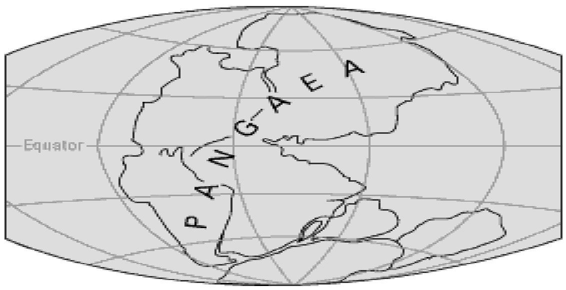
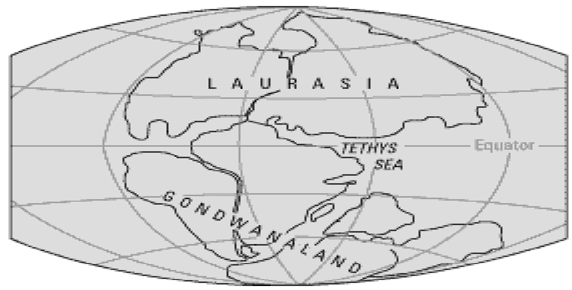
Plate Tectonics and Alfred Wegener

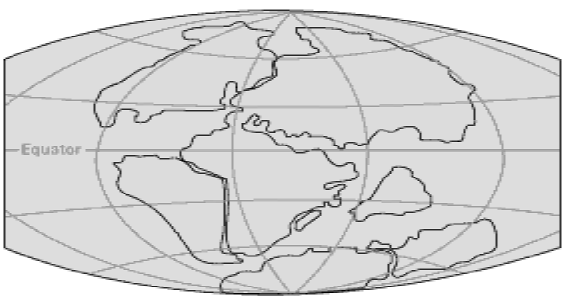
In geologic terms, a *plate* is a large, rigid slab of solid rock. The word *tectonics* comes from the Greek root "to build." Putting these two words together, we get the term *plate tectonics,* which refers to how the Earth's surface is built of plates. The *theory of plate tectonics* states that the Earth's outermost layer is fragmented into a dozen or more large and small plates that are moving relative to one another as they ride atop hotter, more mobile material. Before the advent of plate tectonics, however, some people already believed that the present-day continents were the fragmented pieces of preexisting 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.



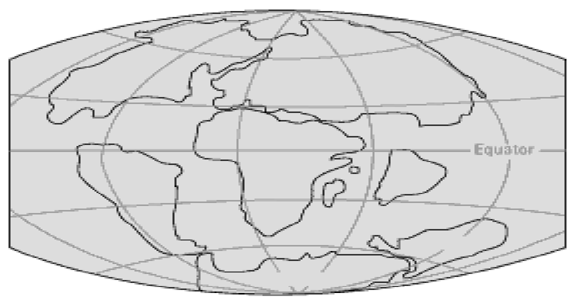
PERMIAN
225 million years ago



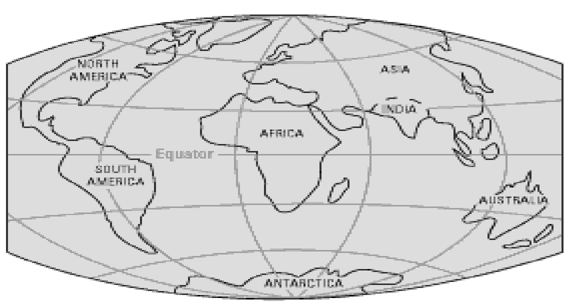
TRIASSIC
200 million years ago



JURASSIC
135 million years ago



CRETACEOUS
65 million years ago



PRESENT DAY

According to the continental drift theory, the supercontinent Pangaea *began to break up about 225-200 million years ago, eventually fragmenting into the continents as we know them today.*

Plate tectonics is a relatively new scientific concept, introduced some 30 years ago, but it has revolutionized our understanding of the dynamic planet upon which we live. The theory has unified the study of the Earth by drawing together many branches of the earth sciences, from *paleontology* (the study of fossils) to *seismology* (the study of earthquakes). It has provided explanations to questions that scientists had speculated upon for centuries -- such as why earthquakes and volcanic eruptions occur in very specific areas around the world, and how and why great mountain ranges like the Alps and Himalayas formed.

Why is the Earth so restless? What causes the ground to shake violently, volcanoes to erupt with explosive force, and great mountain ranges to rise to incredible heights? Scientists, philosophers, and theologians have wrestled with questions such as these for centuries. Until the 1700s, most Europeans thought that a Biblical Flood played a major role in shaping the Earth's surface. This way of thinking was known as "catastrophism," and *geology* (the study of the Earth) was based on the belief that all earthly changes were sudden and caused by a series of catastrophes. However, by the mid-19th century, catastrophism gave way to "uniformitarianism," a new way of thinking centered around the "Uniformitarian Principle" proposed in 1785 by James Hutton, a Scottish geologist. This principle is commonly stated as follows: *The present is the key to the past.* Those holding this viewpoint assume that the geologic forces and processes -- gradual as well as catastrophic -- acting on the Earth today are the same as those that have acted in the geologic past.

The belief that continents have not always been fixed in their present positions was suspected long before the 20th century; this notion was first suggested as early as 1596 by the Dutch map maker Abraham Ortelius in his work *Thesaurus Geographicus*. Ortelius suggested that the Americas were "torn away from Europe and Africa . . . by earthquakes and floods" and went on to say: "The vestiges of the rupture reveal themselves, if someone brings forward a map of the world and considers carefully the coasts of the three [continents]." Ortelius' idea surfaced again in the 19th century. However, it was not until 1912 that the idea of moving continents was seriously considered as a full-blown scientific theory -- called *Continental Drift* -- introduced in two articles published by a 32-year-old German meteorologist named Alfred Lothar Wegener. He contended that, around 200 million years ago, the supercontinent Pangaea began to split apart. Alexander Du Toit, Professor of Geology at Johannesburg University and one of Wegener's staunchest supporters, proposed that Pangaea first broke into two large continental landmasses, *Laurasia* in the northern hemisphere and *Gondwanaland* in the southern hemisphere. Laurasia and Gondwanaland then continued to break apart into the various smaller continents that exist today.

Wegener's theory was based in part on what appeared to him to be the remarkable fit of the South American and African continents, first noted by Abraham Ortelius three centuries earlier. Wegener was also intrigued by the occurrences of unusual geologic structures and of plant and animal fossils found on the matching coastlines of South America and Africa, which are now widely separated by the Atlantic Ocean. He reasoned that it was physically impossible for most of these organisms to have swum or have been transported across the vast oceans. To him, the presence of identical fossil species along the coastal parts of Africa and South America was the most compelling evidence that the two continents were once joined.

In Wegener's mind, the drifting of continents after the break-up of Pangaea explained not only the matching fossil occurrences but also the evidence of dramatic climate changes on some continents. For example, the discovery of fossils of tropical plants (in the form of coal deposits) in Antarctica led to the conclusion that this frozen land previously must have been situated closer to the equator, in a more temperate climate where lush, swampy vegetation could grow. Other mismatches of geology and climate included distinctive fossil ferns *(Glossopteris)* discovered in now-polar regions, and the occurrence of glacial deposits in present-day arid Africa, such as the Vaal River valley of South Africa.

The *theory of continental drift* would become the spark that ignited a new way of viewing the Earth. But at the time Wegener introduced his theory, the scientific community firmly believed the continents and oceans to be permanent features on the Earth's surface. Not surprisingly, his proposal was not well received, even though it seemed to agree with the scientific information available at the time. A fatal weakness in Wegener's theory was that it could not satisfactorily answer the most fundamental question raised by his critics: What kind of forces could be strong enough to move such large masses of solid rock over such great distances? Wegener suggested that the continents simply plowed through the ocean floor, but Harold Jeffreys, a noted English geophysicist, argued correctly that it was physically impossible for a large mass of solid rock to plow through the ocean floor without breaking up.

Undaunted by rejection, Wegener devoted the rest of his life to doggedly pursuing additional evidence to defend his theory. He froze to death in 1930 during an expedition crossing the Greenland ice cap, but the controversy he spawned raged on. However, after his death, new evidence from ocean floor exploration and other studies rekindled interest in Wegener's theory, ultimately leading to the development of the *theory of plate tectonics.*

Plate tectonics has proven to be as important to the earth sciences as the discovery of the structure of the atom was to physics and chemistry and the theory of evolution was to the life sciences. Even though the theory of plate tectonics is now widely accepted by the scientific community, aspects of the theory are still being debated today. Ironically, one of the chief outstanding questions is the one Wegener failed to resolve: What is the nature of the forces propelling the plates? Scientists also debate how plate tectonics may have operated (if at all) earlier in the Earth's history and whether similar processes operate, or have ever operated, on other planets in our solar system.

Alfred Lothar Wegener: Moving continents

Perhaps Alfred Wegener's greatest contribution to the scientific world was his ability to weave seemingly dissimilar, unrelated facts into a theory, which was remarkably visionary for the time. Wegener was one of the first to realize that an understanding of how the Earth works required input and knowledge from *all* the earth sciences.

Wegener's scientific vision sharpened in 1914 as he was recuperating in a military hospital from an injury suffered as a German soldier during World War I. While bed-ridden, he had ample time to develop an idea that had intrigued him for years. Like others before him, Wegener had been struck by the remarkable fit of the coastlines of South America and Africa. But, unlike the others, to support his theory Wegener sought out many other lines of geologic and paleontologic evidence that these two continents were once joined. During his long convalescence, Wegener was able to fully develop his ideas into the *Theory of Continental Drift,* detailed in a book titled *Die Entstehung der Kontinente und Ozeane* (in German, *The Origin of Continents and Oceans*) published in 1915.

Wegener obtained his doctorate in planetary astronomy in 1905 but soon became interested in meteorology; during his lifetime, he participated in several meteorologic expeditions to Greenland. Tenacious by nature, Wegener spent much of his adult life vigorously defending his theory of *continental drift*, which was severely attacked from the start and never gained acceptance in his lifetime. Despite overwhelming criticism from most leading geologists, who regarded him as a mere meteorologist and outsider meddling in their field, Wegener did not back down but worked even harder to strengthen his theory.

A couple of years before his death, Wegener finally achieved one of his lifetime goals: an academic position. After a long but unsuccessful search for a university position in his native Germany, he accepted a professorship at the University of Graz in Austria. Wegener's frustration and long delay in gaining a university post perhaps stemmed from his broad scientific interests. As noted by Johannes Georgi, Wegener's longtime friend and colleague, "One heard time and again that he had been turned down for a certain chair because he was interested also, and perhaps to a greater degree, in matters that lay outside its terms of reference -- as if such a man would not have been worthy of any chair in the wide realm of world science."

Ironically, shortly after achieving his academic goal, Wegener died on a meteorologic expedition to Greenland. Georgi had asked Wegener to coordinate an expedition to establish a winter weather station to study the jet stream (storm track) in the upper atmosphere. Wegener reluctantly agreed. After many delays due to severe weather, Wegener and 14 others set out for the winter station in September of 1930 with 15 sledges and 4,000 pounds of supplies. The extreme cold turned back all but one of the 13 Greenlanders, but Wegener was determined to push on to the station, where he knew the supplies were desperately needed by Georgi and the other researchers. Travelling under frigid conditions, with temperatures as low as *minus* 54 °C, Wegener reached the station five weeks later. Wanting to return home as soon as possible, he insisted upon starting back to the base camp the very next morning. But he never made it; his body was found the next summer.

Wegener was still an energetic, brilliant researcher when he died at the age of 50. A year before his untimely death, the fourth revised edition (1929) of his classic book was published; in this edition, he had already made the significant observation that shallower oceans were geologically younger. Had he not died in 1930, Wegener doubtless would have pounced upon the new Atlantic bathymetric data just acquired by the German research vessel *Meteor* in the late 1920s. These data showed the existence of a central valley along much of the crest of the Mid-Atlantic Ridge. Given his fertile mind, Wegener just possibly might have recognized the shallow Mid-Atlantic Ridge as a geologically young feature resulting from thermal expansion, and the central valley as a *rift valley* resulting from stretching of the oceanic crust. From stretched, young crust in the middle of the ocean to seafloor spreading and plate tectonics would have been short mental leaps for a big thinker like Wegener. This conjectural scenario by Dr. Peter R. Vogt (U.S. Naval Research Laboratory, Washington, D.C.), an acknowledged expert on plate tectonics, implies that "Wegener probably would have been *part* of the plate-tectonics revolution, if not the actual instigator, had he lived longer." In any case, many of Wegener's ideas clearly served as the catalyst and framework for the development of the theory of plate tectonics three decades later.