Drifting Continents

Five hundred years ago, the sea voyages of Columbus and other explorers changed the map of the world. The continents of Europe, Asia, and Africa were already known to mapmakers. Soon mapmakers were also showing the outlines of the continents of North and South America. Looking at these world maps, many people wondered why the coasts of several continents matched so neatly. For example, the coasts of Africa and South America look as if they could fit together like jigsaw puzzle pieces. In the 1700's, geologists thought that the continents had always remained in the same place. But early in the 1900s, one scientist began to think that the continents could have once been joined in a single landmass.

Continental Drift

In 1910, a young German scientist named Alfred Wegener became curious about the relationship of the continents. He hypothesized that Earth's continents had moved!! **Wegener's hypothesis was that all the continents were once joined together in a single landmass and have since drifted apart.** Wegener's idea that the continents slowly moved over Earth's surface became known as **continental drift.**

According to Wegener, the continents drifted together to form the super continent **Pangaea** meaning "all lands." According to Wegener, Pangaea existed about 300 million years ago. This was the time when reptiles and winged insects first appeared. Great tropical forests, which later formed coal deposits, covered large parts of Earth's surface.

Over tens of millions of years, Pangaea began to break apart. The pieces of Pangaea slowly moved toward their present-day locations, becoming the continents as they are today.

Wegener gathered evidence from different scientific fields to support his ideas about continental drift. He studied land features, fossils, and evidence of climate change. In 1915, Wegener published his evidence for continental drift in a book called *The Origin of Continents and Oceans.*

Evidence From Land Features

Mountains and other features on the continents provided evidence for continental drift. For example, when Wegener pieced together maps of Africa and South America, he noticed that mountain ranges on both continents lined up. He noticed that European coal fields match up with similar coal fields in North America.

Evidence From Fossils

Wegener also used fossils to support his argument for continental drift. A **fossil** is any trace of an ancient organism that has been preserved in rock. For example *Glossopteris* was a fernlike plant that lived 250 million years ago.

Glossopteris fossils have been found in rocks in Africa, South America, Australia, India, and Antarctica. The occurrence of *Glossopteris* on these widely separated landmasses convinced Wegener that Pangaea had existed.

Other examples include fossils of the freshwater reptiles *mesosaurus and Lystrosaurus. These* fossils have also been found in places now separated by oceans. Neither reptile could have swum great distances across salt water. Wegener inferred that these reptiles lived on a single landmass that has since split apart.

Evidence From Climate

Wegener used evidence of climate change to support his hypothesis. As a continent moves toward the equator, its climate becomes warmer. As a continent moves toward the poles, its climate becomes colder. But the continent carries with it the fossils and rocks that formed at its previous location. For example, fossils of tropical plants are found on Spitsbergen, an island in the Arctic Ocean. When these plants lived about 300 million years ago, the island must have had a warm and mild climate. According to Wegener, Spitsbergen must have been located closer to the equator.

Geologists found evidence that when it was warm in Spitsbergen, the climate was much colder in South Africa. Deep scratches in rocks showed that continental glaciers once covered South Africa. Continental glaciers are thick layers of ice that covered hundreds of thousands of square kilometers. But the climate of South Africa is too mild today for continental glaciers to form. Wegener concluded that when Pangaea existed, South Africa was much closer to the South Pole. According to Wegener, the climates of Spitsbergen and South Africa changed because these landmasses had moved.

Wegener's Hypothesis Rejected

Wegener attempted to explain how continental drift took place. He suggested that the continents plowed across the ocean floors. **Unfortunately, Wegener could not provide a satisfactory explanation for the force that pushes or pulls the continents.** Because Wegener could not identify the cause of continental drift, most geologists rejected his idea.

For geologists to accept continental drift, they would also have had to change their ideas about how mountains form. In the early 1900's many geologists thought that mountains formed because Earth was slowly cooling and shrinking. According to this hypothesis, mountains formed when the crust wrinkled like the skin of a dried-up apple.

Wegener said that if these geologists were correct, then mountains should be found all over Earth's surface. But mountains usually occur in narrow bands along the edges of continents. Wegener developed a hypothesis that better explained where mountains occur and how they form. Wegener proposed that when continents collide, their edges crumple and fold. The folding continents push up huge mountains.

Sea-Floor Spreading

Deep in the ocean, the temperature is near freezing. There is no light, and living things are generally scarce. Yet some areas of the deep-ocean floor are teeming with life. One of these areas is the East Pacific Rise, a region of the Pacific Ocean floor off the coasts of Mexico and South America. Here, ocean water sinks through cracks, or vents, in the crust. The water is heated by contact with hot material from the mantle and then spurts back into the ocean.

Around these hot-water vents live some of the most bizarre creatures ever discovered. Giant, red-tipped tube worms sway in the water. Nearby sit giant clams nearly a meter across. Strange spider-like crabs scuttle by. Surprisingly, the geological features of this strange environment provide some of the best evidence for Wegener's hypothesis of continental drift.

Mid-Ocean Ridges

The East Pacific Rise is just one of many **mid-ocean ridges** that wind beneath Earth's oceans. In the mid-1900's, scientists mapped the mid-ocean ridges using sonar. **Sonar** is a device that bounces sound waves off underwater objects and then records the echoes of these sound waves. The time it takes for the echo to arrive indicates the distance to the object.

Mid-ocean ridges curve like the seam of a baseball along the sea floor, extending into all of Earth's oceans.

Most of the mountains in the mid-ocean ridge system lie hidden under hundreds of meters of water. But in a few places the ridge pokes above the surface. For example, the island of Iceland is part of the mid-ocean ridge that rises above the surface in the North Atlantic Ocean. A steep-sided valley splits the top of some mid-ocean ridges.

What is Sea-Floor spreading?

Harry Hess, an American geologist, was one of the scientists who studied mid-ocean ridges. Hess carefully examined maps of the mid-ocean ridge system. Then he began to think about the ocean floor in relation to the problem of continental drift. Finally, he reached a startling conclusion: Maybe Wegener was right!! Perhaps the continents do move.

In 1960, Hess proposed a radical idea. He suggested that a process he called **sea-floor spreading** continually adds new material to the ocean floor. **In sea-floor spreading, the sea floor spreads apart along both sides of a mid-ocean ridge as new crust is added. As a result, the ocean floors move like conveyor belts, carrying the continents along with them.**

Sea-floor spreading begins at a mid-ocean ridge, which forms along a crack in the oceanic crust. Along the ridge, molten material that forms several kilometers beneath the surface rises and erupts. At the same time, older rock moves outward on both sides of the ridge. As the molten material cools, it forms a strip of solid rock in the center of the ridge. When more molten material flows into the crack, it forms a new strip of rock.

Evidence for Sea-floor spreading

Several types of evidence supported Hess's theory of sea-floor spreading; eruptions of molten material, magnetic stripes in the rock of the ocean floor, and the ages of the rocks themselves. This evidence led scientists to look again at Wegener's hypothesis of continental drift.

Evidence From Molten Material

In the 1960's, scientists found evidence that new material is indeed erupting along mid-ocean ridges. The scientists dived to the ocean floor in *Alvin*, a small submarine built to withstand the crushing pressures four kilometers down in the ocean. In a ridge's central valley, *Alvin's* crew found strange rocks shaped like pillows or like toothpaste squeezed from a tube. Such rocks form only when molten material hardens quickly after erupting under water. These rocks showed that molten material has erupted again and again along the mid-ocean ridge.

Evidence From Magnetic Stripes

When scientists studied patterns in the rocks of the ocean floor, they found more support for sea-floor spreading. The Earth behaves like a giant magnet, with a north pole and a south pole. Surprisingly, Earth's magnetic poles have reversed themselves many times during Earth's history. The last reversal happened 780,000 years ago. If the magnetic poles suddenly reversed themselves today, you would find that your compass needle points south.

Scientists discovered that the rock that makes up the ocean floor lies in a pattern of magnetized "stripes". These stripes hold a record of reversals in Earth's magnetic poles. When the rock hardened completely, it locked the iron bits in place, giving the rocks a permanent "magnetic memory."

Using sensitive instruments, scientists recorded the magnetic memory of rocks on both sides of a mid-ocean ridge. They found that stripes of rock that formed when Earth's magnetic field pointed north alternate with stripes of rock that formed when the magnetic field pointed south.

Evidence From Drilling Samples

The final proof of sea-floor spreading came from rock samples obtained by drilling into the ocean floor. The *Glomar Challenger,* a drilling ship built in 1968, gathered the samples. The *Glomar Challenger* sent drilling pipes through water six kilometers deep to drill holes in the ocean floor. This feat has been compared to using a sharp-ended wire to dig a hole into a sidewalk from the top of the Empire State Building.

Samples from the sea floor were brought up through the pipes. Then the scientists determined the age of the rocks in the samples. They found that the farther away from a ridge the samples were taken, the older the rocks were. The youngest rocks were always in the center of the ridges. This showed that sea-floor spreading really has taken place.

Subduction at Trenches

How can the ocean floor keep getting wider and wider? The answer is that the ocean floor generally does not just keep spreading. Instead, the ocean floor plunges into deep underwater canyons called deep-ocean trenches. At a deep-ocean trench, the oceanic crust bends downward. What occurs at trenches? **In a process taking tens of millions of years, part of the ocean floor sinks back into the mantle through deep-ocean trenches.**

The process of Subduction

The process by which ocean floor sinks beneath a deep-ocean trench and back into the mantle is called **subduction**. As subduction occurs, crust closer to a mid-ocean ridge moves away from the ridge and toward a deep-ocean trench. Sea-floor spreading and subduction work together. They move the ocean floor as if it were on a giant conveyor belt.

New oceanic crust is hot. But as it moves away from the mid-ocean ridge, it cools and becomes more dense. Eventually, gravity pulls this older, denser oceanic crust down beneath the trench.

Subduction and Earth's Oceans

The process of subduction and sea-floor spreading can change the size and shape of the oceans. Because of these processes, the ocean floor is renewed about every 200 million years. That is the time it takes for new rock to form at the mid-ocean ridge, move across the ocean and sink into a trench

The vast Pacific Ocean covers almost one third of the planet. And yet it is shrinking. How can that be? Sometimes a deep ocean trench swallows more oceanic crust than a mid-ocean ridge can produce. Then, if the ridge does not add new crust fast enough, the width of the ocean will shrink. In the Pacific Ocean, subduction through the many trenches that ring the ocean is occurring faster than new crust can be added.

On the other hand, the Atlantic Ocean is expanding. Unlike the Pacific Ocean, the Atlantic Ocean has only a few short trenches. As a result, the spreading ocean floor has virtually nowhere to go. In most places, the oceanic crust of the Atlantic Ocean floor is attached to the continental crust of the continents around the ocean. So as the Atlantic's ocean floor spreads, the continents along its edges also move. Over time, the whole ocean gets wider.

The Theory of Plate Tectonics

Have you ever dropped a hard-boiled egg? If so, you may have noticed that the eggshell cracked in an irregular pattern of pieces. Earth's lithosphere, its solid outer shell, is not one unbroken layer. It is more like that cracked eggshell. It is broken into pieces separated by jagged cracks.

A Canadian scientist, J. Tuzo Wilson, observed that there are cracks in the continents similar to those on the ocean floor. In 1965, Wilson proposed a new way of looking at these cracks. According to Wilson, the lithosphere is broken into separate sections called **plates.** The plates fit together along cracks in the lithosphere. The plates carry the continents or parts of the ocean floor, or both. Wilson combined what geologists knew about sea-floor spreading, Earth's plates, and continental drift into a single theory. A **scientific theory** is a well-tested concept that explains a wide range of observations.

How Plates Move

The theory of **plate tectonics** states that pieces of Earth's lithosphere are in slow, constant motion, driven by convection currents in the mantle. **The theory of plate tectonics explains the formation, movement and subduction of Earth's plates.**

How can Earth's plates move? What force is great enough to move the heavy continents? Geologists think that movement of convection currents in the mantle is the major force that causes plate motion. During subduction, gravity pulls one edge of a plate down into the mantle. The rest of the plate also moves. This slow movement is similar to what happens in a pot of soup when gravity causes the cooler, denser soup near the surface to sink.

As the plates move, they collide, pull apart, or grind past each other, producing spectacular changes in Earth's surface. These changes include volcanoes, mountain ranges, and deep- ocean trenches.

Plate Boundaries

The edges of Earth's plates meet at plate boundaries. Plate boundaries extend deep into the lithosphere. **Faults --** breaks in Earth's crust where rocks have slipped past each other -- form along these boundaries. **There are three kinds of plate boundaries: divergent boundaries, convergent boundaries, and transform boundaries. A different type of plate movement occurs along each type of boundary.**

Scientists have used instruments on satellites to measure plate motion very precisely. The plates move at amazingly slow rates: from about 1 to 10 centimeters per year. The North American and Eurasian plates are moving apart at a rate of 2.5 centimeters per year -- that's about as fast as your fingernails grow. This may not seem like much, but these plates have been moving apart for tens of millions of years.

Divergent Boundaries

The place where two plates move apart, or diverge, is called a **divergent boundary**. Most divergent boundaries occur along the mid-ocean ridges where sea-floor spreading occurs.

Divergent boundaries also occur on land. When a divergent boundary develops on land, two of Earth's plates slide apart. A deep valley called a **rift valley** forms along the divergent boundary. For example, the Great Rift Valley in east Africa marks a deep crack in the African continent.

Convergent Boundaries

The place where two plates come together, or converge, is called a **convergent boundary.** When two plates converge, the result is called a collision. When two plates collide, the density of the plates determines which one comes out on top.

Oceanic crust becomes cooler and denser as it spreads away from the mid-ocean ridge. Where two plates carrying oceanic crust meet at a trench, the plate that is more dense sinks under the other plate.

Sometimes a plate carrying oceanic crust collides with a plate carrying continental crust. Oceanic crust is more dense than continental crust. The less dense continental crust can't sink under the more dense oceanic crust. Instead, subduction occurs as the oceanic plate sinks beneath the continental plate

When two plates carrying continental crust collide, subduction does not take place. Neither piece of crust is dense enough to sink into the mantle. Instead, the collision squeezes the crust into mighty mountain ranges.

Transform Boundaries

A **transform boundary** is a place where two plates slip past each other, moving in opposite directions. Earthquakes often occur along transform boundaries, but crust is neither created nor destroyed.

Plate Motions Over Time

The movement of Earth's plates has greatly changed Earth's surface. Geologists have evidence that, before Pangaea existed, other super continents formed and split apart over billions of years. Pangaea itself formed when Earth's landmasses drifted together about 260 million years ago. Then, about 225 million years ago, Pangaea began to break apart.