Plate Tectonics

One of the greatest mysteries of our planet is its puzzle-like appearance. Close examination of the shape of the continents shows that they would fit together if placed side by side. For example, the West African coastline seems matches nicely with the east South American coastline and the Caribbean Sea. A similar fit appears across the Pacific. This fit is even more striking when the underwater continental shelves are compared rather than just the continents' coastlines.

In 1912, a geologist named Alfred Wegener (1 880-1930) made the same observation. He proposed that until about 300 million years ago the continents were compressed into a single **protocontinent** that he called *Pangaea* (meaning "all lands"). He suggested that over time the protocontinent broke into pieces that drifted apart into their current distribution -- the idea of **continental drift**. The idea was initially dismissed -- Wegener's hypothesis lacked a geological process to explain how the continents could drift across the Earth's surface the way he proposed.

The Early Evidence

In his search for evidence that would support his idea, Wegener came across a paper. It suggested that a **land bridge** had once connected Africa with Brazil. This proposed bridge was an attempt to explain the observation that identical fossilized plants and animals from the same geological time periods were found in both South America and Africa. The same was true for fossils found in Europe and North America, as well as in Madagascar and India. Many of these organisms would not have been able to travel across the vast oceans that currently exist. But Wegener's drift theory seemed more plausible than the idea that numerous land bridges connected all of the continents.

Additional support was evidence left behind by continent-sized glaciers that once covered the planet. **Striae** [striped-shaped markings] left by the scraping of glaciers over the land surface showed the same patterns in both Africa and South America, indicating that these two land areas had been close together during an ancient ice age. Still, all this was very circumstantial evidence, and most scientists were not convinced.

Wegener continued to develop his drift hypothesis, which he used to provide an alternate explanation for the formation of mountains (**orogenesis**). The theory being discussed at the time was the "Contraction Theory." It suggested that the planet was once a molten ball and in the process of cooling the surface cracked and folded up on itself. The problem with this idea was that if it were true, then all mountain ranges should be approximately the same age. However, this was not the case. Wegener proposed instead that as the continents moved, their leading edges would encounter resistance. As they plowed into other land masses, they would crumple and fold upwards, forming mountains. He suggested that the Sierra Nevada mountains on the Pacific coast of North America and the Andes on the coast of South America were good examples of where this might have occurred. Still, Wegener was unable to provide an adequate explanation of the forces responsible for continental drift. And since most scientists believed that the Earth was solid and immovable, they dismissed his theories out of hand.

In 1929, another scientist named Arthur Holmes elaborated on one of Wegener's many hypotheses -- the idea that the Earth's mantle undergoes thermal convection [mixing]. This idea is based on the fact that, as a substance heats up, its density decreases. It therefore rises to the surface until it cools and then sinks again. This repeated heating and cooling results in a flow of material that may be enough to cause continents to move. He suggested that this thermal convection was like a conveyor belt, and that the material's upward pressure could break apart a continent and then force the pieces in opposite directions. Still, there was little evidence to support Holmes' idea at the time. Not until the 1 960s, when scientists could actively test them, did any of these hypotheses received the attention they deserved.

The Earth's Structure

With advancements in technology such as computer hardware and software, and new detection devices, scientists have been able to gather the evidence that Wegener and Holmes could not. The Earth is not a solid ball of rock. As it formed from the gas and dust of the early solar system, the denser materials, such as iron and nickel, sank into the planet's innermost regions to form the partly solid-partly molten core. Within the core region, extremely high pressure and temperature (even after 4.5 billion years it remains about 3 000^{o}C) kept the rock in a semi-liquid state. Convection currents developed as the lighter compounds separated out and rose towards the surface, forming the brittle crust. These compounds, together with the top part of the still-molten mantle, created hard slabs of crustal material known as **lithosphere**. The continents we observe are embedded in these slabs. Between the core and the crust lies the mantle. It is composed mainly of solid rock near the surface, and molten rock, called **magma**, near the core, Temperatures there are also high, at about 2000^{o}C (see Figure 1).

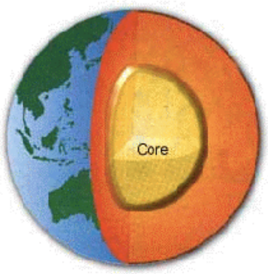

Figure 1: The Earth's structure.

This cutaway section of the Earth reveals its layers: the innermost (yellow) region is called the core; the surrounding molten (orange) region is the mantle, and the outermost (blue and green) region forms the crust.

The lithosphere itself can be divided into **oceanic** and **continental** crusts. Oceanic crust forms the floor of the deep oceans; it is comparatively thin, about 7 kilometers on average, and made up of relatively dense rocks like basalt. Continental crust is much thicker, averaging about 33 kilometers, and is composed of relatively light material such as granite.

Both oceanic and continental crusts, together with the upper part of the mantle, are divided into huge slabs called plates. The movement of these plates can be explained by Wegener's drift hypothesis. There are eight major identified plates, plus an assortment of smaller ones. The major plates include the Eurasian plate, the African plate, the North American plate, the South American plate, the Antarctic plate, the Indoaustralian plate, the Pacific plate and the Nazca plate (see Figure 2).

Sea-floor spreading is the process by which the ocean floor is extended when two undersea plates move apart. The rocks break apart and form cracks between them; magma [molten rock] rises through the cracks and seeps out onto the ocean floor like a long, thin, undersea volcano. The lower-density crust floats on top of the magma, moving away from the seeping cracks and causing the continents to "drift" apart.

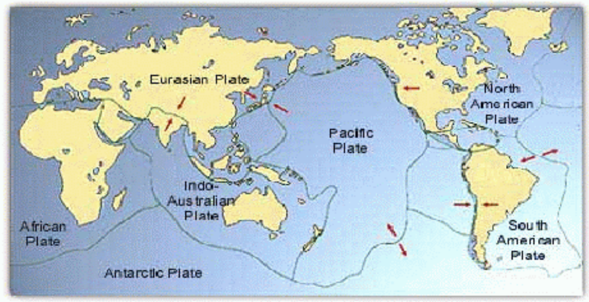

Figure 2: The major continental plates.

There are eight major continental plates, reflecting the distribution of both oceanic and continental crust.

As magma meets the water above it, it cools and solidifies, adding to the edges of the sideways-moving plates. The magma piles up along the crack, gradually forming a long chain of mountains on the ocean floor. This type of mountain chain is known as an **oceanic ridge**. A good example of this type of formation is the Mid-Atlantic Ridge, one part of a system of mid-oceanic ridges that stretches for 50,000 miles beneath the surface. The boundaries where the plates move apart are called "constructive" because new crust is formed there. The ocean floor gradually extends, and the size of the plates increases.

Boundaries can also be "destructive," in what is the ultimate in *planetary recycling*. The newly created lithosphere cools as it ages and eventually becomes dense enough to sink back into the mantle in a process called **subduction**. The subducted crust, after a few hundred million years, will be reheated, carried by convection currents back to the surface, and will appear again at areas of seafloor spreading to form new continents and further drive the process of continental drift.

Earthquakes

A third piece of evidence for Wegener's "continental drift" proposal comes from earthquakes, a phenomenon that occurs when one plate collides with another. This is only possible if the plates are in motion. In fact, the faults that produce the earthquakes serve to define the boundaries of the continental plates.

There are three main types of faults: **extensional, transform**, and **compressional** (see Figure 3), depending on the type of stress the crust endures. Each produces its own type of earthquake and has its own special hazards. Extensional boundaries, such as those at seafloor ridges, occur when two plates move apart from each other; here earthquakes are shallow, line up strictly along the direction of spreading, and tend to be smaller than magnitude 8 (see sidebar).

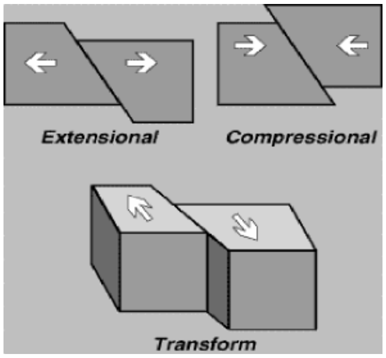

Figure 3: The three main types of faults.

Faults, stress fractures in the crust that produce earthquakes, are defined by the type of stress they undergo: extensional faults exist where continental plates pull away from each other; compressional faults exist where the plates push against each other, and transform faults occur where the plates slide past each other.

Transform boundaries or faults occur when the plates slide past each other, producing ground motion from side-to-side rather than the sinking or lifting seen with extensional or compressional regions. Here earthquakes are shallow, running only about 25 km below the surface, and tend to be smaller than magnitude 8.5. The San Andreas fault in California is an example of a transform fault, one which separates the Pacific and North American plates.

Compressional boundaries occur when two plates run into each other. With nowhere else to go, the crust buckles upward, often forming the type of mountain ranges Wegener originally proposed in his drift hypothesis. Earthquakes along these faults can range from very near the surface to several hundred kilometers deep, and it is here that some of the largest and most devastating quakes can be found. Some events in Alaska and Chile have exceeded magnitude 9.

The Richter Scale

In order to determine how much energy is released during an earthquake, **seismologists** [scientists who study earthquakes] use a scale called the *Richter Scale*. The numbers on the scale are referred to as **magnitudes**, and each whole number on the scale is 10 times more powerful than the previous number (for example, 2 is ten times stronger than 1; 5 is 1,000 times stronger than 2). Here are the typical effects of earthquakes in various magnitude ranges:

Magnitude	Effects
Less than 3.5	Generally not felt, but recorded.
3.5-5.4	Often felt, but rarely causes damage.
5.4-6.0	Mostly slight damage over small regions.
6.1-6.9	Can be destructive in areas up to about 100 kilometers across.
7.0-7.9	Major earthquake. Can cause serious damage over larger areas.
8 or greater	Serious damage over areas several hundred kilometers across.