

Continental Drift, Paleomagnetism, and Plate Tectonics

History – Continental Drift

Continental Drift – Alfred Wegener (1915)

He was the first strong proponent of continental drift

He published *The Origin of Continents and Oceans*

He proposed that a supercontinent named Pangaea (pan = all, gaea = Earth) split into the present continents

Wegener's Evidence for Continental Drift

Fit of the continents

Fossil evidence

Rock type and structural similarities

Paleoclimatic evidence

Fit of the continents

Wegener noticed that coastlines on opposite sides of oceans fit like a puzzle.

Fit of the Continents... Like doing a puzzle

In addition to the puzzle pieces fitting together, the picture must be continuous as well

Alfred Wegener wrote:

“It is just as if we were to refit the torn pieces of a newspaper by matching their edges and then check whether the lines of print run smoothly across. If they do, there is nothing left but to conclude that the pieces were in fact joined in this way.”

Fossil evidence

Identical fossils of Mesozoic life are found on widely separated landmasses.

Some type of land connection is needed to explain this.

Rock type and structural similarities

If the continents were once joined, the rocks on both continents should match in age and type... they do!

Rocks and mountain belts of identical age can be matched across the continents

Example: 2.2-billion-year-old igneous rock in Brazil and Africa.

Example: Matching mountain ranges across the Atlantic.

Paleoclimatic (“ancient climate”) evidence

Rocks show that near the end of the Paleozoic era (about 300 million years ago):

Ice sheets covered large areas of South America, Africa, Australia, India, and Antarctica.

Tropical swamps existed in United States, Europe, and Siberia.

Fossils of tree ferns that only grow in tropics

Trees did not have growth rings (because little change in temperature in the tropics).

Reconstructing Pangea puts today's northern landmasses at the equator, and the southern landmasses at the south pole.

The Rejection of Wegener's Ideas

Although Wegener seemed to have strong evidence there were problems

Lack of a driving mechanism for moving continents
Incorrectly suggested the gravitational force between the moon and sun pulled the continents apart
Incorrectly suggested that continents pushed and broke through the ocean crust
Theory was too radical for the times
Strong opposition to the hypothesis from all areas of the scientific community
From 1924 to 1930 he faced constant opposition
He died on the Greenland ice sheet in 1930

Renewed interest came from paleomagnetism

Magnetized minerals (magnetite) in rocks Show the direction to Earth's magnetic poles
When heated above the Curie point, magnetic minerals lose their magnetism.
When they cool, below their Curie point (585°C for magnetite), they become magnetized in the direction of the existing magnetic field of the Earth.
When they solidify, the magnetism is "frozen" in that position.

Curie Point Demonstrations

<http://www.youtube.com/watch?v=X8ZHQQUusGo>

<http://www.youtube.com/watch?v=haVX24hOwOI>

http://www.youtube.com/watch?v=YzwGzJm41_o

Magnetized minerals also provide a means of determining their latitude of origin

The inclination or dip of the mineral also aligns with the magnetic field

At the poles, they dip straight down.

At the equator, they are horizontal.

Earth's magnetic field consists of lines of force much like a giant bar magnet.

Polar wandering

The Earth's magnetic field is not stable

Currently 12 degrees off from the true poles

500 million years ago, the magnetic poles were much further away.

Since then, they have migrated to their current position in a long sweeping arc.

Example: Magnetic information from rocks on North America and Europe

The results were not the same; got 2 different magnetic north poles separated by 24 degrees longitude

However, if you put the continents back together, and then let them drift away from each other, you get one magnetic north pole!

Seafloor Studies

After WWII (ended in 1945): Mapped the Seafloor!

After WWII, funding from the US Office of Naval Research and technological advances permitted extensive mapping of the ocean floor

Found:

Mid-Ocean Ridges with rift valleys

Trenches, seamounts, guyots

All seafloor is young (oldest is 180 million years old)

Sediment in the deep ocean is thin

Seafloor Spreading

Harry Hess's (1962) Proposals

Based on a small amount of evidence from seafloor studies, Hess made a radical proposal.

Magma intrudes and forms new oceanic crust at mid-ocean ridges/rises

The new crust travels across the ocean basin

This crust is subducted when it collides with another plate at an oceanic trench

Sea-Floor Spreading and Plate Boundaries

Sea Floor Spreading Hypothesis

More Evidence

- Earthquakes at ridges and subduction zones
- Heat flow highest at ridges, decreases away from ridges
- Radiometric dating shows oldest rocks on sea floor of 200 m.y.
- Sediments older away from ridges
- Earth's magnetic field reverses, this change recorded by iron minerals in rocks

Continued study of the seafloor by towing magnetometers behind vessels showed magnetic stripes on the seafloor. Geomagnetic Reversals

The Earth's Magnetic Field

Earth's magnetic field resembles that produced by a large bar magnet.

Magnetic north is not in the same location as true north

Paleomagnetism and Geomagnetic Reversals

Magnetic field of the Earth is imprinted upon iron-bearing rocks when they form

Provides a record of magnetic reversals and original latitude

Seafloor mapping in 1950's and 1960's revealed magnetic striping on the ocean floor.

Earth's magnetic field periodically reverses polarity – the north pole becomes the south pole, and vice versa.

Probably related to chaotic motions in the liquid outer core.

Reversals – Animation: <http://www.youtube.com/watch?v=oldW-ngRZMs>

Rocks with the same magnetism as the present magnetic field are of **normal polarity**.

Rocks with opposite magnetism are of **reverse polarity**.

Found that all rocks of the same age had the same polarity; they were either normal or reversed.

Therefore, Earth's magnetic field has reversed.

It reverses about every 1 million years, and sometimes every 100,000 years.

Geomagnetic reversals are recorded as "stripes" in the ocean crust

How geomagnetic reversals are recorded on the Ocean Floor

Lava erupts from the center of the mid-ocean ridge, causing symmetric lava flows on both sides of it.

As it cools, it locks in the magnetic field present at the time in the iron rich minerals (magnetite).

Because of seafloor spreading, the magnetized strip of seafloor would get wider with time.

When the magnetic field reverses, the new seafloor forming in the middle would have opposite polarity.

A symmetric pattern is developed on both sides of the ridge.

Putting it all together: The Theory of Plate Tectonics

Now: GPS Data too!

Break up of Pangaea: approximately 200 million years ago

Plate Tectonics - J. Tuzo Wilson

Suggested that the Earth's outer shell is broken into several "rigid plates" that interact with each other.

Plate Tectonics Was Born!

By 1968, the concepts of continental drift and seafloor spreading were united to form the theory of plate tectonics.

Plate tectonics: the theory that proposes that Earth's outer shell consists of individual plates that interact in various ways and thereby produce earthquakes, volcanoes, mountains, and the crust itself.

Earth's Plates

Made of broken pieces of lithosphere (the crust and uppermost mantle).

The lithospheric plates move over the weaker region in the mantle called the asthenosphere.

Most plates include both continental and oceanic crust.

Therefore, Wegener's idea of continents plowing through the seafloor was wrong.

Why do the plates move? Convection of the mantle (specifically the asthenosphere)!

Plate Boundaries

Intense geologic activity occurs at plate boundaries.

Boundaries were first established by mapping locations of earthquakes.

Plate Movement

Plates move relative to each other at a very slow but continuous rate

About 5 centimeters (2 inches) per year. (About as fast as your fingernails grow.)

Move due to unequal distribution of heat within Earth.

Hot material in the mantle moves upward

Cooler, denser slabs of oceanic lithosphere descend into the mantle

Three Types of Plate Boundaries

1. Divergent boundary
(“Di” means two or apart)
2. Convergent boundary
(“Con” means together or with)
3. Transform boundary
(“Trans” means across or beyond)

Divergent Plate Boundaries

Where two plates move apart.

Where are the oldest rocks on the seafloor?

Results in upwelling of the mantle to create new seafloor

AKA constructive plate margins since this is where new oceanic lithosphere is constructed.

AKA spreading centers because seafloor spreading occurs here.

Most are located along the crests of mid-ocean ridges

Mid-ocean ridge: wide volcanic mountain range on the floor of the ocean where divergence occurs.

At the top of the mid-ocean ridge is the rift valley.

Rift valley: a long, narrow trough bounded by normal faults. It represents a region where divergence is taking place.

Most divergent plate boundaries are located along the crests of oceanic ridges

A few are on land; Continental Rifting

Continental rifting splits landmasses into two or more smaller segments along a continental rift

Example:

East African rift valley

Extensional forces stretch and thin the continental crust.

Upwelling of the mantle pushes up an area

Convergent Boundaries

Where two plates move together.

AKA destructive plate margin because older portions of oceanic plates are “destroyed” here (returned to the mantle).

Remember: Earth is not growing larger. As new lithosphere is being created at divergent boundaries, it is also descending into the mantle at convergent boundaries.

Three situations for convergent boundaries:

Oceanic-Continental

Oceanic-Oceanic

Continental-Continental

Oceanic-Continental Collision

Trench: a narrow, elongated depression on the seafloor where subduction occurs.

Subduction: the process by which oceanic lithosphere sinks into the mantle at a trench.

Subduction zone: A long, narrow zone where one lithospheric plate descends beneath another.

Subduction: the process by which oceanic lithosphere sinks into the mantle at a trench.

Depends on density.

Oceanic crust is more dense than continental crust.

Therefore, it is always oceanic lithosphere that is subducted.

Continental crust is not dense enough to go back into the Earth.

Angle of subduction depends on density

When MOR is near a subduction zone, the lithosphere is still warm and buoyant.

Therefore, descent angle is small.

As lithosphere ages and is further from MOR, it cools becoming more dense and will sink when given the chance.

Therefore, sinks at higher angle.

Average angle is 45°

Oceanic-Continental Convergence

Denser oceanic slab sinks into the asthenosphere

When it gets to a depth of about 100km it is hot enough for partial melting of the asthenosphere to begin.

The subducted plate contains water (from sediments and the plate itself), which is released as the plate is subducted.

The water enters the mantle wedge, which lowers the melting point of the rocks in the mantle wedge.

Therefore, the rocks melt, and rise to either be erupted forming volcanoes, or to solidify, thickening the crust.

Melted mantle has a composition of basalt. (Basalt is what erupts from a MOR).

However, if it has to go through a continent, it melts some of it, making it more silica rich.

Resulting volcanic mountain chain is called a continental volcanic arc (ex. Andes and Cascades)

Cascade Mountains, Pacific NW

Oceanic-Oceanic Convergence

When two oceanic slabs converge, the more dense one descends beneath the other.

Same story for melting...water released...decreases melting point...blah, blah, blah...

Forms volcanoes on the ocean floor called island arc is formed (Japan, Aleutian islands, Tonga islands)

Continental-Continental Convergence

Continued subduction can bring two continents together.

Example: India and Eurasia

Less dense, buoyant continental lithosphere does not subduct.

Resulting collision produces huge mountains (Himalayas, Alps, Appalachians)

Made of: deformed and metamorphosed rocks

Transform Boundaries

Plates slide past one another

AKA conservative plate margin because no new lithosphere is created or destroyed

Example: San Andreas Fault

Will we “fall off” into the ocean when “the big one” hits?

No, if the same plate movement continues, we will instead be neighbors with San Francisco!