

Alfred Wegener – From Continental Drift to Plate Tectonics

A J Saigeetha and Ravinder Kumar Banyal

What is the nature of the force or mechanism that moves massive continents thousands of miles across? What causes violent earthquakes to displace huge landmasses abruptly? How could great mountain ranges like Himalayas and Alps rise to such incredible heights? What makes earth's interior so restless? Answers to some of these questions may lie in understanding the Earth's interior itself.

From time immemorial, the beauty and the grandeur of nature have never failed to fascinate the imaginations of the creative minds. The colourful landscapes, changing seasons, twinkling stars, vast sky, majestic oceans, exotic life forms, great mountains, and deep valleys -have all been the source of veneration for the primitive human being. The roots of modern science lie in man's eternal quest to comprehend these phenomena by careful and systematic observations that gradually led to many discoveries of nature and its laws. The new scientific ideas and inventions have profoundly changed the way we view our world today. *Plate tectonics*, one of the most important and far-reaching discoveries of the last century has completely revolutionized our understanding of the planet Earth. The credit goes to a brilliant interdisciplinary scientist from Germany, Alfred Lothar Wegener, who in the year 1912, proposed the scintillating idea of continental drift that set the foundation for the development of the theory of plate tectonics in later years. The aim of this article is to briefly introduce the concept of plate tectonics and also to highlight the role that Wegener played to advance it. In view of the intended range and modest scope of the article, we have kept the complex and the intricate subject details to bare minimum. A serious reader is urged to consult the references given in the



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Keywords

Continental drift, plate tectonics.



‘suggested reading’ for a more elaborate and in depth discussion on the related topics.

Historical Introduction

Several dynamic mechanisms have been at work to reshape the pattern of land and sea throughout the geological history of the Earth. Its surface features are constantly being altered by various external processes like slow erosion and deposition as well as by internal processes such as sudden earthquake and volcanic eruption. Geologists and meteorologists were long aware of the Earth’s dynamic conditions. However, towards the end of 19th century there were several intriguing discoveries that were clearly lacking in proper scientific explanation. A major geological problem was the question of how mountains form in the first place and how could crustal rocks comprising mountains, have once existed on the world’s ocean floor. Eduard Suess from Austria, the most influential theorist of his time postulated that oceans and continents are not stationary, but experience irregular periods of up and down motion, causing global redistribution of water and land. Some of the eminent American scientists like James Dwight Dana, and Yale, favoured different theories. They suggested that mountains were raised up as a result of folding of the entire crust due to massive sedimentary accumulation in basin along the coasts. These crustal warps were called *geosynclines*. Both these theories had common underlying assumption that the Earth was gradually cooling and therefore shrinking. The slow ongoing contraction was thought to be the ultimate force behind subsidence, mountain building and other geological processes. Nevertheless, the contracting Earth theory failed to give any plausible explanation for the observed correlation in stratigraphy, glaciation and palaeontological studies across the continents.

The fossil remains and the rock structures found along the coastline of South America, Africa and India were remarkably similar despite being widely separated by Atlantic and Indian Ocean. The modern day plants and animals in different conti-

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Figure 1 (left). Alfred Lothar Wegener (1880-1930), who established the theory of continental drift.

Photograph courtesy: Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany (AWI).

Figure 2 (right). The last photograph of Alfred Wegener and Rasmus Villumsen, taken just before they left the 'Eismittee' station on November 1, 1930.

Photograph courtesy: AWI

nents, on the contrary, do not bear any such resemblance. The deposit of coal mines (formed from tropical plants) found in a frozen and deserted place like Antarctica could not be understood based on prevailing views. So how does one explain this remarkable shift through space and time?

Another school of thought led by America's foremost paleontologist Charles Schuchert, firmly believed that continents are permanently fixed on the Earth's surface and their positions do not change with time. In order to explain a wide range of confusing geological data, they supported the existence of huge *land bridges* that seem to have connected the far-flung continents in the past but are now broken and sunken into the sea. But, all these theories would soon be challenged by Alfred Wegener (see *Box 1* for biography) who for the first time put the idea of continental drift on firm scientific footing.

Theory of Continental Drift

In a lecture delivered at the annual meeting of the Geological Association in Frankfurt on January 6, 1912, Wegener rejected the unrealistic concept of sunken land bridges, and expounded the new theory of continental drift. He realized that apparently distinct clues drawn from many branches of Earth sciences indeed point to same underlying reality. According to the new



Box 1. Brief Biography of Alfred Wegener

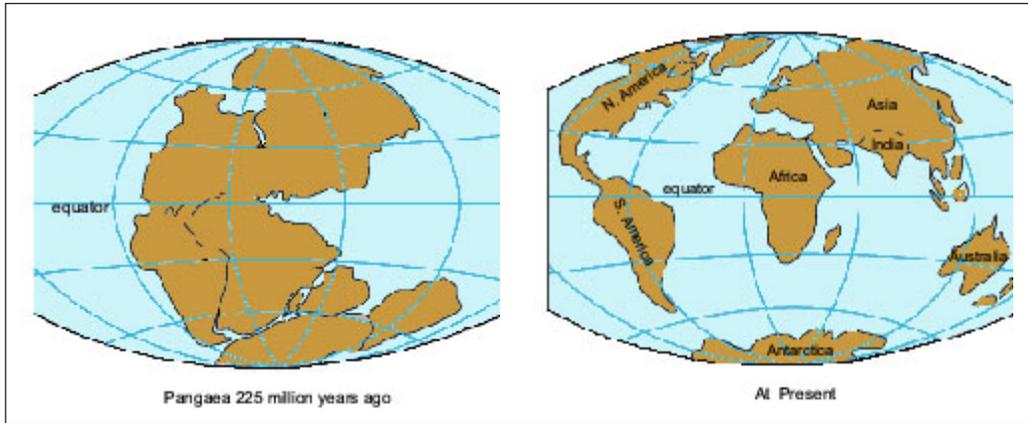
Alfred Lothar Wegener was born in Berlin on November 1, 1880. He studied natural sciences at the University of Berlin and earned a PhD degree in planetary astronomy in 1904. But his interests soon shifted from astronomy to meteorology. He then joined his older brother Kurt as an assistant at the Prussian Aeronautical Laboratory. He was actively involved in tracking air circulation of upper atmosphere with the help of kites and balloons. In fact he and his brother Kurt set a new world record by staying aloft in a hot air balloon for more than 52 hours.

His commitment and hard work, won him an opportunity in 1906 to join a Danish led expedition that were to map the unexplored northeast coast of Greenland. Wegener was the first to use kites and fixed balloons to study the polar atmosphere during the expedition that lasted for two years. After returning to Germany he was offered a private position in the University of Marburg where he taught astronomy and meteorology. Wegener compiled his meteorology lecture notes into a book, *The Thermodynamics of the Atmosphere* (published in 1911), in which he correctly explained the theory of raindrop formation in temperate latitudes. This book later became a standard text throughout Germany.

At Marburg in the autumn of 1911, Wegener came across a scientific paper that listed fossils of identical plants and animals found on opposite sides of the Atlantic. It was then that the idea of continental drift began to take shape as he collected more corroborating and similar evidences. He later recalled, “a conviction of the fundamental soundness of the idea took root in my mind.” In 1912, at the age of 31, Wegener published two articles in which he hypothesized the theory of continental drift. Immediately after his wedding with Else in 1913, Wegener had to go to serve in the First World War as a soldier. While recovering from the war injury in a military hospital he could devote ample time to further refine his work on continental drift. He authored another book in 1915 *The origin of Continents and Oceans* which became one of the most influential and controversial books in the history of science. Expanded editions were subsequently published in 1920, 1922, and 1929. At the end of the war, in December 1918 he obtained his first regular academic post by replacing his father-in-law, Vladimir Köppen, as a professor of meteorology at Hamburg. In 1924, the University Graz in Austria appointed him a professor of meteorology and geophysics. In November 1930, shortly after his 50th birthday (see *Figure 2*) he and his companion Rasmus Villumsen died while returning from the camp in the middle of the Greenland ice to the base camp on the west coast of Greenland.

Wegener’s ideas were fully recognized by the world only after his death. His theory gave new directions to research in the Earth sciences. Further refinement of his ideas have led to better understanding of earthquakes, volcanic eruptions, formation of mountains and valleys and various geological processes. Wegener’s greatest contribution was his ability to interlace many seemingly unrelated and diverse facts into a single unified theory.





theory, the present day continents and oceans are not the permanent features of the Earth, as it was generally believed. The continents are formed from a big monolithic landmass called supercontinent or Pangaea that existed in distant geological past.

Around 200 million years back Pangaea began to break into smaller pieces that slowly drifted away from each other and eventually reached the present state as depicted in *Figure 3*. *“Doesn’t the east coast of South America fit exactly against the west coast of Africa, as if they had once been joined? Don’t the coal deposits found in Antarctica lead to the conclusion that it must have been near to the equator for the rich vegetation to thrive?”* argued Wegener. He also noted that the continents are made of a different, and less dense granite material than the volcanic basalt that makes up the deep-sea floor.

As it happens in the realm of science, any radical idea, regardless of its merit, does not gain immediate acceptance among scientific community. A famous quote from Albert Einstein aptly summarizes it, *“Great spirits have always found violent opposition from mediocre minds. The latter cannot understand it when a man doesn’t thoughtlessly submit to hereditary prejudices but honestly and courageously uses his intelligence.”* Needless to say, Wegener’s new theory sparked a fierce controversy all over the world and outraged many leading scientists in the field. The geologists

Figure 3. From Pangaea to the present day continents.

According to the new theory, the present day continents are formed from a big monolithic landmass called supercontinent or Pangaea that existed in distant geological past.



One often – repeated criticism of Wegener’s model was that there was no adequate force that could displace the continents.

ridiculed his idea and their response was often harsh and scathing. “If we are to believe [this] hypothesis, we must forget everything we have learned in the last 70 years and start all over again,” remarked an American scientist. Anyone who “valued his reputation for scientific sanity” would never dare support such a theory, said another British geologist. One often – repeated criticism of Wegener’s model was that there was no adequate force that could displace the continents.

Unmoved by the mounting criticism, Wegener continued to work even more vigorously to gather additional evidence to defend his theory. He suggested that the movement of the Indian plate towards the Eurasian plate had led to the formation of the greatest topographic features of the World, the Himalayas. Wegener also pointed out that the continents move up and down to maintain equilibrium in a process called isostasy. As a proof, he cited the example of sinking of the Northern Hemisphere lands, which submerged under the weight of continental ice slabs during the last ice age, and subsequently resurfaced after the ice melted some 10,000 years ago. Paleoclimatic validation became one of the strongest proofs of his theory. Mountain belts of similar age and structure are found in what are now widely

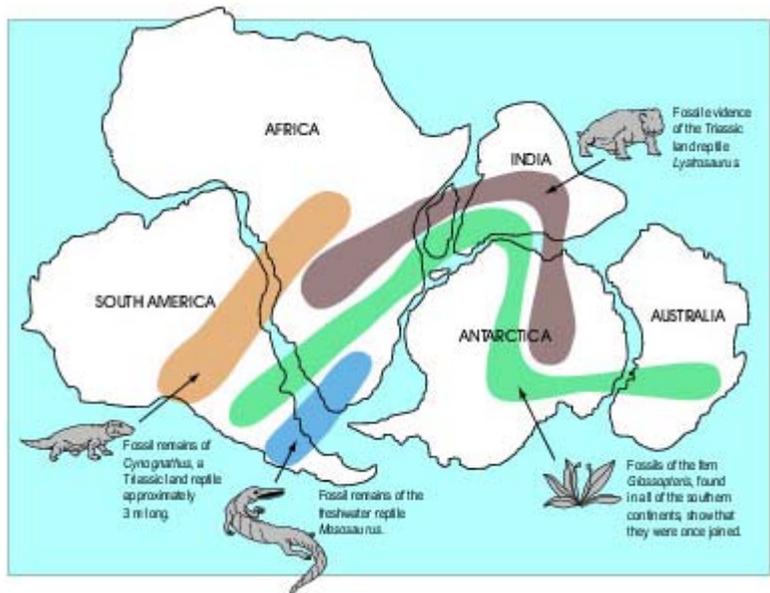


Figure 4. Identical fossil remains across the continents that supported the existence of Pangaea.

Photograph courtesy: United State Geological Survey (USGS).



separated areas of the world. If Pangaea is reassembled, these belts connect up. Fossils revealed that the climate of a certain place during Permo Carboniferous era was utterly different from the climate existing today. He found fossils of tropical plants such as ferns and cycads, in the Arctic island of Spitsbergen. The overall picture that emerged from all the evidences is recapitulated in *Figure 4*, where different colour bands are shown to connect the continents with identical fossil remains. The green band indicates fossils of the fern *Glossopteris*, found in all of the southern continents. Orange indicates the fossil remains of *Cynognathus*, a Triassic land reptile. Brown indicates fossil evidence of the Triassic land reptile *Lystrosaurus* and the blue indicates fossil remains of *Mesosaurus*, a freshwater reptile.

Earth's Interior

Even though the theory of continental drift was accepted slowly drawing support from several sources, it didn't have a satisfactory answer to the following fundamental question. What is the nature of the force or mechanism that is strong enough to move massive continents thousands of miles across? Closely related with this are several other questions like: What causes violent earthquakes to displace huge landmasses abruptly? What drives the volcanic eruption to spew out volumes of magma within seconds? How could great mountain ranges like Himalayas and Alps rise to such incredible heights? What makes Earth's interior so restless? Answers to some of these questions may lie in understanding the Earth's interior itself that we proceed to explain next.

Modern understanding of the structure of the Earth is derived largely from the seismological observations that measure the reflection of seismic waves from the Earth's interior. Scientists now understand that the Earth is made up of three basic layers that are called crust, mantle and core. *Figure 5* shows a simplified cross-sectional view of the Earth's interior. The outermost layer crust has an average thickness of about 30 km. However, under large mountain ranges it can vary up to 100 km, while the crust

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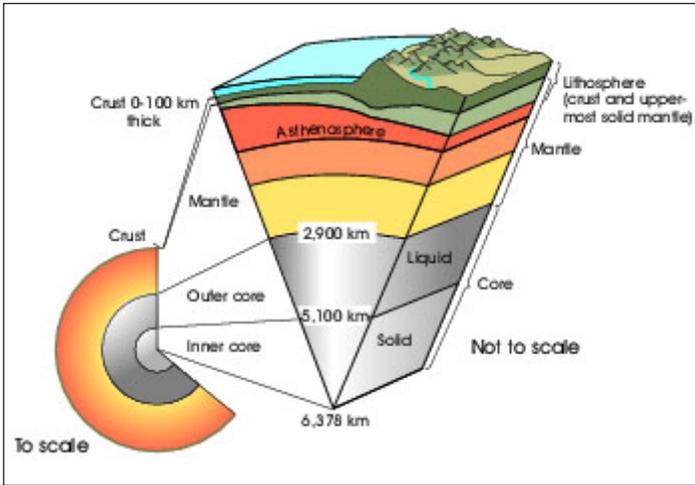


Figure 5. A simplified cross sectional view of Earth's interior.

Photograph courtesy: USGS.

beneath the ocean is only 5-7 km thick. The second layer, the mantle, lies beneath the crust and has thickness extending up to about 2,900 km. At the center lies the metallic core, which is twice as dense as the mantle and comprises mainly nickel and iron. Interestingly, the metals in the outer core exist in molten state, whereas the inner core is solidified due to extreme pressure and density. The tem-

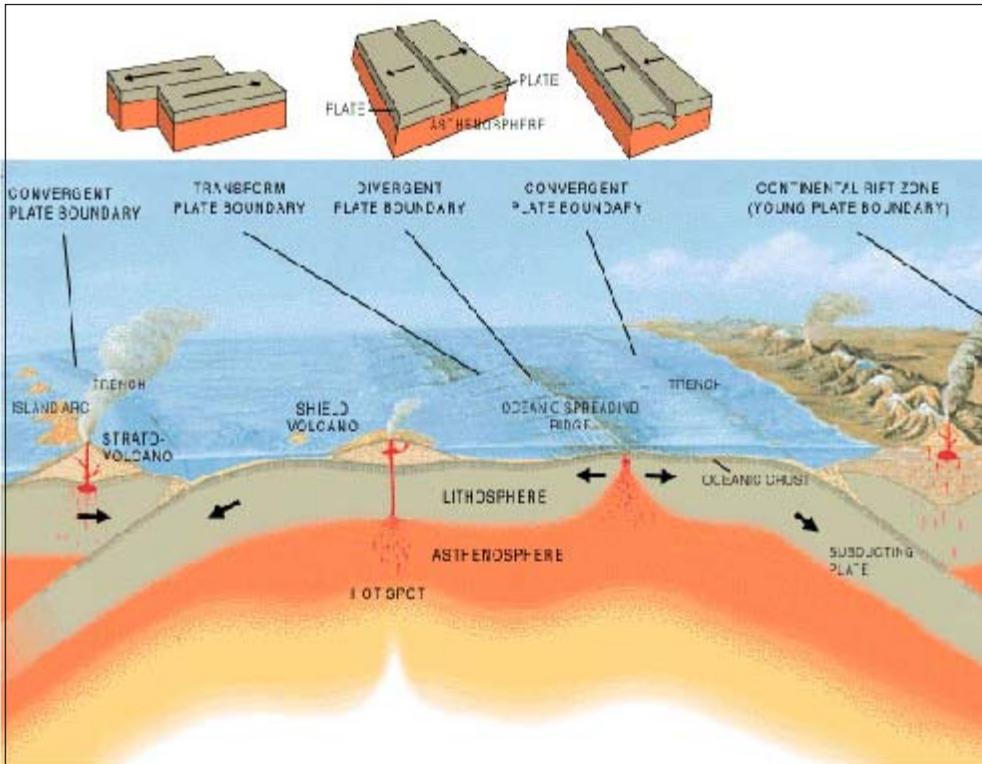
perature in the core is hotter than the Sun's surface. This intense heat from the inner core causes material in the outer core and mantle to move around. Dynamo theory proposes a mechanism by which a celestial body such as the Earth generates a magnetic field. In the case of the Earth, the magnetic field is believed to be caused by the electric currents generated by the convection of molten iron and nickel in the outer core. Geophysical and electromagnetic theories provide clear and convincing evidence of polar magnetic field reversal throughout the course of Earth's history. Several paleomagnetic studies have proved that the Earth's magnetic fields have flipped (changed from one geographic pole to the other) many times in the past.

Plate Tectonics

Geophysical studies show that the crust and the upper part of the mantle are relatively cooler and brittle. Together they constitute the *lithosphere* that has a thickness averaging approximately 80-100 km. The lithosphere is fragmented into separate tectonic plates that carry overlying continents and oceans. The Earth's surface is divided into as many as seven huge plates and several small plates. These plates are constantly moving relative to each other. A stress begins to build up whenever the plates come in contact with one another. A sudden release of the accumulated stress may then cause catastrophic events, such as volcanic

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eruption and earthquakes, which in turn can trigger the destructive ocean waves known as *tsunamis*.¹ As demonstrated in Figure 6, almost all the geological activities such as earthquakes and the creation of topographic features like mountains, volcanoes and oceanic trenches are concentrated near plate boundaries. There are three types of plate boundaries, namely, *convergent boundaries*, *divergent boundaries* and *transform boundaries*. These boundaries are characterized by the way the plates move relative to each other.

Convergent boundaries are formed when two plates slide towards each other. The nature of a convergent boundary depends on the type of lithosphere in the plates that are colliding. Because both colliding plates resist subduction, the impact of collision crumples and compresses the rocky material, forming extensive mountain ranges. The ongoing collision between the Indian and the Eurasian plate is a vivid example that has resulted in the mighty Himalayan Mountains that continue to increase in height each

Figure 6. A graphical illustration showing different geophysical processes occurring at the plate boundaries.

Photograph courtesy: USGS.

¹ Satish R Shetye, *Tsunamis*, *Resonance*, Vol.10, No.2, p.8, 2005.



There is no simple explanation of the mechanism that drives plate tectonics. The process appears to be caused by convection within the upper mantle that carries the continents along – much like a conveyor belt.

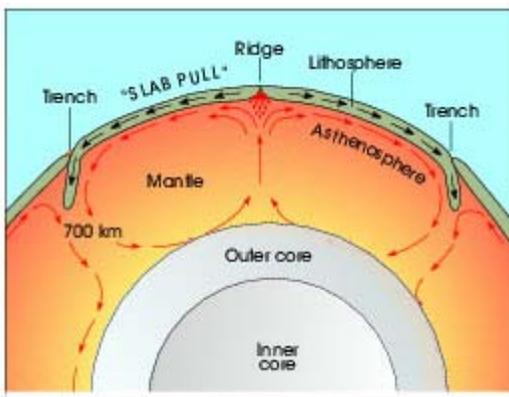
year. The European Alps have been formed in similar manner, starting some 80 million years ago when the outlying continental fragments of the African Plate collided with the Eurasian Plate. The relentless pressure between the two plates is resulting in the gradual closing up of the Mediterranean Sea.

Divergent boundaries are areas under tension where two plates are pushed apart by upwelling magma from the mantle. New oceanic crust is created at divergent boundaries that are sites of sea-floor spreading. Mid-ocean ridges, as the East Pacific Rise and the Galapagos Ridge, are examples of this type of boundary. As discussed in the next section, the growing acceptance of plate tectonics was chiefly due to the overwhelming evidences that came from sea-floor spreading.

Transform boundaries occur where plates slide, or grind, past each other. Due to the friction the stress builds up in both plates and eventually reaches a level that exceeds the slipping-point of rocks on either side of the transform-faults. The massive amounts of energy that are released causes earthquakes, a common phenomenon along transform boundaries. A typical example of this type of plate boundary is the San Andreas Fault zone, which marks the boundary between the Pacific plate moving north and the North American plate moving south.

Figure 7. A proposed convective model that seems to be the driving force for plate movements.

Photograph courtesy: USGS.



There is no simple explanation of the mechanism that drives plate tectonics. The process appears to be caused by convection within the upper mantle (partially molten asthenosphere) that carries the continents along – much like a conveyor belt. The convection currents are believed to be generated by the uprise of the molten rocks near the radioactive cores and sinking of the cooler mantle rocks. This movement of warmer and cooler material, in turn, creates pockets of circulation within the mantle called convection cells. A simple but instructive model depicting the convective flow in mantle is illustrated in *Figure 7*. We can



notice that the convection currents rise and spread along ridges near divergent boundaries and converge and descend down trenches along convergent boundaries. The powerful convective cells also bring out large quantities of basaltic magma from within the mantle and dump it on the sea floor to form ocean ridges. The injection of magma at the spreading centers pushes plates apart, thereby causing plate movement. Recent studies indicate that gravity-controlled subduction processes could be more important in driving the plates than the convective mechanism. However, the final word on this contentious issue is yet to be written.

Sea Floor Spreading

The seawater occupies more than 70% of the Earth's surface. Several oceanographic studies and deep-sea surveys carried out after the World War II, established the fact that the ocean basement is not as flat and featureless as it was originally thought. The sea floor consists of Mid-Ocean ridges, huge volcanic mountains, deep-sea trenches, and broad plateaus. The most prominent feature, the Mid-Ocean ridges is about 2,400 km wide, a continuous chain of undersea mountains that rises up to 4,500 m at certain places and wiggles its way through 60,000 km of the world's oceans. It is here, at Mid-Ocean ridges that are also the structurally weak zones where hot magma emerges out of the deep mantle to rip apart the two plates. As a result the Earth's crust is continually growing near the divergent boundaries where the two plates drift apart. *Figure 8* shows the network of the Mid-Ocean ridges that span the globe.

In the early 1960s, Princeton geologist Harry Hess proposed the hypothesis of sea-floor spreading, in which basaltic magma from the deep mantle rises to create new floor at Mid-Ocean ridges.

Figure 8. Topography of ocean floor showing the Mid-Ocean ridges in red strips.

Photograph courtesy: USGS.

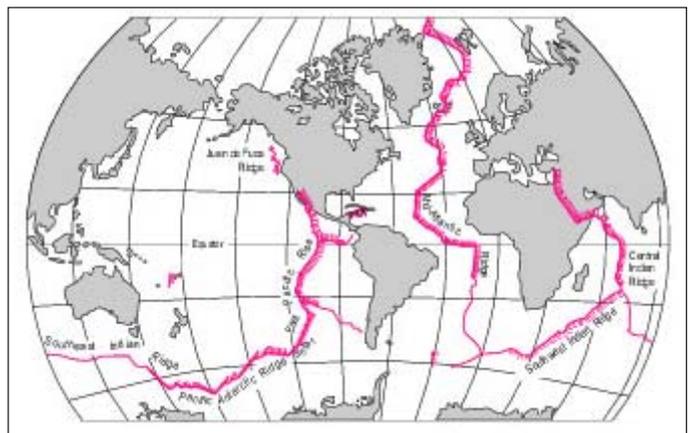
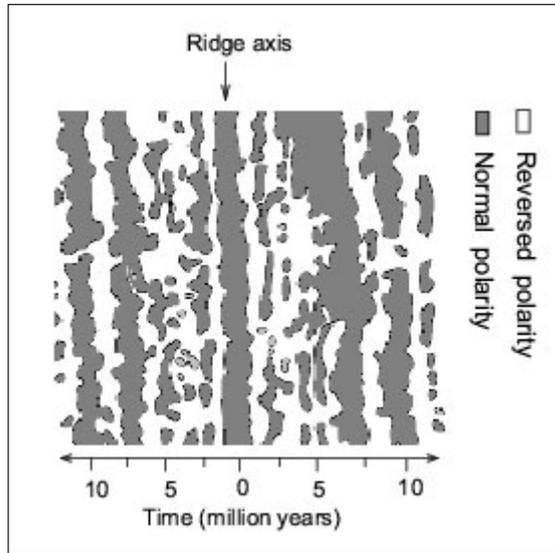


Figure 9. The magnetic polarity reversal recorded in the material on either side of the Mid-Atlantic ridge.



This hypothesis was supported by isotopic age determination of the rock samples near the Mid-Ocean ridges. The rocks near the crest of the ridge (spreading centers) were found to be younger in age than the older material that has progressively moved away from the ridge crust due to slow and continuous spreading. Similar to the age of rocks, identical fossils were found in bands and zones equidistant from divergent boundaries, showing a high degree of correspondence and shared history of the events.

The compelling evidence that swayed opinions of most geologists in favour of the plate tectonics was the demonstration of the existence of symmetrical, equidistant magnetic anomalies in rocks centered on the Mid-Atlantic Ridge.

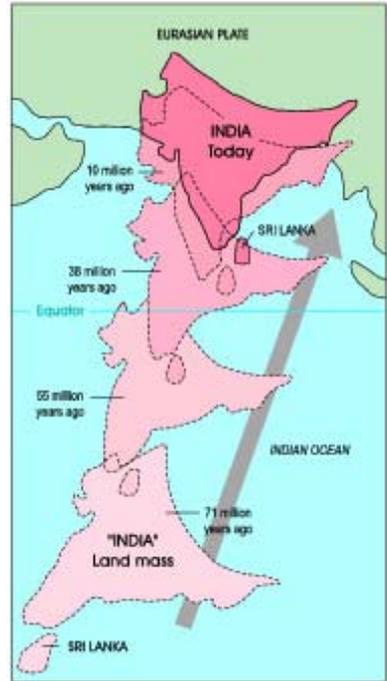
The compelling evidence that swayed opinions of most geologists in favour of the plate tectonics was the demonstration of the existence of symmetrical, equidistant magnetic anomalies in rocks centered on the Mid-Atlantic Ridge. The study revealed a distinct and curious pattern of magnetic stripes – stronger and weaker magnetic signals in parallel bands on either side of the ridge crest. The zebra-like pattern of the Earth's magnetic field mapped near Mid-Atlantic ridge is shown in *Figure 9*.

In order to explain the observed magnetic stripping, Fred Vine and Drummond Matthews in 1963, suggested that newly formed crustal rocks from cooling magma near ridges would also record an imprint of the strength and orientation of Earth's magnetic



field at that epoch. If spreading of the ocean floor occurs as Harry Hess suggested, and if the Earth's magnetic field had reversed² in between two eruptions in geologic past, then the lava flows would preserve a set of parallel bands with different magnetic properties.

The overall size of the Earth's crust has not varied appreciably in the past despite the strong evidences that suggest sea-floor spreading. This is mainly because the 'spread' in ocean floor at the mid-ocean ridges is compensated by two plates moving towards each other in another region of the Earth. The ocean plate can also plunge beneath the buoyant continent into the mantle in a process known as subduction. This is happening today along the west coast of South America and the eastern boundary of Indian Plate near Andaman archipelago. Additional evidences continue to support the sea-floor spreading hypothesis.



Motion of the Indian Plate

According to the theory of plate tectonics, the Indian continent has travelled around 6,000 km northward before colliding with the Eurasian plate ~57 million years ago. An ancient ocean called *Tethys Ocean* is believed to have existed between Eurasia and Africa before the Indian and Eurasian Plates collided. A chronology of motion based on palaeomagnetic analysis of the Indian plate in the last 70 million years is depicted in *Figure 10*. The history of the long and impressive journey of the Indian plate has been recorded in the fossils recovered from ocean drilling. After the collision a slow and sustained convergence uplifted the Himalayas to their present height, spanning India, Pakistan, Nepal, and Bhutan. Likewise, the Eurasian plate also suffered upliftment with the rise of the great Tibetan plateau to an enormous height of about 4.5 km. The collision has not only led to the deformation of the Indian plate but also to 2000 km of shortening and 60-70 km thickening of the crust. Tectonic motion can be estimated from a variety of space geodetic technologies such as Global Positioning System (GPS), Very Long

Figure 10. A long cruise of Indian plate before it collided with Eurasian plate.

Photograph courtesy USGS.

² Latest findings of Dr. Brad Clement of Florida International University, reported in the journal *Nature* (08 April 2004), show that the Earth's magnetic field reverses its polarity in approximately 7000 years.

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Box 2. Space Geodesy using GPS

Geodesy is the science that concerns with the measurement of size, shape, position and motion of different features of the Earth's surface. The Global Positioning System (GPS) is a satellite based navigation and surveying network, which determines the precise position (longitude, and latitude) of a point on Earth's surface. It is a constellation of 24 satellites that orbit the Earth at about 20,200 km elevation. These satellites are distributed in six circular orbital planes equally spaced in angle and having orbital period of 12 hours.

Assuming that the positions of the satellites are known, the location of a receiver can be calculated by determining the distance from each of the satellites to the receiver using a method called *triangulation*. For example, the location of any point P (see *Figure A*) in a two dimensional plane (2-D) can be uniquely determined provided we know its distances from at least three reference points A, B, and C. This is because the circles centered around the reference points with radii equal to their respective distances, result in a unique intersection point P. Similarly, for a point in three-dimensional space (3-D), distances of the point from four known positions are necessary to uniquely locate its position (i.e., two spheres intersect in a circle, three spheres intersect at two points and four spheres intersect at single unique point).

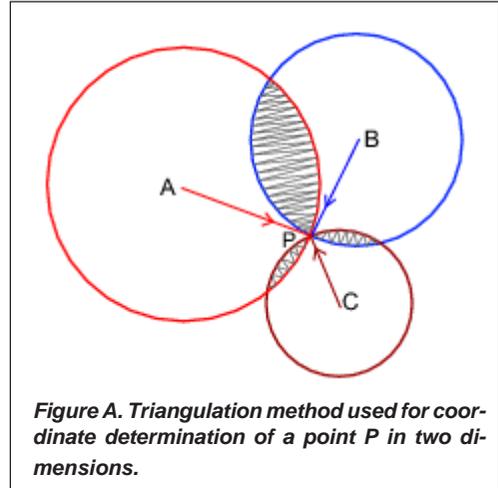


Figure A. Triangulation method used for coordinate determination of a point P in two dimensions.

Precisely for this reason a receiver on the ground should have 'timing signals' from minimum four satellites passing simultaneously in its visible range. The more satellites we have the more accurate results we can get. Each satellite carries an operating atomic clock and broadcasts timed signals that are intercepted by receivers placed on different locations on ground. These atomic clocks are synchronizing with each other within a precision of a few nanoseconds. Along with precisely timed data, the broadcast signal also contains information about the actual position of the satellite within the constellation. There is a small delay between the time the signal leaves the satellite and the time they arrive at a GPS receiver. The delay increases progressively as a satellite recedes away from a receiver. A GPS receiver uses these delays to determine its distance from the satellites. The raw data is corrected to eliminate the effect of different errors in measurements. The receiver then uses triangulation method to determine its position on the Earth.

Baseline Interferometry (VLBI), and Satellite Laser Ranging (SLR). However, the wide distribution of GPS sites, good global coverage and comparatively lower cost have made GPS based space geodesy more accurate and reliable than others methods (see the *Box 2*).



Today, plate tectonics is able to explain virtually all the major geological features of the Earth. The earthquake and the volcano prone regions have been successfully identified and mapped all over the world using the plate tectonic model.

2500 km stretch of the Himalayan arc from Kashmir to Arunachal Pradesh is about 1-2 cm/yr, whereas, southern peninsular India moves as a rigid plate with a constant velocity.

Concluding Remarks

The modern theory of plate tectonics, centered on Wegener's idea of continental drift – but transcending much beyond, has greatly contributed to the research in the Earth sciences and other related fields. Today, plate tectonics is able to explain virtually all the major geological features of the Earth. Among others, the long-standing human concerns for public safety from natural disasters have immensely benefited from the gradual understanding of the Earth's dynamics. The earthquake and the volcano prone regions have been successfully identified and mapped all over the world using the plate tectonic model. The Earth's natural resources, although limited, are vital to the survival and development of the human population. We need to explore untapped natural resources that lie on the ocean floor, the polar continents and deep within the Earth's crust. Finding and developing such resources would constitute an important and challenging problem in future research.

Both earthquakes and volcanic eruptions pose a potential hazard to people living near active sites. Earthquakes, especially those that occur beneath seas or oceans, can give rise to powerful tsunami waves. These waves can travel thousands of miles with little or no dissipation of energy and cause a colossal damage over a larger area far away from the vicinity of their origin. For example, the December 2004 tsunami, deadliest in the recorded history, has originated from a massive earthquake that occurred near Sumatra island of Indonesia. It has not only killed people in Thailand, Malaysia, Bangladesh, India, Sri Lanka, and the Maldives but has gone even as far as Kenya, Tanzania and Somalia in eastern Africa.

Human ingenuity can do little to avert these awesome natural disasters. To address the issue of their predictability, with a goal



to mitigate their impact requires strong theoretical, computational and experimental tools. These tools are essential to investigate the properties of surface strain, plate boundary motion, dynamics of the Earth's interior, frictional properties of faults and mechanical properties of the Earth's crust. The present day technology has reached a state that provides very exciting and challenging opportunities for understanding and modeling of these phenomena. The efforts put in these directions will surely help us to establish reliable and robust warning systems to predict earthquakes, tsunamis and volcanic eruptions well in advance, minimizing human and material losses. However, the scientific and the technological endeavour alone would not suffice. It has to be adequately complemented with efficient hazard assessment, control and management skills. Some stringent measures may be required to ensure a timely coordination, and collaboration among concerned institutions and agencies. Most importantly, widespread awareness about natural disasters should be made a national priority. Initiating public outreach and education programs at individual and organizational levels might go a long way to achieve this goal.

Suggested Reading

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- [2] Marha Kiger and Jane Russel, *This Dynamic Earth*, USGS Publication, 1996.
- [3] Alfred Wegener, *The Origins of Continents and Oceans*, Penguin Press, 1966.
- [4] Neil Schlager, *Science in Dispute*, Thomson Gale, Vol.1, 2002.
- [5] Carla W Montgomery, *Physical Geology*, Wm. C Brown Publishers, 1987.
- [6] Sridevi Jade, Estimates of plate velocity and crustal deformation in the Indian subcontinent using GPS geodesy, *Current Science*, Vol. 86, 25 May, 2004.

Additional information about Alfred Wegener can be found at the following web sites

- <http://www.ucmp.berkeley.edu/history/wegener.html>
- <http://www.awi-bremerhaven.de/AWI/geschichte/wegener.html>
- <http://my.execpc.com/~acmelasr/mountains/wghnf.html>

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