Plate Tectonics, Continental Drift

1960s - theory of plate tectonics fostered a revolution in geology.

Tectonics

1) movements of the earth's crust
2) deformation of crust and resulting formation of structural features.

Plate tectonics

movements of discrete segments of Earth's crust in relation to one another.

the theory holds that continents move over the surface of the Earth because they form parts of moving plates.

continents can break apart or fuse together to form larger continents.

helps to explain the occurrence of major geologic phenomena:

1) why most volcanoes and earthquakes occur along curved belts of seafloor
2) why mountain belts tend to develop along the edges of continents
3) why the present ocean basins are very young from a geologic perspective.

The History of Opinion About Continental Drift

Background

Early 20th century geologic thought on earth's tectonic deformation of the crust and resulting formation of structural features:

1) the oceans were old.
2) oceans and continents were permanent features.
3) mountains resulted from contraction of Earth due to gradual cooling. As the interior cooled and contracted, the outer skin or crust was deformed.

Past few decades - a revolution in the earth sciences changing ideas about the structure and workings of the earth:

1) Continents gradually migrate across the globe.
2) splitting of land masses results in new ocean basins.
3) older areas of sea floor are being recycled at ocean trenches.
4) Earth's great mountain masses result of continental collisions.

Continental drift

idea that continents move horizontally over Earth's surface, failed to receive support in Europe or North America.

Alfred Wegener (1915) - The Origins of the Continents and Oceans:

1) set forth his hypothesis of **Continental Drift**.

2) ~200 Ma, a supercontinent called **Pangaea** existed after which it began to split up.

Based on:

1) fit of South America and Africa;
2) fossil evidence;
3) paleoclimatic evidence, and
4) rock structures.

Early Evidence

1) Obvious fit of certain continents.

coasts on two sides of Atlantic fit together like separated parts in a jig saw puzzle

west coast of Africa matches east coast of South America.

constituted first evidence that continents might once have broken apart and moved across earth's surface.

Pellegrini (1858) - a great continent had once broken apart.

Edward Bullard (1960s) produced a fit of the continents 900m below sea level and achieved a remarkable fit using seaward edge of continental shelf.

2) Fossils

existence of similar fossils in land masses widely separated.

a) Mesosaurus (aquatic reptile) in South America and Africa.

occurred at or near the Carboniferous - Permian boundary (~286 Ma) in Brazil and South Africa in dark shales along with fossil insects and crustaceans. It couldn't swim across the ocean (lived in freshwater and brackish environments), so continents must have been joined.

Geologists who didn't believe in drift suggested great land bridges connecting the continents once existed but later subsided to form portions of the modern seafloor.

b) the *Glossopteris* flora - a variety of seed fern found in late Paleozoic coal deposits of India, South Africa, Australia, South America and Antarctica.

grew only in subpolar climates

large seeds which are not dispersed easily

This led Edward Suess to suggest that land masses connected all of these continents. He called this hypothetical continent Gondwanaland.

3) Rock types and structural similarities

similar chronologies and types of rocks found in adjacent regions.

a) Appalachians - occur in North America and extend to parts of Greenland, Ireland, Great Britain and Norway

4) Paleoclimatic data

a) similar glacial deposits were found in areas in South America and Africa which are presently subtropical. orientation of glacial scour marks indicated the movement of glaciers from areas were there are no longer land masses to support large glaciers. If the continents were united, if wouldn't be difficult to account for these readings. Ice flow might have emanated from the center of a large continent that supported large glaciers under cold climate conditions.

Correlation of the Gondwana Sequence

Gondwana sequence - the general stratigraphic sequence of late Paleozoic rock units that yield the *Glossopteris* flora

occurs with remarkable similarity in South America, South Africa, India, and Antarctica.

Pangaea did not form until late in the Paleozoic Era.

Before Pangaea was formed:

Gondwanaland existed as a distinct southern supercontinent ,
Laurasia **-** the northern supercontinent

The Rejection of Continental Drift

geologists of the Northern Hemisphere continued to view the theory of continental drift with considerable skepticism.

absence of a driving mechanism by which continents could move over long distances.

Geophysicists knew that both continental crust and oceanic crust were discontinuous above the Moho

could not imagine how continents could be made to move laterally-to plow through oceanic crust.

Arthur Holmes (1930s) proposed convection cells in the mantle to drive continental drift.

The Puzzle of Paleomagnetism

Paleomagnetism - study of fossil magnetism;

the magnetization of ancient rocks at the time of their formation.

studies in rock magnetism in the 1950s renewed interest in continental drift due to collection of new evidence.

Earth's magnetic field has reversed its polarity on many occasions. During this period, they also wondered whether the north and south magnetic poles also wandered about periodically.

Earth's magnetic field is like a bar magnet-dipole with invisible lines of force extending through one pole to the other.

Ancient magnetism uses minerals that lock in paleomagnetism

iron minerals such as magnetite.

When heated above a certain temperature - the **Curie point** - they lose their magnetism. When they cool below this point (~580^{o}C) they become magnetized to the direction of the existing magnetic field. It is locked in.

From dip needles' angle (horizontal at equator; vertical at poles) one can measure paleolatitude.

They not only record the direction to the poles, but also the latitude of origin.

When rocks were studied, developed polar wandering paths which implied either poles changed, or continents drifted.

e.g. coal producing deposits near Europe where near equator when formed-supported by paleoclimate data.

Apparent polar wandering paths for North America and Europe. the apparent polar-wander paths of North America and Europe did coincide almost exactly from both Paleozoic and early Mesozoic time. This evidence strongly suggested that the continents had indeed drifted apart, carrying their magnetized rocks with them.

The Rise of Plate Tectonics

Sea-Floor Spreading

Harry Hess (1960) proposed a hypothesis called **sea-floor spreading**:

Ocean ridges - located above upwelling portions of large convection cells in the mantle.

As rising material is spread laterally, sea-floor is carried is a conveyer belt fashion away from the ridge crest.

As sea-floor moves away, newly formed crust replaces it at tension gashes at the top.

Downward limbs of these convection cells are located beneath deep ocean trenches. They are gradually consumed as they descend into the mantle.

Hess suggested that the felsic continents had not plowed through the dense mafic crust of the ocean at all but that instead the entire crust had moved.

Hess on apparent youth of the ocean basins.

deep sea sediment was accumulating at a pace of ~1/2 inch per thousand years, so for 4 billion years of earth history there would be 20 kms (~25 miles) of sediment.

However, the average thickness of sediment in the deep sea is only 1.3 kms (less than 1 mile). Allowing for compaction, estimated that the layer of sediment on the deep sea floor represented about 260 million years of accumulation.

Hess noted central location of the Mid-Atlantic Ridge, and that midocean ridges are centrally located within ocean basins.

1) they are characterized by a high rate of upward heat flow from the mantle to neighboring segments of seafloor.

2) seismic waves from earthquakes move through the ridges at unusually low velocities.

3) along the crest of each ridge there is a deep furrow.

4) volcanoes frequently rise up from midocean ridges.

This led Hess to suggest:

1) midocean ridges represented narrow zones where oceanic crust forms as material from the mantle moves upward and undergoes chemical changes.

2) as this material rises, it carries heat from the mantle to the surface of the seafloor. The expanded condition of the warm, newly forming crust thus accounts for the swollen condition of the crust there - the presence of a ridge.

3) that material within the earth's mantle rotates by means of large- scale thermal convection. The material of the mantle, existing at high temperatures and pressures, must flow like a very thick liquid. The mantle is heated by the decay of radioactive isotopes within it and is cooled from above by loss of heat through the crust.

Consequently, the upper part of the mantle, being cool, is more dense than the lower part and thus tends to sink while the lower part tends to rise. In a deep body of liquid the result is convection.

Convection motion within the mantle.

Earth's liquid like mantle is divided into **convection cells** whose low-density material forms crust as it rises and cools.

the crust then bends laterally to become one flank of a ridge.

volcanoes along mid-ocean ridges allow escape of mantle material

low velocity of earthquake waves passing through a ridge would result from the fact that the rocks of the ridge exist at a high temperature and are extensively fractured where they bend laterally to form the basaltic seafloor.

Guyots

the seafloor adjacent to the midocean ridges moves laterally away from the spreading center.

The volcanoes that form along midocean ridges sometimes grow up to sealevel (e.g. Ascension Island in the Atlantic). As a volcano moves laterally from the ridge along with the crust on which it stands, it moves away from the source of its lava.

It then becomes an inactive seamount, and its tip is quickly planned off by erosion. The seafloor gradually deepens away from midoceanic ridges, because newly formed crust cools and therefore shrinks as it moves laterally away from the ridge.

Thus a truncated seamount is gradually transported out into deep water as if it were on a conveyer belt, and it then becomes a guyot. Hess calculated a spreading rate of 1 cm/yr.

Continents

enormous bodies that float in oceanic crust by virtue of their low density.

ride passively along like guyots.

continental fragmentation occurs when convective cells in the mantle change their locations, and the upwelling limbs of two adjacent cells must sometimes come to be positioned beneath a continent.

Convective spreading should then **rift** the continent into two fragments apart from the newly formed spreading center.

New ocean floor should subsequently form at the same rate on each side of the spreading center.

Hess further maintained that the spreading center would continue to operate along the midline of the new ocean basin-and thus persist as a midocean ridge - as long as the convective cell remained in its new location.

If oceanic crust forms and flows laterally without an enormous change in thickness, however, it must disappear somewhere.

it must be swallowed up again by the mantle along the great **deep-sea trenches** that exist at certain places in the ocean floor.

Hess estimated that the formation of new crust along midocean ridges and the simultaneous disappearance of crust into the deep-sea trenches would produce an entirely new body of crust for the world's oceans every 300-400 million years.

Hess's hypothesis of seafloor spreading allowed the observation that continents move along with oceanic crust.

Geomagnetic Reversals

Hess's hypothesis initially created no major stir in the geologic profession. Still needed a convincing test of the basic idea of sea-floor spreading. Paleomagnetism provided this basic test.

Earth's magnetic field periodically reverses polarity.

Present day field-normal polarity

reverse polarity is opposite magnetism.

Measured reversals of lava flow over the past few million years by towing **magnetometers** over the ocean floor; discovered high and low intensity patterns paralleling mid ocean ridge.

High intensity - normal magnetism

low intensity - reverse magnetism.

Magnetized at mid-ocean ridges when added to the ocean floor.

Fred Vine and Drummond Matthews:

newly formed rocks lying above the axis of the central ridge of the Indian Ocean had normal magnetism.

However, seamounts on the flanks of the Indian Ocean ridge were magnetized in the reverse way.

Discovered magnetic stripping; crust forming along any midocean ridge axis must be magnetized with present day field, while reversed polarity should be encountered some distance away from the ridge, and further away back to normal polarity.

The stripes are called **anomalies** because their magnetism, if it is normal, adds to Earth's present magnetic field, and if it is reversed, it weakens the magnetic field.

Thus the presence of magnetic stripes causes measurements of regional magnetism to be abnormal or anomalous.

The data base for geomagnetic reversals was expanded with the measurement of the magnetic polarity of terrestrial rocks of known age and the development of a late Cenozoic time scale based on magnetic reversals.

It was then found that the relative widths of seafloor stripes were proportional to the time intervals that these stripes represented

e.g., long intervals were represented by broad stripes, while short intervals were represented by thin stripes.

Thus the detailed patterns of striping were found to match the known timing of magnetic reversals.

Now can measure rate of sea floor spreading.

North Atlantic 1-2 cm/year; East Pacific Rise-3-8cm/yr.