Plate Tectonics

Inside the Earth

The size of the Earth -- about 12,750 kilometers (km) in diameter--was known by the ancient Greeks, but it was not until the turn of the 20th century that scientists determined that our planet is made up of three main layers: crust, mantle, and core. This layered structure can be compared to that of a boiled egg.

The crust, the outermost layer, is rigid and very thin compared with the other two. Beneath the oceans, the crust varies little in thickness, generally extending only to about 5 km. The thickness of the crust beneath continents is much more variable but averages about 30 km; under large mountain ranges, such as the Alps or the Sierra Nevada, however, the base of the crust can be as deep as 100 km. Like the shell of an egg, the Earth's crust is brittle and can break.

Cutaway views showing the internal structure of the Earth. Below: This view drawn to scale demonstrates that the Earth's crust literally is only skin deep. Below right: A view not drawn to scale to show the Earth's three main layers (crust, mantle, and core) in more detail.

Below the crust is the mantle, a dense, hot layer of semi-solid rock approximately 2,900 km thick. The mantle, which contains more iron, magnesium, and calcium than the crust, is hotter and denser because temperature and pressure inside the Earth increase with depth. As a comparison, the mantle might be thought of as the white of a boiled egg.
At the center of the Earth lies the core, which is nearly twice as dense as the mantle because its composition is metallic (iron-nickel alloy) rather than stony. Unlike the yolk of an egg, however, the Earth's core is actually made up of two distinct parts: a 2,200 km-thick liquid outer core and a 1,250 km-thick solid inner core. As the Earth rotates, the liquid outer core spins, creating the Earth's magnetic field.

Not surprisingly, the Earth's internal structure influences plate tectonics. The upper part of the mantle is cooler and more rigid than the deep mantle; in many ways, it behaves like the overlying crust. Together they form a rigid layer of rock called the lithosphere (from lithos, Greek for stone). The lithosphere tends to be thinnest under the oceans and in volcanically active continental areas. Averaging at least 80 km in thickness over much of the Earth, the lithosphere has been broken up into the moving plates that contain the world's continents and oceans. Scientists believe that below the lithosphere is a relatively narrow, mobile zone in the mantle called the asthenosphere (from asthenes, Greek for weak). This zone is composed of hot, semi-solid material, which can soften and flow after being subjected to high temperature and pressure over geologic time. The rigid lithosphere is thought to "float" or move about on the slowly flowing asthenosphere.

**Plate Tectonics - The Theory**

The theory of plate tectonics, rests upon the hypothesis that the earth’s crust is made up of a number irregularly shaped lithospheric plates. These plates are moving in different directions and at different rates. These rigid plates are covered by continental or oceanic crust. The plates ‘ride’ on a less rigid layer of ‘lubricating’ rock, the Athenosphere.

The driving force behind the movement of the lithospheric plates is the earth’s internal energy flow system – mantle convection.

Before the advent of plate tectonics, however, some people already believed that the present-day continents were the fragmented pieces of pre-existing larger landmasses ("supercontinents"). The diagrams below show the break-up of the supercontinent Pangaea (meaning "all lands" in Greek), which figured prominently in the theory of continental drift – the forerunner to the theory of plate tectonics.
Plate Tectonics - The History

1600 — development of a comprehensive world map (missing details of some continents such as Australia and Antarctica).

1620 — Francis Bacon noted the similarity of the shape of the continents on either side of the Southern Atlantic — Africa and South America.

1666 — François Placé suggested that prior to the Great Flood the land was undivided by oceans and that the Atlantic formed when Atlantis sank.

1858 — Antonio Snider developed a theory that when the Earth cooled from a molten mass continents formed only on one side. This created instability causing the Americas to be pulled away from the rest of the continents.

1879 — Sir George Darwin said that the Pacific Ocean was the scar left behind when the Moon pulled away from the Earth. After this happened, the continents moved to create a balanced planet.

1890s — Edward Suess suggested that at one stage all the continents were joined as one massive continent which he called Gondwanaland. His evidence for this was the location of mountain ranges and common fossils.

1924 — Alfred Wegener developed the theory of Continental Drift to explain the similarities of rocks, fossils and other geological structures on either side of the Atlantic. At this time it was accepted that the continents sat like icebergs on the mantle and as the continents eroded they rose out of the mantle. Wegener suggested as well as moving up and down in the mantle, continents could move sideways in the mantle. — Wegener was a meteorologist and his theory was not well accepted. (He died on an expedition in Greenland collecting ice samples).

1928 — Arthur Holmes suggested that convection currents in the mantle as the driving force of continental drift. He had no evidence to support his theory.

1950s — Extensive mapping of the ocean floor, especially the Mid-Atlantic Ridge.

1960s — Harry Hess suggested that sea floor separates at the mid-oceans ridges and new sea floor is created by up-welling of the mantle.

1970s — Theory of plate tectonics well accepted.
Plate Tectonics - The Evidence

Some examples of evidence for the existence of the original super-continent (Pangea) and the idea of plate tectonics are as follows:

♦ Jigsaw Fit of the Continents
A study of the shape of the present day continents shows that they seem to be like the pieces in a jigsaw puzzle, which if pieced together might form a single continent with Africa at the centre. An almost perfect fit results if the continental shelves (the actual edges of the continents) are taken into account.

♦ Landforms at Plate Boundaries
There is a strong relationship that exists between the location pattern of relatively major chains of young fold mountains and volcanoes and the positions of plate boundaries.

♦ Earthquakes at Plate Boundaries
Studies have revealed that a close relationship also exists between areas, which are prone to earthquakes, and plate boundaries

♦ Matching Rocks
A study of the ages of rocks provides evidence. Oceanographers using radioactive dating have found that the youngest rocks on the sea floor are closer to ocean ridges, whilst the oldest rocks are found closer to continental landmasses. Proof of diverging plate movement.

♦ Rock Magnetism
The earth has a magnetic field. We make use of this when we use a compass. When molten rock is cooled, some minerals in the rock (such as iron) become magnetised and are set pointing north. At various times in the earth’s history the earth’s polarity has reversed, so the North Pole has acted like the South Pole. We know when these events have occurred. Rock sampling in different parts of the world have their compasses pointing in a multitude of directions – evidence that plate have constantly been on the move.

♦ Plant and Animal Fossils
The same fossils of extinct plants and animals older than 200 million years have been found in several continents indicating that the continents were once joined.

Activity: Fit of the Continents. Cut out the continents from the handout on the next page and try to recreate the super-continent of Pangea. Once you have got the puzzle correct, glue to a sheet of file paper.
Three Types of Plate Movement

1. **Diverging (Constructive) Plates** – these occur under the ocean. Two plates moving apart are known as sea-floor spreading. Examples include The Mid-Atlantic Ridge, and The Mid-Pacific Ridge.

2. **Converging (Destructive) Plates** – when two plates come together. Effects depend upon what kind of plates is colliding.

3. **Sliding (Conservative) Plates** – In this type of boundary contact, one plate slides or shears past the other. Examples include, The San Andreas Fault on the west coast of The U.S.A and In Turkey, the two banks of the Jordan river are sliding in opposite directions.

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Activities:
1. Watch the video Tectonic Forces.
2. What are tectonic plates?
3. What causes plates to move? (include a sketch in your answer)
4. Use a mnemonic to remember the types of evidence supporting the Theory of plate tectonics. Use the first letter of each evidence example to make up a silly/memorable sentence- you may be amazed at how easily you remember it!
Patterns and Processes at Plate Boundaries

Diagram 1: Diverging Boundaries
- Ocean Basin Widens
- Rift Valley
- New Ocean basin formed by New Oceanic crust
- Continental crust
- Plate uplifted and stretched

Process: Sea-floor spreading

Diagram 2: Oceanic Plate Meets Continental Plate
- Sea Iews
- Trench
- Continental Lithosphere
- Mantle Subduction
- Continental Lithosphere
- Mantle
- Oceanic crust
- Mountain Range
- Explosive volcanic chain
- Magma rising to form volcanoes
- Batholith (pluton)

Diagram 3: Oceanic Plates Meet
- Subduction Zone
- Melting
- Mantle
- Subduction
- Sliding of Plates
- Transform Fault

Diagram 4: Continental Plates Meet
- Sediments
- Ocean Basin
- Sediments
- Trench
- Movement
- Subduction
- Collision
- Fold Mountains
- Ocean Crust
(a) SOME POSITIVE EFFECTS OF PLATE MOVEMENT

The continents on which we live display an enormous variety of environments. Their climates have been largely determined by their positions (latitude) on the globe. Climate has also been influenced by the distribution of oceans, the arrangement and shapes of the continents and even the position, size and shape of the various tectonic landforms they contain. The physical landscapes, together with their environmental conditions and the plant life that developed within them have produced a global system of environmental regions. These regions possess a unique set of environmental qualities that support distinctive ecosystems. Examples of environmental regions are the tropical rainforest, the desert and the savanna grasslands.

Each environmental region presents opportunities for utilisation by humans who use their valuable resources, such as soil, to produce food. They also use a variety of other valuable resources such as metallic ores and fossil fuels. It is becoming increasingly clear that the distribution pattern of many of the world’s minerals can be explained by plate tectonics, since many of them are found concentrated at past or present plate boundaries.

Another advantage of plate movement is that the earth contains a highly diverse array of plants and animals which would not exist if the continents had not separated from Pangaea. Continental drift resulted in this great diversity of species. This occurred through the development of plants and animals which bear a close resemblance to those on other continents, and the development through isolation of new varieties of plants and animals. Examples of animals which developed from a common Pangaean ancestor are the African ostrich, the Australian emu and the South American rhea. Examples of plants include the Australian banksias, waratahs and grevilleas and the South African proteas. The fact that over three quarters of the plant species of Australia, many of them eucalypts, are found nowhere else is the result of its isolation.

Volcanic activity has played an important part in forming many of the world’s resources. Volcanic lava and ash from volcanic eruptions, after it has weathered, usually provides very fertile soil, as does the lava that flowed out onto some high plateaus. This results in intensive agriculture and high population densities, as exist in Java. Volcanic activity also produces mineral deposits, such as the gold deposits of volcanic island arcs. Pumice, a light, glass-like rock that is sometimes ejected from volcanoes during eruptions, is used as a construction material. Geysers (jet-like emissions of steam and hot water) from beneath the earth’s surface, and hot springs may be used to generate power and to heat homes. Volcanoes also have great aesthetic appeal, and many of them are designated as national parks, attracting tourists and climbers. Some volcanoes, such as Mount Fuji in Japan, have great religious significance.

Fold mountains and block-rift formations also provide numerous advantages for humans. They possess valuable metallic mineral resources, such as tin in the Andes Mountains, and fossilised fuels such as petroleum, found, for example, in sediments along fault planes associated with large rifts. Timber resources are also utilised. Although the soils are often thin and stony in mountain areas, valuable fertile lowlands are formed by sediments accumulating on the floors of rift valleys.

Mountains also provide valuable water resources. They provide catchment areas in which run off feeds important river systems such as the Ganges and Indus Rivers in south Asia. The fertile floodplain soil formed either side of these rivers is intensively farmed, resulting in high population densities. The narrow, steep-sided valleys in mountainous areas provide good dam sites where water is trapped and stored to produce hydroelectric power and water for irrigation, industrial and domestic purposes.

Mountains also have the capacity to influence climate, thereby influencing agricultural and other activities. As an example, mountains which occur across the path of winds from the ocean will receive a higher rainfall on the ocean-facing side than on the other side which may be very dry.
Some mountains even have the capacity to block air masses, keeping temperatures cooler or warmer, depending on the temperature of the air mass. Temperatures decrease with altitude, affecting agricultural activities. For example, in some mountainous parts of the world, transhumance is practised whereby herders moving their sheep or goats alternatively up the mountain when the snows melt, and back down to the lower slopes in winter. On high plateaus in tropical areas such as the Brazilian Plateau coffee and other crops can be grown.

Like volcanoes, mountains attract tourists who come to view the spectacular scenery, such as that of the European Alps and the Himalayas, and to participate in winter sports such as skiing, and camping, hiking, fishing and climbing.

The sub-marine landforms of the world, like continental mountains, also contain mineral deposits. Sediments from the sea and land collect in trenches, and oil and gas form from the slow decomposition of plant and animal remains. Gold deposits and other minerals such as silver, zinc, lead and molybdenum are also found at these subduction zones. Iron, manganese, copper and nickel are found in sediments at ridges, having dissolved out from heated rocks and later being precipitated out onto the ocean floor in concentrated amounts. Vast areas of the ocean floor are littered with manganese nodules which also contain copper, cobalt and nickel.
(b) NEGATIVE IMPACTS OF PLATE MOVEMENT ON THE HUMAN ENVIRONMENT

(i) Earthquakes

Intense earthquakes are the most frequently occurring and destructive of all geological hazards. Every year they cause loss of life, injury and damage to the natural environment and its cultural features, particularly in those areas adjacent to subduction zones and areas where plates are sliding past each other. The greatest hazards to humanity occur in heavily populated areas. If quakes are centred on a big city their destructive powers may be enormous.

Earthquakes are often preceded by a loud rumbling noise. The ground may shake or vibrate for a few seconds or minutes, though sometimes tremors can occur over several days. Intense earthquakes can produce wave-like vertical movements (caused by 8 or more vibrations per second), and horizontal earth movements may occur at the same time. The initial earthquake is usually followed by after-shocks, which although decreasing in severity, can still cause damage, particularly if buildings are already weakened by the initial quake.

Earthquakes cause great loss of life and injury. About 20 thousand people are killed or seriously injured every year. The worst twentieth century earthquake hit the Japanese cities of Tokyo and Yokohama in 1923. The quake and the floods which followed killed 300,000 people. This high death rate was in part the result of fires which broke out as many people were cooking on gas burners (in homes made largely of bamboo and paper) when the earthquake struck. More recently a devastating earthquake in India in October 1993 claimed more than 20,000 lives when entire towns and villages were flattened.

Most deaths and injuries occur from falling objects and debris as the shocks shake, damage or demolish buildings, crushing people and burying them under the rubble. In the 1993 Indian earthquake many died instantly and many were wounded as simply constructed stone and concrete homes were flattened while most residents were sleeping. Thousands were trapped under the debris. In the densely populated Mexico City in September 1985 over 4,000 people died and many more were injured as blocks of flats, hotels, apartments and a large hospital collapsed, trapping people alive in the ruins.

Fires are often a major threat after an earthquake. These may be caused by broken gas lines and damaged electricity supplies, broken chimneys or even chemical spills. After the famous 1906 San Francisco earthquake gas mains exploded, electrical wires were broken and fire raged for three days, racing through wooden buildings.

Other forms of structural damage occur as a result of earthquakes. Underground water and sewerage pipes may crack, irrigation channels may be damaged and dams may burst their walls causing flooding. Communications links are disrupted as railway lines are deformed and road, freeway overpasses and bridges are damaged. Telecommunication links may be cut, and airports may even have to close down. Lack of communications links may hamper emergency services and stop essential supplies getting through to affected areas.

Much of the damage to buildings and communication links occurs as a result of the changes in the shape and appearance of the physical landscape. Landslides may be produced and cracks may open up in the ground. In some cases whole slabs of the earth may rise or subside along these fault lines. As a result of an earthquake in Napier, New Zealand in 1931 a beach was raised three metres. Water courses may also be changed during an earthquake, resulting in flooding.

In many coastal areas lives are lost and great damage is caused by tsunamis. These are huge seismic sea waves which are caused by shallow earthquakes originating below the ocean. Sometimes mistakenly called tidal waves, they cause a rise in water level which may flood low-lying coastal areas, in some cases wiping out entire fishing fleets and coastal villages. A tsunami which struck the Japanese coast at Awa in 1903 killed 100,000 people. More recently, tsunamis have struck the island of Flores (Indonesia) and Nicaragua (South America) in 1992, causing much damage.