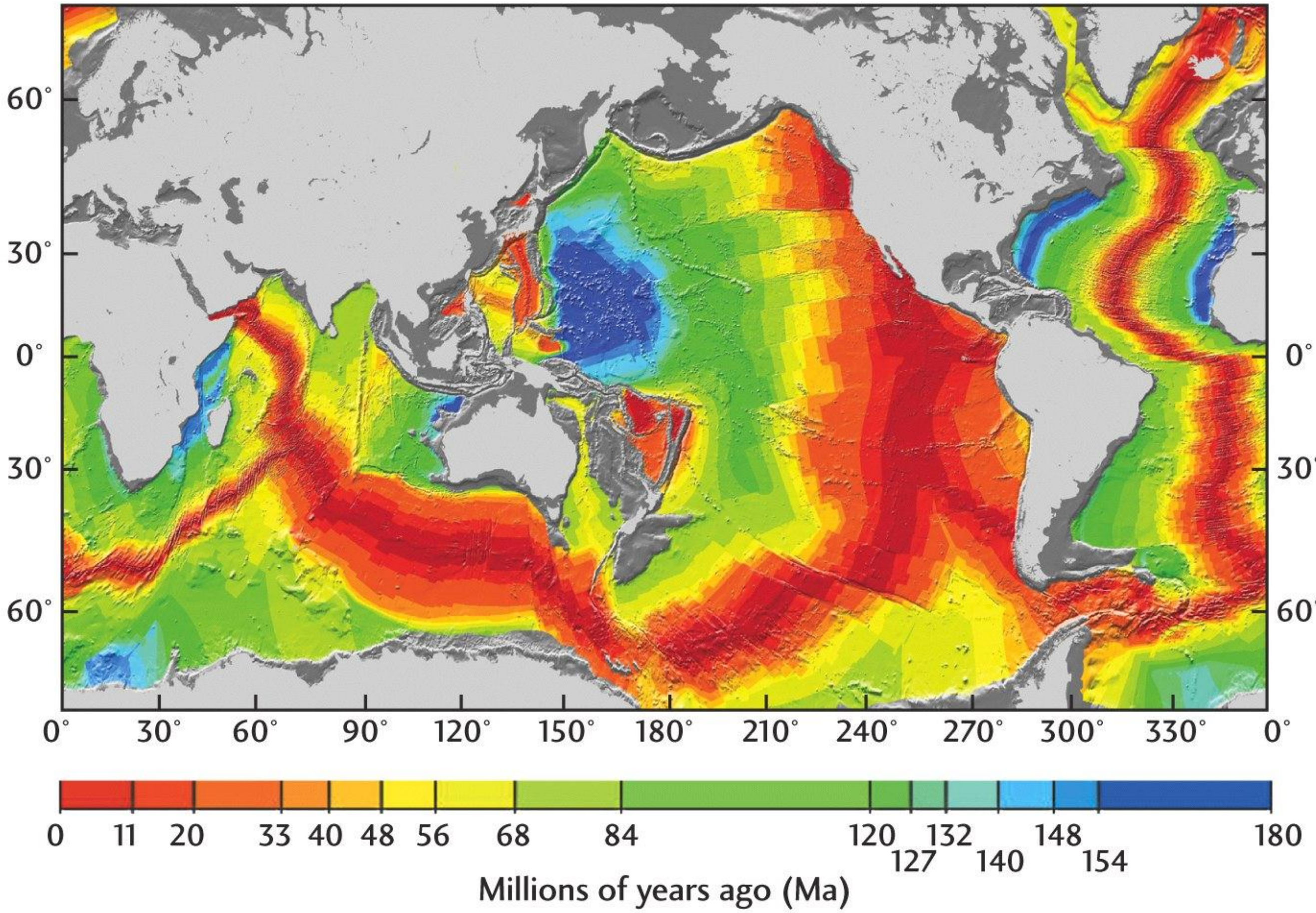
Seafloor Spreading



The iron minerals in the basalt become magnetized in the prevailing direction of the Earth's magnetic field

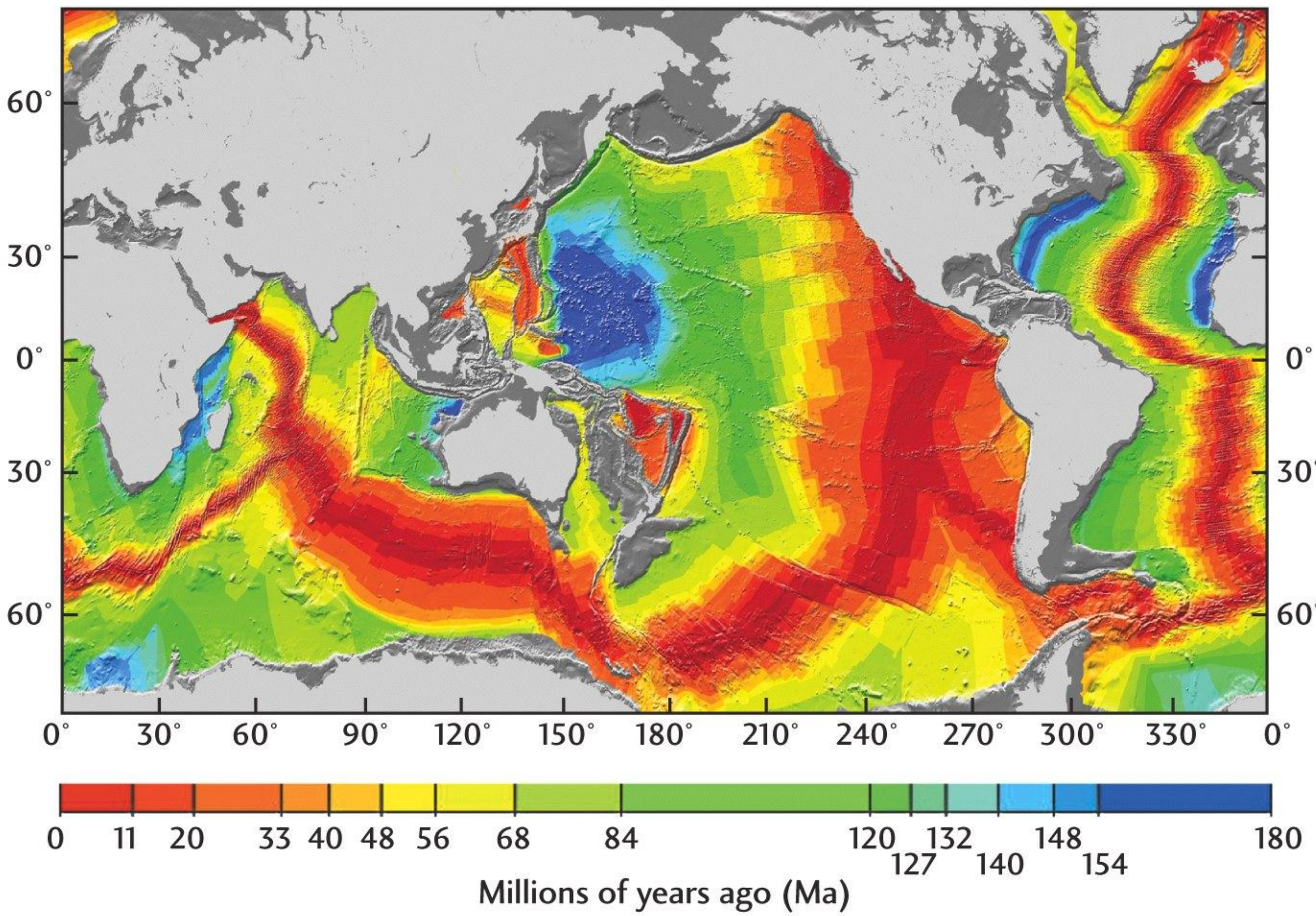
Seafloor Spreading

Mid-oceanic ridges and seafloor spreading was found to occur in all the oceans on Earth



Seafloor Spreading

Note that ALL of the oceans are younger than 180 million years old



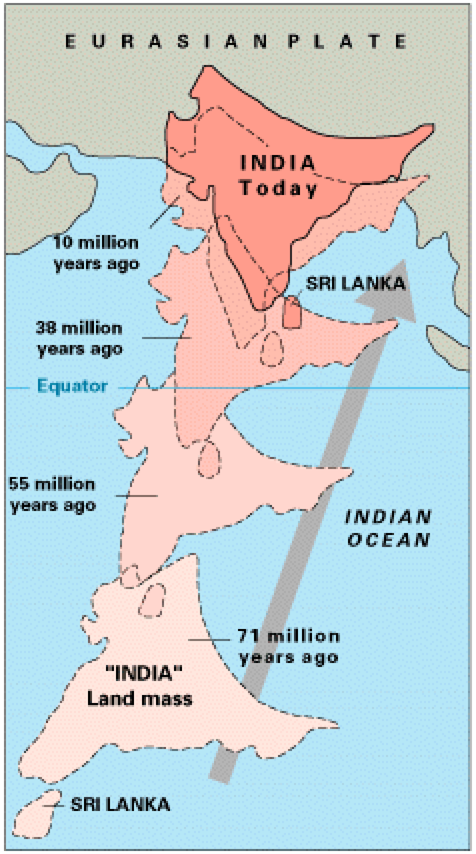
Plates that Move

In 1965 Wilson proposed the concept that the crust of the Earth is a mosaic of interacting plates – hence "plate tectonics"

These plates move relative to each other

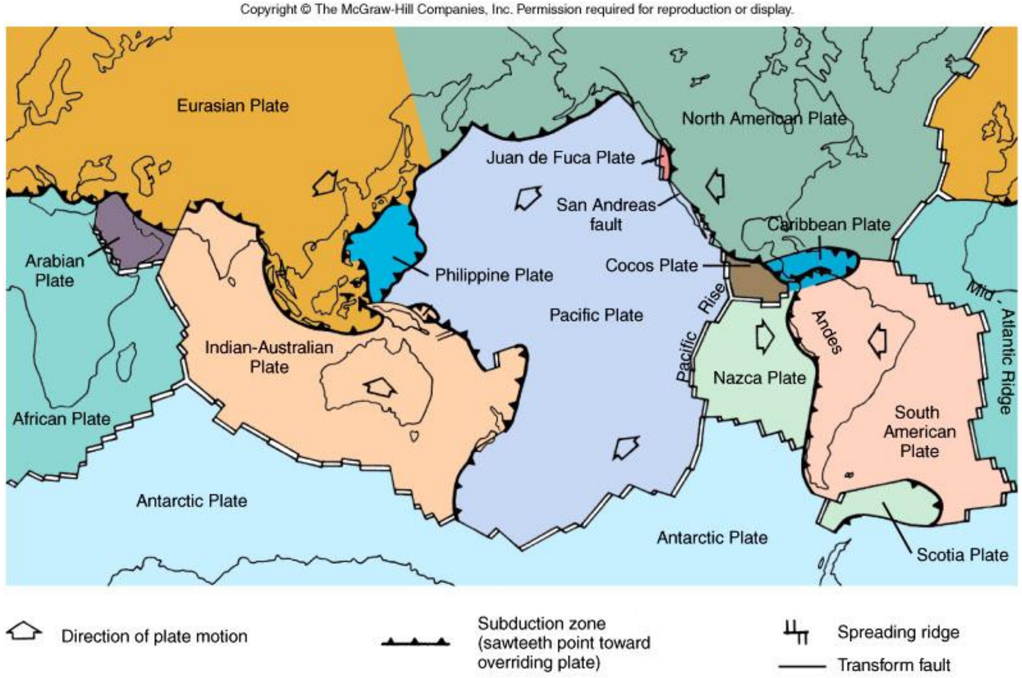
The continents ride on these plates

Geologic features, such as mountains, volcanoes and earthquakes occur along the plate boundaries

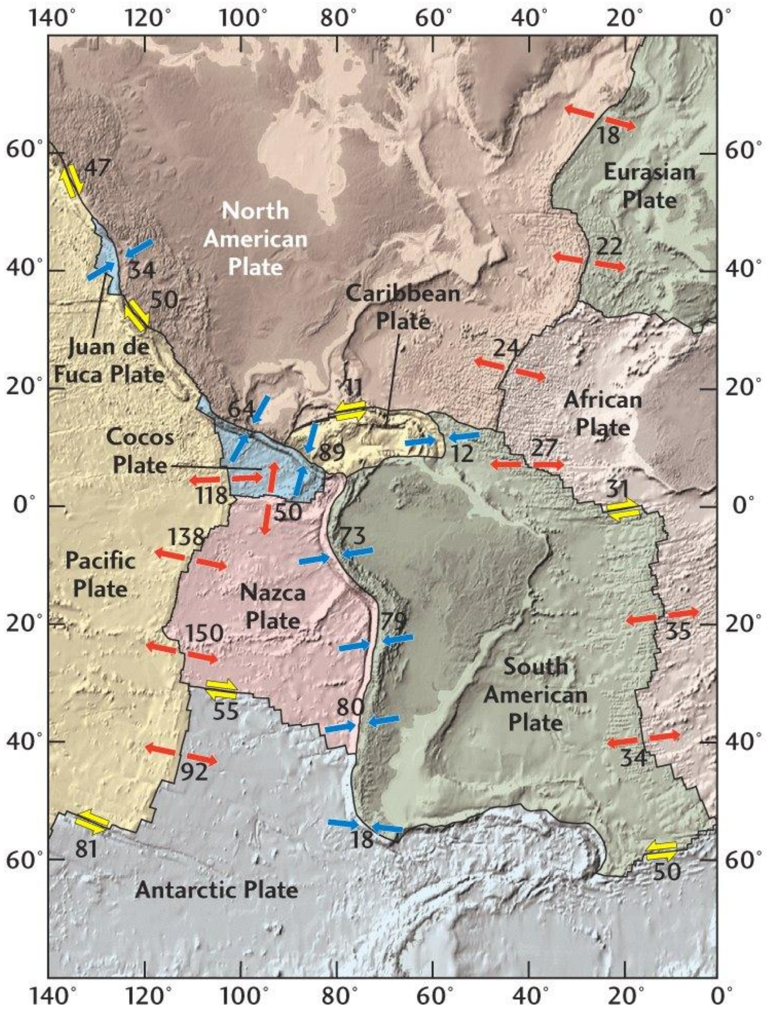


Plates that Move

Note that we are on the North American Plate



Plates that Move Very Slowly



Plates move at different speeds:

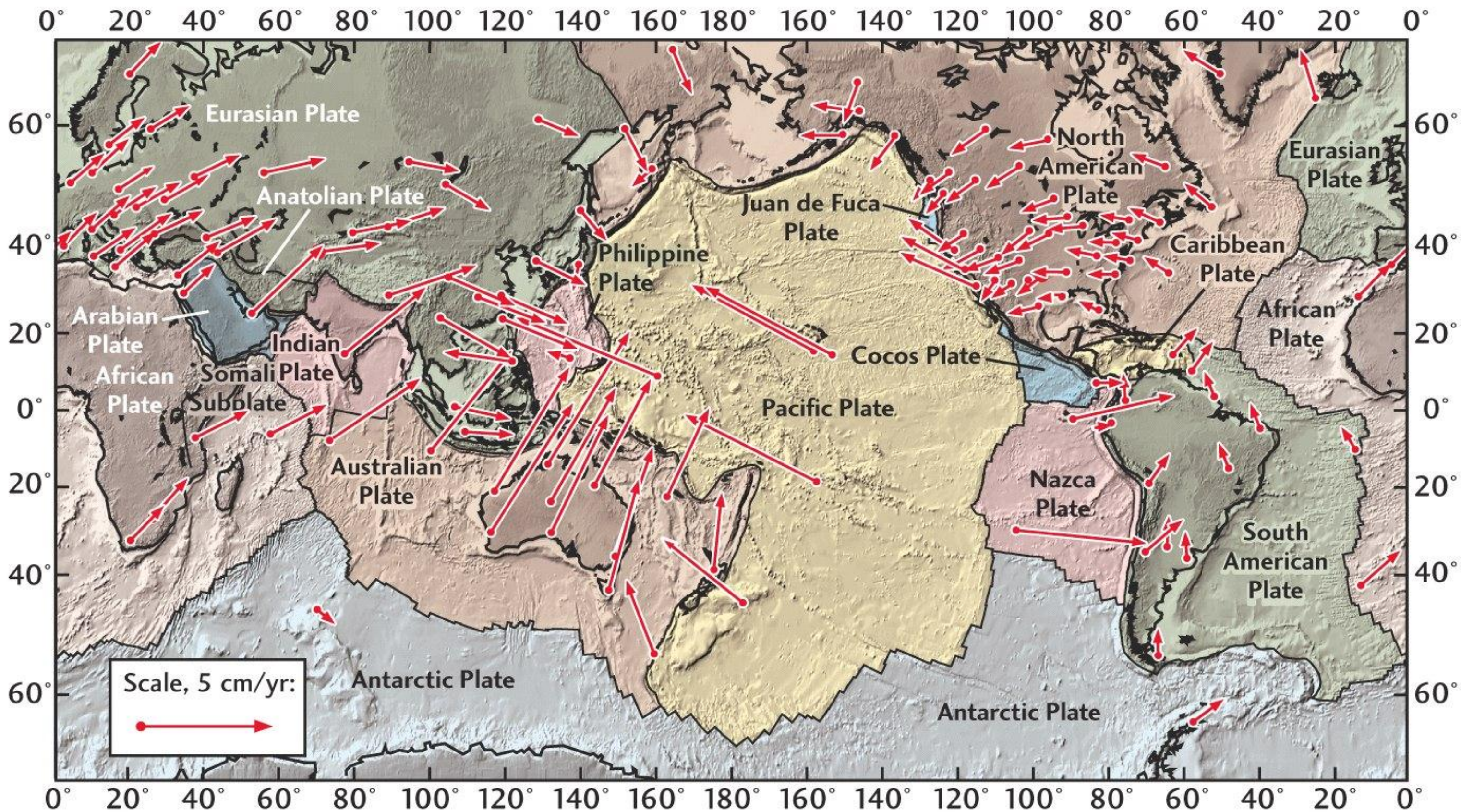
Measured using GPS and magnetic data

Most plates move from ~15 to ~100 millimeters per year (The Nazca Plate is moving at ~150 mm/year)

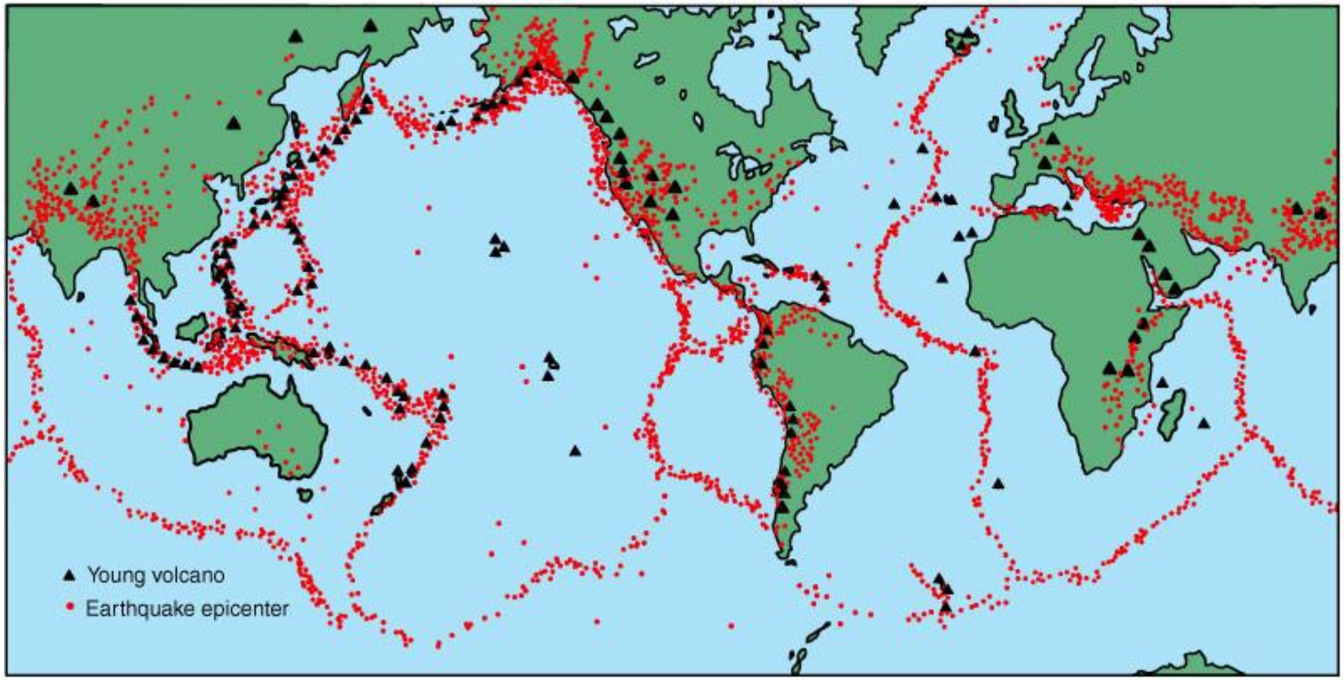
Or about the thickness of a fingernail in one day

Plates that Move Very Slowly

Plate movement is best described as chaotic

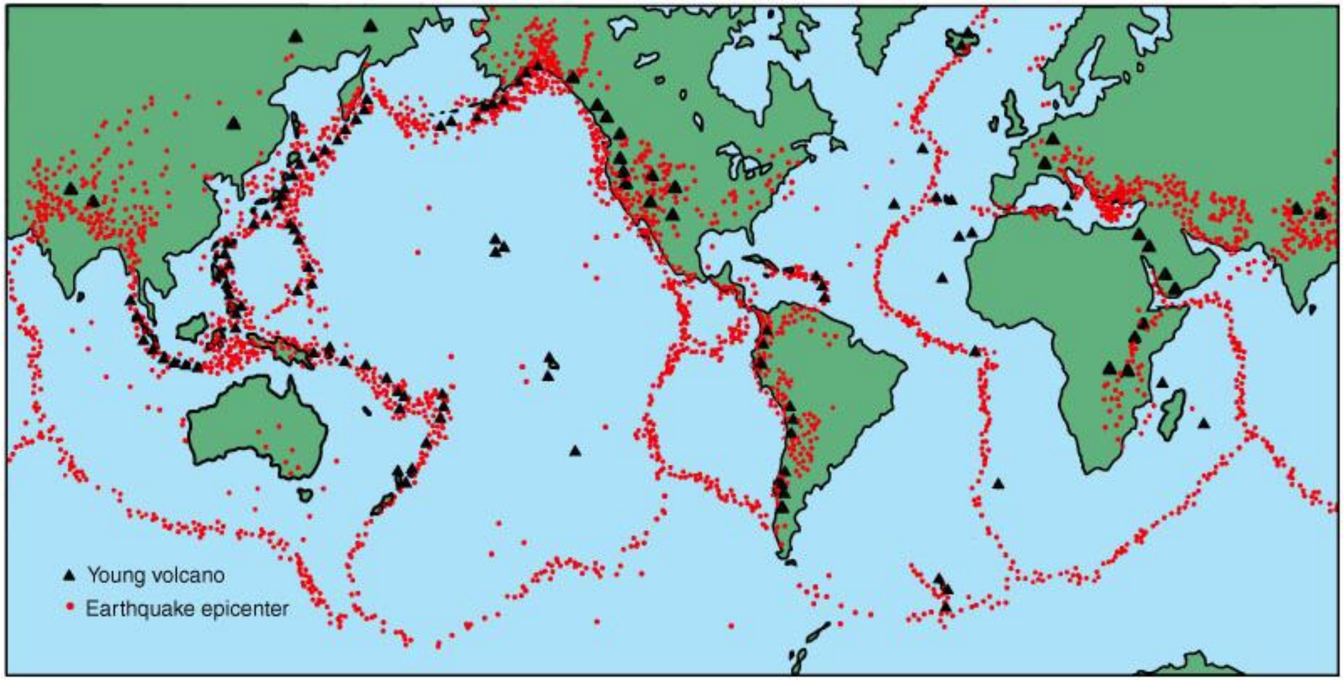


Plates that Move



The red dots show that most major earthquakes occur along plate boundaries

Plates that Move

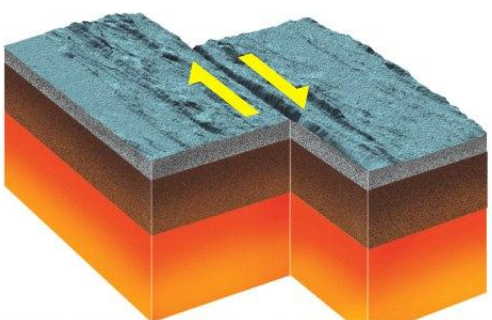


The black triangles show that volcanoes commonly occur along plate boundaries

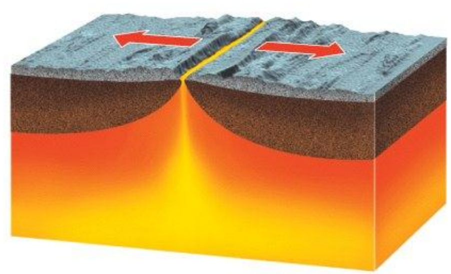
3 Types of Plate Boundaries

In 1965, the Canadian Geologist, J. Tuzo Wilson, proposes that tectonic plates interact in three different ways along their boundaries

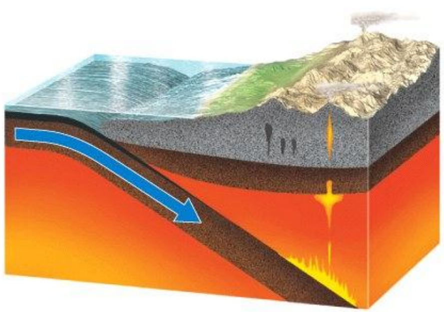
1. Transform **2. Divergent** **3. Convergent**



At transform-fault boundaries, plates slide horizontally past each other.



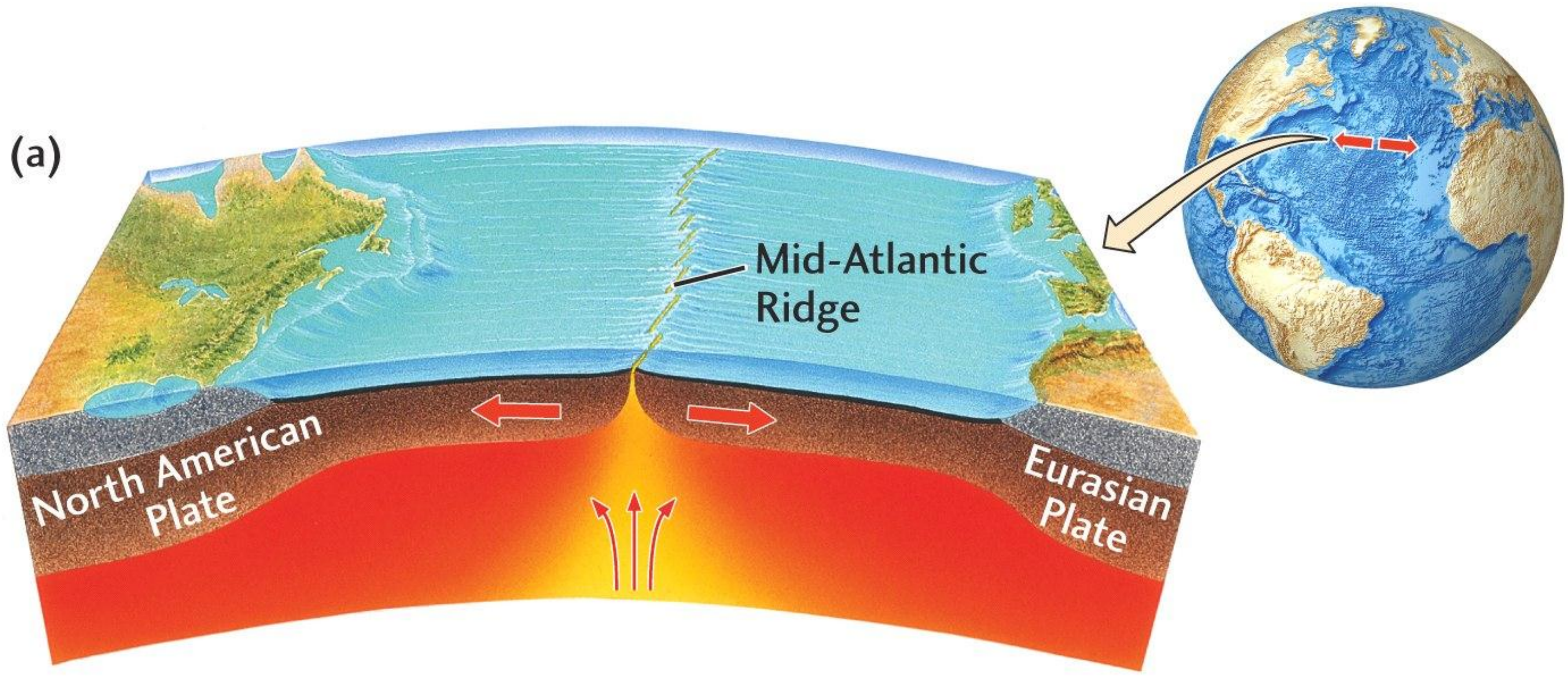
At divergent boundaries, plates move apart and create new lithosphere.



At convergent boundaries, plates collide and one is pulled into the mantle and recycled.

Divergent Plate Boundaries

Usually start within continents
Can grow to become ocean basin

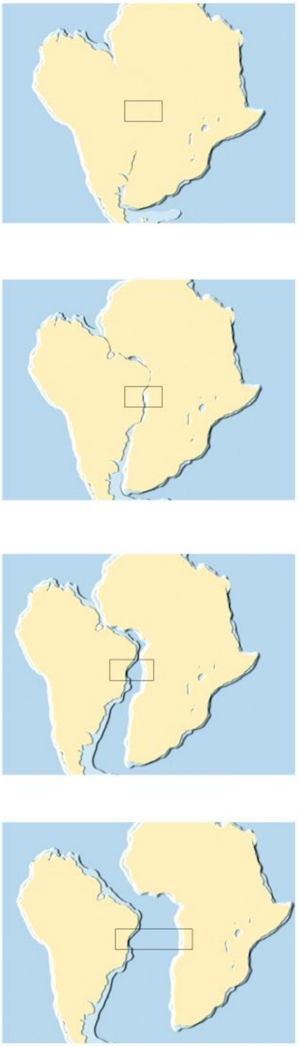


Birth of an Ocean Basin

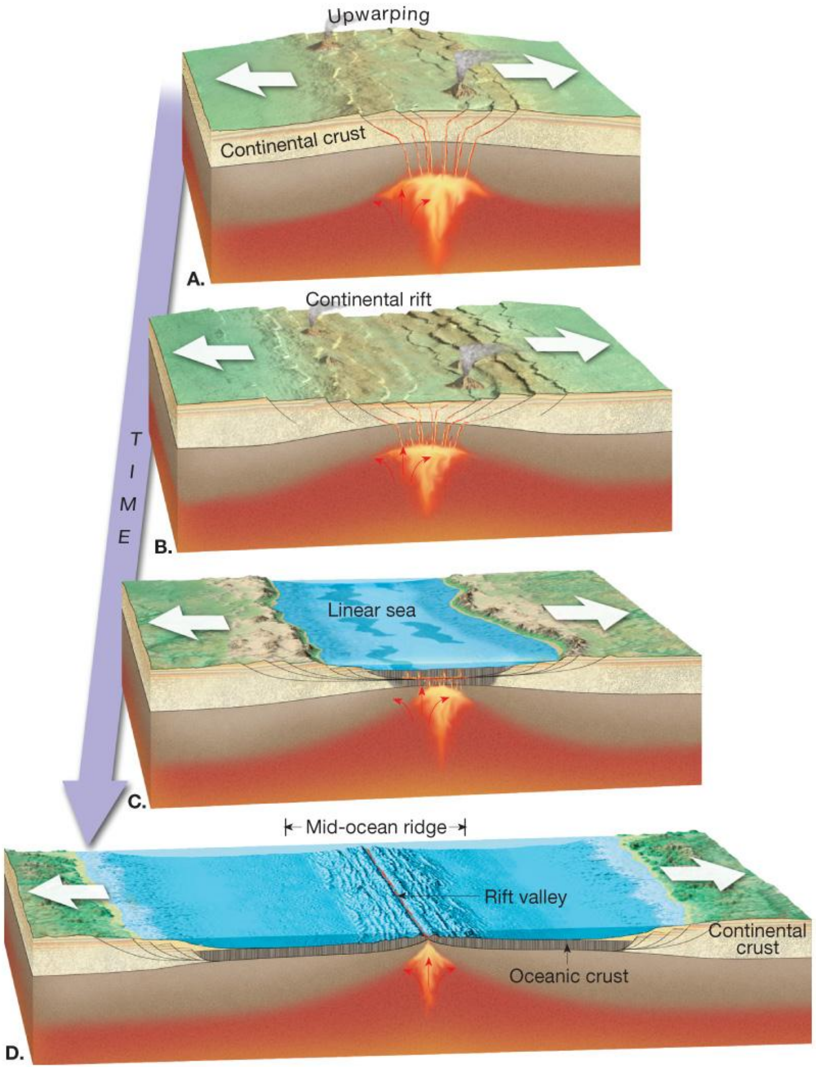
For example, the Atlantic Ocean was form when North and South America split away from Europe and Africa

(The original supercontinent is called “Pangaea” by geologists)

How does this process occur?

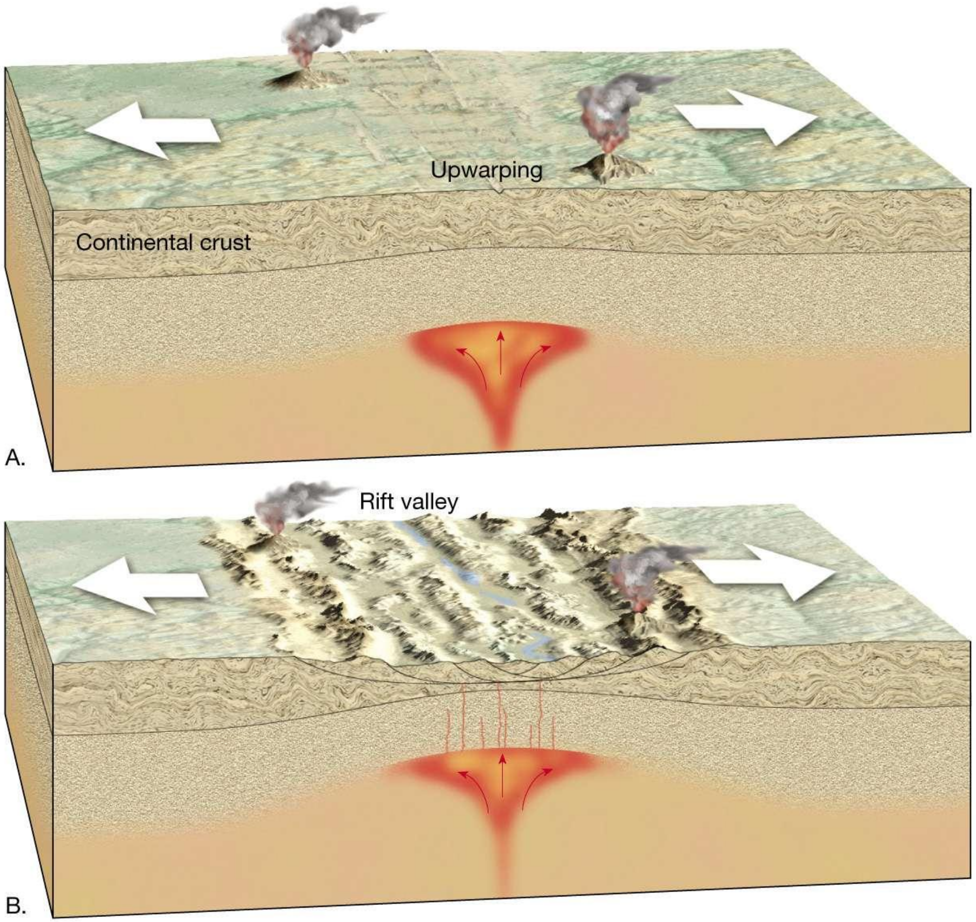


Divergent Plate Boundaries



New oceans are slowly created over millions and tens of millions of years along divergent plate boundaries

Divergent Plate Boundaries



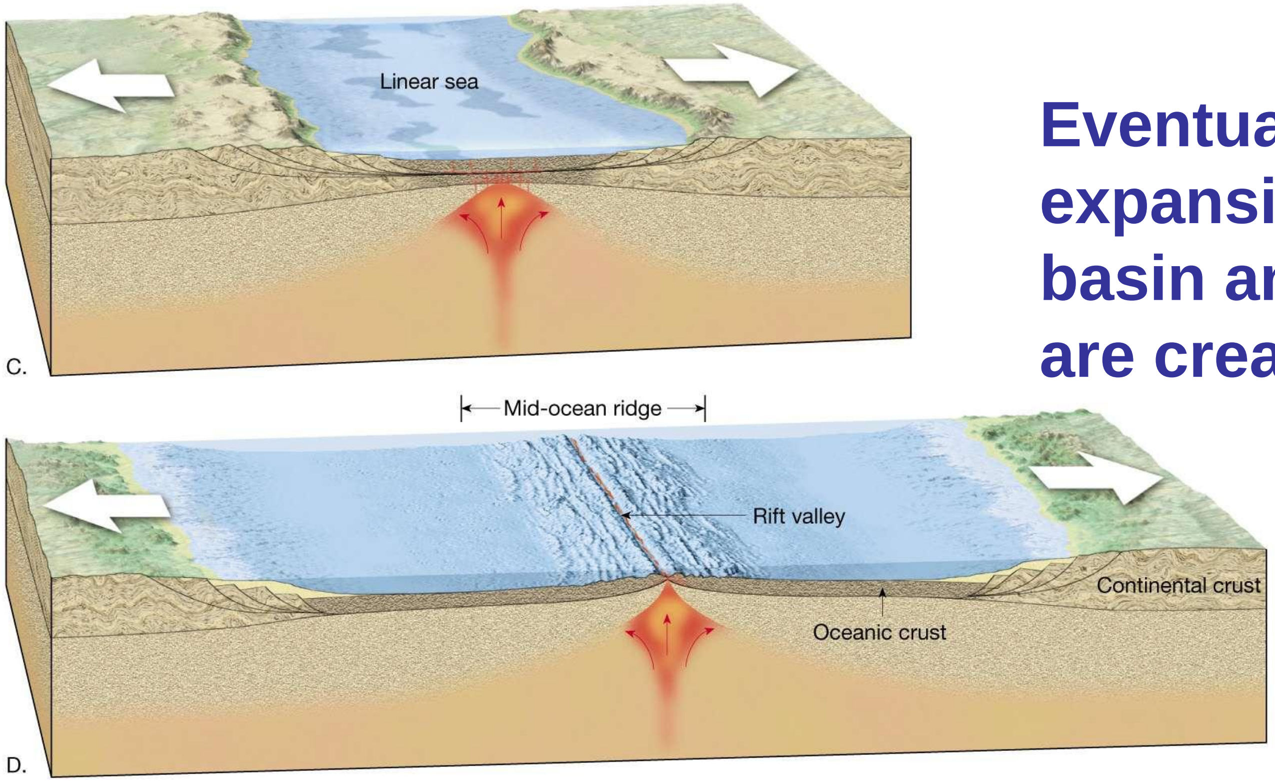
Rifting occurs where tensional forces thin the crust, magma ascends and volcanoes form

The crust is pulled apart, forming a valley

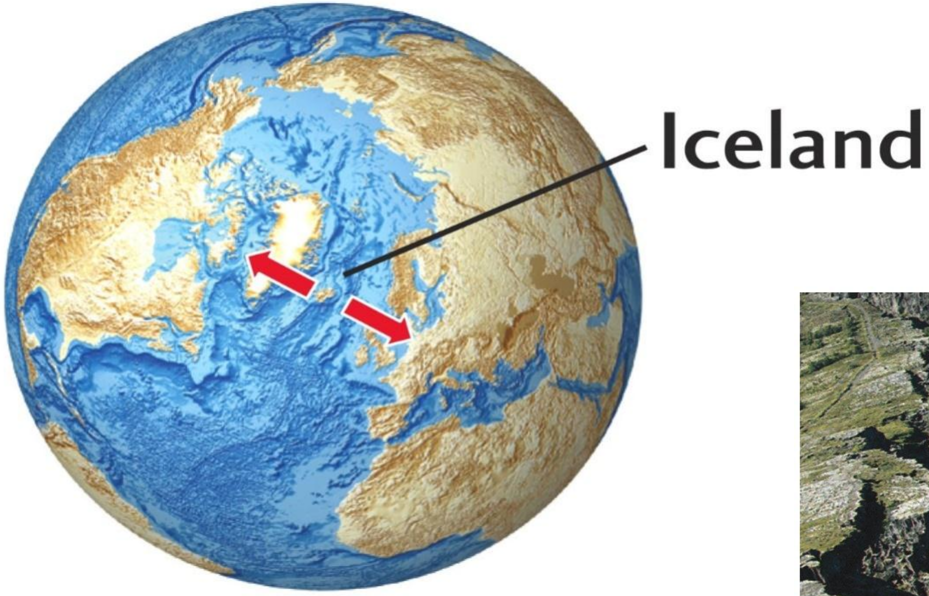
Divergent Plate Boundaries

As spreading continues, a long, narrow sea can form when ocean water slowly floods the valley

Eventually, an expansive ocean basin and ridge are created



Divergent Plate Boundaries



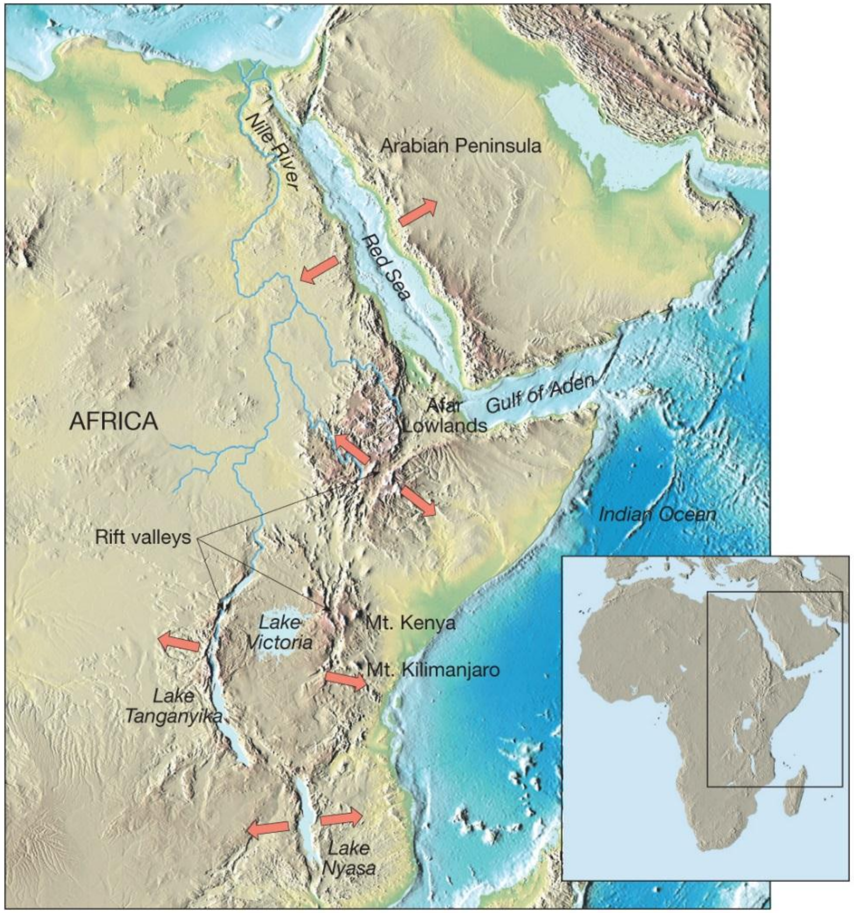
Can see the spreading on the island of Iceland, which sits on top of the mid-Atlantic Ridge

East African Rift Zone

The most interesting and spectacular divergent plate boundary currently occurring on the Earth’s land surface

The crater of Kilimanjaro with its famous concentric structure of nested calderas (photo courtesy: P. Nicholson)

A Future Ocean?



This rifting started about 20 million years ago

It is at the junction of three plates that are all pulling away from each other

The Red Sea formed about 5 million years ago along a rift

Is the Earth Expanding?

NO!

The Earth is maintaining a constant diameter

New crust is created at mid-oceanic ridges

The old crust sinks back into the Earth at subduction zones along convergent plate boundaries

Convergent Boundaries

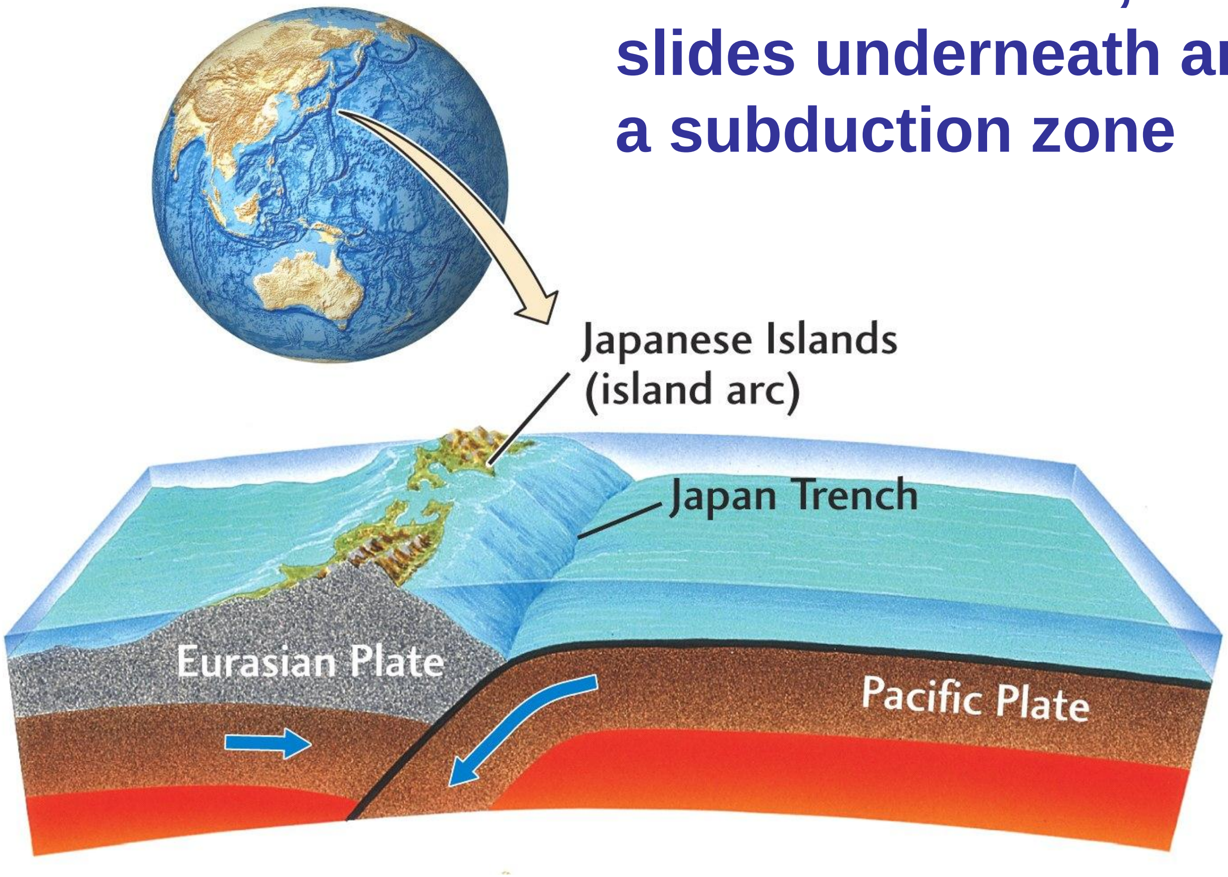
There are three types of convergent plate boundaries

Oceanic–Oceanic	Japanese Islands
Oceanic–Continent	Andes Mountains
Continent–Continent	Himalaya Mountains

We will look at each type

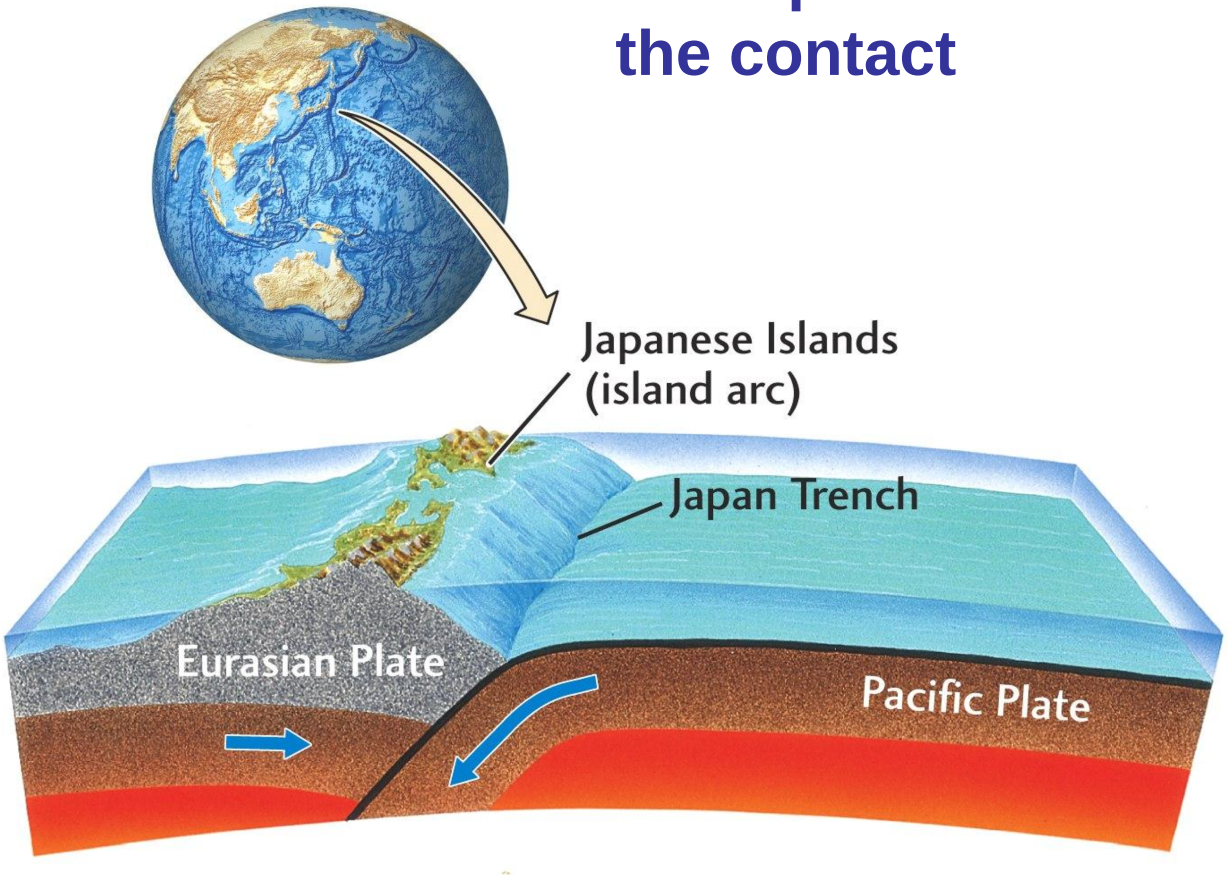
Oceanic - Oceanic

Under the ocean, one plate slides underneath another at a subduction zone



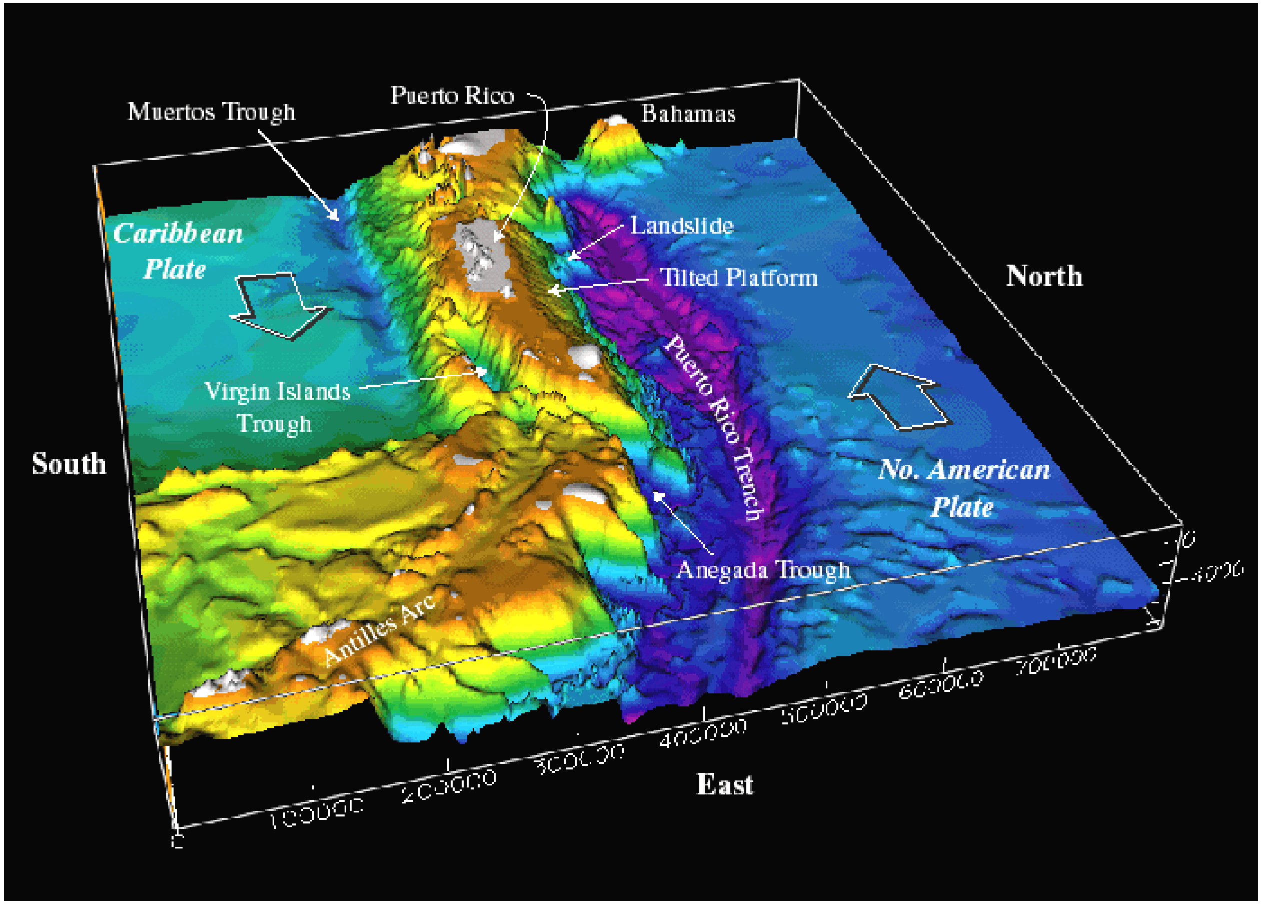
Oceanic - Oceanic

A deep trench forms along the contact



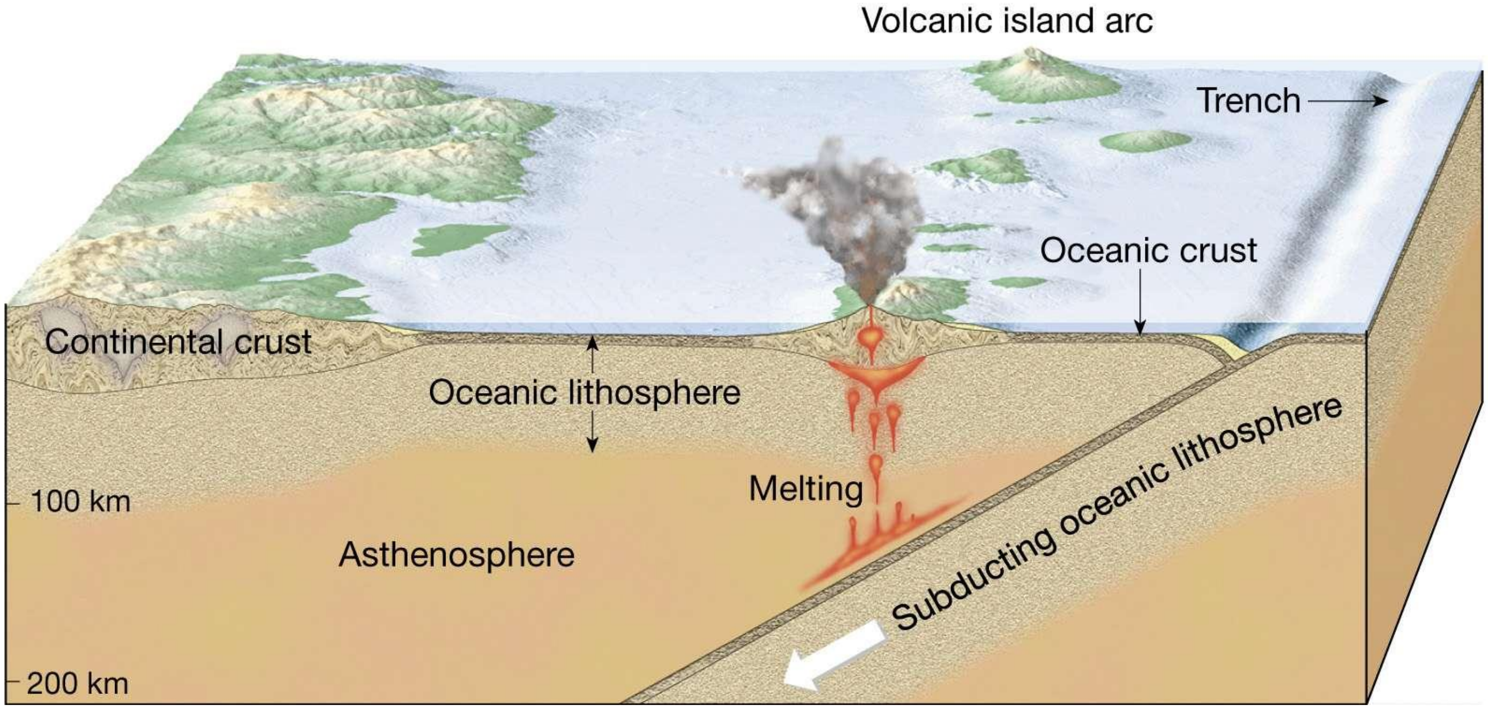
Why?

Because deep trenches form where an oceanic plate is being subducted under a continental plate



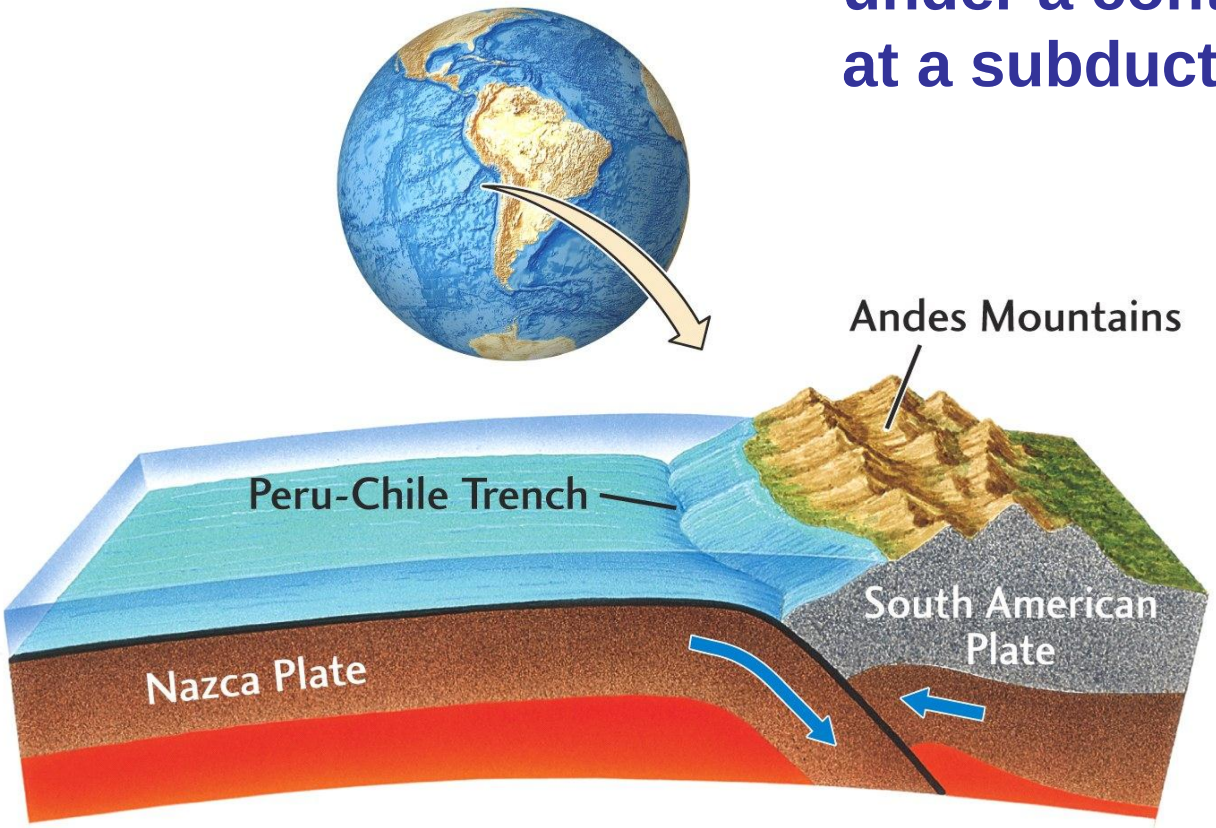
Oceanic - Oceanic

Magma wells up along the subduction zone creating volcanoes, which can form volcanic island arcs such as the Japanese Islands



Oceanic - Continent

An oceanic plate slides under a continental plate at a subduction zone



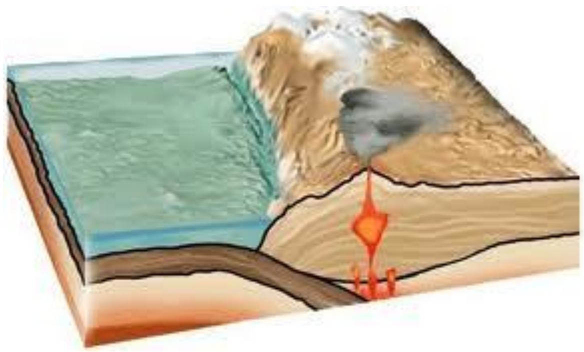
Oceanic - Continent

The relative densities of the oceanic crust versus the continental crust are important:

The continental crust is lighter and has an average density of 2.8 g/cm^3

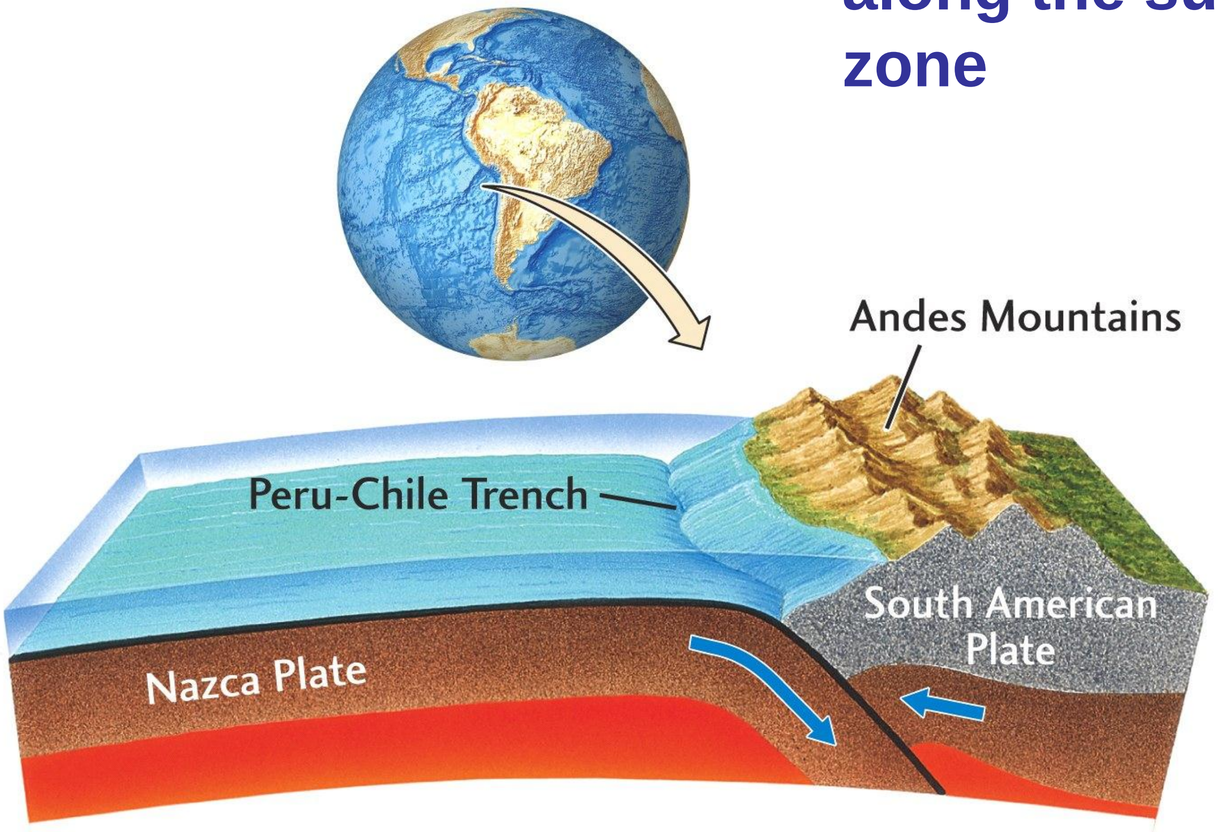
The oceanic crust is heavier and has an average density 3.2 g/cm^3

Therefore, the heavier oceanic crust sinks beneath the more buoyant, lighter continental crust



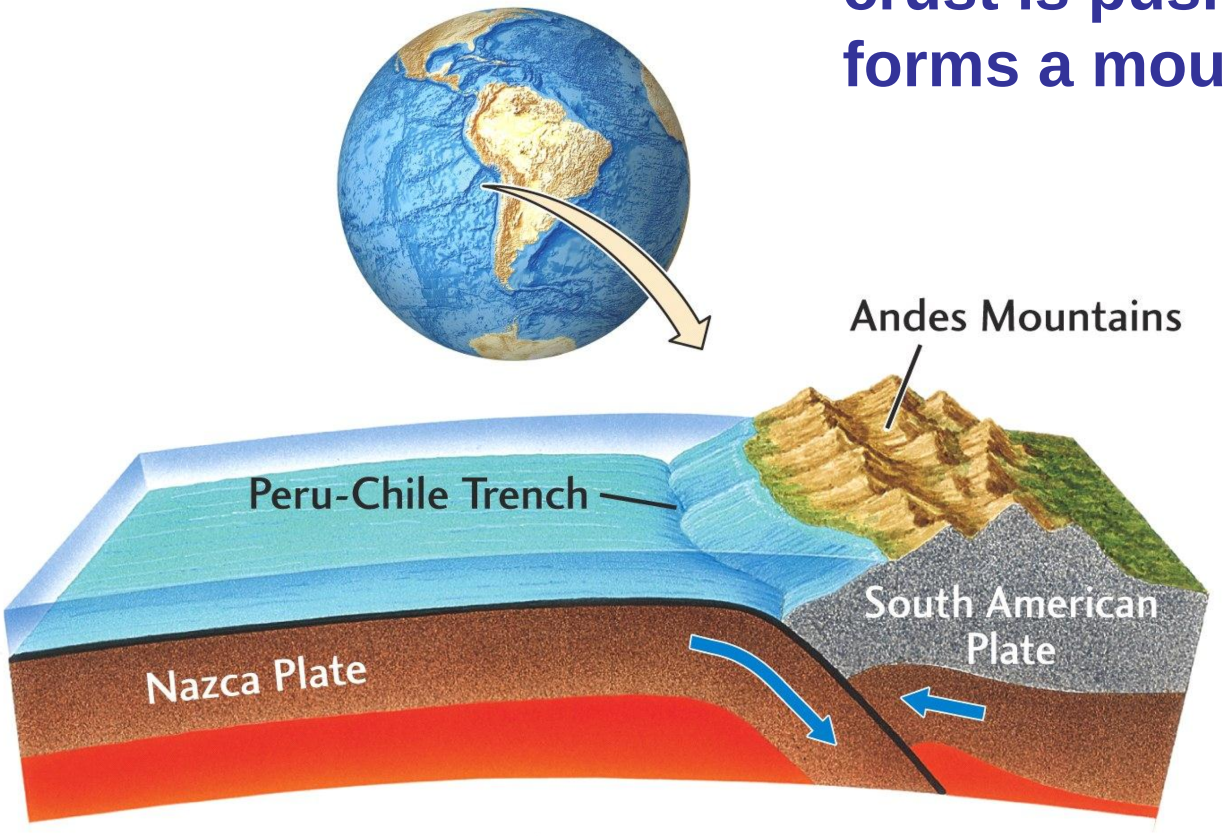
Oceanic - Continent

A deep trench forms along the subduction zone



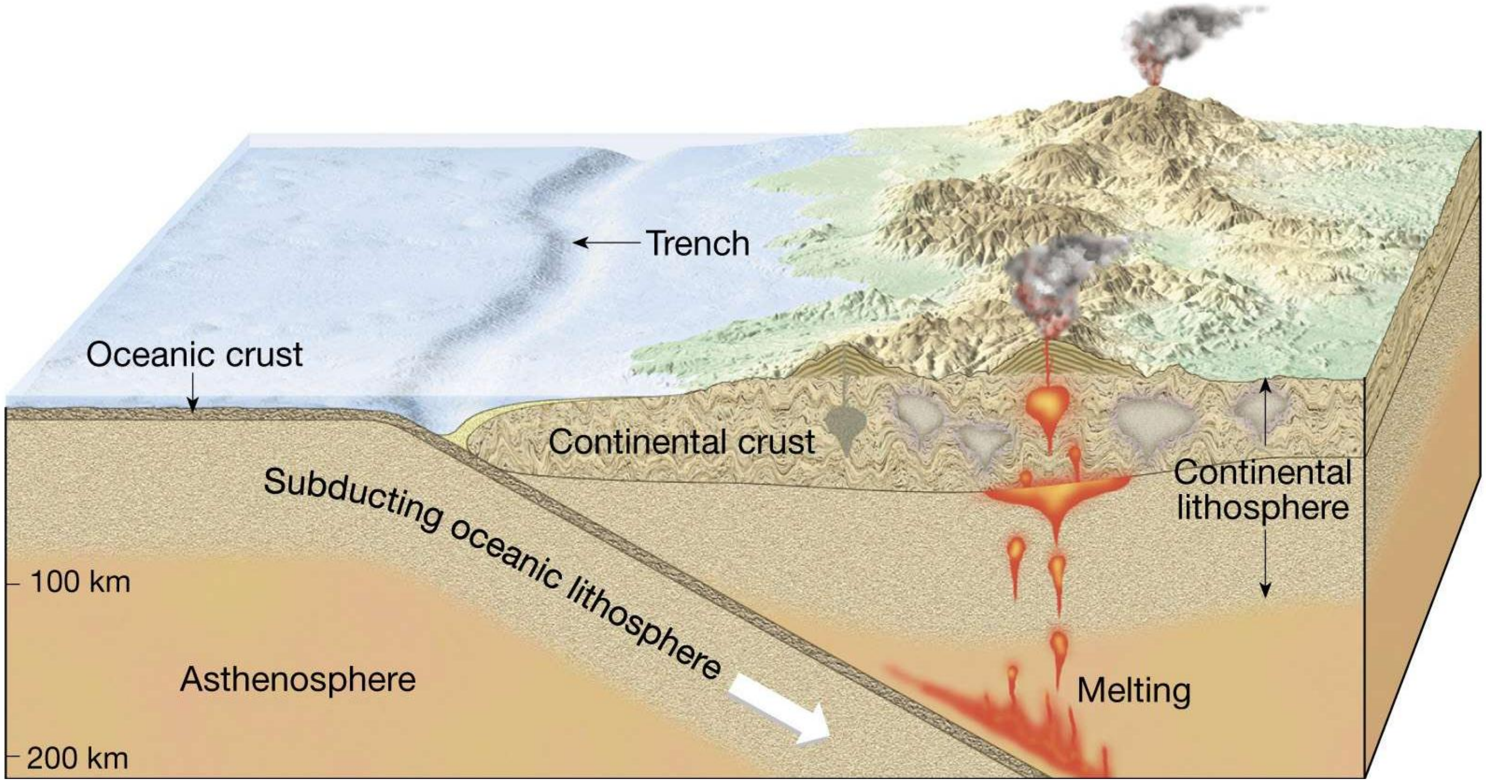
Oceanic - Continent

The lighter continental crust is pushed up and forms a mountain range

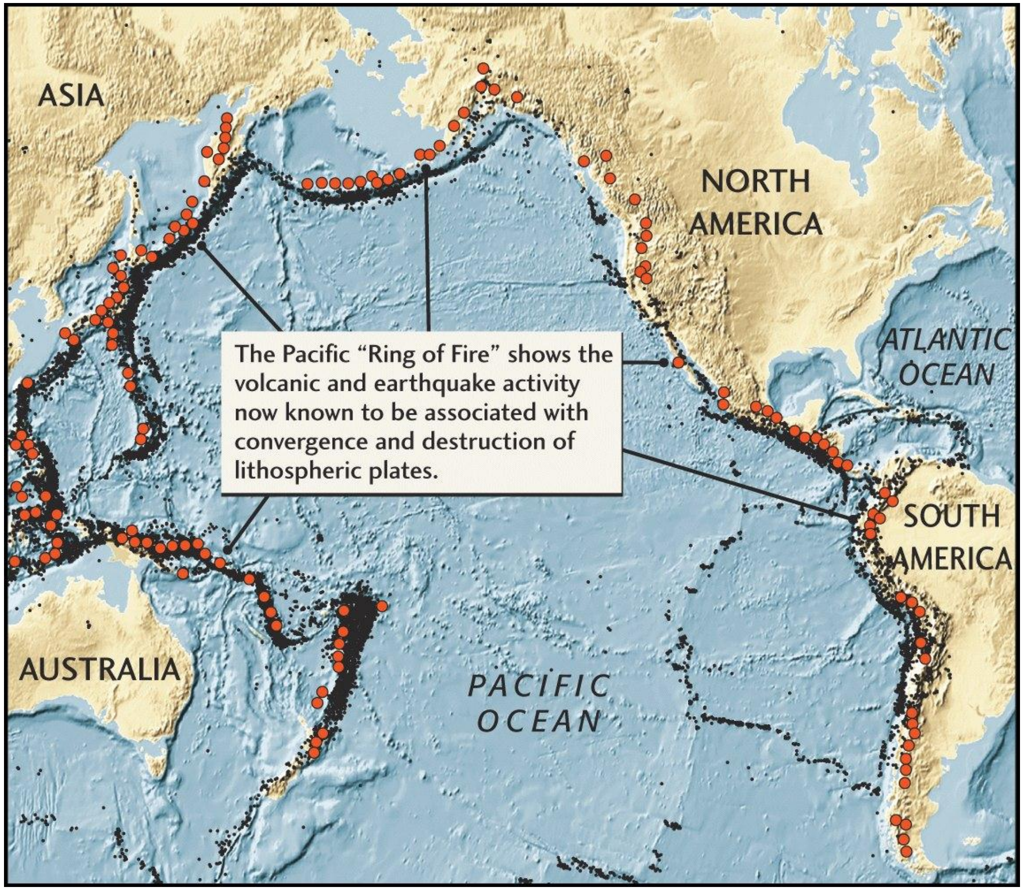


Oceanic - Continent

Magma wells up along the subduction zone creating volcanoes, which adds to the size of the mountains and creates a continental volcanic arc



Pacific Ring of Fire



Andes Mountains

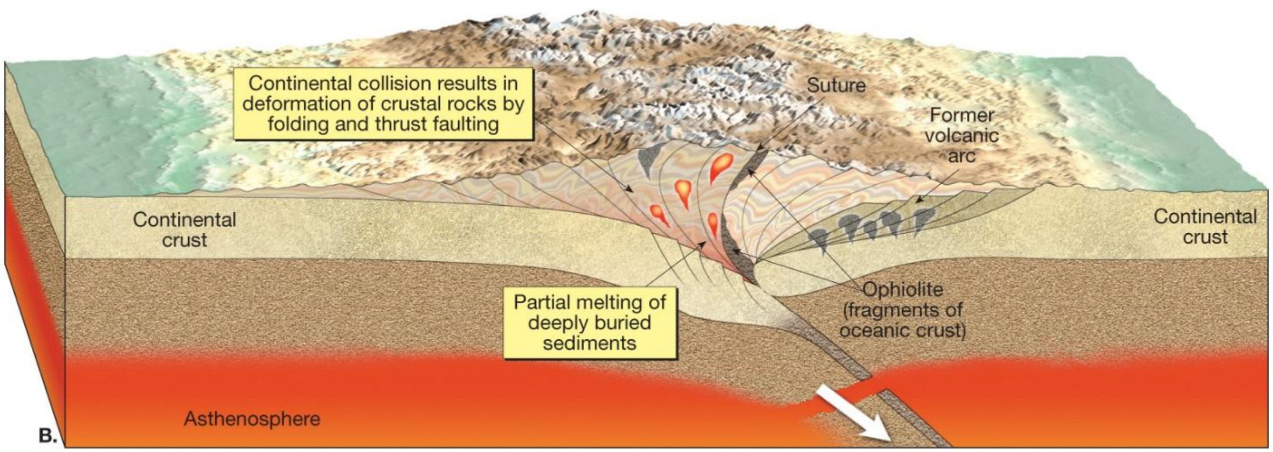
The Andes Mountains stretch over 5500 miles along the Pacific side of South America

When Continents Collide

When two continental plates collide, one does not sink beneath the other

Rather they smash together

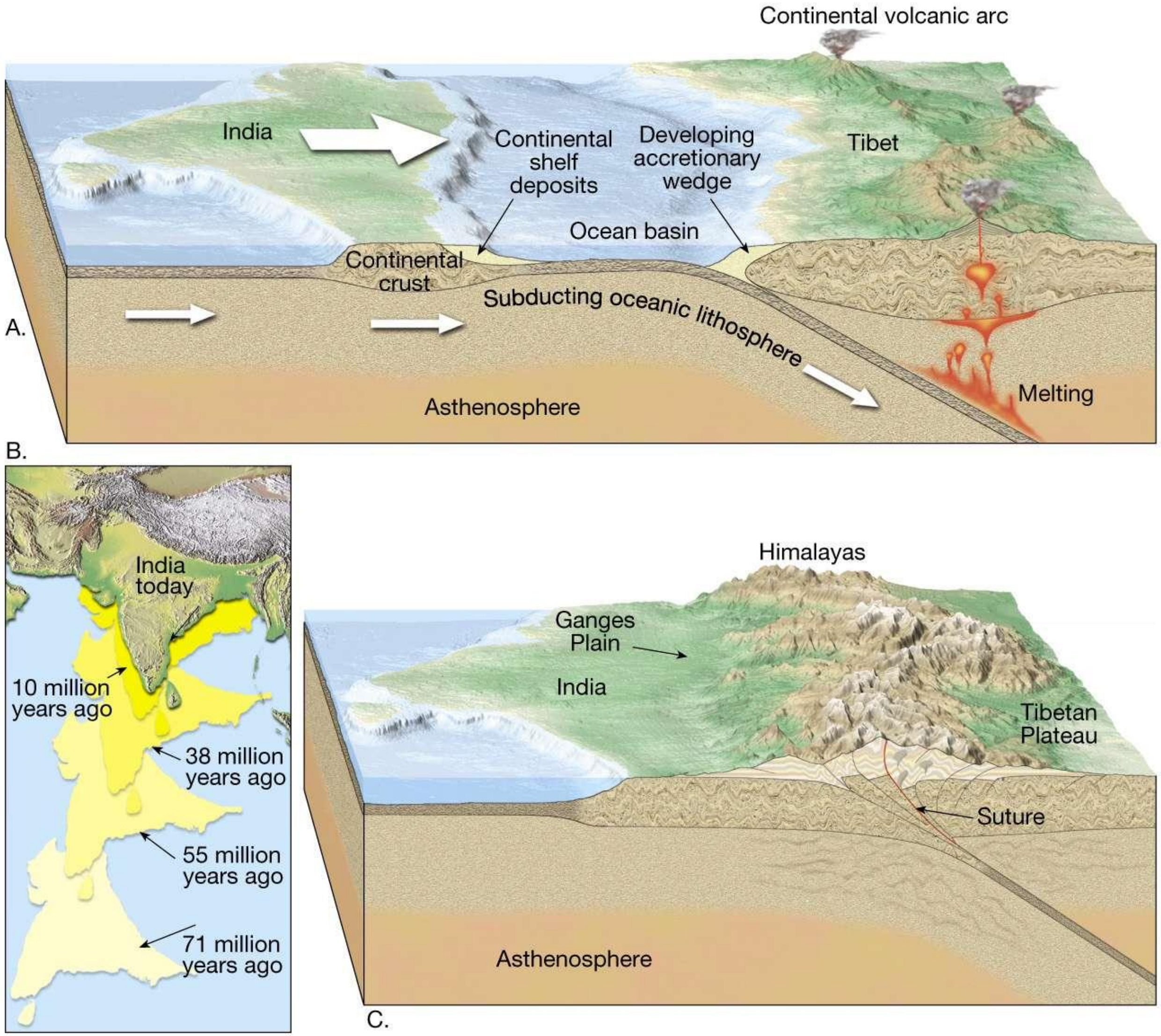
The continental crust is deformed and uplifted, creating mountains such as Mount Everest



Why?

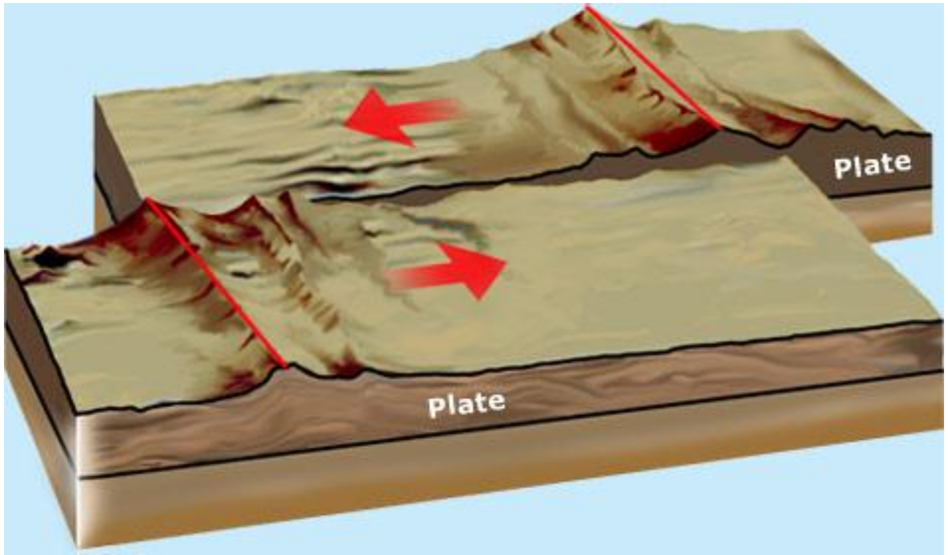
Why is Mount Everest 29,035 feet (8850 meters) high?

Because the continent of India collided with the continent of Asia


Continental volcanic arc
India
Continental shelf deposits
Developing accretionary wedge
Tibet
Ocean basin
Continental crust
Subducting oceanic lithosphere
A.
Melting
Asthenosphere
B.
India today
10 million years ago
38 million years ago
55 million years ago
71 million years ago
Himalayas
Ganges Plain
India
Tibetan Plateau
Suture
Asthenosphere
C.

Transform Plate Boundaries

A transform fault plate boundary occurs when two plate slide past each other in opposite directions



Transform Plate Boundaries

The most famous example is the San Andreas Fault Zone in California

The portion of California in blue is heading northwest to Alaska

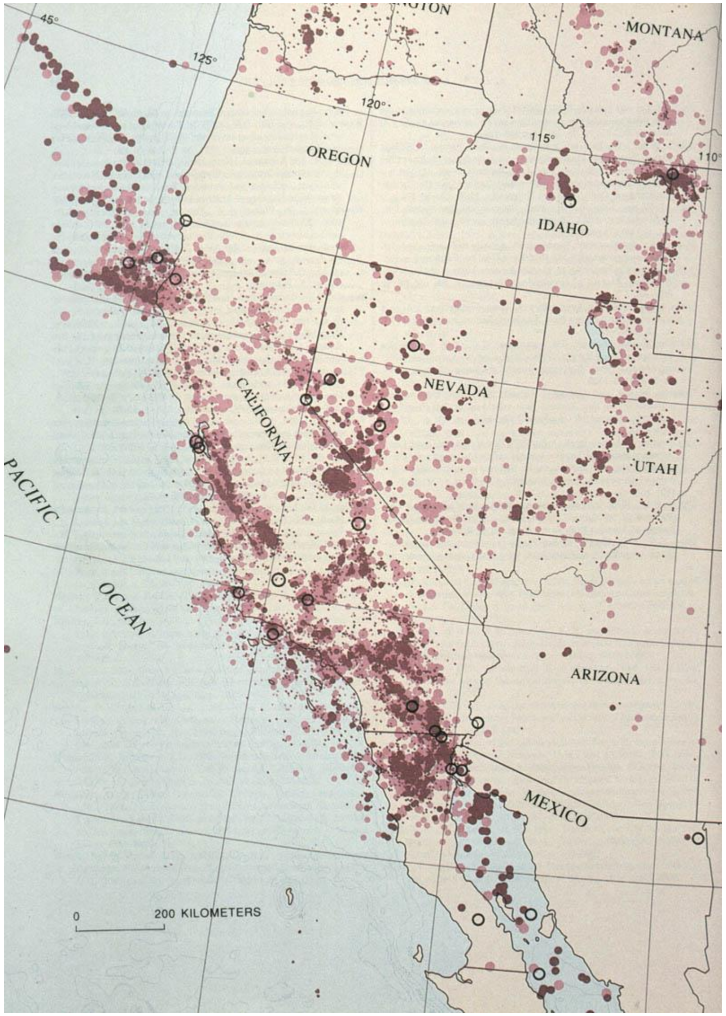
This is the most studied fault zone in the world

San Andreas Fault Earthquakes

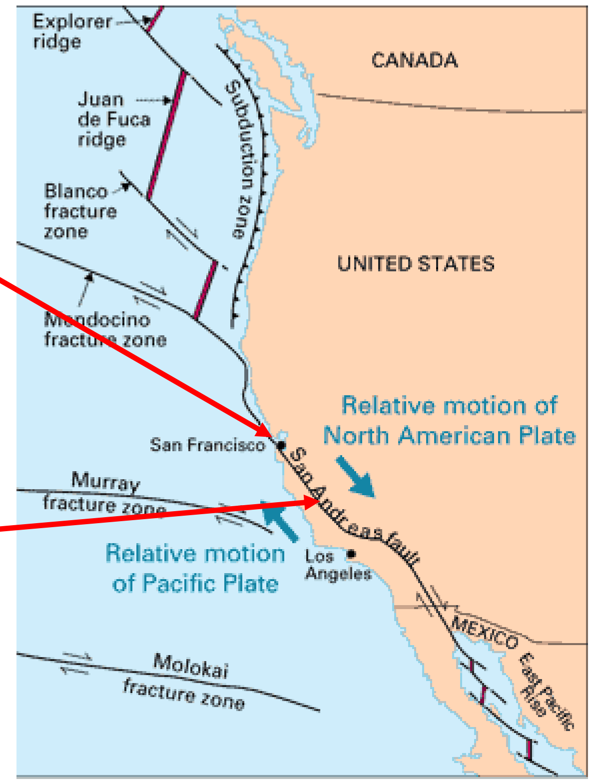
Each red dot marks an earthquake

Notice how many have occurred in California

They are not kidding when they talk about the "BIG ONE"



San Andreas Fault Zone



References

1. Plate Tectonics: An Insider's History of the Modern Theory by Naomi Oreskes
2. Plate Tectonics: Continental Drift and Mountain Building by Wolfgang Frisch, Martin Meschede, Ronald C. Blakey